DPG Fall Meeting (FM)

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Overview of Invited Talks and Sessions

(Lecture rooms Audi Max, Aula, 1009, 1010, 1015, 1098, 1199, 2004, 2006, 3042, 3043, and 3044; Poster Tents and 1114)

Plenary Talks

FM 1.1	Mon	8:30– 9:30	Audi Max	**Tensor Networks for Classical and Quantum Machine Learning** — •Miles Stoudenmire
FM 25.1	Tue	8:30– 9:30	Audi Max	**Scalable quantum computing with trapped ion qubits** — •Ferdinand Schmidt-Kaler
FM 45.1	Wed	8:30– 9:30	Audi Max	**Quantum Technologies - Challenges and Chances from an Industry Perspective** — •Jürgen Gross
FM 68.1	Thu	8:30– 9:30	Audi Max	**Silicon Based Quantum Computing** — •Michelle Simmons
FM 88.1	Fri	8:30– 9:30	Audi Max	**What can be done with extreme entanglement?** — •Richard Cleve

Introductory Talks

FM 2.1	Mon	9:30–10:30	Audi Max	**Quantum Algorithms** — •Ronald de Wolf
FM 26.1	Tue	9:30–10:30	Audi Max	**Machine Learning** — •Katharina Morik
FM 46.1	Wed	9:30–10:30	Audi Max	**Quantum sensing enabled by diamond** — •Fedor Jelezko
FM 69.1	Thu	9:30–10:30	Audi Max	**Hybrid Spin-Superconducting Circuits for Spin-Sensing and Quantum Information** — Bartolo Albanese, Jessica-Fernanda Da Silva Barbosa, Emanuele Albertinale, Marianne Le Dantec, Vishal Ranjan, Moonjoo Lee, Milos Rancic, Emmanuel Flurin, Denis Vion, Patrice Bertet, •Daniel Esteve
FM 89.1	Fri	9:30–10:30	Audi Max	**Generation of pure quantum light in the solid-state** — •Pascale Senellart

Focus Talks

FM 4.1	Mon	11:00–12:00	2004	**Quantum simulation with ultracold atoms in optical lattices** — •Monika Aidelsburger
FM 28.1	Tue	11:00–12:00	2004	**An introduction to quantum spectroscopy** — •Frank Schlawin
FM 48.1	Wed	11:00–12:00	2004	**Photonic Quantum Memories and Interfaces** — •Hugues de Riedmatten
FM 71.1	Thu	11:00–12:00	2004	**Optimal control of quantum systems** — •Steffen J. Glaser

Invited Talks

FM 3.1	Mon	11:00–11:30	Aula	**Wann, wie und wozu sollte Quantenphysik an der Schule vermittelt werden?** — •Stefan Heusler
FM 3.2	Mon	11:30–12:00	Aula	**Neue Entwicklungen in der Quantenphysik - Neue Chancen für die Lehre** — •Martin Wilkens
FM 3.3	Mon	12:00–12:30	Aula	**Quanteninformation im Physikunterricht - eine neue Möglichkeit?** — •Gesche Pospiech
FM 3.4	Mon	12:30–13:00	Aula	**Quantenmechanik für Lehramtsstudierende** — •Thomas Filk
FM 7.4	Mon	14:45–15:15	1009	**Certification and estimation of quantum randomness** — •Stefano Pironio

FM 8.1	Mon	14:00–14:30	1010	**Quantum dots as sources for quantum light** — •Peter Michler
FM 10.1	Mon	14:00–14:30	1199	**Engineered electronic states in atomic lattices and hybrid 2D systems** — •Peter Liljeroth
FM 11.1	Mon	14:00–14:30	2004	**Correlations in many-body states: The simplest constraints for their distribution** — •Jens Siewert
FM 12.1	Mon	14:00–14:30	2006	**Quantum sensors with matter waves: geodesy, navigation and general relativity** — •Philippe Bouyer
FM 13.1	Mon	14:00–14:30	3042	**Quantum Information Concepts in Open Systems** — •Bassano Vacchini
FM 14.1	Mon	14:00–14:30	3044	**Quantum simulation and computation with spins in quantum dots** — •Uditendu Mukhopadhyay, Juan P Dehollain, Vincent P. Michal, Yao Wang, Bernhard Wunsch, Christian Reichl, Werner Wegscheider, Mark S. Rudner, Eugene Demler, Lieven M. K. Vandersypen
FM 18.1	Mon	16:30–17:00	1015	**Generation of strongly correlated photons using nanofiber-coupled atoms** — Adarsh Prasad, Jakob Hinney, Klemens Hammerer, Sahand Mahmoodian, Samuel Rind, Philipp Schneeweiss, Anders S. Sørensen, Jürgen Volz, •Arno Rauschenbeutel
FM 19.1	Mon	16:30–17:00	1199	**Topological superconductivity in full shell proximitized nanowires** — •Roman Lutchyn
FM 21.1	Mon	16:30–17:00	2006	**Generative training of quantum Boltzmann machines with hidden units** — •Nathan Wiebe, Leonard Wossnig
FM 22.1	Mon	16:30–17:00	3042	**Control Engineering Taken to the Limits of Quantum Systems Theory** — •Thomas Schulte-Herbrüggen, Ville Bergholm, Witlef Wieczorek, Michael Keyl
FM 23.1	Mon	16:30–17:00	3043	**Learning to violate Bell inequality with reinforcement learning** — •Alexey Melnikov, Pavel Sekatski, Nicolas Sangouard
FM 23.2	Mon	17:00–17:30	3043	**Quantum policy gradient methods for reinforcement learning** — •Sofiene Jerbi, Hans Briegel, Vedran Dunjko
FM 27.1	Tue	11:00–11:30	Audi Max	**Frontiers in quantum acoustics** — •Andrew Cleland
FM 27.2	Tue	11:30–12:00	Audi Max	**The state of the art of quantum key distribution.** — •Hugo Zbinden
FM 27.3	Tue	12:00–12:30	Audi Max	**Towards Quantum Communication Networks using Solid-State Quantum-Light Sources** — •Tobias Heindel
FM 27.4	Tue	12:30–13:00	Audi Max	**Towards quantum networks based on single trapped atoms** — •Wenjamin Rosenfeld
FM 30.1	Tue	14:00–14:30	Aula	**Quantum Sensors on the way to commercial opportunities** — •Kai Bongs
FM 31.1	Tue	14:00–14:30	1009	**Certifying randomness from quantum black-box devices** — •Nicolas Brunner
FM 32.1	Tue	14:00–14:30	1010	**Next-generation single-photon sources for satellite-based quantum communication** — •Tobias Vogl, Ruvi Lecamwasam, Ben C. Buchler, Yuerui Lu, Ping K. Lam, Falk Eilenberger
FM 33.1	Tue	14:00–14:30	1015	**Quantum Networking, fully connected and international** — •Rupert Ursin
FM 34.1	Tue	14:00–14:30	1199	**Understanding the Interplay between Magnetism and Topology** — •Matthew Gilbert
FM 36.1	Tue	14:00–14:30	2006	**Building Trust** — •Elham Kashefi
FM 39.1	Tue	14:00–14:30	3044	**Applications of Quantum Computing with Superconducting Qubits** — •Stefan Filipp
FM 47.1	Wed	11:00–11:20	Aula	**Enabling Industrial Quantum Technology** — •Michael Förtsch
FM 47.2	Wed	11:20–11:40	Aula	**An industry perspective on Quantum Technologies** — •Nils Trautmann
FM 47.3	Wed	11:40–12:00	Aula	**A proposal for a topological phase modulator with π Berry phase shift** — •Ulrich Gaubatz
FM 47.4	Wed	12:00–12:20	Aula	**Quantum Technologies in Thales** — •Thierry Debuisschert
FM 47.5	Wed	12:20–12:40	Aula	**Opticlock: Towards a transportable and user-friendly optical single-ion clock** — •Juergen Stuhler, opticlock Consortium
FM 47.6	Wed	12:40–13:00	Aula	**Quantum-dot based single photon sources: Commercialization of near optimal solid-state sources for Quantum Applications** — •Valerian Giesz, Niccolo Somaschi

FM 51.1	Wed	14:00–14:20	Aula	**Early-stage quantum computing in an industrial context** — •Florian Neukart
FM 51.2	Wed	14:20–14:40	Aula	**Quantum communication and quantum sensing at Airbus** — •Friedhelm Serwane, Thierry Botter
FM 51.3	Wed	14:40–15:00	Aula	**Quantum Computing in the Chemical Industry - First impressions and resource estimations for quantum chemistry on quantum computers** — •Michael Kuehn, Sebastian Zanker, Peter Deglmann, Michael Marthaler, Horst Weiss
FM 51.4	Wed	15:00–15:20	Aula	**A Semiconductor Corporation View on Quantum Technologies** — •Sebastian M. Luber, Thomas Kurth
FM 51.5	Wed	15:20–15:40	Aula	**Scalable instrumentation for quantum computing** — •Sadik Hafizovic
FM 51.6	Wed	15:40–16:00	Aula	**Approach and use cases: When and where may we start to search for quantum applications?** — •Tim Leonhardt
FM 52.1	Wed	14:00–14:30	1009	**Entanglement transport in the presence of noise** — •Clemens Gneiting
FM 53.1	Wed	14:00–14:30	1010	**Efficient single photon sources for quantum information science** — •Tobias Huber, Jan Donges, Simon Betzold, Magdalena Moczała-Dusanowska, Łukasz Dusanowski, Stefan Gerhardt, Jonathan Jurkat, Andreas Pfenning, Christian Schneider, Sven Höfling
FM 54.1	Wed	14:00–14:30	1015	**Quantum memories for photons** — •Mikael Afzelius
FM 55.1	Wed	14:00–14:30	1098	**Quantum Mean Embedding of Probability Distributions** — •Jonas M. Kübler, Krikamol Muandet, Bernhard Schölkopf
FM 56.1	Wed	14:00–14:30	2004	**New quantum many-body phases enabled by ergodicity breakdown** — •Dmitry Abanin
FM 57.1	Wed	14:00–14:30	2006	**Probing and manipulating Andreev Bound States** — •Cristian Urbina, Leandro Tosi, Cyril Metzger, Marcelo F. Goffman, Hugues Pothier, Sunghun Park, Alfredo Levy Yeyati, Jesper Nygård, Peter Krogstrup
FM 58.1	Wed	14:00–14:30	3042	**Thermodynamic uncertainty relations from exchange fluctuation theorems** — •John Goold
FM 60.1	Wed	14:00–14:30	3044	**Scalable Quantum Error Correction with the Bosonic GKP Code** — •Barbara Terhal
FM 70.1	Thu	11:00–11:30	Audi Max	**Hofstadter Topology** — •Bogdan A. Bernevig
FM 70.2	Thu	11:30–12:00	Audi Max	**Topological superconductors and Majorana fermions** — •Yoichi Ando
FM 70.3	Thu	12:00–12:30	Audi Max	**Majorana bound states in hybrid superconductor-semiconductor systems** — •Karsten Flensberg
FM 70.4	Thu	12:30–13:00	Audi Max	**Status of the search for Majorana zero modes in semiconductor nanowires** — •Sergey Frolov
FM 74.1	Thu	14:00–14:30	1009	**Quantum Computing and Cryptography** — •Nico Döttling
FM 76.1	Thu	14:00–14:30	1015	**Enhancing the precision of measurements with entanglement** — •Manuel Gessner
FM 77.1	Thu	14:00–14:30	1098	**Integrating Quantum Key Distribution into Telecom Networks** — •James Dynes
FM 78.1	Thu	14:00–14:30	1199	**Quantum Information Processing using Trapped Atomic Ions and MAGIC** — Theeraphot Sriarunothai, Sabine Wölk, Gouri S. Giri, Nicolai Friis, Vedran Dunjko, Hans J. Briegel, Patrick Barthel, Patrick Huber, •Christof Wunderlich
FM 80.1	Thu	14:00–14:30	2006	**Photon-Qubit and Qubit-Qubit Interactions in Semiconductor Circuit Quantum Electrodynamics (QED)** — •Andreas Wallraff
FM 81.1	Thu	14:00–14:30	3042	**Electrostatically defined quantum devices in bilayer graphene** — •Christoph Stampfer
FM 82.1	Thu	14:00–14:30	3044	**Deep Learning Advances in Particle Physics** — •Yannik Rath, Martin Erdmann, Benjamin Fischer, Erik Geiser, Jonas Glombitza, Dennis Noll, Thorben Quast, Marcel Rieger
FM 90.1	Fri	11:00–11:30	Audi Max	**How to use quantum light to machine learn graph-structured data** — •Maria Schuld, Kamil Bradler, Robert Israel, Daiqin Su, Brajesh Gupt

FM 90.2	Fri	11:30–12:00	Audi Max	**Ensuring safety for AI methods - from basic research to Bosch applications** — •David Reeb
FM 90.3	Fri	12:00–12:30	Audi Max	**Boltzmann machines and tensor networks for simulating quantum many body systems** — •Frank Verstrate
FM 90.4	Fri	12:30–13:00	Audi Max	**Response operators in Machine Learning: Response Properties in Chemical Space** — •Anders Christensen
FM 91.1	Fri	11:00–11:40	2004	**Information Theoretic Methods in Inflationary Cosmology** — •Achim Kempf
FM 91.2	Fri	11:40–12:20	2004	**Quantum Information and Cosmic Inflation** — •Jerome Martin
FM 91.3	Fri	12:20–13:00	2004	**Collective excitations as quantum sensors for fundamental physics** — •Ivette Fuentes

Outreach Events

FM 44	Tue	20:00–21:00	Audi Max	**Outreach: Einstein-Slam**
FM 67.1–67.1	Wed	19:30–21:00	Audi Max	**Outreach: Public panel discussion (fishbowl format)**
FM 87.1–87.1	Thu	19:30–21:00	Audi Max	**Outreach: Public science evening**

Sessions

FM 1.1–1.1	Mon	8:30– 9:30	Audi Max	**Plenary Talk: Quantum Machine Learning**
FM 2.1–2.1	Mon	9:30–10:30	Audi Max	**Introductory Talk: Quantum Algorithms**
FM 3.1–3.4	Mon	11:00–13:00	Aula	**Special Session: Teaching Quantum Science**
FM 4.1–4.1	Mon	11:00–12:00	2004	**Focus Talk: Quantum Simulation**
FM 5	Mon	13:00–14:00	Aula	**Lunch Talk: Experiments for Teaching QM**
FM 6	Mon	14:00–16:00	Aula	**Panel Discussion: Teaching Quantum Science**
FM 7.1–7.7	Mon	14:00–16:00	1009	**Secure Communication & Computation I**
FM 8.1–8.7	Mon	14:00–16:00	1010	**Enabling Technologies: Sources of Quantum States of Light I**
FM 9.1–9.7	Mon	14:00–15:45	1098	**Quantum Networks: Platforms and Components I**
FM 10.1–10.6	Mon	14:00–15:45	1199	**Topology: Artificial Systems**
FM 11.1–11.7	Mon	14:00–16:00	2004	**Entanglement: Many-Body States I**
FM 12.1–12.7	Mon	14:00–16:00	2006	**Quantum Sensing: Hardware Platforms**
FM 13.1–13.7	Mon	14:00–16:00	3042	**Open and Complex Quantum Systems I**
FM 14.1–14.7	Mon	14:00–16:00	3044	**Quantum Computation: Hardware Platforms I**
FM 15.1–15.3	Mon	16:00–16:30	1114	**Poster: Teaching Quantum Science**
FM 16.1–16.8	Mon	16:30–18:30	Aula	**Teaching Quantum Science**
FM 17.1–17.6	Mon	16:30–18:00	1010	**Quantum Computation: Simulation I**
FM 18.1–18.7	Mon	16:30–18:30	1015	**Quantum Networks: Interfaces & Hybrid Systems**
FM 19.1–19.7	Mon	16:30–18:30	1199	**Topology: Majoranas**
FM 20.1–20.8	Mon	16:30–18:30	2004	**Entanglement: Many-Body States II**
FM 21.1–21.7	Mon	16:30–18:30	2006	**Quantum Computation: Algorithms**
FM 22.1–22.6	Mon	16:30–18:15	3042	**Quantum Control**
FM 23.1–23.6	Mon	16:30–18:30	3043	**Quantum & Information Science: Neural Networks, Machine Learning, and Artificial Intelligence I**
FM 24.1–24.8	Mon	16:30–18:30	3044	**Quantum Sensing: Entanglement and Beyond Shot Noise**
FM 25.1–25.1	Tue	8:30– 9:30	Audi Max	**Plenary Talk: Ion Trap based Quantum Computing**
FM 26.1–26.1	Tue	9:30–10:30	Audi Max	**Introductory Talk: Machine Learning**
FM 27.1–27.4	Tue	11:00–13:00	Audi Max	**Special Session: Quantum Networks**
FM 28.1–28.1	Tue	11:00–12:00	2004	**Focus Talk: Quantum Spectroscopy**
FM 29	Tue	12:30–13:45	2006	**Lunch Talk: Funding for Quantum Projects**
FM 30.1–30.7	Tue	14:00–16:00	Aula	**Quantum Sensing: Applications I**
FM 31.1–31.6	Tue	14:00–15:45	1009	**Secure Communication & Computation II**
FM 32.1–32.7	Tue	14:00–16:00	1010	**Enabling Technologies: Sources of Quantum States of Light II**
FM 33.1–33.7	Tue	14:00–16:00	1015	**Quantum Networks: Concepts & Applications**
FM 34.1–34.4	Tue	14:00–15:15	1199	**Topology: Solid State Systems**
FM 35.1–35.8	Tue	14:00–16:00	2004	**Entanglement: Many-Body Dynamics I**
FM 36.1–36.8	Tue	14:00–16:15	2006	**Quantum Computation: Benchmarking and Certification**

FM 37.1–37.8	Tue	14:00–16:00	3042	**Open and Complex Quantum Systems II**
FM 38.1–38.8	Tue	14:00–16:00	3043	**Enabling Technologies: Quantum Dots, Quantum Wires, Point Contacts and Excitonic Systems**
FM 39.1–39.7	Tue	14:00–16:00	3044	**Quantum Computation: Hardware Platforms II**
FM 40.1–40.11	Tue	16:30–18:30	Tents	**Poster: Quantum Computation: Hardware Platforms**
FM 41.1–41.28	Tue	16:30–18:30	Tents	**Poster: Quantum Sensing**
FM 42.1–42.13	Tue	16:30–18:30	Tents	**Poster: Quantum Computation**
FM 43	Tue	18:30–20:00	Aula	**Networking event of the Working Group on Industry and Business (AIW) with free beer and pretzels, including the BMBF award ceremony of the "Quantum Futur Award 2019"**
FM 44	Tue	20:00–21:00	Audi Max	**Outreach: Einstein-Slam**
FM 45.1–45.1	Wed	8:30– 9:30	Audi Max	**Plenary Talk: Industry**
FM 46.1–46.1	Wed	9:30–10:30	Audi Max	**Introductory Talk: Quantum Sensing**
FM 47.1–47.6	Wed	11:00–13:00	Aula	**Industry I: Photonics**
FM 48.1–48.1	Wed	11:00–12:00	2004	**Focus Talk: Quantum Memories & Interfaces**
FM 49	Wed	12:30–13:45	2006	**Lunch Talk: Centers of Quantum Information Science**
FM 50.1–50.2	Wed	13:15–13:55	Audi Max	**Lunch Talk: Awards and Challenges**
FM 51.1–51.6	Wed	14:00–16:00	Aula	**Industry II: Computing**
FM 52.1–52.4	Wed	14:00–15:15	1009	**Entanglement: Transport**
FM 53.1–53.7	Wed	14:00–16:00	1010	**Enabling Technologies: Sources of Quantum States of Light III**
FM 54.1–54.7	Wed	14:00–16:00	1015	**Quantum Networks: Quantum Memory and Gates**
FM 55.1–55.5	Wed	14:00–15:30	1098	**Quantum & Information Science: Neural Networks, Machine Learning, and Artificial Intelligence II**
FM 56.1–56.7	Wed	14:00–16:00	2004	**Entanglement: Many-Body Dynamics II**
FM 57.1–57.7	Wed	14:00–16:00	2006	**Quantum Sensing: Spectroscopy I**
FM 58.1–58.7	Wed	14:00–16:00	3042	**Quantum Information Concepts in Thermodynamics**
FM 59.1–59.8	Wed	14:00–16:00	3043	**Enabling Technologies: Quantum Dots and Superconductivity-based Systems**
FM 60.1–60.7	Wed	14:00–16:00	3044	**Quantum Computation: Fault Tolerance & Error Correction**
FM 61.1–61.3	Wed	16:30–18:30	Aula	**Industry III: The Future of High Performance Computing (Presentations plus Panel Discussion)**
FM 62.1–62.6	Wed	16:30–18:30	Tents	**Poster: Open and Complex Quantum Systems**
FM 63.1–63.23	Wed	16:30–18:30	Tents	**Poster: Enabling Technologies: Quantum Materials, Quantum Dots, Quantum Wires, Point Contacts and Superconducting Systems**
FM 64.1–64.6	Wed	16:30–18:30	Tents	**Poster: Topology**
FM 65.1–65.6	Wed	16:30–18:30	Tents	**Poster: Quantum & Information Science**
FM 66.1–66.8	Wed	16:30–18:30	Tents	**Poster: Entanglement**
FM 67.1–67.1	Wed	19:30–21:00	Audi Max	**Outreach: Public panel discussion (fishbowl format)**
FM 68.1–68.1	Thu	8:30– 9:30	Audi Max	**Plenary Talk: Silicon Based Quantum Computing**
FM 69.1–69.1	Thu	9:30–10:30	Audi Max	**Introductory Talk: Hybrid Quantum Computation Platform**
FM 70.1–70.4	Thu	11:00–13:00	Audi Max	**Special Session: Topology**
FM 71.1–71.1	Thu	11:00–12:00	2004	**Focus Talk: Quantum Control**
FM 72	Thu	12:30–13:45	2006	**Lunch Talk: Start-ups**
FM 73.1–73.8	Thu	14:00–16:00	Aula	**Quantum Sensing: Applications & Spectroscopy**
FM 74.1–74.5	Thu	14:00–15:30	1009	**Secure Communication & Computation III**
FM 75.1–75.7	Thu	14:00–15:45	1010	**Quantum Computation: Simulation II**
FM 76.1–76.5	Thu	14:00–15:30	1015	**Entanglement: Spectroscopy**
FM 77.1–77.6	Thu	14:00–15:45	1098	**Quantum Networks: Platforms and Components II**
FM 78.1–78.5	Thu	14:00–15:30	1199	**Quantum Computation: Hardware Platform III**
FM 79.1–79.6	Thu	14:00–15:30	2004	**Entanglement: Neural Networks for Many-Body Dynamics**
FM 80.1–80.7	Thu	14:00–16:00	2006	**Enabling Technologies: Cavity QED**
FM 81.1–81.7	Thu	14:00–16:00	3042	**Enabling Technologies: Quantum Materials**
FM 82.1–82.6	Thu	14:00–15:45	3044	**Quantum & Information Science: Neural Networks, Machine Learning, and Artificial Intelligence III**
FM 83.1–83.14	Thu	16:30–18:30	Tents	**Poster: Enabling Technologies Sources of Quantum States of Light**
FM 84.1–84.19	Thu	16:30–18:30	Tents	**Poster: Quantum Networks**
FM 85.1–85.8	Thu	16:30–18:30	Tents	**Poster: Enabling Technologies: Cavity QED**
FM 86.1–86.9	Thu	16:30–18:30	Tents	**Poster: Secure Communication & Computation**

FM 87.1–87.1	Thu	19:30–21:00	Audi Max	**Outreach: Public science evening**
FM 88.1–88.1	Fri	8:30– 9:30	Audi Max	**Plenary Talk: Extreme Entanglement**
FM 89.1–89.1	Fri	9:30–10:30	Audi Max	**Introductory Talk: Quantum Light Sources**
FM 90.1–90.4	Fri	11:00–13:00	Audi Max	**Special Session: Quantum Physics for AI & AI for Quantum Physics**
FM 91.1–91.3	Fri	11:00–13:00	2004	**Special Session: Quantum Information Concepts in Astrophysics**

FM 1: Plenary Talk: Quantum Machine Learning

Time: Monday 8:30–9:30 Location: Audi Max

Plenary Talk FM 1.1 Mon 8:30 Audi Max
Tensor Networks for Classical and Quantum Machine Learning — •Miles Stoudenmire — Flatiron Institute, New York, NY, USA

Tensor networks are a powerful tool developed in physics to describe wavefunctions, but which could have broad applicability outside of physics too. One interesting area of application is machine learning, where the adjustable parameters or "weights" of the function to be learned can be viewed as a large tensor, represented as a tensor network. I will review some empirical and theoretical results on the use of tensor networks to learn classical data. One interesting advantage of tensor network machine learning models is they can be implemented on either classical or quantum hardware, since they are precisely equivalent to class of quantum circuits. This points toward some interesting directions, such as whether a quantum computer can be viewed as a device for contracting tensors, and how to best define the boundary beyond which quantum computers become useful.

FM 2: Introductory Talk: Quantum Algorithms

Time: Monday 9:30–10:30 Location: Audi Max

Introductory Talk FM 2.1 Mon 9:30 Audi Max
Quantum Algorithms — •Ronald de Wolf — CWI and University of Amsterdam

This talk will give an introduction to quantum algorithms, which are the core of the "software" of quantum computers. We will go into algorithms relevant for cryptography (such as Shor's factoring algorithm) and for optimization tasks (such as Grover search and the HHL algorithm). We will also briefly look at known limitations of quantum computers.

FM 3: Special Session: Teaching Quantum Science

Time: Monday 11:00–13:00 Location: Aula

Invited Talk FM 3.1 Mon 11:00 Aula
Wann, wie und wozu sollte Quantenphysik an der Schule vermittelt werden? — •Stefan Heusler — Universität Münster, Institut für Didaktik der Physik

Quantenphysik ist die Basis aktueller Technologien wie dem Laser oder dem MRT, und von Zukunftstechnologien wie dem Quanteninternet und Quantencomputern.

Trotz dieser rasanten Entwicklungen ist der Zugang zur Quantenphysik im Schulunterricht oftmals nach wie vor geprägt von halbklassischen Modellen wie dem Bohrschen Atommodell, und historischen Zugängen wie dem Fotoeffekt. In diesem Übersichtsvortrag werden neuere didaktische Ansätze zur Vermittlung von moderner Quantenphysik in Theorie und Experiment vorgestellt, insbesondere unter Einsatz digitaler Medien. Hierbei diskutieren wir sowohl formelles als auch informelles Lernen und die Frage, ob und wie diese Zugänge in der Schule integriert werden könnten.

Invited Talk FM 3.2 Mon 11:30 Aula
Neue Entwicklungen in der Quantenphysik - Neue Chancen für die Lehre — •Martin Wilkens — Universität Potsdam

Der "Information-Turn" der Quantenmechanik reflektiert nicht nur auf die jüngsten Anwendungen quantenmechanischer Prinzipien für die Informationsverarbeitung, sondern bietet insbesondere alternative bzw. ergänzende Zugangswege für die Lehre, die besonders für jüngere SchülerInnen und StudentInnen attraktiv erscheinen. Schon am einzelnen Qubit oder an Paaren von Qubits lassen sich ohne allzu großen mathematischen Ballast die ungewöhnlichen Effekt der Quantenmechanik erläutern. Technologisch umgesetzt schaut man hier auf Anwendungen, die üblicherweise der Science Fiction zugeordnet werden. Andererseits werfen die Effekte der linearen Überlagerung und der Verschränkung Fragen auf, die eher der Philosophie bzw Metaphysik zugeordnet werden können. Anhand ausgesuchter Beispiele wird im Vortrag gezeigt, wie sich in der Quanteninformatik die Hochzeit von Science Fiction und Metaphysik vollzieht, und warum sich gerade diese Paarung für SchülerInnen und StudentInnen als besonders zugkräftig erweisen könnte.

Invited Talk FM 3.3 Mon 12:00 Aula
Quanteninformation im Physikunterricht - eine neue Möglichkeit? — •Gesche Pospiech — TU Dresden, Dresden

Quanteninformation und damit verbundene Technologien gewinnen seit mittlerweile drei Jahrzehnten zunehmend an Bedeutung und weisen immer raschere Fortschritte auf. Entsprechend finden sich populärwissenschaftliche Berichte hierzu immer wieder in den Medien. Daher scheint die Zeit reif, Quanteninformation als ein Thema des schulischen Physikunterrichts zu etablieren und so zugleich zu einer Modernisierung seiner Inhalte beizutragen.

In diesem Vortrag wird diskutiert, wie im Kontext der Quanteninformation sowohl die grundlegenden Charakteristika der Quantenphysik als auch ihre Bedeutung beispielsweise für Quantenkryptographie oder Quantencomputer vermittelt werden können. Damit soll auch im Sinne einer Allgemeinbildung ein Beitrag zum kompetenten Umgang mit entsprechenden Medienberichten geleistet werden.

Invited Talk FM 3.4 Mon 12:30 Aula
Quantenmechanik für Lehramtsstudierende — •Thomas Filk — Institute of Physics, University of Freiburg, Germany

Eine eigene Vorlesung "Quantenmechanik für Lehramtsstudierende" - ist das notwendig? Die Anforderungen an zukünftige Lehrer und Lehrerinnen gerade in Bezug auf die Kenntnisse zur Quantentheorie sind größtenteils andere als die an zukünftige Forscher oder Produktentwickler, und von daher erscheint eine eigene Vorlesung mit eigenen Schwerpunkten und Zielen durchaus sinnvoll.

Die besonderen Anforderungen für die zukünftigen Lehrer und Lehrerinnen beziehen sich unter anderem auf grundlegende Konzepte, wissenschaftsphilosophische Aspekte des heutigen Formalismus der Quantentheorie und natürlich auf das Problem der Elementarisierung, das gerade bei einer Theorie, die sich weitgehend über ihren mathematischen Formalismus definiert, besonders schwierig ist.

Darüber hinaus werde ich zeigen, dass sich die Polarisationsfreiheitsgrade von Licht zur Einführung fast aller Konzepte der Quantentheorie eignen, bis hin zu komplementären Observablen und Unschärferelationen. Dadurch lassen sich Parallelen zur Wellenmechanik ziehen, die es oft erlauben, auch bei "heiklen" Fragen von Schülern und Schülerinnen durch einen Perspektivenwechsel fundiertere Antworten geben zu können.

FM 4: Focus Talk: Quantum Simulation

Time: Monday 11:00–12:00 Location: 2004

Focus Talk FM 4.1 Mon 11:00 2004

Quantum simulation with ultracold atoms in optical lattices — •Monika Aidelsburger — Fakultät für Physik, Ludwig-Maximilians-Universität München, Germany — Munich Center for Quantum Science and Technology (MCQST), München, Germany

Ultracold atoms can be trapped in optical lattices to form artificial crystalline systems with highly-tunable parameters. They constitute powerful experimental platforms, which enable the controlled simulation of a variety of phenomena ranging from condensed matter to statistical physics. These systems are well isolated from the environment and the dynamic controllability of their parameters naturally facilitates the investigation of complex out-of-equilibrium phenomena. Moreover, high-resolution imaging techniques provide unprecedented insight into the fundamental physics of quantum many-body systems via the direct observation of the underlying microscopic processes.

A promising new direction was recently opened with the successful realization of paradigmatic topological lattice models. Topological states of matter exhibit unique conductivity properties, one of the most prominent examples being the quantum Hall effect. I will discuss how topological systems can be engineered with charge-neutral atoms in optical lattices, explain related experiments on topological phenomena and present ongoing efforts towards the engineering of complete gauge theories.

FM 5: Lunch Talk: Experiments for Teaching QM

Time: Monday 13:00–14:00 Location: Aula

Curious about simple experiments for teaching quantum information science?

Which experiments can be presented in lectures? Which are suited for lab-courses? With ever improving technology for experiments in quantum physics more and more of them reach a level, where the stability, robustness, and simplicity is sufficient to be useful for teaching applications. Here you find, amongst others, a source for single photons based on quantum-dots, as well as hand-on experiments for demonstrating the special properties of entangled photon pairs, and for teaching the basics of quantum cryptography.

FM 6: Panel Discussion: Teaching Quantum Science

Time: Monday 14:00–16:00 Location: Aula

Die Quantenphysik erfährt derzeit einen grundlegenden Paradigmenwechsel. In der „zweiten Quantenrevolution“ rückt der Fokus auf technische Anwendungen, bei denen Quanteneffekte wie Superposition und Verschränkung genutzt werden. Schlagworte wie Qubits, Quantencomputer und Quantenkryptographie sind bereits häufig in der öffentlichen Diskussion zu hören.

Die Quantenphysik ist seit vielen Jahren ein etablierter Teil des Physikunterrichts in der Oberstufe. In der Podiumsdiskussion wird erörtert, ob die „Quantenphysik 2.0“ auch einen „Quantenphysikunterricht 2.0“ nach sich ziehen muss. Sollen die Quantentechnologien zukünftig eine größere Rolle im Physikunterricht der Oberstufe spielen? In welcher Form kann das gelingen und wie sehen zeitgemäße Vermittlungskonzepte aus? Expertinnen und Experten aus Fachphysik, Fachdidaktik, Schule und anderen Institutionen diskutieren, wie der Quantenphysikunterricht der Zukunft aussehen könnte.

FM 7: Secure Communication & Computation I

Time: Monday 14:00–16:00 Location: 1009

FM 7.1 Mon 14:00 1009

A theoretical framework for PUFs and QR-PUFs — •Giulio Gianfelici, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

We introduce a theoretical framework to describe Physical Unclonable Functions (PUFs), including extensions to quantum protocols, so-called Quantum Readout PUFs (QR-PUF).

(QR-) PUFs are physical systems with challenge-response behaviour intended to be hard to clone or simulate. Their use has been proposed in several cryptographic protocols, with particular emphasis on authentication.

We design a general authentication protocol, which is applicable to different physical implementations of (QR-) PUFs, and discuss the main properties which quantify the quality of such devices.

Our purpose is to find an agreement about theoretical assumptions and definitions behind the intuitive ideas of (QR-) PUFs, improving our ability to characterise the security of such devices in cryptographic protocols and to compare the performances between different (QR-) PUFs.

Such an agreement will allow us to derive security thresholds for (QR-) PUF authentication and possibly to develop further new authentication protocols.

FM 7.2 Mon 14:15 1009

Parameter regimes for surpassing the PLOB bound with error-corrected qudit repeaters — •Daniel Miller, Timo Holz, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

A potential quantum internet would open up the possibility of realizing numerous new applications, including provably secure communication. Since losses of photons limit long-distance, direct quantum communication and widespread quantum networks, quantum repeaters are needed. The so-called PLOB-repeaterless bound [Pirandola et al., Nat. Commun. 8, 15043 (2017)] is a fundamental limit on the quantum capacity of direct quantum communication. Here, we analytically derive the quantum-repeater gain for error-corrected, one-way quantum repeaters based on higher-dimensional qudits for two different physical encodings: Fock and multimode qudits. We identify parameter regimes in which such quantum repeaters can surpass the PLOB-repeaterless bound and systematically analyze how typical parameters manifest themselves in the quantum-repeater gain. This benchmarking provides a guideline for the implementation of error-corrected qudit repeaters.

We have uploaded a preprint with the same title: https://arxiv.org/abs/1906.05172

FM 7.3 Mon 14:30 1009

Secure quantum remote state preparation of squeezed microwave states — •S. Pogorzalek[1,2], K. G. Fedorov[1,2], M. Renger[1,2], Q.-M. Chen[1,2], M. Partanen[1], E. Xie[1,2], A. Marx[1], F. Deppe[1,2,3], and R. Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

Quantum communication protocols employ nonclassical correlations as a resource for an efficient transfer of quantum states. As a fundamental protocol, remote state preparation (RSP) aims at the preparation of a known quantum state at a remote location using classical communication and quantum entanglement. We use flux-driven Josephson parametric amplifiers and linear circuit elements in order to generate propagating two-mode squeezed (TMS) microwave states acting as our quantum resource. Combined with a feedforward, we use the TMS states to experimentally demonstrate the continuous-variable RSP protocol by preparing single-mode squeezed states at a distant location [1]. Finally, security of RSP is investigated by using the concept of the one-time pad and measuring the von Neumann entropies.

We acknowledge support by Germany's Excellence Strategy EXC-2111-390814868, Elite Network of Bavaria through the program ExQM, the European Union via the Quantum Flagship project QMiCS (Grant No. 820505).

[1] S. Pogorzalek *et al.*, Nat. Commun. **10**, 2604 (2019).

Invited Talk FM 7.4 Mon 14:45 1009

Certification and estimation of quantum randomness — •Stefano Pironio — Laboratoire d'Information Quantique, Université libre de Bruxelles (ULB), Belgium

Contrarily to classical physics, quantum physics allows for the generation of numbers which are random even to a potential adversary that could have a complete knowledge of the randomness generating device. Furthermore, the generated entropy can be certified and estimated even if the devices are not entirely trusted thanks to the concept of self-testing. In this talk, I review and explain the theoretical framework used to assess the entropy generated by such self-testing quantum devices.

FM 7.5 Mon 15:15 1009

Quantum random number generation by phase diffusion in gain-switched semiconductor laser - new insights — •Sakshi Sharma, Brigitta Septriani, Oliver de Vries, and Markus Gräfe — Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Jena, Germany

Randomness is essential for applications such as cryptography, stochastic simulation, gambling, and fundamental science experiments. Conventionally, random numbers are generated from mathematical algorithms using Pseudo-random number generators. We are interested in tackling this problem with quantum technology. Phase diffusion in spontaneous emission events is a quantum phenomenon with inherent randomness. Implementations of this scheme using pulsed lasers can yield high-speed quantum random number generation (QRNG). The general interest in the laser phase diffusion QRNG setup has been motivated by the speed of the random number generations. We reanalyze the process of phase diffusion based QRNG and give an intuitive explaining picture of the underlying physics. Our findings show that a pulsed process is beneficial over the continuous-wave approach and give an upper bound of the maximum random bit rate for a given experimental setting. Furthermore, we show how the QRNG probability distribution is influenced by several experimental factors such as the quality of the interference process and the noise in the detection system. Our theoretical, as well as experimental findings can help to find physical standards for QRNG verification rather than the ones based on classical statistical information theory.

FM 7.6 Mon 15:30 1009

Device-independent secret key rate from optimized Bell inequality violation — •Sarnava Datta, Timo Holz, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätstraße 1, D-40225, Düsseldorf, Germany

We introduce a Device-Independent Quantum Key Distribution(DIQKD) scenario where a Bell inequality (BI) will be constructed fromthe performed measurement data instead of using a predetermined BI. Given the observed data of a DIQKD protocol involving n parties, m measurement settings per party and k outcomes per measurement, our goal is to find an optimal (n,m,k) BI which maximizes the achievable DI secret key rate [1].

References: [1] L. Masanes, S. Pironio, and A. Acin, *Secure device-independent quantum key distribution with causally independent measurement devices,* Nature Communications, vol. 2, p. 238, 2011.

FM 7.7 Mon 15:45 1009

Bipartite and multipartite QKD via single-photon interference — •Federico Grasselli[1], Álvaro Navarrete[2], Marcos Curty[2], Hermann Kampermann[1], and Dagmar Bruss[1] — [1]Heinrich-Heine-Universität, Düsseldorf, Germany — [2]Escuela de Ingenieria de Telecomunicación, University of Vigo, Spain

Twin-Field (TF) QKD has been proven to beat the point-to-point private capacity of a lossy quantum channel, thanks to performing single-photon interference in an untrusted node. We focus on the TF-QKD protocol introduced by Curty et al., whose security relies on the estimation of the detection statistics of Fock-states through the decoy-state method. We derive analytical bounds on these quantities assuming either two, three or four independent decoy intensity settings for each party, and we investigate the protocol's performance (arXiv:1902.10034). We show that two decoy intensity settings are enough to beat the point-to-point private capacity of the channel, that the protocol is fairly robust against uncorrelated intensity fluctuations of the optical pulses and that one can extract a secret key even when the losses in the two channels are highly asymmetric.

We then generalize the protocol to the multipartite scenario, by devising a conference key agreement (CKA) protocol where the users simultaneously distill a secret conference key through single-photon interference. The new CKA is better suited to high-loss scenarios than previous multipartite QKD schemes and employs for the first time a W-class state as its entanglement resource. We compare its performance with the iterative use of bipartite QKD protocols.

FM 8: Enabling Technologies: Sources of Quantum States of Light I

Time: Monday 14:00–16:00 Location: 1010

Invited Talk FM 8.1 Mon 14:00 1010

Quantum dots as sources for quantum light — •Peter Michler — University of Stuttgart, Institute for Semiconductor Optics and Functional Interfaces, Stuttgart, Germany

Semiconductor quantum dots (QD) are appealing as a platform for the generation of ultra-bright and pure single and entangled photon pairs. Applying resonant π-pulse excitation, coherent photons are obtained on-demand, being indistinguishable for successively emitted photons. However, in solid state systems, fluctuating magnetic and electric fields in the mesoscopic environment of a quantum emitter cause emission frequency drifts over several time scales. Even for Fourier-limited photons, these fluctuations broaden the emission spectrum and translate in the observation of reduced indistinguishability once larger time-differences between consecutive photons are considered.

In my talk, I will present a comprehensive study on fluctuations in the emission frequency of single quantum dots under resonant π-pulse excitation. Slow-light spectroscopy is introduced which reveals the total time dependence of spectral disusion processes in a single photon-correlation measurement. This technique will serve as a fast and reliable tool for quantifying the effects of frequency fluctuations, especially to predict and understand the time-dependent photon indistinguishability. Furthermore, recent developments on QD telecom-wavelength quantum light sources are reported.

FM 8.2 Mon 14:30 1010

Deterministic integration of QDs into on-chip multimode interference couplers via in-situ electron beam lithography — Peter Schnauber[1], •Johannes Schall[1], Samir Bounouar[1], Jin-Dong Song[2], Theresa Höhne[3], Sven Burger[3], Tobias Heindel[1], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Korea Institute of Science and Technology, Seoul, Korea — [3]Zuse Institut Berlin, Freie Universität Berlin, Berlin, Germany

The deterministic integration of quantum emitters into on-chip photonic elements is crucial for the implementation of scalable on-chip quantum circuits. Recent activities include multistep-lithography [1] as well as AFM tip transfer [2]. Here we report on the deterministic integration of single QDs into on-chip beam splitters using single step in-situ electron beam lithography [3]. In order to realize 50/50 coupling elements acting as central building blocks of on-chip quantum circuits we chose tapered multimode interference (MMI) splitters which feature relaxed fabrication tolerances and robust 50/50 splitting ratio. We demonstrate the functionality of the deterministic QD-waveguide structures by μPL spectroscopy and photon cross-correlation between the two MMI output ports. The latter confirms single-photon emission and on-chip splitting associated with g(2)(0) < 0.5 [4].

[1] Coles et al., Nature Communications 7, 11183 (2016)
[2] Zadeh et al., Nano Letters 16, 2289 (2016)
[3] Gschrey et al., Nature Communications 6, 7662 (2015)
[4] Schnauber et al., Nano Letters 18, 2336 (2018)

FM 8.3 Mon 14:45 1010

Towards Synchronization of Photons from a SPDC Source — •Janik Wolters[1,3], Chris Müller[2], Gianni Buser[3], Roberto Mottola[3], Tim Kroh[2], Sven Ramelow[2], Oliver Benson[2], and Philipp Treutlein[3] — [1]DLR Institut für optische Sensorsysteme, Berlin — [2]HU Berlin, Institut für Physik — [3]Universität Basel, Departement Physik

Photonic quantum technologies have a striking need for photon sources that emit coherent, single mode photons, on demand with high efficiency, and can be built in a reproducible fashion. To satisfy this need, we follow a compound approach [1]: The probabilistic generation of photons by spontaneous parametric downconversion (SPDC) [2] is synchronized with an atomic vapor quantum memory [3].

As a key component of the envisioned compound source, we present an efficient, bright and robust source of photons at the rubidium D1-line (795 nm), based on non-degenerate SPDC in a monolithic cavity.

First experimental results on combining the source with a previously developed Rb vapor memory [3] are presented. Single photons are stored and read out with a signal to noise ratio well above unity. Second order correlation measurements reveal the preservation of nonclassicality after photon readout.

[1] J. Nunn, et al., *Phys. Rev. Lett.* **110**, 133601 (2013).
[2] A. Ahlrichs et al., *Applied. Phys. Lett.* **108**, 021111 (2016).
[3] J. Wolters et al., *Phys. Rev. Lett.* **119** 060502 (2017).

FM 8.4 Mon 15:00 1010

Photonic Quantum Gases in Microstructured Potentials for Light — •Andreas Redmann[1], Christian Kurtscheid[1], David Dung[1], Julian Schmitt[1,2], Frank Vewinger[1], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn — [2]present address: Department of Physics, University of Cambrigde, Cambridge, United Kingdom

In earlier work, Bose-Einstein Condensation of light has been realised in a dye-filled optical microcavity at room temperature. A low-frequency cutoff is introduced by the short mirror spacing and thermal contact to the dye solution is obtained by repeated absorption and re-emission cycles on the dye molecules. Here we report on advances in a spatially resolved delamination-based adaptive optics technique to imprint arbitrarily shaped trapping potentials for light in optical dye microcavities. To characterize the imprinting technique, we have studied the mirror reflectivity versus the delamination height. At present, we have thermalized a photon gas in the low-energy spatial superposition state of a double-well potential, which allows us to demonstrate irreversible splitting of light by cooling. Our technique holds promise for the generation of highly entangled optical many body states.

FM 8.5 Mon 15:15 1010

Heralded dissipative preparation of nonclassical states in a Kerr oscillator — •Martin Koppenhöfer, Christoph Bruder, and Niels Lörch — Department of Physics, University of Basel, Basel, Switzerland

We present a heralded state preparation scheme for driven nonlinear open quantum systems. The protocol is based on a continuous photon counting measurement of the system's decay channel. When no photons are detected for a period of time, the system has relaxed to a measurement-induced pseudo-steady state. We illustrate the protocol by the creation of states with a negative Wigner function in a Kerr oscillator, a system whose unconditional steady state is strictly positive.

FM 8.6 Mon 15:30 1010

D-dimensional frequency-time entangled cluster states with on-chip frequency combs — •Michael Kues[1,2], Christian Reimer[2,3], Stefania Sciara[2,4], Piotr Roztocki[2], Mehedi Islam[2], Luis Romero Cortés[2], Yanbing Zhang[2], Bennet Fisher[2], Sébastian Loranger[5], Raman Kashyap[5], Alfonso Cino[4], Sai T. Chu[6], Brent E. Little[7], David J. Moss[8], Lucia Caspani[9], William J. Munro[10,11], José Azaña[2], and Roberto Morandotti[2,12,13] — [1]Hannover Center for Optical Technologies — [2]Institut National de la Recherche Scientifique — [3]HyperLight Corporation — [4]University of Palermo — [5]Polytechnique Montreal — [6]City University of Hong Kong — [7]Chinese Academy of Science — [8]Swinburne University of Technology — [9]University of Strathclyde — [10]NTT Corporation — [11]National Institute of Informatics — [12]University of Electronic Science and Technology of China — [13]ITMO University

Cluster states, a specific class of multi-partite entangled states, are of particular importance for quantum science, as such systems are equivalent to the realization of one-way quantum computers. Here, we demonstrated the generation of d-level cluster states using a high-dimensional time-frequency-domain approach in combination with a deterministic controlled phase gate. We then implemented d-level measurement-based quantum computing operations and showed the state*s high tolerance towards noise.

FM 8.7 Mon 15:45 1010

Non-Gaussian Continuous-Variable Graph States — •Mattia Walschaers, Young-Sik Ra, Adrien Dufour, Claude Fabre, Valentina Parigi, and Nicolas Treps — Laboratoire Kastler Brossel - Sorbonne Université, CNRS, Ecole Normale Supérieure, Collège de France, Paris, France

Graph states are the backbone of measurement-based continuous-variable quantum computation. However, experimental realizations of these states induce Gaussian measurement statistics for the field quadratures, which poses a barrier to obtain a genuine quantum advantage. In this contribution, we propose mode-selective photon subtraction as an experimentally feasible pathway to introduce non-Gaussian features in such continuous-variable graph states. In particular, the induced non-Gaussian properties are shown to spread up to next-to-nearest neighbours of the graph's vertex in which the photon was subtracted. Finally, we explore the importance of entanglement in this transfer of non-Gaussianity, as compared to what can be achieved with classical light or classical correlations.

FM 9: Quantum Networks: Platforms and Components I

Time: Monday 14:00–15:45 Location: 1098

FM 9.1 Mon 14:00 1098

Fabrication of Diamond Membranes for Photonic Structures — •Julia Heupel, Johann Peter Reithmaier, and Cyril Popov — Institute of Nanostructure Technologies and Analytics, Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Due to its exceptional physical and chemical characteristics, diamond in a form of thin membranes is a particularly promising material for high quality photonic devices. In this work we address at first the fabrication of two-dimensional photonic crystal slabs utilizing nanocrystalline diamond (NCD) membranes deposited on silicon dioxide/silicon substrates. For adjusting the NCD film thickness as well as for smoothening the intrinsically rough surface, a planarization process utilizing polymerized spin-on glass (SOG) was developed. The photonic crystal structures were prepared in NCD samples with planarized surface by means of electron beam lithography (EBL) and inductively coupled plasma reactive ion etching (ICP RIE). By underetching of the sacrificial silicon dioxide layer with a hydrofluoric acid solution, the photonic crystals were suspended in air. Additionally, we report on the structuring progress for thin monocrystalline diamond (MCD) membranes by ICP RIE, utilizing a diamond bulk mask with angled holes as an etch mask and different etching mixtures.

FM 9.2 Mon 14:15 1098

Demonstration of ultra stable single quantum defects in silicon carbide nanophotonics structures — •Charles Babin, Timo Goerlitz, Naoya Moriaka, Roland Nagy, Rainer Stöhr, Matthias Niethammer, Yu-Chen Chen, Florian Kaiser, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology IQST, Germany

Solid state quantum systems with optically interfaced spins are promising platforms for quantum information processing. A scalable system should be insensitive to the environment, and emit a large fraction of photons resonantly. [1]. As we have recently shown, those criteria are met by the silicon vacancy center (VSi) in silicon carbide [2].

A remaining bottleneck is the low fluorescence rate, which is limited by a strong phonon coupling to a metastable state manifold. Further, the associated spin flip processes represent a limitation for the single shot readout fidelity. This talk addresses strategies to overcome these issues. I will show the first promising results on the stability of single defects inside nano-waveguide structures. This marks the first step toward the incorporation of single emitters in nano-photonics cavities to increase fluorescence rates via Purcell enhancement. I will also present a pathway to realize a deterministic readout of the electron spin via a nuclear spin memory [3].

[1] David D. Awschalom, Ronald Hanson, Jörg Wrachtrup & Brian B. Zhou, Nature Photonics 12, 516*527 (2018)

[2] R. Nagy & al., Nature Communications 10, 1954 (2019)

[3] P. Neuman& al., Science 329, 542*544 (2010)

FM 9.3 Mon 14:30 1098

Remote two-Photon interference in the telecom C-band of frequency converted quantum dots — •Simone Luca Portalupi[1], Jonas H. Weber[1], Benjamin Kambs[2], Jan Kettler[1], Simon Kern[1], Julian Maisch[1], Hueseyin Vural[1], Michael Jetter[1], Christoph Becher[2], and Peter Michler[1] — [1]IHFG-University of Stuttgart, IQST and SCoPE, Stuttgart, Germany — [2]Fachrichtung Physik, Universität des Saarlandes, Saarbrücken, Germany

Nowadays, efforts are made to transfer quantum technology from laboratory-based demonstrations to real world applications, such as the implementation of quantum networks for the secure transmission of information over long distances. Within the required components, sources of non-classical light are of key importance. Semiconductor quantum dots are one of the most promising candidates for the generation of single, indistinguishable, and entangled photons. Currently, the best emitters are operating well inside the near infrared regime (∼780-900 nm), so not compatible with existing silica-based fibre networks. Here we make use of quantum frequency conversion (QFC) to change the wavelength of the photons emitted by two distinct quantum dots from ∼900 nm to ∼1550 nm. We perform two-photon interference between two remote emitters to prove one of the fundamental quantum operations needed in future quantum networks. We prove that the QFC does not modify the photon properties, making this approach very appealing in realistic long-distance quantum applications [1].

[1] J. H. Weber, et al. Nat. Nanotechnol. 14, 23 (2019).

FM 9.4 Mon 14:45 1098

High-repetition-rate frequency comb conversion in synchronously driven non-centrosymmetric optical microresonators — •Jan Szabados[1], Ingo Breunig[1,2], and Karsten Buse[1,2] — [1]Laboratory for Optical Systems, Department of Microsystems Engineering - IMTEK, University of Freiburg, Georges-Köhler-Allee 102, D - 79110 Freiburg, Germany — [2]Fraunhofer Institute for Physical Measurement Techniques IPM, Heidenhofstraße 8, D - 79110 Freiburg, Germany

We demonstrate the broadband conversion of a high-repetition rate frequency comb from the near-infrared (NIR) to the mid-infrared (MIR), visible (VIS) and ultraviolet (UV) spectral ranges. The employed lithium niobate microresonators are synchronously pumped by a frequency comb with a repetition rate in excess of 10 GHz and pico- to femtosecond pulse duration. Cascaded second-order nonlinear-optical processes transfer significant parts of the fundamental frequency comb to harmonic and sub-harmonic optical frequencies. This way, the second and the third harmonics in the visible and the fourth harmonic in the ultra-violet spectral region are generated. Also, subharmonic generation of the fundamental comb lines into the mid-infrared spectral range via degenerate parametric oscillation is demonstrated. Nondegenerate processes enable wavelength-tunable signal- and idler-comb generation. Furthermore, first steps towards generating frequency combs based purely on second-order nonlinearities will be discussed.

FM 9.5 Mon 15:00 1098

Adiabatic frequency conversion in high-Q lithium niobate whispering gallery resonators — •Yannick Minet[1], Luís Reis[1], Ingo Breunig[1,2], and Karsten Buse[1,2] — [1]Laboratory for Optical Systems, Department of Microsystems Engineering, IMTEK, University of Freiburg, Georges- Köhler-Allee 102, D-79110 Freiburg, Germany — [2]Fraunhofer Institute for Physical Measurement Techniques IPM, Heidenhofstraße 8, D-79110 Freiburg, Germany

Over the past two decades, optical frequency conversion techniques with whispering gallery resonators (WGRs) have evolved remarkably. The frequency conversion process is mostly based on the nonlinear response of material polarization caused by intense laser light. For example, in mm-sized WGRs made of non-centrosymmetric materials, tunable optical parametric oscillators have been realized. Another way for frequency conversion is the so-called adiabatic tuning. Here, the optical path length of the circumference of the resonator is changed during its ringdown time. This induces a frequency shift for the circulating light. An advantage of adiabatic tuning is, in contrast to nonlinear optical conversion methods, that this process has an efficiency of 100 %. So far, adiabatic tuning has been achieved by changing the refractive index by generating free electrons or via the AC-Kerr effect. Both schemes require an additional pump laser. We present a setup omitting a second pump laser and employing the Pockels effect for the refractive index change needed. Using this method, we can generate almost arbitrary frequency shifts of several tens of GHz. Furthermore, the use of this technique in the field of LIDAR will be discussed.

FM 9.6 Mon 15:15 1098

Polarisation Modulation in Lithium Niobate Waveguides at 0.8K — •Frederik Thiele[1], Jan Philipp Höpker[1], Patrick Bartkowiak[2], Felix vom Bruch[2], Viktor Quiring[2], Raimund Ricken[2], Christof Eigner[2], Christine Silberhorn[2], and Tim J. Bartley[1] — [1]Mesoskopische Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Integrierte Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Lithium niobate is an important platform for integrated quantum photonics given its high second-order nonlinearity and electro-optic properties. In this material, high-speed electro-optic modulation and polarization conversion can be realised, typically at room temperature. However, superconducting detectors as well as some other quantum optic devices require cryogenic temperatures to operate. The aim of this work is to implement modulators at cryogenic temperatures to demonstrate that these techniques have compatible operating conditions. We report on the realisation of a cryogenic polarisation modulator at 0.8K, based on periodically poled, titanium in-diffused lithium niobate waveguides. High coupling efficiency from single mode fibres from room temperature to the device inside a closed cycle cryostat have been realised, as well as adapting quasi-phase matching to cryogenic temperatures.

FM 9.7 Mon 15:30 1098

Integration of electro-optical devices in $LiNbO_3$ for quantum-optic applications — •Felix vom Bruch, Silia Babel, Raimund Ricken, Victor Quiring, Harald Herrmann, and Christine Silberhorn — Universität Paderborn, Warburger Str. 100, 33098 Paderborn

The interest in practical quantum technologies has been steadily increasing over the last years. Many concepts are based on the utilisation of light and its quantum properties for encoding and transferring information. Comparable to integrated electronic devices, integrated electro-optical elements enable one to scale complex laboratory setups down to convenient and handy dimensions. Furthermore, this approach is suitable for an effective reduction of the expense for setups and experiments. From many numerous telecom applications it is well known that ferroelectric $LiNbO_3$ provides an excellent platform for devices, e.g. frequency converters or phase and polarization modulators. For this purpose, the non-linear electro-optic properties of this material can be used to tailor conversion processes and modulators. Functionalities and characteristics of the latter are mainly governed by the design of the deployed electrodes. However, scaling and integration of devices for quantum-optic applications remains challenging in terms of performance and robustness. To overcome this challenge, detailed studies of different concepts and architectures are required. Here the influence of silicon dioxide layers, used as buffer layers for modulator electrodes, is examined systematically in terms of e.g. excess loss, switching behaviour and long-term stability.

FM 10: Topology: Artificial Systems

Time: Monday 14:00–15:45 Location: 1199

Invited Talk FM 10.1 Mon 14:00 1199

Engineered electronic states in atomic lattices and hybrid 2D systems — •Peter Liljeroth — Department of Applied Physics, Aalto University School of Science, PO Box 15100, 00076 Aalto, Finland

Constructing designer materials with engineered electronic properties is one of the emerging topics in condensed matter physics. I will discuss this approach using examples based on atomic manipulation by the tip of a scanning tunneling microscope (STM), molecular self-assembly, and direct growth of hybrid 2D materials to reach the desired structures.

Using atomic manipulation, it is possible to construct lattices where every atom is in a well-defined, predetermined position. This opens possibilities for creating artificial materials and I will illustrate this concept by showing how chlorine vacancies on Cu(100) [1] can be used to implement various one-dimensional artificial lattices with topological domain wall states and engineered band structures with flat bands.[2,3]

In the second part of the talk, I will focus on the kind of engineered electronic states that can be realized in hybrid structures consisting of magnetic and superconducting transition metal dichalcogenides. Direct molecular-beam epitaxy growth allows the construction of vertical heterostructures with clean and high-quality interfaces,[4] which is of importance for the realization of the possible edge modes.

[1] F.E. Kalff et al. Nat. Nanotech. 11, 926 (2016). [2] R. Drost et al. Nat. Phys. 13, 668 (2017). [3] Md N. Huda et al. in preparation. [4] S. Kezilebieke et al. in preparation.

FM 10.2 Mon 14:30 1199

Topologically Protected Giant End Spins in Carbon Nanotubes — •Gergely Zarand[1], Pascu Moca[1,2], Wataru Izumida[3], Balazs Dora[4], and Örs Legeza[5] — [1]BME-MTA Exotic Quantum Phases Research Group, Institute of Physics, Budapest University of Technology and Economics, Hungary — [2]Department of Physics, University of Oradea, Romania — [3]Department of Physics, Tohoku University, Sendai, Japan — [4]Department of Theoretical Physics and MTA-BME Lendulet Topology and Correlation Research Group, Budapest University of Technology and Economics, Hungary — [5]Strongly Correlated Systems Lendület Research group, Wigner Research Centre for Physics, Budapest, Hungary

Carbon nanotubes can be classified according to topological classes. For most chiralities, semiconducting nanotubes display topologically protected end states of multiple degeneracies. We study these end states in the presence of Coulomb interactions by means of DMRG-based quantum chemistry tools and demonstrate the formation of giant end spins, the close analogues of ferromagnetic states emerging at graphene nanoribbon edges. The interaction between the two ends is sensitive to the length of the nanotube, its dielectric constant, as well as the size of the end spins: for $S=1/2$ end spins their interaction is antiferromagnetic, while for $S>1/2$ it changes from antiferromagnetic to ferromagnetic with increasing nanotube length. The interaction between end spins can be designed by controlling the dielectric constant of the environment, thereby providing a possible platform for two-spin quantum manipulations.

FM 10.3 Mon 14:45 1199

The Creutz-Hubbard ladder: a multi-purpose setup — •Matteo Rizzi — Institute for Theoretical Physics, Universität zu Köln, Germany — Institute for Quantum Control (PGI-8), Forschungszentrum Jülich, Germany

We briefly review recent contribution of ours about the Creutz Hubbard ladder, which allows to explore topological flat bands and undoubled Dirac cones, (symmetry-protected) fractional interacting phases as well as exotic transport properties, all in a single tunable setup. We provide experimental recipes for cold atomic gases. We employ analytical mappings onto effective models and numerical tensor networks calculations, thereby computing static and dynamical observables and entanglement properties, too.

References: J. Jünemann, A. Piga, S.-J. Ran, M. Lewenstein, M. Rizzi, A. Bermudez, PRX 7, 031057 (2017) M. Bischoff, J. Jünemann, M. Polini, M. Rizzi, PRB 96, 241112(R) (2017); A. Bermudez, E. Tirrito, M. Rizzi, M. Lewenstein, S. Hands, Ann. Phys. 339, 149 (2018); E. Tirrito, MR, G. Sierra, M. Lewenstein, and A. Bermudez, PRB 99, 125106 (2019); S. Barbarino, D. Rossini, M. Rizzi, R. Fazio, G.E. Santoro, and M. Dalmonte, NJP 21, 043048 (2019).

FM 10.4 Mon 15:00 1199

Identifying Quantum Phase Transitions using Artificial Neural Networks on Experimental Data — Benno Rem[1,2], •Niklas Käming[1], Matthias Tarnowski[1,2], Luca Asteria[1], Nick Fläschner[1], Christoph Becker[1,3], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]ILP Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]ZOQ Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Machine learning techniques such as artificial neural networks are currently revolutionizing many technological areas and have also proven successful in quantum physics applications. Here we employ an artificial neural network and deep learning techniques to identify quantum phase transitions from single-shot experimental momentum-space density images of ultracold quantum gases and obtain results, which were not feasible with conventional methods. We map out the complete two-dimensional topological phase diagram of the Haldane model and provide an accurate characterization of the superfluid-to-Mott-insulator transition in an inhomogeneous Bose-Hubbard system. Our work points the way to unravel complex phase diagrams of general experimental systems, where the Hamiltonian and the order parameters might not be known.

FM 10.5 Mon 15:15 1199

Creating anomalous Floquet Chern insulators with magnetic quantum walks — M. Sajid[1], J. K. Asbóth[2], D. Meschede[1], R. F. Werner[3], and •A. Alberti[1] — [1]Institut für Angewandte Physik, Universität Bonn, Germany — [2]Wigner Research Centre for Physics, Budapest, Hungary — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

We propose a realistic scheme to construct anomalous Floquet Chern topological insulators using spin-1/2 particles carrying out a discrete-time quantum walk in a two-dimensional lattice [1]. By Floquet engineering the quantum-walk protocol, an Aharonov-Bohm geometric phase is imprinted onto closed-loop paths in the lattice, thus realizing an Abelian gauge field, the analog of a magnetic flux threading a two-dimensional electron gas. We find that because of the nonperturbative nature of the periodic driving, a second topological number in addition to Chern number is necessary to fully characterize the anomalous Floquet topological phases of magnetic quantum walks and to compute the number of topologically protected edge modes expected at the boundaries between different phases. We discuss an implementation of this scheme using neutral atoms in two-dimensional spin-dependent optical lattices, which enables the generation of arbitrary magnetic-field landscapes, including those with sharp boundaries. Magnetic quantum walks may open a new route to studying topological properties of charged particles in strong magnetic fields.

[1] M. Sajid *et al.*, Phys. Rev. B (in press, 2019)

FM 10.6 Mon 15:30 1199

Topological bands and Anomalous Floquet-Anderson Insulators in two-dimensional quantum walks — •Janos Asboth[1] and Tibor Rakovszky[2] — [1]Wigner Research Centre for Physics of the H.A.S., and Budapest University of Technology and Economics — [2]Technical University of Munich

We study the interplay of topology and Anderson localization in two-dimensional periodically driven systems, specifically, quantum walks. In previous work, we have found that when disorder is introduced by onsite potential "kicks" to the simplest two-dimensional quantum walks (two Floquet bands, vanishing Chern number), they undergo Anderson localization, but their edge states survive, realizing a so-called Anomalous Floquet-Anderson Insulator (AFAI). Choosing more complicated walk protocols, we tune the topological invariants of the Floquet bands, and investigate what happens to Floquet-Chern insulators under the effect of disorder. We find Anderson localization via the "levitation and annihilation" of the bands, and ask whether this mechanism can also lead to an Anomalous Floquet-Anderson Insulator.

FM 11: Entanglement: Many-Body States I

Time: Monday 14:00–16:00 Location: 2004

Invited Talk FM 11.1 Mon 14:00 2004

Correlations in many-body states: The simplest constraints for their distribution — •Jens Siewert — University of the Basque Country UPV/EHU, 48080 Bilbao, Spain — IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Spain

It has long been known that correlations in many-body systems cannot be freely distributed. Correspondingly, not all choices of reduced states (the marginals) are compatible with a joint global state of the system. This difficulty is known as the quantum marginal problem. In solid-state physics and quantum chemistry problems of this kind were discussed in the context of 'N-representability', whereas in quantum information the term 'monogamy of entanglement' (and other correlations) was coined.

Surprisingly, this problem is not completely solved even in the simplest of its variants, the existence of so-called absolutely maximally entangled states of N distinguishible quantum systems, each of which has d levels. However, substantial progress in this field was achieved recently by analyzing the Bloch representation of quantum states: This representation corresponds to an expansion of an N-party density matrix into all its k-particle correlations ($k \leqq N$). The simplest correlation quantifiers based on this are the k-sector lengths. By using these tools, constraints for the distribution of correlations viz. sector lengths can be derived systematically and transparently. They may also be viewed as monogamy relations for entanglement as well as, e.g., inequalities for the linear entropy or conditions for the existence of quantum error correcting codes.

FM 11.2 Mon 14:30 2004

Characterizing Quantum States using Sector Lengths — •Nikolai Wyderka[1], Jens Siewert[2,3], and Otfried Gühne[1] — [1]Naturwissenschaftlich Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany — [2]University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [3]IKERBASQUE Basque Foundation for Science, E-48013 Bilbao, Spain

A powerful tool to study entanglement properties of multi-partite quantum states are LU invariants, and sector lengths, quantifying the amount of k-body correlations in a state, are a particularly useful subset of these invariants. These quantify, for different k, the amount of k-partite correlations in a quantum state in a basis-independent manner.

I will show how sector lengths can be used to detect different types of entanglement. Furthermore, I will highlight connections to monogamy of entanglement, limiting the entanglement between certain subgroups of the particles.

FM 11.3 Mon 14:45 2004

Reference-frame independent quantification of bipartite entanglement — •Michael Krebsbach, Heinz-Peter Breuer, and Andreas Ketterer — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

The experimental detection of entanglement usually involves a number of appropriately chosen local quantum measurements aligned with respect to a previously shared common reference-frame. Establishing the latter, however, requires the exchange of classical information which represents an additional technical overhead, in particular if the involved parties are in motion. In this work we investigate the reference-frame independent quantification of bipartite entanglement using moments of randomly measured correlation functions [1]. In particular, we find that the concurrence of Bell-diagonal states is determined by the first three non-vanishing moments, a result that leads to lower bounds on the concurrence of general two-qubit states. Lastly, extensions of the presented methods to systems of larger local dimensions are considered as well.

[1] A. Ketterer, N. Wyderka, O. Gühne, Phys. Rev. Lett. **122**, 120505 (2019).

FM 11.4 Mon 15:00 2004

Detection of Genuine Multipartite Entanglement Without Any Reference Frames — •Jan Dziewior[1,2], Lukas Knips[1,2], Waldemar Klobus[3], Wieslaw Laskowski[3], Tomasz Paterek[4,5], Harald Weinfurter[1,2], and Jasmin Meinecke[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Department für Physik, Ludwig-Maximilians-Universitaät, 80797 München, Germany — [3]Institute of Theoretical Physics and Astrophysics, University of Gdansk, 80-308 Gdansk, Poland — [4]School of Physical and Mathematical Sciences, Nanyang Technological University, 637371 Singapore — [5]MajuLab, CNRS-UCA-SU-NUS-NTU International Joint Research Unit, UMI 3654 Singapore

Quantum entanglement is usually revealed by a carefully chosen set of measurements. Under a number of experimental conditions, especially for communication in multiparty quantum networks, the relative measurement directions fluctuate and are hard to calibrate. Yet, even with absolutely random measurements one can still gain information about the state and its entanglement. Here we extend previous attempts and perform numerical as well as experimental analysis of the performance of the method. From detailed distributions of measurement outcomes and their correlations different types of multipartite entanglement are identified making our method useful for entanglement verification in the presence of noise. It overcomes any type and strength of localized unitary noise as long as the rate of entanglement generation is sufficiently high.

FM 11.5 Mon 15:15 2004

Optimal measurement strategies for fast entanglement detection — •Nadia Milazzo[1,2], Daniel Braun[1], and Olivier Giraud[2] — [1]Institut für theoretische Physik, Universität Tübingen, 72076

Tübingen, Germany — [2]LPTMS, CNRS, Univ. Paris-Sud, Université Paris-Saclay, 91405 Orsay, France

The recent emergence of small quantum processors in quantum information technology has seen the increasing need of characterizing their behavior as "truly" quantum mechanical or not. Already for an unknown quantum state, verifying whether the statistics arising from it can be explained by a classical state is challenging, as long as non-classicality measures or witnesses are based on full tomography. Which is then the most efficient measurement strategy to prove that a state is entangled (or more generally: non-classical)? We tackle this problem by introducing the statistics of lengths of measurement sequences that allow one to certify entanglement across a given bi-partition of a multi-qubit system over the possible sequence of measurements of random unknown states. Perfectly suited for this approach is the formalism of "truncated moment sequences", that allows one to deal naturally with incomplete information about a quantum state. We use it to identify the best measurement strategy in the sense of the (on average) shortest measurement sequence of (multi-qubit) Pauli-measurements. We find that the set of measurements corresponding to diagonal entries of the moment matrix associated to the state are particularly efficient. For symmetric states their number grows like the third power of the number of qubits and their efficiency increases rapidly with that number.

FM 11.6 Mon 15:30 2004

Many-body entanglement criteria and the truncated moment problem — •Bharath H. M.[1] and Grigoriy Blekherman[2] — [1]Fakultät für Physik, LMU München — [2]School of Mathematics, Georgia Tech

A central problem in quantum technologies is to prepare, measure and control many-body entangled states. The latter has applications in quantum information, communication and metrology. A mathematical challenge in this problem is to develop criteria to decide whether a many-body state prepared in the lab is entangled based on a small number of measured observables. While instances of this problem have been addressed by several measures of entanglement, the general problem itself scales unfavorably in the number of atoms. We show that this problem is related to the so-called truncated moment problem, well known in convex algebraic geometry, and that a powerful set of tools is available to tackle it. The space of separable mixed states is convex and so is the space of the corresponding observable values. Therefore, the problem of determining whether a set of observable values come from an entangled state is tantamount to checking for membership in a convex set, also known as a moment cone, of a point with coordinates given by the set of observable values. The latter is an instance of the truncated moment problem. Here, we develop asymptotically tight criteria for entanglement in a many-body system of bosonic atoms by importing techniques from convex algebraic geometry [1].

[1] Grigoriy Blekherman and Bharath Hebbe Madhusudhana, arXiv: 1904.00072.

FM 11.7 Mon 15:45 2004

Entanglement witnesses 2.0 : entanglement witnesses can be compressed — •Joonwoo Bae[1], Dariusz Chruscinski[2], and Beatrix Hiesmayr[3] — [1]School of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea — [2]Institute of Physics, Faculty of Physics, Astronomy, and Informatics, Nicolaus Copernicus University, Grudziadzka 5, 87-100 Torun, Poland — [3]University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria

An entanglement witness is an observable detecting entanglement for a subset of states. We present a framework that makes an entanglement witness twice as powerful due to the general existence of a second (lower) bound, in addition to the (upper) bound of the very definition. This second bound, if non-trivial, is violated by another subset of entangled states. Differently stated, we prove via the structural physical approximation that two witnesses can be compressed into a single one. Consequently, our framework shows that any entanglement witness can be upgraded to a witness 2.0. The generality and its power are demonstrate by applications to bipartite and multipartite qubit/qudit systems.

FM 12: Quantum Sensing: Hardware Platforms

Time: Monday 14:00–16:00 Location: 2006

Invited Talk FM 12.1 Mon 14:00 2006

Quantum sensors with matter waves: geodesy, navigation and general relativity — •Philippe Bouyer — LP2N - CNRS, IOGS, Univ. Bordeaux; Talence

The remarkable success of atom coherent manipulation techniques has motivated competitive research and development in precision metrology. Matter-wave inertial sensors * accelerometers, gyrometers, gravimeters * based on these techniques are all at the forefront of their respective measurement classes. Atom inertial sensors provide nowadays about the best accelerometers and gravimeters and allow, for instance, to make the most precise monitoring of gravity or to device precise tests of the weak equivalence principle (WEP). I present here some recent advances in these fields: The outstanding developments of laser-cooling techniques and related technologies allowed the demonstration of matter-wave interferometers in micro-gravity. Using two atomic species (for instance 39K and 87Rb) allows to verify that two massive bodies will undergo the same gravitational acceleration regardless of their mass or composition, allowing a test of the Weak Equivalence Principle (WEP). New concepts of matter-wave interferometry can be used to study sub Hertz variations of the strain tensor of space-time and gravitation. For instance, the MIGA instrument, which is currently built in France, will allow the monitoring of the evolution of the gravitational field at unprecedented sensitivity, which will be exploited both for geophysical studies and for Gravitational Waves (GWs) detection.

FM 12.2 Mon 14:30 2006

Quantum Technology projects: a main pillar within the German space physical sciences program — •Thomas Driebe — DLR Space Administration, Bonn, Germany

As German Space Agency, the DLR Space Administration manages the German space program. This program integrates the German participation in the ESA programs and the activities in Germany's national program. As part of the space program, the German microgravity program is based on the provision of microgravity platforms, the development of flight hardware, and the preparation, execution, and analysis of both life and physical sciences experiments under space conditions.

The German Physical Sciences Program deals with gravity-dependent effects on physical and chemical processes and covers the research disciplines material sciences, fundamental physics, soft matter, fluid physics and combustion. The main program goal is to gain scientific knowledge by addressing fundamental questions in physics, to foster new technological developments and to reveal new application potentials from both fundamental as well as application-oriented research. Over the last two decades Quantum Physics and Quantum Technology projects have evolved into a main pillar of this programme.

In this talk, highlights of past and on-going Quantum Physics projects will be introduced along with the programmatic framework and priorities. In addition, opportunities and platforms for future research and technology development will be presented.

FM 12.3 Mon 14:45 2006

Fabrication of diamond AFM tips and nanopillars as hardware platforms for quantum sensing and memory — •Alexander Schmidt, Johann P. Reithmaier, and Cyril Popov — Institute of Nanostructure Technologies and Analytics (INA), University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

We report on the fabrication of mono- and nanocrystalline diamond AFM tips and highly dense arrays of nanopillars (200 nm diameter) for implementation in quantum sensing and quantum memories. Both structures are fabricated by electron beam lithography and oxygen plasma reactive-ion etching. They are implemented on nanocrystalline diamond membranes by KOH etching of the silicon substrate for further processing, e.g. mounting the AFM cantilevers or deterministic ion implantation into the pillars. This technique could be transferred to monocrystalline diamond membranes, as demonstrated by preliminary works. Another accessible fabrication method for nanocrystalline AFM tips involving the moulding technique, conventional optical lithography and anisotropic wet etching in KOH of the silicon substrate will also be presented. Upon incorporation of nitrogen-vacancy centers, those structures can be envisioned for quantum sensing of magnetic fields at a nanoscale or implementation as quantum memories.

FM 12.4 Mon 15:00 2006

Quantum sensing with ultracold atomic collisions — •Krzysztof Jachymski[1], Tomasz Wasak[2], Antonio Negretti[3], and Tommaso Calarco[1] — [1]Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), Jülich, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Zentrum für Optische Quantentechnologien, Universität Hamburg, Hamburg, Germany

Feshbach resonances, which allow for tuning the interactions of ultracold atoms with an external magnetic field, have been widely used to control the properties of quantum gases. We propose a scheme for using scattering resonances as a probe for external fields, showing that by carefully tuning the parameters it is possible to reach a 10^-5G (or nT) level of precision with a single pair of atoms. We show that for our collisional setup it is possible to saturate the quantum precision bound with a simple measurement protocol.

FM 12.5 Mon 15:15 2006

Stable optical and vacuum systems for quantum technology applications in space — •Moritz Mihm[1], Sören Boles[1], Jean Pierre Marburger[1], André Wenzlawski[1], Ortwin Hellmig[6], Patrick Windpassinger[1], and the MAIUS Team[1,2,3,4,5,6] — [1]Institut für Physik, JGU Mainz — [2]Institut für Physik, HU Berlin — [3]IQO, LU Hannover — [4]FBH, Berlin — [5]ZARM, Bremen — [6]ILP, UHH Hamburg

Space-based quantum technology applications face harsh stability requirements while making high demands on system size and mass. We have developed a Zerodur based optical bench system for highly robust and miniaturized optical systems that overcomes these hurdles and that we are currently extending to include vacuum systems. I will present the fundamentals of our technology and the optical modules of MAIUS-2 as an example application. MAIUS-2 is a quantum gas experiment performing atom interferometry with Bose-Einstein condensates of potassium and rubidium onboard a sounding rocket.

Furthermore, I will discuss current efforts to build Zerodur based vacuum systems. The miniaturization of the chamber in conjunction with our laser system technology allows the development of highly robust and fully integrated quantum optical systems for space and other field applications.

Our work is supported by JGU Stufe 1 Funding and the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers 50 WP 1433 and 50 WP 1703.

FM 12.6 Mon 15:30 2006

Testing Foundations of Quantum Mechanics with a Waveguide Interferometer — •Sebastian Gstir[1], Robert Keil[1], Thomas Kauten[1], Toni Eichelkraut[2], Alexander Szameit[3], and Gregor Weihs[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [2]Institute of Applied Physics, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, Germany — [3]Institut für Physik, Universität Rostock, Germany

In this work we designed and built an integrated three-path waveguide interferometer in fused silica [1] for measuring so-called higher-order interferences [2] and higher-dimensional phases [3]. These hypothetical higher-order interferences and higher-dimensional phases do not occur in ordinary quantum mechanics or classical electrodynamics and thus the experiment tests the foundations of these theories. In our interferometer miniature mechanical shutters switch the individual arms on and off. Our main goal was to avoid cross-talk between the shutter state in a path and the transmissivity or phase in any other path. Using a laser source we were able to bound the occurrence of any higher-order interferences to be less than $8(12) \cdot 10^{-5}$, normalized to the expected two-path interference and the occurrence of any higher-dimensional phases to be less than 2%.

[1] T. Meany et al., Laser Phot. Rev. 9, 363 (2015).
[2] R. D. Sorkin, Mod. Phys. Lett. A 09, 3119 (1994).
[3] A. Peres, Phys. Rev. Lett. 42, 683 (1979).

FM 12.7 Mon 15:45 2006

An optical dipole trap as a source of ultracold atoms in microgravity; the PRIMUS project — •Christian Vogt[1], Marian Woltmann[1], Sven Herrmann[1], and the PRIMUS Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM) — [2]LU Hannover, Institute of Quantum Optics

Cold atom based sensor have proven to be effective tools with wide applications in measuring weakest forces and thereby in testing fundamental physics e.g. the weak equivalence principle. As the sensitivity of atom interferometer measurements scales with the square of interrogation time, great effort has been made to bring these techniques to microgravity (μg) environments. For example the first BEC in space was created and effective temperatures down to the pK regime were demonstrated in the drop tower in Bremen. While all of these results in μg were achieved with magnetic traps on atom chips, the PRIMUS-project develops an optical dipole trap for use in weightlessness as an alternative source of cold atom ensembles. Dipole traps have several advantages like a symmetric trap shape and the accessibility of Feshbach resonances. They are well established in ground-based experiments and will most likely play a significant role in space-borne experiments as well. In this manner our project also serves as a pathfinder experiment for future cold atom experiments in weightlessness. With this talk we will present the current staus of the experiment and latest results of evaporative cooling in an optical dipole trap in μg. The PRIMUS-Project is supported by the DLR with funds provided by the BMWi under grant No. DLR 50 WM 1642.

FM 13: Open and Complex Quantum Systems I

Time: Monday 14:00–16:00 Location: 3042

Invited Talk FM 13.1 Mon 14:00 3042

Quantum Information Concepts in Open Systems — •Bassano Vacchini — Dipartimento di Fisica Aldo Pontremoli, Università degli Studi di Milano, Via Celoria 16, I-20133 Milan, Italy — INFN, Sezione di Milano, Via Celoria 16, I-20133 Milan, Italy

The talk is aimed at providing an introduction to the foundations of open system theory in the light of quantum information concepts. We will briefly introduce the basic assumptions and general concepts of the theory, such as complete positivity and quantum dynamical map, relevant to the description of dissipation and decoherence effects in quantum mechanics. We will consider some of the main methods for the treatment of open system dynamics, pointing to the relevance of correlations such as entanglement and discord. We will further mention recent developments for the definition and treatment of non-Markovian dynamics as well as quantum thermodynamical systems, where quantum information notions appear to play an important role. Relevant open questions and possibly promising future research directions will be finally mentioned.

FM 13.2 Mon 14:30 3042

Reachability in Infinite Dimensional Unital Open Quantum Systems with Switchable GKS-Lindblad Generators — •Frederik vom Ende[1], Gunther Dirr[2], Michael Keyl[3], and Thomas Schulte-Herbrüggen[1] — [1]TU Munich, 85748 Garching, Germany — [2]University of Würzburg, 97074 Würzburg, Germany — [3]Freie Universität Berlin, 14195 Berlin, Germany

In quantum systems theory one of the fundamental problems boils down to: given an initial state, which final states can be reached by the dynamic system in question. Here we consider infinite dimensional open quantum dynamical systems following a unital Kossakowski-Lindblad master equation extended by controls. More precisely, their time evolution shall be governed by an inevitable (potentially unbounded) Hamiltonian drift term, finitely many bounded control Hamiltonians allowing for (at least) piecewise constant control amplitudes plus a bang-bang switchable noise term in Kossakowski-Lindblad form (generated by some compact Lindblad-V). Generalizing standard majorization results from finite to infinite dimensions, we show that such bilinear quantum control systems allow to approximately reach any target state majorized by the initial one as up to now only has been known in finite dimensional analogues.

FM 13.3 Mon 14:45 3042

Quantum information and open-system dynamics: Complete positivity, divisibility and time-dependent transport — •Maarten Wegewijs[1,2], Viktor Reimer[2], Konstantin Nestmann[2], and Mikhail Pletyukhov[2] — [1]Peter Grünberg Institute, Forschungszentrum Jülich, Germany — [2]Institute for Theory of Statistical Physics, RWTH Aachen University, Germany

Time-evolution in quantum information theory hinges on complete-positivity (CP) which is equivalent to the Kraus form of the dynamical map and closely tied to entanglement. To exploit this in the study of the dynamics of open systems – beyond the framework of Lindblad equations – it is advantageous to strike a bridge to methods of statistical physics based on quantum master equations. In this talk, I will explain how this can be done on a very general level using standard real-time techniques, expressing Kraus operators in Keldysh diagrams. I will illustrate how the Kraus operators provide new insights into the dynamics, in particular, into the dynamics of *the environment* as it is affected by the system. Even for a system as simple as a resonant level this provides some surprising insights and allows the *continuous* fermionic bath into which the fermion decays to be effectively reduced to just two fermions. I furthermore show that different notions of Markovianity (semigroup- and CP-divisibility) correspond to clearly measurable features in the time-dependent transport current.

V. Reimer, M. Wegewijs, et al, arXiv: 1903.04195
V. Reimer, M. Wegewijs, K. Nestmann, M. Pletyukhov, arXiv:1808.09395.

FM 13.4 Mon 15:00 3042

Measurement of quantum memory effects in a trapped-ion system — •Matthias Wittemer, Govinda Clos, Ulrich Warring, Heinz-Peter Breuer, and Tobias Schaetz — University of Freiburg, Freiburg im Breisgau, Germany

Any realistic quantum system interacts with its environment. Thereby, the *open* system builds up entanglement and correlations with the environment and exchanges information. Trapped ions offer a high level of control of internal (electronic) and external (motional) degrees of freedom and are well-suited to engineer closed and open quantum systems. This allows for systematic studies of entanglement, decoherence, and thermalization in quantum systems of variable complexity [1]. With our trapped-ion system we experimentally study the flow of information in a closed quantum system between an open subsystem and its environment and measure associated quantum memory effects [2]. Thereby, we reveal that the nature of projective measurements in quantum mechanics can lead to a nontrivial bias in a measure for the degree of quantum non-Markovian behavior [3]. We prepare the environment in different quantum states and realize different interactions between system and environment to characterize the non-Markovianity and its bias as a function of these parameters, illustrating the fundamental implications of our findings for future applications.

[1] G. Clos *et al.*, Phys. Rev. Lett. **117**, 170401 (2016)
[2] M. Wittemer *et al.*, Phys. Rev. A **97**, 020102(R) (2018)
[3] H.-P. Breuer *et al.*, Phys. Rev. Lett. **103**, 210401 (2009)

FM 13.5 Mon 15:15 3042

Quantum transport between finite reservoirs — •Giulio Amato[1,2,3], Heinz-Peter Breuer[1], Sandro Wimberger[2,3], Alberto Rodriguez[1], and Andreas Buchleitner[1] — [1]Albert-Ludwigs-Universität Freiburg — [2]Universita' degli Studi di Parma — [3]Istituto Nazionale di Fisica Nucleare

We study non-interacting many-particle quantum transport across an open quantum system connecting two finite reservoirs which are initially prepared with a finite particle number imbalance. Equilibration of the reservoirs leads to a non-stationary current which vanishes once a balanced particle distribution is reached. This behaviour has been qualitatively observed in quantum transport experiments with ultracold fermionic atoms, with tunable interparticle interactions [1]. We present a theoretical model based on a set of coupled quantum-classical master equations, describing the evolution of the system together with the temporal variation of the particle number in the reservoirs. We apply this formalism to investigate nonstationary currents across a one dimensional (Bose-)Hubbard lattice. Furthermore, characteristic differences between the fermionic and bosonic dynamics will be highlighted.

[1] S. Krinner, T. Esslinger and J.-P. Brantut, J. Phys.: Condens. Matter 29, 343003 (2017)

FM 13.6 Mon 15:30 3042

Revealing hidden information by counting — •Björn Kubala[1], Andrew D. Armour[2], and Joachim Ankerhold[1] — [1]Institute for Complex Quantum Systems and IQST, Ulm University, Albert Einstein-Allee 11, 89069 Ulm, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, University of Nottingham, Nottingham NG7 2RD, UK

The full counting statistic of emitted photons and the investigation of large deviations of the emission power are known to provide useful insights into the dynamics of driven, dissipative quantum-optical systems. In particular, the 'rare' dynamics can reveal information about the system's behavior for a wide region of the parameter space; beyond the actual physically-realized driving and damping parameters.

Here, we employ these tools for a theoretical exploration of a Josephson-photonics device, where Cooper pairs tunneling across a voltage biased Josephson junction create photonic excitations in a microwave resonator, which is connected in series to the junction. By biasing at the corresponding excitation energy, such devices can realize a nonlinearly driven oscillator or (a nonlinear versions of) a parametric oscillator and have been shown to exhibit interesting dynamical critical points. When the state of the cavity is conditioned on measurements of the number of photons emitted one can reveal fragile features, such as cat states, which are lost within the usual unconditioned dynamics.

FM 13.7 Mon 15:45 3042

Quantum information scrambling in open systems — •Jan Tuziemski — Stockholm University, Stockholm, Sweden

Recent theoretical and experimental studies have shown significance of quantum information scrambling for problems encountered in quantum information, high-energy physics, and condensed matter. Due to complexity of quantum many-body systems it is plausible that new developments in this field will be achieved by experimental explorations. Since noise effects are inevitably present in experimental implementations, there is a need for a better theoretical understanding of quantum information scrambling in systems affected by noise. In this talk we study indicators of quantum scrambling - out-of-time-ordered correlation functions (OTOCs) in open quantum systems. As most experimental protocols for measuring OTOCs are based on backward time evolution we consider two possible scenarios of joint system-environment dynamics reversal: In the first one the evolution of the environment is reversed, whereas in the second it is not. We derive general formulas for OTOCs in those cases as well as study in detail the model of a spin chain coupled to the environment of harmonic oscillators. In the latter case we derive expressions for open systems OTOCs in terms of Feynman-Vernon influence functional. Subsequently, assuming that dephasing dominates over dissipation, we provide bounds on open system OTOCs and illustrate them for a spectral density known from the spin-boson problem. Our results also advance understating of decoherence in processes involving backward time evolution. Based on arXiv:1903.05025

FM 14: Quantum Computation: Hardware Platforms I

Time: Monday 14:00–16:00 Location: 3044

Invited Talk FM 14.1 Mon 14:00 3044

Quantum simulation and computation with spins in quantum dots — •Uditendu Mukhopadhyay[1], Juan P Dehollain[1], Vincent P. Michal[1], Yao Wang[2], Bernhard Wunsch[2], Christian Reichl[3], Werner Wegscheider[3], Mark S. Rudner[4], Eugene Demler[2], and Lieven M. K. Vandersypen[1] — [1]TU Delft — [2]Harvard University — [3]ETH Zürich — [4]University of Copenhagen

Electrostatically defined quantum dots in semiconductors are one of the leading platforms for the development of quantum technologies, owing to their fast and efficient control and measurement, as well as their compatibility with industrial semiconductor fabrication. At the Vandersypen lab, we use the electrons confined in quantum dots to perform quantum simulation and computation.

In this talk, I will delve into some of our latest experiments. I will begin with a description of the types of quantum dot arrays that we operate, highlighting the techniques that we have developed recently to overcome the problem of disorder and efficient control, which is crucial to the operation and scale-up of these systems as quantum simulators and processors. I will then describe our latest quantum simulator device-a 2x2 plaquette of quantum dots in a GaAs heterostructure-which we use to demonstrate Nagaoka ferromagnetism, one of the well-known theories of ferromagnetism based on the Hubbard model, which had yet to be demonstrated experimentally. Finally, I will present the capabilities of our silicon-based 2-qubit quantum information processor, with an outlook on how this technology can be further developed towards a large-scale universal quantum computer.

FM 14.2 Mon 14:30 3044

Engineering Si-based quantum devices viable as hardware back-end in a full-stack quantum computer prototype — •Thorsten Last, Nodar Samkharadze, Amir Sammak, Delphine Brousse, Pieter Eendebak, Richard Versluis, Menno Veldhorst, Lieven Vandersypen, and Jeremy Veltin — QuTech - TU Delft/TNO, Lorentzweg 1, 2628 CJ Delft, NL

We will present a technology development framework in which Si spin qubit based quantum devices can become a viable option as hardware back-end in prototype quantum computers (QC). A chip which is considered to be a component of such an architecture asks for more stringent specs in stability than required for proof of principle experiments. Taking this requirement into account we developed a manufacturing feedback loop including materials, fabrication and electrical screening. However, implementing these device manufacturing needs in shared R&D facilities is found to be a challenging task. Still, parts of the feedback loop have been applied to manufacture Si-based devices made to host two spin qubits. Our devices consist of gate-defined double quantum dots formed in an undoped Si-28 quantum well embedded in a SiGe heterostructure. Fast readout of the quantum dot states is performed with a nearby single electron transistor. The devices consistently reach the few-electron regime. Spin lifetimes of around 30 ms are in line with previous results on Si. The device tune up to qubit-level is ongoing. If completed these devices will be utilized as processing units in our QC prototype platform (www.quantum-inspire.com).

FM 14.3 Mon 14:45 3044

Spin relaxation induced by valley-orbit coupling in a single Si quantum dot — •Amin Hosseinkhani and Guido Burkard — Department of Physics, University of Konstanz, Germany

The spin of isolated electrons in Silicon quantum dot heterostructures is a promising candidate for quantum information processing. While silicon offers weak spin-orbit coupling and nuclear-spin free isotopes, the valley degree of freedom in silicon couples to spin and can degrade the qubit performance by opening a relaxation channel. We build on effective mass theory to obtain the valley phase and splitting for a single quantum dot spin qubit as a function of the applied magnetic and electric field. These enable us to develop the theory of spin-relaxation induced by valley-orbit coupling. We show that it is important to consider all four physical spin-valley states into the qubit logical states in order to describe the qubit relaxation.

FM 14.4 Mon 15:00 3044

Low-temperature ohmic contacts to n-ZnSe for all-electrical quantum devices — •Felix Hartz[1], Johanna Janssen[2], Till Huckemann[1], Malte Neul[1], Lars R. Schreiber[1], and Alexander Pawlis[2] — [1]JARA - Institute for Quantum Information, RWTH Aachen University, Germany — [2]Peter Grünberg Institute 9 and JARA - FIT, Forschungszentrum Jülich GmbH, Germany

The most advanced semiconductor spin qubits are realized in gate defined quantum dots in ^{28}Si. Qubit performance has been improved by isotopical purification and qubit integration in Si/SiGe heterostructures finally limited by spin valley splitting. ZnSe is an ideal host material for gate defined quantum dots as it has no valleys, provides a photonic link [1] and is potentially nuclear spin free after isotopical purification [2]. Prerequisite to all-electrical qubits are ohmic contacts to ZnSe operating at cryogenic temperatures that have not been realized so far. Here we present a complete analysis on ohmic contacts to n-type ZnSe. By $in-situ$ Al metallisation of the ohmic contact without breaking ultra-high vacuum conditions, we avoid the natural ZnSe oxide and therefore achieve a record contact resistivity of $(2.3\pm0.8)\cdot10^{-5}\,\Omega\mathrm{cm}^2$ at room temperature and $(4\pm2)\cdot10^{-5}\,\Omega\mathrm{cm}^2$ at 4 K. We demonstrate local ohmic contacts combining the $in-situ$ technique with selective regrowth yielding low resistivity contacts with $(1.7\pm0.2)\cdot10^{-4}\,\Omega\mathrm{cm}^2$ also operating at 4 K ($(1.4\pm0.4)\cdot10^{-3}\,\Omega\mathrm{cm}^2$). This allows for a new type of quantum devices such as gate defined quantum dots in ZnSe. [1] K. Sanaka ea., Nano Lett. (2012) [2] A. Pawlis ea., Appl. Electron. Mater. (2019)

FM 14.5 Mon 15:15 3044

Long-Distance Charge Transport in (Al,Ga)As — •Matthias Künne[1], Stefan Trellenkamp[2], Julian Ritzmann[3], Arne Ludwig[3], Andreas D. Wieck[3], and Hendrik Bluhm[1] — [1]JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, D-52074 Aachen, Germany — [2]Helmholtz Nano Facility, Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany — [3]Lehrstuhl für angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44801 Bochum, Germany

For scalable quantum computing architectures, a transfer of the qubit information over distances of at least a few microns is advantageous, e.g. for making space for signal vias [1]. For electron spin qubits, one possibility is to move the electrons themselves.

In my talk, I will present a device designed to allow the shuttling of electrons over 7 microns. We employed high-yield, multi-layer electron beam lithography to fabricate the required metallic gates. I will show initial results on the characterization of the device.

[1] L. M. K. Vandersypen et al., npj Quantum Inf. 3, 34 (2017)

FM 14.6 Mon 15:30 3044

Fast universal holonomic manipulation of a two-qubit register — •Vlad Shkolnikov and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

Geometric phases arising from cyclic evolution of quantum systems open new strategies for quantum technologies. Here we consider theoretically the perspective to use these phases to achieve universal control over the defect registers in diamond. In particular we focus on the electron spin of a nitrogen-vacancy center coupled to the nuclear spin of a neighbouring carbon-13 atom. By tuning the system first to the ground state level anticrossing and then mixing the electronic $m_s = 0$ and $m_s = -1$ levels, we achieve that the nuclear spin quantization axis becomes dependent on the state of the electron spin. This allows one to perform hyperfine assisted universal set of holonomic gates on this two qubit register using microwave tones only. This has a clear advantage over the conventional methods that use radio frequency pulses to couple to the nuclear spin due to its low gyromagnetic ratio. We will discuss the pulse protocols to realize the set of gates necessary for universal computation and show how one can initialize and read out the system in our scheme.

FM 14.7 Mon 15:45 3044

Scalable Rare Earth Ion Quantum Computing Nodes (SQUARE) — •David Hunger — Karlsruhe Institute of Technology, Karlsruhe, Germany

Quantum technologies rely on materials that offer the central resource of quantum coherence, that allow one to control this resource and to harness interactions to create entanglement. Rare earth ions (REI) doped into solids have an outstanding potential in this context and could serve as a scalable, multi-functional quantum material. REI provide a unique physical system enabling a quantum register with a large number of qubits, strong dipolar interactions between the qubits allowing fast quantum gates, and coupling to optical photons - including telecom wavelengths - opening the door to connect quantum processors in a quantum network. The flagship project SQUARE aims at establishing individually addressable rare earth ions as a fundamental building block of a quantum computer, and to overcome the main roadblocks on the way towards scalable quantum hardware. The goal is to realize the basic elements of a multifunctional quantum processor node, where multiple qubits can be used for quantum storage, quantum gates, and for coherent spin-photon quantum state mapping.

FM 15: Poster: Teaching Quantum Science

Time: Monday 16:00–16:30 Location: 1114

FM 15.1 Mon 16:00 1114

Teaching quantum informatics the hands-on way — •Martin Saip — Institute of Physics of Materials CAS, Žižkova 22, 616 62 Brno-střed; Czech Republic — Faculty of Informatics, Botanická 68a, 602 00 Brno; Czechia

Education of quantum informatics has, until recently, relied on theory only. No sooner than in this decade were well-functioning quantum computer simulators developed, together with languages for programming them. And nowadays, we have working quantum Turing machines. Unfortunately, most schools are late to the party, having no practical courses - one of the reasons is difficulty of choosing and subsequently setting up the necessary software, another one: teachers unaware of recent hardware and software developments.

I will talk about this progress, as well as mentioning the pitfalls of installing/building such quantum computing programs and their (mostly undocumented) solutions.

FM 15.2 Mon 16:00 1114

Classical to Quantum – Schlüsselexperimente im Lernprozess — •Moritz Waitzmann[1], Rüdiger Scholz[2] und Susanne Wessnigk[1] — [1]Institut für Didaktik der Mathematik und Physik, Leibniz Universität Hannover — [2]Institut für Quantenoptik, Leibniz Universität Hannover

"An educational approach ... in the form of conceptual and intuitive understanding is needed." (Mishina, Oxana et. al. (2019). Strategic Agenda Summary: Education for QT. https://qt.eu/app/uploads/2019/04/Strategic-Agenda-Summary-Education-for-QT_08.04.19.pdf). Sehr klar formuliert hier das europäische Quantum Flagship neue Ausbildungsziele.

In unserem Beitrag beschreiben wir Details einer experimentellen Perspektive auf den Konzeptwechsel für ein tieferes Verständnis von quantenphysikalischen Wesensmerkmalen (Nichtlokalität, Superpositionsprinzip). Wir schildern den Einsatz von quantenoptischen Schlüsselexperimenten (Koinzidenzexperimente mit Einzelphotonen am Strahlteiler und im Interferometer), verbunden mit einem auf Schulmathematik beschränkten Erklärungskonzept (Binomialinterpretation der Superposition von Wahrscheinlichkeitsamplituden), um das Interesse an einem ungewohnten quantenphysikalischen Modell zu entwickeln.

Der Einsatz im Schülerlabor foeXlab weist auf positive Rückwirkungen bei den Lernenden hin, hinsichtlich ihrer Bereitschaft, sich mit quantenphysikalischen Inhalten zu beschäftigen; ein empirisch gestützter Nachweis der Schlüsselwirkung bei der Konzeptentwicklung "classical to quantum" wird derzeit entwickelt. Erste Ergebnisse werden bis zur Tagung erwartet.

FM 15.3 Mon 16:00 1114

Networked Education and Outreach Initiatives in the Hannover-Braunschweig Region — Gunnar Friege[1], Fumiko Kawazoe[2], •Tara Cubel Liebisch[3], Rainer Müller[4], Rüdiger Scholz[1], Moritz Waitzmann[1], and Susanne Wessnigk[1] — [1]Leibniz Universität Hannover, Welfengarten 1 30167 Hannover — [2]Max-Planck-Institut für Gravitationsphysik, Hannover (AEI), Callinstraße 38 30167 Hannover — [3]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100 38116 Braunschweig — [4]Technische Universität Braunschweig, Bienroder Weg 82 38106 Braunschweig

Within the framework of the Cluster of Excellence QuantumFrontiers, a range of Education and Outreach initiatives are supported, with the goals of (1) enhancing public and school engagement with the topics of quantum physics, nanotechnology, and metrology and (2) providing structured education for all levels of University students in these topics. We will present an overview of these activities, namely: (a) an initiative of MasterClasses aimed at high-school students, teachers and undergraduates to provide insights into and methods of basic research, (b) an out-of-school Laboratory foeXlab, which has provided hands-on experience with contemporary optics to over 500 students, (c) a course of studies in Quantum Engineering aimed at providing a common quantum Physics and nanoengineering curriculum, and (d) an international research school, which intensely links the physics and engineering disciplines in the training of scientists.

FM 16: Teaching Quantum Science

Time: Monday 16:30–18:30 Location: Aula

FM 16.1 Mon 16:30 Aula

Präzision lehren mit Anwendungen – Vom klassischen Sensor zum Quantensensor — •Kim-Alessandro Weber[1], Rüdiger Scholz[1] und Gunnar Friege[2] — [1]Institut für Quantenoptik — [2]Institut für Didaktik der Mathematik und Physik

Qutega und das Quantumflagship stellen den Bedarf von Ausbildungsprogrammen zur Quantenphysik heraus.

Der Beitrag hier beschreibt einen Weg vom klassischen Sensor zum Quantensensor. Messtechnische Fragestellungen stehen dabei im Zentrum: Was zeichnet Quantensensoren gegenüber klassischen Sensoren aus und welche Anwendungen existieren? Zur Zielgruppe gehören Masterstudierende aus den Ingenieurswissenschaften.

Der Ausgangspunkt des Beitrags ist das Michelson-Interferometer. Dieses wird als klassischer (!) Sensor eingeführt, um Werkstücke und deren Eigenschaften zu analysieren (zum Beispiel: Steigung von Gewinden). Geleitet von dem Präzisionsgedanken wird darauf aufbauend ein Konzept zu hands-on Erfahrungen mit Quantensensoren vorgestellt. Bei der Gegenüberstellung von klassischem und Quantensensor liegt der Fokus auf der Rauschcharakteristik der Sensoren.

Der Versuch zum klassischen Sensor "Michelson-Interferometer" wird derzeit im Physikalischen Praktikum für Ingenieure getestet. Erfahrungen und die didaktisch reflektierte Versuchsentwicklung werden vorgestellt. Im Rahmen einer Machbarkeitsanalyse wurden darüber hinaus Informationen über kommerzielle Quantensensoren zusammengestellt, um den Einsatz in der Lehre zu prüfen.

FM 16.2 Mon 16:45 Aula

Verschränkung erleben und verstehen — Oliver Bodensiek, •Franziska Gerke und Rainer Müller — TU Braunschweig, IFdN, Abteilung Physik und Physikdidaktik, Bienroder Weg 82, 38106 Braunschweig, Germany

Die Verschränkung von Quantenobjekten entwickelt sich derzeit von einer wenig beachteten Randerscheiungung zu einer Ressource, die in technischen Produkten genutzt wird und in industriellen Zusammenhängen zum Einsatz kommen soll. In Zukunft werden auch Studierende der Ingenieurwissenschaften über "Quantum Awareness" verfügen müssen, um in diesem Bereich tätig zu werden.

Anhand einfacher Experimente zur Polarisationsverschränkung von Photonen sollen die Besonderheiten der Verschränkung erfahrbar gemacht und verdeutlicht werden. Dabei wird lediglich auf Vorkenntnisse zur Polarisation und dem Verhalten von Photonen am Polarisationsfilter (quantenphysikalischer Messprozess) aufgebaut, sodass der Einsatz bereits zu Beginn eines ingenieurwissenschaftlichen Studiums möglich ist

FM 16.3 Mon 17:00 Aula

Teaching Experiments: Akzeptanzbefragung zur Elementarisierung quantenoptischer Realexperimente — •Philipp Bitzenbauer und Jan-Peter Meyn — FAU Erlangen, Germany

Quantenoptische Realexperimente mit einzelnen Photonen wurden in ein einführendes Unterrichtskonzept zur Quantenphysik eingebettet. In Teaching Experiments wurde mit Schülerinnen und Schülern der gymnasialen Oberstufe erstmals die Akzeptanz der erarbeiteten Erklärungsansätze mit empirischen Methoden untersucht. Die Ergebnisse liefern Indizien, dass quantenoptische Konzepte von Schülerinnen und Schülern verstanden werden können und bilden daher die Grundlage weiterer empirischer Erhebungen mit größeren Stichproben und quantitativen Methoden. Die Ergebnisse der Teaching Experiments werden genauso vorgestellt, wie das Unterrichtskonzept.

FM 16.4 Mon 17:15 Aula

Quantenkryptographie als Zugang zur Quantenphysik — •Gesche Pospiech — TU Dresden, Dresden, Germany

In den letzten Jahren gewinnt die Quanteninformation erheblich an Bedeutung. Nachdem es bereits seit etlichen Jahren Vorschläge für die Etablierung der Quanteninformation als Zugang zur Quantenphysik in der Schule gibt, ist es nun an der Zeit konkrete Unterrichtsgänge zu entwickeln. In dem Vortrag wird ein Zugang über die Quantenkryptographie vorgestellt, der in der Lehramtsausbildung erprobt und mittlerweile auch für Schüler des Gymnasium fortentwickelt wurde. Dabei wird besonderer Wert darauf gelegt, dass die zentralen Begriffe der Quantenphysik wie Unbestimmtheit und Verschränkung in ihrer Bedeutung sowohl für das physikalische Weltbild wie auch für die Quanteninformation verstanden werden. Unterstützt wird diese Einheit durch passende Modellexperimente,

FM 16.5 Mon 17:30 Aula

Unterrichtskonzepte zur Quantentheorie – Ein kritischer Vergleich — •Oliver Passon — Universität Wuppertal

In diesem Vortrag werden verschiedene Unterrichtsvorschläge zur Quantenmechanik aus der akademischen Fachdidaktik und bekannten Schulbüchern untersucht und miteinander verglichen. Die zentralen Kriterien dafür sind fachliche Korrektheit (bzw. Anschlussfähigkeit) und Lernwirksamkeit. Es zeigen sich gravierende Mängel in verbreiteten Darstellungen.

FM 16.6 Mon 17:45 Aula

Gestalttreue und Funktionalitätstreue als unabhängige Faktoren mentaler Modelle am Beispiel der Quantenphysik — •Malte Ubben und Stefan Heusler — Institut für Didaktik der Physik, Münster, Germany

Der konzeptuelle Wandel zur Quantenphysik gestaltet sich für Lernende aus mehreren Gründen als schwierig. Zum einen ist die Anschlussfähigkeit an Begriffe aus dem vorangegangenen Physikunterricht, wie etwa zum Bahnbegriff in der klassischen Physik, nicht mehr ohne weiteres gegeben. Zum anderen wird ein Modellverständnis gefordert, welches neue Herausforderungen bezüglich der abstrakten Interpretation von Modellen erfordert. In einer quantitativen Studie (N=3108) haben wir zum einen das Verständnis von naturwissenschaftlichen Modellen getestet und zum anderen gängige Modellvorstellungen zu Elektronen in der Atomhülle erhoben.

Als Ergebnis zeigen sich die zwei unabhängigen Faktoren Gestalttreue und Funktionalitätstreue, welche sowohl allgemein Aspekte des physikalischen Modellverständnisses als auch die einzelnen Lernendenvorstellungen beschreiben. Dabei beschreibt die Gestalttreue, inwieweit ein (mentales) Modell die Gestalt von etwas passend abbildet und die Funktionalitätstreue, inwieweit ein (mentales) Modell die Funktionalität von etwas passend abbildet. Vor allem wird dann der Faktor der Gestalttreue thematisiert, welcher besonders in der Quantenphysik zu großen Problematiken bei der Entwicklung von Lernendenvorstellungen führen kann.

FM 16.7 Mon 18:00 Aula

Teaching quantum informatics the hands-on way — •Martin Saip — Institute of Physics of Materials CAS, Žižkova 22, 616 62 Brno-střed; Czech Republic — Faculty of Informatics, Botanická 68a, 602 00 Brno; Czechia

Education of quantum informatics has, until recently, relied on theory only. No sooner than in this decade were well-functioning quantum computer simulators developed, together with languages for programming them. And nowadays, we have working quantum Turing machines. Unfortunately, most schools are late to the party, having no practical courses - one of the reasons is difficulty of choosing and subsequently setting up the necessary software, another one: teachers unaware of recent hardware and software developments.

I will talk about this progress, as well as mentioning pitfalls of installing/building such quantum computing programs and their (mostly undocumented) solutions.

FM 16.8 Mon 18:15 Aula

Quantum physics for politicians and elementary school teachers — •Hans Peter Dreyer — IfE, University of Zurich, Switzerland

The quantum computer is an attractive object for students who are already interested in STEM topics. In Switzerland, those 30% will choose physics and mathematics or biology and chemistry as their main subjects. For the other 70%, among them 70% female, physics is the least interesting of the mandatory subjects in upper secondary school. An introduction into quantum physics seems important and might be attractive especially for those who will later form our future as lawmakers and educators.

FACETTEN DER QUANTENPHYSIK is a didactically reconstructed course for 11th (What is light?) and 12th grade (Matter: Particle or wave?) with a focus on Nature of Science. Preliminary tests show that it is possible to learn in 14 - 18 lessons experimental evidence and the laws indicating the dualism of light and matter. In addition, relations between physics and technology and between theory and experiment are reflected on a historical and biographical background. Some results concerning change of physical concepts, nature of science and motivation will be presented.

FM 17: Quantum Computation: Simulation I

Time: Monday 16:30–18:00 Location: 1010

FM 17.1 Mon 16:30 1010

Quantum Simulation of the Quantum Rabi Model in the Deep Strong Coupling Regime — •Johannes Koch[1], Geram Hunanyan[1], Simone Felicetti[2], Enrique Rico[3,4], Enrique Solano[3,4], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany — [2]Laboratoire Matériaux et Phénomènes Quantiques, Universite of Paris 7, Bâtiment Condorcet, Case courrier 7021, 75205 Paris Cedex 13, Paris, France — [3]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, E-48080 Bilbao, Spain — [4]IKERBASQUE, Basque Foundation for Science, Maria Diaz de Haro 3, E-48013 Bilbao, Spain

The Quantum Rabi Model describing the interaction between a two-level quantum system and a single bosonic mode has been well studied in the moderate and strong coupling regimes, while the experimental study of more extreme parameter regimes has long been a technical challenge. Here we investigate the Quantum Rabi Model in the deep strong coupling regime, in which the characteristic frequencies of the coupling exceeds those of the two-level system and the bosonic mode.

Our experimental implementation uses ultracold rubidium atoms in a tailored optical lattice potential, with the two-level system provided by two Bloch bands. This effective qubit interacts with a quantum harmonic oscillator mode provided by the atomic motion in an optical dipole potential superimposed to the lattice potential. The time evolution of the system provides insights into the evolution of the Quantum Rabi Model. The present status of the experiment will be presented.

FM 17.2 Mon 16:45 1010

Simulating a Mott insulator using attractive interaction — •Marcell Gall, Chun Fai Chan, Nicola Wurz, and Michael Köhl — Physikalisches Institut, University of Bonn, Wegelerstraße 8, 53115 Bonn, Germany

Particles can be transformed into their anti-particles by a charge conjugation, and a symmetry upon such conjugation plays a crucial role in physics. For example, all fundamental forces, except weak interaction, obey such symmetry. However, even in the low-energy domain of condensed matter physics, the symmetry gives rise to novel effects and provides stability to exotic quantum states.

In our experiment, we study the particle-hole symmetry in a quantum simulator of the two-dimensional Hubbard model using ultracold fermionic atoms in an optical lattice. In this talk we will demonstrate mapping between charge and spin degrees of freedom. In particular, we show the occurrence of a state with incompressible magnetisation for attractive interactions, corresponding to the Mott phase in the density sector and repulsive interactions.

FM 17.3 Mon 17:00 1010

Defect-free assembly of 2D clusters of more than 100 single-

atom quantum systems in a multilayer Talbot optical lattice — •Malte Schlosser, Daniel Ohl de Mello, Dominik Schäffner, Tilman Preuschoff, Lars Kohfahl, Jan Werkmann, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Efficient quantum simulation and quantum information processing requires scalable architectures that guarantee the allocation of large-scale qubit resources. In our work, we focus on the implementation of multi-site geometries based on microoptical elements that readily provide thousands of sites for single-atom quantum systems with Rydberg-mediated interactions.

We report on the realization of a novel platform for the creation of 3D multilayer configurations of planar arrays: a microlens-generated Talbot optical lattice [1]. We demonstrate the trapping and imaging of rubidium atoms in integer and fractional Talbot planes and realize the in-plane assembly of defect-free arrays of up to 111 neutral atoms, building on a 361-site subset of traps [2]. By performing multiple assembly cycles in rapid succession, we drastically increase achievable structure sizes and success probabilities. We implement repeated target pattern reconstruction after atom loss and deterministic transport of partial atom clusters.

[1] M. Schlosser et. al., arXiv:1902.05424 (2019).
[2] D. Ohl de Mello et. al., Phys. Rev. Lett. **122**, 203601 (2019).

FM 17.4 Mon 17:15 1010

Simulating long-range interacting systems with cold atoms in resonators — •Simon B. Jäger, Luigi Giannelli, Francesco Rosati, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

Dilute atomic gases in optical cavities are versatile platforms to simulate the statistical mechanics of long-range interacting systems. The long-range potential shares the same non-additivity of gravitational and Coulomb forces and here emerges from multiply-scattered cavity photons. In addition, photon losses and retardation effects give rise to long-range dissipative forces, which are expected to play a peculiar role in the approach to equilibrium. We analyze the stationary phases of cold atoms in optical cavities and their relaxation dynamics towards steady state. We focus in particular on the dynamics following quenches across different stationary phases and investigate the onset and stability of metastable states in the regime in which quantum fluctuations are a small perturbation to the dynamics. Our analysis shows that cold atoms in resonators can provide a promising setup to verify in a laboratory hypothesis developed for the statistical mechanics of cosmic structures.

FM 17.5 Mon 17:30 1010

Ions and atoms in optical dipole traps: a new platform for quantum simulations — Pascal Weckesser, Fabian Thielemann, Isabelle Lindemann, Florian Hasse, Tobias Schaetz, and •Leon Karpa — Physikalisches Institut, Albert-Ludwigs Universität Freiburg, Germany

The combination of ions and neutral atoms has been brought forward as a candidate for realizing novel quantum simulations by making use of their advantageous interaction. One of the most sought after goals in the recently emerged field studying cold ion-atom collisions is gaining access to a quantum dominated regime of ion-atom interactions. So far, experiments in hybrid systems combining ions in Paul traps and optically trapped atoms show that the energy scales in the combined system are limited to temperatures on the order of mK, even in the case of ultracold ensembles. This limitation is the consequence of micromotion-induced heating inherent to all radiofrequency traps.

Here we present a new approach based on all-optical trapping of ions and atoms which avoids the use of any radiofrequency techniques, and show sympathetic cooling of ions to sub-Doppler temperatures. Together with our recent findings demonstrating optical trapping of ion Coulomb crystals and long lifetimes on the order of seconds, these results pave the way to ultracold ion-atom interactions, a novel class of quantum simulations and investigations of structural quantum phase transitions.

FM 17.6 Mon 17:45 1010

Easing the Monte Carlo Sign Problem — •Dominik Hangleiter[1], Ingo Roth[1], Daniel Nagaj[2], and Jens Eisert[1] — [1]FU Berlin, 14195 Berlin — [2]Slovak Academy of Sciences, Bratislava, Slovakia

Quantum Monte Carlo (QMC) methods are the gold standard for studying equilibrium properties of quantum many-body systems – their phase transitions, their ground and thermal state properties – but also quantum circuit simulation. However, QMC methods face the severe limitation of a 'sign problem' for many quantum systems, in particular so for fermionic systems. Here, we introduce a novel universal and versatile framework for 'easing the sign problem' by local basis changes in practical condensed-matter applications, realising that it is a basis-dependent property. We introduce the optimisation problem of finding the basis in which the sign problem is smallest by means of minimizing the positive part of the Hamiltonian matrix. We then demonstrate that this problem is practically feasible using geometric optimization methods by the example of frustrated ladder systems, showing that the sign problem can be greatly reduced. Complementing this pragmatic mindset, as our main rigorous result we show that easing the sign problem can be a computationally hard task, even in situations in which deciding whether an exact solution exists can be done efficiently.

FM 18: Quantum Networks: Interfaces & Hybrid Systems

Time: Monday 16:30–18:30 Location: 1015

Invited Talk FM 18.1 Mon 16:30 1015

Generation of strongly correlated photons using nanofiber-coupled atoms — Adarsh Prasad[1], Jakob Hinney[1], Klemens Hammerer[2], Sahand Mahmoodian[2], Samuel Rind[1], Philipp Schneeweiss[1,3], Anders S. Sørensen[4], Jürgen Volz[1,3], and •Arno Rauschenbeutel[1,3] — [1]Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria — [2]Institute for Theoretical Physics, Institute for Gravitational Physics (Albert Einstein Institute), Leibniz University Hannover, Appelstraße 2, 30167 Hannover, Germany — [3]Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [4]Center for Hybrid Quantum Networks (Hy-Q), Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, 2100 Copenhagen, Denmark

Typical schemes for generating correlated states of light require a highly nonlinear medium strongly coupled to an optical mode. Such approaches are often impaired by unavoidable dissipative processes which reduce the nonlinearity and cause photon loss. Here, we experimentally demonstrate the opposite approach, where a highly dissipative, weakly coupled medium can be harnessed to generate and study strongly correlated states of light. Specifically, we show that light transmitted through an ensemble of atoms that weakly couple to the optical mode of an optical nanofiber exhibits antibunched or bunched photon statistics depending on the optical depth of the atomic ensemble. This opens a new avenue for generating nonclassical states of light and for exploring photon correlations in non-equilibrium systems using a mix of nonlinear and dissipative processes.

FM 18.2 Mon 17:00 1015

Towards a Suburban Quantum Network Link — •Tim van Leent[1], Robert Garthoff[1], Kai Redeker[1], Matthias Bock[2], Wei Zhang[1], Wenjamin Rosenfeld[1,3], Christoph Becher[2], and Harald Weinfurter[1,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany — [2]Fachrichtung Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [3]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Quantum repeaters will allow scalable quantum networks, which is essential for large scale quantum communication and distributed quantum computing. Yet, still missing on the road towards a quantum repeater, is to achieve entanglement between quantum memories over long distances.

Here we present results on observing atom-photon entanglement between a Rubidium 87 atom and a telecom photon over 10 km optical fiber with a fidelity of 85%. For this purpose, we use quantum frequency conversion, where the spontaneously emitted photon at 780 nm is mixed with a strong pump field at 1600 nm inside a nonlinear waveguide crystal in a Sagnac-type interferometer configuration [1,2]. The atomic coherence time is extended to hundreds of μs by suppressing magnetic field fluctuations with a guiding field. Installing frequency conversion for the second atom will allow to generate atom-atom entanglement on a suburban scale [3].

[1] M. Bock et al., Nat. Comm. **9**, 1998 (2018)
[2] R. Ikuta et al., Nat. Comm. **9**, 1997 (2018)
[3] W. Rosenfeld et al., Phys. Rev. Lett. **119**, 010402 (2017)

FM 18.3 Mon 17:15 1015

Device-indepedent certification of quantum network link — •Xavier Valcarce[1], Jean-Daniel Bancal[1], Kai Redeker[2], Pavel Sekatski[1], Wenjamin Rosenfeld[3,2], and Nicolas Sangouard[1] — [1]Quantum Optics Theory Group, Universität Basel, CH-4056 Basel, Switzerland — [2]Department fur Physik, Ludwig-Maximilians-Universität, 80797 Munchen, Germany — [3]Max-Planck-Institut fur Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, German

Device-independent characterization, also known as self-testing, provides a certification of devices from the result of a Bell test that is suitable for a wide range of applications. We here show advantages and recently derived limits of CHSH self-test, as well as how it can be used in an elementary link of a quantum network. Being based on a Bell test free of detection and locality loopholes, our certification is fully device-independent, that is, it does not rely on a knowledge of how the devices work. This guarantees that our link can be integrated in a quantum network for performing long-distance quantum communications with security guarantees that are independent of the details of the actual implementation.

FM 18.4 Mon 17:30 1015

grAl SQUID resonators for magnetomechanical coupling — •Christian Markus Florian Schneider[1,2], Mathieu Juan[2], David Zöpfl[1,2], and Gerhard Kirchmair[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Austria

Granular Aluminum (grAl) has been proven to be an ideal material for magnetic coupling. The high critical field of this dirty superconductor allows operation in 100 - 500 mT magnetic fields. Recent experiments have further demonstrated high coherences of grAl resonators and qubits. We implement a superconducting quantum interference device (SQUID) made out of grAl constriction junctions to construct a flux sensitive grAl resonator. By placing a ferromagnetic cantilever on top of the SQUID loop, we achieve a strong magnetomechanical coupling. This approach could allow us to enter the strong single photon coupling regime between a macroscopic mechanical system and superconducting circuits - a milestone in the field of cavity optomechanics.

FM 18.5 Mon 17:45 1015

Simple smooth pulses for fast dispersive cavity and network measurements — •Felix Motzoi[1,2], Lukas Buchmann[1], and Christian Dickel[3] — [1]Aarhus University — [2]Forschungszentrum Jülich, Peter Grünberg Institute — [3]Kavli Institute of Nanoscience, Delft University of Technology,

We demonstrate a quantum non-demolition measurement pulse shaping technique that allows for arbitrarily fast dispersive, single-quadrature measurements using cavities and quantum networks. For single-qubits, current cQED measurements are limited to the 99% fidelity range due to relaxation for long durations, traded off with cavity leakage at shorter times. These effects can be suppressed using simple smooth readout shapes, related to unitary DRAG transmon pulses. Here, an exact open-system solution is found for arbitrarily many measurement modes, network elements, and mea- sured states. It also generalizes to any linear measurement apparatus, and maximizes efficiency by retaining information in a single field quadrature. Beyond single cavities, the technique generalizes to more complex networks, such as using Purcell filter cavities (where depopulating is a major chal- lenge), cascaded cavity systems (e.g for fast remote entanglement generation), continuous-variable field operations, or (non-dispersive) single-photon networks.

FM 18.6 Mon 18:00 1015

Quantum synchronization — •Christoph Bruder — Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel

Experimental progress in optomechanical systems, in trapped-ion setups, and in superconducting circuit-QED architectures has motivated the study of synchronization in *quantum systems*. This gives rise to a number of conceptual questions, like the relation between quantum synchronization and the generation of entanglement, and leads to paradoxial phenomena like the quantum synchronization blockade [1]. Recently, we have addressed the question what is the smallest possible system that can be synchronized. We have shown that whereas qubits cannot be synchronized due to the lack of a limit cycle, a single spin 1 can be phase-locked to a weak external signal of similar frequency and exhibits all the standard features of the theory of synchronization [2]. We have also studied synchronization in a two-node spin-1 network and have shown that phase locking between these quantum oscillators can be achieved even for limit cycles that cannot be synchronized to an external semi-classical signal [2]. Finally, we have explored the relation between quantum synchronization and the generation of entanglement. [1] N. Lörch, S.E. Nigg, A. Nunnenkamp, R.P. Tiwari, and C. Bruder, Phys. Rev. Lett. **118**, 243602 (2017). [2] A. Roulet and C. Bruder, Phys. Rev. Lett. **121**, 053601 (2018); *ibid.*, 063601 (2018).

FM 18.7 Mon 18:15 1015

A SiO2 Photonic Platform for the On-Chip Integration of Quantum Emitters — •Florian Böhm[1], Niko Nikolay[1], Christoph Pyrlik[2], Jan Schlegl[2], Andreas Thies[2], Andreas Wicht[2], and Oliver Benson[1] — [1]AG Nanooptik & IRIS Adlershof, Humboldt-Universität zu Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

An important prerequisite for future nanophotonic devices is the scalable on-chip integration of single photon emitters.

Here we present the deterministic integration of a single solid-state qubit, the nitrogen-vacancy (NV) center, with a photonic platform consisting exclusively of SiO2 grown thermally on a Si substrate. The platform stands out by its ultra-low fluorescence and the ability to produce various passive structures such as high-Q microresonators and mode-size converters [1].

An numerically optimized structure for the efficient coupling of a dipole emitter to the guided mode was integrated with a preselected NV emitter using an atomic force microscope. We then could demonstrate the on-chip excitation of the quantum emitter as well as the coupling of single photons to the guided mode of the integrated structure [2].

Our approach shows the potential of this platform as a robust nanoscale interface of on-chip photonic structures with solid-state qubits.

[1] Pyrlik, C. et al., IEEE Phot. Technol. Lett. (2019): 31 479-82
[2] Böhm, F. et al., New Journal of Physics 21.4 (2019): 045007.

FM 19: Topology: Majoranas

Time: Monday 16:30–18:30 Location: 1199

Invited Talk FM 19.1 Mon 16:30 1199

Topological superconductivity in full shell proximitized nanowires — •Roman Lutchyn — Microsoft Quantum, Microsoft Station Q, University of California, Santa Barbara, California 93106-6105 USA

I will discuss a new model system supporting Majorana zero modes based on semiconductor nanowires with a full superconducting shell. I will demonstrate that, in the presence of spin-orbit coupling in the semiconductor induced by a radial electric field, the winding of the superconducting order parameter leads to a topological phase supporting Majorana zero modes. The topological phase persists over a large range of chemical potentials and can be induced by a predictable and weak magnetic field piercing the cylinder. The system can be readily realized in semiconductor nanowires covered by a full superconducting shell, opening a pathway for realizing topological quantum computing proposals.

FM 19.2 Mon 17:00 1199

Non-Abelian Majorana fermions in topological s-wave Fermi superfluids — •Lauri Toikka — University of Innsbruck, Austria

By solving the Bogoliubov-de Gennes equations analytically, we derive the fermionic zero-modes satisfying the Majorana property that exist in vortices of a two-dimensional s-wave Fermi superfluid with spin-orbit coupling and Zeeman spin-splitting. The Majorana zero-mode becomes normalisable and exponentially localised to the vicinity of the vortex core when the superfluid is topologically non-trivial. We calculate the energy splitting due to Majorana hybridisation and identify that the s-wave Majorana vortices obey non-Abelian statistics.

FM 19.3 Mon 17:15 1199

Parity-to-charge conversion for readout of topological Majorana qubits — •Gábor Széchenyi[1] and András Pályi[2] — [1]Eötvös University, Budapest, Hungary — [2]Budapest University of Technology and Economics, Budapest, Hungary

We theoretically study a scheme to distinguish the two ground states of a one-dimensional topological superconductor, which could serve as a basis for the readout of Majorana qubits. The scheme is based on parity-to-charge conversion, i.e., the ground-state parity of the superconductor is converted to the charge occupation on a tunnel-coupled auxiliary quantum dot. We describe how certain error mechanisms, degrade the quality of the parity-to-charge conversion process. We consider (i) leakage due to a strong readout tunnel pulse, (ii) incomplete charge Rabi oscillations due to slow charge noise, and (iii) charge relaxation due to phonon emission and absorption. To describe these effects, we use simple model Hamiltonians based on the ideal Kitaev chain, and draw conclusions to generic one-dimensional topological superconductors wherever possible. In general, the effects of the error mechanisms can be minimized by choosing an optimal strength for the readout tunnel pulse. In a case study based on InAs heterostructure device parameters, we estimate that the parity-to-charge conversion error is mainly due to slow charge noise for weak tunnel pulses and leakage for strong tunnel pulses.

FM 19.4 Mon 17:30 1199

Transport signatures of electron-tunneling-assisted non-Abelian braiding — Sunghun Park[1], Heung-Sun Sim[2], and •Patrik Recher[3] — [1]Departamento de Física Teórica de la Materia Condensada, Condensed Matter Physics Center (IFIMAC) and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, Spain — [2]Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 34141, Korea — [3]Institute for Mathematical Physics, TU Braunschweig, D-38106 Braunschweig, Germany

We present a theory of coherent time-dependent electron tunneling from a metal tip into a Corbino geometry topological Josephson junction where four Majorana bound states (MBSs) rotate. The time averaged tunneling conductance exhibits, as a function of bias voltage between the tip and the Josephson junction, distinctive conductance peaks that are separated by $h/(4T_J)$ (where T_J is the time period of the system Hamiltonian). This separation is a result of interference between processes where electron tunneling between the tip and the junction interrupts the rotation of the MBSs after different number of round trips. The interference effect is shown to be a direct consequence of two non-commuting braiding operations—a rotation of the four MBSs along the Josephson junction and a tunneling assisted rotation—reflecting the non-Abelian nature of MBSs. This mechanism of non-Abelian state evolution actively utilizes electron tunneling that changes the fermion occupation number parity of the system rather than avoiding it while the MBSs are spatially decoupled from each other and hence are not fused physically.

FM 19.5 Mon 17:45 1199

Fully in situ fabricated Josephson devices via the Jülich process — •Peter Schüffelgen[1], Daniel Rosenbach[1], Chuan Li[2], Tobias W. Schmitt[1], Michael Schleenvoigt[1], Benjamin Bennemann[1], Lidia Kibkalo[1], Martina Luysberg[1], Gregor Mussler[1], Erwin Berenschot[2], Niels Tas[2], Alexander A. Golubov[2], Alexander Brinkman[2], Thomas Schäpers[1], and Detlev Grützmacher[1] — [1]Peter Grünberg Institute, Forschungszentrum Jülich — [2]MESA+ Institute, University of Twente

Networks of topological insulator (TI) nanostructures in proximity to superconductors (S) have been predicted to provide a platform for topologically protected quantum computing. A combination of selective area growth and stencil lithography allowed us to fabricate $Nb-(Bi,Sb)_2Te_3$ S-TI hybrid devices fully under ultra-high vacuum conditions. The so-called Jülich process yields highly transparent S-TI interfaces and provides a protective capping layer to the devices before they are exposed to ambient conditions. Measurements on as-prepared Josephson junctions show signatures of Majorana bound states. By restricting TI growth to selected areas only, it is possible to move from single Josephson junctions towards complex circuitry for future topological quantum computation architectures.

FM 19.6 Mon 18:00 1199

Integration of topological Josephson junctions into superconducting quantum circuits — •Tobias W. Schmitt[1,2], Malcolm R. Connolly[3], Michael Schleenvoigt[2], Abdur R. Jalil[2], Dennis Heffels[2], Chenlu Liu[3], Stefan Trellenkamp[2], Florian Lentz[2], Elmar Neumann[2], Gregor Mussler[2], Peter Schüffelgen[2], Karl D. Petersson[4], and Detlev Grützmacher[2] — [1]JARA-FIT Institute Green IT, RWTH Aachen University — [2]Peter Grünberg Institute, Forschungszentrum Jülich — [3]Imperial College, London — [4]Center for Quantum Devices, Station Q Copenhagen, Niels Bohr Institute, University of Copenhagen

The interface of a 3D topological insulator (3D TI) and an s-wave superconductor (S) is predicted to host elusive Majorana modes. In lateral topological S-TI-S Josephson junctions Majorana bound states (MBS) are assumed to contribute to transport. Due to superimposed conventional Andreev bound states (ABS), observation of unambiguous Majorana signatures in transport measurements is hindered. In order to differentiate MBS from ABS signatures, it has been proposed to integrate S-TI-S junctions into superconducting qubits [1]. A technical challenge in this fabrication process is the protection of the TI surface from degradation at ambient conditions while maintaining a pristine interface to the s-wave superconductor. In this contribution, I will report on recent progress in the integration of in situ fabricated S-TI-S junctions in superconducting quantum circuits and present preliminary results on these devices. [1] arXiv:1902.07229

FM 19.7 Mon 18:15 1199

Dephasing and relaxation of topological many-body states in quantum Ising models — •Hannes Weisbrich, Wolfgang Belzig, and Gianluca Rastelli — University of Konstanz

Inspired by recent progress in coupled arrays of qubits, we study the dephasing and relaxation dynamics of topological states in an extended class of quantum Ising chains of finite length [1]. We assume a local dephasing interaction of each spin with a local thermal bath, from which we derive a Lindblad equation. This kind of interaction preserves the parity in the system [2]. We demonstrate a correlation between the decoherence in the ground state subspace manifold and the topology in the spin chain, characterized by a winding number g. In particular, in the topological regime and at low temperature, the decoherence rates can be exponentially suppressed. For the simple case of the transverse Ising model (g=1) this simply corresponds to the exponentially small overlap of the two localized Majorana zero energy modes of the equivalent Kitaev chain. We generalize this result to a chain with a three body, next nearest neighbor interaction (with g=2) in which the ground state subspace is fourfold degenerate with two ground states in each parity sector (even and odd), namely with four Majorana modes.

[1] H. Weisbrich, W. Belzig, G. Rastelli, SciPost Phys. 6, 037 (2019).
[2] H. Weisbrich, C. Saussol, W. Belzig, G. Rastelli, Phys. Rev. A 98, 052109 (2018).

FM 20: Entanglement: Many-Body States II

Time: Monday 16:30–18:30 Location: 2004

FM 20.1 Mon 16:30 2004

Single-shot holographic compression from the area law — •Henrik Wilming[1] and Jens Eisert[2] — [1]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

The area law conjecture states that the entanglement entropy of a region of space in the ground state of a gapped, local Hamiltonian only grows like the surface area of the region. We show that, for any quantum state that fulfills an area law, the reduced quantum state of a region of space can be unitarily compressed into a thickened surface of the region. If the interior of the region is lost after this compression, the full quantum state can be recovered to high precision by a quantum channel only acting on the thickened surface. The thickness of the boundary scales inversely proportional to the error for arbitrary spin systems and logarithmically with the error for quasi-free bosonic systems. Our results can be interpreted as a single-shot operational interpretation of the area law. The result for spin systems follows from a simple inequality showing that probability distributions with low entropy can be approximated by distributions with small support, which we believe to be of independent interest. We also discuss an emergent approximate correspondence between bulk and boundary operators and the relation of our results to tensor network states.

FM 20.2 Mon 16:45 2004

Symmetry-adapted decomposition of tensor operators and the visualization of coupled spin systems — David Leiner[1], •Robert Zeier[1,2,3], and Steffen J. Glaser[1,4] — [1]Technische Universität München, Department Chemie, Lichtenbergstrasse 4, 85747 Garching, Germany — [2]Adlzreiterstrasse 23, 80337 München, Germany — [3]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 54245 Jülich, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstrasse 4, 80799 München, Germany

We study the representation and visualization of finite-dimensional, coupled quantum systems. In order to establish a generalized Wigner representation, multi-spin operators are decomposed into a symmetry-adapted tensor basis and they are mapped to multiple spherical plots that are each assembled from linear combinations of spherical harmonics. We explicitly determine the corresponding symmetry-adapted tensor basis for up to six coupled spins 1/2 (qubits) using a first step that relies on a Clebsch-Gordan decomposition and a second step which is implemented with two different approaches based on explicit projection operators and coefficients of fractional parentage. Our approach is illustrated with various examples for the cases of four to six coupled spins 1/2. We also treat the case of two coupled spins with arbitrary spin numbers (qudits) and highlight a quantum system of a spin 1/2 coupled to a spin 1 (qutrit). Our work offers a much more detailed understanding of the symmetries appearing in coupled quantum systems. http://arxiv.org/abs/1809.09006

FM 20.3 Mon 17:00 2004

Semiclassical approach in Bose-Hubbard models: from eigenstate statistics to self trapping dynamics — •Remy Dubertrand[1], Mathias Steinhuber[1], Juan-Diego Urbina[1], Klaus Richter[1], and Steve Tomsovic[2] — [1]Institut für Theoretische Physik Universität Regensburg Universitätsstraße 31 D-93053 Regensburg — [2]Department of physics and astronomy, Washington State Univ ersity, Pullman, WA USA

Semiclassical techniques from quantum chaos have been recently generalised to describe many-body interacting bosonic systems written as second quantised models. To understand many-body coherent effects I will motivate how to build a quantum/classical correspondence. This will be used first to describe the eigenstates following a statistical approach. This involves more precisely the connection with Berry's ansatz of ensembles of eigenstates represented by Gaussian distributions with an universal covariance matrix. In particular this allows us to go beyond the naive Random Matrix Theory's approximation. A second, more recent, application aims at studying the far from equilibrium dynamics, where the semiclassical perspective enables one to fully characterise the self trapping transition (well beyond the truncated Wigner range of validity) using quantum signatures, e.g. entanglement properties of the eigenstates.

FM 20.4 Mon 17:15 2004

Many-body localization in the two-dimensional Bose-Hubbard-model — •Andreas Geissler[1,2] and Guido Pupillo[1,3] — [1]ISIS, University of Strasbourg, Strasbourg, France — [2]Institut für Theoretische Physik, Goethe-Universität, Frankfurt am Main, Germany — [3]IPCMS, University of Strasbourg, Strasbourg, France

Some experiments [1,2] already have shown signatures of many-body localization (MBL) for the bosonic Hubbard model in one and two dimensional ultracold atomic gases in optical lattices. A proper theoretical understanding of the MBL phenomenon depends on knowledge about the full eigenstate spectrum. Therefore, commonly used exact numerical studies have been limited to small system sizes. Applying a recently extended beyond-Bogoliubov quasiparticle expansion [3] I have performed a detailed finite size scaling analysis of the quasiparticle eigenstate fractal dimension and gap ratio showing Berezinskii-Kosterlitz-Thouless (BKT) scaling consistent with recent predictions [4]. The low energy mobility edge terminates at the MBL transition. Furthermore, I present theoretical results for a recent experiment [2] showing comparable signatures of localization while suggesting that the observed localization also strongly depends on the confining potential.

[1] C. D'Errico et al., PRL 113, 095301 (2014)
[2] J.-y. Choi et al., Science 352, 1547 (2016)
[3] A. Geissler et al., PRA 98, 063635 (2018)
[4] A. Goremykian et al., PRL 122 040601 (2019); P. Dumitrescu et al., PRB 99 094205 (2019); A. Morningstar et al., arXiv:1903.02001

FM 20.5 Mon 17:30 2004

Shareability of USp⊗USp symmetric states — •Zoltán Zimborás[1], Michael Keyl[2], Thomas Schulte-Herbrüggen[3], and Robert Zeier[3,4] — [1]Wigner Research Centre for Physics, H-1021 Budapest, Hungary — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [3]Technical University Munich, Department of Chemistry, Lichtenbergstrasse 4, 85747 Garching, Germany — [4]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 54245 Jülich, Germany

It is notoriously hard to calculate entanglement measures for generic quantum states. Therefore, from the beginning of entanglement theory it has been useful to consider examples of entangled states with high symmetry, since representation theoretic methods can then be used to greatly simplify the computations of the measures and the characterization of entanglement properties. In the present work, we continue this program by studying states that are invariant with respect to $\mathrm{USp}(2n)\otimes\mathrm{USp}(2n)$ transformations. This symmetry defines a two-parameter family of states in any $2n \times 2n$ dimensional bipartite Hilbert-space. The two free parameters are related by partial transposition in much the same way as isotropic and Werner states, but unlike those states the studied family also contains a region with bound entangled states. Using group theoretical methods, we calculate the one-distillability and two- and three-shareability regions for this set of states, and discuss how these relate to mean-field many-body problems.

FM 20.6 Mon 17:45 2004

Searching for a generalization of the I3322 Bell inequality — •Fabian Bernards[1], Denis Rosset[2], and Otfried Gühne[1] — [1]Universität Siegen, Siegen, Germany — [2]Perimeter Institute, Waterloo, Canada

We present a symmetric and extremal Bell inequality for three parties and three measurements per party with two outcomes each. Further, we investigate the relevance of the Bell inequality, i.e whether it can detect states as entangled that could not be detected with previously known Bell inequalities and discuss whether it can be regarded as a generalization of the I3322 inequality.

FM 20.7 Mon 18:00 2004

Positive maps and matrix polynomial inequalities from the symmetric group — •Felix Huber — ICFO Barcelona, Av. Carl Friedrich Gauss 3, 08860 Castelldefels (Barcelona), Spain

We introduce a hierarchy of positive (but not completely positive) maps acting upon multipartite quantum systems of finite-dimensions. The construction arises from irreducible representations of the symmetric group and can either be seen as a non-linear generalisation of the universal state inversion, or as a lifting of the generalized shadow inequality as introduced by Rains to that of an operator inequality. When applied to multiple copies of some given state, it yields a positive but not completely positive map that is non-linear.

FM 20.8 Mon 18:15 2004

Shell structure and deterministic preparation of microscopic two dimensional systems — •Luca Bayha, Marvin Holten, Ralf Klemt, Keerthan Subramanian, Philipp Preiss, and Selim Jochim — Physics Institute, Heidelberg University, Germany

The interplay between strong paring and shell structures arising from finite numbers creates very rich physics. For example the state of fermions in the BEC-BCS crossover is determined by the competition between pairing and single particle gaps. Here I will present our progress on quantum simulation of such mesoscopic fermionic systems using ultracold atoms. We recently archived the deterministic preparation of up to 12 fermions in the ground state of a two dimensional trap and observed the shell structure of the sample. We use a Feshbach resonance to tune interactions and study the finite size BEC-BCS crossover. For filled shells there is a minimal required attraction for pairing to overcome the single particle gap. Thus the ground state of the BEC-BCS crossover undergoes a quantum phase transition from normal to superfluid. This phase transition is accompanied by a Higgs mode. Remarkably, we found a precursor of this mode in a microscopic system consisting of only 6 fermions. Doing spectroscopy we observed mode softening close the critical binding energy of the many body system. This mode consists mainly of pair excitations, which we show by measuring the full counting statistics. In the future we plan to investigate the system using momentum and spin resolved single particle imaging. This will give insight into the pairing mechanisms, entanglement and correlations of the strongly interacting Fermi gas.

FM 21: Quantum Computation: Algorithms

Time: Monday 16:30–18:30 Location: 2006

Invited Talk FM 21.1 Mon 16:30 2006

Generative training of quantum Boltzmann machines with hidden units — •Nathan Wiebe[1,3] and Leonard Wossnig[2] — [1]University of Washington, Seattle, USA — [2]University College London, London, USA — [3]Microsoft Research, Redmond, USA

In this article we provide a method for fully quantum generative training of quantum Boltzmann machines with both visible and hidden units while using quantum relative entropy as an objective. This is significant because prior methods were not able to do so due to mathematical challenges posed by the gradient evaluation. We present two novel methods for solving this problem. The first proposal addresses it, for a class of restricted quantum Boltzmann machines with mutually commuting Hamiltonians on the hidden units, by using a variational upper bound on the quantum relative entropy. The second one uses high-order divided difference methods and linear-combinations of unitaries to approximate the exact gradient of the relative entropy for a generic quantum Boltzmann machine. Both methods are efficient under the assumption that Gibbs state preparation is efficient and that the Hamiltonian are given by a sparse row-computable matrix.

FM 21.2 Mon 17:00 2006

Quantum Generative Adversarial Networks for Learning and Loading Random Distributions — •Christa Zoufal[1,2], Aurélien Lucchi[2], and Stefan Woerner[1] — [1]IBM Research - Zurich, Rueschlikon, Switzerland — [2]ETH, Zurich, Switzerland

Quantum algorithms have the potential to outperform their classical counterparts in a variety of tasks. The realization of the advantage often requires the ability to load classical data efficiently into quantum states. However, the best known methods for loading generic data into an n-qubit state require $\mathcal{O}(2^n)$ gates. This scaling can easily predominate the complexity of a quantum algorithm and, thereby, impair potential quantum advantage.

Our work demonstrates that quantum Generative Adversarial Networks (qGANs) facilitate efficient loading of generic probability distributions into quantum states. More specifically, the qGAN scheme employs the interplay of a quantum channel, a variational quantum circuit, and a classical neural network to learn the probability distribution underlying given data samples and load it into the quantum channel. The resulting quantum channel loads the learned distribution with $\mathcal{O}(poly(n))$ gates and can, thus, enable the exploitation of quantum advantage induced by quantum algorithms, such as Quantum Amplitude Estimation.

We implement the qGAN distribution learning and loading method with Qiskit and test it using a quantum simulation as well as actual quantum processors provided by the IBM Q Experience. Furthermore, we demonstrate the use of qGANs in a quantum finance application.

FM 21.3 Mon 17:15 2006

Quantum Algorithm for Solving Tri-Diagonal Linear Systems of Equations — •Almudena Carrera Vazquez[1,2], Albert Frisch[3], Dominik Steenken[3], Harry S. Barowski[3], Ralf Hiptmair[2], and Stefan Woerner[1] — [1]IBM Research, Zurich, Switzerland — [2]ETH Zurich, Zurich, Switzerland — [3]IBM Systems, Boeblingen, Germany

Numerical simulations, optimisation problems, statistical analysis and computer graphics are only a few examples from the wide range of real-life applications which rely on solving large systems of linear equations. The best classical methods can approximate the solution of sparse systems in time $poly(N, s, \kappa, \log(1/\epsilon))$, where N denotes the number of unknowns, s the sparsity, κ its condition number and ϵ the accuracy of the approximation. In 2009, A. Harrow, A. Hassidim and S. Lloyd (HHL) proposed a quantum algorithm with a running time of $poly(\log N, s, \kappa, 1/\epsilon)$ under the assumptions of the availability of efficient methods for loading the data, Hamiltonian simulation and extracting the solution. This talk presents efficient implementations for the missing oracles and analyzes the overall performance of the algorithm. The main result presented is a novel procedure for reducing the dependency of the complexity on the error from $1/\epsilon$ to $log^3(1/\epsilon)$. This method could also be used more generally to obtain a similar reduction in the gate complexity of a circuit for Hamiltonian simulation. A complete implementation of the HHL algorithm running in $polylog(N, \kappa, 1/\epsilon)$ is given for the case of a special class of tri-diagonal symmetric matrices.

FM 21.4 Mon 17:30 2006

Quantum Heuristic Algorithms for Hard Planning Problems from Aerospace Research — •Tobias Stollenwerk[1], Elisabeth Lobe[2], and Müller Thorge[1] — [1]German Aerospace Center (DLR), Linder Höhe, 51147 Cologne, Germany — [2]German Aerospace Center (DLR), Lilienthalplatz 7, 38108 Braunschweig, Germany

Quantum heuristic algorithms do not have a proven advantage over classical algorithms. However, there are indications that these approaches might outperform classical approaches for certain applications. Moreover, they are believed to work without quantum error correction and are therefore amenable to early quantum computing devices. Hard combinatorial optimization problems as they occur in logistics or traffic management are highly relevant for society and business. Even minor improvements in the solution quality can have a enormous impact in terms of costs.

We present our work on mapping and solving hard real world planning problems from aerospace research with quantum heuristic algorithms like the Quantum Approximate Optimization Algorithm (QAOA) and quantum annealing (QA). In particular, we discuss the choice of representative but small problem instances as well as the mapping of the original problem to a form compatible with the device and algorithm at hand. The latter includes various obstacles like the handling of constraints, the choice of algorithm parameters and compiling.

FM 21.5 Mon 17:45 2006

Not all entangling gates are universal for quantum computing — •Jonas Haferkamp, Dominik Hangleiter, Jens Eisert, and Juani Bermejo-Vega — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

It has become folklore knowledge that entanglement together with 1-qubit unitaries enables full universal quantum computing. A statement along these lines was indeed proven by J. L. and R. Brylinsky: Any 2-local entangling gate plus 1-qubit unitaries is universal. Here, we show that this fails to be true for 3-local entangling gates. We present an infinite family of 3-local entangling gates. Using the Schur-Weyl duality, we find a short and simple proof for the fact that access to these gates together with all 1-qubit unitaries is not universal for quantum computing.

FM 21.6 Mon 18:00 2006

Improved variational quantum algorithms for optimization problems in a quantum computer — •Panagiotis Barkoutsos[1], Giacomo Nannicini[2], Anton Robert[1], Ivano Tavernelli[1], and Stefan Woerner[1] — [1]IBM Research - Zurich Research Lab — [2]IBM T.J. Watson Research Center

Recent advances in Noisy Intermediate-Scale Quantum (NISQ) computers allow us to find solutions for combinatorial optimization problems encoded in Hamiltonians via hybrid quantum/classical variational algorithms. Current approaches minimize the expectation of the problem Hamiltonian for a parameterized trial state generated in the quantum circuit. The expectation is obtained by sampling the full outcome of an ensemble of measurements of the corresponding matrix element, while the trial wavefunction parameters are optimized classically. This procedure is fully justified for quantum mechanical observables (i.e. molecular energy). However, in the case of the simulation of classical optimization problems, which yield diagonal Hamiltonians, we argue that it is more natural to aggregate the samples using a different aggregation function than the expected value. This is because our goal is simply to determine with good probability which basis state is the optimum. In this talk, we present results of the aforementioned scheme for a plethora of interesting optimization problems where we demonstrate faster convergence towards more accurate solutions.

FM 21.7 Mon 18:15 2006

Variational Quantum Eigensolver on small scale Fermi-Hubbard Models — •Andreas Woitzik[1], Clara Fuchs[1], Andreas Ketterer[1], Panagiotis Barkoutsos[2], Ivano Tavernelli[2], and Andreas Buchleitner[1] — [1]Albert-Ludwigs-Universität Freiburg, Freiburg im Breisgau, Deutschland — [2]IBM Research - Zurich, Rüschlikon, Schweiz

Algorithms processing quantum information seem to be a good candidate for optimisation processes as well as simulations of quantum systems. Due to limited capabilities of currently available quantum hardware the application of these algorithms is restricted to proof-of-principle examples. We elaborate on a quantum-classical variational algorithm applied to small scale Fermi-Hubbard models. The impact of noise on the algorithm is discussed and we present its numerically achieved accuracy depending on the complexity of the quantum circuit by applying an argument based on the Solovay-Kitaev theorem. We find that the algorithm's noise resilience strongly depends on the classical optimisation scheme which is used.

FM 22: Quantum Control

Time: Monday 16:30–18:15 Location: 3042

Invited Talk FM 22.1 Mon 16:30 3042

Control Engineering Taken to the Limits of Quantum Systems Theory — •Thomas Schulte-Herbrüggen[1], Ville Bergholm[1], Witlef Wieczorek[2], and Michael Keyl[3] — [1]Dept. Chem., TU-Munich (TUM), Munich, Germany — [2]Dept. Microtechnology and Nanoscience, Chalmers University of Technology, Sweden — [3]Dahlem Centre for Complex Quantum Systems, FU Berlin, Germany

Quantum optimal control is often key to exploiting the full potential of experimental set-ups pertinent to quantum emerging technologies.

We sketch a Lie frame for quantum systems theory, where symmetries and conservation laws are in quantum Noether-type 1:1 correspondence. Thus one gets a full assessment of controllability, obervability, and accessibility in quantum engineering. We now see which symmetries to break for more control and we show how to apply optimal control to exploit quantum dynamics within the enlarged accessible territory.

Our recent proposal for an optomechanical oscillator extended by a two-level atom perfectly illustrates these principles: without breaking the system symmetries of the optomechanical oscillator, one can only interconvert *within* states of the same Wigner negativity. Coupling to the atom breaks the symmetry and thus allows to go *between* them, e.g., from Gaussian states to non-classical ones.

The example thus elucidates guiding principles for quantum technologies 2.0.

FM 22.2 Mon 17:00 3042

Optimal Control of Superconducting Qubits — •Max Werninghaus[1], Daniel J. Egger[1], Marc Ganzhorn[1], Federico Roy[2], Shai Machnes[2], Frank Wilhelm-Mauch[2], and Stefan Filipp[1] — [1]IBM Research Zurich — [2]Saarland University

Fast and accurate two-qubit gates are a key requirement to perform complex algorithms on current quantum computers. Ideally, the duration of the gate should be much shorter than the coherence time of the system. However, shorter gates can result in unwanted leakage out of the computational subspace. Optimal control theory aims to design fast control pulses suppressing such side effects of the driving field. However, even with an accurately calibrated system model, control pulses require a tune-up to accommodate for parameter-drifts and -inaccuracies. Here we present our work on techniques to speed up calibration routines of control pulses defined by up to 20 parameters. We improve the interplay of control instruments and multidimensional optimization algorithms to reduce hardware constraints to realize efficient tune-up feedback-loops.

FM 22.3 Mon 17:15 3042

Coherent control of two-photon absorption via entangled photons — •Edoardo Carnio[1], Frank Schlawin[2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany — [2]Clarendon Laboratory, University of Oxford, United Kingdom

Coherent control exploits the coherence of classical light to drive an initial quantum state to a desired final state. In two-photon absorption (TPA), in particular, two photons are used to excite a molecule from the ground to an excited state. Under certain conditions, frequency-entangled photons drive the transition more efficiently than in the classical case [1]. We quantify the correlations in the state with the entropy of entanglement, which we compare to the enhancement of the transition. We perform this analysis in the two cases of finite and infinite interaction time.

[1] Schlawin, F. & Buchleitner, A. *Theory of coherent control with quantum light.* New J. Phys. 19, 013009 (2017).

FM 22.4 Mon 17:30 3042

Collective dephasing of tripartite Werner states — •Clément Canard, Edoardo Carnio, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany

An improved understanding of the entanglement dynamics of multipartite quantum states coupled to a noisy environment is an indispensable prerequisite for scalable quantum information processing. As a specific example, we consider the fate of highly symmetric, three-partite Werner states [1,2] under structural perturbations of their rotational symmetry, and subsequently investigate the robustness of their entanglement properties under collective dephasing, as a ubiquitous source of decoherence e.g. in ion trap experiments.

[1] Werner, R.F. *Quantum states with Einstein-Podolsky-Rosen correlations admitting a hidden-variable model.* Phys. Rev. A 40, 4277 (1989).
[2] Eggeling, T. & Werner, R. F. *Separability properties of tripartite states with $U \otimes U \otimes U$ symmetry.* Phys. Rev. A 63, 042111 (2001).

FM 22.5 Mon 17:45 3042

Quantum-state-controlled reactive atom-atom collisions — Tobias Sixt, Jiwen Guan, Markus Debatin, Frank Stienkemeier, and •Katrin Dulitz — Institute of Physics, University of Freiburg, 79104 Freiburg i. Br., Germany

In our experiments, we study quantum-state-controlled reactive collisions between lithium atoms and metastable helium atoms to explore the influence of electron-spin polarization on the reaction rate and to observe quantum resonance effects at low collision energies. Eventually, these experiments are aimed at controlling the outcome of chemical reaction rates, e.g., using coherent control techniques. In our approach, we use an experimental apparatus which consists of a discharge source for the production of metastable helium atomic beams and a magneto-optical trap (MOT) for ultracold lithium atoms [1]. In this contribution, I will show results illustrating that the reaction rate dramatically depends on the initial electronic state of both metastable helium and lithium, respectively. To distinguish between the relative contribution of the $He(2^1S_0)$ and $He(2^3S_1)$ states to the reaction rate, we make use of an original optical quenching scheme [2] which makes it possible to fully deplete the population of $He(2^1S_0)$ in the supersonic beam via optical excitation to the 4^1P_1 state.

[1] Jonas Grzesiak, Takamasa Momose, Frank Stienkemeier, Marcel Mudrich and Katrin Dulitz, *J. Chem. Phys.* **150**(3), 034201, 2019. [2] Jiwen Guan, Vivien Behrendt, Pinrui Shen, Simon Hofsäss, Thilina Muthu-Arachchige, Jonas Grzesiak, Frank Stienkemeier, and Katrin Dulitz, *Phys. Rev. Appl.*, **11**(5), 054073, 2019.

FM 22.6 Mon 18:00 3042

Generalized Filter Functions for Sequences of Quantum Gates — •Julian Teske, Pascal Cerfontaine, Tobias Hangleiter, and Hendrik Bluhm — JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, 52074 Aachen, Germany

When sequences of quantum gates are executed in the presence of non-Markovian noise, the process description of the entire operation is not given by the composition of the individual quantum processes. In my talk I will first present an extension of the filter function formalism to allow the efficient calculation of quantum processes in the presence of correlated noise, e.g. the 1/f-like noise found in many solid-state qubit systems. I will then use this formalism to obtain correction terms for sequences of quantum gates which depend on the individual gates' process descriptions and the structure of the algorithm. For all of these purposes we present an efficient and easy-to-use software implementation.

FM 23: Quantum & Information Science: Neural Networks, Machine Learning, and Artificial Intelligence I

Time: Monday 16:30–18:30 Location: 3043

Invited Talk FM 23.1 Mon 16:30 3043

Learning to violate Bell inequality with reinforcement learning — •Alexey Melnikov, Pavel Sekatski, and Nicolas Sangouard — Department of Physics, University of Basel

Quantum experiments push the envelope of our understanding of fundamental concepts in quantum physics. The designing of modern quantum experiments is difficult and often clashes with human intuition. In my talk, I will address the question of whether a reinforcement learning agent can propose novel quantum experiments. In our works, we answer this question in the affirmative in the context of quantum optics experiments, although our techniques are more generally applicable. I will talk about reinforcement learning and demonstrate how the projective simulation model can be used to design quantum experiments and discover experimental techniques by considering two examples. In the first example, a reinforcement learning agent learns to create high-dimensional entangled multiphoton states [1]. In the second example, our reinforcement learning agent learns to design quantum experiments in which photon pairs violate a Bell inequality. As a result of this learning process, the agent finds several optical setups with high CHSH values for various detection efficiencies, which is an important step towards realistic device-independent quantum cryptography. Our findings highlight the possibility that machine learning could have a significantly more creative role in future quantum experiments.

[1] A.A. Melnikov, H. Poulsen Nautrup, M. Krenn, V. Dunjko, M. Tiersch, A. Zeilinger, and H.J. Briegel. Proc. Natl. Acad. Sci. U.S.A., 115(6):1221, 2018

Invited Talk FM 23.2 Mon 17:00 3043

Quantum policy gradient methods for reinforcement learning — •Sofiene Jerbi[1], Hans Briegel[1,2], and Vedran Dunjko[3] — [1]University of Innsbruck, Innsbruck, Austria — [2]University of Konstanz, Konstanz, Germany — [3]University of Leiden, Leiden, Netherlands

Recent advances in quantum reinforcement learning have been considering a fully quantum learning scenario, where agent, environment and their interaction are granted quantum mechanical abilities. Such scenario is of particular interest for simulatable environments (e.g., fully specified Markov Decision Processes (MDPs)) with large state and action spaces. Indeed, in this case, finding the agent's optimal policy by solving the MDP becomes computationally intractable, which constraints the agent to learn the optimal policy through (quantum) interaction with the environment. The questions that naturally arise are then: what advantage in learning efficiency can we get from a quantum interaction? How can we exploit a quantum interaction to extract useful information for a classical agent? In this work, we tackle these questions by defining a quantization of so-called policy gradient methods. These latter turn the reinforcement learning task into a direct optimization problem on a set of parameters characterizing the agent's policy (e.g., the weights of a neural network) "solvable" with gradient ascent on these parameters. In our quantization, we explore how a quantum interaction can speed-up the computation of the gradients required for these methods.

FM 23.3 Mon 17:30 3043

Machine learning for quantum chemistry with quantum computers — •Tomislav Piskor — HQS Quantum Simulations, Karlsruhe, Germany

Simulating chemical systems is a major field of interest not only for the pharma and chemistry, but also for the automotive industry. One such example is the simulation of functional groups of a large molecule or proteine, which can be useful for the development of new medicine. In order to get the exact ground state, we might use quantum computers in the future. However, every call to a quantum computer will be relatively expensive, making high-throughput simulations with quantum computers unfeasible.

To bypass this, a few single point calculations are determined with an expensive method and then extended to more conformations with, e.g., machine learning methods. The less time-consuming method of choice is density functional theory (DFT). Our approach is to take a hybrid functional, such as B3LYP, which consists of three exchange and two correlation functionals. Each of these functionals has a certain weight which can be modified. Using, for example, a root finding optimizer the functional parameters are optimized in such a way that the energy and the corresponding nuclear gradients of the time-consuming method match the DFT results. In this work, we use coupled-cluster methods with single and double excitations (CCSD) and complete active space self-consistent-field (CASSCF) methods as our computationally expensive methods.

FM 23.4 Mon 17:45 3043

Improving the dynamics of quantum sensors with reinforcement learning — Jonas Schuff, •Lukas Fiderer, and Daniel Braun — Eberhard-Karls-University Tuebingen

Quantum sensors so far have been based almost exclusively on integrable systems, such as precessing spins or harmonic oscillators (e.g., modes of an electro-magnetic field). Non-classical initial states promise large enhancements in measurement precision but are experimentally very difficult to prepare and protect against decoherence.

We recently proposed a new approach that achieves quantum enhancements by rendering the dynamics of the quantum sensor chaotic while using classical initial states that are easy to prepare. Starting from an integrable sensor, the dynamics can be rendered chaotic by applying nonlinear kicks during the parameter-encoding transformation. In this work we deal with the following question: Given the possibility of applying non-linear kicks, what the best strategy to choose the position and strength of these kicks?

This a difficult optimization problem which we tackle with reinforcement learning. As a reward for the learning agent we calculate the quantum Fisher information. At the example of a spin subjected to superradiant damping, we demonstrate how the agent is able to find new strategies. Most strikingly, it is able to adopt to the superradiance decoherence model: quantum Fisher information can be increased further even when it would decay to zero for sensor dynamics without kicks.

FM 23.5 Mon 18:00 3043

Photonic architecture for reinforcement learning — •Fulvio Flamini, Arne Hamann, Sofiène Jerbi, Lea M. Trenkwalder, Hendrik Poulsen Nautrup, and Hans J. Briegel — Institut für Theoretische Physik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria

Artificial intelligence and photonic technologies are driving the limits of present computing devices. Motivated by the recent success in both fields, this work will bring together their state of the art within the framework of reinforcement learning (RL). Specifically, we present the blueprint for a photonic implementation of an active learning agent that can accommodate well-established RL algorithms, such as SARSA, Q-learning, and projective simulation. We numerically investigate its performance within typical task environments, demonstrating that the approach is effective at solving standard RL problems. The simulation is carried out considering imperfect experimental implementations, where we observe that realistic levels of noise can be tolerated or even be beneficial for the learning process. The proposed architecture, based on single-photon evolution on a mesh of tunable beamsplitters, is simple, scalable, and a first integration in portable systems appears to be within the reach of near-term technology.

FM 23.6 Mon 18:15 3043

Machine Learning on Near-Term Universal Quantum Computers — •Manuel Rudolph[1,2], Fred Jendrzejewski[1], and Sebastian Schmitt[2] — [1]Kichhoff-Institute for Physics, Heidelberg, Germany — [2]Honda Research Institute Europe GmbH, Offenbach/Main, Germany

Implementing near-term quantum computers with a small number of qubits and imperfect gate fidelities for real world challenges has been a flourishing field of research in recent years. Quantum-classical hybrid algorithms with shallow quantum circuits for state preparation are being used with success in fields like quantum chemistry and machine learning. This work focuses on the use of near-term quantum computers for unsupervised machine learning on classical data sets with different model infrastructures. It is shown that the quantum state is able to learn the statistics and correlations of data using shallow variational state preparation. Simple data sets are used to study general aspects such as learning, sampling and generalization of such quantum machine learning implementations in search of practical applications for small quantum machines.

FM 24: Quantum Sensing: Entanglement and Beyond Shot Noise

Time: Monday 16:30–18:30 Location: 3044

FM 24.1 Mon 16:30 3044

Entanglement Enhanced Quantum Microscopy — •Raphael Nold, Joel Schmidt, Tobias Linkewitz, Florian Kaiser, and Jörg Wrachtrup — 3. Physikalisches Institut Universität Stuttgart, Stuttgart, Germany

In metrology, interferometers are widely used for precision measurements. The sensitivity of interferometers with classical light is limited by the shot noise. To overcome this classical standard quantum limit one can make use quantum correlated particles. However, the associated detection schemes are generally very complex and slow. To overcome those issues, we present a nonlinear two-photon interferometer were photons pairs are produced by a PPKTP down converting crystal. By passing through this crystal two times we entangle two paths, which leads to interference in the signal-photon intensity (instead of the ordinary photon pair interference). We exploit the associated measurement speed advantage to investigate the possibility of an entanglement enhanced quantum microscope for cell analysis. Our goal is to enhance hereby the signal to noise ratio beyond the classical limitation.

FM 24.2 Mon 16:45 3044

Squeezing and entanglement in spinor Bose-Einstein condensates — Karsten Lange[1], Jan Peise[1], Ilka Kruse[1], Giuseppe Vitagliano[2,3], Iagoba Apellaniz[3], Matthias Kleinmann[3], Géza Tóth[3], and •Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria — [3]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain

Spin-changing collisions can be employed for the generation of entanglement in spinor Bose-Einstein condensates, in close analogy to optical parametric down-conversion. I will present the creation of two types of entangled states, Twin-Fock states and two-mode squeezed states. Both states can be applied for interferometry beyond the Standard Quantum Limit.

We have demonstrated that such entangled states can be separated in the spatial domain to transfer the entanglement from internal to external degrees of freedom [1]. I will discuss methods to employ spin-entangled Bose-Einstein condensates for inertially sensitive atom interferometers.

[1] K. Lange, J. Peise, B. Lücke, I. Kruse, G. Vitagliano, I. Apellaniz, M. Kleinmann, G. Toth, C. Klempt, Entanglement between two spatially separated atomic modes, Science 360, 416 (2018).

FM 24.3 Mon 17:00 3044

Probing Quantum Vacuum Fluctuations Using Electro-Optical Sampling — •Frieder Lindel[1], Robert Bennett[1,2], and Stefan Yoshi Buhmann[1,2] — [1]Albert-Ludwigs-Universität Freiburg, 79104 Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, 79104 Freiburg, Germany

Quantum vacuum fluctuations of the electromagnetic field present an intrinsic limit to the sensitivity of optic based detectors, such as for example the one used recently to detect gravitational waves. Furthermore they govern important observable processes in nature like spontaneous emission, the Lamb shift or dispersion forces. More recently, a new way to access these fluctuating vacuum fields has been established using electro-optical sampling [1].

Using macroscopic quantum electrodynamics we derive a general theoretical framework for the propagation of a laser field through a nonlinear crystal in the presence of vacuum fluctuations. This formalism includes absorption and dispersion as well as possible effects stemming from scattering events. We apply the framework to explore how electro-optical sampling can be used to probe different properties of the vacuum field in an experiment such as e.g. how it changes in the present of cavities or how one can access their spectral distribution and spatial correlations. Our theory can also be used for the description of spontaneous parametric down-conversion and hence for the generation of entangled photons.

[1] C. Riek et al., Science 350, 420 (2015)

FM 24.4 Mon 17:15 3044

Quantum Fourier Transform algorithm for sensing applications — •Vadim Vorobev, Sebastian Zaiser, Nikolas Abt, Durga Dasari, and Jörg Wrachtrup — 3rd Physical Institute, University of Stuttgart, Stuttgart, Germany

In recent decade several milestones were reached along the way to perform nanolocalised nuclear magnetic resonance sensing with chemical resolution [1,2, 3]. Among the others a significant step towards increasing the resolution of the sensor is the usage of the quantum memory associated with the nuclear spin [4] which gives the possibility to perform correlation spectroscopy measurements with record resolution. The drawback of such approach is a long time overdraft due to the waiting time between the two correlation steps. This time could be efficiently used for storing processing the information sensed by the electron spin within multi qubit register formed by nearby nuclear spins. Here we present an experimental demonstration of the quantum phase estimation algorithm for sensing external classical and quantum signals.

References:
[1] N. Aslam et. al. Science 2017

[2] M. Pfender et. al. Nano Let. 2019
[3] P. Neumann et. al. Science 2010
[4] M. Pfender et. al. Nat. Com. 2017

FM 24.5 Mon 17:30 3044

Maximal quantum Fisher information for mixed states — •Lukas J. Fiderer[1], Julien M.E. Fraïsse[2], and Daniel Braun[1] — [1]Eberhard-Karls-University Tuebingen — [2]Seoul National University

The optimal initial state for estimating a parameter encoded to the state through unitary dynamics has been known since long: an equal superposition of eigenstates corresponding to the largest and smallest eigenvalue of the generator of the unitary dynamics. In principle, such an optimal initial state can be prepared by applying an appropriate unitary transformation to an available pure state.

However, access to pure states is not always granted in realistic measurement setups, for instance, due to noise or interactions with an environment. In the present work, we answer the following question: Given a mixed state, what is the optimal initial state that can be prepared with the help of a unitary transformation?

We give the quantum Fisher information for this optimal initial state and extend results from Pang et al. for optimal quantum metrology with pure states and Hamiltonian control to the regime of mixed states. In particular, we prove that even from thermal states of arbitrary finite temperature we can prepare initial states that allow for Heisenberg scaling.

FM 24.6 Mon 17:45 3044

Approximate quantum non-demolition measurements — Sami Boulebnane, Mischa P. Woods, and •Joseph M. Renes — Institute of Theoretical Physics, ETH Zürich

With the advent of gravitational wave detectors employing squeezed light, quantum waveform estimation—estimating a time-dependent signal by means of a quantum-mechanical probe—is of increasing importance. As is well known, backaction of quantum measurement limits the precision with which the waveform can be estimated, though these limits can in principle be overcome by "quantum nondemolition" (QND) measurement setups found in the literature. Strictly speaking, however, their implementation would require infinite energy, as their mathematical description involves Hamiltonians unbounded from below. This raises the question of how well one may approx- imate nondemolition setups with finite energy or finite-dimensional realizations. Here we consider a finite-dimensional waveform estimation setup based on the "quasi-ideal clock" and show that the estimation errors due to approximating the QND condition decrease slowly, as a power law, with increasing dimension. As a result, we find that good QND approximations require large energy or dimensionality. We argue that this result can be expected to also hold for setups based on truncated oscillators or spin systems.

FM 24.7 Mon 18:00 3044

Fundamental limits of the coherence in a two-component BEC — •Yifan Li[1], Tilman Zibold[1], Boris Décamps[1], Matteo Fadel[1], Paolo Colciaghi[1], Krzysztof Pawlowsky[2], and Philipp Treutlein[1] — [1]Department of Physics, University of Basel — [2]Center for Theoretical Physics, Polish Academy of Sciences, Poland

We report experiments on the fundamental limits of coherence in two-component Bose-Einstein condensates (BECs) of 87Rb on an atom chip. We measure the increase of phase noise with time by performing Ramsey interferometry and find that the coherence of two-component BECs is mainly limited by interaction induced phase noise. This so-called clock-shift effect results in a dominant source of phase noise which depends on the fluctuations of total numbers of atoms and can be only partially canceled in data analysis due to the random nature of atom loss. To further understand the decoherence, we prepare nearly pure BECs in superpositions of hyperfine states and measure the rates of the dominant collisional loss processes. The decoherence process can be mitigated by relaxing the trapping potential and further suppressed by tuning the interactions with a state-dependent potential. Our experimental findings are relevant for compact atomic clocks realized in similar cold or ultracold atomic systems where atomic interactions are a limiting factor.

FM 24.8 Mon 18:15 3044

Investigation of noise sources down to the shot-noise limit in Ytterbium-doped fiber amplifiers — •Alexandra Popp[1,2,3], Victor Distler[4], Kevin Jaksch[1,2,3], Florian Sedlmeir[1,2], Christian R. Müller[1,2], Nicoletta Haarlammert[4], Thomas Schreiber[4], Christoph Marquardt[1,2], Andreas Tünnermann[4], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany. — [2]Department of Physics, University of Erlangen-Nuremberg (FAU), Erlangen, Germany. — [3]SAOT, Graduate School in Advanced Optical Technologies, Erlangen, Germany. — [4]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Jena, Germany.

Ytterbium-doped fiber laser amplifiers are known for their high single-pass gain and average powers up to the kilowatt range in single mode operation. Recently, amplitude noise in these systems has attracted attention due to its suspected capabilities as a potential source of phase disturbance leading to transverse mode instabilities [1]. We use balanced self-homodyne detection to measure the amount of noise in a Ytterbium-doped fiber pre-amplifier typically used in kW experiments, quantifying the impact of different noise sources at various frequencies with respect to the fundamental shot-noise limit.

[1] C. Stihler *et al.* Opt. Express 26, 19489-19497 (2018)

FM 25: Plenary Talk: Ion Trap based Quantum Computing

Time: Tuesday 8:30–9:30 Location: Audi Max

Plenary Talk FM 25.1 Tue 8:30 Audi Max

Scalable quantum computing with trapped ion qubits — •Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz

I describe the approach of trapped ion qubits [1] for scalable quantum computing. This includes a discussion of different architectures [2], the required trap technologies and fabrication methods, control electronics for quantum register reconfigurations, and recent improvements of qubit coherence and gate performance. Using a segmented micro-ion trap for implementing a reconfigurable qubit register [3] we have realized multi-qubit entanglement [4]. Topological quantum error correction [5] is a current aim. I conclude with current challenges and an overall assessment of this platform for a future quantum computer.

[1] Blatt, Wineland, Nat. 453, 1008 (2008) [2] Kielpinski, Wineland, Nat. 417, 709 (2002), Schindler et al, NJP 15, 123012 (2013), Friis et al, Phys. Rev. X 8, 021012 (2018), Debenath et al, Nat. 536, 63 (2016) [3] Kaufmann et al, PRA 95, 052319 (2017) [4] Kaufmann et al, PRL 119, 150503 (2017) [5] Bermudez et al, PRX 7, 041061 (2017)

FM 26: Introductory Talk: Machine Learning

Time: Tuesday 9:30–10:30 Location: Audi Max

Introductory Talk FM 26.1 Tue 9:30 Audi Max

Machine Learning — •Katharina Morik — TU Dortmund University, Dept. Computer Science VIII, 44221 Dortmund

Machine learning is a broad field which offers far more methods than convolutional neural networks or random forests, to name the most well-known ones. Probabilistic graphical models (or information field theory) offer algorithms for estimations that are of good use for problems in physics. In addition, particular learning solutions are developed for specific problems. Machine learning aims at insights into methods that make computers learn. Properties of the methods are investigated and tight bounds of their correctness, robustness, efficiency are sought. For this purpose, machine learning uses results of many fields: statistics is an important basis, computer architecture is another one, data bases and big data is the third and theoretical computer science is a necessary foundation. Medicine, linguistics, physics are typical sciences whose data are analysed by machine learning methods. Practical applications in mobility, manufacturing, sales, and logistics are more commercially interesting. This talk introduces into the scientific questions which are discussed in machine learning. Examples of results are shown and some applications in astrophysics are given. Given the focus of this year*s scientific programme, a link to quantum computing should not be missing.

FM 27: Special Session: Quantum Networks

Time: Tuesday 11:00–13:00 Location: Audi Max

Invited Talk FM 27.1 Tue 11:00 Audi Max
Frontiers in quantum acoustics — •Andrew Cleland — Pritzker School of Molecular Engineering, University of Chicago Chicago IL 60637 USA

Superconducting qubits provide unique opportunities as a testbed for quantum communication as well as developing hybrid quantum systems. Here, I will discuss applications for superconducting qubits in generating and detecting individual phonons, in the form of surface acoustic wave (SAW) excitations, and using these phonon states to generate remote quantum entanglement. Specifically, I will describe recent experiments [1,2] where we have demonstrated the use of reasonably high finesse acoustic Fabry-Perot structures to store acoustic phonon Fock states, in which we can measure the Wigner tomograms of individual Fock states as well as their superpositions. In more recent work, we have coupled two superconducting qubits to a long SAW resonator with a 500 ns phonon bounce time. We can release and recapture individual itinerant phonons using one of the two qubits, as well as transfer quantum states between the two qubits.

In this talk, I will introduce the superconducting qubits we use for these experiments, explain details of how the acoustic systems are integrated with the qubits, and describe how we use the qubits to achieve quantum control over acoustic phonons.

[1] K. J. Satzinger et al., “Quantum control of surface acoustic wave phonons”, Nature 563, 661-665 (2018). [2] A. Bienfait et al., “Phonon-mediated quantum state transfer and remote qubit entanglement”, Science 364, 368-371 (2019).

Invited Talk FM 27.2 Tue 11:30 Audi Max
The state of the art of quantum key distribution. — •Hugo Zbinden — University of Geneva, Switzerland

I will give a short introduction into Quantum Key Distribution, which could play an important role in future secure communications. Some experimental challenges, in particular for QKD over long distances and at high rates are discussed. I will present a recent experiment of QKD over 400km of optical fibre and options for increasing this distance using quantum repeaters or satellites.

Invited Talk FM 27.3 Tue 12:00 Audi Max
Towards Quantum Communication Networks using Solid-State Quantum-Light Sources — •Tobias Heindel — Institute of Solid-State Physics, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Tremendous progress has been achieved in the engineering of solid-state-based non-classical light sources during the last two decades. In this context, quantum-light sources based on semiconductor quantum dots (QDs) are of particular interest. Allowing for the generation of close-to-ideal flying qubits these devices are predestinated for implementations of quantum communication.

In my talk, I will review our progress in this field, striving towards the ultimate goal of a global secure communication. I will revisit proof-of-concept quantum key distribution (QKD) experiments [1] and discuss the development of state-of-the-art components for QKD, such as plug-and-play single-photon sources and receiver modules. In this framework, we show how to optimize the performance of QKD implementations and demonstrate real-time security monitoring for QKD with sub-poissonian light sources [2]. Assembling these building blocks to build functional multi-user quantum-secured communication networks will be a grand challenge in photonic quantum technologies, which is tackled within my recently founded Junior Research Group at Technische Universität Berlin.

[1] T. Heindel et al., New J. Phys. 14, 083001 (2012)
[2] T. Kupko et al., in preparation (2019)

Invited Talk FM 27.4 Tue 12:30 Audi Max
Towards quantum networks based on single trapped atoms — •Wenjamin Rosenfeld — Ludwig-Maximilians-Universität, München — Max-Planck-Institut für Quantenoptik, Garching

Quantum networks hold promise for enabling secure communication and distributed quantum computing. In this context, single trapped atoms represent a mature platform featuring a high level of control of internal and external degrees of freedom, long coherence times and reliable coupling to photonic channels. These features recently enabled distribution of entanglement between single atoms over macroscopic distances [1] and certification of its properties allowing for applications in an elementary quantum network link [2].

Current work is focused on extending the distance of entanglement distribution. Since the ground-state optical transitions in atoms are typically in the visible or near-infrared regime, for efficient long-distance transport of photons over optical fibers quantum frequency conversion into telecom wavelength range is required. Based on a nonlinear conversion process, this method was already successfully demonstrated for trapped ions [3] and is now being developed for the neutral atom platform. First measurements show a promising capability for distributing entanglement over few tens of kilometers - a realistic distance for implementing an elementary link of a quantum repeater.

[1] W. Rosenfeld *et al.*, Phys. Rev. Lett., **119**, 010402 (2017).
[2] J.-D. Bancal *et al.*, arXiv:1812.09117 [quant-ph] (2018).
[3] M. Bock *et al.*, Nature Communications **9**, 1998 (2018)

FM 28: Focus Talk: Quantum Spectroscopy

Time: Tuesday 11:00–12:00 Location: 2004

Focus Talk FM 28.1 Tue 11:00 2004
An introduction to quantum spectroscopy — •Frank Schlawin — Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom

Quantum light is an intriguing candidate for novel spectroscopic applications due to its nonclassical fluctuations, which can enhance the nonlinear response of a sample. For instance, it has been long established that squeezed states of light show a linear, rather than quadratic, intensity scaling of the two-photon absorption signal [1]. In addition, entangled states of light feature strong time and frequency correlations that can be further used to manipulate or control nonlinear optical signals [2].

In this focus talk, I will present an introduction into the theory of quantum spectroscopy, outline different ideas to exploit quantum features of light in spectroscopic measurements and review the current state of experiments.

[1] N. P. Georgiades et al., Phys. Rev. Lett. 75, 3426 (1995).
[2] K. E. Dorfman, F. Schlawin and S. Mukamel, Rev. Mod. Phys. 88, 045008 (2016).

FM 29: Lunch Talk: Funding for Quantum Projects

Time: Tuesday 12:30–13:45 Location: 2006

Curious about where to get money for your ideas?

With a series of national and international initiatives there are a number of different opportunities to get support for your research. But how to find the best format for basic science or for applied research? This meeting gives you the chance to learn about from representatives from various funding organisations and representatives. This podium discussion includes presentations on funding opportunities by Dr. F. Schlie (BMBF), Dr. A. Deschner (DFG), Dr. T. Driebe (DLR).

FM 30: Quantum Sensing: Applications I

Time: Tuesday 14:00–16:00 Location: Aula

Invited Talk FM 30.1 Tue 14:00 Aula

Quantum Sensors on the way to commercial opportunities — •Kai Bongs — Physics and Astronomy,University of Birmingham

The UK Quantum Technology Programme is set to reach 1bn GPB over the next few years. This programme is focused on realising the economic benefit promised by quantum technologies, with quantum sensors being a front-runner in industry engagement. I will report on the current developments and future plans of the UK National Quantum Technology Hub in Sensors and Timing and present the main application-led strands in moving forward.

FM 30.2 Tue 14:30 Aula

Single-atom quantum probes for ultracold gases using nonequilibrium spin dynamics — Quentin Bouton[1], •Jens Nettersheim[1], Daniel Adam[1], Tobias Lausch[1], Daniel Mayer[1], Felix Schmidt[1], Eberhard Tiemann[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS Technische Universität Kaiserslautern, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

Quantum probes are atomic-sized devices mapping information of their environment to quantum mechanical states. By improving measurements and at the same time minimizing perturbation of the environment, they form a central asset for quantum technologies. Here, we present a realization of single-atom quantum probes for local thermometry based on the spin dynamic of individual neutral Caesium (probe) atoms in an ultracold gas (bath) of Rubidium atoms. The competition of inelastic endo- and exoergic spin-exchange processes map the temperature onto the quasi-spin population of the probe. The sensitivity of the thermometer can be adjusted via the external magnetic field changing the Zeeman energy splitting. Sensitivity can also be enhanced, if temperature information is obtained from the nonequilibrium dynamic, instead of the steady-state distribution, of the probe, maximizing the information obtained per inelastic collision and thus minimizing the perturbation of the bath. Moreover, our probe is not restricted to measure temperature, but it allows sensing any mechanism affecting the total collisional energy in a spin-exchange collision, such as the magnetic field.

FM 30.3 Tue 14:45 Aula

Quantum dots as charge detectors for nanoscale defect tomography — •Jens Kerski[1], Pia Lochner[1], Arne Ludwig[2], Andreas D. Wieck[2], Annika Kurzmann[1], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Self-assembled semiconductor quantum dots (QDs) can be used as single-photon sources in visionary applications in quantum information technologies. However, spin and charge noise in the vicinity destroy the needed Fourier-transform limited linewidth [1].

In this contribution, we use a single quantum dot as a nanoscale electrometer to investigate the charging process of individual defects with electrons from the nearby n-doped back contact. Spectral and time-resolved resonance fluorescence measurements allow us to identify four nearby defect states by small shifts in the resonance energy of the exciton transition [2]. From the occupation probability of the individual states, the position of these defects in the growth direction, as well as their binding energy were determined. Their spatial position allowed to identify the states as defects.

Our results give rise to further investigations, e.g. triangulation of individual defects using multiple QDs, optical transport measurements at a single QD [3] and nanoscale low level transient spectroscopy.

[1] A. V. Kuhlmann et al., Nature Physics 9, 570-575 (2013).
[2] J. Houel et al., Phys. Rev. Lett. 108, 107401 (2012).
[3] A. Kurzmann et al., Phys. Rev. Lett. in press (2019).

FM 30.4 Tue 15:00 Aula

The photonic Bose–Einstein condensate as a precision quantum sensor — •Stefan Yoshi Buhmann[1,2] and Robert Bennett[1,2] — [1]University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

Photonic Bose–Einstein condensates have recently been realised as a new quantum state of light. Here, the photons inside a driven dye-filled cavity macroscopically occupy the ground state. We demonstrate that this extreme selectivity of the ground state can be exploited to construct a quantum sensor for the intra-cavity medium.

We propose to monitor the polarisation degree of freedom of the photonic Bose–Einstein condensate signal emerging from the cavity [2]. When introducing anisotropic or chiral molecules into the cavity, this polarisation will be governed by the handedness or the orientation of these molecules, respectively. In this way, enantiomeric excess or molecular anisotropy can be monitored in real time with unprecedented precision [3].

[1] J. Klaers, J. Schmitt, F. Vewinger, M. Weitz, Nature **468**, 545 (2010).

[2] R. I. Moodie, P. Kirton, J. Keeling, Phys. Rev. A **96**, 043844 (2017).

[3] R. Bennett, Y. Gorbachev, S. Y. Buhmann, preprint arXiv:1905.07590 (2019).

FM 30.5 Tue 15:15 Aula

Quantum Technology Competence Center (QTZ) at PTB — •Nicolas Spethmann — Physikalisch-Technische Bundesanstalt (PTB), 38116 Braunschweig, Germany

Quantum technologies will have a substantial impact on German economy. PTB as the National Metrology Institute of Germany has a long tradition in quantum technology and performs world-leading research in several fields, with a focus on quantum sensing and metrology. Examples include, but are not limited to, precise quantum standards for electrical quantities, ultracold atoms and ion traps, sensitive sensors for magnetic fields, single photon sources and detectors and ultrastable and precise optical clocks. This expertise in quantum technology, together with PTB's mission to support industry in metrology as a governmental body, puts PTB into an ideal and natural position to transfer quantum technology from science to application in collaboration with industry and academia. For this task, PTB has recently established the Quantum Technology Competence Center (QTZ) at PTB. The QTZ will focus on the development of user-friendly and robust components for quantum sensing and metrology and on providing calibrations, services and user facilities accessible for external partners from industry and academia. Furthermore, QTZ will offer hands-on training and seminars for quantum technology and support start-ups. In my talk, I will introduce the QTZ and report on latest activities and future plans.

FM 30.6 Tue 15:30 Aula

Analyzing semiconductor quantum dot under mechanical strain tuning — •Marco Schmidt, Marcel Darmstädter, Sarah Fischbach, Arsenty Kaganskiy, Sven Rodt, Tobias Heindel, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Advanced applications of quantum information processing require sources of single, indistinguishable photons as well as polarization entangled photon pairs as key building blocks. Semiconductor quantum dots (QPs) are excellent single-photon emitters and accomplish these requirements. The spectral properties, e.g. emission energy, fine structure splitting and binding energy, of QPs determined by the self-assembled growth and and can be manipulated by applying external mechanical strain. We demonstrate a tunable single-photon source based on an InGaAs QD inside a thin GaAs membrane that is bounded to a piezoactuator via the flip-chip goldbonding technique. Optical and quantum optical studies of the system will be presented which include the stabilization of the QD emission energy, tuning of the fine structure splitting and quantum tomographic measurements to demonstrate the emission polarization entangled photon pairs.

FM 30.7 Tue 15:45 Aula

Experimental Saturation of the Heat-Bath Algorithmic Cooling bound — •Durga B Rao Dasari[1], Sebastian Zaiser[1], Chun Tung Cheung[2], Sadegh Raeisi[3], and Joerg Wrachtrup[1] — [1]3. Physics Institute, University of Stuttgart, Stuttgart, Germany — [2]Chinese University of HongKong, Shatin, HongKong, China — [3]Sharif University of Technology, Tehran, Iran

Heat-Bath Algorithmic cooling (HBAC) techniques provide ways to selectively enhance the polarization of target quantum subsystems. However, the cooling in these techniques is bounded. Here we report the first experimental observation of the HBAC cooling bound. We use HBAC to hyperpolarize nuclear spins in diamond. Using two carbon nuclear spins as the source of polarization (reset) and the 14N nuclear spin as the computation bit, we demonstrate that repeating a single cooling step increases the polarization beyond the initial reset polarization and reaches the cooling limit of HBAC. We benchmark the performance of our experiment over a range of variable reset polarization. With the ability to polarize the reset spins to different initial polarizations, we envisage that the proposed model could serve as a testbed for studies on Quantum Thermodynamics.

FM 31: Secure Communication & Computation II

Time: Tuesday 14:00–15:45 Location: 1009

Invited Talk FM 31.1 Tue 14:00 1009

Certifying randomness from quantum black-box devices — •Nicolas Brunner — Department of Applied Physics, University of Geneva, Switzerland

Besides its fundamental interest, randomness represents a key resource for many applications. Since quantum processes can be fundamentally random, they are ideally suited for the task of producing randomness. A strong research interest has thus been devoted to quantum randomness generation (QRNG), leading to first commercial products, but also to a deeper understanding of the concept of randomness in quantum theory. Current research explores the "device-independent" approach to QRNG, where quantum devices are viewed as black boxes. This represents a novel generation of QRNG protocols, achieving the highest level of security. Entropy can be estimated in real-time, based on minimal assumptions about the setup, allowing for the continuous generation of certified random numbers. Moreover, such schemes can now be implemented using only standard optical components and achieve rates comparable to commercial QRNG devices.

FM 31.2 Tue 14:30 1009

Exploring the potential of device-independent quantum cryptography — •Gláucia Murta — Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

Current secure communication is based on cryptographic methods whose security relies on computational assumptions. While this approach works well at the moment, if more powerful computers become available in the future, the content of encrypted messages exchanged today could be revealed (what is called retroactive attacks). Quantum key distribution (QKD) offers a solution to this problem because security is established directly from fundamental laws of physics. However, while unbreakable in principle, the security of QKD protocols relies on a very precise characterization of their physical implementation, which can be very hard to obtain in practice. In fact, this has led to hacking of several quantum cryptosystems. Surprisingly, quantum mechanics also offers a solution to this problem. In the so-called device-independent (DI) setting, security can be guaranteed even if the users are completely ignorant about the internal working of their devices. In this setting, security relies on the violation of a Bell inequality. So far, most of the proposed protocols are based on the CHSH inequality. Very little is known about the use of general Bell inequalities. A big challenge is that many theoretical tools used to deal with the CHSH inequality do not apply to Bell inequalities with more inputs and outputs. In order to get an insight on the potential of general Bell inequalities, we analyze the performance of different Bell inequalities for DIQKD under the assumption that the underlying system has a fixed dimension d.

FM 31.3 Tue 14:45 1009

Magneto-optical properties of InAs/InP quantum dots emitting at the C-band — •Marek Burakowski[1], Wojciech Rudno-Rudziński[1], Anna Musiał[1], Grzegorz Sek[1], Andrei Kors[2], Johann Peter Reithmaier[2], and Mohamed Benyoucef[2] — [1]Wrocław University of Science and Technology, Wrocław, Poland — [2]University of Kassel, Kassel, Germany

Hereby we experimentally determine magneto-optical properties of molecular beam epitaxy grown, symmetric and low-density InAs/InP quantum dots (QDs) emitting at the telecom C-band. Polarization-resolved microphotoluminescence, performed in magnetic field up to 5 T in Faraday and Voigt configuration, indicates exciton fine structure splitting below 20 μeV. The exciton g factor and the diamagnetic coefficient are determined in Faraday configuration to be in the range of $0.7-1.5$ and $9-12$ $\frac{\mu eV}{T^2}$, accordingly, and consequently extension of the exciton wavefunction is in the range of $14-18$ nm, confirming the strong confinement regime. Our results are important for modeling of the excitonic structure of the investigated QDs and indicate they are suitable for quantum photonics applications at the telecom C-band.

Supported by the "Quantum dot-based indistinguishable and entangled photon sources at telecom wavelengths" project, carried out within the HOMING programme of the Foundation for Polish Science co-financed by the European Union under the European Regional Development Fund. This work was also financially supported by the German Federal Ministry of Education and Research (BMBF) within projects Q.com-H and Q.Link.X.

FM 31.4 Tue 15:00 1009

Microphotoluminescence of symmetric InP based single quantum dots emitting in the telecom C-band — •M. Mikulicz[1], P. Wyborski[1], A. Musiał[1], G. Sek[1], A. Kors[2], J. P. Reithmaier[2], and M. Benyoucef[2] — [1]Wrocław University of Science and Technology, Poland — [2]University of Kassel, Germany

Single-photon sources are indispensable for implementation of quantum communication and cryptography schemes. Hereby we present microphotoluminescence (μPL) results of new generation of MBE-grown low-density symmetric InAs/InP quantum dots (QDs) on distributed Bragg reflector emitting in the 3rd telecom window suitable for nonclassical light generation. The main focus is to determine the fundamental physical properties of these application relevant structures and to identify excitonic complexes, in particular, biexciton-exciton (XX-X) cascade. Nine QDs were investigated in detail by means of excitation power-dependent and polarization-resolved μPL. They all exhibit low fine structure splitting (below setup spectral resolution of 20 μeV) proving their symmetry, XX binding energy in the range of 1 meV and XX to X lifetime ratio of 2 suggesting strong spatial confinement and slow spin-flip. Supported by the "Quantum dot-based indistinguishable and entangled photon sources at telecom wavelengths" project, carried out within the HOMING programme of the Foundation for Polish Science co-financed by the European Union under the European Regional Development Fund. This work was also financially supported by the German Federal Ministry of Education and Research

(BMBF) within projects Q.com-H and Q.Link.X.

FM 31.5 Tue 15:15 1009

Performance Optimization and Security Monitoring for Single-Photon QKD — •Timm Kupko, Lucas Rickert, Martin v. Helversen, Stephan Reitzenstein, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Solid-state single-photon sources (SPSs) have the potential to boost the performance of quantum-key-distribution (QKD) systems [1,2]. To fully exploit realistic sub-poissonian light sources for applications in quantum communication, however, a detailed analysis and optimization of the receiver side is necessary.

Here, we analyze the effect of temporal filtering on the performance of QKD systems implemented with realistic quantum-light sources. For this purpose, we developed a basic QKD testbed comprising a deterministically fabricated QD-based SPS and a receiver module designed for four-state polarization coding. We analyze the sifted key fraction, the quantum bit error ratio, and $g^{(2)}(0)$ expected in full implementations of the BB84 protocol under variation of the acceptance time-window. This routine enables us to choose optimal filter settings depending on the losses of the quantum channel. Furthermore, we demonstrate real-time security monitoring by evaluating $g^{(2)}(0)$ inside the quantum channel during key distillation. The presented approach can be adapted and extended for most other applications in quantum communication employing realistic quantum light sources.

[1] E. Waks et al., Phys. Rev. A **66**, 042315 (2002)
[2] T. Heindel et al., New J. Phys. 14, 083001 (2012)

FM 31.6 Tue 15:30 1009

Simulation of generation and transmission of photons from SPDC for quantum key distribution with phase-time coding — •Julian Nauth, Erik Fitzke, Alexander Sauer, Gernot Alber, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

We are working on a QKD system with phase-time coding. A source generates entangled photons which are measured by the parties to generate a secure key. In theory, the influence of a potential hacker is detected by determining the quantum bit error rate. In practice, however, these errors may also be caused by the effects of real-world component properties and environmental influences. Therefore, we developed a simulation to estimate these influences.

The simulation is a quantum mechanical description of the generation and transmission of photons modeling the states of the system and the processes that change these states. Modeling is based on a multi-mode Gaussian state description of the states and the SPDC is calculated by Schmidt decomposition. The description in frequency space allows to model effects by the spectral distribution of the photons and chromatic dispersion.

Finally, the simulation predicts how the results of the detectors from the parties correlate at different times. On this basis, the assessment of the security of the key can be improved. We present the methodology and structure of the software and compare the calculations to experimental results.

FM 32: Enabling Technologies: Sources of Quantum States of Light II

Time: Tuesday 14:00–16:00 Location: 1010

Invited Talk FM 32.1 Tue 14:00 1010

Next-generation single-photon sources for satellite-based quantum communication — •Tobias Vogl[1,2], Ruvi Lecamwasam[1], Ben C. Buchler[1], Yuerui Lu[1], Ping K. Lam[1], and Falk Eilenberger[2] — [1]The Australian National University, Canberra, Australia — [2]Friedrich-Schiller-Universität, Jena, Germany

Color centers in solid state crystals have become a frequently used system for single-photon generation, advancing the development of integrated photonic devices for quantum optics and quantum communication applications. Recently, defects hosted by two-dimensional (2D) hexagonal boron nitride (hBN) attracted the attention of many researchers, due to its chemical and thermal robustness as well as high single-photon luminosity at room temperature.

Here, we present recent advances in engineering this new type of emitter. The quantum emitter is coupled with a nanophotonic cavity, improving its performance so that the single-photon source is feasible for practical quantum information processing protocols. The cavity-coupled device is characterized by an increased collection efficiency and quantum yield, combined with off-resonant noise suppression and improvement of photophysics. Moreover, the complete source, including all control units and driving electronics is implemented on a 1U CubeSat platform. An application of particular interest is satellite-based single-photon quantum key distribution. Simulations predict the performance of the source is sufficient to outperform conventional decoy state protocols, the most efficient state-of-the-art protocols for quantum cryptography.

FM 32.2 Tue 14:30 1010

Quantum efficiency measurement of single photon emitters in hexagonal Boron Nitride — •Niko Nikolay[1], Noah Mendelson[2], Ersan Özelci[1], Bernd Sontheimer[1], Florian Böhm[1], Günter Kewes[1], Milos Toth[2], Igor Aharonovich[2], and Oliver Benson[1] — [1]AG Nanooptik & IRIS Adlershof, Humboldt-Universität zu Berlin, Germany — [2]School of Mathematical and Physical Sciences, University of Technology Sydney, Australia

Single photon emitters (SPEs) in two-dimensional hexagonal Boron Nitride (hBN) are promising candidates for future sources of quantum states of light [1]. In this paper the direct and absolute measurement of the quantum efficiency (QE) of these emitters in few layers hBN is discussed [2]. In contrast to earlier approaches to determine the QE of SPEs in hBN, we use a method [2] that is independent of incomplete excitation saturation, indirect excitation paths through the yet unknown energy level system, or the detection efficiency of the setup. We used a Drexhage-type configuration and performed lifetime measurements of the SPEs as a function of their distance to a metal hemisphere attached to the tip of a Atomic Force Microscope. Two emitter families with different QEs can be identified. The highest QEs found approach 87(7) % at a zero phonon line wavelength of 580 nm.

[1] Tran, Toan Trong, et al., Nature nanotechnology 11.1 (2016): 37.
[2] Nikolay, Niko, et al., arXiv preprint arXiv:1904.08531 (2019).

FM 32.3 Tue 14:45 1010

Towards directional, ultrafast and bright single-photon sources based on color centers in diamond — •Lukas Hunold, Assegid M. Flatae, Hossam Galal, Stefano Lagomarsino, Haritha Kambalathmana, Florian Sledz, and Mario Agio — Laboratory of Nano-Optics, University of Siegen

Diamond color centers exhibit promising properties for future applications in quantum information science. For example, they have high photo-stability and narrow bandwidth at room temperature. However, their effective count-rate is still limited by non-radiative decay channels, radiation at wide angles and total internal reflection at the diamond interface.

We develop techniques to tackle these main drawbacks, mainly focused on the silicon-vacancy (SiV) color center. We create single SiV centers in a controlled manner in different diamond samples (nanomembranes, micro-membranes and bulk) in a large range of implantation fluxes and energies [1]. Position accuracy is achieved by a mask with pinholes, which enables a matrix type of implantation. We also introduce resonant plasmonic nanostructures to achieve ultrafast single-photon emission at room temperature [2] and we develop schemes for efficient electrical pumping. Finally, we show how to increase the out-coupling efficiencies of the color centers by using planar Yagi-Uda antennas [3].

References [1] S. Lagomarsino, et al., Diam. Relat. Mater. 84, 196 (2018). [2] A. M. Flatae, et al., J. Phys. Chem. Lett. 10, 11, 2874-2878 (2019). [3] H. Galal, et al., arXiv:1905.03363 (2019).

FM 32.4 Tue 15:00 1010

A cavity-based optical antenna for color centers in diamond — •Philipp Fuchs, Thomas Jung, and Christoph Becher — Universität des Saarlandes, Fakultät NT - FR Physik, Campus E2.6, 66123 Saarbrücken

Color centers in diamond, e.g. the nitrogen (NV), silicon (SiV) or recently the tin (SnV) vacancy center, have become very promising candidates for the implementation of stationary qubits in quantum communication settings. One of the most challenging problems when working with these defects is the low rate of collectible photoluminescence (PL) out of unstructured diamond material. Because of total internal reflection at the diamond-air-interface, this problem cannot be solved simply by using high NA objectives and the collectible PL rate is limited to a few percent of the total PL rate.

Here, we present a simple but efficient design of a monolithic Fabry-Pérot-cavity based on thin ($< 1\ \mu$m) single crystal diamond membranes, fabricated in commercially available, high purity diamond material via reactive ion etching. By applying appropriate metallo-dielectric coatings, we enable the cavity to work as an optical antenna, enhancing both the coupling of the excitation light to the color center as well as the outcoupling of the PL, while introducing also a moderate Purcell enhancement. Saturation measurements show that the the collectible PL rate of single SnV centers can easily be increased by more than an order of magnitude for a large fraction of emitters inside the membrane compared to unstructured diamond films.

FM 32.5 Tue 15:15 1010

Towards high-dimensional quantum communication in Space — Fabian Steinlechner[1,2], Oliver de Vries[1], •Daniel Rieländer[1,3], Markus Gräfe[1], and Erik Beckert[1] — [1]Fraunhofer IOF, Jena, Germany — [2]Friedrich Schiller University Jena, Abbe Center of Photonics, Jena, Germany — [3]Current address: University of Freiburg, Freiburg, Germany

Entangled photon pairs are a fundamental resource in quantum information processing and their distribution between distant parties is a key challenge in quantum communications. Optical satellite links allow transmitting entangled photons over longer distances than currently possible on ground and could provide a path towards global-scale quantum communication networks.

A key pre-requisite towards the next generation of challenging experiments and the realization of future quantum communication networks, is the development of space-proof entangled photon sources (EPS) with high pair yield and entanglement quality.

Here, we report on the development of a power-efficient polarizationentangled photon source that can sustain the strong vibrations and thermal fluctuations of space flight and operation in space. We outline the factors that led to the baseline optical design and opto-mechanical implementation and discuss some of the critical EPS performance parameters. We outline avenues towards further improvement of EPS performance and conclude with an overview of our efforts towards exploiting high-dimensional entanglement for free-space quantum communications channels with increased capacity.

FM 32.6 Tue 15:30 1010

Efficient fiber-coupling of spectrally filtered and unfiltered photon pairs — •Tobias B. Gäbler[1,2], Marta G. Basset[1,2], Markus Gräfe[1], Juan P. Torres[3,4], and Fabian Steinlechner[1,5] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, 07745 Jena, Germany — [2]Friedrich-Schiller-Universität Jena, Institute of Applied Physics, Max-Wien-Platz 1, 07743 Jena, Germany — [3]ICFO-Institut de Ciencies Fotoniques, 08860 Castelldefels, Spain — [4]Universitat Politecnica de Catalunya, Jordi Girona 1-3, 08034 Barcelona, Spain — [5]Friedrich Schiller University Jena, Abbe Center of Photonics, Albert-Einstein-Str. 6, 07745 Jena, Germany

Efficient coupling of photon pairs, generated by SPDC, into single spatial modes is of great relevance to studies of quantum physics and technologies. While several studies have addressed the issue of Gaussian mode coupling in SPDC, these often involved different approximations and experimental configurations, thus arriving at different conclusions.

We analyze the spatial properties of SPDC emission from periodically poled nonlinear crystals in the framework of transverse momentum. We study the impact of Gaussian beam parameters on fiber-coupling efficiency and present the results of a comprehensive series of experiments. We elaborate on trade-offs between heralding and pair-collection efficiency, in different spectral case and the dependency of pair emission rates on crystal length. These results will serve as a design guideline for ultra-efficient sources as required for quantum technologies.

FM 32.7 Tue 15:45 1010

Spectral Compression of Narrowband Single Photons — Mathias A. Seidler[1], •Xi Jie Yeo[1], Alessandro Cerè[1], and Christian Kurtsiefer[1,2] — [1]Centre for Quantum Technologies, Singapore — [2]National University of Singapore, Singapore

We present a successful experimental demonstration of a spectral compression of heralded single photons with narrow spectral bandwidth around 795 nm. The original photons are generated through four-wave mixing in a cloud of cold Rubidium-87 atoms and have a bandwidth about 3 times larger than the corresponding atomic transition. Our spectral compression method was inspired by techniques to compress ultra-fast pulses. We chose an asymmetric cavity as the dispersion medium. The design of the cavity also ensures that spectral compression can be performed, in principle, without any optical losses. Experimentally. we were able to compress the spectral bandwidth of the photons by a factor of 2.6, from 20.6 MHz to less than 8 MHz, almost matching the corresponding atomic transition linewidth of 6 MHz. The better matching of photon bandwidths allow for more efficient of photon-atom interaction, which is crucial in many applications involving quantum interfaces.

FM 33: Quantum Networks: Concepts & Applications

Time: Tuesday 14:00–16:00 Location: 1015

Invited Talk FM 33.1 Tue 14:00 1015

Quantum Networking, fully connected and international — •Rupert Ursin — Institute for Quantum Optics and Quantum Information - Vienna, Austrian Academy of Sciences, Austria

Quantum communication is most advanced under the quantum technologies discussed in the scientific literature, such as quantum computing and quantum sensing. One challenge of Quantum Key Distribution (QKD) is how to spread that intrinsic point-to-point protocol to the public users in a scalable manner. I will present a proof-of-principle experiment spreading the quantum information to four users in a novel network architecture which enables scalable quantum communication based on polarisation-entangled photon pairs at telecommunications wavelength [1]. Our scheme uses frequency multiplexing to share 6 two-photon entangled states between each pair of clients in a mesh-like network topology using only one fiber per client.

Furthermore I will present our efforts to use a satellite to distribute quantum information also on an international scale [2]. The mission of the Chinese Academy of Sciences into space will be described and the experiment we did with the Chinese satellite will be presented in my talk.

[1] S. Wengerowsky, et al., Nature, 564(7735), (2018).
[2] SS.-K. Liao et al., Phys. Rev. Lett., 120:030501, (2018).

FM 33.2 Tue 14:30 1015

Free-space channels: entanglement distribution and teleportation — •Martin Bohmann[1,2], Kevin Hofmann[1], Andrii A. Semenov[1,3], Jan Sperling[4], and Werner Vogel[1] — [1]Universität Rostock, Rostock, Germany — [2]QSTAR, INO-CNR, and LENS, Firenze, Italy — [3]Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine — [4]University of Paderborn, Paderborn, Germany

Global quantum communication based on atmospheric free-space channels is a rapidly developing and growing research area. In this contribution, we address the question of how fluctuating losses in such channels affect continuous-variable entanglement distribution and quantum state teleportation. We perform a rigorous analysis of the quantum states after passing through the turbulent atmosphere and study Gaussian and non-Gaussian entanglement. We identify optimal strategies for the transmission of entangled states, and we show that atmospheric channels differ essentially from constant-loss scenarios. Eventually, we propose strategies for the successful quantum-state teleportation through free-space channels.

FM 33.3 Tue 14:45 1015

Tolerances of Photon Pair Sources for Satellite-Based Quantum Communication — •Rana Sebak[1,2] and Fabian Oliver Steinlechner[1] — [1]Fraunhofer Institute for Applied Optics and

Precision Engineering IOF, Albert-Einstein-Straße 7, 07745 Jena — [2]Friedrich-Schiller University Jena, Abbe School of Photonics, Albert-Einstein-Str. 5, 07745 Jena, Germany

Satellite-based quantum communication is considered to be one possible way to guarantee unconditional security for communication, by using quantum information protocols enabling quantum key distribution (QKD). High-performance entangled photon-pair sources are the bottleneck for such applications. The efficiency of the photon-pair sources depends critically on their alignment.

The goal of this work is to achieve a robust entangled photon-pair source suitable for harsh environments as present in space. The angular and lateral tolerances of the collection optics were calculated for different pump and collection parameters with various brightness efficiencies. Additionally, they are evaluated experimentally in a type-II phase matched ppKTP crystal pumped at 405 nm. Moreover, different crystal lengths have been investigated while keeping all other parameters constant. We present results on the corresponding spectral power densities.

FM 33.4 Tue 15:00 1015

Quantum network routing and local complementation — Frederik Hahn, •Anna Pappa, and Eisert Jens — Dahlem Center for Complex Quantum Systems, Freie University Berlin

Quantum communication between distant parties is based on suitable instances of shared entanglement. For efficiency reasons, in an anticipated quantum network beyond point-to-point communication, it is preferable that many parties can communicate simultaneously over the underlying infrastructure; however, bottlenecks in the network may cause delays. Sharing of multi-partite entangled states between parties offers a solution, allowing for parallel quantum communication. Specifically for the two-pair problem, the butterfly network provides the first instance of such an advantage in a bottleneck scenario. The underlying method differs from standard repeater network approaches in that it uses a graph state instead of maximally entangled pairs to achieve long-distance simultaneous communication. We will demonstrate how graph theoretic tools, and specifically local complementation, help decrease the number of required measurements compared to usual methods applied in repeater schemes. We will examine other examples of network architectures, where deploying local complementation techniques provides an advantage. We will finally consider the problem of extracting graph states for quantum communication via local Clifford operations and Pauli measurements, and discuss that while the general problem is known to be NP-complete, interestingly, for specific classes of structured resources, polynomial time algorithms can be identified.

FM 33.5 Tue 15:15 1015

Quantum Shannon theory with superpositions of trajectories — Giulio Chiribella[1,2] and •Hlér Kristjánsson[2] — [1]Department of Computer Science, The University of Hong Kong, Hong Kong — [2]Department of Computer Science, University of Oxford, Oxford, United Kingdom

Shannon's theory of information was built on the assumption that the information carriers were classical systems. Its quantum counterpart, quantum Shannon theory, explores the new possibilities arising when the information carriers are quantum systems. Traditionally, quantum Shannon theory has focussed on scenarios where the internal state of the information carriers is quantum, while their trajectory is classical. Here we propose a second level of quantisation where both the information and its propagation in spacetime is treated quantum mechanically. The framework is illustrated with a number of examples, showcasing some of the counterintuitive phenomena taking place when information travels simultaneously through multiple transmission lines [1].

[1] G. Chiribella and H. Kristjánsson, *Proc. R. Soc. A* **475**, 20180903 (2019).

FM 33.6 Tue 15:30 1015

Single- and multiphoton interference using time-multiplexed network — •Syamsundar De[1], Thomas Nitsche[1], Evan Meyer-Scott[1], Johannes Tiedau[1], Aurél Gábris[2,3], Sonja Barkhofen[1], Jan Sperling[1], Benjamin Brecht[1], Igor Jex[2], and Christine Silberhorn[1] — [1]Integrated Quantum Optics, University of Paderborn, Warburger Strasse 100, 33098 Paderborn, Germany — [2]Department of Physics, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Břehová 7, 115 19 Praha 1 - Staré Město, Czech Republic — [3]Department of Quantum Optics and Quantum Information, Wigner Research Centre for Physics, Budapest, Konkoly-Thege M. U. 29-33, H-1121 Budapest, Hungary

Time-multiplexed networks constitute a versatile platform to extract benefits from the optical coherence linked to their high flexibility and reconfigurability as well as excellent efficiency and stability. Such time-multiplexing schemes show great potentials for fundamental studies as well as applications in quantum technology. Examples include quantum-walk, boson sampling, generation of large-scale cluster states, measurement-based quantum computing, to name only a few. In this study, we exploit our well-established fiber optical-loop design for time-multiplexing to synthesize the modal structure of the photon wave-packets and to test the quantum-classical nature of the involved optical states. We utilize single- and multiphoton quantum interference in the time-multiplexed network to recover both the modal structure and the quantum-classical nature of pulsed light.

FM 33.7 Tue 15:45 1015

Interaction-free discrimination of quantum channels — •Markus Hasenöhrl and Michael M. Wolf — Technische Universität München, Munich, Germany

Interaction-free measurement, as proposed by Elizur and Vaidman in their famous bomb-tester experiment is a way to employ the counterintuitive laws of quantum mechanics to obtain information about an object, without influencing it in an essential way. For example, finding out if there is an ultra-sensitive bomb in a given black box, without causing the bomb to explode. In my talk, I will show how to reinterpret the bomb-tester experiment as a quantum channel discrimination problem and create a framework that generalizes the notion of interaction-free to arbitrary quantum channels. Furthermore, we explore the implications of this new model. We arrive at two major conclusions: the first one being that we can always find out, whether or not there is an object in a given black box, without influencing the object. This is true, even if we have no prior knowledge which object it might be. The second finding then is that it is impossible to find out, which object is present in the black box, without influencing it. Together these results yield a complete characterization of what is possible and impossible to achieve with interaction-free measurements.

FM 34: Topology: Solid State Systems

Time: Tuesday 14:00–15:15 Location: 1199

Invited Talk FM 34.1 Tue 14:00 1199

Understanding the Interplay between Magnetism and Topology — •Matthew Gilbert — Department of Electrical and Computer Engineering, University of Illinois - Urbana-Champaign, Urbana, IL 61801 USA — Department of Electrical Engineering, Stanford University, Stanford, CA 94305 USA

For many years, topological materials have been the subject of great interest from condensed matter experimentalists and theorists. While there is a continued push to predict and measure new topological phenomena there exists a large class of *known* topological materials, or those that have been thoroughly characterized for their basic topological properties, that may serve as a testbed for new physics and applications by utilizing the inherent properties of these topological materials. To this end, recent work attempting to exploit the properties of topological materials has focused on the interactions between topological and magnetic materials yet little is understood about the physics of these interactions. In this talk, I will address some of the open problems associated with magnetic interactions in topological materials with a focus on understanding recent experimental results.

FM 34.2 Tue 14:30 1199

A fractional Weyl semimetal — Fabian Hotz[1], Apoorv Tiwari[2], Oguz Turker[3], Tobias Meng[3], Ady Stern[4], •Maciej Koch-

Janusz[1], and Titus Neupert[2] — [1]ETH Zurich, Switzerland — [2]University of Zurich, Switzerland — [3]TU Dresden, Germany — [4]Weizmann Institute of Science, Israel

We construct an exactly solvable lattice model of a fractional Weyl semimetal (FWS). The low energy theory of this strongly interacting state is that of a Weyl semimetal built out of fractionally charged fermions. We show the existence of a universally quantized and fractional circular photogalvanic effect (CPGE) and a violation of the Wiedemann-Franz law in the system. Together with a spectral gap in the single-particle electronic Green's function they provide strong experimental signatures for this exotic gapless state of matter.

FM 34.3 Tue 14:45 1199

Chiral Majorana fermions in proximity-modified graphene — •Petra Högl[1], Tobias Frank[1], Denis Kochan[1], Martin Gmitra[2], and Jaroslav Fabian[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Department of Theoretical Physics and Astrophysics, Pavol Jozef Šafárik University, 04001 Košice, Slovakia

Chiral Majorana fermions are massless self-conjugate fermions which arise as propagating edge states of 2d topological superconductors. Recently, a scheme for topological quantum computation based on chiral Majorana fermions has been proposed [1]. We show the appearance of chiral Majorana edge modes in graphene by computing zigzag and armchair ribbon spectra. For this we use an effective model of graphene which takes into account proximity induced spin-orbit coupling and exchange field. This leads to a quantum anomalous Hall state which turns into a topological superconductor by adding superconducting proximity coupling. We prove the topological nature of the system by analyzing the Chern number of the 2d bulk. This work has been supported by DFG SFB 1277 (Project B07) and EU Seventh Framework Programme under Grant Agreement No. 604391 Graphene Flagship.

[1] B. Lian, X.-Q. Sun, A. Vaezi, X.-L. Qi, S.-C. Zhang, PNAS 115, 10938 (2018)

FM 34.4 Tue 15:00 1199

Simulation of chiral topological phases in driven quantum dot arrays — •Beatriz Perez-Gonzalez, Miguel Bello, Alvaro Gomez-Leon, and Gloria Platero — Instituto de Ciencia de Materiales de Madrid

Recent experimental evidence on scalable quantum dot devices demonstrates a reproducible and controllable 12-quantum-dot device, which opens up the possibility of simulating 1D topological insulators (TIs) upon quantum dot chains.

A canonical example of TI in 1D is the SSH model, displaying two topological phases. In this talk, we analyze the extension of this model to include long range hopping, and study how this affects the topological properties of the system. We conclude that for certain hopping configurations, one can have topological phases beyond those of the standard tight-binding Hamiltonian with first-neighbour couplings, hence allowing for the presence of more pairs of edge states.

Finally, we show that a quantum simulator for 1D topological phases, including those appearing in the extended SSH model, can be obtained by periodically driving an array of quantum dots with long-range hopping. Our driving protocol triggers topological behavior in an otherwise trivial setup, opening the door for the simulation of a wide range of Hamiltonians with a non-trivial band structure.

FM 35: Entanglement: Many-Body Dynamics I

Time: Tuesday 14:00–16:00 Location: 2004

FM 35.1 Tue 14:00 2004

Evolution of quantum coherence — •Jan Sperling[1,2] and Ian Walmsley[2,3] — [1]University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany — [2]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, UK — [3]Imperial College London, Exhibition Road, London SW7 2AZ, UK

Quantum interference phenomena have been identified as a versatile resource for quantum information processing, leading to the notion of quantum coherence. In this contribution, we discuss the concept of temporal quantum coherence. In contrast to the commonly applied input-output formalism, we assess the quantum coherence of a process by deriving equations of motions for the classical, i.e., incoherent, evolution of a system. When compared to the quantum dynamics, this approach enables us to study the quantum properties of a system's evolution itself, independently of or in conjunction with the coherence of initial and final states. As an example, we apply our theoretical framework to characterize the dynamics of entanglement, being one form of quantum coherence, in correlated many-body systems.

FM 35.2 Tue 14:15 2004

Entanglement-ergodic quantum systems equilibrate exponentially well — •Henrik Wilming[1], Marcel Goihl[2], Ingo Roth[2], and Jens Eisert[2] — [1]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

One of the outstanding problems in non-equilibrium physics is to precisely understand when and how physically relevant observables in many-body systems equilibrate under unitary time evolution. General equilibration results show that equilibration is generic in interacting systems provided that the initial state has overlap with sufficiently many energy levels. But strong results not referring to typicality which show that natural initial states actually fulfill this condition are lacking. In this work, we present stringent results for equilibration for systems in which Rényi entanglement entropies in energy eigenstates with finite energy density are extensive for at least some, not necessarily connected, sub-system. Our results reverse the logic of common arguments, in that we derive equilibration from a weak condition akin to the eigenstate thermalization hypothesis, which is usually attributed to thermalization in systems that are assumed to equilibrate in the first place.

FM 35.3 Tue 14:30 2004

Quantum walk with entangled qubits — •Shahram Panahiyan and Stephan Fritzsche — Helmholtz-Institut Jena, Jena, Germany

In this talk, we discuss how arbitrary number of entangled qubits affects properties of quantum walk. We consider variance, positions with non-zero probability density and entropy as criteria to determine the optimal number of entangled qubits in quantum walk. We point it out that for a single walker in one-dimensional position space, walk with three entangled qubits show better efficiency in considered criteria comparing to the walks with other number of entangled qubits. We also confirm that increment in number of the entangled qubits results into significant drop in variance of probability density distribution of the walker, change from ballistic to diffusive (suppression of quantum propagation), localization over specific step-dependent regions (characteristic of a dynamical Anderson localization) and reduction in entropy on level of reaching the classical walk's entropy or even smaller (attain deterministic behavior).

FM 35.4 Tue 14:45 2004

Stabilizing a dissipative discrete time crystal — Droenner Leon[1], •Finsterhölzl Regina[1], Heyl Markus[2], and Carmele Alexander[1] — [1]Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187, Dresden, Germany

Experimental evidence of time reversal symmetry breaking in many-body Floquet systems has led to the discovery of a new phase of matter out-of-equilibrium, the so called discrete time crystal (DTC) [1]. The DTC shows periodic oscillations with an integer number of the Floquet period. An essential ingredient is random disorder such that the system is many-body localized (MBL) to remain out-of-equilibrium due to the suppression of entanglement growth within the isolated many-body system.

In case of an open quantum system, dissipation naturally melts the DTC [2]. However, we are able to stabilize the DTC against dissipation by coupling it to a non-Markovian bath making use of quantum feedback dynamics. Similar to MBL for the isolated system, the idea is to suppress entanglement growth with external degrees of freedom. With this, the oscillations become independent of the coupling to the environment. Our numerical simulations are based on tensor network methods which enable us to efficiently access this large Hilbert space.

[1] J. Zhang et al, Nature 543, 217-220 (2017). [2] A. Lazarides and R. Moessner, Phys. Rev. B 95, 195135 (2017). [3] L. Droenner, R. Finsterhölzl, M. Heyl, A. Carmele, arXiv:1902.04986 [quant-ph] 2019.

FM 35.5 Tue 15:00 2004

Stabilizing a dissipative discrete time crystal — Droenner Leon[1], •Finsterhölzl Regina[1], Heyl Markus[2], and Carmele Alexander[1] — [1]Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187, Dresden, Germany

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FM 35.6 Tue 15:15 2004

Reversible quantum information spreading in many-body systems near criticality — •Benjamin Geiger, Quirin Hummel, Juan-Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg

Quantum chaotic interacting N-particle systems are assumed to show fast and irreversible spreading of quantum information on short (Ehrenfest) time scales $\sim \log N$. Here we show that, near criticality, certain many-body systems exhibit fast initial scrambling, followed subsequently by oscillatory behavior between reentrant localization and delocalization of information in Hilbert space. Specifically, we consider quantum critical bosonic systems with attractive contact interaction that exhibit locally unstable dynamics in the corresponding many-body phase space of the large-N limit. Semiclassical quantization of the latter accounts for many-body correlations in excellent agreement with simulations. Most notably, it predicts an asymptotically constant local level spacing $\sim 1/\tau$, again given by $\tau \sim \log N$, if the quantum phase transition is driven by a single (slow) degree of freedom. This unique timescale governs the long-time behavior of out-of-time-order correlators and entanglement entropies that, in certain scenarios, feature quasi-periodic recurrences indicating reversibility.

FM 35.7 Tue 15:30 2004

Quantification of quantum dynamics with input-output games — Roope Uola[1], •Tristan Kraft[2], and Alastair Abbott[1] — [1]Département de Physique Appliquée, Université de Genève, CH-1211 Genève, Switzerland — [2]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany

Recent developments regarding resource theories have shown that any quantum state or measurement resource, with respect to a convex (and compact) set of resourceless objects, provides an advantage in a tailored subchannel or state discrimination task, respectively. Here we show that an analogous, more general result is also true in the case of dynamical quantum resources, i.e., channels and instruments. In the scenario we consider, the tasks associated to a resource are input-output games. The advantage a resource provides in these games, in terms of success probability, is naturally quantified by a generalized robustness measure. We illustrate our approach by applying it to a broad collection of examples, including classical and measure-and-prepare channels, measurement and channel incompatibility. We finish by showing that our approach generalizes to higher-order dynamics where it can be used, for example, to witness causal properties of supermaps.

FM 35.8 Tue 15:45 2004

Many-body effects in cold molecules using phase-modulated two-dimensional coherent spectroscopy — •Friedemann Landmesser, Ulrich Bangert, Lukas Bruder, Marcel Binz, Daniel Uhl, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Germany

Many-body quantum states are considered to play a crucial role in atomic and molecular systems with respect to dissipation as well as excitation and energy transfer processes [1]. We aim to investigate collective effects in organic molecules by means of multiple-quantum coherence experiments where multiphoton processes can be separated from one-photon transitions and can be assigned to specific particle numbers [2,3]. In a first step, we will adapt a detection scheme that is based on phase-modulated two-dimensional coherent spectroscopy and which was already used to investigate multi-atom Dicke states in potassium vapor [3,4]. Measurements on a rubidium vapor will serve as a benchmark. In a second step, collective effects in organic molecular systems will be studied. To this end, we will adapt our helium nanodroplet source to produce solid rare gas clusters, that can be doped with hundreds of organic molecules. The cluster surface acts as a well-defined, cold environment [5]. In lifetime measurements we already identified collective effects of the interacting molecules at increasing doping densities [5].

FM 36: Quantum Computation: Benchmarking and Certification

Time: Tuesday 14:00–16:15 Location: 2006

Invited Talk FM 36.1 Tue 14:00 2006

Building Trust — •Elham Kashefi — University of Edinburgh & CNRS, Sorbonne Universite

Over the next decades we will see a state of flux as quantum technologies become part of the mainstream computing and communicating landscape. In the meantime we can expect to see quantum devices with high variability in terms of architectures and capacities. Adopting and applying such a highly variable and novel technology is both costly and risky as this quantum approach has an acute verification and validation problem:

On the one hand, since classical computations cannot scale up to the computational power of quantum mechanics, verifying the correctness of a quantum-mediated computation is challenging; on the other hand, the underlying quantum structure resists classical certification analysis.

This talk provides an overview of all different approaches to quantum certification, ranging from advanced tomographic tools such as compressed sensing, to fidelity estimation and witnessing and the verification of arbitrary quantum computations in an interactive fashion.

FM 36.2 Tue 14:30 2006

Benchmarking quantum computers with Qiskit Ignis — •James Wootton — IBM Research - Zurich

There are many ways that imperfections can arise in a quantum computation. It is important to assess what these do to our qubits, how they affect our ability to run programs with the devices, and how to mitigate their effects. Many different methods have been developed to do this, from the randomized benchmarking that focuses on single gates to the quantum volume that characterizes entire devices. This talk will introduce some of these methods, and show how they can be used in practice.

FM 36.3 Tue 14:45 2006

Certifying the building blocks of quantum computers from Bell's theorem — •Jean-Daniel Bancal[1,2], Pavel Sekatski[2], and Nicolas Sangouard[2] — [1]Department of Applied Physics, University of Geneva, 1211 Geneva, Switzerland — [2]Quantum Optics Theory Group, Universität Basel, CH-4056 Basel, Switzerland

Quantum computers hold great promises, but as their experimental realization concretizes it becomes clear that, like most quantum technologies, they are sensitive to implementation imperfections. Due to their large spectrum of possible application, device-independent certification schemes are needed to guarantee their proper working and certify their results. Recently, it was shown that practical imperfections do not constitute a fundamental barrier to this goal: black-box certification is in principle possible [see e.g. B. W. Reichard et al., Nature 496, 456 (2013)]. Realistic recipe that could be used in today's experiments were however not provided. Here, we present a framework for the device-independent certification of quantum channels that is inherently noise-tolerant. We show that it provides a generic tool for a bottom-up certification of quantum computers and technologies. We certify building blocks such as multi-qubit gates, quantum memories, quantum converters, Bell state measurements, quantum instruments, etc. Our test validates the capability of an imperfect device to be used in a larger quantum technology device, independently of its actual implementation and of the purpose for which it is used. This brings device-independent certification to the scope of currently available devices.

FM 36.4 Tue 15:00 2006

Sample complexity of device-independently certified "quantum supremacy" — •Dominik Hangleiter[1], Martin Kliesch[2], Jens Eisert[1], and Christian Gogolin[3] — [1]FU Berlin, Berlin — [2]Heinrich-Heine-Universität, Düsseldorf — [3]Universität Köln, Köln

Results on the hardness of approximate sampling are seen as important stepping stones towards a convincing demonstration of the superior computational power of quantum devices. The most prominent suggestions for such experiments include boson sampling, IQP circuit sampling, and universal random circuit sampling. A key challenge for any such demonstration is to certify the correct implementation. For all these examples, and in fact for all sufficiently flat distributions, we show that any non-interactive certification from classical samples and a description of the target distribution requires exponentially many uses of the device. It is an ironic twist of our results that the same property that is a central ingredient for the approximate hardness results, prohibits sample-efficient certification: namely, that the sampling distributions, as random variables depending on the random unitaries defining the problem instances, have small second moments.

FM 36.5 Tue 15:15 2006

Self-Consistent Calibration of Quantum Gate Sets — Pascal Cerfontaine, •René Otten, and Hendrik Bluhm — JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, 52074 Aachen, Germany

The precise and automated calibration of quantum gates is a key requirement for building a reliable quantum computer. Unlike errors from decoherence, systematic errors can in principle be completely removed by tuning experimental parameters. In this talk, we present an iterative calibration routine which can remove systematic gate errors on several qubits. A central ingredient is the construction of pulse sequences that extract independent indicators for every linearly independent error generator. We show that decoherence errors only moderately degrade the achievable infidelity due to systematic errors. Furthermore, we investigate the convergence properties of our approach by performing simulations for a specific qubit encoded in a pair of electron spins. Our results indicate that a gate set with 230 gate parameters can be calibrated in about ten iterations, after which incoherent errors limit the gate fidelity.

FM 36.6 Tue 15:30 2006

Gate set tomography via tensor completion — •Raphael Brieger[1], Ingo Roth[2], and Martin Kliesch[1] — [1]Institute for Theoretical Physics, Heinrich Heine University Düsseldorf, Germany — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Germany

Flexible characterization techniques that quantify and identify unwanted noise are crucial in the development of accurate quantum gates. Such techniques must work under realistic assumptions on the state-preparations and measurements available in NISQ devices. Gate set tomography (GST) has been proposed as a technique that simultaneously extracts tomographic information on an entire set of quantum gates, the state preparation and the measurements under minimal assumptions. We argue that the problem of reconstructing the gate set can naturally be cast as the problem of completing a translation-invariant matrix product state (MPS) from the knowledge of some of its entries. Such structured completion problems can be studied using the mathematical framework of compressed sensing. Extending recent results from the compressed sensing literature, we develop a new approach to the GST data processing task. We show numerically that an MPS completion algorithm can be used for the reconstruction of gate sets. Potential advantages of this approach are the ability to include physicality and low-rank constraints as well as prior knowledge on the gate implementations. Our approach is a promising first step towards more scalable GST schemes amenable to theoretical guarantees building on rigorous results available for MPS completion algorithms.

FM 36.7 Tue 15:45 2006

Mitigation of readout noise by classical post-processing based on Quantum Detector Tomography — Filip Maciejewski[1], Michał Oszmaniec[2], and •Zoltán Zimborás[3] — [1]University of Warsaw, Faculty of Physics, Ludwika Pasteura 5, 02-093 Warszawa, Poland — [2]National Quantum Information Centre, Faculty of Mathematics, Physics and Informatics, University of Gdansk, Wita Stwosza 57, 80-308 Gdansk, Poland — [3]Wigner Research Centre for Physics H-1525 Budapest, P.O.Box 49, Hungary

We propose a simple scheme to reduce readout errors in experiments on quantum systems with finite number of measurement outcomes. Our method relies on performing classical post-processing which is preceded by Quantum Detector Tomography, i.e., the reconstruction of a Positive-Operator Valued Measure describing the given quantum measurement device. If the measurement device is affected only by an invertible classical noise, it is possible to correct the outcome statistics of future experiments performed on the same device. We provide a characterization of readout noise occurring in IBM and Rigetti quantum devices and observe a good agreement with this noise model, which suggests that classical noise might be a dominant form of noise for superconducting transmon qubits. Moreover, we analyze the influence of the presence of coherent errors on and finite statistics on the performence of our correction procedure. We also test our scheme experimentally on the IBM 5-qubit device and observe a significant improvement of results for the implementation of a number of algorithms and other quantum information processing tasks.

FM 36.8 Tue 16:00 2006

Blind tomography via sparse de-mixing — •Ingo Roth, Jadwiga Wilkens, Dominik Hangleiter, and Jens Eisert — Freie Universität, Berlin, Germany

The envisioned applications of quantum technologies require to achieve an enourmous precision in engineering its individual components. This is why efficient and flexible methods for extracting information about quantum devices from measurements are crucial. One important task is to fully determine a quantum state from the measured data, e.g. in order to improve devices for state preparation. Experimental schemes for quantum state tomography typically require measurement devices that are calibrated to a high precision. At the same time, the precision of the measurement's calibration ultimately relies on an accurate state preparation creating a vicious cycle. In this work, we develop the framework of blind tomography which breaks this vicious cycle using only very mild and generic structure assumptions. We propose a scheme allowing for incomplete knowledge of the measurement device during the tomography of a low-rank quantum state. The scheme simultaneously determines both the device's calibration and the quantum state with minimal resources and efficient classical post-processing. Building on recent techniques from the field of compressed sensing, we derive algorithmic strategies for blind tomography and provide analytical performance guarantees. We further demonstrate the performance of our scheme in numerical simulations.

FM 37: Open and Complex Quantum Systems II

Time: Tuesday 14:00–16:00 Location: 3042

FM 37.1 Tue 14:00 3042

Gauge optimization in locally purifying tensor network states — •Lennart Bittel[1], Albert H. Werner[2], and Martin Kliesch[1] — [1]Heinrich Heine University Düsseldorf, Germany — [2]University of Copenhagen, Denmark

We have developed cost effective methods for finding good unitary gauges for locally purified tensor network quantum states. Tensor network methods have proven to be a useful tool to simulate interacting quantum systems. Such methods have also been extended from closed to open quantum systems. By relying on so-called *local purifications* positivity issues can be avoided and trace norm error control can be provided. However, purifications of quantum states have a unitary gauge freedom on the purifying system. This gauge freedom is shared by locally purified states and can practically lead to significant errors and large bond dimensions. In this work, we develop gauge optimization algorithms based on conjugate gradient methods and a version of adaptive linear regression. We demonstrate that this gauge optimization can be applied locally in order to significantly reduce the bond dimensions and to improve the accuracy of algorithms relying on local purifications with a small overhead.

FM 37.2 Tue 14:15 3042

Dissipation-assisted matrix product factorization — •Alejandro D. Somoza, Oliver Marty, James Lim, Susana F. Huelga, and Martin B. Plenio — Institut für Theoretische Physik and IQST, Universität Ulm, Ulm, Germany

Charge and energy transfer in biological and synthetic organic materials are strongly influenced by the coupling of electronic states to a highly structured dissipative environment. Non-perturbative simulations of these systems require a substantial computational effort and current methods can only be applied to large systems if environmental structures are severely coarse-grained. Time evolution methods based on tensor networks are fundamentally limited by the times that can be reached due to the buildup of entanglement in time, which quickly increases the size of the tensor representation, i.e., the bond dimension. In this work, we introduce a dissipation-assisted matrix product factorization (DAMPF) method that combines a tensor network representation of the vibronic state within a pseudomode description of the environment where a continuous bosonic environment is mapped into a few harmonic oscillators under Lindblad damping. This framework is particularly suitable for a tensor network representation, since damping suppresses the entanglement growth among oscillators and significantly reduces the bond dimension required to achieve a desired accuracy. We show that dissipation removes the *time-wall* limitation of existing methods, enabling the long-time simulation of large vibronic systems consisting of 10-50 sites coupled to 100-1000 underdamped modes in total and for a wide range of parameter regimes.

FM 37.3 Tue 14:30 3042

Design principles for long-range energy transfer at room temperature — •Andrea Mattioni, Felipe Caycedo-Soler, Susana Huelga, and Martin Plenio — Ulm University, Ulm, Germany

Typical room temperature conditions hinder ballistic long-range transfer of excitations, and are hence considered to prevent quantum phenomena to serve as tools for the design of efficient and controllable energy transfer over significant time and length scales. However, it is well-known that relevant dynamical properties of many-body systems depend on the quantum properties of minimal repeating units and, as we show here, excitonic energy transfer is no exception. With the support of an exactly solvable model, we are able to show how exciton delocalization and the ensuing formation of dark states within unit cells can be harnessed to support classical propagation over macroscopic distances. We specifically discuss the role of such factors in nanofabricated arrays of bacterial photosynthetic complexes via extensive simulations. This allows us to resolve the until now unexplained experimental observation of exciton diffusion lengths in such arrays in terms of an interplay between intra-unit cell thermalization and delocalization, which cooperate to create and use robust dark states at room temperature. Based on these factors, we provide quantum design guidelines at the molecular scale to optimize both energy transfer speed and diffusion range over macroscopic distances in artificial light-harvesting architectures.

FM 37.4 Tue 14:45 3042

Wave-particle duality of many-body quantum states — •Christoph Dittel[1,2], Gabriel Dufour[2,3], Gregor Weihs[1], and Andreas Buchleitner[2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany — [3]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität-Freiburg, Albertstr. 19, 79104 Freiburg, Germany

We formulate a quantitative theory of wave-particle duality for many-body quantum states and derive complementarity relations for the wave and particle character of many identical bosons or fermions equipped with a tunable level of distinguishability. We show that our complementarity relations fundamentally constrain measurement statistics and interference visibilities in general experimental settings with possibly interacting particles, and, thereby, provide a versatile framework to certify and benchmark complementarity and particle indistinguishability in many-body quantum protocols.

FM 37.5 Tue 15:00 3042

Eigenstate Complexity of Interacting Bosons on a Lattice — •Lukas Pausch, Alberto Rodríguez, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Multifractality has proven to be an efficient quantifier of the complexity of many-particle states in Fock space, and it has been used to expose ground state phase transitions [1,2]. In our present numerical study, we use multifractality to investigate Fock space complexity for the full set of eigenstates of the Bose-Hubbard Hamiltonian. We examine the evolution of the distribution of generalized fractal dimensions as a function of interaction strength and in relation to the behaviour of the energy spectrum. This analysis reveals that the eigenstate structure in Hilbert space changes drastically across the energy canvas for different values of the interaction. Furthermore, we investigate possible connections between multifractality and the emergence of quantum chaos.

[1] J. Lindinger, A. Buchleitner and A. Rodríguez, Phys. Rev. Lett. 122, 106603 (2019).

[2] D. J. Luitz, F. Alet and N. Laflorencie, Phys. Rev. Lett. 112, 057203 (2014).

FM 37.6 Tue 15:15 3042

Quantum walks of two cobosons — •mama kabir njoya mforifoum[1], gabriel dufour[1,2], and andreas buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Germany

A quantum walker is a particle evolving coherently over a network of sites, and therefore has the ability to interfere with itself, contrary to its classical counterpart. The extension to many-particle quantum walks, together with non-vanishing particle-particle interactions, leads to many-particle interference phenomena which are controlled by the particles' statistics (bosonic or fermionic), their degree of mutual distinguishability, and the interaction strength. We focus on the scenario of two interacting co-bosons (pairs of bound fermions) on a 1D lattice, systematically explore characteristic dynamical features as determined by the location in parameter space, and discriminate the observed behaviour against that of two elementary bosons.

FM 37.7 Tue 15:30 3042

Observation and stabilization of photonic Fock states in a hot radio-frequency resonator — Mario F. Gely[1], •Christian Dickel[3,1], Marios Kounalakis[1], Jacob Dalle[1], Remy Vatre[1], Brian Baker[2], Mark D. Jenkins[1], and Gary A. Steele[1] — [1]Kavli Institut of Nanoscience, Delft University of Technology, The Netherlands — [2]Department of Physics and Astronomy, Northwestern University, United States of America — [3]Institute of Physics II, University of Cologne, Germany

In quantum mechanics, the ultimate limit of a weak field is a single-photon. Detecting and manipulating single photons at megahertz frequencies presents a challenge because thermal fluctuations are significant, even at millikelvin temperatures. Here, we use a superconducting transmon qubit to directly observe photon-number splitting of the transition frequency due to a megahertz electrical resonator. Using the qubit, we achieve quantum control over thermal photons, sideband cooling the system and stabilizing photonic Fock states. Releasing the resonator from our control, we directly observe its re-thermalization with nanosecond resolution. Extending circuit quantum electrodynamics to a new regime, we enable the exploration of thermodynamics with photon-number resolution and allow interfacing quantum circuits with megahertz systems, for example, electro-mechanical oscillators.

FM 37.8 Tue 15:45 3042

Discrete quantum time crystal signature of nuclear spins coupled to nitrogen-vacancy centers in diamond — •Jianpei Geng — 3rd Institute of Physics, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

In view of spacetime invariance, it is quite natural to consider about the concept of time crystal in analogy to crystal. A time crystal is expected to show periodic pattern in time and to break time translation symmetry. Although a quantum time crystal of a static equilibrium system has been ruled out, discrete quantum time crystal can exist for periodically driven systems. The discrete quantum time crystal signature has been observed in several systems such as trapped ions, ensemble nitrogen-vacancy centers, and nuclear spins in NMR samples. However, an insight what interaction of the system would lead to the time crystal signature is still lacking. Here, we broaden the insight by showing that nuclear spins with negligible coupling between each other can still exhibit discrete quantum time crystal signature. The time crystal signature is stimulated by the coupling between the nuclear spins and a nitrogen-vacancy center or coupled nitrogen-vacancy centers.

FM 38: Enabling Technologies: Quantum Dots, Quantum Wires, Point Contacts and Excitonic Systems

Time: Tuesday 14:00–16:00 Location: 3043

FM 38.1 Tue 14:00 3043

Real-time detection of Auger recombination in a self-assembled quantum dot — •Pia Lochner[1], Annika Kurzmann[1], Jens Kerski[1], Philipp Stegmann[1], Jürgen König[1], Rüdiger Schott[2], Andreas D. Wieck[2], Arne Ludwig[2], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Auger recombination is a non-radiative process, where the recombination energy of an electron hole pair is transferred to a third charge carrier. In colloidal quantum dots (QDs), this is a common effect, which quenches the radiative emission with recombination times in the order of ps [R. Vaxenburg, et al., Nano Lett. **15**, 2092 (2015).]. In self-assembled QDs it has become possible to observe Auger recombination only recently, with recombination times in the order of μs [A. Kurzmann, et al., Nano Lett. **16**, 3367 (2016).].

In this contribution, we use real-time measurements of the random telegraph signal [A. Kurzmann, et al., PRL, accepted (2019).] to investigate Auger recombination in a single self-assembled QD. This is coupled to a charge reservoir with a small tunneling rate in the order of ms^{-1}. We are able to detect every single Auger recombination, as well as the "resetting" of the quantum dot to the singly charged state by single electron tunneling. By changing the laser power for resonant trion excitation, we can precisely tune the Auger rate while the tunneling rate remains constant and can thus determine the corresponding statistics of the processes.

FM 38.2 Tue 14:15 3043

The development of the optically active gate-defined quantum dots — •Thomas Descamps[1], Feng Liu[1], Chao Zhao[1], Arne Ludwig[2], and Hendrik Bluhm[1] — [1]JARA-FIT Insitute Quantum Information, Forschungzentrum Jülich GmbH and RWTH Aachen Universit, 52074 Aachen, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Rhur-Universität Bochum, D-44780 Bochum, Germany

GaAs gate defined quantum dots (GDQD) have been extensively studied as a platform for spin qubits. To improve the scalability, one method to transfer the information relies on the coupling of the electron spin to a photon. In this work, we pursue the coupling of the spin qubit to excitons in a new type of optically active gate-defined quantum dots.

FM 38.3 Tue 14:30 3043

LO-phonon emission by electrons from single-electron sources — •Clarissa Barratt, Lewis Clark, and Clive Emary — Joint Quantum Centre Durham-Newcastle, School of Mathematics, Statistics and Physics, Newcastle University, Newcastle Upon Tyne, NE1 7RU, UK

There is substantial interest in the use of dynamic quantum dots as sources of single electrons, both to explore fundamental issues off solid-state physics as well as pursue quantum-technology applications. This is due to their high accuracy and speed, and the high energy of injection [1].

In this contribution we consider the effect of longitudinal-optical-phonon emission on the relaxation of electrons from a single electron source. Previous approaches to modelling such systems have been semiclassical, using the classical probability distribution only [2].

We derive the complete quantum master equation for this system which takes into account the coherence terms of the density matrix as well as the population previously considered. Our aim is to have a full quantum mechanical description of the electron transport process. These results will be used to calculate arrival times of the electrons, as well as for input into potential future experiments.

[1] Giblin, S. P. et al., An accurate high-speed single-electron quantum dot pump, NJP 12, 073013 (2010)

[2] Emary, C. et al., Phonon emission and arrival times of electrons from a single-electron source, PRB 93, 035436 (2016)

FM 38.4 Tue 14:45 3043

Probing Formation of Conductive Mesocrystalline Superlattice of Nanocrystals on Liquid/Air Interface by in-situ X-ray Scattering — •Santanu Maiti[1,2], Sonam Maiti[2], Andrey Chumakov[3], Marcus Scheele[1], and Frank Schreiber[1] — [1]Forschungszentrum Jülich, Jülich, Germany — [2]University of Tuebingen, Tuebingen, Germany — [3]European Synchrotron Radiation Facility (ESRF), Grenoble, France

Directional cross-linking of organic semiconductors (OSC) with nanocrystals (NC) produces superlattices exhibiting novel structural and electronic properties [1,2]. We will present the result of a study on the in-situ formation of conductive, iso-oriented mesocrystalline superstructures with cubic PbS NCs at the acetonitrile/air interface, investigated simultaneously by grazing incidence small angle X-ray scattering (GISAXS) and grazing incidence X-ray diffraction (GIXD) in real-time [3]. We observe a continuous contraction of superlattices with elapsed time, preserving their superlattice symmetries and attribute these contractions to the complete replacement of native oleic acid ligands with small OSC cross-linker cobalt/copper tetraaminophthalocyanine [4]. Such investigations provide crucial visualizations into the formation mechanism of such nanostructures, which already find applications. [1] M. Scheele et al., Phys. Chem. Chem. Phys. 17, 97 (2015) [2] S. Maiti et al., J. Phys. Chem. Lett. 9, 739 (2018) [3] S. Maiti et al., J. Phys.: Condens. Matter 29, 095101 (2017) [4] S. Maiti et al, J. Phys. Chem. C 123, 1519 (2019)

FM 38.5 Tue 15:00 3043

Tracking wavepacket dynamics through a conical intersection in an organic photovoltaic oligomer aggregate — Ephraim Sommer[1], Xuan Trung Nguyen[1], Lynn Gross[2], Thomas Frauenheim[2], Elena Mena-Osteritz[3], Peter Bäuerle[3], Christoph Lienau[1], and •Antonietta De Sio[1] — [1]Institut für Physik, Universität Oldenburg — [2]BCCMS, Universität Bremen — [3]Institut für organische Chemie II und neue Materialien, Universität Ulm

Conical intersections(CoIns) of potential energy surfaces may profoundly influence the dynamics and yield of energy and charge transfer processes. So far, however, their importance for the dynamics in organic photovoltaics (OPV) materials has not yet been discussed. Here we use two-dimensional electronic spectroscopy, with sub-10-fs time resolution, to probe the light-induced dynamics in an acceptor-donor-acceptor oligomer aggregate used in efficient OPV devices. Upon impulsive optical excitation, we detect a grid-like peak pattern suggesting coherent wavepacket motion in the excited state. After <50 fs, this pattern completely transforms into a broader and nearly featureless single peak. Concurrently, we observe an increase of oscillation period and an abrupt vanishing of the optically excited wavepacket, followed by the emergence of a new one with different oscillatory components. Our experimental results, supported by nonadiabatic excited state molecular dynamics simulations, show that ultrafast energy transfer in stacked dimers of this oligomer thin film involves passage of the optically excited wavepacket through an intermolecular CoIn within <50 fs.

FM 38.6 Tue 15:15 3043

Charge Reconfiguration in Isolated Quantum Dot Arrays — •Johannes C. Bayer, Timo Wagner, Eddy P. Rugeramigabo, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Hanover, Germany

The quantum dot device is based on a GaAs/ALGaAs heterostructure. Up to four lateral quantum dots in series are defined by potentials applied to metallic Schottky gates. Two quantum point contacts in the vicinity are used as charge detectors, allowing real-time detection of electrons tunneling through the array [1, 2].

In the isolated regime, charge detectors are utilized to observe charges tunneling inside the quantum dot array. Our highly tunable device allowed the investigation of isolated double, triple and quadruple quantum dot configurations. Experimental results are complemented by simulations, which enable the identification of the different transitions occurring in these systems. Tunable higher order tunneling transitions between non-neighboring quantum dots are observed for triple and quadruple quantum dot arrays [3, 4].

References

[1] T. Wagner, *et. al.*, Nat. Nanotechnol. **12**, 218-222 (2017).
[2] T. Wagner, *et. al.*, Nat. Phys. **15**, 330-334 (2019).
[3] J. C. Bayer, *et. al.*, Phys. Rev. B **96**, 235305 (2017).
[4] J. C. Bayer, *et. al.*, Ann, Phys (Berlin), **531**, 1800393 (2019).

FM 38.7 Tue 15:30 3043

Quantum State Transfer in Quantum Dot Arrays — Jordi Picó-Cortés, Yue Ban, Sigmund Kohler, and •Gloria Platero — Instituto de Ciencia de Madrid, CSIC

The effect of ac electric fields on the transport properties of low dimensional systems has been a topic of intense research in the last years. Applying ac electric fields to coupled quantum dots allows to transfer charge between them by means of photo-assisted transitions. Experiments in triple quantum dots unambiguously show direct electron transfer between the outer dots, without the participation of the intermediate region other than virtual, thus minimizing the effect of decoherence and relaxation . In the presence of ac driving the direct transfer of electrons between distant dots takes place by means of photo-assisted virtual transitions. I will focus on a protocol for preparing a quantum state at the left edge of a triple quantum dot and directly transferring it to the right edge by means of ac gate voltages. I will show that by the controlled generation of dark states it is possible to increase the fidelity of the transfer protocol . I will discuss as well other protocols which allow for long range charge transfer in quantum dot arrays, as coherent transfer by adiabatic passage (CTAP). I will show how these protocols can be speeded up by shortcuts of adiabaticity. Furthermore, it allows for long range transfer of two electron entangled states in quantum dot arrays with high fidelity. The proposed protocols offer an alternative and robust mechanism for quantum information processing.

FM 38.8 Tue 15:45 3043

Dephasing of Andreev bound states revealed by iterative summation of path integrals — •Stephan Weiss and Jürgen König — Theoretische Physik, Universität Duisburg-Essen, Lotharstr. 1, 47048 Duisburg & CENIDE

Multiple coherent reflections of electrons at superconductor/normal conductor interfaces lead to Andreev bound states (ABS), which have an energy that is smaller than the superconducting gap. As Andreev bound states are current-carrying, they may be probed within quantum-transport measurements. Coupling to a normal metal induces dephasing. We investigate a minimal model, which exhibit a tuneable ABS spectrum, i.e. an interacting quantum dot with a single spin-degenerate level that is brought into proximity to a superconductor. Iterative path-integral summations [1-3] are carried out to obtain the tunnelling current. Our method is numerically exact and treats spin-dependent resonant-tunnelling processes in a natural manner [2,3]. It furthermore allows to take into account small to intermediate Coulomb interactions. A tunnel-coupled normal metal is used to monitor the spectrum of the quantum dot together with the induced dephasing of the Andreev bound states over a wide range of gate- and bias voltages at finite temperatures [3].

[1] S. Weiss, et. al, Phys. Stat. Sol. B, 250, 2298 (2013).
[2] S. Weiss and J. König, submitted, (2019).
[3] S. Mundinar, Ph. Stegmann, J. König, and S. Weiss, Phys. Rev. B 99, 195457 (2019).

FM 39: Quantum Computation: Hardware Platforms II

Time: Tuesday 14:00–16:00 Location: 3044

Invited Talk FM 39.1 Tue 14:00 3044

Applications of Quantum Computing with Superconducting Qubits — •Stefan Filipp — IBM Research - Zurich

In the recent years we have observed a rapid development of quantum technologies for the realization of quantum computers that promise to outperform conventional computers in certain types of problems. These include problems in optimization and machine learning, but also in the computation of complex many-body physical systems such as molecules or condensed matter. Assisted by conventional computing systems, hybrid quantum-classical architectures may soon allow us to solve some of today's computational challenges. Because of their relatively long coherence times and scalable fabrication methods superconducting quantum circuits are a promising candidate to realize such a quantum computing platform. We employ a variational algorithm that is based on a classical optimizer to guide the preparation of the quantum state on the quantum processor which encodes the solution to a given problem. This method is suited best for near-term applications on non-error corrected quantum hardware because it relies only on a small number of quantum operations and finishes within the coherence time of the system. First results in the field of quantum chemistry for computing the energy spectra of small molecules and in machine learning for classification protocols demonstrate the potential of this technology.

FM 39.2 Tue 14:30 3044

Fast control of quantum circuits — •Jan Goetz[1,2], Kuan Tan[1,2], Vasilii Sevriuk[1], Eric Hyyppä[1], Matti Silveri[1], Matti Partanen[1], Mate Jenei[1], Joni Ikonen[1], Visa Vesterinen[3], Leif Grönberg[3], Juha Hassel[3], and Mikko Möttönen[1,2,3] — [1]IQM, Vaisalantie 6C, 02130 Espoo, Finland — [2]QCD Labs, QTF Centre of Excellence, Department of Applied Physics, Aalto University, PO Box 13500, FI-00076 Aalto, Finland — [3]VTT Technical Research Centre of Finland Ltd, P.O. Box 1000, FI-02044, Espoo, Finland

We report on a fast in-situ control of superconducting quantum circuits. Namely, the fast tunability of an electromagnetic environment coupled to a superconducting resonator and a novel fast readout scheme for superconducting qubits. As tunable environment, we utilize a recently-developed quantum-circuit refrigerator (QCR) to experimentally demonstrate a dynamic tunability in the total damping rate of the resonator up to a factor of 30, with a consequently theoretically predicted change in the internal damping rate by four orders of magnitude. For the fast qubit readout, we experimentally implement a method of measuring a qubit by driving it close to the frequency of a dispersively coupled bosonic mode. Our experiments pave the way towards significant speedup in two relevant operations of a superconducting quantum computer, qubit reset and readout.

FM 39.3 Tue 14:45 3044

Non-equilibrium quasiparticles in superconducting circuits: photons vs. phonons — •Gianluigi Catelani[1] and Denis Basko[2]

— [1]JARA Institute for Quantum Information, Forschungszentrum Jülich, Germany — [2]CNRS, Grenoble, France

We study the effect of non-equilibrium quasiparticles on the operation of a superconducting device (a qubit or a resonator), including heating of the quasiparticles by the device operation. Focusing on the competition between heating via low-frequency photon absorption and cooling via photon and phonon emission, we obtain a remarkably simple non-thermal stationary solution of the kinetic equation for the quasiparticle distribution function. We estimate the influence of quasiparticles on relaxation and excitation rates for transmon qubits, and relate our findings to recent experiments.

FM 39.4 Tue 15:00 3044

Photon-assisted charge-parity jumps in a superconducting qubit — Manuel Houzet[1], Kyle Serniak[2], •Gianluigi Catelani[3,4], Michel Devoret[2], and Leonid Glazman[2] — [1]CEA, Grenoble, France — [2]Depts. of Physics and Applied Physics, Yale University, New Haven, USA — [3]JARA Institute for Quantum Information, Forschungszentrum Jülich, Germany — [4]Yale Quantum Institute, Yale University, New Haven, USA

We evaluate the rates of energy and phase relaxation of a superconducting qubit caused by stray photons with energy exceeding the threshold for breaking a Cooper pair. All channels of relaxation within this mechanism are associated with the change in the charge parity of the qubit, enabling the separation of the photon-assisted processes from other contributions to the relaxation rates. Among the signatures of the new mechanism is the same order of rates of the transitions in which a qubit loses or gains energy. Our theory offers a natural explanation of recent measurements.

FM 39.5 Tue 15:15 3044

cross-resonance-based gates between different superconducting quibt types — •xuexin xu[1], mohammad ansari[1], Jaseung ku[2], yebin liu[2], britton plourde[2], jared hertzberg[3], markus brink[3], and jerry chow[3] — [1]Peter Grünberg Institute, Forschungszentrum Jülich — [2]Syracuse University — [3]IBM T.J. Waston Research Center

We theoretically model an experiment on a superconducting circuit made of a capacitively shunted flux qubit (CSFQ) and a Transmon qubit both capacitively coupled to a bus resonator in dispersive regime. To model this circuit we take into account the contribution of higher excited states in qubits and block-diagonalize the Hamiltonian perturbatively in the regime of small interaction couplings compared to frequency detuning. We apply external driving microwave pulses over all energy levels and consider the transitions they impose effectively within the computational subspace. More specifically we apply entirely microwave two-qubit gate, the so called cross-resonance, on CSFQ at sweet spot and away from it. Interestingly the two-qubit fidelity is largely enhanced at certain external flux away from the sweet spot. This enhancement takes place as the result of suppressed leakage out of computational subspace. This will introduce further tunability into two-qubit gate fidelity. Our theoretical results are in agreement with experiment, showing a promising approach to controllably improve single- and two-qubit gate operations in such circuits due to the relatively large and positive anharmonicity of CSFQ.

FM 39.6 Tue 15:30 3044

Analog quantum simulation using superconducting qubits — •Stefan Oleschko[1,2], Oscar Gargiulo[1,2], Maximilian Zanner[1,2], Aleksei Sharafiev[1,2], and Gerhard Kirchmair[1,2] — [1]Institute for Quantum Optics and Quantum Information, A-6020 Innsbruck, Austria — [2]Institute for Experimental Physics, University of Innsbruck, A-6020 Innsbruck, Austria

In this talk I want to present the research activities of the Superconducting Quantum circuits group at the Institute for Quantum Optics and Quantum Information in Innsbruck. I will show how we want to use 3D circuit QED architectures to realize a platform for quantum many body simulations of dipolar XY models on 2D lattices using state of the art circuit QED technology. The central idea is to exploit the naturally occurring dipolar interactions between 3D superconducting qubits to simulate models of interacting quantum spins. The ability to arrange the qubits in essentially arbitrary geometries allows us to design spin models with more than nearest-neighbor interaction in various geometries. We will be able to investigate quantum phenomena in 2D where qualitatively new features emerge and existing numerical and analytical approaches reach their limitations.

FM 39.7 Tue 15:45 3044

Real-time precompensation for fast conditional sequence branching — •Bruno Küng, Yves Salathé, Niels Haandbaek, and Jan Sedivy — Zurich Instruments AG, Zurich, Switzerland

We present a real-time precompensation technology in an arbitrary waveform generator (AWG) for distortion corrections of superconducting qubit magnetic flux pulses [1].

In contrast to conventional precompensation of the waveform shape in software, real-time filtering applies corrections to the signal right before playback in the AWG. As a consequence, our implementation can incorporate the full history of the played pulse sequence, even when using fast conditional branching as is required for quantum error correction [2].

A signal level accuracy of 0.1% is achieved by optimized filter design which satisfies the requirement for low latency and enables to precompensate commonly occurring artifacts in cryogenic wiring.

For this precompensation method, the repeatability of flux pulses was quantified with two succeeding net-zero waveforms in [2]. The phase the qubits acquired during two subsequent fluxes pulses was identical within 1 deg and independent of the temporal separation between them.

[1] https://www.zhinst.com/products/hdawg/hdawg-pc
[2] M. A. Rol, et al. arXiv:1903:02492 [quant-ph], 2019

FM 40: Poster: Quantum Computation: Hardware Platforms

Time: Tuesday 16:30–18:30 Location: Tents

FM 40.1 Tue 16:30 Tents

Tunable refrigerator for superconducting quantum circuits — •Hao Hsu and Gianluigi Catelani — Forschungszentrum Jülich, Jülich, Germany

Fast initialization with high reset fidelity is a necessary criterion for realizing quantum computing. Recently, a "quantum circuit refrigerator" (QCR) was demonstrated which can cool superconducting resonators [1]. Here we extend the theory [2] to study a QCR coupled to generic superconducting circuits. We identify two working temperature regimes, depending on the QCR electron temperature T_N: the thermal activation regime and the low-temperature regime. In the thermal activation regime, the effective temperature T_T at which the circuit is cooled is proportional to T_N, while T_T is independent of T_N in the low-temperature regime. In typical transmon and capacitively shunted flux qubits, we find that in both regimes, the effective temperature limits the reset fidelity. In the practically relevant low-temperature regime, we predict 99.99 % reset fidelity in a reset time of few tens of nanoseconds.

[1] K. Y. Tan et.al., Nat. Commun. 8 15189 (2017) [2] M. Silveri et.al., Phys. Rev. B 96, 094524 (2017)

FM 40.2 Tue 16:30 Tents

Individually controlled Ion Trap Arrays for Quantum Simulations — •Frederick Hakelberg, Philip Kiefer, Deviprasath Palani, Lennart Guth, Jan-Philipp Schröder, Matthias Wittemer, Ulrich Warring, and Tobias Schaetz — Uni Freiburg

Trapped ions present a promising system for quantum simulations [1]. Surface-electrode traps in contrast to conventional ion traps offer the advantage of scalability to larger system size and dimension while maintaining individual control: Dedicated radio-frequency electrode shapes allow the creation of two-dimensional trap arrays [2] while control electrodes allow localized manipulation of the trapping potential tuning motional frequencies and mode orientations [3].
Our setup consists of a basic but scalable array of three Mg^+ ions individually trapped in an equilateral triangle with 40 μm inter-site distance. We present the first realization of inter-site coupling, until now only realized for one-dimensional arrangements [4]. We demonstrate its tuning in real time, and show interference of large coherent states [5].

Furthermore we employ the individual control for modulation of the local trapping potentials to realize phonon-assisted tunnelling between adjacent sites [6].

[1] T. Schaetz *et al.*, New J. Phys. **15**, 085009 (2013)
[2] R. Schmied *et al.*, Phys. Rev. Lett. **102**, 233002 (2009)
[3] M. Mielenz *et al.*, Nature Communications **7**, 11839 (2016)
[4] K. Brown *et al.* & M. Harlander *et al.*, Nature **471**, 196-203 (2011)
[5] F. Hakelberg *et al.*, arXiv:1812.08552, 196-203 (2018)
[6] A. Bermudez *et al.*, Phys. Rev. Lett. **107**, 150501 (2011)

FM 40.3 Tue 16:30 Tents

A spin qubit in ^{28}Si/SiGe with 60 ppm ^{29}Si — •Floyd Schauer[1], Tom Struck[2], Arne Hollmann[2], Andreas Schidbauer[1], Carlo Peiffer[1], Veit Langrock[2], Helge Riemann[3], Nikolay V. Abrosimov[3], Lars R. Schreiber[2], and Dominique Bougeard[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Regensburg, Germany — [2]JARA-FIT Institute Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany — [3]Leibniz-Institut für Kristallzüchtung, Berlin, Germany

^{28}Si is a strong candidate for hosting spin qubits, promising long qubit coherence times in a technologically scalable environment. Electrostatically-defined quantum dots in ^{28}Si/SiGe heterostructures have been proven to robustly allow the implementation of spin qubits, as long as their device-inherent valley splitting energy is sufficiently large to operate the qubit.

Here, we present the characterization of a gate-defined single spin qubit in a quantum dot layout with an integrated nanomagnet. The qubit is hosted in a molecular-beam epitaxy-grown ^{28}Si/SiGe heterostructure presenting only 60 ppm residual ^{29}Si. We determine the relevant single electron quantum dot energies, finding a robust valley splitting beyond 200 μeV and a well separated orbital energy beyond 1 meV. Below the valley splitting energy, we observe spin relaxation times $T_1 > 1$ s which are independent of the externally applied magnetic field. Using electron dipole spin resonance, the manipulation of the qubit yields $T_2^* \sim 22\,\mu$s and long $T_2^{echo} \sim 127\,\mu$s.

FM 40.4 Tue 16:30 Tents

Rydberg atoms in strong electric fields and in superconducting microwave cavities — •Andreas Günther[1], Conny Glaser[1], Manuel Kaiser[1], Lorinc Sárkány[1], Dieter Kölle[1], Reinhold Kleiner[1], David Petrosyan[2], and József Fortágh[1] — [1]Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Institute of Electronic Structure and Laser, FORTH, GR-71110 Heraklion, Crete, Greece

Using a novel quantum gas microscope, we directly measure the excitation blockade for strongly Stark-shifted Rydberg states close to the classical ionization limit. Therefore, we developed a novel scheme for tuning the interactions and controlling the ionization rate, using an avoided crossing in the corresponding Stark map. We investigate the dipole blockade by analyzing the spatial correlations of the excited Rydberg atoms for different values of the initial dipole moment and compare our findings to theoretical simulations.

Interparticle interactions, such as the dipole-dipole blockade, are of specific importance for Rydberg based quantum gates. In view of such a scheme, we study the coupling of Rydberg atoms to a superconducting coplanar microwave cavity. Depending on the microwave power, we observe Rabi oscillations at different frequencies, which allow for coherent state manipulations and may lead to coupling of Rydberg state pairs via the cavity field.

FM 40.5 Tue 16:30 Tents

Static and dynamic quantum speed limit of single neutral atoms in optical lattices — •Manolo Rivera[1], Thorsten Groh[1], Natalie Peter[1], Jan Uckert[1], Gal Ness[4], Carsten Robens[1], Wolfgang Alt[1], Dieter Meschede[1], Antonio Negretti[2], Tommaso Calarco[3], Simone Montagero[3], and Andrea Alberti[1] — [1]Institut für Angewandte Physik, Bonn, Germany — [2]Zentrum für Optische Quantentechnologien, Hamburg, Germany — [3]Institut für komplexe Quantensysteme, Ulm, Germany — [4]Physics Department, Technion - IIT, Haifa, Israel

We report on fast, high-fidelity transport of single atoms in spin-dependent optical lattices with a high-precision polarization synthesizer, which allows us to displace the lattice potentials with angstrom precision. The transport sequences computed from quantum optimal control theory are believed to reach the fundamental speed limit of our optical lattice system (dynamical quantum speed limit), corresponding to one lattice site in $30\mu s$. During transport operations close to the quantum speed limit the atoms are excited, but are then refocused to the ground state at the end of the transport. This is confirmed by measuring the fraction of atoms in the ground state after transport using a novel detection scheme based on microwave sideband spectroscopy. Our transport sequences preserve the coherence of the two spin states, this has been shown by single atom interferometry. Additionally we verify the Mandelstam-Tamm inequality which poses a lower bound to the time evolution between an initial state to an orthogonal state in the static lattice (static quantum speed limit).

FM 40.6 Tue 16:30 Tents

Digital single-atom interferometer in a two-dimensional state-dependent optical lattice — •Gautam Ramola, Richard Winkelmann, Muhib Omar, Karthik Chandrashekara, Wolfgang Alt, Dieter Meschede, and Andrea Alberti — Institute for Applied Physics, Bonn, Germany

We demonstrate a single atom interferometer with a Caesium atom, localized on a two-dimensional state-dependent optical lattice, where we achieve robust and precise control over both the external and internal degrees of the freedom of the particle [1]. Such precise control over the atomic wave packet allows for nondestructive probing of microscopic quantum systems and measuring potential gradients at ultrashort length scales [2]. The two-dimensional state-dependent lattice enables us to enclose large areas between the interfering arms, while the trapped nature of the interferometer allows us to insert an arbitrary amount of probing time. Both these factors contribute to increasing the sensitivity of our interferometer, which is proportional to the space-time area enclosed. Furthermore, precise control over the atom's position allows us to create arbitrary interferometric geometries, paving the way for implementing novel protocols to study multi particle interactions. One such proposal we plan to implement is the direct interferometric measurement of the exchange phase between two indistinguishable Caesium atoms [3].

[1]C. Robens et al.,Phys. Rev. A. **9**, 034016 (2018)
[2]A. Steffen et al., Proc. Natl. Acad. Sci. USA **109**, 9770 (2012).
[3]C. F. Roos et al., Phys. Rev. Lett. **119**, 160401 (2017)

FM 40.7 Tue 16:30 Tents

Optimization of the Readout of a Superconducting Qutrit — •Susanna Kirchhoff — Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany

Superconducting qubits can be read out by driving a resonator coupled to the qubit and measuring the response. An arbitrary qubit state can be reconstructed using the responses of the basis states. For a three level system (qutrit) the readout is more challenging. In this work methods to improve the readout of a three level system are explored. The simulation data is based on the solution of a Bloch-type system of equations that was derived using the Jaynes-Cummings Hamiltonian with and without dispersive approximation. The results are compared to experimental data.

FM 40.8 Tue 16:30 Tents

Testing a photonic chip with entangled photons — •Bülent Demirel, Weikai Weng, Shreya Kumar, and Stefanie Barz — University of Stuttgart, FMQ, Stuttgart, Germany

Multipartite entangled states are useful for applications such as quantum networking and computing but also enable intriguing experiments on fundamental questions of quantum physics. Today's quantum technologies are based on the properties of large ensembles of particles, however, increasing the number of entangled parties is not a trivial process and requires increasing the number of components. Here, we show the generation of 4-photon entanglement, in particular a maximally entangled 4-photon GHZ state and a cluster state. We show how to generate those states using integrated optics. The presented results form the basis for subsequent few-photon experiments and future tests of quantum protocols on photonic chips.

FM 40.9 Tue 16:30 Tents

Optimal control pulses for a scalable quantum memory — •Nicolas Wittler, Shai Machnes, and Frank K. Wilhelm — Saarland University

Achieving high fidelities for operations on systems with low anharmonicity and complex crowded spectra, such as transmon qubits, is in general required for scalable quantum technologies.

A promising implementation of a quantum memory for a transmon consists of using an electromagnetic mode of the 3D cavity that is already used for readout and control of the transmon, as shown in an experiment by Frank Deppe's group at the Walther-Meißner-Institute in Munich.

The read and write operations for this memory are exchanges of excitations between the qubit and cavity. In order to profit of the life time of the cavity state ($T_1 = 9.5\mu s, T_2 = 13\mu s$) compared to the transmon ($T_1 = 1.4\mu s, T_2 = 3.5\mu s$), these gates must be fast and accurate. The high drive power needed to reach short gate times makes it necessary to control leakage out of the computational subspace into higher transmon states.

With theoretical pulse shaping techniques such as DRAG and GOAT that engineer the frequency spectrum of a control pulse, unwanted transitions can be suppressed and an increase in fidelity or shortening of the gate time can be achieved.

FM 40.10 Tue 16:30 Tents

Parametric amplification of broadband microwave signals — •Michael Renger[1,2], Kirill G. Fedorov[1,2], Stefan Pogorzalek[1,2], Qi-Ming Chen[1,2], Matti Partanen[1], Achim Marx[1], Frank Deppe[1,2,3], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik Department, TU München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

Phase-preserving amplification of quantum signals is a crucial part of many protocols in microwave quantum information processing, such as quantum teleportation or remote state preparation. Superconducting Josephson parametric amplifiers (JPA's) allow amplification close to the quantum limit, implying a fundamental bound of 1/2 for the maximal quantum efficiency η for narrow-band input signals. We demonstrate that this bound does not hold for broadband input signals. We find that $\eta = 70\%$ can be achieved by exploiting a JPA for amplification of broadband thermal signals. Furthermore, we study the noise properties of non-degenerate and degenerate amplification of two serially connected JPA's.

We acknowledge support by the Germany's Excellence Strategy EXC-2111-390814868, Elite Network of Bavaria through the program ExQM, and the European Union via the Quantum Flagship project QMiCS (Grant No. 820505).

FM 40.11 Tue 16:30 Tents

A sustainable sub-Kelvin cooling technology for quantum electronics — •Klaus Eibensteiner[1,2], Alexander Regnat[1,2], Jan Spallek[1,2], Tomek Schulz[1,2], Christopher Duvinage[1], Nico Huber[1], Carolina Burger[1], Anh Tong[1], and Christian Pfleiderer[1] — [1]Physik-Department, Technical University of Munich, Germany — [2]kiutra GmbH, Munich, Germany

Cooling devices providing temperatures well below 1 K are a key prerequisite for modern research and development, e.g. in materials science, quantum electronics and the cooling of sensors and detectors. Commercially available state-of-the art cooling solutions require typically the rare and costly helium isotope, helium-3. Here we present a versatile and compact demagnetization refrigerator for the cryogen-free, continuous generation of sub-Kelvin temperatures based on prevalent and affordable solid-state cooling media.

FM 41: Poster: Quantum Sensing

Time: Tuesday 16:30–18:30 Location: Tents

FM 41.1 Tue 16:30 Tents

Fast and high-fidelity motional state control of trapped ions — •Jan-Philipp Schröder, Matthias Wittemer, Frederick Hakelberg, Philip Kiefer, Daniel Rieländer, Ulrich Warring, and Tobias Schaetz — Department of Experimental Atomic, Molecular, and Optical Physics, University of Freiburg, Germany

Laser-cooled ions, trapped in radio-frequency potentials, are well established experimental systems for quantum simulations [1]. Here, we report on a hardware platform compound of Mg^+ ions in a linear rf Paul trap. We manipulate and couple the ions electronic (pseudo spin-$\frac{1}{2}$) and motional (bosonic) states. Via resolved sideband cooling they are initialized in their motional ground state. As recently demonstrated, we can real-time control the ion's storage potential and non-adiabatically evolve its ground state wavefunction into a squeezed motional state [2]. We make use of this quantum squeezed state by performing measurements of residual electric stray fields with enhanced sensitivity.

[1] H. Schmitz, et al., Appl. Phys. B (2009) 95: 195
[2] M. Wittemer, et al., arXiv:1903.05523 [quant-ph] (2019)

FM 41.2 Tue 16:30 Tents

Detecting the motion of mechanical oscillators with superconducting quantum interference devices — •K. Uhl[1], J. Hofer[2], J. Slater[2], C. Schneider[3], G. Kirchmair[3], O. F. Kieler[4], T. Weimann[4], M. Aspelmeyer[2], D. Koelle[1], and R. Kleiner[1] — [1]Physikalisches Institut and Center for QuantumScience (CQ) in Lisa+, Universität Tübingen, Germany — [2]Vienna Center for Quantum Science and Technology, University of Vienna, Austria — [3]Institute for Experimental Physics, University of Innsbruck, Austria — [4]Fachbereich Quantenelektronik, Physikalisch- Technische Bundesanstalt (PTB) Braunschweig, Germany

Levitating solid-state objects, like a superconducting particle in a magnetic trap or a cantilever with a superconducting strip, offer a unique approach to the realization of nano- or even micro-sized quantum systems with potentially minimal decoherence. In combination with cryogenic temperatures, the coherence times in the quantum mechanical ground state can be increased significantly. Our goal is to employ a superconducting quantum interferometer to gain information on position and oscillatory behavior of the levitated objects. To optimize magnetic coupling between oscillator and SQUID, we performed numerical simulations based on London equations and evaluated various SQUID designs. The results of the numerical simulations and experimentally determined SQUID performance will be presented.

FM 41.3 Tue 16:30 Tents

Chip-based magnetic traps for superconducting levitation of μm-sized particles — •Martí Gutierrez Latorre, David Niepce, Matthias Rudolph, and Witlef Wieczorek — Quantum Technology Laboratory, Chalmers University of Technology, Gothenburg, Sweden

Levitated mechanical resonators are a unique platform capable of reaching unrivaled performance in quantum-enhanced sensing and, potentially, in realizing macroscopic quantum superposition states. This is enabled by their expected ultra-low coupling to the environment, resulting in ultra-high mechanical quality factors. Furthermore, the trapping frequency of such a levitated resonator can be increased by exploiting high magnetic field gradients achievable via miniaturization. As a first step, we develop chip-based traps and particles for superconducting magnetic levitation. We present FEM simulations of integrated trap architectures for levitation of μm-sized particles. The force, potential energy and magnetic field on the levitated particles are calculated, showing that trapping frequencies of a few hundreds of kHz are readily achievable and that the corresponding mechanical motion can be detected via pick-up coils connected to high-sensitivity SQUIDs. We further demonstrate the fabrication of such integrated magnetic traps and superconducting particles made of Nb on Si substrates via conventional micro-fabrication techniques. Our results pave the way to observing and sensing superconducting levitated μm-sized particles at 4K.

FM 41.4 Tue 16:30 Tents

High-reflectivity AlGaAs-based on-chip optomechanical devices for quantum optics experiments — •Sushanth Kini M[1], Karim Elkhouly[1], Jamie Fitzgerald[2], Shu Min Wang[3], Phillippe Tassin[2], and Witlef Wieczorek[1] — [1]Quantum Technology Laboratory, Department of Microtechonolgy and Nanoscience, Chalmers University of Technology, Sweden — [2]Department of Physics, Chalmers University of Technology, Sweden — [3]Photonics Laboratory, Department of Microtechonolgy and Nanoscience, Chalmers University of Technology, Sweden

Cavity optomechanical devices exploit the interaction between light and mechanical motion for controlling mechanical resonators down to the quantum regime. A major challenge in the field remains access-

ing a strong interaction on the level of single quanta. The concept of multi-element optomechanics has been proposed to reach this regime. In the present work, we fabricate mechanical devices in an AlGaAs heterostructure with the goal to realise this concept. One of the requirements to achieve single photon strong coupling is to have highly reflective mechanical devices. Therefore, we pattern the mechanical devices with a photonic crystal that results in an out-of-plane reflectivity close to unity. We show results on simulation, fabrication and the optical and mechanical characterization of the optomechanical resonators. Our device concept should allow for a fully integrated realization of multi-element optomechanical system in the near future.

FM 41.5 Tue 16:30 Tents

Zerodur®-based optical setup for a transportable aluminium ion quantum logic optical clock — •Benjamin Kraus[1], Stephan Hannig[1], Ortwin Hellmig[2], Moritz Mihm[3], Patrick Windpassinger[3], and Piet O. Schmit[1,4] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Universität Hamburg, 20148 Hamburg, Germany — [3]Johannes Gutenberg-Universität Mainz, 55122 Mainz, Germany — [4]Leibniz Universität Hannover, 30167 Hannover, Germany

We present Zerodur®-based optical components for applications in a transportable aluminium ion quantum logic optical clock.

A transportable optical ion clock requires a compact and robust setup. These requirements are fulfilled by rigid Zerodur®-based breadboards[1] as shown for sounding rocket missions. We present a distribution board, where light with the wavelengths 375 nm, 397 nm, 422 nm 854 nm and 866 nm is coupled into an LMA fibre. The temperature and acceleration stability of the setup will be characterized and compared to a classical optical setup. As a second step, we show a design study of a Zerodur®-based double pass AOM setup for a wavelength of 397 nm. Both setups are developed for a transportable aluminium ion quantum logic optical clock. However, such Zerodur® breadboards could become part of robust laser systems for a broad range of quantum optics experiments in the future.

[1] Mihm, Moritz, et al, “ZERODUR® based optical systems for quantum gas experiments in space.” Acta Astronautica 159, 166-169 (2019); https://doi.org/10.1016/j.actaastro.2019.03.060

FM 41.6 Tue 16:30 Tents

Zerodur based optical and vacuum systems for the field application of quantum technologies — •Moritz Mihm[1], Sören Boles[1], Jean Pierre Marburger[1], André Wenzlawski[1], Ortwin Hellmig[2], and Patrick Windpassinger[1] — [1]Institut für Physik, JGU Mainz — [2]ILP, UHH Hamburg

Numerous quantum technologies are used in extreme environments. The operation outside the laboratory makes high demands on the experiment and especially the laser system regarding miniaturization and power consumption as well as mechanical and thermal stability.

We have developed a technology for stable fiber-coupled optical modules, consisting of Zerodur based optical benches with free-space optics. Our toolkit allows the assembly of modules e.g. for laser frequency stabilization as well as distribution, overlap and switching of laser beams. Developed in the context of atom interferometry with ultracold atoms in space, suitability of the technology has been demonstrated in the successful sounding rocket missions FOKUS, KALEXUS and MAIUS.

I will present the fundamentals of our technology and discuss current efforts to build Zerodur based vacuum systems. The combination of miniaturized and stable vacuum chambers with our laser system technology allows the development of integrated quantum optical systems for applications outside laboratory environments.

Our work is supported by JGU Stufe 1 Funding and the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers 50 WP 1433 and 50 WP 1703.

FM 41.7 Tue 16:30 Tents

Design and optimization of a confocal microscopy setup for the investigation of nitrogen-vacancy centres in diamond — •Lukas Götz, Tingpeng Luo, Felix Hahl, and Jan Jeske — Fraunhofer IAF, Freiburg, Germany

Nitrogen vacancy centres in diamond are a promising and widely employed system in a variety of applications as a highly sensitive or nanoscale magnetic field sensor. Diamond as a carrier material as well as the NV centre have to be characterized with high precision. In our work, we focus on crucial points and improvements in the design of a custom-built confocal microscope for this purpose.

We present a combined confocal setup for fluorescence maps, identification of single NVs, optical spectra, optically detected magnetic resonance (ODMR), and pulsed coherence time measurements of the NV centre. Our setup aims to combine flexibility with rigorous stability and fast measurements (collection efficiency and control). The setup presented here relies largely on fibres. In particular, the coupling into a fibre substitutes the confocal pinhole, and a fibre beam splitter allows for the Hanbury-Brown-Twiss (HBT) experiment. The stability and advantages of the fibre solution will be discussed.

FM 41.8 Tue 16:30 Tents

NV-doped diamond for ultrasensitive laser threshold magnetometry — Felix Hahl, Tingpeng Luo, Lukas Götz, Julia Langer, Volker Cimalla, and •Jan Jeske — Fraunhofer-Institut für Angewandte Festkörperphysik (IAF), Tullastr. 72, 79108 Freiburg, Germany

The concept of laser threshold magnetometry (LTM) suggests using nitrogen-vacancy (NV) centres in diamond as a laser medium to realise a magnetic-field dependent laser output and laser threshold. This could improve the sensitivity significantly to a theoretical shot-noise limit with NV-doped bulk diamond rivalling the best current sensors. While the evidence of stimulated emission in NV doped diamond is further motivation, an NV laser poses strong material demands.

We performed theoretical calculations of the laser threshold, required pump power and loss rates and identified high NV density, combined with low absorption and birefringence the major challenges in the material properties of NV diamond for LTM. In order to tackle these we combine characterization methods of absorption, birefringence, nitrogen concentration and NV spin properties with chemical vapour deposition (CVD) growth of diamond and have preliminary results on highly nitrogen-doped CVD diamonds.

Based on our simulations we furthermore developed a cavity design with a geometry to minimize power requirements for lasing. The cavity is designed to characterize diamond samples through cavity loss rates, measure amplification and work towards lasing with NV centres.

FM 41.9 Tue 16:30 Tents

Sensitive DC magnetometry with nitrogen-vacancy center ensembles in diamond — •Chen Zhang[1], Vadim Vorobyov[1], Junichi Isoya[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Research center for knowledge communities, University of Tsukuba, Japan

Negatively charged nitrogen vacancy (NV-) center ensembles in diamond has demonstrated a great potential with achieving a subpicotesla magnetic field sensitivity (T. Wolf, 2015), which makes it a competitive candidate for various applications in bio-sensing and brain-science. In order to take full advantages of the diamond magnetometer, the DC field sensitivity need to be further improved to meet the requirements. In this work, 13C purified diamonds with an extraordinary T2* time of 10 μs and T2 time of 200 μs were used, demonstrating a ~80 kHz continuous wave optically detected magnetic resonance (CW-ODMR) linewidth and ensuring the high DC sensitivity limit. A BaLn2Ti4O12 wide band MW resonator is used to provide homogeneous MW field for multi-frequency MW driving of all the hyperfine lines as well as NV-ensembles of different orientations (P. Kapitanova, 2018; C. Zhang, 2018), in order to improve the fluorescence contrast which is linearly related to the sensitivity limit. Balanced detection and lock-in amplifier are used to suppress optical fluctuation and to figure out the noise floor of the setup. By all the techniques we present, we are reaching a DC magnetic field sensitivity of 15 pT/Hz^(1/2) and targeting to 10 pT/Hz^(1/2), which could meet the basic requirement for the MEG signal sensing with a distance of 1 cm from the brain surface.

FM 41.10 Tue 16:30 Tents

Cavity design and simulations for a NV centre laser and laser threshold magnetometry — •Felix Hahl, Lukas Götz, and Jan Jeske — Fraunhofer-Institut für Angewandte Festkörperphysik IAF, Freiburg, Germany

The concept of laser threshold magnetometry (LTM) suggests to use nitrogen-vacancy (NV) centre in diamond as a laser medium to realise a magnetic-field dependent laser output and laser threshold. This could improve the sensitivity significantly to a theoretical shot-noise limit with NV doped bulk diamond of fT/sqrt(Hz). The first step for realising a lasing system out of diamond was the evidence of stimulated emission of NV doped diamond. However, to achieve a lasing system the diamond needs to be highly NV doped and of a good optical quality, meaning minimizing the absorption caused by nitrogen defects and minimizing deviations from perfect single crystal structure, causing birefringence. Via simulations, we have estimated the cavity and pump power requirements to realise NV lasing based on measured material properties. We furthermore quantify how material improvements such as reduced absorption or increased NV density can significantly lower required pump powers. Based on the simulations we present a macroscopic cavity design for two purposes: precise characterisation of material through cavity-enhanced absorption spectroscopy measurements and our work towards lasing with NV centres. This is the major step towards LTM, which would strongly improve magnetic sensing for medical applications such as magnetoencephalography.

FM 41.11 Tue 16:30 Tents

VECSEL system for quantum manipulation of trapped magnesium ions — •Till Rehmert[1,2], Maximilian J. Zawierucha[2], Jan Christoph Heip[2], Fabian Wolf[2], and Piet O. Schmidt[1,2] — [1]Leibniz Universität Hannover, Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Optical pumped vertical-external-cavity surface-emitting lasers (VECSEL) have been demonstrated to be a promising technology for applications ranging from spectroscopy to quantum computing and quantum simulation [1]. VECSELs combine compact size and high optical power and the advantage of a wide wavelength coverage.

We employ a gain mirror from Vexlum Ltd consisting of GaInAs/GaAs quantum wells strained with GaAsP layers to achieve a centre wavelength of 1118 nm with a tuning range of 30 nm [2]. With an optical-to-optical efficiency of approximately 25% we achieve up to 5 watts of optical output power.

For quantum logic spectroscopy with trapped magnesium ions the 1118 nm light has to be frequency doubled twice to access our target wavelength of 280 nm. We expect an overall UV output power of 20 mW and a laser linewidth of tens of MHz which allows us to use it for Doppler cooling, repumping and Raman transition.

[1] Burd et al, Optica Vol.3, No. 12 (2016)
[2] Ranta et al, J. Cryst. Growth 355, 4-9 (2011)

FM 41.12 Tue 16:30 Tents

Optical dipole trapping in a drop tower experiment — •Marian Woltmann[1], Christian Vogt[1], Sven Herrmann[1], Claus Lämmerzahl[1], and the PRIMUS Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM) — [2]LU Hannover, Institute of Quantum Optics

The application of an atom interferometer in weightlessness offers the potential of largely increased interrogation times. As the interferometers sensitivity scales with the square of the free evolution time, the sensitivity is significantly increased. While most such microgravity based experiments use magnetics traps formed by an atom chip, we develop an optical dipole trap for use in weightlessness as an alternative source of cold atom ensembles. Optical dipole traps offer unique advantages like an improved symmetry of the trapping potential and the accessibility of Feshbach resonances. Using a 10W trapping laser at a wavelength of 1949nm, we implement a dual species (Rb and K) cold atom experiment for use in the drop tower in Bremen. With our poster, we will give an overview of the experiment and report on the latest results for the evaporation from an optical dipole trap in microgravity. The PRIMUS-project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 1642.

FM 41.13 Tue 16:30 Tents

Characterisation of wavelength-shifted Photon Pairs for Quantum Imaging Applications — •Florian Herbst[1], Florian Elsen[2], Bernd Jungbluth[2], Hans-Dieter Hoffmann[2], and Reinhart Poprawe[1,2] — [1]Chair for Laser Technology RWTH Aachen University, Aachen, Germany — [2]Fraunhofer Institute for Laser Technology, Aachen, Germany

The mid-infrared spectral range (MIR) is gaining more and more importance for analytics and research, e.g. via spectroscopy and imaging applications. Such techniques usually require both photon generation and photon detection. By utilising spontaneous parametric down-conversion (SPDC), G. B. Lemos et al. (Nature, 2014) have demonstrated the feasibility of imaging with undetected photons. This even allows for imaging in spectral ranges for which detectors are not available. While many previous works that employed this scheme relied on visible (VIS) and near-infrared (NIR) photons, we aim to expand this scheme by using MIR photons instead of NIR ones. For this, our investigations started by examining emission properties of wavelength-shifted photon pairs generated from SPDC in the experimentally easily accessible regime of VIS and NIR, focussing on time-wise correlations. This source was then used to build an NIR-imaging device. With investigations going on, these setups serve as benchmarks for the prospective SPDC-based MIR-imaging prototype.

FM 41.14 Tue 16:30 Tents

Modeling and simulation of SPDC sources for quantum imaging experiments — •Felix Riexinger[1,2], Patricia Bickert[1], Björn Haase[1,2], Mirco Kutas[1,2], Daniel Molter[1], Michael Bortz[1], and Georg von Freymann[1,2] — [1]Fraunhofer-Institute for Industrial Mathematics ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), 67663 Kaiserslautern, Germany

Quantum imaging is a promising method to improve imaging applications in many sectors. Most setups use nonlinear crystals pumped in the low-gain regime as a source for entangled photons. We developed and implemented a general model for these SPDC sources, taking into account the finite extent of the crystal. This model allows us to explore the source characteristics without relying on certain approximations.

To allow for a comparison with the experimental spectra we also modeled the optical system of the experiment. The model agrees well with experimental results for various lithium niobate crystals pumped at 660nm. We applied our model to predict relevant quantities for imaging experiments, e.g., visibility and field of view.

Understanding the influence of the source parameters on the emitted photons allows for the design of optimal sources leading to improved imaging setups. Our work is an important step towards an improved development cycle for quantum imaging experiments and applications.

FM 41.15 Tue 16:30 Tents

A quantum acousto-optical transducer based on induced coherence without induced emission — •Joel Schmidt, Raphael Nold, Tobias Linkewitz, Florian Kaiser, and Jörg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

Laser and fibre microphones are amongst the most sensitive sound recording devices. They enable applications such as interaction-free long-range sound recognition and espionage, intestinal medical exams and high-sensitivity hearing-aids. Quantum optical sensors can achieve performance beyond the classical shot noise limit, however, sampling rates are severely limited by the necessity of using photon number resolving detectors (PNRD). Here, we show how to perform quantum-enhanced optical phase sensing using entangled photon pairs that are created via induced coherence without induced emission. This removes the necessity for PNRDs and promises much higher sampling rates. Our goal is to make humans hear the quantum advantage by demonstrating a quantum optical microphone with sub-shot noise performance.

FM 41.16 Tue 16:30 Tents

Master equation for enseble of multilevel atoms — •Aleksei Konovalov, Andreas Buchheit, and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

The development of stable atomic clocks for quantum metrology requires an accurate knowledge of the spectroscopic properties of atomic ensembles. Line shifts due to quantum interference in the decay channels of single atoms are measurable [1] and shall be reliably described by a master equation formalism. In this work we present a master equation formalism which systematically includes the interference effects in the incoherent decay of an ensemble of multilevel atoms. This master equation has the Lindblad form. In the single-atom limit it can be reduced to the master equation for a single atom including the cross damping terms, which lead to quantum interference in dissipative process [2], while for two-level atoms it reproduces the well-known master equation for superradiance [3]. We determine the spectroscopic signals for an ensemble of Hydrogen atoms and show that the interplay between crossdamping terms and superradiant decay can lead to significant modifications of the line shapes.

References

[1] N. Kolachevsky, A. Beyer, L. Maisenbacher et al, AIP Conference Proceedings 1936, 020015 (2018) [2] Andreas Alexander Buchheit and Giovanna Morigi, PHYSICAL REVIEW A 94, 042111 (2016) [3] M. Gross, S. Haroche, Superradiance: an essay on the theory of collective spontaneous emission, PHYSICS REPORTS 93, No 5 (1982) 301-396

FM 41.17 Tue 16:30 Tents

Progress Towards an Al^+ Quantum Logic Optical Clock — Johannes Kramer[1], Fabian Dawel[1], •Nicolas Spethmann[1], Sara Panahandeh[1], and Piet Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

We present the status of our aluminum ion optical clock, based on a single $^{27}Al^+$ clock ion trapped together with a $^{40}Ca^+$ logic ion used for sympathetic cooling and quantum logic state readout. $^{27}Al^+$ provides a narrow clock transition and low sensitivity to external field shifts. A measurement of the trap temperature combined with numerical simulations allows us to bound the black-body radiation shift to smaller than 10^{-19}. Micromotion has been compensated to a level well below a fractional frequency uncertainty of 10^{-17}. We developed double-bright electromagnetically induced transparency (D-EIT) cooling as a novel, fast multi-mode ground state cooling technique. Using D-EIT we demonstrated for the first time ground-state cooling of all three motional degrees of freedom of a trapped $^{40}Ca^+$ ion within a single, short cooling pulse. Extrapolating from these results, we expect a fractional second order Doppler shift from residual motion of an Al^+/Ca^+ crystal of well below 10^{-18}. We will present results of reading out the state of $^{27}Al^+$ using quantum logic and progress towards quantum logic spectroscopy of the clock transition.

FM 41.18 Tue 16:30 Tents

Control of the spin relaxation in hot atomic ensembles for spatially resolved magnetometry — •Victor Lebedev, Stefan Hartwig, and Thomas Middelmann — PTB 8.21, Abbestr. 2-12, D-10587 Berlin, Germany

Spin relaxation, both longitudinal and transverse, plays an essential role in quantum sensors based on thermal spin-polarized vapor. In case of magnetic field sensor, balance between pumping on one side, and collisional and inhomogeneous broadening, on the other side, defines the sensitivity and spatial resolution of the sensing atomic subensemble. Recent developments in optical pumping techniques open new ways in such ensemble preparation, using diode lasers with high spatial and temporal coherence, spatially resolved and high-bandwidth light-polarization instrumentation and fast intelligent control electronics. We investigate various approaches for the local spin preparation, ranging from conventional pump-probe techniques to structured light pumping and spin polarization imaging. We discuss fundamental and technical limitations of such systems and their possible applications. Our pilot results on inhomogeneous broadening suppression in alkali vapor magnetometer will be presented at the meeting.

FM 41.19 Tue 16:30 Tents

Microwave Raman Transitions in the Multilevel Electronic Ground State of the NV Center — •Sascha Neinert[1,2], Florian Böhm[1,2], Niko Nikolay[1,2], Nikola Sadzak[1,2], Bernd Sontheimer[1,2], and Oliver Benson[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Germany — [2]IRIS Adlershof, Humboldt-Universität zu Berlin, Germany

The nitrogen-vacancy (NV) center in diamond is the most prominent defect in diamond due to its outstanding properties as a quantum light source and its manipulable electron spin. NV applications range from quantum information processing to high sensitivity nanomagnetometry.

We discuss our recent progress of the population swapping via microwave Raman transitions in the multilevel electronic ground state of a single NV center. The here presented scheme relies on the polarization of the nuclear spin of the NV center at low magnetic fields. This hyperpolarization of the NV center's intrinsic nitrogen-15 can be achieved by recursive polarization via the NV center's electron spin [1,2].

[1] Pagliero, D. et al., Appl. Phys. Lett. 105.24 (2014): 242402.
[2] Chakraborty, T. et al., NJP 19.7 (2017): 073030.

FM 41.20 Tue 16:30 Tents

100 kHz Attosecond Pulse Source for Coincidence Spectroscopy — •Dominik Ertel[1], Anna-Lena Jäger[1], Samuel Kellerer[1], Matteo Moioli[1], Hamed Ahmadi[1], Fabio Frassetto[2], Luca Poletto[2], and Giuseppe Sansone[1] — [1]Institute of Physics, University of Freiburg, Stefan-Meier-Str. 19, 79104 Freiburg, Germany — [2]CNR-Institute of Photonics and Nanotechnologies (CNR-IFN), via Trasea 7, 35131 Padova, Italy

Attosecond coincidence spectroscopy builds a powerful tool to study ultrafast phenomena in atoms and molecules. Here, we present an attosecond XUV pulse source with high repetition rates up to 100 kHz, developed for photoelectron/-ion coincidence spectroscopy. Near infrared (NIR) laser pulses with up to 400 μJ pulse energy and a pulse duration of around 300 fs are temporally compressed using a gas-filled hollow-core fiber. Afterwards we use these pulses to generate trains of attosecond pulses via high-order harmonic generation in noble gases. RABITT (Reconstruction of Attosecond Beating by Interference of Two-photon Transitions) based coincidence pump-probe spectroscopy is performed using a reaction microscope. The long acquisitions measurements require an ultrastable control of the delay between pump (XUV) and probe (NIR). A novel non-interferometric delay line enables intrinsic delay synchronisation within a few attoseconds over several hours. Our unique coincidence spectroscopy setup will enable the investigation of electronic and coupled electronic-nuclear dynamics. Thus, shedding new light on the first instants of photoionization and subsequent nuclear dynamics in small size molecules.

FM 41.21 Tue 16:30 Tents

State-resolved photoionization time delays in CF_4 using two-color coincidence laser spectroscopy — •s. h. Ahmadi[1,2], m. moioli[1], e. plesiat[3], a. palaciosp[3], m. reduzzi[2], a. Stenftlebens[4], f. frassetto[5], l. poletto[5], f. bragheri[6], r. osellame[6], p. decleva[7], c. d. schröter[8], r. moshammer[8], t. pfeifer[8], f. martin[3], and g. sansone[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [2]Dipartimento di Fisica, Politecnico, Milano, Italy — [3]Departamento de Qumica, Universidad Autónoma de Madrid, Madrid, Spain — [4]Institute of Physics and CINSaT, University of Kassel, Kassel, Germany — [5]Istituto di Fotonica e Nanotecnologie, CNR, Padova, Italy — [6]Istituto di Fotonica e Nanotecnologie, CNR, Milano, Italy — [7]Dipartimento di Scienze Chimiche e Farmaceutiche, Universitá di Trieste, Trieste, Italy — [8]Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Photoionization time delays between photoelectrons leaving CF_4^+ in its X $^2T_1$ and C $^2T_2$ states are experimentally measured and simulated using pump(XUV)-probe(IR) coincidence laser spectroscopy in the photon-energy range of 20-46 eV. We acquired the photoelectron spectra as a function of the relative delay between the XUV and IR pulse. Simulations are performed by numerically solving TDSE using density functional theory. The results suggest complex photoionization dynamics on an attosecond time scale between photoelectrons leaving these two electronic states. The molecular-frame angular dependence of the photoelectrons can also be accessed and will be discussed.

FM 41.22 Tue 16:30 Tents

Attosecond pulse generation at FERMI FEL — •Praveen Kumar Maroju — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg Hermann-Herder-Straße 3, 79104 Freiburg, Germany

Extreme ultraviolet table-top sources based on high-order harmonic generation (HHG) in gases deliver attosecond pulses (trains and isolated), but at rather low photon flux, due to the intrinsic low-conversion efficiency of the HHG-process. On the other hand, Free Electron Lasers (FELs) deliver femtosecond pulses with energies up to the mJ-level. However, the majority of FELs operating in the XUV and X-ray spectral range are based on the self-amplified spontaneous emission (SASE) mechanism, resulting in a poor longitudinal coherence. Recently the temporal coherence between two harmonics of the same seed wavelength, was demonstrated at the seeded-FEL FERMI[1]. This experiment suggested the possibility to synthetize a comb of phase-locked frequencies, which should correspond in the time domain to a train of attosecond pulses. In this work we demonstrate for the first time the attosecond pulse train generation and characterisation at the FERMI FEL along with independent amplitude and phase control.

References:

1. K. C. Prince et al., Nat. Photonics 10, 176, (2016)

FM 41.23 Tue 16:30 Tents

Quantum Sensing of Microwave Magnetic Fields with Sensor Unlimited Resolution — •Jonas Meinel, Vadim Vorobyov, Boris Yavkin, Durga Dasari, and Jörg Wrachtrup — Universität Stuttgart, 3. Physikalisches Institut, Stuttgart, Germany

Diamond quantum sensors are sensitive to weak microwave magnetic fields resonant to the transitions in the quantum system [1]. The state of the art sensing protocols improved the sensors spectral resolution beyond T2* and are ultimately limited by T1. Here we demonstrate that heterodyne detection methods, widely applied for quantum sensing of radio frequency fields [2], could be extended to the microwave regime. We use phase control of the initial pulses of the sequences, which allows to create correlations between consecutive measurements. We show experimentally a Fourier limited linewidth for a single frequency source. Additional we resolve two 500 Hz separated frequencies demonstrating a corresponding spectral resolution beyond coherence time of the sensor. This work allows to sense ultra long coherent microwave fields, e.g. maser radiation, using a quantum sensor with a wide tuning range covering the full microwave spectrum (1 - 100 GHz).

[1] Joas, Timo, et al. "Quantum sensing of weak radio-frequency signals by pulsed Mollow absorption spectroscopy." Nature communications 8.1 (2017): 964. [2] Schmitt, Simon, et al. "Submillihertz magnetic spectroscopy performed with a nanoscale quantum sensor." Science 356.6340 (2017): 832-837.

FM 41.24 Tue 16:30 Tents

Nanodiamonds in three-dimensional direct-laser-written Waveguides for On-Tip-Sensing — •Jonas Gutsche[1,2], Stefan Dix[1], Alexander Landowski[1], and Artur Widera[1,2] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Kaiserslautern, Germany

Waveguide-coupled sensors have several applications such as magnetometry, electrometry or thermometry, harnessing the resolution of nano-sized probes as well as tight light control in macroscopic waveguide networks.

We present the incorporation of nanodiamonds into direct-laser-written (DLW) three-dimensional photonic structures. The nanodiamonds house ensembles of 10^3 nitrogen vacancy (NV) centers, acting as probes that can be read-out optically. Guided by on-chip waveguide structures and three-dimensional out of plane couplers integrated nanodiamonds are addressed and read out using a single microscope objective from below the substrate. We show optically detected magnetic resonance spectra together with Rabi oscillations on an effective two-level system in waveguide-embedded nanodiamonds. We compare their performance with free-space emission and numerical simulations.

Based on these structures, we show our approach to utilize DLW for further miniaturization of components needed for NV-magnetometry to a fiber tip. This approach paves the way for on-tip three-dimensional structures leading to a single-device endoscope for optically integrated spin-based sensing.

FM 41.25 Tue 16:30 Tents

Quantum sensing with superconducting microwave circuits — •Matti Partanen[1], Kirill G. Fedorov[1,2], Stefan Pogorzalek[1,2], Michael Renger[1,2], Qi-Ming Chen[1,2], Achim Marx[1], Frank Deppe[1,2,3], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

Quantum mechanics offers intriguing opportunities for sensing applications with accuracies beyond the classically obtainable limits. An especially interesting approach is based on using entangled microwave photons for radar applications. Here, we discuss a novel frequency-degenerate scheme for quantum sensing with superconducting microwave circuits. The same microwave regime is utilized in conventional radars owing to the transparency window of the atmosphere. Hence, our scheme suffers no conversion losses and, therefore, is promising for future real-world applications.

We acknowledge the support by the Germany's Excellence Strategy EXC-2111-390814868, Elite Network of Bavaria through the program ExQM, and the European Union via the Quantum Flagship project QMiCS (Grant No. 820505).

FM 41.26 Tue 16:30 Tents

Optimal sensing with NV Centers in Diamond. — •Nimba Oshnik Pandey and Elke Neu — Universität des Saarlandes, Saarbrücken, Germany

Quantum optimal control theory has been extensively utilized in fields like NMR, atomic/molecular physics, Quantum computation to overcome various limitations posed by the experimental conditions and setup [1]. In this work we aim to develop and test nano-photonic diamond scanning probe structures containing Nitrogen Vacancy centers and implement optimal control fields to improve the sensitivity and robustness of the quantum sensing protocols.

NV centers in diamond have been well studied and utilized as quantum sensors owing to their long spin coherence times, and also the spin-dependent fluorescence. Using such atomic scale single-spin sensors in a scanning probe geometry enables sensing and imaging with maximum spatial resolution; in principle down to order of few nm [2]. We aim to develop control techniques using quantum optimal control algorithms for enhancing the full imaging capability, and to achieve desired robustness against control field amplitude variations and experimental limitations, further test optimization approaches for spin manipulation followed by first proof of principle experiments on optimized sensing.

[1] Glaser, S., Boscain, U., Calarco, T. et al. Eur. Phys. J. D (2015) 69: 279

[2] Fuchs et. al. New J. Phys. 20 125001. 2018.

FM 41.27 Tue 16:30 Tents

Some practical considerations of quantum inertial sensors in navigation — •Benjamin Tennstedt and Steffen Schön — Institut für Erdmessung, Leibniz Universität Hannover, 30167 Hannover

In this contribution we will present some application cases for atom interferometry as an inertial sensor for navigation purposes. While there are more complex attempts for a six-degrees of freedom setup [2], which have not yet been realized and tested in a navigation filter framework, a simple setup of two counterpropagating interferometers, eg. [3], is already sufficient for specific navigation purposes like estimating the 2D-position and orientation of a non-holonomic vehicle on a plane, like it is the case with driverless transportation vehicles.

For 3D-navigation, additional supporting sensors are needed. By using error models based on real data [4] and our navigation simulation framework, we will point out some concrete examples and use-cases of the proposed setup in navigation, while also giving a hint on the specifications like sensitivity and stability the new sensors need to provide.

[1] M. Kasevich and S. Chu (1991), Atomic interferometry using stimulated Raman transitions, Phys. Rev. Lett. 67, pp. 181-184.

[2] B. Canuel et al. (2006), Six-axis inertial sensor using cold-atom interferometry, Phys. Rev. Lett. 97, 010402:1-010402:4.

[3] A. Gauguet et al. (2009), Characterization and limits of a cold atom Sagnac interferometer, <hal-00403630v3>.

[4] P. Berg et al. (2015), Composite-Light-Pulse Technique for High-Precision Atom Interferometry, Phys. Rev. Lett. 114, 063002.

FM 41.28 Tue 16:30 Tents

T^3-interferometry — •Matthias Zimmermann[1], Maxim A. Efremov[1], Omer Amit[2], Yair Margalit[3], Frank A. Narducci[4], Wolfgang P. Schleich[1], and Ron Folman[2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, Ulm, Germany — [2]Department of Physics, Ben-Gurion University of the Negev, Be'er Sheva, Israel — [3]Research Laboratory of Electronics, MIT-Harvard Center for Ultracold Atoms, Department of Physics, MIT, Cambridge, USA — [4]Department of Physics, Naval Postgraduate School, Monterey, USA

By exploiting the Kennard phase [1], we have proposed an atom interferometer [2] probing a linear potential and having a phase shift that scales as T^3, in contrast to conventional atom interferometers with a phase scaling as T^2, where T denotes the total interferometer time.

In this scheme we make use of two magnetic sensitive atomic states $|1\rangle$ and $|2\rangle$ leading to the respective state-dependent accelerations a_1 and a_2. Based on this work [2] a Stern-Gerlach interferometer [3] has been constructed which reveals the pure cubic phase scaling and represents the first atom optics observation of the Kennard phase. As this device does not require light pulses and its accumulated phase is very sensitive to magnetic fields, it may serve as a unique probe for magnetic surface properties.

[1] G. Rozenman et al., *Phys. Rev. Lett.* **122**, 124302 (2019)
[2] M. Zimmermann et al., *Appl. Phys. B* **123**, 102 (2017)
[3] O. Amit et al., submitted to *Phys. Rev. Lett.* (2019)

FM 42: Poster: Quantum Computation

Time: Tuesday 16:30–18:30 Location: Tents

FM 42.1 Tue 16:30 Tents

A generalized search algorithm for quantum reinforcement learning — •Sabine Wölk, Arne Hamann, and Hans J. Briegel — Institut für Theoretische Physik, Universität Innsbruck, 6020 Innsbruck, Austria

Grover's search is a well-known example of a quantum algorithm that provides a computational speedup with respect to the best classical counterpart. Among its several applications, Grover's search has been used also in quantum machine learning and specifically to speed up algorithms for reinforcement learning. However, the search space in reinforcement learning tasks is not necessarily static, that is, the length of a single entry, as well as the number of entries and the target space are flexible. This represents a critical issue for the exploration stage during learning. Here, we propose a generalization of Grover's search algorithm to monotonically increasing search spaces that is beneficial to tackle this issue in quantum reinforcement learning.

FM 42.2 Tue 16:30 Tents

Quantum Approximate Optimization for Industry Use Cases — •David Headley[1,2] and Frank Wilhelm-Mauch[2] — [1]Daimler AG, Stuttgart, Germany — [2]Universität des Saarlandes, Saarbrücken, Germany

The Quantum Approximate Optimization Algorithm (QAOA) is one of several quantum algorithms that may be capable of outperforming classical algorithms using a quantum computer without full quantum error correction. In this work, we explore the applicability of QAOA to use cases from industry. We consider techniques to pre-satisfy constraints and mix within constraint-satisfying sub-spaces and show how some problems can be pre-compiled to smaller, maximally hard subproblems. Methods such as these will allow quantum computers that are small, noisy, and connectivity-limited to provide greatest performance.

FM 42.3 Tue 16:30 Tents

Neural Decoders for the Toric Code — •Thomas Wagner, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität Düsseldorf, Institute for Theoretical Physics 3

Surface codes are a promising method of quantum error correction. However, their efficient decoding is still a problem. Recently, approaches based on machine learning techniques have been proposed by Torlai and Melko, as well as Varsamopoulos et al. A significant problem is that these methods require large amounts of training data even for relatively small code distances. The above-mentioned methods were tested on the rotated surface code which encodes one qubit. Here, we show they are viable even for the toric surface code which encodes two qubits. Furthermore, we explain how symmetries of the toric code can be exploited to reduce the amount of training data that is required to obtain good decoding results.

FM 42.4 Tue 16:30 Tents

Performance of trapped-ion based quantum error correction under crosstalk noise. — •Pedro Parrado Rodriguez, Ciaran Ryan-Anderson, and Markus Muller — Swansea University,Singleton Park, Swansea SA2 8PP, United Kingdom

Protecting quantum information from errors is essential for large-scale quantum computation. In this work, we study the performance of a distance-3 color code in a trapped ions setup, with particular focus on the effects of crosstalk errors and the different ways to suppress them.

FM 42.5 Tue 16:30 Tents

Neural Network Decoders for Topological Codes — •Kai Meinerz and Simon Trebst — Institute for Theoretical Physics, Cologne

Currently, topological error correction codes, especially the surface code, are the most achievable roadmap for large-scale fault-tolerant quantum computation. For the realization it is of importance to obtain fast and flexible decoding algorithms for these codes. Using neural networks, it is possible to learn the possibility distribution of errors in an error correcting code and in addition, these distributions can be traced back to the syndrome of the corresponding errors. We present various implementations of such an algorithm that can be applied to any stabilizer code. We demonstrate the decoders on the well-known two dimensional toric code.

FM 42.6 Tue 16:30 Tents

Gaussian Sums on the IBM Q Experience — •Alexander Wolf[1] and Wolfgang Schleich[1,2] — [1]Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany — [2]Institute for Quantum Science and Engineering (IQSE), Department of Physics and Astronomy, Texas A&M University, College Station, TX 77843, USA

Using the IBM Quantum Experience we investigate two qubits implementing a state which resembles a special case of a Gaussian sum. That state is a superposition of the four two-qubits basis states with phases rising quadratically in the summation index. Hence, measuring this state in the superposition basis yields the modulus squared of the sum hidden within the statistics of multiple runs. We construct an explicit gate sequence and run it for different time parameters that determine the phases. Subsequently a one-parameter Kraus decomposition is used to explain the difference between results of the quantum and classical calculation.

FM 42.7 Tue 16:30 Tents

Neural Networks for Reconstructing Quantum Gas Microscope Images — •Bastian Lunow, Niklas Käming, Andreas Kerkmann, Michael Hagemann, Mathis Fischer, Klaus Sengstock, and Christof Weitenberg — ILP Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Quantum gas microscopes allow to image single atoms in optical lattices and therefore give a new window into many-body physics with microscopic access. One challenge is to reconstruct the occupation of the atoms on the lattice from finite fluorescence signal, even when the lattice sites are not fully optically resolved by the imaging system. Reconstruction algorithms allow to reconstruct them anyway. It has already been shown that this can be done with conventional methods, but we hope to achieve better results by using neural nets which are known to be efficient in extracting features from image data. Here we investigate the use of machine learning techniques in order to improve upon the conventional reconstruction algorithms with the promise to yield a faithful and faster reconstruction already for lower fluorescence counts. Using the concrete example of a triangular pinning lattice, we focus on realistic parameters for lithium atoms. Fruitful architectures include variational autoencoders and the use of weight initializations. These approaches would open a path to applying quantum gas microscopes to more general setup and more exotic atomic species.

FM 42.8 Tue 16:30 Tents

Investigating ultracold interactions between Ba^+ ions and Li atoms — •Pascal Weckesser, Fabian Thielemann, Daniel Hoenig, Isabelle Lindemann, Florian Hasse, Leon Karpa, and Tobias Schaetz — Physikalisches Institut, Albert-Ludwigs-Universitaet, Germany

The interplay of ultracold atoms and ions has recently gained interest [1], due to its wide applications in quantum simulations of solid state systems [2] as well as in quantum computing [3]. In order to implement a reliable atom-ion platform, it is necessary to prepare the mixture at ultracold temperatures. Optical trapping of ions [4] provides a new pathway to achieve these ultracold atom-ion mixtures, as it overcomes the intrinsic micromotion heating effects of a conventional Paul trap [5].

In this poster we present our experimental hybrid-setup combining individual $^{138}Ba^+$ ions in a linear Paul trap with ^6Li atoms in a crossed optical dipole trap. First reaction measurements between the two constituents will be shown. We further analyse elastic collisions leading to possible cooling within the Paul trap and discuss its current limitations. In the future we want to overcome these limitations by confining both species in a combined optical dipole trap.

[1] A. Haerter et al., Cont. Phys., Vol. 55, issue 1, pages 33-45 .
[2] U. Bissbort et al., Phys.Rev.Lett. 111.8 (2013): 080501.
[3] Doerk et al., Phys. Rev. A 81.1 (2010): 012708.
[4] T. Schaetz, Journal of Physics B: 50.10 (2017): 102001.
[5] M.Cetina et al., Phys.Rev.Lett. 109,253201 (2012)

FM 42.9 Tue 16:30 Tents

Rapid counter-diabatic and inhomogeneous sweeps in lattice gauge adiabatic quantum computing — •Andreas Hartmann[1] and Wolfgang Lechner[2] — [1]Institute for Theoretical, University of Innsbruck, A-6020, Austria — [2]Institute for Theoretical, University of Innsbruck, A-6020, Austria

We present a coherent counter-diabatic quantum protocol to prepare ground states in the lattice gauge mapping of all-to-all Ising models (LHZ) with considerably enhanced final ground state fidelity compared to a quantum annealing protocol. We make use of a variational method to find approximate counter-diabatic Hamiltonians that has recently been introduced by Sels and Polkovnikov [Proc. Natl. Acad. Sci. 114, 3909 (2017)]. The resulting additional terms in our protocol are time-dependent local on-site y-magnetic fields. A single free parameter is introduced which is optimized via classical updates. The protocol consists only of local and nearest-neighbor terms which makes it attractive for implementations in near term experiments.

We further present an inhomogeneous driving protocol in LHZ with modified transverse fields with improved ground state fidelity and enlarged minimal energy gaps. The inhomogeneously driven transverse field introduces an additional time-dependent parameter that improves the efficiency of the method. For the 2D lattice gauge model LHZ we analytically derive the free energy term and numerically verify it.

FM 42.10 Tue 16:30 Tents

Wigner Crystals in Two-Dimensional Materials as a Platform for Quantum Simulation — •Johannes Knörzer[1], Martin J. A. Schuetz[2], Geza Giedke[3,4], Richard Schmidt[1], Dominik S. Wild[1], Kristiaan de Greeve[2], Mikhail D. Lukin[2], and J. Ignacio Cirac[1] — [1]Max-Planck-Institut f. Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Physics Department, Harvard University, Cambridge, MA 02318, USA — [3]Donostia International Physics Center, Paseo Manuel de Lardizabal 4, E-20018 San Sebastian, Spain — [4]Ikerbasque Foundation for Science, Maria Diaz de Haro 3, E-48013 Bilbao, Spain

We analyze and characterize Wigner crystals in two-dimensional semiconductors and highlight their suitability as a platform for quantum information processing. Self-assembled crystals constitute a rich playground of quantum many-body physics. In particular, Wigner crystals are prime candidates for the realization of regular electron lattices with minimal requirements on external control and electronics. In agreement with previous works, we find that transition metal dichalcogenides (TMDs) offer an ideal platform for the observation of quantum Wigner crystals, even at finite temperature and residual disorder. Here we demonstrate how these systems can be used to investigate interacting spin networks. Owing to their unique electronic and optical properties, we find that those semiconductors may allow for an an all-optical non-destructive read-out of Wigner crystals.

FM 42.11 Tue 16:30 Tents

Superfluid phases of long-range interacting bosons — •Rebecca Kraus[1], Shraddha Sharma[1], Krzysztof Biedroń[2], Jakub Zakrzewski[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, Saarbrücken, Germany — [2]Instytut Fizyki imienia Mariana Smoluchowskiego, Uniwersytet Jagielloński, Kraków, Poland

The quantum statistical mechanics of long-range interacting systems is to large extent unexplored. The simulation in the laboratory using cold atom systems would allow one to test predictions and gain understanding on a problem, which is often intractable numerically. In this work we theoretically analyse the interplay of long-and short-range interactions on the onset of superfluidity in a gas of bosons in an optical lattice. We first show that long-range interactions give rise to additional hopping terms which depend nonlineary on the onsite density, and which have different forms depending on the range of the interactions. We then focus on van-der-Waals and on dipolar interactions in a quasi one dimensional geometry. In this regime superfluid phases have been predicted, which have different properties as a function of the density and of the strength of the interactions. We characterize their stability and properties by means of DMRG numerical simulations. We then compare our predictions to the mean-field predictions of the superfluid phases of all-connected atoms, as for ultracold atoms in optical resonators. Our study is performed using experimental accessible parameters, our predictions can be verified in existing experimental setups.

FM 42.12 Tue 16:30 Tents

Interplay between phase transitions and excitation dynamics in Coulomb crystals — •Lars Timm[1], Tanja E. Mehlstäubler[2], Luis Santos[1], and Hendrik Weimer[1] — [1]Institute for theoretical physics, Leibniz University, Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

In the last decade the field of energy transport and thermodynamics in low-dimensional systems regained interest. Main motivation for these studies is the question which essential processes lead to the phenomenologically established Fourier's law.

Therefore, simple low-dimensional lattice models with various interactions and external potentials have been developed. Heat transport turned out to be not trivial at all in these systems. Diverging thermal conductivity and the lack of temperature gradients pose clear contrasts to Fourier's law.

An excellent system to study thermodynamics, in arbitrary dimensions in the classical as well as in the quantum regime, are trapped ions. In addition to the precise control of the particles in ion traps, Coulomb crystals captivate due to the possibility of solitonic defects (kinks) with additional dynamics and symmetry broken phases.

In this work, we investigate how energy transport takes place in different phases of a Coulomb crystal. The dynamics of a local excitation in the crystal and the transport properties of kinks are analyzed. The results hint towards interesting thermodynamical phenomena of ion crystals with defects.

FM 42.13 Tue 16:30 Tents

A multi-site quantum register of neutral atoms — •Malte Schlosser, Daniel Ohl de Mello, Dominik Schäffner, Tilman Preuschoff, Lars Kohfahl, Jan Werkmann, Lukas Brozio, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Advanced quantum technologies, such as quantum simulation, computation, and metrology are thriving for the implementation of large-scale configurations of identical quantum systems. Sets of atoms and molecules have the advantage of having identical intrinsic properties but need to be placed in identical environments as well. We introduce a unique micro-optical platform of arrays of optical tweezers and demonstrate the compensation of the differential Stark shift caused by the optical trapping potential. This results in a strong suppression of dephasing effects and a significant increase of the coherence time for atomic ensembles of ^{85}Rb. The experimental method does not require the existence of a so called magic wavelength and is expandable to other atomic species trapped in various dipole trap configurations of arbitrary wavelength.

Furthermore, we implement Rydberg interacting systems in defect-free 2D clusters of individual atoms and discuss recent work with microlens arrays fabricated by femtosecond direct laser writing, which enables the on-demand production of highly adaptable geometries for neutral-atom based quantum engineering [2].

[1] M. Schlosser et. al., arXiv:1902.00370 (2019).
[2] D. Schäffner et. al., arXiv:1905.06929 (2019).

FM 43: Networking event of the Working Group on Industry and Business (AIW) with free beer and pretzels, including the BMBF award ceremony of the "Quantum Futur Award 2019"

Time: Tuesday 18:30–20:00 Location: Aula

Networking event of the Working Group on Industry and Business (AIW)

Have some free beer & pretzels and talk to people from industry and academia, working in your field. A set-up of tables with thematic focus ensures an easy match.

Embedded in the event is the award ceremony for the "Quantum Futur Award" of the German Ministry of Education and Research (BMBF). By this award the Ministry honours outstanding and innovative scientific work with a clear application context in the field of quantum technologies. The prize is awarded in the categories Master Theses and Doctoral Theses. The winners were selected by a jury of experts from industry and science.

FM 44: Outreach: Einstein-Slam

Time: Tuesday 20:00–21:00 Location: Audi Max

Einstein-Slam is the art of making complex science accessible to a wider audience in an entertaining and comprehensive way. Selected researchers present complex issues, state-of-the-art research, emerging technologies, and up-to-date topics in a series of 10-minutes talks on stage. At this event we proudly present intriguing and engaging talks with a focus on the interplay of quantum technologies and information science. At the end, the audiences' applause evaluates the presentations and determines a favorite.

All presentations will be given in German. For more information please see www.einstein-slam.de.

FM 45: Plenary Talk: Industry

Time: Wednesday 8:30–9:30 Location: Audi Max

Plenary Talk FM 45.1 Wed 8:30 Audi Max
Quantum Technologies - Challenges and Chances from an Industry Perspective — •Jürgen Gross — Robert Bosch GmbH, Renningen

Quantum Technologies, according to the European Quantum Flagship initiative, comprise the four technology areas Quantum Communication, Quantum Computation, Quantum Simulation, and Quantum Sensing & Metrology.

Our **motivation** as Bosch to engage in Quantum Technologies has the following aspects:

(1) Bosch is a leading supplier in miniaturized **sensor products**, both for automotive as for consumer sensors. This motivates continuous innovation and evaluation of new sensor concepts in our Corporate Research branch, now focusing especially also on quantum sensors.

(2) The **Internet of Things** transformation will rapidly change markets and ecosystems. Unprecedented numbers of sensors will create and transmit vast amounts of data, including sensitive person-related data. For safe and secure data transmission **quantum cryptography** and here especially **quantum random number generation** is expected to play an increasingly important role.

(3) Substantial progress in **quantum computing** is expected to enable new computation principles that outperform "classical" high performance computers with certain tasks. We are actively exploring application spaces for quantum computers of the first and second generation, in particular in the fields of materials simulation and optimization

To build up necessary competencies in Quantum Technologies, close **cooperation** with leading academic experts is mandatory. Due to the early engagement of Bosch in the European Quantum Flagship initiative, Bosch is recognized as a competent and active collaboration partner within the quantum research programs on national and European level.

At Bosch, newly acquired expertise in quantum technologies will be combined with existing experience in design, fabrication, and setup of hardware and system prototypes to develop specific "quantum products".

Bosch's five major Quantum Technology projects are presented, the business context is given, and the technological principles are explained. The embedding of these projects in large public funded projects is shown. The presentation is concluded with an outlook on the success factors that we consider crucial for the economic success of Quantum Technology.

FM 46: Introductory Talk: Quantum Sensing

Time: Wednesday 9:30–10:30 Location: Audi Max

Introductory Talk FM 46.1 Wed 9:30 Audi Max
Quantum sensing enabled by diamond — •Fedor Jelezko — Institute of Quantum Optics, Ulm University

Single nitrogen vacancy (NV) color centers in diamond currently have sufficient sensitivity for detecting single external nuclear spins and resolve their position within a few angstroms. The ability to bring the sensor close to biomolecules by implantation of single NV centers and attachment of proteins to the surface of diamond enabled the first proof of principle demonstration of proteins labeled by paramagnetic markers and label-free detection of the signal from a single protein. Single-molecule nuclear magnetic resonance (NMR) experiments open the way towards unraveling dynamics and structure of single biomolecules. However, for that purpose, NV magnetometers must reach spectral resolutions comparable to that of conventional solution state NMR. New techniques were proposed for this purpose and realized recently including technique that employs quantum entanglement. The ability to sense nuclear spins by NV centers also enables the transfer of polarization from optically polarized spins of NV centers to external nuclear spins. Such diamond based techniques for dynamic nuclear spin polarization are very promising for the enhancement of sensitivity of conventional MRI imaging.

Most of mentioned above results obtained so far with diamond centers are based on optical detection of single NV color centers. Recently it was shown that photoelectrical detection of NV centers base on spin selective photoionization can provide robust and efficient access to spin state of individual color centers

FM 47: Industry I: Photonics

Time: Wednesday 11:00–13:00 Location: Aula

Invited Talk FM 47.1 Wed 11:00 Aula

Enabling Industrial Quantum Technology — •Michael Förtsch — Q.ANT GmbH, Handwerkstraße 29, 70565 Stuttgart

After more than 30 years of successful scientific demonstration of quantum mechanical phenomena, we are reaching the point to realize first industrial products with this novel technology. It is expected that in the 21st century quantum phenomena will create significant economic value in at least four technology fields: Communication, Computing, Imaging, and Sensing.

This expectation for everyday products is bringing key industrial parameters such as usability, price, durability and scalability into the focus of current developments. I am convinced that this shift in priorities can only succeed, if we:

1. Establish education in quantum technology beyond physics
2. Collaborate together in highly multidisciplinary teams
3. Generate public interest by explaining the advantages and possibilities instead of 'how it works'
4. Manage the expectations both in terms of value proposition and 'time-to-market'

It is time to develop the next generation of technologies.
Let's drive quantum technology to industry.

Invited Talk FM 47.2 Wed 11:20 Aula

An industry perspective on Quantum Technologies — •Nils Trautmann — Carl Zeiss AG, Oberkochen, Germany

At the beginning of the 20th century, quantum technology first revolutionized physics and then it also revolutionized technology. Without quantum physics, we would have no lasers, no LEDs, no integrated circuits, no smartphones, no fiber optic networks, no internet. This explains, at least in part, industry's great interest in the quantum technology of the early 21st century. While the quantum technology of the 20th century uses the quantum properties of matter, quantum technology of the 21st century controls them. Now the quantum states of individual or coupled systems are in focus. The question that concerns industrial players is which industrial applications will benefit from quantum technologies. In which areas do we expect significant benefits from QT that we cannot otherwise receive? Where can we provide completely new solutions (new imaging modalities, ..) or where can we improve specifications by at least one order of magnitude? Four foreseeable applications are in the focus of the community: (i) quantum communication, (ii) quantum sensors & metrology, (iii) quantum computing & simulation, and (iv) quantum-enhanced imaging. In this talk, their relationship to optics will be discussed with a specific focus on optical imaging and sensing.

Invited Talk FM 47.3 Wed 11:40 Aula

A proposal for a topological phase modulator with π Berry phase shift — •Ulrich Gaubatz — Coriant R&D GmbH - Part of the Infinera Group

A proposal is made for a π phase shift of a polarized laser field when it passes an elementary birefringent wave plate. With a slight reorientation of the wave plate relative to the input polarization state the overall phase of the light field (common to x and y component) suddenly changes by π which could be used for binary signal generation in modern high speed phase modulated optical transmission systems. The π phase shift is a topological or Pancharatnam-Berry phase variation which promises a new type of high speed optical modulators with low drive voltage. Due to the topological nature of the phenomena this type of modulator should be robust and well suited for optical integration. One experiment from the past is presented suggesting the existence of the proposed π jump, but also the non-supporting outcome from a single photon experiment. Topological arguments for the existence are discussed.

Invited Talk FM 47.4 Wed 12:00 Aula

Quantum Technologies in Thales — •Thierry Debuisschert — Thales Research and Technology, 1 avenue Augustin Fresnel, 91767 Palaiseau Cedex

The ability of quantum technologies to control matter on the scale of a single quantum object opens up entirely new possibilities for many applications. Quantum technologies have been identified by Thales as leading-edge technologies with a high potential impact on future navigation, detection and communication systems. In recent years, we have studied technologies such as spin impurities in diamond, rare earth-doped crystals, cold atoms, quantum photonics, with a particular focus on practical operational considerations. Quantum technologies, combined with integration techniques, will improve the performance of navigation systems through ultra-precise compact atomic clocks, accelerometers and gyroscopes. They will improve magnetic field sensors but also electric field or pressure sensors. They will have an impact on radar and electromagnetic detection as well. In addition, quantum technologies are expected to have a strong impact on secure communications, particularly in the space sector.

Invited Talk FM 47.5 Wed 12:20 Aula

Opticlock: Towards a transportable and user-friendly optical single-ion clock — •Juergen Stuhler[1] and opticlock Consortium[2] — [1]TOPTICA Photonics AG — [2]www.opticlock.de

Today's most precise clocks are research prototypes based on optical reference transitions of neutral atoms or single ions. Their unprecedented precision of few parts in 10^{18} opens up numerous applications, e.g. improved network synchronization or navigation as well as geodetic height measurements.

The opticlock consortium of industrial and academic partners (www.opticlock.de) is developing an easy-to-use optical clock based on a single $^{171}Yb^{+}$ ion. The complete clock system will be integrated into two mobile 19" rack assemblies. It comes with a fully autonomous control system and is designed for reliable operation in a standard industrial environment. The key technologies of this project will extend the portfolio of commercially available components to the benefit of many applications of quantum technology.

We will give an overview of the opticlock system design, present the current development status of selected subsystems or components and report on first clock performance tests.

This work is funded by the German Federal Ministry of Education and Research within the program "pilot projects quantum technologies" (FKZ 3N14380).

Invited Talk FM 47.6 Wed 12:40 Aula

Quantum-dot based single photon sources: Commercialization of near optimal solid-state sources for Quantum Applications — •Valerian Giesz and Niccolo Somaschi — Quandela, Palaiseau, France

Quantum light sources are key building blocks for the development of quantum enhanced technologies. Single photon sources based on semiconductor quantum dots have emerged as an excellent platform for high efficiency quantum light emission. However, the question of commercialization of such devices remains a challenge.

In this talk, we report about the first commercialization of efficient single photon sources based on self-assembled quantum dots. We demonstrate the robustness and the repeatability of the fabrication of efficient sources by using innovative fabrication techniques.

FM 48: Focus Talk: Quantum Memories & Interfaces

Time: Wednesday 11:00–12:00 Location: 2004

Focus Talk FM 48.1 Wed 11:00 2004
Photonic Quantum Memories and Interfaces — •Hugues de Riedmatten — ICFO, Castelldefels (Barcelona), Spain

The coherent and reversible transfer of quantum information between matter and light is an important requirement in quantum information science. It enables the realization of a quantum memory for light, which is required in many applications in this field, including optical quantum computing and quantum information networks. Quantum memories are also crucial building blocks for quantum repeaters that have been proposed to overcome losses in the transport of photonic quantum information over long distances.

In this talk, I will introduce the physical processes and some of the protocols that have been proposed to demonstrate a quantum memory for light in atomic and solid-state media. I will also describe the experimental state of the art and recent progresses in this very active field of research. The main focus will be on approaches based on collective effects in large ensembles of atoms, implemented both in atomic gases and in the solid state with rare-earth doped crystals. These systems are attractive because they allow efficient and long-lived storage of a large number of quantum bits, without the use of high-finesse cavities to enhance the light-matter interaction. I will also briefly introduce other systems enabling quantum memories with quantum processing capabilities between stored qubits. Finally, I will introduce quantum interfaces allowing quantum state transfer between disparate remote quantum systems using single photons.

FM 49: Lunch Talk: Centers of Quantum Information Science

Time: Wednesday 12:30–13:45 Location: 2006

Curious about what Quantum Information Science is done where?

During the recent years quantum science and became a research focus in many faculties and research institutions. This is best documented by the success of several research initiatives in the recent round for clusters of excellence or for projects within the EU-Quantum-Flagship. In addition several research and competence centers have been installed all over Germany. In this podium discussion an overview will be given by representatives from German clusters of excellence and competence centers of QIS in Germany (more infos also in the exhibition).

FM 50: Lunch Talk: Awards and Challenges

Time: Wednesday 13:15–13:55 Location: Audi Max

Lunch Talk FM 50.1 Wed 13:15 Audi Max
ZEISS Quantum Sensing & Imaging Challenge — •Michael Totzeck — Carl Zeiss AG, Oberkochen, Germany

Sensing and imaging are key technologies in research and industry with a continuous quest for better performance. Using quantum technologies of the second kind, i.e. based on the ability to control quantum states of individual or coupled systems, should be the perfect way to achieve significant performance improvements. However, although quantum technologies are getting more and more mature in the lab, industrial applications are still missing, not to mention actual products. We know this gap. It is called the "valley of death".

Let's bridge the gap between academic research and industrial applications together.

Join the ZEISS Quantum Sensing & Imaging Challenge!

The rules of this Challenge are simple: We present you current problems of high relevance in the areas of medical technology, microscopy, and industrial metrology.

You show us how these problems can be solved by using quantum technologies.

Impress us with your innovative solution and learn about the cutting edge sensor and imaging needs.

Lunch Talk FM 50.2 Wed 13:45 Audi Max
Announcement of the 2019 New Journal of Physics (NJP) Early Career Award — •Antigoni Messaritaki — IOP Publishing, Bristol

This award recognises the talents of exceptional young researchers, who are making a significant contribution to their respective field of research. For more information please visit https://iopscience.iop.org/journal/1367-2630/page/early-career-award .

Co-owned by the Deutsche Physikalische Gesellschaft and the Institute of Physics, New Journal of Physics (https://iopscience.iop.org/journal/1367-2630) is an open-access, electronic-only journal publishing original research across the whole of physics.

FM 51: Industry II: Computing

Time: Wednesday 14:00–16:00 Location: Aula

Invited Talk FM 51.1 Wed 14:00 Aula
Early-stage quantum computing in an industrial context — •Florian Neukart — Volkswagen Group of America, San Francisco, California, United States of America

With the computers we use today, some of the most important problems will never be solved, among these simulated chemistry, drug discovery, transportation, and artificial intelligence. Practical quantum computers herald a new era in information technology, and it*s happening right now. In industry, we must be aware of it, understand why and when quantum computers are more powerful than classical computers, and develop knowledge about architectures, algorithms, and programming languages. It*s an exciting field, of which it is clear that despite the progress made, many hurdles still have to be taken. The audience will learn about early-stage quantum computing in an industrial context and about potential benefits today and in the future in the most practical way.

Invited Talk FM 51.2 Wed 14:20 Aula
Quantum communication and quantum sensing at Airbus — •Friedhelm Serwane and Thierry Botter — Airbus Blue Sky - Central R&T, Taufkirchen

Quantum systems are emerging as enabling technology in a variety of areas, ranging from communication and computation to sensing.

Airbus Blue Sky is Airbus' gateway to new technologies. As part of the Airbus Central Technology Office, we define the direction of fundamental research at the centre of the international organization. We explore emerging technologies including quantum systems, biomaterials and neuromorphic computing, for the benefits of aerospace.

An overview over Airbus activities on quantum technologies will be presented with a focus on quantum secured communication and quantum sensing.

Invited Talk FM 51.3 Wed 14:40 Aula

Quantum Computing in the Chemical Industry - First impressions and resource estimations for quantum chemistry on quantum computers — •Michael Kuehn[1], Sebastian Zanker[2], Peter Deglmann[1], Michael Marthaler[2], and Horst Weiss[1] — [1]BASF SE, Ludwigshafen, Germany — [2]HQS Quantum Simulations, Karlsruhe, Germany

The study and prediction of chemical reactivity is probably one of the most important application areas of molecular quantum chemistry. Fully error-tolerant quantum computers could provide exact or near-exact solutions to the underlying electronic structure problem with exponentially less effort than a classical computer thus enabling highly accurate predictions for comparably large molecular systems. In the nearer future, however, only noisy devices with a limited number of qubits will be available. For such near-term quantum computers the hybrid quantum-classical variational quantum eigensolver algorithm in combination with the unitary coupled-cluster ansatz (UCCSD-VQE) has been an intensively discussed approach that could provide accurate results before the dawn of error-tolerant quantum computing. After a brief introduction to our activities in the field of Digitalization in R&D, we present a study applying our UCCSD-VQE implementation to the calculation of reaction energies of small, exemplary chemical reactions and compare to well-established electronic structure methods like traditional coupled-cluster and density functional theory. Finally, we roughly estimate the required quantum hardware resources to obtain "useful" results for practical purposes when using UCCSD-VQE.

Invited Talk FM 51.4 Wed 15:00 Aula

A Semiconductor Corporation View on Quantum Technologies — •Sebastian M. Luber and Thomas Kurth — Infineon Technologies AG, 85579 Neubiberg

Quantum technologies based on influencing individual quantum systems have gained increasing attention during the last decade in academic research as well as in the private sector. Especially the bright prospects of quantum computing are being discussed prominently on information technology events and in the media. Cleary, the effect on the business of traditional semiconductor companies e.g. in the field of security technologies could be large, potentially even disruptive. Hence, Infineon Technologies has already engaged in the research on quantum technologies in collaboration with leading academic experts. In this talk, we will give an industry view on quantum technologies sharing insights into related research activities at Infineon.

Invited Talk FM 51.5 Wed 15:20 Aula

Scalable instrumentation for quantum computing — •Sadik Hafizovic — Zurich Instruments AG, Zurich, Switzerland

Building a quantum computer is one of the most demanding challenges scientist and engineers are currently facing. All promising realizations of physical qubits share a common challenge: the need for classical instrumentation with unprecedented requirements which scales from a single qubit to 100s of qubits. Zurich Instruments' mission is to support scientists and engineers in that challenge by providing the most advanced instrumentation to efficiently link their analog qubits with the digital domain. We are presenting a Quantum Computing Control System (QCCS) that we have developed and tested in close collaboration with our project partners Leo DiCarlo (TU Delft, QuSurf project) and Andreas Wallraff (ETH Zurich, QuSurf and OpenSuperQ projects). The QCCS integrates 3 building blocks: The HDAWG Arbitrary Waveform Generator to provide the control pulses for qubit gates. The UHFQA Quantum Analyzer to readout and discriminate the quantum states. And the PQSC, Programmable Quantum System Controller, which completes the control system by ensuring the synchronization of all channels, fast gate operation, and reliable real-time execution of algorithms. The quantum scientists can work both on waveform-level or connect to higher levels of the quantum stack like the Qiskit framework, which is natively supported by the QCCS.

Invited Talk FM 51.6 Wed 15:40 Aula

Approach and use cases: When and where may we start to search for quantum applications? — •Tim Leonhardt — Accenture

From application perspective quantum computing maturity evaluations and derived predictions are challenging: Hardware benchmarks are plentiful and improvements are - arguably "doubly-exponential" - rapid. Strategies with quantity or quality focus enabled magnetic phase transition or chemical accuracy molecular simulation. In parallel "Software" with an algorithm landscape from heuristics to "big-O" reduces resource requirements, generating "quantum-inspired" solutions alongside. On user-side the stage for QC applications needs to be set identifying business value-added use cases and translating into QC problem archetypes followed by implementation challenges similar to ML applications. The time of fruitful intersection of the QC advent and application readiness period depends on full-stack development and work in a partner network illustrated by a use case, model and solution approach in optimization.

FM 52: Entanglement: Transport

Time: Wednesday 14:00–15:15 Location: 1009

Invited Talk FM 52.1 Wed 14:00 1009

Entanglement transport in the presence of noise — •Clemens Gneiting — Riken, Wako-shi, Saitama 351-0198, Japan

The reliable transport of quantum properties, such as coherence and entanglement, constitutes one of the essential building blocks for the realization of quantum technologies, ranging from quantum communication devices to quantum computers. Think, for instance, of the distribution of entangled photon pairs in quantum cryptography protocols, or of quantum sensors leveraging many-particle interference. Among the main obstacles towards the successful implementation of such devices is noise, stemming both from the undesired coupling to an environment (dissipation and decoherence) and from uncontrolled parameter fluctuations within the devices themselves (disorder). We review strategies towards mitigating and counteracting the detrimental effects of noise in entanglement transport. In particular, we discuss how different ways of encoding the quantum information can result in noise-prone or noise-robust entanglement transport. We present quantum master equations as a unifying framework to analyze the different noise sources.

FM 52.2 Wed 14:30 1009

Quantum-correlated photons generated by non-local electron transport — •Felicitas Hellbach[1], Wolfgang Belzig[1], Fabian Pauly[2,1], and Gianluca Rastelli[1] — [1]Physik, Universität Konstanz, D-78457 Konstanz — [2]OIST Graduate University, Onna-son, Okinawa 904-0395, Japan

Since the realization of high-quality superconducting microwave cavities, one can envisage the possibility to investigate the coherent interaction of light and matter [1]. We study a parallel double quantum dot device operating as single-electron splitter interferometer, with each dot linearly coupled to a local photon cavity. We explore how quantum correlation and entanglement between the two cavities is generated by the coherent transport of a single electron passing simultaneous through the two different dots. We calculate the covariance of the cavity occupations by use of a diagrammatic perturbative expansion (Keldysh Green's functions) to the fourth order in the dot-cavity interaction strength, taking into account vertex diagrams. In this way, we demonstrate the creation of entanglement by showing that the Cauchy-Schwarz inequality can be violated.

[1] C. Wang et al. Science **352**, 1087-1091 (2016),
A. Stockklauser et. al., Phys. Rev. X **7**, 011030 (2017),
X. Mi et al., Science **355**, 156-158 (2017),

J. J. Viennot et. al., Science **349**, 408-411 (2015).

FM 52.3 Wed 14:45 1009

Enhancing Resonance Energy Transfer by Means of Coherence and Entanglement — •Severin Bang[1], Robert Bennett[1], and Stefan Yoshi Buhmann[1,2] — [1]Institute of Physics, University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

Resonance energy transfer usually refers to a transfer between two partners. In this talk, we explore how the process can be enhanced by replacing a single donor by an entangled donor system coherently sharing excitations. We demonstrate this for the example of donors initially prepared in a superradiant Dicke state.

We describe the process by quantum electrodynamics in terms of dipole moments coupled via an exchange of virtual photons, whose propagation is encoded in Green's tensors [1]. We focus on the possibility of enhancing the energy transfer rate and on its dependence on the spacial configurations of donors and acceptors.

[1] J. L. Hemmerich, R. Bennett, S. Y. Buhmann, Nature Commun. **9**, 2934 (2018).

FM 52.4 Wed 15:00 1009

High-dimensional entanglement in atmospheric turbulence — •Giacomo Sorelli[1], Nina Leonhard[2], Claudia Reinlein[2], Vyacheslav N. Shatokhin[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg i. Br. — [2]Fraunhofer Institute for Applied Optics and Precision Engineering, Jena

Discrete high-dimensional quantum states (qudits) offer several advantages over their two dimensional counterpart (qubits). In particular, qudits increase the amount of information encoded into a single carrier. Moreover, in entanglement-based QKD the intervention of an eavesdropper is excluded by the violation of a Bell inequality, which is the more violated the larger the dimensionality of the employed states. Spanning a discrete infinite-dimensional Hilbert space, the orbital angular momentum (OAM) of light can be used to realize such high-dimensional quantum systems. However, its use in free-space QKD is severely limited by phase distortions introduced by random refractive index fluctuations due to atmospheric turbulence.

We discuss the efficiency of adaptive optics (AO) in mitigating turbulence-induced signal and entanglement losses of OAM states, for a vast range of atmospheric conditions. We show that the stronger Bell correlations available in higher dimensions are nullified by their faster turbulence-induced decay. In contrast, AO corrections allow to restore non-locality, and thus the security of entanglement-based quantum communication, even for high-dimensional states in moderate turbulence.

FM 53: Enabling Technologies: Sources of Quantum States of Light III

Time: Wednesday 14:00–16:00 Location: 1010

Invited Talk FM 53.1 Wed 14:00 1010

Efficient single photon sources for quantum information science — •Tobias Huber[1], Jan Donges[1], Simon Betzold[1], Magdalena Moczała-Dusanowska[1], Łukasz Dusanowski[1], Stefan Gerhardt[1], Jonathan Jurkat[1], Andreas Pfenning[1], Christian Schneider[1], and Sven Höfling[1,2] — [1]Lehrstuhl für Technische Physik, Universität Würzburg, Würzburg, Germany — [2]SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, UK

Self-assembled semiconductor quantum dots are good sources of indistinguishable single photons and entangled photon pairs. Furthermore, the ground state spin of a trapped electron or hole can be used as a spin qubit. Due to the high refractive index of the host material, only a small fraction of light can be collected and used in further experiments. So solve this issue, quantum dots have been embedded into various kinds of photonic structures to enhance their photonic properties due to cavity quantum electrodynamics.

Here, we present our latest results in strain tunability of quantum dots when embedded in micropillar cavities as well as some preliminary data on quantum dots in circular grating cavities.

FM 53.2 Wed 14:30 1010

Towards Coupling Quantum Dots to a Rb-Memory — •Liang Zhai[1], Matthias C. Löbl[1], Giang N. Nguyen[1,2], Jan-Philipp Jahn[1], Julian Ritzmann[2], Andreas D. Wieck[2], Armando Rastelli[3], Arne Ludwig[2], and Richard J. Warburton[1] — [1]University of Basel, 4056 Basel, Switzerland — [2]Ruhr-Universität Bochum, 44780 Bochum, Germany — [3]Johannes Kepler University Linz, 4040 Linz, Austria

Combining a solid-state quantum dot (QD) with an atomic memory is a promising hybrid-system for application in quantum communication [1]. Coupling the QD to a quantum memory, such as a Rb-memory, can circumvent the short coherence time of QDs. For coupling both systems, the photons emitted by the QD have to match the atomic ensemble in bandwidth and frequency [2,3].

We use droplet-etched GaAs QDs embedded in AlGaAs as a source of coherent single photons and investigate how their optical properties are connected to the QD-growth [4]. For tuning the QD-frequency we present two approaches: Applying mechanical strain to the sample [5] and applying an electric field to QDs in a diode structure [6,7].

[1] N. Sangouard *et al.*, Phys. Rev. A **76**, 050301 (2007).
[2] J.-P. Jahn *et al.*, Phys. Rev. B **92**, 245439 (2015).
[3] L. Beguin *et al.*, Phys. Rev. B **97**, 205304 (2018).
[4] M. C. Löbl *et al.*, arXiv:1902.10145 (2019).
[5] D. Huber *et al.*, Phys. Rev. Lett. **121**, 033902 (2018).
[6] L. Bouet *et al.*, Appl. Phys. Lett. **105**, 082111 (2014).
[7] F. Langer *et al.*, Appl. Phys. Lett. **105**, 081111 (2014).

FM 53.3 Wed 14:45 1010

Prospects of GaAs-based quantum dots emitting in the telecom wavelength regime for quantum communication schemes — •Cornelius Nawrath[1], Jingzhong Yang[2], Robert Keil[3], Michael Zopf[2], Fabian Olbrich[1], Matthias Paul[1], Fei Ding[2], Michael Jetter[1], Simone Luca Portalupi[1], Oliver Schmidt[3], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart — [2]Institute for Solid State Physics, Leibniz University of Hannover, Appelstr. 2, 30167 Hannover — [3]IFW Dresden, Helmholtzstraße 20, 01069 Dresden

The emission of semiconductor quantum dots (QDs) has been shown to exhibit excellent properties in terms of single photon purity, photon indistinguishability and entanglement fidelity, i.e. essential prerequisites for quantum communication. Emission in the telecom O- or C-band will boost the range of communication schemes due to the favourable absorption and dispersion properties of silica fibers employed in the existing global fiber network. The coherence properties of photons emitted by InAs/InGaAs QDs emitting directly in the telecom C-band, are examined under above-band excitation and in resonance fluorescence. Furthermore, under two-photon excitation, the single-photon purity and post-selected degree of indistinguishability are determined. To boost the extraction efficiency, the applicability of an approach combining a nano-membrane containing QDs, with a GaP hemispherical lens is presented for a sample emitting in the telecom O-band.

FM 53.4 Wed 15:00 1010

Ultrafast high-frequency electronics in cryogenic environments: Perspectives for Quantum Technologies — •Kai J. Spychala, Alex Widhalm, Björn Jonas, Sebastian Krehs, and Artur Zrenner — Department of Physics, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany

The implementation of quantum effects in computation, simulation, sensing and communication requires a miniaturization and standardization effort, which makes it compatible with existing technologies. Beside the efforts to operate communication systems in the telecom bands, a very important prerequisite for scalability is the application of state of the art electronics for steering, read-out, as well as pre- and post-processing, in order to benefit from existing semiconductor technologies. As quantum phenomena are mostly short-lived and observed under cryogenic environments, robust high-frequency electronics, which can operate in the cryogenic regime, is needed.

We report our results on the design of ultrafast BiCMOS chips and their application for the steering of single self-assembled semiconductor QDs and QD molecules for quantum communication purposes. We show results on the ultrafast electric phase manipulation of an exciton qubit [1], the rapid adiabatic passage of an exciton qubit and present a scheme for Ramsey-based optoelectronic sampling. We also present a chip design for the implementation of an electric pulse protocol, that can be used to entangle spin-qubits in a QD molecule, in order to get a spin-photon interface for future quantum repeater applications.
Ref: [1] A. Widhalm et al., APL 112, 111105 (2018).

FM 53.5 Wed 15:15 1010

Towards a single-photon source electrically driven by a single-electron pump — •Eric Reutter[1], Julian Maisch[2], Simone L. Portalupi[2], Peter Michler[2], and Jürgen Weis[1] — [1]Max Planck Institute for Solid State Research, Heisenbergstraße 1, 70569 Stuttgart, Germany — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, IQST and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Integrated photonic circuits step up to be a very promising candidate for future applications in quantum computing, quantum simulation, and quantum key distribution in telecommunication. In particular this requires the integration of devices for the generation of single photons on demand, optically passive and active components allowing photons to interact, and finally devices for the detection of single photons.

We investigate the feasibility of electrically pumping a quantum dot single-photon source by a single-electron pump. We will discuss fundamental requirements, restraints and limits of such a device operated under a large applied bias. Monte-Carlo rate equation simulations of the complex electrical circuit, incorporating all parts of the system, are presented to further understand the single-electron tunnelling dynamics and single-photon emission of such a system. From simulations and model, the constraining design features for such a device are determined. A prospect of a suitable material platform is given and discussed.

FM 53.6 Wed 15:30 1010

Photon-pair generation mediated by coupling of emitters to nonlinear photonic nanostructures — •Sina Saravi[1,4], Alexander Poddubny[2,3], Thomas Pertsch[1], Frank Setzpfandt[1], and Andrey A. Sukhorukov[4] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena, Jena, Germany — [2]ITMO University, St. Petersburg, Russia — [3]Ioffe Institute, St. Petersburg, Russia — [4]Nonlinear Physics Centre, Research School of Physics and Engineering, Australian National University, Canberra, Australia

We theoretically investigate a hybrid system of an atom-like emitter coupled to a nanostructured nonlinear photonic system. In our proposed configuration, the response of the nonlinear optical system is suppressed to achieve a regime where the response of the hybrid system is dominating. Using a rigorous Green's function quantization method to model the system, we show that in photonic nanostructures with spectral gaps with zero optical density-of-states, nonlinear effects like spontaneous photon-pair generation are prohibited if the frequency of one of the generated photons is in the gap. Moreover, we show that a coupled emitter with a transition frequency in the photonic gap mediates the otherwise forbidden generation of photon pairs, where one photon directly excites the emitter and the other occupies an optical mode. This effect can serve as a sensitive indicator for the presence and excitation of single atoms. Furthermore, this scheme could be used to directly interface quantum memories with photon-pair sources or to realize a deterministic and tunable single-photon source.

FM 53.7 Wed 15:45 1010

Imaging quantum emitters with parabolic mirrors — •Markus Sondermann[1,2] and Gerd Leuchs[1,2,3] — [1]Friedrich-Alexander-University of Erlangen-Nürnberg, Department of Physics, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany — [3]Department of Physics, University of Ottawa, Canada

Quantum emitters naturally radiate photons into the full solid angle. Therefore, in our experiments we collect the photons emitted by such sources with a deep parabolic mirror. This enables the imaging of the full spherical emission pattern onto a plane or, alternatively, the localization of the source with high spatial precision.

We discuss two examples of applications that benefit from such a set-up. The first one is imaging a single ion held in a radio frequency trap and determining its temperature as well as the excess heating rate, including the case of extremely weak excitation of the ion. The second example treats the imaging of nano-rod quantum-emitters held in an optical trap. Here, the imaging process enables the verification of the alignment of such rods along the electric field of the trap laser and yields the decomposition of the nano-rod emission into its constituting linear and circular dipole components.

FM 54: Quantum Networks: Quantum Memory and Gates

Time: Wednesday 14:00–16:00 Location: 1015

Invited Talk FM 54.1 Wed 14:00 1015

Quantum memories for photons — •Mikael Afzelius — Department of Applied Physics, University of Geneva

Optical quantum memories are devices that can store and later retrieve quantum states encoded onto single photons [1]. These are essential components of future quantum technologies such as quantum repeaters, which can increase quantum communication (e.g. quantum cryptography) to continental distances.

In this talk I will introduce quantum memories, their role in quantum repeaters and challenges in terms of memory requirements for repeaters. I will then briefly introduce different quantum memory schemes and some physical systems where memories are currently investigated, with a specific focus on current state-of-the-art in solid-state memories based on rare-earth doped crystals.

[1] Quantum memory for photons, M. Afzelius, N. Gisin, and H. de Riedmatten, Physics Today 68, 42 (2015)

FM 54.2 Wed 14:30 1015

Towards a single photon memory based on electromagnetically induced transparency — •Esteban Gomez Lopez[1], Tim Kroh[1], Chis Müller[1], Janik Wolters[2], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, Germany — [2]Universität Basel, Switzerland

Quantum networks promise to bring secure communications to our increasingly technology-dependent society. In order to create a truly scalable quantum network, quantum repeaters are needed to overcome the irremediable losses in quantum channels [1]. Such devices have at their core a quantum memory capable of mapping the state of a photon into a long lived matter state, such as a spin coherence, in a reversible manner [2]. Here we present a variable delay stage for photons using electromagnetically induced transparency (EIT) as a first step towards an EIT quantum memory. A maximum EIT window width of 150 MHz was obtained in Cs. This bandwidth is compatible with photon pairs emitted by a cavity enhanced SPDC source [3]. Faint light pulses were delayed up to 62.4(0.7) ns. This storage device can be used as the base for a quantum memory if also the coupling beam is pulsed. Storage times of up to seconds are feasible [4].

[1] N. Gisin and R. Thew, Nat. Photonics 1, 165 (2007).
[2] A. I. Lvovsky, B. C. Sanders, and W. Tittel, Nat. Photonics 3, 706 (2009).
[3] A. Ahlrichs and O. Benson, Appl. Phys. Lett. 108, 021111 (2016).
[4] O. Katz and O. Firstenberg, Nat. Commun. 9, 2074 (2018).

FM 54.3 Wed 14:45 1015

Quantum Memories for Single Photons — •Tom Schmit, Luigi Giannelli, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

Quantum memories are storage units of a quantum network [1]. In this work we theoretically characterize quantum memories for flying qubits based on single photons [2]. The quantum memories we analyse are i) a single atom inside an optical resonator and ii) a solid-state medium such as a rare-earth-ion doped crystal. We determine the efficiency of storage protocols based on adiabatic dynamics in the different setups and identify the parameter regimes where adiabatic protocols are preferable. We further discuss analogies and differences between the storage dynamics of a single photon [3] and of a weak coherent pulse [4]. Finally, we analyse the dynamics of propagation of a single photon which dispersively interact with an inhomogeneously broadened medium and explore perspectives to use inhomogeneous broadening for tailoring the single photon's spectral shape.

[1] H. J. Kimble, Nature **453**, 1023 (2008).
[2] N. Sangouard and H. Zbinden, Jour. of Mod. Opt., **59:17**, 1458-1464 (2012).
[3] L. Giannelli, T. Schmit, T. Calarco, C. P. Koch, S. Ritter, and G. Morigi, New J. Phys. **20**, 105009 (2018)
[4] L. Giannelli, T. Schmit, and G. Morigi, Phys. Scr. **94**, 014012 (2018).

FM 54.4 Wed 15:00 1015

Storing single photons in a room temperature vapor cell — •Roberto Mottola[1], Gianni Buser[1], Janik Wolters[1,2], Chris Müller[3], Tim Kroh[3], Sven Ramelow[3], Oliver Benson[3], and Philipp Treutlein[1] — [1]Universität Basel, Schweiz — [2]DLR Institut für optische Sensorsysteme Berlin — [3]HU Berlin

Quantum memories are a key ingredient for the realization of quantum networks [1]. Furthermore, they allow the synchronization of probabilistic single photon sources significantly enhancing the generation rates of multiphoton states [2].

We implemented a broadband, optical quantum memory in hot Rb vapor with on-demand storage and retrieval [3]. With a bandwidth matched spontaneous parametric downconversion (SPDC) source, we can generate heralded single photons suited for storage [4] with a heralding efficiency ≈ 50%. We report on our recent achievements in storing SPDC single photons with a linewidth of 230MHz with an end-to-end efficiency $\eta_{e2e} = 1.3(1)\%$ for a storage time of $T = 50$ns. A signal to noise ratio of 1.9(2) and a memory lifetime $\tau = 380$ns are achieved. The measurement of the second order autocorrelation of retrieved single photons results in $g^{(2)} = 0.91(3)$, showing that the non-classical properties of the stored light are maintained.

[1] N. Sangouard et al., *Rev. Mod. Phys.* **83**, 33 (2011).
[2] J. Nunn et al., *Phys. Rev. Lett.* **110**, 133601 (2013).
[3] J. Wolters, et al., *Phys. Rev. Lett.* **119**, 060502 (2017).
[4] A. Ahlrichs et al., *Appl. Phys. Lett.* **108**, 021111 (2016).

FM 54.5 Wed 15:15 1015

Electronic Dipole Spin Resonance of 2D Semiconductor Spin Qubits — •Matthew Brooks and Guido Burkard — Universität Konstanz, Konstanz, DE

Monolayer transition metal dichalcogenides (TMDs) offer a novel two-dimensional platform for semiconductor devices. One such application, whereby the added low dimensional crystal physics (i.e. optical spin selection rules) may prove TMDs a competitive candidate, are quantum dots as qubits. The band structure of TMD monolayers offers a number of different degrees of freedom and combinations thereof as potential qubit bases, primarily electron spin, valley isospin and the combination of the two due to the strong spin orbit coupling known as a Kramers qubit. Pure spin qubits in monolayer MoX_2 (where $X =$ S or Se) can be achieved by energetically isolating a single valley and tuning to a spin degenerate regime within that valley by a combination of a sufficiently small quantum dot radius and large perpendicular magnetic field. Within such a TMD spin qubit, we theoretically analyse single qubit rotations induced by electric dipole spin resonance. We employ a rotating wave approximation within a second order time dependent Schrieffer-Wolf effective Hamiltonian to derive analytic expressions for the Rabi frequency of single qubit oscilations, and optimise the mechanism or the parameters to show oscilations up to 250 MHz.

FM 54.6 Wed 15:30 1015

Dipolar interactions for robust entangling gates in the solid-state — •Eleanor Crane[1], Alexander Schuckert[2], Nguyen Huy Le[3], and Andrew Fisher[1] — [1]London Centre for Nanotechnology, University College London, Gower Street, London WC1E 6BT, United Kingdom — [2]Department of Physics, Technical University of Munich, 85748 Garching, Germany — [3]Advanced Technology Institute and Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom

Electron and nuclear spins of dopants in silicon offer some of the longest coherence times of all proposed quantum computing platforms. However, oscillations in the exchange interactions due to the periodicity of the crystal lattice make the fabrication of entangling gate configurations challenging. We study the feasibility of using dipolar interactions for the implementation of an entangling gate in silicon. These interactions decay as a power law with no oscillatory behavior, providing robustness to inter-donor distance fluctuations and thereby offering a route to scalability. Our study focuses on qubits encoded in the long-lived electron spin ground states of Si:Se+ and Si:P and we present several schemes with different technical requirements.

FM 54.7 Wed 15:45 1015

A temporally multiplexed quantum repeater node based on laser-cooled atoms — •Lukas Heller[1], Pau Farrera[1], and Hugues de Riedmatten[1,2] — [1]ICFO - Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, Castelldefels, Barcelona, Spain — [2]ICREA-Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

Future quantum repeater architectures, capable of efficiently distributing information encoded in quantum states of light over large distances, rely on quantum memories for light. Quantum repeaters can benefit from a modal multiplexing implementation of the memory, essentially scaling up the repeater's throughput. In this work we demonstrate a temporally multiplexed quantum repeater node in a laser-cooled cloud of 87 Rb atoms [1]. We employ the DLCZ protocol where pairs of photons and single collective spin excitations (so called spin-waves) are created [2]. The latter can then be efficiently transferred into a second single photon. For selective readout, we need to control the dephasing and rephasing of the spin-waves created in different temporal modes. We achieve this by a mag netic field gradient, which induces an inhomogeneous broadening of the involved atomic hyperfine levels [3]. By employing this steering technique, combined with cavity-enhanced emission and feed forward readout, we demonstrate distinguishable retrieval of up to 10 temporal modes. For each mode, we prove non-classical correlations between the first and second photon. Furthermore, an enhancement in rates of correlated photon-photon pairs is observed as we increase the number of temporal modes stored in the memory. The reported device is a crucial key element of a quantum repeater architecture implementing multiplexed quantum memories.

[1] C. Simon, H. de Riedmatten and M. Afzelius; Phys. Rev. A 82 010304(R) (2010)
[2] L. Duan, M. Lukin, J. Cirac and P. Zoller, P; Nature 414 413 (2001)
[3] B.Albrecht, P. Farrera, G. Heinze, M. Cristiani and H. de Riedmatten; Phys. Rev. Lett. 115 160501 (2015)

FM 55: Quantum & Information Science: Neural Networks, Machine Learning, and Artificial Intelligence II

Time: Wednesday 14:00–15:30 Location: 1098

Invited Talk FM 55.1 Wed 14:00 1098

Quantum Mean Embedding of Probability Distributions — •Jonas M. Kübler, Krikamol Muandet, and Bernhard Schölkopf — Max Planck Institute for Intelligent Systems, Tübingen, Germany

The kernel mean embedding of probability distributions is commonly used in machine learning as an injective mapping from distributions to functions in an infinite dimensional Hilbert space. It allows us, for example, to define a distance measure between probability distributions, called maximum mean discrepancy (MMD). In this work we propose to represent probability distributions in a pure quantum state of a system that is described by an infinite dimensional Hilbert space and prove that the representation is unique if the corresponding kernel function is c_0-universal. This is a new method for encoding classical data in a quantum state and enables us to work with an explicit representation of the mean embedding, whereas classically one can only work implicitly with an infinite dimensional Hilbert space through the use of the kernel trick. We show how this explicit representation can speed up methods that rely on inner products of mean embeddings and discuss the theoretical and experimental challenges that need to be solved in order to achieve these speedups.

FM 55.2 Wed 14:30 1098

Training Deep Neural Networks by optimizing over paths in hyperparameter space — Vlad Pushkarov[1], Jonathan Efroni[1], Mykola Maksymenko[2], and •Maciej Koch-Janusz[3] — [1]Technion, Haifa, Israel — [2]SoftServe Inc., Lviv, Ukraine — [3]ETH Zurich, Switzerland

Hyperparameter optimization is both a practical issue and an interesting theoretical problem in training of deep architectures. Despite many recent advances the most commonly used methods almost universally involve training multiple and decoupled copies of the model, in effect sampling the hyperparameter space. We show that at a negligible additional computational cost, results can be improved by sampling paths instead of points in hyperparameter space. To this end we interpret hyperparameters as controlling the level of correlated noise in the training, which can be mapped to an effective temperature. The usually independent instances of the model are then coupled and allowed to exchange their hyperparameters throughout the training using the well established parallel tempering technique of statistical physics. Each simulation corresponds then to a unique path, or history, in the joint hyperparameter/model-parameter space. We provide empirical tests of our method, in particular for dropout and learning rate optimization. We observed faster training and improved resistance to overfitting and showed a systematic decrease in the absolute validation error, improving over benchmark results.

FM 55.3 Wed 14:45 1098

Metric Gaussian Variational Inference — •Jakob Knollmüller[1,2] and Torsten Ensslin[1,2] — [1]Max-Planck Institute for Astrophysics, Garching — [2]Ludwig-Maximilian University, Munich

A variational Gaussian approximation of the posterior distribution can be an excellent way to infer posterior quantities. However, to *capture all posterior correlations the parametrization of the full covariance is required, which scales quadratic with the problem size. This scaling prohibits full-covariance approximations for large-scale problems. As a solution to this limitation we propose Metric Gaussian Variational Inference (MGVI). This procedure approximates the variational covariance such that it requires no parameters on its own and still provides reliable posterior correlations and uncertainties for all model parameters. We approximate the variational covariance with the inverse Fisher metric, a local estimate of the true posterior uncertainty. This covariance is only stored implicitly and all necessary quantities can be extracted from it by independent samples drawn from the approximating Gaussian. MGVI requires the minimization of a stochastic estimate of the Kullback-Leibler divergence only with respect to the mean of the variational Gaussian, a quantity that scales linearly with the problem size. We motivate the choice of this covariance from an information geometric perspective. We validate the method against established approaches, demonstrate its scalability into the regime over a million parameters and capability to capture posterior distributions over complex models with multiple components and strongly non-Gaussian prior distributions. (J. Knollmüller et al. (2019) ArXiv:1901.11033)

FM 55.4 Wed 15:00 1098

Vector field divergence of predictive model output as indication of phase transitions — •Frank Schäfer and Niels Lörch — Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

We introduce an alternative method to identify phase boundaries in physical systems. It is based on training a predictive model such as a neural network to infer a physical system's parameters from its state. The deviation of the inferred parameters from the underlying correct parameters will be most susceptible and diverge maximally in the vicinity of phase boundaries. Therefore, peaks in the vector field divergence of the model's predictions are used as indication of phase transitions. Our method is applicable for phase diagrams of arbitrary parameter dimension and without prior information about the phases. Application to both the two-dimensional Ising model and the dissipative Kuramoto-Hopf model show promising results.

FM 55.5 Wed 15:15 1098

Optimal Renormalization Group Transformation from Information Theory — Patrick M. Lenggenhager[1], Zohar Ringel[2], Sebastian D. Huber[1], and •Maciej Koch-Janusz[1] — [1]ETH Zurich, Switzerland — [2]Hebrew University of Jerusalem, Israel

The connections between information theory, statistical physics and quantum field theory have been the focus of renewed attention. In particular, the renormalization group (RG) has been explored from this perspective. Recently, a variational algorithm employing machine learning tools to identify the relevant degrees of freedom of a statistical system by maximizing an information-theoretic quantity, the real-space mutual information (RSMI), was proposed for real-space RG. Here we investigate analytically the RG coarse-graining procedure and the renormalized Hamiltonian, which the RSMI algorithm defines. By a combination of general arguments, exact calculations and toy models we show that the RSMI coarse-graining is optimal in a sense we define. In particular, a perfect RSMI coarse-graining generically does not increase the range of a short-ranged Hamiltonian, in any dimension. For the case of the 1D Ising model we perturbatively derive the dependence of the coefficients of the renormalized Hamiltonian on the real-space mutual information retained by a generic coarse-graining procedure. We also study the dependence of the optimal coarse-graining on the prior constraints on the number and type of coarse-grained variables. We construct toy models illustrating our findings.

FM 56: Entanglement: Many-Body Dynamics II

Time: Wednesday 14:00–16:00 Location: 2004

Invited Talk FM 56.1 Wed 14:00 2004

New quantum many-body phases enabled by ergodicity breakdown — •Dmitry Abanin — University of Geneva, Geneve, Switzerland

The experimental advances in synthetic quantum systems, such as ultracold atoms, have enabled researchers to probe quantum thermalization and its breakdown. Thermalization occurs in ergodic systems and erases quantum information contained in the initial many-body states. Therefore, to create long-lived quantum states, it is of particular interest to find mechanisms of thermalization breakdown. One way of suppressing thermalization is by introducing strong quenched disorder, which induces many-body localization (MBL). MBL systems exhibit a new kind of emergent robust integrability and a wealth of novel dynamical phenomena. Surprisingly, MBL systems may also avoid heating under periodic driving, which opens up the possibility of having stable, Floquet-MBL phases with unusual properties. I will discuss one example of such a phase: a two-dimensional Anomalous Floquet Insulator, characterized by fully localized bulk states and chiral, thermalizing edge states.

Further, I will argue that MBL may not be the only way to break ergodicity. I will propose another mechanism, quantum many-body scarring, which bears a similarity to the well-known phenomenon of quantum scars in few-body chaos, and leads to a weaker form of ergodicity breaking that was recently observed in a many-body system of Rydberg atoms.

FM 56.2 Wed 14:30 2004

Development of a software based lock-in amplifier for phase-modulated spectroscopy — •Daniel Uhl, Friedemann Landmesser, Ulrich Bangert, Marcel Binz, Lukas Bruder, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Germany

Recently, many-body effects of interacting molecules doped on rare gas clusters have been observed [1]. Detecting these weak higher order signals requires a particularly sensitive measurement scheme. We established such a method based on a phase modulated quantum beat experiment combined with lock-in detection to isolate multiple-quantum coherences (MQCs) in a low density alkali vapor [2,3]. Here, the MQC signatures show up at higher harmonics of the modulation frequency and can be extracted with harmonic lock-in detection. Hence, it is possible to simultaneously isolate several MQC signals in a single measurement using multiple lock-in amplifiers (LIA). To further improve our detection scheme we developed a software based LIA. This opens the possibility to demodulate our signal at different harmonics and thus gives us the advantage to observe any desired separate multiphoton processes in the pre-analysis. The algorithm is mainly based on a digital phase locked loop to detect the phase and frequency of the incoming reference signal. Hence, it is possible to demodulate the signal for different harmonics by conserving the phase information.

[1] S. Izadnia et al., J. Phys Chem Lett 8, 2068 (2017)
[2] L. Bruder et al., Phys. Rev. A 92, 053412 (2015)
[3] L. Bruder et al., Phys. Chem. Chem. Phys. 21, 2276 (2019)

FM 56.3 Wed 14:45 2004

Many-body effects in cold molecules using phase-modulated two-dimensional coherent spectroscopy — •Friedemann Landmesser, Ulrich Bangert, Lukas Bruder, Marcel Binz, Daniel Uhl, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Germany

Many-body quantum states are considered to play a crucial role in atomic and molecular systems with respect to dissipation, excitation and energy transfer (cf. [1]). We aim to investigate collective effects in organic molecules by multiple-quantum coherence experiments where multiphoton processes can be separated from one-photon transitions and can be assigned to specific particle numbers [2,3]. We will adapt a detection scheme based on phase-modulated two-dimensional coherent spectroscopy which was already used to investigate multi-atom Dicke states in potassium vapor [3,4]. Measurements on a rubidium vapor will serve as a benchmark. To study collective effects in organic molecular systems, we will adapt our helium nanodroplet source to produce solid rare gas clusters, that can be doped with hundreds of organic molecules. The cluster surface acts as a well-defined, cold environment [5]. In lifetime measurements we already identified collective effects of the interacting molecules at increasing doping densities [5].

[1] F. Fassioli et al., J. Royal Soc. Interface 11, 20130901 (2014).
[2] L. Bruder et al., Phys. Rev. A 92, 053412 (2015).
[3] S. Yu et al., Opt. Lett. 44, 2795 (2019).
[4] L. Bruder et al., Phys. Chem. Chem. Phys. 21, 2276 (2019).
[5] S. Izadnia et al., J. Phys. Chem. Lett. 8, 2068 (2017).

FM 56.4 Wed 15:00 2004

Dynamical driving a Cavity-BEC System from self-organized into non equilibrium — •Christoph Georges[1], Hans Kessler[1], Jayson G. Cosme[1,2], Ludwig Mathey[1,2], and Andreas Hemmerich[1,2] — [1]Institut für Laser-Physik and Zentrum für Optische Quantentechnologien, Universität Hamburg, D-22761 Hamburg, Germany — [2]The Hamburg Center of Ultrafast Imaging, Luruper Chaussee 149, D-22761 Hamburg, Germany

The generation and manipulation of density wave order in many body systems are considered as models for solid-state phenomena such as light-induced superconductivity.

In our recent research, we investigated the role of modulation on the formation of long-range order in a Cavity-Atom System. For this, a Bose-Einstein Condensate of Rubidium Atoms is placed inside the light field of a high finesse cavity. By pumping the atoms with a sufficient strong transversal optical standing wave, the system can go through a phase transition. The arising phase is characterized by an intracavity light field due to the formation of particle density waves [1].

By modulating the amplitude of pump field, the DW-order can either be suppressed [2] or new DW-orders can be excited [3]. In the present work, we modulated the light field with a frequency close to a collective resonance. We observe the excitation of a higher DW-order and the rise of a subradiant non-equilibrium phase.

[1] J. Klinder et. al. PNAS 112, 3290 (2015)
[2] Ch. Georges et. al. PRL 121, 220405 (2018)
[3] J. G. Cosme et. al. PRL 121, 153001 (2018)

FM 56.5 Wed 15:15 2004

Interacting bosons in an asymmetric double-well potential — •Jonathan Brugger and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Federal Republic of Germany

The fundamental equations of quantum mechanics are well-established, but their numerical solution can still be challenging, even for apparently simple quantum systems. Despite the ever increasing computational power available, new numerical and algorithmic approaches are key.

We investigate the quantum dynamics of two or more interacting bosons, trapped in an asymmetric double-well potential, by exact numerical diagonalization of their many-body Hamiltonian. Since the underlying Hilbert space is infinite-dimensional, we are seeking for an approximate solution in a subspace spanned by tensor products of polynomial B-Splines – an approach which has become popular over the last three decades in atomic and molecular physics.

FM 56.6 Wed 15:30 2004

Non-local emergent hydrodynamics in a long-range interacting spin system — •Alexander Schuckert[1,2], Izabella Lovas[1,2], and Michael Knap[1,2] — [1]Department of Physics and Institute for Advanced Study, Technical University of Munich, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München

Short-range interacting quantum systems with a conserved quantity exhibit universal diffusive behavior at late times in the absence of long-lived quasiparticle excitations. We show how this universality is replaced by a more general transport process in the presence of long-range interactions that decay algebraically with distance as $r^{-\alpha}$. While diffusion is recovered for large exponents $\alpha > 1.5$, longer-ranged interactions with $0.5 < \alpha \leq 1.5$ give rise to effective classical Lévy flights; a random walk with step sizes following a heavy-tailed distribution. We investigate this phenomenon in a long-range interacting XY spin chain, conserving the energy and the total magnetization, at infinite temperature by employing non-equilibrium quantum field theory and semi-classical phase-space simulations. We find that the space-time dependent spin density profiles are self-similar, with scaling functions given by the stable symmetric distributions. Moreover, autocorrelations show hydrodynamic tails decaying in time as $t^{-1/(2\alpha-1)}$ when $0.5 < \alpha \leq 1.5$. Our findings can be readily verified with current trapped ion experiments.

FM 56.7 Wed 15:45 2004

Entanglement and partial distinguishability in many-body systems — •Eric Brunner[1], Christoph Dittel[1], Gabriel Dufour[1,2], and Andreas Buchleitner[1] — [1]Quantenoptik und -statistik, Physikalisches Institut, Albert-Ludwigs-Universität Freiburg — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg

Exploring the structural properties of many-body interference in complex quantum systems plays a key role for an improved understanding and control of the underlying dynamics. Many-body interference in the involved constituents' dynamical degrees of freedom is controlled by their mutual (in)distinguishability. This, in turn, can be tuned by addressing suitable "labelling" degrees of freedom. Through a systematic analysis of correlations between dynamical and labelling degrees of freedom, we define a hierarchy of indistinguishability measures for general many-body states. To reveal those correlations, we identify robust features of many-body interference patterns and propose an experimentally feasible protocol to quantify partial distinguishability in generic non-interacting many-body systems.

FM 57: Quantum Sensing: Spectroscopy I

Time: Wednesday 14:00–16:00 Location: 2006

Invited Talk FM 57.1 Wed 14:00 2006

Probing and manipulating Andreev Bound States —

•Cristian Urbina[1], Leandro Tosi[1], Cyril Metzger[1], Marcelo F. Goffman[1], Hugues Pothier[1], Sunghun Park[2], Alfredo Levy Yeyati[2], Jesper Nygård[3], and Peter Krogstrup[3] — [1]Quantronics Group, SPEC (CNRS), CEA-Saclay, Université Paris-Saclay, France — [2]Departamento de Física Teórica de la Materia Condensada, Condensed Matter Physics Center (IFIMAC) and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, Spain — [3]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Denmark

The quantum states on which information is stored and manipulated in currently implemented superconducting platforms correspond to bosonic electromagnetic modes of circuits made non-linear by Josephson junctions. I will present experiments on a radically different platform based on Andreev states, which are fermionic, microscopic states in superconducting weak links.

I will first present the coherent manipulation of Andreev states on a fully metallic weak link (a one-atom contact between two Al reservoirs) and then the spectroscopy of a semiconducting weak link (Al-InAs-Al) revealing a "fine structure" in the Andreev spectrum due to the strong spin-orbit coupling in InAs. Such devices could be used to coherently manipulate the spin of a single quasiparticle.

FM 57.2 Wed 14:30 2006

Quantum Sensing using the Stochastic Quantum Zeno Effect

— •Matthias M. Müller — Institute of Quantum Control, Peter Grünberg Institut, Forschungszentrum Jülich

The dynamics of quantum systems are unavoidably influenced by their environment and in turn observing a quantum system (probe) can allow one to measure its environment: Dynamical decoupling sequences as an extension of the Ramsey interference measurement allow to spectrally resolve a noise field coupled to the probe [1]. Here, we report also on dissipative manipulations of the probe leading to so-called Stochastic Quantum Zeno (SQZ) phenomena that can be seen as an extension of the Rabi measurement. Recently, we could detect time correlations in the noise through an ergodicity breaking in SQZ dynamics [2], and the concept was experimentally demonstrated with a BEC on a chip [3]. We present a robust method to reconstruct an unkown spectrum from measurements of the survival probability of the SQZ dynamics.

[1] C. L. Degen, F. Reinhard, and P. Cappellaro, Rev. Mod. Phys. 89, 035002 (2017). [2] M.M. Müller, S. Gherardini, and F. Caruso, Sci. Rep. 6, 38650 (2016). [3] S. Gherardini, C. Lovecchio, M.M. Müller, P. Lombardi, F. Caruso, and F.S. Cataliotti, Quantum Science and Technology 2 (1), 015007 (2017). [4] M.M. Müller, S. Gherardini, A. Smerzi, and F. Caruso, Phys. Rev. A 94, 042322 (2016). [5] M.M. Müller, S. Gherardini, and F. Caruso, Scientific Reports 8, 14278 (2018).

FM 57.3 Wed 14:45 2006

Dynamical detection of dipole-dipole interactions in dilute atomic gases —

•Benedikt Ames, Edoardo Carnio, Vyacheslav Shatokhin, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Recent experimental studies have revealed collective effects in fluorescence spectra of dilute atomic gases using a pump-probe measurement scheme within phase-modulated nonlinear spectroscopy [1]. The corresponding spectral features can be discerned down to the lowest experimentally accessible densities of $\sim 10^7\,\mathrm{cm}^{-3}$, and can be interpreted as a sensitive probe of residual dipole-dipole interactions.

To provide a quantitative theoretical description of this phenomenology, we adapt an open quantum system treatment which was already employed [2] to model coherent backscattering from a dilute cloud of atomic (hence, manifestly quantum) scatterers. It includes the retarded interaction as mediated by the quantized vacuum field, and is hence valid across all length scales (or densities). Approximate analytical results are compared to a fully numerical treatment of the resulting master equation, and a first confrontation of our theoretical approach with published experimental data is presented.

[1] L. Bruder et al., Phys. Chem. Chem. Phys. **21**, 2276–2282 (2019)
[2] V. Shatokhin, C. Müller, A. Buchleitner, Phys. Rev. A **73**, 063813 (2006)

FM 57.4 Wed 15:00 2006

Robust optical clock transition in $^{40}\mathrm{Ca}^+$ by dynamical decoupling —

•Lennart Pelzer[1], Kai Dietze[1], Ludwig Krinner[1], Stephan Hannig[1], Nicolas Spethmann[1], Nati Aharon[2], Alex Retzker[2], Tanja E. Mehlstäubler[1], and Piet O. Schmidt[1,3] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Israel — [3]Leibniz Universität Hannover, 30167 Hannover, Germany

Optical clocks based on single trapped ions are hindered by long averaging times caused by the quantum projection noise-limited statistical uncertainty. Long probe times on the order of many seconds would significantly reduce the statistical uncertainty. However, currently the phase coherence of available laser systems limits the probe time. We propose to improve the phase coherence of a laser by stabilizing it to a transition in a multi-ion crystal with a large signal-to-noise ratio. Relevant frequency shifts in a crystal of several hundred $^{40}\mathrm{Ca}^+$ ions are canceled by employing a continuous dynamical decoupling scheme. Both Zeeman manifolds of the $\mathrm{S}_{1/2} \leftrightarrow \mathrm{D}_{5/2}$ clock transition in $^{40}\mathrm{Ca}^+$ get doubly-dressed by four tailored driving RF-fields to form a robust optical clock transition, essentially free of homogeneous magnetic field and inhomogeneous electric quadrupole and tensor polarizability shifts as well as shifts due to amplitude fluctuations in the driving fields. Experimental results implementing this scheme in our segmented Paul-trap setup will be presented.

FM 57.5 Wed 15:15 2006

Rare-earth electron spin spectroscopy on single Ce^{3+}:YSO

— •Thomas Kornher[1], Roman Kolesov[1], Kangwei Xia[2], Dawu Xiao[3], Fiametta Sardi[1], Nan Zhao[3], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Department of Physics, The Chinese University of Hong Kong, Shatin, Hong Kong, China — [3]Beijing Computational Science Research Center, Haidan District, Beijing, China

Experimental results on optically resolved single Ce^{3+} ions in yttrium orthosilicate (YSO) are presented. The electron spin associated with Ce^{3+} is initialized, and read-out optically at 4 K temperature. Coherent manipulation allows for probing the local environment of the electron spin and shows the influence of the yttrium bath onto the electron spin. Additionally, frozen core effects, predicted by ab initio calculations, can be observed. Spin-lattice relaxation time of $T_1 > 2.6$ ms was measured and spin coherence time T_2 is suggested to be T_1-limited by ab initio calculations. Furthermore, sensing of nearby ^{29}Si nuclear spins is investigated, since Ce^{3+} electron spin can potentially be exploited as interface between photons and proximal, long-lived nuclear spins, such as yttrium and ^{29}Si.

FM 57.6 Wed 15:30 2006

Spectroscopic precision probing of velocity-dependent atom-surface interactions —

•Nico Strauss[1] and Stefan Yoshi Buhmann[1,2] — [1]University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

The Casimir-Polder force between atoms or molecules and is of quantum mechanical origin and forms the basis of quantum friction, which is predicted to occur when two objects move at distance on the order of nanometers relative to each other. Frequency-selective reflection spectroscopy [1] is a tool for determining atomic transition frequencies and linewidths from a changes in the reflection coefficients of a modulated laser beam incident on the boundary between a dielectric and a gas of moving atoms. It is so sensitive that it has been successfully used to verify surface-induced shifts of the energies of extremely short-lived excited states. Here, we propose to push the limits of the tool a step further by detecting velocity-dependent surface-induced shifts of transmission frequencies and linewidths [2]. We start by laying out the basic theory of such velocity-dependent effects which are intricately related to quantum friction. We then discuss how motion-induced quantum vacuum effects are expected to manifest themselves in the reflection signal.

[1] J. Klatt, R. Bennett and S. Y. Buhmann, Phys. Rev. A **94**, 063803 (2016).

[2] M. Ducloy and M. Fichet, J. Phys. **II**, 1529 (1991).

FM 57.7 Wed 15:45 2006

Mid-Infrared Spectroscopy with Nonlinear Interferometers — •Chiara Lindner, Sebastian Wolf, Jens Kiessling, and Frank Kühnemann — Fraunhofer Institute for Physical Measurement Techniques IPM, Heidenhofstraße 8, 79110 Freiburg, Germany

Spontaneous parametric down-conversion (SPDC) is one of the most important sources for entangled photon pairs in quantum optics. Its application in nonlinear interferometers is the foundation of quantum imaging and spectroscopy. Nonlinear interferometers rely on a quantum effect: The signal photons of two SPDC-sources show interference if the corresponding idler photons are indistinguishable. Any absorption of the idler photons in between the sources lowers the visibility of both signal and idler interference contrast. This allows measuring the absorption and dispersion of samples in the mid-IR range by detecting the interference pattern of the visible photon counterparts.

In our work, we present a nonlinear interferometer for mid-infrared spectroscopy in Michelson-configuration. Hereby, we infer the spectral information on the mid-infrared light directly from the visible interference pattern without the need for spectral selection. Using non-collinear broadband SPDC created in a periodically poled lithium niobate crystal, our interferometer covers a large spectral bandwidth ($> 100\,\mathrm{cm}^{-1}$ in mid-infrared) in one single measurement. With different poling periods and crystal temperatures, an infrared spectrum ranging from 3.2-3.8 μm wavelength is demonstrated. Our experimental results are discussed and compared to other works in our field.

FM 58: Quantum Information Concepts in Thermodynamics

Time: Wednesday 14:00–16:00 Location: 3042

Invited Talk FM 58.1 Wed 14:00 3042

Thermodynamic uncertainty relations from exchange fluctuation theorems — •John Goold — Trinity College Dublin, Dublin, Ireland

Thermodynamic uncertainty relations (TURs) place strict bounds on the fluctuations of thermodynamic quantities in terms of the associated entropy production. In this work we identify the tightest (and saturable) matrix-valued TUR that can be derived from the exchange fluctuation theorems describing the statistics of heat and particle flow between multiple systems. Our result holds for both quantum and classical systems, undergoing general non-Markovian and non-stationary processes. Moreover, it provides bounds not only for the variances, but also for the correlations between thermodynamic quantities. To demonstrate the relevance of TURs to the design of nanoscale machines, we consider the operation of a two-qubit SWAP engine undergoing an Otto cycle and show how our results can be used to place strict bounds on the correlations between heat and work.

FM 58.2 Wed 14:30 3042

Coherence and catalysis in the Jaynes-Cummings model — •Anette Messinger, Atirach Ritboon, Frances Crimin, Sarah Croke, and Stephen M. Barnett — School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, United Kingdom

Coherence is a crucial principle of quantum physics describing the difference between a quantum superposition and a classical statistical mixture. Like energy and entanglement, it can be described as a resource. In particular the creation of superposition in the energy basis and its impact on quantum thermodynamics received a lot of attention in recent years. It has been suggested that coherence can be created catalytically, that is without degrading the resource state which is used in the process [1]. This idea runs into difficulties, however, when taking correlations into account [2].

Here we study the repeated interaction of a cavity field initialized in a coherent state with a sequence of two-level atoms in the Jaynes-Cummings model and ask the question to what extent the production of atomic superposition states is catalytic in this setup. We investigate the degradation of coherence in the cavity during multiple rounds and show that the process is much more robust against failure than the original proposal of catalytic coherence [1] and correlations only have a small effect on the overall efficiency. We furthermore study the role of squeezing in the cavity and give an analytic expression for the ideal squeezing strength.

[1] Åberg, Phys. Rev. Lett. 113, 150402 (2014), [2] Vaccaro et al., J. Phys. A: Math. Theor. 51, 414008 (2018)

FM 58.3 Wed 14:45 3042

Von Neumann entropy from unitarity — Paul Boes[1], Jens Eisert[1], Rodrigo Gallego[1], Markus P. Müller[2,3], and •Henrik Wilming[4] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria — [3]Perimeter Institute for Theoretical Physics, Waterloo, ON N2L 2Y5, Canada — [4]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland

The von Neumann entropy is a key quantity in quantum information theory. It quantifies the amount of quantum information contained in a state when many identical and independent (i.i.d.) copies are available. We provide a new operational characterization of the von Neumann entropy which neither requires an i.i.d. limit nor any explicit randomness. We do so by showing that the von Neumann entropy fully characterizes single-shot state transitions in unitary quantum mechanics, as long as one has access to a suitable ancillary system whose reduced state remains invariant in the transition and an environment which has the effect of dephasing in an arbitrary preferred basis. Furthermore we formulate and provide evidence for the catalytic entropy conjecture, which states that the above holds true even in the absence of a decohering environment. If true, it would prove an intimate connection between single-shot state transitions in unitary quantum mechanics and the von Neumann entropy. We also discuss implications of these insights to thermodynamics.

FM 58.4 Wed 15:00 3042

Collective performance of a finite-time quantum Otto cycle — •Michal Kloc[1], Pavel Cejnar[2], and Gernot Schaller[3] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [2]Institute of Particle and Nuclear Physics, Faculty of Mathematics and Physics, Charles University, V Holešovičkách 2, Prague, 18000, Czech Republic — [3]Institut für Theoretische Physik, Technische Universität Berlin, D-10623 Berlin, Germany

We study the quantum Otto cycle where a collective spin system is used as the working fluid. Starting from a simple one-qubit system we analyze the transition to the limit cycle in the case of a finite-time thermalization. If the system consists of a large sample of independent qubits interacting coherently with the heat bath, the superradiant equilibration is observed. We show that this phenomenon can boost the power of the engine.

FM 58.5 Wed 15:15 3042

A truly quantum Szilárd demon — •Konstantin Beyer, Kimmo Luoma, and Walter T. Strunz — TU Dresden, Institut für Theoretische Physik

In a Szilárd engine the demon can extract work from a Gibbs state because she has knowledge about the actual microstate of the work medium. In quantum models of this gedankenexperiment the demon usually performs a quantum measurement on the system to obtain this necessary information.

In our approach we adopt a more global point view and consider a situation where the local Gibbs state arises from an entangled state between the work medium and its environment (eigenstate thermalization hypothesis). In such a bipartite situation a quantum demon who observes the environment can, in principle, exploit these correlations to help another party with the work extraction from the work medium. In particular, the possible work extraction schemes are manifold if the demons knowledge about the state of the system originates from an entangled state

Under suitable scenarios the average work extraction can be higher than what could be explained by any classical statistical model. This can be seen as the violation of a quantum steering task and, therefore, represents a semi-device-dependent test of quantumness. The asymmetry of a steering task reflects the typical partition into system and bath in many settings of quantum thermodynamics.

FM 58.6 Wed 15:30 3042

Quantum entropy flow is different — •Alwin van Steensel and Mohammad Ansari — Forschungszentrum Jülich, Jülich Aachen Reseach Alliance (JARA), Jülich, Germany

In quantum physics physical quantities are linear in density matrix, e.g. energy, current, spin, etc. However, this is not the case in quantum information theory as informational measures are nonlinear functions in density matrix; examples are entropy, fidelity loss, purity, etc. Is there any way to measure information in the lab using physical quantities? This is an important question that I will address in this talk. I will present a new correspondence between entropy and physical quantities and how it may introduce new physics.

References: [1] MH Ansari, Entropy production in a photovoltaic cell, Physical Review B 95 (17), 174302 (2017); [2] MH Ansari, YV Nazarov, Keldysh formalism for multiple parallel worlds, Journal of Experimental and Theoretical Physics 122 (3), 389-401 (2016); [3] MH Ansari, YV Nazarov, Exact correspondence between Renyi entropy flows and physical flows, Physical Review B 91 (17), 174307 (2015); [4] MH Ansari, YV Nazarov, Renyi entropy flows from quantum heat engines, Physical Review B 91 (10), 104303 (2015).

FM 58.7 Wed 15:45 3042

Energtic cost of quantum control protocol — •Obinna Abah — Queen's University Belfast, United Kingdom

We quantitatively assess the energetic cost of several well-known control protocols that achieve a finite time adiabatic dynamics, namely counterdiabatic and local counterdiabatic driving, optimal control, and inverse engineering. By employing a cost measure based on the norm of the total driving Hamiltonian, we show that a hierarchy of costs emerge that is dependent on the protocol duration. As case studies we explore the Landau- Zener model, quantum harmonic oscillator, and Jaynes-Cummings model and establish that qualitatively similar results hold in all cases. For the analytically tractable Landau-Zener case we further relate the effectiveness of a control protocol with the spectral features of the new driving Hamiltonians and show that in the case of counterdiabatic driving, it is possible to further minimize the cost by optimizing the ramp employed via Lagrange multipliers.

FM 59: Enabling Technologies: Quantum Dots and Superconductivity-based Systems

Time: Wednesday 14:00–16:00 Location: 3043

FM 59.1 Wed 14:00 3043

Full Counting statistics of a driven single electron quantum dot — •Adrian Schmidt, Johannes C. Bayer, Timo Wagner, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Hanover, Germany

The AC driving of a single electron quantum dot shows as function of frequency and tunnelling rate clear signature of a quantum stochastic resonance. [1] We now analysed the tunnelling through such a single electron quantum dot in terms of full counting statistics.

For this we used a quantum dot formed by split gates in a GaAs/AlGaAs heterostructure with a nearby quantum point contact. The QPC allows to measure single electron tunnelling through the ac driven quantum dot in real time. From these data the full counting statistics for the driven tunnelling can be extracted. We analysed the collected data to identify the occurring transitions in the system and extracted the time dependend tunnelling rates for different modulations.

Reference

[1] T. Wagner, P. Talkner, J. C. Bayer, *et. al.*, Nat. Phys. **15**, 330-334 (2019).

FM 59.2 Wed 14:15 3043

Metallic magnetic calorimeters for photon sensing with sub-eV energy resolution — Matthäus Krantz, Andreas Fleischmann, Christian Enss, and •Sebastian Kempf — Kirchhoff-Institute for Physics, Heidelberg University, Heidelberg, Germany

Energy-dispersive single photon detection with high quantum efficiency is a key technology for modern quantum science. But despite its great importance, there is a lack of detector concepts providing simultaneously an excellent energy resolution, a quantum efficiency close to 100 %, a fast timing as well as linear detector response.

During the last decade, metallic magnetic calorimeters (MMCs) have proven to fill this gap. MMCs are calorimetric single photon detectors typically operated at temperatures well below 50 mK. They use a paramagnetic temperature sensor strongly coupled to a photon absorber to convert the photon energy into a magnetic flux change that is measured using a current-sensing dc-SQUID via a superconducting flux transformer. The present record energy resolution is 1.6 eV (FWHM) for 6 keV photons. To challenge this limit we have started to develop next-generation MMCs combining temperature sensor and SQUID within a single device to grealty enhance the signal to noise ratio. Our most recent prototype comprises a gradiometric meander-shaped SQUID inductance and planar temperature sensors made of Ag:Er and gives strong reasons to expect that we can achieve sub-eV energy resolution for photon energies up to several keV. We describe the design, microfabrication and optimization of our prototype and discuss the presently achieved performance.

FM 59.3 Wed 14:30 3043

Sensing the quantum limit in scanning tunneling microscopy: tunneling between single quasiparticle levels at atomic scale — •Haonan Huang[1], Jacob Senkpiel[1], Robert Drost[1], Ciprian Padurariu[2], Simon Dambach[2], Björn Kubala[2], Juan Carlos Cuevas[3], Alfredo Levy Yeyati[3], Joachim Ankerhold[2], Christian R. Ast[1], and Klaus Kern[1,4] — [1]MPI für Festkörperforschung, Germany — [2]Institut für komplexe Quantensysteme, Universität Ulm, Germany — [3]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Spain — [4]EPFL, Switzerland

Tunneling processes between discrete electronic levels offer the possibility of the protection of coherence and entanglement, as well as the determination of lifetime and environmental effect. These processes have been studied extensively via quantum dots. However, to push these observations to the atomic scale remains challenging. Using a scanning tunneling microscope at 15mK, we can study the tunneling between tip and sample Yu-Shiba-Rusinov (YSR) states, the sharp in-gap states generated by magnetic atoms on a superconductor. We call these new tunneling processes Shiba-Shiba tunneling, which is a realization of tunneling between single levels at the atomic scale. Shiba-Shiba tunneling indeed inherits features of tunneling between discrete levels, and the dependency of the transport on the normal state conductance provides a direct measurement of quasiparticle lifetime with atomic precision, which shows great potential as a general tool of measuring the lifetime of an impurity or topological levels such as Majorana bound states.

FM 59.4 Wed 14:45 3043

Practical guide to simple characterization of superconducting quantum dots — •Martin Žonda[1], Alžběta Kadlecová[2], Vladislav Pokorný[2], and Tomáš Novotný[2] — [1]Albert Ludwig University of Freiburg, Institute of Physics, Freiburg, Germany — [2]Department of Condensed Matter Physics, Charles University, Prague, Czech Republic

Quantum dots attached to superconducting leads can be viewed as tunable Josephson junctions. Their qualitative properties, including the point of $0-\pi$ impurity quantum phase transition, can be externally controlled by the gate voltage or the superconducting phase difference of the leads. This makes them a promising candidate for future components of superconducting circuit computers. However, quantitative characterization of these devices, which is necessary for their future implementation, often requires broad scans throughout the parameter space of their theoretical models. This turned to be challenging if precise numerical methods, like NRG or QMC, are used. These methods are especially inconvenient for the initial data analysis.

We offer some inexpensive, fast and reliable alternatives to these procedures. We present analytical formuleas which allow for a very good estimation of the position of the $0-\pi$ phase boundary in the complementary weakly interacting and strongly correlated (Kondo) regimes. We also suggest an approach for efficient determination of the quantum phase boundary from measured finite-temperature data.

[1] A. Kadlecová et al., Phys. Rev. B 95, 195114 (2017)
[2] A. Kadlecová et al., Phys. Rev. Applied 11, 044094 (2019)

FM 59.5 Wed 15:00 3043

Towards semiconductor-superconductor hybrid qubits based on core/shell nanowires — •Patrick Zellekens[1,2], Russell Deacon[3,4], Pujitha Perla[1,2], Steffen Schlör[5], Mihail Ion Lepsa[1,2], Martin Weides[5], Koji Ishibashi[3,4], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institute, Forschungszentrum Jülich, 52428 Jülich, Germany — [2]JARA-FIT, Fundamentals of Future Information Technology — [3]RIKEN Center for Emergent Matter Science, 351-0198 Saitama, Japan — [4]Advanced Device Laboratory, RIKEN, 351-0198 Saitama, Japan — [5]Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

State-of-the-art qubits are typically tuned in frequency by a magnetic field. Our goal is to fabricate and characterize electrically tunable qubits, i.e. Gatemon and Andreev qubits, using a semiconductor nanowire Josephson junction as nonlinear element.

The main limitation for the qubit performance is the semiconductor-superconductor interface. We present a detailed analysis of the DC- and AC-properties of InAs/Al and InAs/Nb nanowire Josephson junctions with epitaxially grown superconductor shells based on Shapiro, emission and gate-dependent VI measurements.

Additionally, we present flux- and gate-dependent measurements of Andreev qubits as well as the spectroscopy of individual Andreev bound states by means of pump-probe experiments. The latter one reveals a Rashba- induced lifting of the spin degeneracy, which is one of the prerequisites for the realization of Majorana fermions.

FM 59.6 Wed 15:15 3043

Quantum phases and quantum phase transitions in frustrated networks of Josephson junctions — •Mikhail Fistul[1,2] and Alexei Andreanov[1] — [1]Center for Theoretical Physics of Complex Systems, Institute for Basic Science (IBS), Daejeon, Republic of Korea — [2]National University of Science and Technology MISiS, Russian Quantum Center, Moscow, Russia

We present a theoretical study of spatial correlations of Josephson phases in *frustrated quantum networks* of Josephson junctions. We focus on one-dimensional sawtooth chains where frustration arises due to the Josephson couplings having alternating signs in a single lattice cell of our model. The classical nonlinear dynamics of such system [1] shows the crossover from non-frustrated to frustrated regimes at the critical value of frustration, f_c. Such crossover is characterized by the thermodynamic spatial correlation functions of phases on vertices, φ_n, i.e. $C(n-m) = \langle \cos(\varphi_n - \varphi_m) \rangle$ displaying the transition from long- to short-range spatial correlations.

In the quantum regime using a direct mapping to the classical one- or two-dimensional lattices of spins with alternating sign long-range interactions, we obtain the zero temperature phase diagram ($\sqrt{E_c/E_J}$)-f, where E_c and E_J are the charge and Josephson coupling energies, respectively. The various macroscopic quantum phases, e.g. quantum vortices/antivortices, quantum vortex-antivortex pairs, quantum superposition states, quantum strip phases, are discussed.

[1] A. Andreanov and M. V. Fistul, J. Phys. A: Math. Theor. **52**, 105101 (2019).

FM 59.7 Wed 15:30 3043

Interaction of Skyrmions and Pearl Vortices in Superconductor-Chiral Ferromagnet Heterostructures — •Samme M. Dahir, Anatoly F. Volkov, and lya M. Eremin — Institut für Theoretische Physik III, Ruhr-Universität Bochum, D-44780 Bochum, Germany

We investigate a hybrid heterostructure with magnetic skyrmions (Sk) inside a chiral ferromagnet interfaced by a thin superconducting film via an insulating barrier. The barrier prevents electronic transport between the superconductor and the chiral magnet, such that the coupling can occur only through the magnetic fields generated by these materials. We find that Pearl vortices (PV) are generated spontaneously in the superconductor within the skyrmion radius, while anti-Pearl vortices ($\overline{\text{PV}}$) compensating the magnetic moment of the Pearl vortices are generated outside of the Sk radius, forming an energetically stable topological hybrid structure. Finally, we analyze the interplay of skyrmion and vortex lattices and their mutual feedback on each other. In particular, we argue that the size of the skyrmions will be greatly affected by the presence of the vortices, offering another prospect of manipulating the skyrmionic size by the proximity to a superconductor.

FM 59.8 Wed 15:45 3043

Microwave spectroscopy reveals the quantum geometric tensor of topological Josephson matter — Raffael Klees[1], Gianluca Rastelli[1], Juan Carlos Cuevas[2], and •Wolfgang Belzig[1] — [1]Department of Physics, University of Konstanz, Germany — [2]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Spain

Concepts like Chern numbers and their relation to physical phenomena have become very familiar, but actually, key quantities like the quantum geometric tensor [1], which provides a much deeper information about quantum states, remain experimentally difficult to access. Recently it has been shown that multiterminal superconducting junctions constitute an ideal playground to mimic topological systems in a controlled manner [2]. We study the spectrum of Andreev bound states in topological Josephson matter and demonstrate that the quantum geometric tensor of the ground state manifold can be extracted with the help of microwave spectroscopy [3]. We develop the concept of artificially polarized microwaves, which can be used to obtain both the quantum metric tensor and the Berry curvature. The quantized integrated absorption provides a direct evidence of topological quantum properties of the Andreev states. [1] M. Kolodrubetz et al., Phys. Rep. 697, 1 (2017) [2] R.-P. Riwar et al., Nat. Commun. 7, 11167 (2016); [3] R. L. Klees et al., arXiv:1810.11277

FM 60: Quantum Computation: Fault Tolerance & Error Correction

Time: Wednesday 14:00–16:00 Location: 3044

Invited Talk FM 60.1 Wed 14:00 3044

Scalable Quantum Error Correction with the Bosonic GKP Code — •Barbara Terhal — TU Delft, The Netherlands

We review the bosonic GKP (Gottesman-Kitaev-Preskill) code which encodes a qubit into an oscillator and its possible implementation in a microwave mode in circuit-QED hardware. We discuss how GKP code states can be created from Schroedinger cat states or from a dispersive interaction with a qubit. We propose a scalable architecture which uses a surface code on top of the GKP qubits. For a noise model of Gaussian stochastic displacement errors, we discuss how to decode such toric-GKP code and give estimates for the threshold standard deviation, corresponding to a low (4 or more) number of average photons in the GKP code states.

FM 60.2 Wed 14:30 3044

Twins Percolation for Qubit Losses in Topological Color Codes — Davide Vodola[1], •David Amaro[1], Miguel Angel Martin-Delgado[2], and Markus Müller[1] — [1]Department of Physics, Swansea University, Singleton Park, Swansea SA2 8PP, United Kingdom — [2]Departamento de Fisica Teorica I, Universidad Complutense, 28040 Madrid, Spain

In our work [1] we establish and explore a new connection between quantum information theory and classical statistical mechanics by studying the problem of qubit losses in 2D topological color codes. We introduce a protocol to cope with qubit losses, which is based on the identification and removal of a twin qubit from the code, and which guarantees the recovery of a valid three-colorable and trivalent reconstructed color code. Moreover, we show that determining the corresponding qubit loss error threshold is equivalent to a new generalized classical percolation problem. We numerically compute the associated qubit loss thresholds for two families of 2D color code and find that with $p = 0.461 \pm 0.005$ these are close to satisfying the fundamental limit of 50% as imposed by the no-cloning theorem. Our findings reveal a new connection between topological color codes and percolation theory, show high robustness of color codes against qubit loss, and are directly relevant for implementations of topological quantum error correction in various physical platforms.

[1] D. Vodola, D. Amaro, M. A. Martin-Delgado, and M. Müller, Phys. Rev. Lett. **121**, 060501 (2018)

FM 60.3 Wed 14:45 3044

recent trends with the AdS/CFT correspondence in the tensor network setting — •Matthew Steinberg[1,2] and Javier Prior[3] — [1]HQS Quantum Simulations — [2]FU Berlin — [3]Politechnical University of Cartagena

In recent years, much attention has been drawn to possible connections between the much-lauded theory of quantum gravity, the AdS/CFT correspondence, and quantum information theory. A natural setting for the study of bulk-boundary correspondences has developed with tensor network methods. These methods, and in particular MERA and perfect tensor networks, have been compared to the AdS/CFT correspondence and partially realize certain aspects of the duality. Hyperinvariant tensor networks have since been proposed in previous work as one model that links both previously described classes of tensor networks. This model, although promising, admittedly faces several challenges that impede an algorithmic realization of hyperinvariant tensor networks. In this talk, we wish to review some of these developments and offer insights into future study of the AdS/CFT correspondence in the tensor network setting. Our hope is that our present work will stimulate interest in hyperinvariant tensor networks in the theoretical community.

FM 60.4 Wed 15:00 3044

Robustness of Magic and Symmetries of the Stabiliser Polytope — •Markus Heinrich and David Gross — Institute for Theoretical Physics, University of Cologne

We give a new algorithm for computing the robustness of magic - a measure of the utility of quantum states as a computational resource. In the magic state model of fault-tolerant quantum computing, non-Clifford operations are effected by injecting non-stabiliser states, which are referred to as magic states in this context. The robustness of magic measures the complexity of simulating such a circuit using a classical Monte Carlo algorithm. It is closely related to the degree negativity that slows down Monte Carlo simulations through the infamous sign problem. Surprisingly, the robustness of magic is sub-multiplicative. This implies that the classical simulation overhead scales subexponentially with the number of injected magic states - better than a naive analysis would suggest. However, determining the robustness of n copies of a magic state involves a costly convex optimisation problem in a 4^n-dimensional space. We make use of inherent symmetries to reduce the problem to n dimensions, leading to a runtime which is super-polynomially faster than previously published methods. This allows us to compute the robustness of up to 10 copies of the most commonly used magic states. Guided by the exact results, we find a finite hierarchy of upper bounds to the robustness where each level can be evaluated in polynomial time. Technically, we use symmetries of the stabiliser polytope to connect the robustness of magic to the geometry of a low-dimensional convex polytope.

FM 60.5 Wed 15:15 3044

The Clifford group, Howe duality and quantum codes — •Felipe Montealegre-Mora and David Gross — University of Cologne, Cologne, Germany

The Clifford group is a central object in the theory of quantum fault-tolerance. It has also been on the spotlight in the mathematics community, because of its connections to the representation theory of symplectic group and Howe duality. In particular, the following questions have become relevant: how do tensor-power representations of the Clifford group decompose and what are their invariants? Here we answer these questions: all sub-representations live in certain self-orthogonal CSS codes. These representations arise from embeddings of lower-order tensor-powers of the Clifford group into the larger tensor-power representation. Our work has implications in Howe duality over finite fields. Furthermore, it may be seen as a generalization of the result that the invariants of the Clifford group are self-dual codes.

FM 60.6 Wed 15:30 3044

On the Second-Order Asymptotics of the Partially Smoothed Conditional Min-Entropy & Application to Quantum Compression — Dina Abdelhadi and •Joseph M. Renes — Institute of Theoretical Physics, ETH Zürich

Recently, Anshu et al. introduced "partially" smoothed information measures and used them to derive tighter bounds for several information-processing tasks, including quantum state merging and privacy amplification against quantum adversaries [arXiv:1807.05630 [quant-ph]]. Yet, a tight second-order asymptotic expansion of the partially smoothed conditional min-entropy in the i.i.d. setting remains an open question. Here we establish the second-order term in the expansion for pure states, and find that it differs from that of the original "globally" smoothed conditional min-entropy. Remarkably, this reveals that the second-order term is not uniform across states, since for other classes of states the second-order term for partially and globally smoothed quantities coincides. By relating the task of quantum compression to that of quantum state merging, our derived expansion allows us to determine the second-order asymptotic expansion of the optimal rate of quantum data compression. This closes a gap in the bounds determined by Datta and Leditzky [IEEE Trans. Inf. Theory 61, 582 (2015)], and shows that the straightforward compression protocol of cutting off the eigenspace of least weight is indeed asymptotically optimal at second order.

FM 60.7 Wed 15:45 3044

Performance Estimator of Codes On Surfaces — •Ciaran Ryan-Anderson — Swansea University, Swansea, United Kingdom

This work discusses the Python package called Performance Estimator of Codes On Surfaces (PECOS). PECOS serves as a framework for studying, developing, and evaluating quantum error-correcting codes (QECCs).

The package attempts to balance usability, functionality, and simplicity. PECOS uses an object-oriented approach to represent basic concepts used to describe and evaluate quantum error-correcting protocols as classes. The classes are highly extendable and can be easily replaced by custom classes developed by the user.

PECOS also boasts an implementation of a new stabilizer simulation algorithm that was developed concurrently with the package PECOS. This stabilizer simulator gives an average square-root speedup for topological stabilizer codes (TSCs) over previous stabilizer simulation algorithms. Stabilizer simulators allow stochastic error models that can apply errors beyond Pauli errors such as Clifford errors and measurement-like errors. Thus, the new stabilizer simulation algorithm, implemented in PECOS, greatly reduces the runtime of Monte Carlo simulations of such error models for TSCs and other similar QECCs.

It is hoped that PECOS will serve as a useful tool in studying and evaluating QEC protocols and encourage code reuse and transparency in the QEC community.

FM 61: Industry III: The Future of High Performance Computing (Presentations plus Panel Discussion)

Session organized by the Working Group on Industry and Business (AIW) of German Physical Society, starting with three short presentations, followed by a 90 minute panel discussion on the future of high performance computing.

Time: Wednesday 16:30–18:30 Location: Aula

FM 61.1 Wed 16:30 Aula

The future of computing: Technical background and reasoning for a future memory-driven computing architecture & The Machine research project — •Martin Brennecke — Hewlett Packard Enterprise

Data explosion, exponentially parallel mass data processing, NP hard problems and the end of Moore's Law require new concepts for the future of standardized and open computing infrastructures. Leaving the von-Neumann-model behind, a different architecture is required to build future computing devices of any size and scale. Using a memory-centric computing model instead, with a non-proprietary photonics-enabled bus, enables the effective usage of specialized units like ASICs, FPGAs or upcoming technologies like commoditized quantum computing devices within standardized and commonly acquirable infrastructures. Get a view into industry research on memory-driven computing, the research project The Machine, the prototyping with the German Center of Neurodegenerative Diseases (DZNE) and the current state of technology development from Hewlett-Packard Labs.

FM 61.2 Wed 16:40 Aula

Quantum and quantum-inspired algorithm for Finance, Insurance and Energy — •Markus Braun — JoS QUANTUM, Frankfurt am Main, Germany

Many problems in finance, insurance and energy can be condensed to mathematical problems that cannot be solved exactly. Solutions can often only be approximated by applying heuristics to the numerical models. JoS QUANTUM brings quantum and quantum-inspired algorithms to finance, insurance and energy to tackle computational bottlenecks. Quantum or quantum-inspired algorithms can achive better performance than classical algorithms, by giving correct results with a lower complexity in the expected number of steps. This talk gives (i) an overview of possible business cases for quantum algorithms in finance, insurance and energy, (ii) a small introduction of JoS QUANTUM and the developed software grundzustand and (iii) the current limitations as expectations for the future of quantum computing in finance, insurance and energy.

FM 61.3 Wed 16:50 Aula

Using quantum computers to simulate molecules and solids — •Michael Marthaler — HQS Quantum Simulations

Quantum computers offer tantalizing possibilities, but are currently strongly limited by their intrinsic sensitivity to errors. We discuss the prospects of using a near term processor containing 50 to 100 qubits to perform ab-initio simulations of materials. At present, the overhead for quantum error correction is so large that it cannot be implemented for near term quantum computers. This means applications have to be planned with the limitations imposed by errors in mind. Material simulations seam to be the most promising near term applications. We discuss how simulations would be performed on quantum computers and how this relates to existing methods in quantum chemistry.

Panel discussion

FM 62: Poster: Open and Complex Quantum Systems

Time: Wednesday 16:30–18:30 Location: Tents

FM 62.1 Wed 16:30 Tents

Study of the role of system-environment correlations in quantum open system dynamics — •Rodrigo Gómez and Heinz-Peter Breuer — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany

In open quantum system dynamics, the system can experience decoherence and/or dissipation due to its interaction with the environment, but it can also get correlated and entangled with the environment in complex ways. We studied the role of system-environment correlations in open quantum system dynamics by taking two approaches: (1) Analyzing the case of an exactly solvable atom-field model, studying the dynamics of the correlations in relation to the parameters describing the open system, such as the spectral density of the environment, decay rate, detuning, etc. Distinguishing the cases when the system behaves Markovian and Non-Markovian; (2) Studying the general change of mutual information in open system dynamics.

We show with the first approach (1) that the system-environment correlations seem to be present during the open system dynamics, and that we can reach maximal degree of system-environment correlations even for Markovian dynamics. With the second approach (2), we highlight some entropic relations between the change of mutual information and the open system dynamics.

FM 62.2 Wed 16:30 Tents

Irreversibility and entropy production in open quantum systems — •Nico Krause and Heinz-Peter Breuer — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany

On the basis of various random matrix models we investigate the degree of irreversibility of the dynamics of open quantum systems. Starting from the exact expression for the irreversible entropy production in terms of relative entropy, our central goal is the derivation of suitable approximate expressions which only refer to open system degrees of freedom. The result allows an efficient determination of the entropy production of quantum thermodynamic processes using information theoretical concepts.

FM 62.3 Wed 16:30 Tents

Exact approach to quantum non-Markovianity in the Caldeira-Leggett model — •Simon Einsiedler, Andreas Ketterer, and Heinz-Peter Breuer — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany

Employing the exact analytical solution of the Caldeira-Leggett model, a paradigmatic model for an open quantum system, we study the non-Markovian quantum dynamics for arbitrary couplings, temperatures and frequency cutoffs. Non-Markovianity is quantified using both the Bures metric (fidelity) and the relative entropy as distance measures for quantum states. This approach enables us to study quantum memory effects in the whole range from weak to strong dissipation.

FM 62.4 Wed 16:30 Tents

Entanglement bounds and entanglement protection with generalized Gaussian non-Markovian unravelings — •Nina Megier[1,2,3], Walter T. Strunz[1], Carlos Viviescas[4], and Kimmo Luoma[1] — [1]Institut für Theoretische Physik, Technische Universität Dresden, Dresden, Germany — [2]Dipartimento di Fisica "Aldo Pontremoli", Università degli Studi di Milano, Milan, Italy — [3]Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Milan, Italy — [4]Universidad Nacional de Colombia, Bogota D.C., Colombia

Generalized Gaussian non-Markovian unravelings are useful tool to describe the dynamics of the open quantum system, where the trajectories fulfill the generalized stochastic Schrödinger equation [1-3]. Here we show a derivation of the evolution equation from the microscopic description of the total system [4]. Our characterization of the dynamics generalizes the standard approach [5], as the complex noise driving the evolution has both a Hermitian correlation and a non-Hermitian correlation. The additional degrees of freedom of our description (resulting from the non-zero non-Hermitian correlation) can be used for quantum informational tasks. We discuss such applications as improving entanglement bounds and environment-assisted entanglement protection.

[1] - L. Diósi, L. Ferialdi, PRL 113, 200403 (2014), [2] - A.A. Budini, PRA 92, 052101 (2015), [3] - L. Ferialdi, PRL 116, 120402 (2016), [4] - N. Megier, W. T. Strunz, C. Viviescas, K. Luoma, PRL 120, 150402 (2018), [5] - W.T. Strunz, L. Diósi, N. Gisin, PRL 82, 1801 (1999)

FM 62.5 Wed 16:30 Tents

Many-particle interference to test Born's rule: Theory and two-particle experiment — •Marc-Oliver Pleinert[1,2], Eric Lutz[3], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91052 Erlangen, Germany — [3]Institute for Theoretical Physics I, University of Stuttgart, D-70550 Stuttgart, Germany

Born's rule, one of the cornerstones of quantum mechanics, relates detection probabilities to the modulus square of the wave function. Single-particle interference is accordingly limited to pairs of quantum paths and higher-order interferences are prohibited. Deviations from Born's law have been quantified via the Sorkin parameter which is proportional to the third-order term. We here extend this formalism to many-particle interferences and find that they exhibit a much richer structure. We demonstrate, in particular, that all interference terms of order (2M+1) and greater vanish for M particles. We introduce a family of many-particle Sorkin parameters, which are exponentially more sensitive to deviations from Born's rule than their single-particle counterpart, and present first results of the Sorkin parameter within two-particle correlations.

FM 62.6 Wed 16:30 Tents

Fisher information of single-photon emitters and thermal light sources in the far field without an imaging system — •Manuel Bojer[1], Anton Classen[1,2], and Joachim von Zanthier[1] — [1]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Institute for Quantum Science and Engineering Texas A&M University, College Station, TX 77843, USA

Rayleigh's criterion states that two light sources are unresolvable close to each other if their images, blurred by diffraction, overlap significantly. However, via quantum estimation theory it could be shown that even for small distances there should be in principle information about the source separation available. We here explicitly calculate the quantum Fisher information for two single-photon emitters emitting photons into the far field without an imaging system. We show that for distinguishable photons emitted by two sources of equal intensity the available information as a function of their separation is constant. We also introduce an optimal measurement basis, namely new orthogonalized spherical harmonics, in order to extract the information. Additionally for two thermal light sources we calculate the Fisher information of various measurement schemes including multiphoton measurements and compare them to the quantum Fisher information.

FM 63: Poster: Enabling Technologies: Quantum Materials, Quantum Dots, Quantum Wires, Point Contacts and Superconducting Systems

Time: Wednesday 16:30–18:30 Location: Tents

FM 63.1 Wed 16:30 Tents

Light-driven nuclei thermodynamics in bulk GaAs and (In,Ga)As/GaAs quantum dots — •Pavel Sokolov[1], Mikhail Petrov[2], Kirill Kavokin[2], Maria Kuznecova[2], Sergey Verbin[2], Dirk Reuter[3], Andreas D. Wieck[4], Dmitri Yakovlev[1,5], and Manfred Bayer[1,5] — [1]Experimentelle Physik 2, Technische Universität Dortmund, D-44221 Dortmund, Germany — [2]Spin Optics Laboratory, Saint Petersburg State University, 198504 St. Petersburg, Russia — [3]Department Physik Universität Paderborn, D-33098 Paderborn, Germany — [4]Angewandte Festkörperphysik Ruhr-Universität Bochum, D-44780 Bochum, Germany — [5]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia

We study experimentally the optical cooling dynamics of nuclei located inside the donor orbit in n-doped GaAs and (In,Ga)As/GaAs quantum dots and show that at slow modulation of excitation polarization (~ 1 s) a noticeable Overhauser field can be observed. The initial cooling rate is strongly dependent on the direction of the external magnetic field with respect to initial electron polarization direction $\pm S_0$. The lowest spin temperature in n-GaAs, $\Theta_N = 1.5$ mK was achieved in this work after cooling for $T_{\text{mod}} = 1$ s. For the microstructure with (In,Ga)As/GaAs quantum dots, the achieved spin temperature is one order of magnitude lower than in n-GaAs: $\Theta_N = 0.1$ mK. Using the implemented technique allows us to verify the polarization of nuclear spins in the external magnetic field in the desired spin polarization state in two different types of semiconductor microstructures studied in this work.

FM 63.2 Wed 16:30 Tents

Phase transitions in double quantum dots coupled to superconducting leads — •Georgios Loukeris[1], Martin Žonda[1], Vladislav Pokorný[2], Tomáš Novotný[2], and Michael Thoss[1] — [1]Albert Ludwig University of Freiburg, Institute of Physics, Freiburg, Germany — [2]Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

Various geometries of double quantum dots coupled to superconducting leads have been recently explored both theoretically and experimentally. It was shown that they can be used for the production of entangled electrons usable in computational protocols in solid state systems as well as for exploring complex quantum phase transitions. The advantage of double quantum dots is their tunability as individual gates can be used to control each dot separately. This can be utilized for setting the devices in different regimes. For example, if the dots are decoupled from each other, the gates can be used to set one dot to the so called 0-phase where its ground state is a BCS singlet and the other in π-phase with doublet ground state.

We investigate theoretically this situations by addressing a superconducting Anderson impurity model. We focus on how the properties of the junction change when we switch on the direct coupling between the dots. We show that the setup can be tuned to go trough various quantum phase transitions and crossovers. In addition the dependence of the supercurrent on the Josephson phase difference can have a complicated non-sinusoidal form.

FM 63.3 Wed 16:30 Tents

Extended nuclear spin coherence in an ensemble of (In,Ga)As/GaAs quantum dots — •Eiko Evers[1], Tomasz Kazimierczuk[1,2], Alex Greilich[1], Dmitri R. Yakovlev[1,3], Andreas D. Wieck[4], Dirk Reuter[5], and Manfred Bayer[1,3] — [1]Experimentelle Physik 2, TU Dortmund University, 44221 Dortmund, GermanyExperimentelle Physik 2, TU Dortmund Univrsity — [2]Institute of Experimental Physics, Faculty of Physics, University of Warsaw, 02-093 Warsaw, Poland — [3]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia — [4]Optoelectronic Materials and Devices, Paderborn University, 33098 Paderborn, Germany — [5]Angewandte Festkörperphysik, Ruhr-Universität Bochum, 44780 Bochum, Germany

Singly-charged (In,Ga)As/GaAs quantum dots (QDs) offer a playground to study the dynamics of the electron-spin (e-spin) confined within a nuclear spin bath. In a magnetic field perpendicular to the growth axis, the μs-long e-spin transverse coherence time allows preferential pumping of e-spins with a precession frequency resonant to the pumping periodicity. The periodical pumping moreover leads to a nuclear bath polarization (Overhauser field) that drives a single e-spin's precession frequency into resonance with the pumping frequency, the so called nuclei-induced frequency focusing (NIFF). While it has been reported that the nuclear spin coherence time for singly-charged QDs is in the μs range, we find that the synchroization of the nuclear-electron spin system also leads to a ms-long nuclear spin coherence time.

FM 63.4 Wed 16:30 Tents

Hybrid Devices of Spin-photon Interfaces for Singlet-triplet Quantum Dots — •Zheng Zeng[1], David Fricker[1], Arne Ludwig[2], Marcel Schmidt[2], Chao Zhao[1], Hendrik Bluhm[3], and Beata Kardynał[1] — [1]Peter Grünberg Institute 9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr- Universität Bochum, 44780 Bochum, Germany — [3]JARA-Institute for Quantum Information, RWTH Aachen University, 52074 Aachen, Germany

Connecting quantum processors over long distances using photon qubits would enable more complex quantum computing architectures and quantum networks. Recently a protocol to transfer a quantum state from a photonic qubit to a singlet-triplet spin qubit in GaAs/AlGaAs heterostructure has been theoretically demonstrated. In practice, the coherent transfer is facilitated by a hybrid device where a GaAs/AlGaAs gate-defined double quantum dot (GDQD) is tunnel coupled to a self-assemble quantum dot (SAQD), in which a conversion between a photon state and a spin state takes place. In this contribution we discuss fabrication techniques to achieve the precise alignment of both types of QDs both in energy as well as in space, which is essential for the device operation. We fabricate front- and back-gates to enable tuning the energy levels of the quantum dots. We discuss the method to align the gates of the GDQD to a SAQD. Further we explore methods of QDs growth to minimize the impact on the GDQDs. In particular we compare the performance of strain-free droplet QDs with high quality Stransky-Krastanov QDs in the hybrid devices.

FM 63.5 Wed 16:30 Tents

Hybrid assembly of the quantum optical elements — •Andreas Schell — Leibniz University Hannover, Germany — PTB, Braunschweig, Germany — CEITEC BUT, Brno, Czechia

Bringing quantum technology from the laboratory to real world applications is a complex, but very rewarding, task. It will enable society to exploit the new opportunities the laws of quantum mechanics offer compared to purely classical physics. However, before the new quantum technology can be deployed, platforms to implement such a technology need to be discovered and developed. Here, we will show our ongoing efforts to implement such a platform using the so called hybrid approach for the assembly of quantum photonic elements. This approach is highly flexible and can be adapted to many different material systems and structures. In particular, we will introduce techniques based on scanning probe microscopy and three-dimensional laser writing. The hybrid quantum photonic elements assembled with these approached include emitter coupled to on-chip resonators and waveguides, different kinds of fiber integrated cavities and incorporate a variety of emitter such as NV centers, quantum dots, and defects in two-dimensional materials, such as hexagonal boron nitride. From these examples it can be seen that photonics elements assembled using hybrid techniques might help to facilitate the transition of quantum photonic networks out of lab to real-world applications.

FM 63.6 Wed 16:30 Tents

Exciton spin and recombination dynamics in CdSe nanocrystals in glass matrix — •Gang Qiang[1], Elena V. Shornikova[1,2], Dmitri R. Yakovlev[1,3], Aleksandr A. Golovatenko[3], Anna V. Rodina[3], Evgeniy A. Zhukov[1], Alexey A. Onushchenko[4], and Manfred Bayer[1,3] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany. — [2]Rzhanov Institute of Semiconductor Physics, Siberian Branch of Russian Academy of Sciences, 630090 Novosibirsk, Russia. — [3]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia. — [4]ITMO University, 199053, St.-Petersburg, Russia

Semiconductor quantum dot spin as one of the carrier candidates for quantum bit or Qubit has attracted much attention during the last few decades. With time going by, the technics to prepare samples also become more and more powerful, such as molecular beam epitaxy, wet-chemical method, solid state reaction and so on. Former experiments have suggested that surface states of nanocrystals (NCs) play an important role in determining their thermodynamic, transport and optical properties. Comparing with colloidal NCs synthesized using wet chemical method, those grown in glass matrix are quite different, especially their surface state. NCs in glass matrix are completely free from passivation and the surface is dominated by dangling bond orbitals which sharply modify their magneto-optical properties. In this work, we studied the spin and recombination dynamics of exciton confined in CdSe nanocrystals grown in glass matrix with diameter range from 2.8 to 6.2 nm.

FM 63.7 Wed 16:30 Tents

In Situ Probing of Conductive Superlattices Formation of Cu1.1S Nanodisks at the Liquid/Air Interface — •Sonam Maiti[1,2], Santanu Maiti[1], Marcus Scheele[2], and Frank Schreiber[1] — [1]Institute of Applied Physics, University of Tuebingen, Tübingen, Germany — [2]Institute of Physical and Theoretical Chemistry, University of Tübingen, Tübingen, Germany

Assembling of colloidal NCs with anisotropic shape into ordered superstructures is one of the existing challenges in nano-fabrication [1,2]. We report the formation of conductive superlattices of Cu1.1S nanodisks through directional cross-linking with CoTAPc molecule at the liquid/air interface monitored by real-time GISAXS. We investigate the structure, symmetry and lattice parameters of the superlattices, formed during solvent evaporation and ligand exchange with elapsed time. Cu1.1S nanodisks self-assemble into 2D hexagonal superlattice with minor in-plane contraction and continuous contraction during ligand exchange reaction. This attributes to the continuous replacement of the native oleylamine surface ligands with smaller CoTAPc molecules. The NDs has a preferential atomic orientation in the superlattices with respect to the substrates. The subsequent superlattices show high electrical conductivity, which corresponds to the successful cross-linking of the nanodisks. Our work thus provides a correlation between the structure and transport of the coupled superstructures of organic and inorganic NCs with anisotropic shape. [1] Saunders et al, Nano Lett. 2006, 6, 12. [2] Maiti et al, JPCL 2018, 9, 4.

FM 63.8 Wed 16:30 Tents

Quantum thermodynamics in driven nanosystems: A hierarchical quantum master equation approach — •Jakob Bätge[1], Wenjie Dou[2], Amikam Levy[2], and Michael Thoss[1] — [1]Institute of Physics, University of Freiburg, Freiburg, Germany — [2]Department of Chemistry, University of California, Berkeley, USA

For the development and optimization of macroscopic engines thermodynamics is fundamental. In view of the tremendous recent progress in experimental techniques to study charge and heat transport in nanostructures based on single atoms or molecules [1], theoretical research on the impact of quantum fluctuations on thermodynamic laws at the nanoscale is of significant interest [2,3].

In this context, we investigate nanosystems with electronic and vibrational degrees of freedom, which are exposed to an environment in nonequilibrium. In particular, we are interested in thermodynamic quantities of driven nanosystems. For this purpose, we use the hierarchical quantum master equation method [4], which generalizes perturbative master equation methods by including higher-order contributions as well as non-Markovian memory and allows for the systematic convergence of the results. This approach allows for treating fermionic and bosonic environments on equal footing.

[1] L. Cui *et al.*, Science **355**, 1192 (2017). [2] R. S. Whitney *et al.*, Phys. Rev. B **98**, 085415 (2018). [3] W. Dou *et al.*, Phys. Rev. B **98**, 134306 (2018). [4] C. Schinabeck *et al.*, Phys. Rev. B **94**, 201407(R) (2016).

FM 63.9 Wed 16:30 Tents

Quantum transport through molecular nanojunctions with conical intersections — •Christoph Kaspar and Michael Thoss — Albert-Ludwigs-Universität, Freiburg, Germany

A conical intersection corresponds to a crossing of two potential energy surfaces in the configuration space of a polyatomic molecule. In the vicinity of the crossing, the coupling between the electronic states diverges resulting in the breakdown of the Born-Oppenheimer approximation [1]. As a consequence, the dynamics of electrons and nuclei is strongly correlated, which can have impact on electron transport through the molecule [2]. In this contribution, we theoretically investigate the characteristics of quantum transport through a molecule exhibiting a conical intersection. To this end, we consider a model for a molecular junction and employ the hierarchical quantum master equation approach, which generalizes perturbative master equation methods by including higher-order contributions as well as non-Markovian memory [3,4]. We show that the transport characteristics is strongly influenced by the interaction with the vibrational modes. In particular, the scenario of two degenerate electronic states coupled to two degenerate vibrational modes leads to interesting new phenomena [2].

[1] Domcke *et al.*, *Conical Intersections* (World Scientific, 2011)
[2] Schultz *et al.*, Phys. Rev. B **77**, 0753223 (2008)
[3] Härtle *et al.*, Phys. Rev. B **98**, 081404 (2018)
[4] Schinabeck *et al.*, Phys. Rev. B **94**, 201407R (2016)

FM 63.10 Wed 16:30 Tents

Tunneling between isolated quasiparticle levels via Cooper pair splitting in an atomic contact — •Haonan Huang[1], Jacob Senkpiel[1], Robert Drost[1], Ciprian Padurariu[2], Simon Dambach[2], Björn Kubala[2], Juan Carlos Cuevas[3], Alfredo Levy Yeyati[3], Joachim Ankerhold[2], Christian R. Ast[1], and Klaus Kern[1,4] — [1]MPI für Festkörperforschung, Germany — [2]Institut für komplexe Quantensysteme, Universität Ulm, Germany — [3]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Spain — [4]EPFL, Switzerland

Tunneling processes between discrete levels have been extensively studied in double quantum dots typically with the size of hundreds of nanometers. Scaling down these devices to the atomic scale remains, however, challenging. One alternative approach is to use scanning tunneling microscopy to build atomic sized tunnel junctions, and use the Yu-Shiba-Rusinov (YSR) states, quasiparticle levels generated by magnetic atoms on a superconductor, as discrete levels. With a scanning tunneling microscope at 15mK, we study the tunneling processes between a YSR state on the tip and a YSR state on the sample, which we call Shiba-Shiba tunneling. While Shiba-Shiba tunneling inherits features of tunneling between discrete levels, the physics is much richer because of the Cooper pair splitting processes involved. Depending on the energy of the Shiba state, four regimes with distinctly different behavior of Shiba-Shiba tunneling exist. This results in different interactions with the environment, which may shed light on the coherence and entanglement of the quasiparticles during tunneling processes.

FM 63.11 Wed 16:30 Tents

Josephson junctions and SQUIDs created by focused helium-ion-beam irradiation of $YBa_2Cu_3O_7$ — •Max Karrer[1], Benedikt Müller[1], Fabienne Limberger[1], Theodor Luibrand[1], Zeynep Kaczmarek[1], Maximilian Becker[1,2], Birgit Schröppel[2], Claus Burkhardt[2], Reinhold Kleiner[1], Edward Goldobin[1], and Dieter Koelle[1] — [1]Physikalisches Institut and Center for Quantum Science (CQ) in LISA+, Universität Tübingen, Germany — [2]NMI Natural and Medical Sciences Institute at the University of Tübingen, Reutlingen, Germany

For epitaxially grown thin films of the high-T_c cuprate superconductor $YBa_2Cu_3O_7$ (YBCO), He focused ion beam (He-FIB) irradiation can be used to directly write Josephson junction (JJ) barriers into the material by driving locally the material into the insulating state [1]. In addition, He-FIB irradiation can also be used to pattern YBCO films on the nanoscale, without removing material [2]; this provides an alternative way to define insulating areas, e.g. for nanoSQUID fabrication. Here, we present our recent progress in the fabrication of He-FIB-induced YBCO JJs and SQUIDs as well as the analysis of their electric transport and noise properties, in particular with respect to the possible control of the critical current density of the JJs by variation of the He-FIB dose [3]. This approach may be also applied to the realization of YBCO-based quantum devices.

[1] S. Cybart *et al.*, Nature Nanotechnol. **10**, 598–602 (2015).
[2] E. Y. Cho *et al.*, Appl. Phys. Lett. **113**, 022604 (2018).
[3] B. Müller *et al.*, Phys. Rev. Applied **11**, 044082 (2019).

FM 63.12 Wed 16:30 Tents

Crossed Andreev reflection in 3d TI-superconductor nanowire hybrid systems — •Michael Barth, Jacob Fuchs, Cosimo Gorini, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

3d topological insulator (TI) nanowires are materials with helical surface states which are protected by time-reversal symmetry [1]. By bringing a normal s-wave superconductor into close proximity to such a wire one can create a topologically non-trivial superconducting state. Furthermore, in such hybrid systems of normal and superconducting materials the process of crossed Andreev reflection (CAR) [2] can occur. This is the effect we are interested in and therefore we are studying quantum transport in a 3d T-junction of normal TIs and a topological superconductor with additional external magnetic fields. Even though in 2d TI systems this phenomenon can be fully suppressed [3], our full 3d numerical simulations show clear signatures of CAR. Moreover in our setup the CAR can in principle be tuned by the external magnetic fields.

[1] J. Ziegler et al., Phys. Rev. B 97, 035157 (2018)
[2] G. Falci, D. Feinberg, and F. W. J. Hekking, EPL 54, 255 (2001)
[3] P. Adroguer et al., Phys. Rev. B 82, 081303 (2010)

FM 63.13 Wed 16:30 Tents

Physical implementation of quantum walks in effective Dirac systems — •Vanessa Junk, Phillipp Reck, Cosimo Gorini, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

Scientific interest in quantum walks (QW) [1] originally arose in the field of quantum computation since QWs can replace classical random walks and thus pose a powerful tool to speed up classical algorithms. In the last years however, QWs have become particularly promising to simulate different topological phases [2].

We will present how to physically implement such a QW in an effective Dirac system like graphene. Our proposal is based on the extension of the concept of the Quantum Time Mirror [3]. In the latter, a pulse coupling both branches of the Dirac cone is used to split an initial wave-packet into two parts moving in opposed directions. The amplitudes of the two parts can be adjusted via the pulse length. Hence, the pulse represents the 'coin toss' [4] in general QWs with the advantage of offering additional degrees of freedom. By periodically repeating the pulse, the initial wave-packet performs a QW. Since the walk is realized in a spatially continuous Dirac system instead of on a fixed graph, we can arbitrarily time the pulses and create a further variety in the resulting probability distribution of the wave-packet in space.

[1] Y. Aharonov, et al., Phys. Rev. A **48**, 1687-1690 (1993)
[2] T. Kitagawa, Quantum Inf Process **11**, 1107 (2012)
[3] P. Reck, et al., Phys. Rev. B **95**, 165421 (2017)
[4] J. Kempe, Contemporary Physics **44**, 307-327 (2003)

FM 63.14 Wed 16:30 Tents

Electronic transport in the spinless Falicov-Kimball model with inhomogeneous charge orderings — •Rudolf Smorka, Martin Zonda, and Michael Thoss — Albert-Ludwigs-Universität Freiburg, Institute of Physics

The ordered phases of the spinless Falicov-Kimball model (FKM) outside the particle-hole symmetric point display a variety of stable inhomogeneous charge orderings. These include exotic charge stripes and charge segregation orderings which are also observed experimentally in various strongly correlated materials. In our work, we investigate theoretically how different ordered phases, both homogeneous and inhomogeneous, influence the non-equilibrium charge transport through a correlated material. We focus on a heterostructure, where a two-dimensional correlated system modelled by FKM on a square lattice is sandwiched between two non-interacting semi-infinite leads. First, we determine the ground state configurations of the central system as a function of chemical potential by employing a canonical Monte-Carlo based simulated annealing procedure. Then we couple the system to the leads with mutually shifted chemical potentials used to introduce a non-equilibrium steady state. The transmission function and the current-voltage characteristics are approached with a non-equilibrium Green's function technique for various stable phases. We show, that different orderings lead to qualitatively different transport characteristics showing metallic, insulating or even multi-gap properties. The study of the most interesting cases is further extended to finite temperatures.

FM 63.15 Wed 16:30 Tents

Complex magnetic and dielectric properties of pyrochlore compounds with application potential for quantum technology — •Thomas Herrmannsdörfer and Sumanta Chattopadhyay — Hochfeld-Magnetlabor Dresden (HLD-EMFL), Helmholtz-Zentrum Dresden - Rossendorf (HZDR), Dresden, Germany

We report the magnetic and dielectric properties of selected pyrochlore compounds such as $Ho_2Ti_2O_7$, $Pr_2Hf_2O_7$ and $Nd_2Hf_2O_7$. In this material class, the particular balance of magnetic interactions between rare-earth Ising spins which are located on a network of corner sharing tetrahedra leads to a wide spectrum of frustrated magnetic ground states, such as spin ice and quantum spin ice behavior as well as all-in-all-out antiferromagnetism. We highlight these properties in the context of their potential use for future quantum technological applications.

FM 63.16 Wed 16:30 Tents

Spectroscopic investigation of the neutral charge state of the tin-vacancy centre in diamond — •Johannes Görlitz[1], Dennis Herrmann[1], Morgane Gandil[1], Philipp Fuchs[1], Gergö Thiering[2], Takayuki Iwasaki[3], Takashi Taniguchi[4], Mutsuko Hatano[3], Adam Gali[2], and Christoph Becher[1] — [1]Fachrichtung 7.2, (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken, Germany — [2]Wigner Research Centre for Physics, Institute for Solid State Physics and Optics, Hungarian Academy of Sciences, Hungary — [3]Department of Electrical and Electronic Engineering, Tokyo Institute of Technology, Meguro, Tokyo 152-8552, Japan — [4]Advanced Materials Laboratory, National Institute for Material Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

Colour centres in diamond, in particular the well studied nitrogen vacancy centre (NV), are highly suitable to tackle many of the challenges occuring in quantum information processing and furthermore constitute sensitive electrical and magnetic field sensors. Nevertheless there are major limitations to the usefulness of the NV centre like the severe spectral diffusion and low photon emission rates into the zero phonon line. A promising candidate in order to outperform the NV in this areas and still maintain its excellent spin coherence is the neutral tin vacancy centre (SnV(0)). Spectral diffusion should be minimized due to its inversion symmetry and theoretical ab initio calculations predict a high Debye-Waller factor and long spin coherence. We here provide experimental evidence of the SnV(0) including emission spectra and the charge transition from the negative to the neutral charge state.

FM 63.17 Wed 16:30 Tents

Spectroscopy of the negatively charged tin-vacancy centre in diamond — •Dennis Herrmann[1], Johannes Görlitz[1], Morgane Gandil[1], Philipp Fuchs[1], Takayuki Iwasaki[2], Takashi Taniguchi[3], Mutsuko Hatano[2], and Christoph Becher[1] — [1]Fachrichtung 7.2, (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken, Germany — [2]Department of Elec-

trical and Electronic Engineering, Tokyo Institute of Technology, Meguro, Tokyo 152-8552, Japan — [3]Advanced Materials Laboratory, National Institute for Material Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

Colour centres in diamond have proven their suitability for applications in quantum information processing. While the nitrogen-vacancy centre (NV) offers milliseconds spin-coherence times at room temperature, the silicon-vacancy (SiV) centre shows superior optical properties such as negligible spectral diffusion and high photon emission rates into its zero phonon line. Phonon mediated effects that have been identified as the source of decoherence in the SiV centre can be supressed for the negatively charged tin-vacancy (SnV(-)) centre due to its larger ground state splitting rendering it a promising candidate for reaching long spin-coherence times already at liquid helium temperatures. We present the SnV(-) centre's optical properties such as lifetime, polarization as well as the temperature dependence of linewidth, line shift and Debye-Waller factor. Furthermore we show lifetime-limited transition linewidths and investigations on the charge state stability under resonant excitation and spectral diffusion of single centres.

FM 63.18 Wed 16:30 Tents

Characterization of in-house grown CVD diamond with NV centers — •Tingpeng Luo[1], Lukas Götz[1], Brett Johnson[2], David Simpson[2], Liam Hall[2], Di Wang[2], Julia Langer[1], Volker Cimalla[1], and Jan Jeske[1] — [1]Fraunhofer IAF, Freiburg, Germany — [2]The University of Melbourne, Melbourne, Australia

Nitrogen-vacancy (NV) centers in diamond with its special optical and spin properties have become a promising instrument for quantum sensing. For sensitive sensing with high NV density, we aim to combine chemical vapour deposition (CVD) growth and consecutive characterization to optimize material parameters, which often are contrary in demand: High NV density concentration, yet long coherence time, low absorption or low birefringence. We design a systematic procedure to investigate the quality of in-house grown NV ensemble CVD diamonds, comparing our CVD diamond with type 1b high-pressure-high-temperature (HPHT) diamond. Multiple methods such as EPR, FTIR, photoluminescence maps, ODMR, UV-Vis spectroscopy and birefringence measurements are applied in the characterization work, to investigate the NV center formation in the synthesis procedure, the absorption, and the birefringence. Moreover, we take ODMR and coherence time measurements to investigate the spin properties. These methods give preliminary results of our first grown CVD diamond series, which assist to establish a further growth plan.

FM 63.19 Wed 16:30 Tents

Nanostructuring diamond with self-organized metal droplets as etching mask — •Patricia Quellmalz, Christian Giese, Peter Knittel, and Christoph Nebel — Fraunhofer Institute for Applied Solid State Physics, 79108 Freiburg, Germany

Diamond has many applications due to its outstanding properties, notably the mechanical hardness, wide optical window or chemical inertness. Nitrogen vacancy centers bring diamond further into focus, especially for quantum technology. Electron beam lithography is state-of-the-art to pattern nanometer-sized features. This technique offers high resolution but is laborious and expensive. A viable alternative is patterning via dewetted metals. By yielding high-aspect diamond nanostructures with enormous surface enlargement, it is of great interest for electrochemical or quantum applications (e.g. supercapacitors or room-temperature hyperpolarisators). We present this fast and low-cost way to nanostructure wafer-scale, polycrystalline diamond (PCD). The PCD is patterned top-down by inductively coupled plasma reactive ion etching (ICP-RIE) employing randomly distributed metal droplets as mask. These nanometer-sized droplets form after dewetting a thin evaporated metal film via rapid-thermal annealing. Various metals and layer thicknesses for mask formation on in-house grown layers of intrinsic and heavily boron doped PCD are investigated in addition to different plasma etching parameters. The material shows a dark black color, which points to strong light absorbance in the visible due to the nanostructuring. We achieve an increase in surface area with micrometer deep coral-like structures of some ten-nanometer size.

FM 63.20 Wed 16:30 Tents

VLS-Growth and characterization of bulk-insulating topological insulator nanowires — •Felix Münning[1], Oliver Breunig[1], Zhiwei Wang[1], Mengmeng Bai[1], Stefan Roitsch[2], Klaus Meerholz[2], Thomas Fischer[3], Sanjay Mathur[3], and Yoichi Ando[1] — [1]Physics Institute II, University of Cologne — [2]Institute of Physical Chemistry, University of Cologne — [3]Institute of Inorganic Chemistry, University of Cologne, Germany

We report on the growth of $Bi_xSb_{2-x}Te_3$ and $Bi_2Te_xSe_{3-x}$ nanowires and their characterizations in terms of morphology, material composition and electronic transport at low temperatures. Growth is performed using the vapour-liquid-solid (VLS) method on Si/SiO_2 substrates decorated with 20-nm Au nanoparticles and devices featuring ohmic contacts to the nanowires are fabricated using electron-beam lithography.

$Bi_xSb_{2-x}Te_3$ nanowires were successfully grown in a bulk-insulating composition, with the chemical potential tunable through the Dirac point by electrostatic gating. While in $Bi_2Te_xSe_{3-x}$ the charge-neutrality point could not be reached, the transport appears to be cleaner, featuring AB-like oscillations over a wide range of the chemical potential within the band-gap.

The observed signatures of the topological surface states are modeled on the basis of their size-quantized sub-bands within the insulating band-gap.

FM 63.21 Wed 16:30 Tents

Recovering the homogeneous absorption of SiV^--ensemble — •Anna Breunig[1], Ohr Lahad[2], Johannes Görlitz[1], Eilon Poem[2], Ofer Firstenberg[2], and Christoph Becher[1] — [1]Universität des Saarlandes, Saarbrücken 66123, Germany — [2]Weizmann Institute of Science, Rehovot 76100, Israel

The negatively-charged silicon-vacancy centre in diamond is a promising system for quantum information processing due to its optically accessible spin states and all-optical coherent spin control, its long spin coherence time (albeit at very low temperatures) and its exceptional homogeneity of optical transitions. The latter recently enabled the demonstration of strong light-matter interactions in an ensemble of SiV^- centres [1] putting within reach applications such as quantum memories or single-photon nonlinearities. However, inhomogeneous broadening due to the local crystal strain remains a limiting factor. To circumvent this limitation, we investigate recovery of the homogeneous absorption line based on light shifts introduced by auxiliary fields. We here present calculations according to the scheme in [2] for a SiV^--ensemble and discuss possible applications.

[1] C.Weinzetl et al., Phy. Rev. Lett. 122, 063601 (2019).
[2] arXiv:1904.06233v2 [quant-ph]

FM 63.22 Wed 16:30 Tents

Anomalous and topological Hall effect in magnetically doped topological insulator thin films — •Gertjan Lippertz[1,2], Andrea Bliesener[1], Alexey Taskin[1], Lino Pereira[2], and Yoichi Ando[1] — [1]Institute of Physics II, University of Cologne, Germany — [2]Instituut voor Kern- en Stralingsfysica, KU Leuven, Belgium

Breaking TRS in a topological insulator (TI) by magnetic doping opens an energy gap at the Dirac point on the top and bottom surface. Thin films of this kind of gapped topological insulator exhibit new quantum phenomena, including the quantum anomalous Hall effect (QAHE), where spontaneous magnetization leads to a dissipationless spin-polarised edge channel and a quantized Hall resistance of h/e^2 [1]. Furthermore, an additional topological Hall component has recently been observed in such samples, possibly originating from the formation of Skyrmions [2].

Here we report on our observation of the anomalous and topological Hall effect in V- and Cr-doped $(Bi_xSb_{1-x})_2Te_3$ films grown by MBE. We will show how a gradient in the Bi/Sb ratio along the growth direction leads to a broken inversion symmetry and the appearance of an additional topological Hall component at the coercive field. Uniform samples on the other hand show the usual anomalous Hall effect close to the quantized Hall resistance of h/e^2.

References:

[1] C.-Z. Chang et al., Nature Materials 14, 473-477 (2015)
[2] K. Yasuda et al., Nature Physics 12, 555-559 (2016)

FM 63.23 Wed 16:30 Tents

Selective area growth of topological insulator nanowires by molecular beam epitaxy — •Andrea Bliesener[1], Gertjan Lippertz[1,2], Oliver Breunig[1], Alexey Taskin[1], and Yoichi Ando[1] — [1]Institute of Physics II, University of Cologne, Germany — [2]Instituut voor Kern- en Stralingsfysica, KU Leuven, Belgium

Inducing superconductivity into a topological insulator nanowire by proximitizing it with an s-wave superconductor is predicted to give rise to Majorana bound states. [1] This strategy promises a more robust alternative to the conventional semiconductor approach.

To realize this platform, we grow Si_3N_4 on a sapphire substrate and pattern it by electron-beam lithography into nanowire devices. We use this pre-patterned substrate to selectively grow topological insulator nanowires by molecular beam epitaxy. Control of the chemical potential is achieved by a side-gate, alleviating the need for additional fabrication steps after growth. The nanowires are characterized using magneto-transport measurements.

Here we show our first results towards growing bulk insulating $(Bi_{1-x}Sb_x)_2Te_3$ (BST) nanowires which have widths below 100nm. Optimizing the composition between n-type Bi_2Te_3 and p-type Sb_2Te_3 can give almost perfect compensation of charge carriers in BST.

[1] L. Fu and C.L. Kane, Phys. Rev. Lett. 100, 096407 (2008)

FM 64: Poster: Topology

Time: Wednesday 16:30–18:30 Location: Tents

FM 64.1 Wed 16:30 Tents

Majorana bound states in hybrid two-dimensional Josephson junctions with ferromagnetic insulators — •Pauli Virtanen — University of Jyväskylä, Finland

We consider a Josephson junction consisting of superconductor/ferromagnetic insulator (S/FI) bilayers as electrodes which proximizes a nearby two-dimensional (2D) electron gas. We address the 2D bound-state problem by a transfer-matrix approach that reduces the problem to an effective 1D Hamiltonian. We consider a narrow channel coupled with multiple ferromagnetic superconducting fingers, and discuss the topological invariants, spectrum, free energy, and multiterminal Josephson currents of the setup.

FM 64.2 Wed 16:30 Tents

Theory of reflectometry-based readout of topological Majorana qubits — •Vahid Derakhshan Maman and Andras Palyi — Budapest University of Technology and Economics, Budapest, Hungary

Qubits based on Majorana zero modes of topological superconductors are thought to be more noise-resilient than conventional qubits. Readout of these qubits is possible only when the topological protection is temporarily lifted, and therefore it is especially important to understand the error mechanisms that affect the readout process. In this work, we theoretically describe errors in a setup where readout is performed using gate reflectometry of an auxiliary quantum dot that is tunnel-coupled to two Majorana zero modes. We use simple tight-binding models (e.g., the few-site Kitaev chain), and we describe readout error caused by low-frequency charge noise. We quantify the readout error as the function of model parameters (proximity-induced gap, strength of charge noise, system size, etc.), and thereby provide guidelines for the design and interpretation of future dynamical experiments aiming at control and readout of topological Majorana qubits.

FM 64.3 Wed 16:30 Tents

Designing transmon qubits to study topological insulator Josephson junctions in a 3D cavity — •Jonas Krause[1,2], Christian Dickel[1], Junya Feng[1], Richard Bounds[1], Shabir Barzanjeh[3], Johannes Fink[3], and Yoichi Ando[1] — [1]University of Cologne — [2]ETH Zurich — [3]IST Austria

Transmon qubits are a leading platform for quantum computing and have also been used to study unconventional Josephson junctions based on proximitized semiconductor nanowires, graphene and carbon nanotubes. We aim to use a transmon to study topological insulator (TI) Josephson junctions. TI-superconductor hybrid devices are predicted to host Majorana bound states that can be used for topological quantum computing. The transmon has in this context been proposed as a readout circuit via charge-parity detection. However, many proposals require considerable magnetic fields. Copper cavities are unaffected by strong magnetic fields and provide a clean microwave environment, making them ideal for the study of the transmon response to magnetic fields. We first study the magnetic-field dependence in conventional aluminum transmons and then move to TI devices. The transmon design for this purpose leads to a few changes from conventional 3D-cavity transmons: Higher charging energies are likely desirable for investigating quasiparticle poisoning dynamics. We will also investigate the effect of vortex traps on coherence and field resilience of the transmons. As opposed to on-chip resonators, the 3D setup requires minimal fabrication steps, thus implementing a fast and easy-to-use microwave probe station for TI junctions.

FM 64.4 Wed 16:30 Tents

Andreev spectroscopy in topological insulating Josephson junctions — •Richard Bounds[1], Christian Dickel[1], Junya Feng[1], Jonas Krause[1,2], Shabir Barzanjeh[3], Johannes Fink[3], and Yoichi Ando[1] — [1]University of Cologne — [2]ETH Zurich — [3]IST Austria

There are currently multiple efforts to realise a new kind of qubit based on topologically protected Majorana zero modes (MBS). One proposed realization resides in topological insulator nanowires proximitized with an s-wave superconductor. Josephson junctions on topological insulator materials would also host Andreev bound states (ABS). We aim to study the ABS spectrum of a topological insulator junction in the RF SQUID configuration coupled to a microwave resonator, in order to better understand the transport in the junction, in particular its dependence of the phase difference across the junction. Such spectroscopy, performed on planar junctions as well as nanowire junctions, will allows us to directly address the possible 4π periodicity of the Andreev levels and quasiparticle poisoning dynamics. The latter would likely also be a limiting factor for MBS physics and is therefore an important prerequisite experiment toward realising MBS qubits.

FM 64.5 Wed 16:30 Tents

Majorana zero modes in skyrmion-vortex pairs — •Jonas Nothhelfer[1], Kjetil Hals[2], Matteo Rizzi[3,4], and Karin Everschor-Sitte[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany — [2]University of Agder, Grimstad, Norway — [3]Institute of Complex Systems, Forschungszentrum Jülich, Germany — [4]Institute for Theoretical Physics, Universität zu Köln

Ferromagnet-superconductor heterostructures have been shown to allow for novel topological composite excitations - skyrmion-vortex pairs [1], which support the occurrence of Majorana bound states [2]. Their non-abelian exchange statistics makes Majorana modes suitable for topological quantum computation. Our goal is to study the braiding of Majorana zero modes via the controlled motion of skyrmions. For this we model a magnetic skyrmion imprinted in the ferromagnet and a vortex in the superconductor. We solve the eigensystem of the superconductor in the Bogoliubov-de Gennes formalism self-consistently for the superconducting gap under the influence of the magnetic field generated by the magnetic thin film and spin orbit coupling. As predicted by [1] we reproduce that composite topological excitations can emerge as pairs of superconducting vortices bound to magnetic skyrmions. Exploiting the finite binding energy, we expect that moving the skyrmion via methods from the spintronics toolbox will also induce a motion of the vortex and the Majorana zero mode bound to it. [1] Kjetil M. D. Hals, Michael Schecter and Mark S. Rudner, Physical Review Letters **117**, 017001 (2016) [2] Stefan Rex, Igor V. Gornyi, Alexander D. Mirlin, arXiv:1904.04177 (2019)

FM 64.6 Wed 16:30 Tents

Top-down fabrication of gate-tuneable bulk-insulating TI nanowires and their quantum transport — •Matthias Rössler, Dingxun Fan, Felix Münning, Oliver Breunig, Andrea Bliesener, Gertjan Lippertz, Alexey Taskin, and Yoichi Ando — II. Physikalisches Institut, Universität zu Köln, Zülpicher Straße 77, D-50937 Köln, Germany -

With proximity-induced superconductivity, bulk-insulating topological insulator nanowires (TI NWs) are expected to serve as a robust platform for realizing Majorana bound states. When exploiting their non-Abelian exchange statistics, these states could enable topological quantum computation schemes. Compared to previous experiments on semiconductor nanowires, a TI-based platform for MBS is predicted to have relaxed requirements for the tuning of chemical potential and magnetic field, resulting from the inherent property of spin-momentum locking. We have performed fabrication and optimization of TI NWs based on a scalable approach, namely etching of MBE-grown high quality BST thin films. Using this technique, highly gate-tuneable bulk insulating TI NWs with a diameter of less than 100 nm can be prepared to form arbitrary networks. Signatures of a so-called π-shift in Aharonov-Bohm-like transport oscillations indicate an opening and reclosing of the topologically protected 1D zero-gap mode unique to TI NWs with an axial magnetic flux dependent quantized 1D surface subband dispersion. Making use of this platform, we present first results on proximity-induced superconductivity in such TI nanowires.

FM 65: Poster: Quantum & Information Science

Time: Wednesday 16:30–18:30 Location: Tents

FM 65.1 Wed 16:30 Tents

Quantum physics and Cosmology: The secured findings — •Hille Helmut — Fritz-Haber-Sraße 34, 74081 Heilbronn

"Especially in times where physics seems to describe not even five percent of the universe while the rest lies in the dark, it could be worth to put the fundamentals of a science to the test and to revise them." (Quotation by Meinard Kuhlmann, June 2016 in the magazine "Physik Journal"). Before starting with it, I think it is important to realize which secured findings on cosmology there are already today, far from all ideology and hypotheses. As I can point out, these findings and their consequences should be sufficient to create a cosmological conception of the world of great simplicity, clearness and beauty by means of quantum physics using its potential. In this way, quantum physics re-establishes the unity in physics and overcomes the standstill in theoretical physics, which the American physicist Richard Feynman called "The melancholy of the 20th century". Preparations of the text see www.helmut-hille-philosophie.de/freiburg2019.html.

FM 65.2 Wed 16:30 Tents

Quantum Technologies in Applications for Satellite Operations — •Andreas Spörl[1], Nikolas Pomplun[1], Tobias Stollenwerk[2], Florian Moll[3], and Steffen Glaser[4] — [1]DLR-RB MIT OP — [2]DLR-KN SAN OP — [3]DLR-SC HPC KP — [4]TUM Chemie

DLR's German Space Operations Center (GSOC) operates various satellite and human spaceflight missions, ranging from low earth to geostationary orbit, e.g. the Columbus Module at the ISS, several earth-observing missions like TanDEM-X and Firebird or the EuropeanDataRelaySystem. To steadily improve quality of operations, future technologies are always under inspection with respect to their potential for applicability in space and ground operations. Several future applications and methods of quantum technology are currently analyzed by GSOC and its partners: i) QuATHMoS: definition and implementation of an interface between an accessible quantum annealing device (D-WAVE) and an inhouse developed anomaly detection software suite (with DLR-KÖLN); ii) GRAPE4SPACE: application of quantum control methods in satellite attitude control systems (with TUM); iii) Support of upcoming quantum key distributing satellite missions and analysis of how quantum keys can be used in space operations.

FM 65.3 Wed 16:30 Tents

Learning and Planning in Quantum Experiments — •Lea Marion Trenkwalder[1], Hendrik Poulsen Nautrup[1], and Hans J. Briegel[1,2] — [1]Institute for Theoretical Physics, University of Innsbruck, Innsbruck, Austria — [2]Department of Philosophy, University of Konstanz, Konstanz, Germany

The focus of this work lies on the study of artificial learning agents that can be used to design quantum protocols and experiments. As has been shown in earlier work, the structure of many quantum information experiments can be mapped to a navigation problem on a complex maze. Using the projective simulation framework, we present an agent capable of learning and planning in this maze structure and show its applications in quantum information, such as quantum error correction protocols and photonic experiments.

FM 65.4 Wed 16:30 Tents

Applications of Neural Networks on Small-Angle X-Ray Scattering Data — •Thomas Stielow, Paula Respondek, and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock

Modern phase retrieval algorithms allow for a detailed reconstruction of two dimensional electronic densities from small-angle scattering patterns obtained in FEL experiments. However, despite major improvements, such algorithms still suffer from convergence to local minima and perform best if structural information such as the object's silhouette is provided [1]. Deep learning algorithms have recently been employed in the reconstruction of wide-angle scattering patterns [2]. Here we demonstrate how such a procedure can be adopted to the small-angle regime. In particular, we show that deep learning models can both be used in orientation and density reconstruction. The observed reconstruction results are highly stable due to the possibility of including known propeerties of the observed system into the neural network.

[1] T. Ekeberg et al., PRL **114**, 098102 (2015).
[2] T. Stielow et al., arXiv:1906.06883 (2019).

FM 65.5 Wed 16:30 Tents

Theoretical study of structure-property relations in disordered magnetic Fe-Al phases with vacancies — •Ivana Miháliková[1,2], Martin Friák[1,2], Nikola Koutná[2,3], David Holec[4], and Mojmír Šob[5,1,6] — [1]Institute of Physics of Materials, Czech Academy of Sciences, Brno, Czech Republic — [2]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Brno, Czech Republic — [3]Institute of Materials Science and Technology, TU Wien, Vienna, Austria — [4]Department of Materials Science, Montanuniversität Leoben, Leoben, Austria — [5]Department of Chemistry, Faculty of Science, Masaryk University, Brno, Czech Republic — [6]Central European Institute of Technology, CEITEC MU, Masaryk University, Brno, Czech Republic

Vacancies are very common point defects in magnetic phases present in Fe-Al-based superalloys. In particular, when focusing on disordered Fe-rich solid solutions of aluminium in iron, there is enormous number of different local environments of vacancies. The chemical composition and locally distorted structure around each vacancy have a significant impact on its properties. We have performed quantum-mechanical calculations to examine these complex structure-property relations. A series of supercells was used and their thermodynamic, magnetic and structural properties were computed employing density-functional theory [1]. We present a statistical analysis of the obtained data and relations among them.

[1] I. Miháliková, M. Friák, N. Koutná, D. Holec and M. Šob, Materials 12 (2019) 1430; https://doi.org/10.3390/ma12091430.

FM 65.6 Wed 16:30 Tents

Anti-/correlations between environment and magnetism of Fe atoms in disordered magnetic Fe-Al-based materials — •Martin Friák[1,2], Ivana Miháliková[1,2], Nikola Koutná[2,3], David Holec[4], and Mojmír Šob[2,1] — [1]Institute of Physics of Materials, Czech Academy of Sciences, Brno, Czech Republic — [2]Faculty of Science, Masaryk University, Brno, Czech Republic — [3]Institute of Materials Science and Technology, TU Wien, Vienna, Austria — [4]Montanuniversität Leoben, Leoben, Austria

The nano-scale structure of Fe-Al-based superalloys is formed by two coherently co-existing phases. They are typically Fe-rich, magnetic and at least partly chemically disordered [1-3]. Next to this intra-phase disorder, there are numerous interfaces which represent another compositional disorder affecting a few layers of atoms away from the interfaces [4,5]. These two types of disorder result in an enormous number of different local environments of Fe atoms. Importantly, local magnetic moments of Fe atoms are known to sensitively depend on surrounding atoms. We have performed high-throughput quantum-mechanical study of anti-/correlations between the local atomic environment of Fe atoms and their magnetic moments in Fe-Al-based superalloy phases.

[1] M. Friák *et al.*, Materials 11 (2018) 1732.
[2] M. Friák *et al.*, Crystals 9 (2019) 299.
[3] M. Friák *et al.*, Materials 11 (2018) 1543.

[4] I. Miháliková *et al.*, Nanomaterials 8 (2018) 1059.

[5] M. Friák, D. Holec, M. Šob, Nanomaterials 8 (2018) 1057.

FM 66: Poster: Entanglement

Time: Wednesday 16:30–18:30 Location: Tents

FM 66.1 Wed 16:30 Tents

Macroscopic boundary effects in the one-dimensional extended Bose-Hubbard model — •Sebastian Stumper, Junichi Okamoto, and Michael Thoss — University of Freiburg, Germany

The one-dimensional extended Bose Hubbard model shows various quantum phases due to its competing interactions. For large on-site interactions, a Mott insulating (MI) phase exists, while a charge density wave (CDW) phase becomes dominant for large nearest-neighbour interactions. In between these phases a topologically non-trivial phase of a Haldane insulator (HI) appears [Phys. Rev. Lett. 97, 260401 (2006)]. Ground state properties and low energy spectra are, however, very sensitive to the treatment of boundary conditions [arXiv:1403.2315 (2014)].

We study an open chain of the extended Bose Hubbard model with different edge potentials using the density matrix renormalization group method based on matrix product states [Comput. Phys. Commun. 225, 59 (2018)]. Without edge potentials, the CDW and HI phases exhibit a non-degenerate ground state, and the order parameters change signs in the middle of the chain. This feature is robust against finite size scaling and is explained by a simple effective picture for the low energy states. On the other hand, with large edge potentials, the sign change of the order parameters disappears, and we recover uniform bulk ground states. The effect of the boundary conditions on the entanglement spectrum is also investigated.

Furthermore, we elaborate on the quench dynamics and discuss the results in terms of our findings on the equilibrium phases.

FM 66.2 Wed 16:30 Tents

Robustness of Topological Order in Toric Code in various setups — •Amit Jamadagni Gangapuram and Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover, Hannover, Germany.

We analyze the robustness of topological order in the toric code in various setups with open boundaries. We probe for the presence of a possible phase transition in (a) closed systems in the presence of external perturbation (b) interpolating different topological phases both in closed and open setups. For the latter, we show that interpolating the underlying topology as well as interpolating between different boundaries induces a phase transition in closed systems and we further extend this to study similar behavior in open systems by engineering effective dissipative collapse operators. To detect the phase transition we compute different numerical signatures like the Ground State Degeneracy (GSD), Topological Entanglement Entropy (TEE), Minimally Entangled States (MES), the expectation of the loop operator among others. The open boundary conditions introduce cases with non-degenerate ground states leading to an interesting analysis of topological order, both in open and closed systems.

FM 66.3 Wed 16:30 Tents

Dynamical driving a Cavity-BEC System from self-organized into non equilibrium — •Christoph Georges[1], Hans Kessler[1], Jayson G. Cosme[1,2], Ludwig Mathey[1,2], and Andreas Hemmerich[1,2] — [1]Institut für Laser-Physik and Zentrum für Optische Quantentechnologien, Universität Hamburg, D-22761 Hamburg, Germany — [2]The Hamburg Center of Ultrafast Imaging, Luruper Chaussee 149, D-22761 Hamburg, Germany

The generation and manipulation of density wave order in many body systems are considered as models for solid-state phenomena such as light-induced superconductivity.

In our recent research, we investigated the role of modulation on the formation of long-range order in a Cavity-Atom System. For this, a Bose-Einstein Condensate of Rubidium Atoms is placed inside the light field of a high finesse cavity. By pumping the atoms with a sufficient strong transversal optical standing wave, the system can go through a phase transition. The arising phase is characterized by an intracavity light field due to the formation of particle density waves [1].

By modulating the amplitude of pump field, the DW-order can either be suppressed [2] or new DW-orders can be excited [3]. In the present work, we modulated the light field with a frequency close to a collective resonance. We observe the excitation of a higher DW-order and the rise of a subradiant non-equilibrium phase.

[1] J. Klinder et. al. PNAS 112, 3290 (2015)
[2] Ch. Georges et. al. PRL 121, 220405 (2018)
[3] J. G. Cosme et. al. PRL 121, 153001 (2018)

FM 66.4 Wed 16:30 Tents

Initial-state dependence of the long-time dynamics in a spin-boson system — •Sebastian Wenderoth and Michael Thoss — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Thermalization of a system refers to the process of approaching a unique steady state that depends only on a few macroscopic observables. Triggered by the development of new experimental tools, the question how an isolated quantum system can equilibrate to such a state under its own dynamics has recently received renewed interest. Various numerical studies suggest that subsystems of isolated quantum systems can equilibrate under unitary time evolution. This relaxation is caused by the remainder of the system acting as an effective bath. However, as the hybridization between the subsystem and the remainder increases this simple picture breaks down and the influence of the remainder on the subsystem can change qualitatively.

Inspired by a recent experiment with trapped-ions [1], we investigate a special type of a spin-boson model. Employing the multilayer multiconfiguration time dependent Hartree method [2], we simulate the dynamics of the system in a numerically exact way. As a function of the spin-boson coupling, we observe a qualitative change of the dynamics of the spin, induced by the coupling to the bosonic modes, ranging from the usual relaxation dynamics for small couplings to non-stationary long-time states of the spin that depend on its initial state.

[1] G.Glos *et al.*, Phys. Rev. Lett. **117**, 170401 (2016)
[2] H. Wang *et al.*, J. Chem. Phys. **119**, 1289 (2003)

FM 66.5 Wed 16:30 Tents

Optimal Control of Schrödinger cat states of increasing size — •Matthias G. Krauss and Christiane P. Koch — Theoretische Physik III - Universität Kassel, D-34132 Kassel, Germany

"Schrödinger cat states" are non-classical superposition states that are useful in quantum information science, for example for computing or sensing. Optimal control theory provides a powerful tool for preparing these superposition states, for example in experiments with superconducting qubits [Ofek et al., Nature 536, 441445 (2016)]. The optimized control fields and the resulting dynamics are typically rather complex and an in depth analysis of dynamics is often omitted. Our goal is to analyze the underlying control mechanisms for Schrödinger cat state preparation and understand the physical strategies found by the algorithm. In particular, our objective is the generation of different cat states in a Bose-Hubbard model with increasing particle number. We use Krotovs method [Reich et al., J. Chem. Phys. 136, 104103 (2012)] to generate the different cat states, analyze the dynamics induced by the optimized fields and investigate whether the control mechanism varies as the particle number is increased.

FM 66.6 Wed 16:30 Tents

Non-equilibrium states of two coupled oscillators and entanglement spectra — •Carsten Henkel — University of Potsdam, Institute of Physics and Astronomy, Germany

We study models of coupled quantum systems that are driven out of (local) equilibrium by coupling to different heat baths [1–6]. Two coupled oscillators, each embedded in its “own” bath of oscillators, provide a simple, analytically solvable system. We study fluctuation-dissipation relations and correlation functions (covariance matrices) beyond the Markov and rotating-wave approximations. Deviations from local equilibrium provide a characterisation in the frequency domain of the entanglement between the two oscillators [2]. Interesting generalisations may involve coupled spins or spin baths. Relevant applications are heat transport [1,4–6] and single molecular emitters coupled to nano-antennas [7].

[1] A. Pérez-Madrid, J. M. Rubí, and L. C. Lapas, Phys. Rev. B 77 (2008) 155417
[2] Anne Ghesquière, Ilya Sinayskiy, and Francesco Petruccione, Phys. Scr. 2012 (2012) 014017
[3] I. Dorofeyev, Can. J. Phys. 91 (2013) 537
[4] Svend-Age Biehs and Girish S. Agarwal, J. Opt. Soc. Am. B 30 (2013) 700
[5] Gabriel Barton, J. Phys. Condens. Matt. 27 (2015) 214005
[6] Gabriel Barton, J. Stat. Phys. 165 (2016) 1153
[7] Ruben Esteban, Javier Aizpurua, and Garnett W Bryant, New J. Phys. 16 (2014) 013052

FM 66.7 Wed 16:30 Tents

Entanglement between Yu-Shiba-Rusinov states in STM devices — •Ciprian Padurariu[1], Haonan Huang[2], Simon Dambach[1], Björn Kubala[1], Christian Ast[2], and Joachim Ankerhold[1] — [1]Institute for Complex Quantum Systems and IQST, Ulm University, 89069 Ulm, Germany — [2]Max-Planck-Institut für Festkörperforschung, 70569 Stuttgart, Germany

We study the theory and experimental realization of tunneling between tip and substrate Shiba states in superconducting STM devices operating at 15 mK. We show that the elementary transport process involves splitting a Cooper pair, thereby entangling the spin of quasiparticles localized in the subgap states.

Our simple analytical results are in good agreement with conductance measurements exhibiting peaks in the tunnel current at a number of sub-gap bias voltages. [1] The voltages are identified as resonances of sub-gap discrete magnetic states, so called Shiba states, that form inside a volume around the magnetic impurity of coherence length size. [2]

The tunnel current between Shiba states gives rise to new resonances. These narrow current peaks are a result of the interplay between spin-entangled quasiparticle pairs and slow decoherence processes arising due to quasiparticle poisoning.

[1] M. Ruby, F. Pientka, Y. Peng, F. von Oppen, B. W. Heinrich, and K. J. Franke, Phys. Rev. Lett. 115, 087001 (2015).
[2] M. I. Salkola, A. V. Balatsky, and J. R. Schrieffer, Phys. Rev. B 55, 12648 (1997).

FM 66.8 Wed 16:30 Tents

Entangled optical clock states in ^{40}Ca^{+} — •Ludwig Krinner[1], Kai Dietze[1], Lennart Pelzer[1], Stephan Hannig[1], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

Single ion optical clocks are limited in their statistical uncertainty by quantum projection noise. Increasing the number of ions while maintaining low systematic uncertainties is demanding. In such a situation, entangling atoms on an optical transition can improve the statistical uncertainty. Furthermore, using especially engineered quantum states, the transition can be made free of the linear Zeeman shift. We present in this poster progress towards preparing a pair of ^{40}Ca^{+} ions in a decoherence free entangled subspace, which is both robust against magnetic field fluctuations and allows shorter interrogation times for a given stability (compared to two uncorrelated ions). We present first results on a successful implementation of Mølmer Sørensen entangling gates and discuss possible avenues of reaching the decoherence free subspace.

FM 67: Outreach: Public panel discussion (fishbowl format)

Time: Wednesday 19:30–21:00 Location: Audi Max

Discussion FM 67.1 Wed 19:30 Audi Max

Forschung zwischen Hype und Hope – Welche Bedingungen braucht gute Wissenschaft? — Jürgen Kaube[1], Jeanne Rubner[2], Joachim Ullrich[3] und Reinhard Werner[4] — [1]Frankfurter Allgemeine Zeitung, Frankfurt a.M. — [2]Bayerischer Rundfunk, München — [3]Physikalisch-Technische Bundesanstalt, Berlin — [4]Leibniz Universität Hannover

Welche Rolle soll Wissenschaft in einer offenen Gesellschaft haben? Darüber sind sich Wissenschaft, Politik und Gesellschaft zunehmend uneins. Das Grundgesetz garantiert einerseits Wissenschaftsfreiheit. Andererseits steigen die Erwartungen an die Forschung, vor allem in Hinsicht auf wirtschaftliche Verwertbarkeit. Universitäten sollen außerdem immer größere Studentenzahlen bewältigen und sind doch chronisch unterfinanziert. Die Wissenschaftspolitik fördert lieber Projekte statt Köpfe, was kurzlebige Trends und Gewissheiten mehr begünstigt als mühsam errungene und schwer kommunizierbare Einsichten. Pointierte Behauptungen versprechen Wettbewerbsvorteile, kritische Rückfragen und Zweifel dagegen – obwohl Kernelement der wissenschaftlichen Methode – sind wenig werbewirksam und mit kurzen Zeithorizonten schwer vereinbar. So stehen Wissenschaftler zunehmend in der Gefahr, zu Lobbyisten ihrer partikularen Forscherinteressen zu werden – statt für Wahrhaftigkeit als wichtigster Voraussetzung für die Glaubwürdigkeit des Wissenschaftsbetriebs einzustehen. In einem von Jeanne Rubner moderierten Gespräch werden Jürgen Kaube, Joachim Ulrich und Reinhard Werner Bedingungen für und Erwartungen an gute Wissenschaft untereinander, sowie im Austausch mit dem Publikum erörtern.

FM 68: Plenary Talk: Silicon Based Quantum Computing

Time: Thursday 8:30–9:30 Location: Audi Max

Plenary Talk FM 68.1 Thu 8:30 Audi Max

Silicon Based Quantum Computing — •Michelle Simmons — Centre of Excellence for Quantum Computation and Communication Technology, School of Physics, University of New South Wales, Sydney NSW 2052 Australia

Down-scaling has been the leading paradigm of the semiconductor industry since the invention of the first transistor in 1947. However miniaturization will soon reach the ultimate limit, set by the discreteness of matter, leading to intensified research in alternative approaches for creating logic devices. One of the most exciting of these is quantum computation. We will present devices that address the ultimate limit of device miniaturization in silicon where we have patterned dopants in a crystalline environment with atomic precision to act as one dimensional leads, single electron transistors and control gates. During this talk I will focus on demonstrating fast, high fidelity single-shot spin read-out, ESR control of precisely-positioned P donors in Si and our recent results to demonstrating a two-qubit gate. We will discuss the benefits of donors as qubits and show our progress to achieving truly atomically precise devices in all three spatial dimensions.

FM 69: Introductory Talk: Hybrid Quantum Computation Platform

Time: Thursday 9:30–10:30 Location: Audi Max

Introductory Talk FM 69.1 Thu 9:30 Audi Max
Hybrid Spin-Superconducting Circuits for Spin-Sensing and Quantum Information — Bartolo Albanese, Jessica-Fernanda Da Silva Barbosa, Emanuele Albertinale, Marianne Le Dantec, Vishal Ranjan, Moonjoo Lee, Milos Rancic, Emmanuel Flurin, Denis Vion, Patrice Bertet, and •Daniel Esteve — Quantronics group, SPEC, CEA,CNRS, Université Paris-Saclay, CEA Saclay 91191 Gif-sur-Yvette, France

The discovery in the mid 1980s that quantum mechanics provides resources for performing computational tasks beyond reach of machines with a classical Von Neumann architecture triggered an intense research of the quantum bits needed for making a quantum computer. In the domain of electrical circuits, superconducting quantum bits based on Josephson junctions are presently the most advanced qubits. I will describe the single Cooper pair box circuit, its transmon version used nowadays, and the operation of an elementary quantum processor. I will explain the scalability challenge induced by quantum error correction, and the alternative routes for facing it. The one we develop is based on spins with superior quantum coherence coupled to quantum superconducting circuits. I will present the progress achieved in the control of a small number of electronic spins, and the perspectives open for quantum information processing.

FM 70: Special Session: Topology

Time: Thursday 11:00–13:00 Location: Audi Max

Invited Talk FM 70.1 Thu 11:00 Audi Max
Hofstadter Topology — •Bogdan A. Bernevig — Princeton University, Department of Physics, Princeton, NJ, USA

A new type of topological stars arise I twisted Moire compounds. We show how they are different from bulk sample topology, as well as how they can be achieved in moderate magnetic fields under Moire conditions.

Invited Talk FM 70.2 Thu 11:30 Audi Max
Topological superconductors and Majorana fermions — •Yoichi Ando — Physics Institute II, University of Cologne, 50937 Cologne, Germany

In this talk, I will give a general introduction to topological superconductivity and Majorana fermions [1], and explain why spin-orbit coupling is useful for generating such novel states of matter. The distinction between dispersive Majorana fermions and localized Majorana zero modes is emphasized; the former are mobile quasiparticles to contribute to novel transport properties in superconducting surface/edge, while the latter obey the non-Abelian statistics and can be used for topological quantum computing. As a material class to realize the former, I will elaborate on the nematic topological superconductors derived from the topological insulator Bi_2Se_3. For the localized Majorana zero modes, I will introduce the concept for using them for topological quantum computing and present our efforts to realize them in proximitized topological insulators.
[1] M. Sato and Y. Ando, Rep. Prog. Phys. **80**, 076501 (2017).

Invited Talk FM 70.3 Thu 12:00 Audi Max
Majorana bound states in hybrid superconductor-semiconductor systems — •Karsten Flensberg — Niels Bohr Institute, University of Copenhagen

It has been theoretically predicted that topological superconductivity can be engineered in hybrid superconductor-semiconductor systems and many experiments have by now realized such candidate systems. In the talk, I will discuss ways to discern Majorana bound states from other non-topological states in transport measurement. Moreover, the talk will discuss proposals for the steps towards showing the nonlocal and nonabelian physics that is theoretically expected for a system of Majorana bound states.

Invited Talk FM 70.4 Thu 12:30 Audi Max
Status of the search for Majorana zero modes in semiconductor nanowires — •Sergey Frolov — University of Pittsburgh

Majorana modes are non-trivial quantum excitations that have remarkable topological properties and can be used to protect quantum information against decoherence. Tunneling spectroscopy measurements on one-dimensional superconducting hybrid materials have revealed signatures of Majorana zero modes which are the edge states of a bulk topological superconducting phase. We couple strong spin-orbit semiconductor InSb nanowires to conventional superconductors (NbTiN, Al) to obtain additional signatures of Majorana modes and to explore the topological phase transition. A potent alternative explanation for many of the recent experimental Majorana reports is that a non-topological Andreev state localizes near the end of a nanowire. We compare Andreev and Majorana modes and investigate ways to clearly distinguish the two phenomena. We explore new materials combinations in the broad superconductor-semiconductor family to find a perfect pair for the realization of topological quantum bits. I will present our progress towards assembling the apparatus for the future Majorana fusion and braiding experiments.

FM 71: Focus Talk: Quantum Control

Time: Thursday 11:00–12:00 Location: 2004

Focus Talk FM 71.1 Thu 11:00 2004
Optimal control of quantum systems — •Steffen J. Glaser — Technische Universität München

Quantum systems can be manipulated by external controls, such as sequences of electromagnetic pulses. Optimal Control Theory offers powerful analytical and numerical tools to explore the physical limits of pulse sequences, providing not only pulse sequences of unprecedented performance but also a deeper understanding of the principles on which the optimal pulse sequences are based (1).

In this focus talk, important concepts of Optimal Control Theory will be reviewed and illustrated with examples of uncoupled and coupled spins/qubits. Furthermore, the concept of concurrently optimized cooperative (COOP) pulses will be discussed. In contrast to individually optimized pulses for a given sub task, COOP pulses provide significant performance gains with respect to the overall task. Examples include ultra-broadband Ramsey and Hahn echo sequences (2,3) for quantum sensing and spectroscopy.

The analysis and the design of quantum control experiments is further enhanced by novel interactive visualization tools based on a generalized Wigner representation. The DROPS representation (4) of spin operators and its implementation in the SpinDrops app (5) make it possible to design and analyze pulse sequences interactively.

References: (1) Glaser et al, Eur Phys J D 69, 279 (2015); (2) Braun et al, New J Phys 16, 115002 (2014); (3) Kallies et al, J Magn Reson 286, 115 (2018); (4) Garon et al, Phys Rev A 91, 042122 (2015); (5) Glaser et al, www.spindrops.org.

FM 72: Lunch Talk: Start-ups

Time: Thursday 12:30–13:45 Location: 2006

Curious about the Dos and Don'ts starting and running your company?

Which ideas could spark off a new company? And what about the enthusiasm, endurance is necessary to overcome all the trapdoors in financing, bureaucracy and selling? In this podium discussion founders of start-up companies will present their companies and tell you about the story behind. They will let you know about the good, the bad and the ugly experiences and about all the useful stuff a physicist never learned at an university.

FM 73: Quantum Sensing: Applications & Spectroscopy

Time: Thursday 14:00–16:00 Location: Aula

FM 73.1 Thu 14:00 Aula

Resolving the positions of defects in superconducting quantum bits — •Alexander Bilmes[1], Anthony Megrant[2], Paul Klimov[2], Julian Kelly[2], Rami Barends[2], John M. Martinis[2], Gerog Weiss[1], Alexey V. Ustinov[1,3], and Juergen Lisenfeld[1] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Google Inc., Santa Barbara, USA — [3]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

We demonstrate a new technique to identify the spatial positions of decoherence-inducing material defects known as Two-Level-Tunneling systems (TLS) in superconducting qubits. For this, we operate a transmon qubit circuit in a DC-electric field that is generated by several electrodes surrounding the sample chip, and study the TLS response by monitoring their resonance frequencies using qubit swap spectroscopy. By comparing measured and simulated coupling strengths of TLS to each DC-electrode, we obtain information about the defect's location and the circuit interface at which it resides. This provides a viable tool applicable to various qubit types, which enables one to optimize qubit fabrication procedures by directly indicating which circuit interfaces must be improved in order to enhance qubit coherence.

FM 73.2 Thu 14:15 Aula

Probing Defects in Superconducting Qubits with Electric Fields — •Jürgen Lisenfeld[1], Alexander Bilmes[1], Anthony Megrant[2], Julian Kelly[2], Rami Barends[2], Paul Klimov[2], John M. Martinis[2], Georg Weiss[1], and Alexey V. Ustinov[1,3] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Google Inc., Santa Barbara, USA — [3]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

The coherence of superconducting quantum bits is severely reduced by atomic-scale material defects which provide a bath of parasitic two-state tunneling systems, so-called TLS. Here, we present a method to distinguish TLS contained in the tunnel barriers of the qubit's Josephson junctions from TLS residing on the surfaces of superconducting electrodes or the substrate. For this, we characterize the defect's responses to applied mechanical strain and electric DC-fields using the qubit as a sensor.

We find that 60% of the total dielectric loss in the investigated Xmon-qubit is due to defects on film interfaces and the substrate, while 40% comes from TLS in the tunnel barriers of Josephson junctions. Measurements of the TLS-qubit coupling strengths reveal that only about 3% of all defects are residing in the small qubit tunnel junctions, while most are contained in the large stray junctions that are used as wiring interconnects. The presented methods guide the way towards improved qubit coherence by indicating the critical circuit interfaces and fabrication steps that are promoting defect formation.

FM 73.3 Thu 14:30 Aula

Biomagnetic measurements with optically pumped magnetometers — •Thomas Middelmann, Stefan Hartwig, Victor Lebedev, Anna Jodko-Wladzinska, Rüdiger Brühl, Lutz Trahms, and Tilmann H. Sander — Physikalisch-Technische Bundesanstalt, Berlin, Germany

Optically pumped magnetometers (OPMs) pose an alternative method to measure tiny magnetic fields (fT-range) for applications that before could only be realized by superconducting quantum interference devices (SQUIDs) which essentially rely on cryogenic cooling. Biomagnetic methods such as Magnetoencephalography (MEG) or Magnetocardiography (MCG) can gain a lot from the flexibility of miniaturized OPMs. They enable to adapt the sensor arrangement to the individual shape of the body by mounting the sensors in a wearable 3D-printed structure. We present biomagnetic measurements with multichannel arrays of miniaturized OPMs, revealing the benefits and limits of today's best available OPMs. In particular we present stress-MCG, demonstrating the newly possible option to fix the sensors on the moving subject, and MEG of auditory evoked potentials, with an anatomy adapted sensor array, which enables a considerable reduction of the distance between field source and detector.

FM 73.4 Thu 14:45 Aula

Spectroscopy of nanoparticles without light — •Johannes Fiedler[1,2], Clas Persson[2], and Stefan Yoshi Buhmann[1,3] — [1]University of Freiburg, Freiburg, Germany — [2]Centre for Materials Science and Nanotechnology, Oslo, Norway — [3]Freiburg Institute for Advanced Studies, Freiburg, Germany

Spectroscopy is a tool for determining the electromagnetic response of particles, which is typically measured directly by exciting the investigated object with light. However, indirect measurements via interactions depending on this response provide an alternative methods. Dispersion forces are suitable candidates as they couple to the complete electromagnetic spectrum [1]. We propose a modification of well-studied Casimir experiments via atomic force microscopy [2] for determining the dielectric response of a test particle by adding a two-component liquid [3], leading to an enhancement of retardation and hence allowing for a reconstruction of spectral information based on spatial measurements.

[1] S.Y. Buhmann, Dispersion forces I, Springer (Heidelberg, 2012). [2] M. Sedighi et al., PRB **93**, 085434 (2016). [3] J. Fiedler et al. submitted to PRB (2019).

FM 73.5 Thu 15:00 Aula

Attosecond Time Delays in Photoionisation of Noble Gas Atoms — •Matteo Moioli[1], Hamed Ahmadi[1,2], Fabio Frassetto[3], Luca Poletto[3], Francesca Bragheri[4], Roberto Osellame[4], Cristian Manzoni[4], Giulio Cerullo[2], Claus Dieter Schröter[5], Robert Moshammer[5], Thomas Pfeifer[5], and Giuseppe Sansone[1] — [1]Physikalisches Institut, Universität Freiburg, Freiburg, Germany — [2]Dipartimento di Fisica, Politecnico, Milano, Italy — [3]Istituto di Fotonica e Nanotecnologie, CNR, Padova, Italy — [4]Istituto di Fotonica e Nanotecnologie, CNR, Milano, Italy — [5]Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Here, we present the preliminary results of the investigation of ultrafast dynamics in photoionisation in noble gas atoms. We also illustrate the scheme of an Optical Parametric Amplifier (OPA) setup for the generation of pulses with a stable Carrier-Envelope-Phase (CEP). In particular, using coincidence photoelectron-photoion spectroscopy, the correlated dynamics between photoelectron(s) and photoion(s) can be explored. In the experiment we investigated attosecond time delays in photoionisation using trains of attosecond pulses and a synchronized infrared (IR) pulse. The measured photoionisation time delays can be resolved in terms of emission angle and energy of the photoelectron. In order to maintain a reproducible electric field of the IR pulse, we generate passively CEP-stable pulses through Difference Frequency Generation (DFG) and then amplify them in an OPA setup. The broad amplification bandwidth of the OPA enables generating few-optical cycle pulses.

FM 73.6 Thu 15:15 Aula

Optomechanical stability of the superradiant laser — •Simon B. Jäger[1], John Cooper[2], Murray J. Holland[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]JILA, National Institute of Standards and Technology and Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA

Time and frequency standards require the realization of extremely stable high-Q oscillators. For lasers this oscillator is usually a small-linewidth resonator mode and the laser linewidth is bounded by fluctuations of the resonator length. Remarkably these limitations can be ovecome by coupling many atoms to a rather large-linewidth resonator mode and storing coherences in the atomic supperadiant collective dipole. In this superradiant laser the linewidth is bounded by the single-particle linewidth that can be of the order of mHz. This prediction has been obtained in studies discarding the effect of inhomogeneous broadening of the medium. In this work we theoretically study the optomechanical dynamics of an ensemble of atoms in the regime in which superradiant lasing is expected. We show that, in absence of an external confinement, self-stabilized lasing structures can form when the superradiant decay rate exceeds a threshold determined by the recoil frequency. The dynamics can become chaotic, leading to the emission of chaotic light, when the pump rate is below a certain threshold. These phases can be revealed in the coherence properties of the light at the cavity output and emerge from the interplay between quantum fluctuations, dissipation, and noise.

FM 73.7 Thu 15:30 Aula

State-to-state chemistry with resolution of magnetic spins — •Markus Deiss, Joschka Wolf, Shinsuke Haze, and Johannes Hecker Denschlag — Institut für Quantenmaterie and Center for Integrated Quantum Science and Technology IQ^{ST}, Universität Ulm, 89069 Ulm, Germany

State-to-state chemistry describes the determination of the quantum states of the final products given the quantum state of the reactants. We have developed and demonstrated a method to probe molecular product states of reactive processes both qualitatively and quantitatively [1]. Using the given method, we have investigated the recombination of three neutral rubidium atoms in an ultracold atomic gas. Now, we have extended the scheme of [1] to also resolve the magnetic quantum number of molecular product states. In this talk, measurements of product molecules as a function of the magnetic field strength and for different reactant states are presented. We can formulate a propensity rule with respect to the magnetic quantum number.

[1] J. Wolf *et al.*, Science 358, 921 (2017).

FM 73.8 Thu 15:45 Aula

Hyperpolarization and Bath Spectroscopy of Individual ^{13}C Nuclei in Diamond — •K. Herb, K.S. Cujia, J. Zopes, and C.L. Degen — Department of Physics, ETH Zurich, Otto Stern Weg 1, 8093 Zurich, Switzerland

70 years ago, Erwin Hahn published the first experimental demonstration of a Free Induction Decay (FID) experiment. Advances in quantum optics and material science enable us today to record the free precession signal of single ^{13}C nuclear spins inside a diamond crystal. The experimental instrumentation to achieve this sensitivity is not of a classical and macroscopic scale as in Hahn's experiment, but rather of a microscopic scale. Indeed, the sensor is an electron spin: the electron spin of the Nitrogen-Vacancy (NV) center in diamond. In this talk, we focus on two key challenges towards single molecule NMR spectroscopy: the hyperpolarization of single nuclei in the vicinity of the NV center at room temperature and the detection scheme. We use the hyperfine coupling of the nuclei to the NV center to transfer electron spin polarization in a ramped-amplitude NOVEL-like scheme. By modulating the amplitude of the spin-lock pulse, we improved the robustness and the efficiency of the protocol for polarizing multiple nuclear spins with a priori unknown hyperfine couplings. To detect the nuclear spins, we propose the use of periodic weak measurements. This allows a continuous FID detection at the single spin level. By that, we demonstrate sensitive, high-resolution NMR spectroscopy of multiple individually resolvable nuclear spins in the vicinity of the NV center.

FM 74: Secure Communication & Computation III

Time: Thursday 14:00–15:30 Location: 1009

Invited Talk FM 74.1 Thu 14:00 1009

Quantum Computing and Cryptography — •Nico Döttling — CISPA Helmholtz Center for Information Security

In the early 1990s cryptography went into a foundational crisis when efficient quantum algorithms were discovered which could break almost all public key encryption schemes known at the time. Since then, an enormous research effort has been invested into basing public key cryptography, and secure computation in general, on problems which are conjectured to be hard even for quantum computers. This research program has been a tremendous success, resulting in cryptographic milestones such as fully homomorphic encryption, which was not known from pre-quantum assumptions. In this talk we will survey several recent developments in the field and provide a perspective on cryptographic protocols for quantum computations.

FM 74.2 Thu 14:30 1009

ppKTP Entangled Photon Source Study and a New Scheme — •Adrià Sansa Perna[1] and Fabian Steinlechner[2] — [1]Friedrich-Schiller University Jena, Abbe School of Photonics, Albert-Einstein-Str. 5, 07745 Jena, Germany. — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF Albert-Einstein-Straße 7 07745 Jena, Germany.

An ultra-bright ppKTP crossed-crystal entangled photon source ready for use in quantum cryptography is designed and studied, leading to the possibility of a new entangled photon source scheme. First, a theoretical study of the efficiency parameters of the source is modelled taking into account deviations in the profile of the entangled photons. The source is thereafter build consistently with this results. It is shown to have a high brightness of 1.78 milion pairs/s/mW a brightness of the order of more complex interferometric sources, and a good quantum state fidelity of 95.6%. Its high brightness allows for the further study of the beam profile of the SPDC generated at different temperatures. This study of the beam profile allows the characterization of the SPDC emission in temperatures below phase-matching, and SPDC is seen to form a ring profile. The profile observed is modelled theoretically and the total amount of photons generated at different phase-matching conditions is calculated. This reveals the possibility of a new kind of source capable of delivering simultaneously entangled photons to various pairs of users. This new scheme for a source would allow to increase the number of users connected in a quantum network, one of the key aspects missing in developing quantum cryptographic technologies.

FM 74.3 Thu 14:45 1009

Quantum key distribution with a hand-held sender unit — Gwenaelle Vest[1], •Peter Freiwang[1], Jannik Luhn[1], Tobias Vogl[2], Markus Rau[1], Wenjamin Rosenfeld[1], and Harald Weinfurter[1,3] — [1]Ludwig Maximilian Universtity (LMU), Munich, Germany — [2]Australian National University (ANU), Canberra, Australia — [3]Max Planck Institute of Quantum Optics (MPQ), Garching, Germany

QKD enables secure communication by detecting eavesdropping attacks. While impressive progress was made in the field of long-distance implementations, user-oriented applications involving short-distance links have mostly remained overlooked. In this work we report on a hand-held free-space QKD system including a micro-optics based sender unit. This system implements a BB84-protocol employing polarization encoded faint laser pulses at a rate of 100 MHz. Unidirectional beam tracking and live reference-frame alignment systems at the receiver side enabled a stable operation over tens of seconds when holding the portable transmitter at a distance of 30 cm. Successful key exchange was performed by different untrained users with an average link efficiency of about 20 % relative to the case of the transmitter being stationary mounted and aligned with key rates ranging from 4.0 kbps to 15.3 kbps at an average QBER of 2.4 %. Given its compactness, this versatile sender unit is also well suited for integration into free-space communication systems for urban or even satellite applications.

FM 74.4 Thu 15:00 1009

Requirements for QKD ground station facilities — •Conrad Rössler[1,2], Kevin Günthner[1,2], Ömer Bayraktar[1,2], Jonas Pudelko[1,2], Kevin Jaksch[1,2], Imran Khan[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nuremberg, Staudtstraße 7/B2, 91058 Erlangen, Germany

During the last years, several space-based [1] quantum key distribution (QKD) setups were presented by various research groups and commercialization is about to start. We want to give insight into several requirements one needs to consider for the design of a space-based QKD system with a focus on the ground station. Both physical parameters as laser wavelength, aperture size, satellite orbit and the Doppler shift resulting from the satellites movement will be part of this presentation as well as a comparison of several encoding protocols. It will also be discussed if and how operation in urban environment is possible, since most research on space communication takes place in wisely chosen locations, usually with very low light pollution.

[1] I. Khan et al., Opt. Photonics News 29(2), 26-33 (2018)

FM 74.5 Thu 15:15 1009

Quantum Key Distribution with Small Satellites — •Ömer Bayraktar[4], Peter Freiwang[3], Daniel Garbe[1], Matthias Grünefeld[6], Roland Haber[1], Lukas Knips[5], Christoph Marquardt[4], Leonhard Mayr[3], Florian Moll[2], Jonas Pudelko[4], Benjamin Rödiger[2], Wenjamin Rosenfeld[3], Klaus Schilling[1], Christopher Schmidt[2], and Harald Weinfurter[1,5] — [1]Center for Telematics (ZfT), Würzburg, Germany — [2]German Aerospace Center (DLR) IKN, Oberpfaffenhofen, Germany — [3]Ludwig-Maximilian-University (LMU), Munich, Germany — [4]Max Planck Institute for the Science of Light (MPL), Erlangen, Germany — [5]Max Planck Institute of Quantum Optics (MPQ), Garching, Germany — [6]OHB System AG, Oberpfaffenhofen, Germany

QKD to satellites will be an important element enabling secure communication in future quantum safe network structures. After the first successful demonstration by the Chinese satellite MICIUS, the question arises how small a satellite can be designed. The space mission QUBE will test two highly integrated QKD sender modules and a quantum random number generator in a three unit CubeSat (10 x 10 x 30 cm^2). The optical communication terminal OSIRIS (effective aperture 20 mm) provides a link from a low earth orbit (LEO, 500 km) to the optical ground station (60 cm telescope) at the DLR in Oberpfaffenhofen. Quantum payloads and OSIRIS require approximately one unit in volume while the remaining two units needed for systems to operate the satellite.

FM 75: Quantum Computation: Simulation II

Time: Thursday 14:00–15:45 Location: 1010

FM 75.1 Thu 14:00 1010

Finding symmetry-broken ground states with variational quantum algorithms — •Nicolas Vogt[1], Sebastian Zanker[1], Jan-Michael Reiner[1], Thomas Eckl[2], Anika Marusczyk[2], and Michael Marthaler[1] — [1]HQS Quantum Simulations GmbH, Karlsruhe, Germany — [2]Robert Bosch GmbH, Renningen, Germany

One of the most promising applications for near-term noisy intermediate scale quantum computers (NISQ) is the preparation of the fully interacting ground state of strongly correlated electron systems. Besides the true ground state energy the properties of interest are, e.g., phases with broken symmetry and the corresponding order parameters.

We study the preparation of ground states with broken symmetry on a gate based quantum computer with different variational algorithms, specifically the variational Hamiltonian ansatz (VHA) including initial state preparation and extensions to deal with broken symmetry. The Hubbard model, which is known for its variety of phases, is used as a toy model to compare the different variational algorithms to each other and to exact diagonalisation. To this end, we simulate the full algorithm including initialisation and read-out running on a gate-based quantum computer. We use a hardware model based on the gates available in current generation superconducting quantum computers.

FM 75.2 Thu 14:15 1010

Finding the ground state of the Hubbard model by variational methods on a quantum computer with gate errors — •Jan-Michael Reiner[1,2], Frank Wilhelm-Mauch[3], Gerd Schön[1,4], and Michael Marthaler[1,2,3] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]HQS Quantum Simulations, c/o CyberLab, Haid-und-Neu-Straße 20, 76131 Karlsruhe — [3]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany — [4]Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), 76021 Karlsruhe, Germany

A key goal of digital quantum computing is the simulation of fermionic systems such as molecules or the Hubbard model. Unfortunately, for present and near-future quantum computers the use of quantum error correction schemes is still out of reach. Hence, the finite error rate limits the use of quantum computers to algorithms with a low number of gates. The variational Hamiltonian ansatz (VHA) has been shown to produce the ground state in good approximation in a manageable number of steps. Here we study explicitly the effect of gate errors on its performance. The VHA is inspired by the adiabatic quantum evolution under the influence of a time-dependent Hamiltonian, where the – ideally short – fixed Trotter time steps are replaced by variational parameters. The method profits substantially from quantum variational error suppression, e.g., unitary quasi-static errors are mitigated within the algorithm. We test the performance of the VHA when applied to the Hubbard model in the presence of unitary control errors on quantum computers with realistic gate fidelities.

FM 75.3 Thu 14:30 1010

Robust Hamiltonian learning of Bose-Hubbard models — •Ingo Roth, Dominik Hangleiter, Lara Booth, Christian Krumnow, Juani Bermejo-Vega, and Jens Eisert — Freie Universität, Berlin, Deutschland

Complex quantum many-body systems can increasingly be controlled with unprecedented precision opening up tremendous potential for quantum analogue simulators as a near-term quantum technology. One of the key problems in the study of quantum simulators is to find ways to certify the correctness of the implementation of the Hamiltonian dynamics from data. In this work, we develop a flexible signal processing framework for the recovery of Hamiltonian models combining super-resolution techniques and non-convex recovery algorithms. We specificably explore the algorthmic approach in the context of learning quadratic Bose-Hubbard Hamiltonians in an experiment with superconducting qubits in collaboration with the Quantum group at Google AI. We arrive at an efficient and very robust learning scheme for such Hamiltonian models. This work provides a essential tool for the high-precision calibration of control models in the experimental implementation.

FM 75.4 Thu 14:45 1010

Spectral properties of optically driven one-dimensional extended Hubbard model: An exact diagonalization study — •Junichi Okamoto[1] and Shunsuke A. Sato[2,3] — [1]Institute of Physics, University of Freiburg, Freiburg, Germany — [2]Center for Computational Sciences, University of Tsukuba, Tsukuba, Japan — [3]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany

Quantum simulation is one of the key innovations in science, and has been elaborated in various platforms, e.g., cold atoms, quantum dots, and superconducting circuits. Recently, periodically driven quantum systems add another tuning knob to realize novel Hamiltonians via Floquet engineering. Notable examples are: control of band topology [PRL 118, 240403 (2017)], creation of artificial gauge fields [Nat. Phys. 9, 738 (2013)], and suppression of tunneling [PRL 100, 040404 (2008)]. Here we study dynamics induced by periodic driving in one-dimensional extended Hubbard model with an exact time-dependent Schrödinger equation solver. We characterize the driven system by transient conductivity and time-resolved spectral functions. We address various consequences due to different forms of driving, e.g., off-resonance, near resonance, continuous driving, or pulsed driving. For instance, when the system undergoes a transition from a Luttinger liquid to a gapped charge-density wave, an in-gap peak appears in the spectral function, while there is no Drude peak in conductivity, indicating localized carrier doping. On the other hand, when a charge-density wave is photodoped, we find no increase of in-gap density of states.

FM 75.5 Thu 15:00 1010

Functional renormalization group analysis of the response functions of the 2D Hubbard model — •Sarah Heinzelmann[1], Cornelia Hille[1], Agnese Tagliavini[1,2], Stefan Käser[3], Philipp Hansmann[4], Carsten Honerkamp[5], Alessandro Toschi[2], and Sabine Andergassen[1] — [1]Institut für Theoretische Physik and Centre for Quantum Science, Uni Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Institute for Solid State Physics, Vienna University of Thechnology, 1040 Vienna, Austria — [3]Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1 — [4]Max-Planck-Institut für Chemische Physik fester Stoffe, Nöthnitzer Straße 40 — [5]Institut for Theoretical Solid State Physics, RWTH Aachen University, 52056 Aachen

We present results for the magnetic, density and superconducting pairing susceptibilities in the weak-coupling regime, as obtained from a fully frequency and momentum dependent functional renormalization group (fRG) calculation, which takes into account all channels in an unbiased way. In contrast to RPA, we observe pronounced renormalisation effects due to the interplay of the channels. We analyse the impact of vertex corrections on both s- and d-wave components of the susceptibilities in different regions of the phase diagram. Including the multiloop extension of the fRG, the present computation schemes paves a promising route towards quantitative studies of more challenging systems and/or parameter regimes.

FM 75.6 Thu 15:15 1010

Closing the gaps of a quantum advantage with short-time Hamiltonian dynamics — •Jonas Haferkamp[1], Dominik Hangleiter[1], Adam Bouland[2], Bill Fefferman[3], Jens Eisert[1], and Juani Bermejo-Vega[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Electrical Engineering and Computer Sciences, University of California, Berkeley — [3]Joint Center for Quantum Information and Computer Science, University of Maryland

Demonstrating a quantum computational speed-up is a crucial milestone for near-term quantum technology. Recently, comparably feasible quantum simulation architectures have been proposed that have the potential to show such a quantum advantage, based on commonly made assumptions. The key challenge in the theoretical analysis of this scheme - as of other comparable schemes - is to lessen the assumptions and close the theoretical loopholes, replacing them by rigorous arguments. In this work, we prove two open conjectures for these architectures of quantum simulators: Anti-concentration of the generated probability distributions and average-case hardness of exactly evaluating those probabilities. The latter is proven building upon recently developed techniques for random circuit sampling. For the former, we develop new techniques that exploit the insight that approximate 2-designs for the unitary group admit anti-concentration. We prove that the translation-invariant, constant depth architectures of quantum simulation form approximate 2-designs in a specific sense, thus obtaining a significantly stronger result.

FM 75.7 Thu 15:30 1010

Simulating non-equilibrium two-electron transfer on a noisy quantum computer — •Sabine Tornow — Munich University of Applied Sciences, Department of Computer Science and Mathematics, Lothstrasse 64, 80335 Munich, Germany

We simulate the dynamics of two correlated electrons modeled by a two-site Hubbard model on a noisy quantum computer. To enable practical implementation we study the influence of both, algorithmic (e.g., the number of Trotter steps) and physical errors (e.g., gate errors and decoherence). Further, different error mitigation techniques such as extrapolation to the zero noise limit are applied. We find good agreement to our earlier results (S. Tornow, R. Bulla, F. Anders, A. Nitzan, Phys. Rev. B 78, 035434 (2008)).

FM 76: Entanglement: Spectroscopy

Time: Thursday 14:00–15:30 Location: 1015

Invited Talk FM 76.1 Thu 14:00 1015

Enhancing the precision of measurements with entanglement — •Manuel Gessner — Département de Physique, École Normale Supérieure, PSL Université, CNRS, 24 Rue Lhomond, 75005 Paris, France — Laboratoire Kastler Brossel, ENS-PSL, CNRS, Sorbonne Université, Collège de France, 24 Rue Lhomond, 75005 Paris, France

Our fundamental understanding of Nature as well as technological developments depend crucially on our ability to implement measurements with better precision. Currently, spectroscopy of atomic frequencies yields some of the most precise measurements and allows us to define time standards with atomic clocks. These measurements are soon expected to reach a classical resolution limit, determined by quantum projection noise, that can only be overcome by making use of quantum strategies. In this talk, we will present an overview of quantum-enhanced methods to improve the sensitivity of intereferometric measurements, such as Ramsey spectroscopy. We will see how the sensitivity of general quantum states can be quantified and how suitable observables for precision measurements can be determined under realistic constraints. Furthermore, we show how entanglement witnesses can be constructed by deriving upper limits on the sensitivity of separable quantum states. We will discuss applications in atomic and photonic experiments.

FM 76.2 Thu 14:30 1015

Quantum discord in squeezed microwaves — •Kirill G. Fedorov[1,2], Stefan Pogorzalek[1,2], Michael Renger[1,2], Qi-Ming Chen[1,2], Matti Partanen[1], Achim Marx[1], Frank Deppe[1,2,3], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

Quantum discord is known as a general measure for quantum correlations in bipartite systems. It encompasses all nonclassical correlations including entanglement. Quantum discord has many intriguing fundamental properties many of which require experimental verification such as the asymptotic robustness towards environmental noise. We experimentally investigate quantum discord in propagating two-mode squeezed (TMS) microwave states generated with the help of superconducting Josephson parametric amplifiers. We exploit asymmetric noise injection into these TMS states which allows us to demonstrate the robustness of quantum discord as opposed to the sudden death of entanglement. Finally, we discuss the relevance of quantum discord as a resource in quantum communication and sensing , in particular with respect to remote state preparation and quantum radar protocols.

We acknowledge support by the Excellence Cluster MCQST, the Elite Network of Bavaria through the program ExQM, and the European Union via the Quantum Flagship project QMiCS (Grant No. 820505).

FM 76.3 Thu 14:45 1015

Quantum Logic Spectroscopy of Highly Charged Ions — •Lukas J. Spiess[1], Steven A. King[1], Peter Micke[1], Tobias Leopold[1], Erik Benkler[1], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Max-Planck Institut für Kernphysik, Heidelberg — [3]Institut für Quantenoptik, Leibniz Universität Hannover

Highly charged ions (HCI) offer extreme properties, making them suitable candidates for the search for physics beyond the standard model or novel optical clocks [1]. Production and storage of HCI commonly occurs at MK temperatures, limiting the spectroscopic resolution to the hundreds of MHz scale. This has been overcome by sympathetically cooling HCI in a linear Paul trap using Be^+ ions [2].

Ar^{13+} ions are produced in an electron beam ion trap, from where they are extracted, transported to and injected into a Paul trap. A Be^+-Ar^{13+} two-ion crystal is prepared and cooled to its motional ground state. Spectroscopy on the $^2P_{1/2}$ to $^2P_{3/2}$ transition in the Ar^{13+} ion at 441 nm is performed using the quantum logic technique [3]. There, the internal state of the Ar^{13+} ion after laser excitation is transferred to the Be^+ ion through their shared motional mode for readout. The achieved sub Hz resolution gives insight into relativistic, interelectronic and QED contributions to the excited state g-factor. The first optical clock based on a HCI is also demonstrated.

[1] M. G. Kozlov *et al.*, Rev. Mod. Phys. 90, 045005 (2018)
[2] L. Schmöger *et al.*, Science 347 1233-1236 (2015)
[3] P. O. Schmidt *et al.*, Science 309 749 (2005)

FM 76.4 Thu 15:00 1015

Nonlinear spectroscopy with nonclassical light — •Fabiano Lever and Markus Ghuer — Universitaet Potsdam

In this work, we explore the quantum-classical transition comparing a classical pump-probe experiment on a diatomic molecule to its quantum enhanced counterpart, where the pump and probe pulses are substituted by the signal and idler beams of a SPDC source.

Two photon absoption of biphotons generated with Spontaneous Parametric Down Conversion (SPDC) exploits quantum time-energy correlations to enhance the overall yeld and selectivity of the process, when compared with a classical pump-probe setup, while mantaining femtosecond time resolution. The results indicate that the quantum improvements in yeld are caused by a more efficient use of the total power available for the process.

FM 76.5 Thu 15:15 1015

Quantum-enhanced imaging for life science — •Marta Gilaberta Basset, Josué R. León Torres, and Markus Gräfe — Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, 07745 Jena

Nowadays, quantum physics turned from purely fundamental science to a research field with real-life applications. In particular, quantum photonics promises novel approaches for quantum enhanced-imaging. For instance quantum imaging with undetected photons was first implemented by the Zeilinger group in Vienna. Based on Mandels induced coherence, it becomes possible to image an object with light that never interacted at all with the object. It is worth to explicitly mentioned, thtat in stark contrast to Ghost imaging, here neither any coincidence detection is necessary nor any detection of the light that interacted with the object. By exploiting non-degenerated spontaneous parametric down conversion, photon pairs with large wavelength difference can be harnessed. The obvious advantage of this technique is that the wavelength of the idler photons can be tailored to match the interesting spectral range of the object (e.g. far IR, THz, deep UV). At the same time, the signal photons, which are actually detected, can stay in the VIS range where, e.g., Si-based detectors are optimized. We present a revised implementation of this imaging scheme. Our ansatz delivers a robust, miniaturized and mobile realization, by employing a single crystal scheme. Hence, it allows to record quantum images at video rate.

FM 77: Quantum Networks: Platforms and Components II

Time: Thursday 14:00–15:45 Location: 1098

Invited Talk FM 77.1 Thu 14:00 1098

Integrating Quantum Key Distribution into Telecom Networks — •James Dynes — Toshiba Research Europe Limited, Cambridge, United Kingdom

Quantum Key Distribution (QKD) is one of the most mature applications of quantum physics to move out of the laboratory. Over the past fifteen years, there has been much progress in maturing QKD technology. In particular, field demonstrations of quantum key distribution (QKD) are an important step towards successful, full scale commercialization of QKD. In this talk we will report on recent progress of incorporating QKD with conventional telecom networks within the UK, thus paving the way towards building large scale commercial QKD networks.

FM 77.2 Thu 14:30 1098

Quantum Information Applications with Single Defect Centers in 4H-SiC — •Florian Kaiser, Naoya Morioka, Roland Nagy, Matthias Niethammer, Izel Gediz, Erik Hesselmeier, Charles Babin, Matthias Widmann, Yu-Chen Chen, Roman Kolesov, Rainer Stöhr, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart and IQST, Stuttgart, Germany

Silicon carbide (SiC) is the gold standard material for high power electronics thanks to outstanding thermal conductivity, breakdown voltage, and a large bandgap energy.

Recently, the SiC platform has also been identified to be very promising for quantum information distribution tasks [1]. In this regard, a critical requirement is stable optical emission of indistinguishable photons through which multiple spintronics systems can be reliably entangled via optical interference [2].

Here, we will show our recent efforts in measuring two-photon indistinguishability of single V1 centres in 4H-SiC via Hong, Ou and Mandel interference. Our results show that the V1 centre in 4H-SiC is a prime candidate for realising memory-assisted quantum network applications using semiconductor-based spin-to-photon interfaces and coherently coupled electron/nuclear spins.

We will additionally discuss near-term reachable network scenarios, and achievable performance parameters.

[1] R. Nagy et al., Nat. Commun. 10, 1954 (2019)
[2] F. Rozpedek et al., Phys. Rev. A 99, 052330 (2019)

FM 77.3 Thu 14:45 1098

Quantum networking tools with single atoms and single photons — •Stephan Kucera, Pascal Eich, Matthias Bock, Matthias Kreis, Jan Arenskötter, Christoph Becher, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

In the context of quantum communication technologies, we are developing a comprehensive set of experimental tools, based on single photons and single atoms (trapped ions), that enable controlled generation, storage, transmission, and conversion of photonic qubits in quantum networks in a programmable manner [1,2]. As experimental applications, we demonstrate high-fidelity transfer of entanglement from a narrowband SPDC photon pair to atom-photon pairs, as well as atom-to-photon qubit teleportation [3]. We also extend our quantum network toolbox into the telecom regime by polarization-preserving quantum frequency conversion of atom-entangled photons [4].

[1] C. Kurz et al., Nat. Commun. **5**, 5527 (2014)
[2] C. Kurz et al., Phys. Rev. A **93**, 062348 (2016)
[3] S. Kucera et al., in preparation
[4] M. Bock et al., Nat. Commun. **9**, 1998 (2018)

FM 77.4 Thu 15:00 1098

Evaluation of Volume Bragg Gratings as a Wavelength Division Multiplexer in Entanglement-Based Free-Space Quantum Link — •Riza Fazili[1] and Fabian Steinlechner[2] — [1]Friedrich-Schiller University Jena, Abbe School of Photonics, Albert-Einstein-Str. 5, 07745 Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany

It has been shown that wavelength division multiplexing (WDM) is feasible in quantum key distribution (QKD) and has many advantages such as raising the key generation rate. Whereas all the previous attempts of multiplexing in quantum communication have been via optical fibers, a WDM in free-space quantum links can play a more crucial role due to technical challenges in particular the limited time window of the satellite-ground communication. Here, we report on designing and implementing the first low-loss WDM in entanglement-based free-space QKD using volume Bragg gratings (VBGs) at ~800 nm. The total insertion loss for two channels is 0.6 dB which matches the state of the art at telecommunication wavelengths (~1550 nm) and surpasses any known WDMs at ~800 nm. The low cross talk of 20 dB in 0.3 nm in our WDM, unleash the potential of having many channels in a given entangled photons spectrum. We demonstrate that our WDM could operate under turbulence effects and the insertion loss is ~0.6 dB for weak and ~2 dB for strong turbulences. This ability would simplify the coupling procedure at the receiving telescope and can be a game changing factor in the future of free-space QKD.

FM 77.5 Thu 15:15 1098

Ultra-compact and ultra-bright photon-pair source for QKD
— •Emma Brambila[1,2], Fabian Steinlechner[1], and Markus Gräfe[1] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, 07745 Jena, Germany. — [2]Friedrich-Schiller University Jena, Abbe School of Photonics, Albert-Einstein-Str. 5, 07745 Jena, Germany.

Polarization entangled photon pairs are the major ingredient for various quantum technology applications, in particular for quantum key distribution (QKD). There, compact, stable, and very bright entangled photon pairs sources (EPS) are demanded for field deployment. Only by providing reliable EPS as user-friendly hardware components, QKD can be commercialized and applied for society outside research lab facilities.

In this work, we present a prototype lab-version of a compact, simplified, highly stable, and ultra-bright EPS. The polarization entangled photon pair source is based on a type-0 phase matched ppKTP crystal in a Sagnac-loop, which is pumped at 405 nm. The EPS is fully fiber coupled and designed as turn-key system. We are going to present data on its characterization like fidelity, spectral distribution of signal and idler photons, and the heralding efficiency.

FM 77.6 Thu 15:30 1098

Interfacing single Erbium ions with photons at telecom wavelength
— •Benjamin Merkel, Pablo Cova Fariña, Alexander Ulanowski, Lorenz Weiss, Andreas Gritsch, and Andreas Reiserer — MPI of Quantum Optics, Garching, Germany

Global quantum networks will require efficient interfaces between long-lived memory nodes and photons at a telecommunications wavelength, where loss in optical fibers is minimal. In this context, individual Erbium ions doped into suited crystals are a promising candidate, as they exhibit both an optical transition at 1.5 μm and spin lifetimes exceeding 100 ms. Unfortunately, the long lifetime of the optical transition ($\simeq$ 10 ms) limits the fluorecence rate and makes it difficult to spectrally resolve and control single ions.

We study different approaches to overcome this limitation: First, we have assembled high-finesse cavities which will lead to an expected 200-fold reduction of the lifetime. We have stabilized their resonance frequencies to a fraction of a linewidth, i.e. to the sub-pm-level, despite the abundance of mechanical vibrations in a closed-cycle cryostat environment. Second, as a first step towards on-chip quantum network nodes, we try to combine Erbium ions with Silicon nanophotonic waveguides and photonic crystal cavities [1]. We will present the current status of the mentioned experiments.

[1] A. M. Dibos et al., Phys. Rev. Lett. 120, 243601 (2018)

FM 78: Quantum Computation: Hardware Platform III

Time: Thursday 14:00–15:30 Location: 1199

Invited Talk FM 78.1 Thu 14:00 1199

Quantum Information Processing using Trapped Atomic Ions and MAGIC
— Theeraphot Sriarunothai[1], Sabine Wölk[4], Gouri S. Giri[5], Nicolai Friis[2], Vedran Dunjko[3], Hans J. Briegel[4], Patrick Barthel[1], Patrick Huber[1], and •Christof Wunderlich[1] — [1]Siegen University, Germany — [2]Austrian Academy of Sciences, Vienna, Austria — [3]Leiden University, Netherlands — [4]Innsbruck University, Austria — [5]Düsseldorf University, Germany

Using ion traps that allow for long-range magnetic gradient induced coupling (MAGIC) [1], laser light can be replaced by long-wavelength radiation in the radio-frequency (RF) regime, thus facilitating scalability.

Using a freely programmable quantum computer (QC) based on MAGIC, we report on a proof-of-principle experimental demonstration of the deliberation process in the framework of reinforcement learning [2]. This experiment at the boundary between quantum information science and machine learning shows that decision making for reinforcement learning is sped up quadratically on a QC as compared to a classical agent.

Then we report on 2-qubit RF gates that are robust against variations in the secular trap frequency and Rabi frequency. In future traps such gates will increase speed and fidelity of multi-qubit gates.

[1] C. Piltz et al.,Science Advances **2**, e1600093 (2016).
[2] Th. Sriarunothai et al., Quantum Sci. Technol.**4**, 015014 (2019).

FM 78.2 Thu 14:30 1199

Local entangling operations on two arbitrary ions in a string of ions
— •Michael Meth[1], Marc Bussjäger[1], Alexander Erhard[1], Lukas Postler[1], Roman Stricker[1], Martin Ringbauer[1], Thomas Monz[1,2], and Rainer Blatt[1,3] — [1]Universität Innsbruck, Institut für Experimentalphysik, Technikerstraße 25, Innsbruck — [2]Alpine Quantum Technologies GmbH — [3]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences

We present a scheme for local entangling operations on two arbitrary ions in a string of currently up to 16 ions. Two acousto-optic deflectors are used to address a single or multiple ions at once, performing parallel quantum gate operations on several quantum bits (qubits) with independent phase control. The deflectors are aligned such that induced frequency shifts are cancelled along the trap axis regardless of the addressed ions. Mølmer-Sørensen (MS) gates are implemented to create entanglement between two arbitrary qubits via coupling to the common motion of the ion string. In conjunction with single qubit gates a universal set of gates is formed. For an arbitrary set of two ions in a string of four the entangling gate fidelities are measured to be comparable with collective MS gates on all qubits and no significant loss in performance has been observed for longer strings. This method can be extended from two qubits to subsets of arbitrary lengths. Simulations of improved optical setups show an addressable range of several hundreds of micrometers, which corresponds to more than 50 qubits.

FM 78.3 Thu 14:45 1199

Towards large-scale microwave quantum devices with trapped ions
— •Amado Bautista[1,2], Henning Hahn[1,2], Giorgio Zarantonello[1,2], Jonathan Morgner[1,2], and Christian Ospelkaus[1,2] — [1]Leibniz University of Hannover, Welfengarten 1, 30176 Hannover — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Currently quantum computing with trapped ions is reaching an unprecedented maturity towards a practical realization of a scalable platform. The field requires also a significant effort on reaching a scalable hardware. Here we present recent advances on the development of a novel method for the realization of large-scale quantum devices [1]. First, I will detail on the trap fabrication and show preliminary results on the characterization of a multilayer ion trap with integrated 3D microwave circuitry [2] towards the implementation of high-fidelity quantum logic control on $^9Be^+$ ions. We demonstrate ion trapping, simple microwave control on a laser cooled $^9Be^+$ ion held at a distance of 35 μm, characterize the magnetic field around the trap center based on our 2D near-field model [3]. Finally, I will discuss new routes and potential new integrated devices in which the multilayer method can be exploited.

[1] A. Bautista-Salvador et al. New J. Phys., 21, 043011 (2019) [2] H. Hahn et al. ArXiv181202445 (2018) [3] M. Wahnschaffe et al. Appl. Phys. Lett., 110, 034103 (2017)

FM 78.4 Thu 15:00 1199

Near-field microwave quantum logic with $^9Be^+$ ions
— Henning Hahn[2,1], Giorgio Zarantonello[1,2], Marius Schulte[3], Jonathan Morgner[1,2], Amado Bautista-Salvador[2,1], Klemens Hammerer[3], and •Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover

Near-field microwave fields allow the implementation of an integrated entangling gate mechanism for trapped-ion qubits in surface-electrode trap arrays [1]. We present a tailored near-field microwave conductor structure which has recently allowed us [2] to realize an entangling gate operation between two $^9Be^+$ ion qubits using long-lived field-independent “clock” states. We establish a gate error budget through comparison to numerical simulations and find that the gate operation is at present not limited by any mechanism inherent to the method, and all leading order infidelity contributions can be dealt with using straigt-forward technical measures that have already been implemented for other (laser and microwave based) implementations. We discuss further methods which we hope will reduce the infidelity significantly and give an outlook towards the extension to multi-zone trap arrays.

[1] C. Ospelkaus *et al.*, Nature **476**, 181 (2011)
[2] H. Hahn *et al.*, arXiv:1902.07028 [quant-ph] (2019)

FM 78.5 Thu 15:15 1199

Ion trap fabrication at PTB — •André P. Kulosa, Alexandre Didier, Malte Brinkmann, and Tanja E. Mehlstäubler — QUEST Institute, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Ion traps are the heart of quantum computers and simulators based on laser-cooled ions, but also a key essential of quantum clocks and precision spectroscopy. Here we report on progress and future prospects of the ion trap fabrication in the QUEST Institute at PTB. As a consequence of the quantum initiative call from the German Federal Government, the BMBF supports the transfer of quantum technology from research to industry enabling the second quantum revolution. Within the BMBF-funded *opticlock* project, our technology platform will be used to demonstrate a compact Yb^+ ion optical clock replacing hydrogen masers as a future frequency reference. In a second funded project, *IDEAL*, we investigate integrated optics on diamond wafer chip traps enabling robust and compact interaction of laser light with the ions for the next generation of ion traps.

In the frame of its mission as governmental body to support German science and industry, PTB placed the corner stone for a Quantum Technology Competence Center (QTZ). The newly founded QTZ will focus on transfer of PTB's expertise in quantum technology from science to application in collaboration with partners from industry and academia. For this purpose, our ion trap technology will be made accessible to external users in a new user facility providing lab infrastructure.

FM 79: Entanglement: Neural Networks for Many-Body Dynamics

Time: Thursday 14:00–15:30 Location: 2004

FM 79.1 Thu 14:00 2004

Quantum many-body dynamics with neural network states — •Markus Schmitt[1] and Markus Heyl[2] — [1]Department of Physics, University of California, Berkeley, USA — [2]Max-Planck-Institute for the Physics of Complex Systems, Dresden, Germany

The growth of entanglement during the non-equilibrium dynamics of quantum many-body systems constitutes a major challenge for numerical simulations on classical computers. We explore the possibility to compress the many-body wave function using artificial neural networks as a versatile approach for the efficient simulation of quantum dynamics. This method allows us to study two-dimensional systems far from equilibrium, which are realized, e.g., in quantum simulators based on ultracold atoms or Rydberg atoms. In our discussion we include subtleties of the time evolution algorithm and ways to assess the accuracy of the results.

FM 79.2 Thu 14:15 2004

Quenches near Ising quantum criticality as a challenge for artificial neural networks — •Martin Gärttner, Stefanie Czischek, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Heidelberg

The near-critical unitary dynamics of quantum Ising spin chains in transversal and longitudinal magnetic fields is studied using an artificial neural network representation of the wave function. A focus is set on strong spatial correlations which build up in the system following a quench into the vicinity of the quantum critical point. We compare correlations obtained by optimizing the parameters of the network states with analytical solutions in integrable cases and time-dependent density matrix renormalization group (tDMRG) simulations. The neural-network representation is shown to yield precise results in a wide parameter regime. However, for quenches close to the quantum critical point the representation becomes inefficient. For nonintegrable models we show that in regimes where tDMRG is limited to short times due to extensive entanglement growth, also the neural-network parametrization converges only at short times.

FM 79.3 Thu 14:30 2004

Many body quantum states and neural networks — •Felix Behrens, Stefanie Czischek, Martin Gärttner, and Thomas Gasenzer — Kirchhoff Institute for Physics Heidelberg

our goal is to represent quantum systems with neaural networks. doing this in a naive way, two major problems which naturally arise are inherent for quantum systems. these are the complex valued probability amplitudes and the exponential scaling of the hilbert space.

operator valued measures (povm) are the tool to map density matrices of abritrary quantum systems to probability distributions in an invertable way. after performing povm measurements, all degrees of freedom are positive real valued numbers. these probabilities are the fundamental link to machine learning systems in general and restricted boltzmann machines (rbm) in our investigations. using these systems (rbm) as generative models for informationally complete quantum measurements feature approximations with polynomially many parameters and allow efficient calculation of expectation values. in this talk, I will present a way how to map the time evolution of a density matrix under a given hamiltonian to a linear evolution equation for the probability distribution in the context of povm.

FM 79.4 Thu 14:45 2004

Efficient training for neural-network quantum states — •Sheng-Hsuan Lin and Frank Pollmann — Department of Physics, T42, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany

Neural networks have been demonstrated to be a promising approach to represent many-body quantum states. However, this approach suffers from difficulties in optimization for realistic models for two main reasons: Inefficiencies in the Markov chain Monte Carlo sampling procedure and the high cost for the stochastic reconfiguration procedure in variational Monte Carlo method. Recently, it has been shown that neural autoregressive quantum states, which are motivated by the architecture known as autoregressive models, lead to an efficient direct sampling procedure which overcomes the first difficulty. Here we consider the approximated second order method proposed in the machine learning community to investigate the possibility to overcome the second difficulty. We benchmark our algorithm by considering the frustrated J1-J2 model on the square lattice.

FM 79.5 Thu 15:00 2004

Emergent Glassy Dynamics in a Quantum Dimer Model — •Johannes Feldmeier, Frank Pollmann, and Michael Knap — Department of Physics, Technical University of Munich, 85748 Garching, Germany

We consider the quench dynamics of a two-dimensional quantum dimer model and determine the role of its kinematic constraints. We interpret the non-equilibrium dynamics in terms of the underlying equilibrium phase transitions consisting of a BKT-transition between a columnar ordered valence bond solid (VBS) and a valence bond liquid (VBL), as well as a first order transition between a staggered VBS and the VBL. We find that quenches from a columnar VBS are ergodic and both order parameters and spatial correlations quickly relax to their thermal equilibrium. By contrast, the staggered side of the first order transition does not display thermalization on numerically accessible timescales. Based on the model's kinematic constraints, we uncover a mechanism of relaxation that rests on emergent, highly detuned multi-defect processes in a staggered background, which gives rise to slow, glassy dynamics at low temperatures even in the thermodynamic limit.

FM 79.6 Thu 15:15 2004

Quantum computing and neural networks: a topological approach — •Torsten Asselmeyer-Maluga — German Aerospace Center (DLR), Rosa-LUxemburg-Str 2, 10178 Berlin, Germany

A neural network but also the brain can be seen as a dynamical graph of neurons with electrical signals having amplitude, frequency and phase.

Because of the complexity of the graph, it is hopeless to include the whole graph. Instead we form areas of neurons having the same state (ground state or excited state). We describe the interaction between these areas by closed loops, the feedback loops. The change of the graph is given by deformations of the loops. At first view, the neuron area interaction as represented by loops cannot be neglected. Then it can be shown that the set of all signals forms a manifold (character variety). In the talk, we will discuss how to interpret learning and intuition in this model. Using the Morgan-Shalen compactification, the limit for large graphs can be analyzed by using quasi-Fuchsian groups as represented by dessins d'enfants (graphs to analyze Riemannian surfaces). These dessins d'enfants are a direct bridge to (topological) Quantum computing with permutation groups. The normalization of the signal reduces the group to SU(2) and the whole model to a quantum network. Then we have a direct connection to quantum circuits. This network can be transformed into operations on tensor products of states. Formally, we obtained a link between machine learning and Quantum computing.

FM 80: Enabling Technologies: Cavity QED

Time: Thursday 14:00–16:00 Location: 2006

Invited Talk FM 80.1 Thu 14:00 2006

Photon-Qubit and Qubit-Qubit Interactions in Semiconductor Circuit Quantum Electrodynamics (QED) — •Andreas Wallraff — Department of Physics, ETH Zurich

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FM 80.2 Thu 14:30 2006

Quantum measurement of a single spin via energy-selective tunneling in a microwave resonator — •Florian Ginzel, Maximilian Russ, and Guido Burkard — University of Konstanz, D-78457 Konstanz, Germany

A modification of the Elzerman scheme for single-shot electron spin readout in a quantum dot embedded into a superconducting cavity is proposed and discussed. Depending on its spin state the electron can tunnel between two quantum dots or between the two dots and a lead. One of the dots is capacitively coupled to a microwave resonator whose output signal is monitored to recover the initial spin state. In this work a model to estimate expectation value and variance of the cavity response is presented. The feasibility of the proposed scheme is discussed by means of timescale, visibility and quantum mechanical back-action of the measurement. As a result, cavity-aided spin readout via spin-selective tunneling is expected to allow for fast, high fidelity measurements and, thus, fulfill a crucial requirement for usage in various quantum technologies ranging from information processing to sensing.

FM 80.3 Thu 14:45 2006

Optimal Dispersive Readout of a Spin Qubit with a Microwave Cavity — •Benjamin D'Anjou and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

Strong coupling of semiconductor spin qubits to superconducting microwave cavities was recently demonstrated. These breakthroughs pave the way for quantum information processing that combines the long coherence times of solid-state spin qubits with the long-distance connectivity, fast control, and fast high-fidelity quantum-non-demolition readout of existing superconducting qubit implementations. Here, we theoretically analyze and optimize the dispersive readout of a single spin in a semiconductor double quantum dot (DQD) coupled to a microwave cavity via its electric dipole moment. The strong spin-photon coupling arises from the motion of the electron spin in a local magnetic field gradient. We calculate the signal-to-noise ratio (SNR) of the readout accounting for both Purcell spin relaxation and spin relaxation arising from intrinsic electric noise within the semiconductor. We express the maximum achievable SNR in terms of the cooperativity associated with these two dissipation processes. We then optimize the SNR as a function of experimentally tunable DQD parameters. We estimate that with current technology, single-shot readout fidelities in the range 82%-95% can be achieved within a few μs of readout time without requiring the use of Purcell filters.

arXiv reference: https://arxiv.org/abs/1905.09702

FM 80.4 Thu 15:00 2006

Optimized cavity-mediated dispersive two-qubit gates between spin qubits — •Mónica Benito[1], Jason Petta[2], and Guido Burkard[1] — [1]University of Konstanz — [2]Princeton University

The recent realization of a coherent interface between a single electron in a silicon quantum dot and a single photon trapped in a superconducting cavity opens the way for implementing photon- mediated two-qubit entangling gates. In order to couple a spin to the cavity electric field some type of spin-charge hybridization is needed, which impacts spin control and coherence. In this work we propose a cavity-mediated two-qubit gate and calculate cavity-mediated entangling gate fidelities in the dispersive regime, accounting for errors due to the spin-charge hybridization, as well as photon- and phonon-induced decays. By optimizing the degree of spin-charge hybridization, we show that two-qubit gates mediated by cavity photons are capable of reaching fidelities exceeding 90% in present-day device architectures. High iSWAP gate fidelities are achievable even in the presence of charge noise at the level of 2 μeV.

[1] M. Benito, J. R. Petta, and G. Burkard, arXiv:1902.07649.

[2] M. Benito, X. Croot, C. Adelsberger, S. Putz, X. Mi, J. R. Petta, and G. Burkard, arXiv:1904.13117.

FM 80.5 Thu 15:15 2006

Scaling up superconducting qubits beyond the dispersive regime — •Mohammad Ansari — Forschungszentrum Jülich, Jülich Aachen Reseach Alliance (JARA), Jülich, Germany

Superconducting circuits consisting of a few transmons coupled to resonators can perform basic quantum computations; however such small scale circuits are unable to perform the power of quantum computation. Scaling up the number of qubits on the other hand will bring the circuit out of quantum control mainly because of noises. In order to come out of such dilemma, we need to look for other possibilities. This requires to further look into theory and improve it. For this aim we develop a new formalism that allows to consistently diagonalize superconducting circuit hamiltonian beyond perturbative regime. This will allow to study qubit-qubit interaction unperturbatively, therefore our formalism remains valid and accurate at any frequency detuning and interaction coupling. Moreover our formalism serves as a theoretical ground for designing qubit characteristics in scaling up.

Reference: M.H. Ansari, Superconducting qubits beyond the dispersive regime, arXiv:1807.00792 (To be published in Phys. Rev. B)

FM 80.6 Thu 15:30 2006

Storage and retrieval of short light pulses via fiber-based atom-cavity systems — •Tobias Macha, Lukas Ahlheit, Wolfgang Alt, Maximilian Ammenwerth, Pooja Malik, Deepak Pandey, Hannes Pfeifer, Eduardo Urunuela, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115, Bonn, Germany

We demonstrate the storage of 5 ns light pulses in a single rubidium atom coupled to a fiber-based optical resonator. Our storage protocol addresses a regime beyond the conventional adiabatic limit, for which the optimal control laser pulse properties are extracted from numerical simulations of the system via a Lindblad master equation approach. We investigate the dependence of the storage efficiency on various control pulse parameters, such as the peak amplitude or the delay with respect to the arrival of the light pulse [1]. For an optimized pulse, we measure storage efficiencies of (8.2 $\pm$ 0.9) %, in close agreement with the maximum expected efficiency for our atomic memory. In the adiabatic limit, we use optimized control pulses for single-photon generation by adapting the impedance-matching based storage scheme of Dilley et al. [2]. We achieve probabilities of 66 % for generating a single, arbitrarily-shaped photon into the cavity mode upon a trigger signal. Such well-controlled and high-bandwidth atom-photon interfaces are key components for future hybrid quantum networks.

[1] arXiv:1903.10922 (2019).

[2] PRA 85, 023834 (2012).

FM 80.7 Thu 15:45 2006

Coupling atoms to a superconducting coplanar microwave cavity — Manuel Kaiser[1], Conny Glaser[1], Lorinc Sárkány[1], Andreas Günther[1], Dieter Koelle[1], Reinhold Kleiner[1], David Petrosyan[1,2], and •József Fortágh[1] — [1]Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen — [2]Institute of Electronic Structure and Laser, FORTH, GR-71110 Heraklion, Crete, Greece

We report on experiments with ultra-cold rubidium atoms trapped on a superconducting atom chip. The focus is on the coupling of atomic Rydberg state pairs to the microwave field of a coplanar superconducting cavity. We discuss the feasibility of coherent long-range interaction between atoms mediated by a microwave cavity in a thermal state and the possibility of realizing Rydberg quantum gates under the given experimental conditions.

FM 81: Enabling Technologies: Quantum Materials

Time: Thursday 14:00–16:00 Location: 3042

Invited Talk FM 81.1 Thu 14:00 3042

Electrostatically defined quantum devices in bilayer graphene — •Christoph Stampfer — JARA-FIT and 2nd Institute of Physics, RWTH Aachen University, 52074 Aachen Germany — Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany, E

Graphene and bilayer graphene (BLG) are attractive platforms for quantum circuits. This has motivated substantial efforts in studying quantum dot (QD) devices based on graphene and BLG. The major challenge in this context is the missing band-gap in graphene, which does not allow confining electrons by means of electrostatics. A widely used approach to tackle this problem was to introduce a hard-wall confinement by etching the graphene sheet. However, the influence of edge disorder, turned out to be a road block for obtaining clean QDs. The problem of edge disorder can be circumvented in clean BLG, thanks to the fact that this material offers a tuneable band-gap in the presence of a perpendicularly applied electric field, a feature that allows introducing electrostatic soft confinement in BLG. Here we present gate-controlled single, double, and triple dot operation in electrostatically gaped BLG. We show a remarkable degree of control of our device, which allows the implementation of two different gate-defined electron-hole double-dot systems with very similar energy scales. In the single dot regime, we reach the very few hole regime, extract excited state energies and investigate their evolution in a parallel and perpendicular magnetic field.

FM 81.2 Thu 14:30 3042

Quantized conductance in topological insulators revealed by the Shockley-Ramo theorem — Paul Seifert[1,2,3], Marinus Kundinger[1,2], Gang Shi[4], Xiaoyue He[4], Kehui Wu[4], Yongqing Li[4], Alexander Holleitner[1,2], and •Christoph Kastl[1,2] — [1]Walter Schottky Institut and Physics Department, Technical University of Munich, Am Coulombwall 4a, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany — [3]ICFO-Institut de Ciencies Fotoniques, Castelldefels, Barcelona, 08860, Spain — [4]Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

Materials with topological order promise coherent transport phenomena even in the presence of disorder and potentially at room temperature. Here, we image the local conductance of helical surface modes in the prototypical topological insulators Bi_2Se_3 and $BiSbTe_3$. We apply the Shockley-Ramo theorem to design an optoelectronic probe circuit for the surface states, and find a conductance quantization at e^2/h without any external magnetic field. The unprecedented response is a signature of local spin-polarized transport, and it can be switched on and off via an electrostatic field effect. The read-out does not require coherent transport between electrodes, in contrast to the Landauer-Büttiker description. It provides a generalizable platform for non-trivial gapless systems, such as Weyl-semimetals and quantum spin-Hall insulators. [1] P. Seifert et al. Quantized Conductance in Topological Insulators Revealed by the Shockley-Ramo Theorem. Phys. Rev. Lett. 122, 146804 (2019).

FM 81.3 Thu 14:45 3042

Scalable production of optical elements for photonics with quantum emitters — •Fiammetta Sardi, Thomas Kornher, Roman Kolesov, Ferdinand Schiller, and Jörg Wrachtrup — 3rd Physics Institute, University of Stuttgart, Stuttgart, Germany

We show different methods to enhance the emission of quantum emitters, such as V_{Si} in SiC and rare-earth ions in $LiNbO_3$. We demonstrate a scalable way of manufacturing solid-immersion lenses (SILs) on 4H-silicon carbide (SiC) to enhance collection efficiency of fluorescence of silicon vacancy defect centers. The fabrication process is based on thermal reflow of a lithographically defined photoresist mask followed by high selectivity reactive ion etching. The procedure results in SILs with high effective NA. The fluorescence collection efficiency enhancement of 3.4 times is confirmed by confocal microscopy of individual V_{Si} centers. We show optical measurements of thin-film $LiNbO_3$ based optical microdisk resonators. Structured with scalable fabrication techniques, we achieved Q-factors of 10^5 with mode volume of $25 \cdot (\lambda/n)^3$, providing the possibility of $\sim$ 300 Purcell enhancement of resonant emitters within these structures. Owing to electro-optic properties of lithium niobate, the resonators are electrically tunable over the range of 300 GHz. Once activated with rare-earth ions, lithium niobate resonators present a flexible and scalable platform for cavity QED with single rare-earth emitters.

FM 81.4 Thu 15:00 3042

Anisotropic CVD growth of diamond pillars for Scanning-NV-Magnetometry — •Arne Götze[1,2], Christian Giese[1], Volker Cimalla[1], and Oliver Ambacher[1,2] — [1]Fraunhofer IAF, Freiburg, Germany — [2]Chair for Power Electronics, INATECH, Uni Freiburg, Germany

The technique of Scanning-NV-Magnetometry promises to be a valuable tool for sciences and the industry. By fitting a diamond nanopillar containing single or multiple NV centers to an atomic force microscope, magnetic fields can be measured with high spatial resolution and sensitivity. The current method to produce these diamond tips is to perform lithography and use an oxygen plasma etch process. NV centers are created by nitrogen-ion implantation and annealing. Both of these process steps damage the diamond lattice around the NV center, whose spin coherence time and magnetic sensitivity deteriorate in consequence. By utilising anisotropic diamond growth in CVD (chemical vapour deposition) reactors we show that it is possible to create diamond pillars without introducing crystalline damage in the vicinity of the NV centers in the tip of the pillars. The properties of the resulting diamond tips, as well as limitations and opportunities of this process are discussed.

FM 81.5 Thu 15:15 3042

Parametric instabilities in a 2D periodically-driven bosonic system — •Thomas Boulier[1], James Maslek[1], Marin Bukov[2], Carlos Bracamontes[1], Eric Magnan[1], Samuel Lellouch[3], Eugene Demler[4], Nathan Goldman[5], and James V. Porto[1] — [1]JQI, NNIST and UMD, College Park, Maryland 20742 USA — [2]Univ. of California Berkeley, CA 94720, USA — [3]LPLAM, Universite Lille 1, CNRS; F-59655 Villeneuve d'Ascq, France — [4]Harvard University, Cambridge, MA 02138, USA — [5]CNPCS, Universite Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium

A promising approach to engineer new states of matter is to rapidly oscillate some parameters, so-called Floquet engineering, where new properties can emerge that are not present in the static system. Such oscillations carry energy which can be absorbed, and one might expect heating. Energy absorption in interacting many-body systems is an interesting open question with practical implications for quantum engineering. Recently, theoretical work predicted that for interacting bosons, Floquet systems can be inherently unstable. We experimentally confirm this prediction with a Bose-Einstein condensate in a periodically shaken 2D optical lattice. At large shaking amplitude, circular drives heat faster than linear drives, which illustrates the non-trivial dependence on the drive geometry. In all cases, we demonstrate that the BEC decay is dominated by the emergence of unstable Bogoliubov modes, rather than scattering in higher Floquet bands. We also report an unexpected additional heating, pointing to effects beyond current theories.

FM 81.6 Thu 15:30 3042

Large and tunable valley splitting in a ^{28}Si/SiGe quantum dot — •Tom Struck[1], Arne Hollmann[1], Veit Langrock[1], Andreas Schmidbauer[2], Floyd Schauer[2], Helge Riemann[3], Nikolay V. Abrosimov[3], Dominique Bougeard[2], and Lars R. Schreiber[1] — [1]JARA-FIT Institute Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Germany — [2]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Regensburg, Germany — [3]Leibniz-Institut für Kristallzüchtung (IKZ), Berlin, Germany

^{28}Si has proven to be the host material of choice for electron spin qubits trapped in electrostatically defined quantum dots (QDs) [1,2]. A major challenge for Si/SiGe is the low valley splitting $E_{\rm VS}$ hampering qubit control. Here we investigate $E_{\rm VS}$ of a ^{28}Si/SiGe QD in a molecular-beam epitaxy-grown heterostructure with a residual ^{29}Si concentration of less than 60 ppm. We extract $E_{\rm VS}$ from the T_1 spin relaxation time as a function of magnetic field. We measure a large $E_{\rm VS} > 200\,\mu$eV, which we can reproducibly tune by voltages applied to the depletion-gates. Investigating several mechanisms, we identify displacement of the QD with respect to atomistic details at the Si/SiGe interface as the dominant tuning mechanism.

[1]Yoneda, J. et al. A > 99.9%-fidelity quantum-dot spin qubit with coherence limited by charge noise. Nature Nanotechnology 13,102-106(2017).
[2]Veldhorst, M. et al. A two-qubit logic gate in silicon. Nature 526, 410-414 (2015).

FM 81.7 Thu 15:45 3042

Towards high-temperature coherence-enhanced transport in few-atomic layers heterostructures — •Chahan Kropf[1], Angelo Valli[2], Paolo Franceschini[4], Luca Celardo[3], Massimo Capone[2], Claudio Giannetti[4], and Fausto Borgonovi[1] — [1]Istituto Nazionale di Fisica Nucleare, Sezione di Pavia, via Bassi 6, I-27100 Pavia, Italy — [2]Scuola Internazionale Superiore di Studi Avanzati (SISSA), and CNR-IOM DEMOCRITOS, Istituto Officina dei Materiali, Consiglio Nazionale delle Ricerche, Via Bonomea 265, I-34136 Trieste, Italy — [3]Benemérita Universidad Autónoma de Puebla, Apartado Postal J-48, Instituto de Física, 72570, Mexico — [4]ILAMP (Interdisciplinary Laboratories for Advanced Materials Physics), Università Cattolica del Sacro Cuore, Brescia I-25121, Italy

The possibility to exploit quantum coherence to enhance the efficiency of charge transport in solid state devices working at ambient conditions would pave the way to disruptive technological applications. We tackled the problem of the quantum transport of photogenerated electronic excitations subject to dephasing, on-site Coulomb interactions, and an intrinsic electric potential in one-dimensional wires. Using quantum master equations and density-mean-field-theory we show that the transport to a continuum of states representing metallic collectors can be optimized by exploiting the "superradiance" phenomena. This is a coherent effect which we estimate to be robust against dephasing and electron-electron interactions in a parameters range that is compatible with actual implementation in few monolayers transition-metal-oxide (TMO) heterostructures.

FM 82: Quantum & Information Science: Neural Networks, Machine Learning, and Artificial Intelligence III

Time: Thursday 14:00–15:45 Location: 3044

Invited Talk FM 82.1 Thu 14:00 3044

Deep Learning Advances in Particle Physics — •Yannik Rath[1], Martin Erdmann[1], Benjamin Fischer[1], Erik Geiser[1], Jonas Glombitza[1], Dennis Noll[1], Thorben Quast[1,2], and Marcel Rieger[1] — [1]III. Physikalisches Institut A, RWTH Aachen University — [2]EP-LCD, CERN

Machine learning methods have found widespread use in high-energy particle physics, their most common application being the identification of particles and the separation of signal and background processes in collision events. Deep learning in particular has seen many recent developments, for example the creation of dedicated neural network architectures incorporating physics knowledge (e.g. JINST 14 (2019) P06006). In addition, increasing attention has been directed towards unsupervised learning methods. Most notably, generative adversarial networks are extensively studied for their potential to speed up event simulations by several orders of magnitude (e.g. T. Comput Softw Big Sci 3 (2019) 4). Further unsupervised approaches based on reinforcement learning are also starting to be investigated. In this talk we present an overview of deep learning applications in high-energy particle physics focusing on most recent advancements.

FM 82.2 Thu 14:30 3044

Mining for Particles from Space – Project C3 of the Collaborative Research Center 876 — •Tim Ruhe, Wolfgang Rhode, Katharina Morik, and Mirko Bunse — TU Dortmund

Project C3 of the Collaborative Research Center SFB 876 aims at answering fundamental questions in neutrino- and Cherenkov-astronomy by developing and applying state-of-the-art algorithms from the field Artificial Intelligence. For the past eight years the project has contributed to a variety of analyses in astroparticle physics. This includes the reconstruction of particle properties and energy spectra, searches for point sources and tau-neutrinos as well as the development of algorithms. This report will provide an overview over the project's activities and discuss the latest results.

FM 82.3 Thu 14:45 3044

 # aict-tools – ML-based Event Reconstruction for Imaging Air Cherenkov Telescopes — •Maximilian Nöthe[1], Kai Arno Brügge[1], and Sabrina Einecke[2] — [1]Astroparticle Physics, TU Dortmund, Germany — [2]Faculty of Sciences, University of Adelaide, Australia

Imaging Air Cherenkov Telescopes (IACTs) cover the highest energy ranges in the electromagnetic spectrum of astronomy.

These telescopes record the faint, nano-second scale flashes of Cherenkov radiation emitted by extensive air showers.

All IACTs face the same three reconstruction tasks, for each event, the primary particle's energy, direction and particle type have to be estimated. The particle type classification is necessary, as most extensive air showers are induced by charged cosmic rays.

Most commonly, IACTs record multiple time slices for each pixel in the camera for each shower, which is subsequently reduced to a few parameters describing each event.

The aict-tools use classical machine learning approaches as implemented by scikit-learn to reconstruct the gamma-ray properties from these image parameters.

Originally developed for the FACT Telescope, the library was extended to also work with data of the upcoming Cherenkov Telescope Array, e.g. the CHEC camera prototype.

The package provides executables to train, validate and apply models. It uses the yaml standard for defining configuration files and can store the resulting models in the pickle, pmml and onnx formats.

FM 82.4 Thu 15:00 3044

Analyzing VLBI Data Using Neural Networks — •Kevin Schmidt — TU Dortmund

Very long baseline interferometry (VLBI) allows the observation of distant astronomical objects with the highest resolution. In this technique, the data of several radio telescopes are combined to achieve an effective diameter equal to the greatest distance between the telescopes.

Radio interferometers measure visibilities depending on the baseline between the individual telescopes. Since they are distributed only sparsely, much visibility space remains uncovered. This lack of information causes noise artifacts in the recorded data. In recent decades, various implementations of the CLEAN algorithm (Clark, 1980) have been used to remove these artifacts from radio images. With the increasing data rates of modern radio telescopes, faster solutions have to be found to analyze the observations in a reasonable time.

A new and faster approach is using neural networks. This presentation gives an overview of the first results.

FM 82.5 Thu 15:15 3044

DSEA+: Deconvolution by Machine Learning — •Tim Ruhe[1], Mirko Bunse[2], Kai Brügge[1], and Tobias Hoinka[1] — [1]Lehrstuhl

Experimentelle Physik 5, TU Dortmund — [2]LS8, Fakultät Informatik, TU Dortmund

The reconstruction of an experimentally inaccessible quantity, e.g. a particle's energy, is a common challenge in particle- and astroparticle physics, where correlated observables are measured instead. The transfer from the variable of interest into an experimentally observable quantity is, however, usually governed by stochastical processes, leading to the Fredholm integral equation of the first kind. Additional smearing, stemming from particle propagation and the detector itself, complicate the problem even further. We present a novel machine learning-based approach, DSEA+, which sidesteps certain limitations of existing algorithms by interpreting deconvolution as a multinominal classification task. We discuss the algorithm and show results obtained from simulations provided by the FACT Open Data Project.

FM 82.6 Thu 15:30 3044

Reconstructing Nanoclusters from Single Wide-Angle Scattering Images with Neural Networks — •Thomas Stielow, Robin Schmidt, Thomas Fennel, and Stefan Scheel — Institut fürPhysik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock

Single-shot diffraction imaging by soft X-ray laser pulses is a valuable tool for structural analyses of unsupported and short-lived nanosystems, although inversion of the scattering patterns still prove challenging [1]. Deep learning, on the other hand, is widely used in data sciences for the extraction of information from images and sees more and more application in various sciences. We demonstrate how neural networks can be utilized in the reconstruction of objects from single-shot wide angle scattering patterns in the case of silver nanoclusters [2]. Our network is trained solely on data obtained by existing physical theories and can be applied to real-world experimental data with little to no prior knowledge of the specific experimental setup. With high quality real-time evaluation results, deep learning may hold the key for a fully automated analysis of scattering data and real-time reconstruction of ultrafast nanoscale dynamics probed at the next generation of X-ray light sources with high repetition rate.

[1] I. Barke et al., Nat. Comm. **6**, 6187 (2015).
[2] T. Stielow et al., arXiv:1906.06883 (2019).

FM 83: Poster: Enabling Technologies Sources of Quantum States of Light

Time: Thursday 16:30–18:30 Location: Tents

FM 83.1 Thu 16:30 Tents

Bi-colour photon pair source for light-matter interactions with nitrogen-vacancy centres in diamond — •Julian Gurs, Erik Hesselmeier, Timo Steidl, Charles Babin, Matthias Niethammer, Thomas Kornher, Roland Nagy, Naoya Morioka, Ilja Gerhardt, Roman Kolesov, Jörg Wrachtrup, and Florian Kaiser — 3rd Physics Institute, University of Stuttgart and IQST, Germany

The nitrogen-vacancy centre (NV) in diamond is a promising platform for quantum information distribution. To unleash the full potential, an efficient interface between the NV's natural emission and telecom-wavelength photons is required. To date, wavelength down-converters from 637 nm to 1550 nm suffer from too high photonic noise [1]. Here, we show an alternative solution. We develop a polarisation entangled photon pair source in which one photon is at a telecom wavelength (1560 nm), and the other is generated at 637 nm to match the resonant absorption line of the NV centre. By absorbing the latter photon in the NV centre [2], we intend to entangle the NV centres electron and nuclear spins with a telecom photon. Regarding the photon pair source, we will show our measures to minimise optical loss, while still maintaining a breadboard transportable setup geometry for applications in the field. We will also evaluate the performance of the above mentioned entangled photon storage protocol.

[1] A. Dréau et al., Phys. Rev. Appl. 9, 064031 (2018) [2] S. Yang et al., Nature Photon. 10, 507 (2016)

FM 83.2 Thu 16:30 Tents

Injection locking and synchronization in Josephson circuits — •Lukas Danner, Ciprian Padurariu, Björn Kubala, and Joachim Ankerhold — Institute for Complex Quantum Systems and IQST, Ulm University, 89069 Ulm, Germany

Motivated by recent progress in realizing sources of quantum states of microwave light using Josephson circuits, we explore reducing the emission linewidth to potentially enable measurements of microwave quantum entanglement [1]. We employ the phenomena of injection locking and synchronization that stabilize the phase of emitted radiation against electrical noises [2].

We study injection locking of a single Josephson cavity and show that the low frequency environment plays an essential role in frequency pulling and locking. We model a realistic circuit that includes the resistive part of the impedance and calculate the radiation spectrum finding good agreement with recent experiments.

We further study the synchronization of two (nearly) degenerate Josephson cavities. At low driving amplitudes we find a competition between squeezing and entanglement production. The steady state Wigner density indicates squeezing along an axis that can be rotated by tuning the ratio of the cavity loss rates. Building on these results, we argue the emergence of non-linear response and synchronization as the driving power is increased.

[1] M. Westig et al., Phys. Rev. Lett. 119, 137001 (2017).
[2] M.C. Cassidy et al., Science 355, 939 (2017).

FM 83.3 Thu 16:30 Tents

Towards demultiplexed photons from GaAs quantum dots for multi-photon interference experiments — •Julian Münzberg[1], Maximilian Prilmüller[1], Siamon Covre Da Silva[2], Daniel Huber[2], Markus Reindl[2], Armando Rastelli[2], Gregor Weihs[1], and Robert Keil[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [2]Institute of Semiconductor and Solid State Physics, Johannes Kepler University, 4040 Linz, Austria

Bright sources of multiple indistinguishable photons are pivotal in experiments on boson sampling [1] and many-particle interference [2]. Demultiplexed photons collected from a quantum dot (QD) are a viable implementation of such a bright multi-photon source [1, 3-5]. In this work, we aim to use droplet-etched GaAs QDs [6] for single-photon generation. Preliminary characterization of the QDs yielded promising results and a setup for two-photon resonant excitation and collection is under construction. We plan to actively route consecutively emitted photons with freespace electro-optical modulators for polarisation rotation in conjunction with polarising beam splitters. These spatially separated photons will be eventually used for a multi-photon interference experiment in femtosecond laser written glass waveguides.

[1] Wang et al. Nat. Photonics 11, 361 (2017). [2] Giordani et al. Nat. Photonics 12, 173 (2018). [3] Lenzini et al. Laser Photonics Rev. 11, 1600297 (2017). [4] Hummel et al. arXiv:1903.08785 (2019). [5] Antón et al. arXiv:1905.00936 (2019). [6] Huber et al. PRL 121, 033902 (2018).

FM 83.4 Thu 16:30 Tents

Strongly Correlated Photon Transport in a Waveguide with Weakly Coupled Emitters — Adarsh Prasad[1], Jakob Hinney[1], Klemens Hammerer[2], Sahand Mahmoodian[2], Samuel Rind[1], •Max Schemmer[3], Philipp Schneeweiss[1,3], Anders Sørensen[4], Jürgen Volz[1,3], and Arno Rauschenbeutel[1,3] — [1]TU Wien, Atominstitut, Stadionallee 2, 1020 Vienna, Austria — [2]Institute for Theoretical Physics, Institute for Gravitational Physics (Albert Einstein Institute), Leibniz University Hannover, Appelstraße 2, 30167 Hannover, Germany — [3]Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [4]Center for Hybrid Quantum Networks (Hy-Q), Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen, Denmark

We experimentally show correlated photon transport through an optical waveguide that contains an ensemble of weakly coupled quantum emitters. We observe that the photon statistics of the transmitted light can be continuously changed from anti-bunched light to bunched light by solely changing the number of emitters. This effect arises due to an interplay of the nonlinear optical response of the emitters, linear optical losses, and interference between the transmitted and the forward-scattered two-photon states. We use laser-cooled atoms confined in a nanofiber-based optical dipole trap and analyze the transmission through the fiber with single-photon counters. The recorded second-order time-correlation function, $g_2(t)$, is in agreement with its theoretical prediction and reaches values as low as $g_2(0) \approx 0.5$.

FM 83.5 Thu 16:30 Tents

Tuning the Emission of Quantum Dots for Coupling to a Rb-Memory — Liang Zhai[1], •Giang N. Nguyen[1,2], Matthias C. Löbl[1], Jan-Philipp Jahn[1], Julian Ritzmann[2], Andreas D. Wieck[2], Armando Rastelli[3], Arne Ludwig[2], and Richard J. Warburton[1] — [1]University of Basel, 4056 Basel, Switzerland — [2]Ruhr-Universität Bochum, 44780 Bochum, Germany — [3]Johannes Kepler University Linz, 4040 Linz, Austria

Combining a solid-state quantum dot (QD) with an atomic memory is a promising hybrid-system for application in quantum communication [1]. Coupling the QD to a quantum memory, such as a Rb-memory, can circumvent the short coherence time of QDs. For coupling both systems, the photons emitted by the QD have to match the atomic ensemble in bandwidth and frequency [2, 3].
We use droplet-etched GaAs QDs embedded in AlGaAs as a source of coherent single photons and present two different methods to match the Rb-frequency of 794 nm: Applying mechanical strain to the material [4] and applying an electric field to the QD which is embedded in a diode structure [5, 6].

[1] N. Sangouard *et al.*, Phys. Rev. A **76**, 050301 (2007).
[2] J.-P. Jahn *et al.*, Phys. Rev. B **92**, 245439 (2015).
[3] L. Beguin*et al.*, Phys. Rev. B **97**, 205304 (2018).
[4] D. Huber *et al.*, Phys. Rev. Lett. **121**, 033902 (2018).
[5] L. Bouet *et al.*, Appl. Phys. Lett. **105**, 082111 (2014).
[6] F. Langer *et al.*, Phys. Lett. **105**, 081111 (2014).

FM 83.6 Thu 16:30 Tents

Reduction of spectral diffusion by applying a sequence of optical control pulses — •Laura Orphal[1], Joseph H. D. Munns[1], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

Lifetime limited emission linewidths are a fundamental requirement for the generation of coherent photons, which are crucial for efficient entanglement of stationary qubits in quantum information systems.

However, for the negatively charged nitrogen-vacancy centre (NV) in diamond, natural linewidths (∼13 MHz) are challenging to achieve. In addition to homogeneous broadening, in particular, spectral diffusion, i.e., the change of optical transition frequency over time, caused by fluctuations of the electrostatic environment, leads to an inhomogeneous broadening of the zero-phonon emission line (ZPL).

While work is done on optimizing material properties, active control schemes are an interesting alternative to suppress spectral diffusion. Recently the approach of pulsed coherent control was proposed [1]. A sequence of optical π-pulses is expected to modify the average rate of phase accumulated between the emitter states, affecting the emission spectrum. In this way the ZPL can be stabilized at a chosen frequency given by the carrier frequency of the pulses.

Here, we present our work towards experimentally implementing the protocol for reducing spectral diffusion of the ZPL of NV defect centres by applying a sequence of optical control pulses.

[1] H. F. Fotso et al., Phys. Rev. Lett. 116, 033603 (2016)

FM 83.7 Thu 16:30 Tents

Exceptional points in optical anisotropic thin films — •Sebastian Henn[1], Evgeny Krüger[1], Chris Sturm[1], Armin Dadgar[2], Matthias Wieneke[2], Marius Grundmann[1], and Rüdiger Schmidt-Grund[1,3] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstr. 5, Leipzig — [2]Otto-von-Guericke-Universität Magdeburg, Institut für Physik, Universitätsplatz 2, Magdeburg — [3]now at: Technische Universität Ilmenau, Institut für Physik, Weimarerstr. 25, Ilmenau

We investigate exceptional points (EP) in optically anisotropic transparent thin films both experimentally and theoretically. Such points represent degeneracies in k-space and were already observed in absorptive biaxial crystals [1] and microcavities [2,3]. At the EP the eigenspace of the optical eigenmodes becomes one-dimensional, yielding degeneracy in the complex energy and polarization state. This is reflected by a complex square root topology of the eigenmode energies [1]. Promising systems for the realization of EP are optically anisotropic thin films, providing symmetry breaking and dissipation through losses at the interfaces. We demonstrate the presence of EP in GaN as well as ZnO thin films using spectroscopic ellipsometry and polarization resolved reflection measurements and present rigorous Maxwell-based calculations. We discuss ways to control the occurrence and direction of the EP by altering the design of the system.

[1] W. Voigt *et al.*, Ann. Phys 314, 367 (1902)
[2] S. Richter *et al.*, Phys. Rev. A 95, 023836 (2017)
[3] J. Wiersig, Phys. Rev. Lett. 112, 203901 (2014)

FM 83.8 Thu 16:30 Tents

Measurement-induced effects in two-mode systems. — •Matvei Riabinin, Polina Sharapova, Tim J. Bartley, and Torsten Meier — Paderborn University, Warburger Strasse 100, D-33098 Paderborn, Germany

In optics, nonlinear effects can lead to various transformations of light. Parametric down-conversion (PDC) and four-wave mixing (FWM) are nonlinear effects that can generate entangled photons, quadrature squeezing, and other nonclassical effects. The generation of these effects typically requires strong light intensities. Another way of creating such non-linear transformations in quantum optics is creating so-called measurement-induced nonlinearities, where nonlinear effects can be acquired by applying detection. The detection provides a photon subtraction and might result in various nonlinear transformations. The advantage of using detection compared to PDC is that fewer incident photons are required to generate nonclassical effects. However, acquired effects have a probabilistic nature. In our work, we model a two-mode interferometer where we input different states such as a coherent state and single photon state and apply detection to each channel. We analyze the aquired nonclassical properties such as entanglement and two-mode squeezing at the output. With certain combinations of system parameters, the detection leads to two-mode squeezing which is absent without detection. It is also possible to generate quantum states similar to two-mode cat states with high fidelity. These results will be used for a theoretical description of quantum photonic chips with superconducting detectors embedded into an integrated platform.

FM 83.9 Thu 16:30 Tents

A fiber-coupled single photon source based on a single molecule — •Guilherme Stein[1], Vladislav Bushmakin[1], Yijun Wang[1], Andreas Schell[2], and Ilja Gerhardt[1] — [1]3. Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology, IQST, Pfaffenwaldring 57, D-70569 Stuttgart — [2]CEITEC, Brno University of Technology, 621 00 Brno, Czech Republic

The generation of non-classical light and single photons is a key element for many quantum communication and information schemes. Organic dye molecules under cryogenic conditions allow for the implementation of narrow-band and very bright sources [1]. The integration of single molecules into dielectric structures allows for the construction of fully integrated devices. Here we present our approach to experimentally implement a fully fiber-coupled single photon source based on a single molecule. The source utilizes a high numerical-aperture fiber, and is operated under cryogenic conditions. The source emits more than 45 000 photons per second, while the spectral width of the molecule is identified as 25 MHz. The implicit Raman background of the fiber leads to some unwanted effects. We compare the free-space excitation, where the single photon emission is solely collected through the fiber and the fiber-based excitation, in which the light to excite the molecule is supplied through the fiber.

[1] - Siyushev et al., Nature, 2014, 509, 66-70

FM 83.10 Thu 16:30 Tents

Growth and Characterization of Quantum Dot Molecules — •Nikolai Bart[1], Ismail Bölükbasi[1], Christian Dangel[2], Jonathan Finley[2], Kai Müller[2], Arne Ludwig[1], and Andreas D. Wieck[1] — [1]Ruhr-Universität Bochum, Lehrstuhl für Angewandte Festkörperphysik, Universitätsstraße 150, 44801 Bochum — [2]Technische Universität München, Walter Schottky Institut, Am Coulombwall 4, 85748 Garching bei München

Quantum repeaters and storage devices are crucial requirements for efficient quantum communication. One possible materials system for these are, along color centers and trapped ions, semiconductor quantum dots (QDs). We examine the molecular-beam-epitaxy-growth and optoelectronic properties of two coupled layers of InAs QDs on GaAs, acting as QD molecules. We show that coupling of the two layers can be achieved by adjusting emission wavelengths of direct and indirect exciton recombinations via size modification and electrical tuning.

FM 83.11 Thu 16:30 Tents

Towards monolithic diamond cavities for highly efficient photon extraction — •Lea Balzert, Philipp Fuchs, Thomas Jung, and Christoph Becher — Universität des Saarlandes, Fakultät NT - FR Physik, Campus E2.6, 66123 Saarbrücken

Color centers in diamond, e.g. the nitrogen (NV), silicon (SiV) or recently the tin (SnV) vacancy center, are promising candidates for the implementation of qubits due to the combination of long spin coherence times and optical control and read out of the spin states. Efficient collection of the emitted photons is mandatory for almost all applications, enabling e.g. enhanced signal-to-noise ratios in quantum sensing or efficient spin-photon interfaces for quantum communication. The latter further profits from fluorescence enhancement by an optical cavity allowing for cavity-assisted spin-photon transfer.

We here investigate optical cavities based on thin ($< 10\ \mu$m) single crystal diamond membranes, fabricated from commercially available, high purity diamond material via reactive ion etching. The devices consist of a solid immersion lens (SIL), which is milled in the front facet of the membrane and works as spherical mirror. The unstructured back facet forms a planar mirror, enabling the whole device to work as a monolithic cavity. With appropriate coatings on both sides , we can tailor the device properties towards an efficient extraction of the emitted photons from a color center placed inside the cavity.

FM 83.12 Thu 16:30 Tents

Optical and morphological characterizations of lanthanide complexes — •Miriam Gerstel[1], Ingo Köhne[2], Artur Lik[2], Rudolf Pietschnig[2], Johann Peter Reithmaier[1], and Mohamed Benyoucef[1] — [1]Institute of Nanostructure Technologies and Analytics (INA) — [2]Institute of Chemistry, CINSaT, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Reliable single-photon sources based on semiconductor or molecular systems are of great interest since they are key elements in promising quantum technology applications. However, complex methods of quantum information processing require a large number of indistinguishable photons. Lanthanide complexes are regarded as attractive luminescent materials due to characteristic narrow emission bands, wide emission spectrum and long lifetime. To enhance the absorbance and thus the emission intensity of transitions, utilizing ligands to sensitize the lanthanide emissions is a suitable choice.

For characterization of synthesized lanthanide molecules, the complexes are dissolved in proper solvent and spin-coated on a substrate. To achieve a low density molecule distribution, the influence of preparation and modification of the substrates, choice of solvent, and concentration of the solution is examined. Morphology and homogeneity of the molecules are discussed. Optical properties of lanthanide complexes are determined by photoluminescence spectroscopy, which reveal emission spectra at visible wavelength region.

This work is supported by the state of Hesse in the frame of LOEWE priority project SMolBits.

FM 83.13 Thu 16:30 Tents

Spatial-temporal correlations of the light of an ion crystal — •Stefan Richter[1], Sebastian Wolf[2], Andre Weber[3], Yury Prokazov[4], Evgeny Turbin[4], Joachim von Zanthier[1], and Ferdinand Schmidt-Kaler[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, German — [3]LIN, Leibniz Institute for Neurobiology, Brenneckestraße 6, 39118 Magdeburg — [4]Photonscore GmbH, Brenneckestraße 6, 39118 Magdeburg

We measured first [1] and second order correlation functions of the light spontaneously emitted from a trapped, cold two-ion crystal for various detector positions in the temporal regime. Strikingly, the $g^{(2)}(\vec{x},\tau)$ signal shows bunching or antibunching for different observer positions [2]. Position sensitive Micro Channel Plate detectors developed for applications in fluorescence lifetime microscopy combining a high spatial resolution with temporal resolution. By using two detectors in correlation mode, it is possible to implement intensity interferometry with the light of a two-ion crystals. The spatial modulation of $g^{(2)}(\vec{x}_1,\vec{x}_2,\tau)$ was predicted in [3] and can now be measured by recording the corresponding two photon events for any time difference ΔT and corresponding positions $\vec{x}_1$ and $\vec{x}_2$. After the event stream is recorded, the correlations for arbitrary geometries can be reconstructed. [1] S. Wolf et al., Phys. Rev. Lett. 116, 183002 (2016) [2] S. Wolf et al., in preparation [3] C. Skornia et al., Phys. Rev. A 64, 063801 (2001)

FM 83.14 Thu 16:30 Tents

Spatio-Temporal Higher Order Photon Correlations of a Few-Atom System — •Lukas Götzendörfer[1], Simon Mährlein[1,2], Kevin Günthner[3,1], Jörg Evers[4], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany — [3]Max Planck Institute for the Science of Light (MPL), 91058 Erlangen, Germany — [4]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany

We study a particular model of independent single photon emitters and resulting multi-photon interferences in space and time: Investigating the time evolution of two-level atoms spontaneously emitting photons gives rise to a time-dependent electric field amplitude in the far field. Utilizing field intensity correlations we are then able to observe the collective emission properties of the atomic system manifesting themselves in modified spontaneous decay rates. The correlations are studied for a system of three atoms, where two of them are very close to each other such that they interact via dipole-dipole interaction. Although the residual atom is separated by a large distance and hence does not interact with the other two atoms it can be used to alter the systems* emission properties. This model system can be interpreted as a generalized free-space Hong-Ou-Mandel setup where the probability of measuring three photons not only depends on space but also on time.

FM 84: Poster: Quantum Networks

Time: Thursday 16:30–18:30 Location: Tents

FM 84.1 Thu 16:30 Tents

Stopped and stationary light at the single-photon level inside a hollow-core fiber — Thorsten Peters, Ta-Pang Wang, Antje Neumann, Lachezar S. Simeonov, •Alexander Bruns, and Thomas Halfmann — Institut für Angewandte Physik, Hochschulstrasse 6, 64289 Darmstadt, Germany

We report on light storage and retrieval as well as stationary light for weak coherent light pulses down to the single-photon level based on electromagnetically induced transparency. The experiments were carried out in an ensemble of laser-cooled atoms loaded into a hollow-core photonic crystal fiber to provide strong light-matter coupling, which is an essential requirement for a quantum information platform.

FM 84.2 Thu 16:30 Tents

Production of nanostructures in silicon carbide and their influence on single defect centres — •Timo Görlitz, Charles Babin, Rainer Stöhr, Roman Kolesov, Vadim Vorobev, Matthias Niethammer, Naoya Morioka, Roland Nagy, Florian Kaiser, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart, Germany

Recently, it was shown that single silicon vacancy centres (V_{Si}) in 4H silicon carbide (SiC) are a promising platform for quantum information distribution [1]. The system combines unprecedented spin and spectral stability thanks to low spin-photon coupling and identical dipole moments in ground and excited state. The low photon count rates of the system represent the system's remaining bottleneck, especially when considering quantum communication tasks. To overcome this issue, nanophotonics structures can be used that boost emission rates via Purcell enhancement and, at the same time, improve light collection efficiency. Here, we will show that V_{Si} centres in SiC preserve excellent spin-optical properties in nanophotonics wave guide structures, which is a key requirement for any further advancements. We will then outline our advancements in our current research direction, i.e. the fabrication and characterization of V_{Si} centres in circular Bragg grating cavities. Those structures provide both Purcell enhancement and better collection efficiency [2], and we will compare our theoretical consideration to the experimentally obtained results.

[1] R. Nagy et al., *Nature Comm.* 10, 1954 (2019)
[2] J. Liu et al., *Nature Nano.* 14, 586 (2019)

FM 84.3 Thu 16:30 Tents

Quantum Memory with Optimal Control — •Stephan Trattnig[1,2], Edwar Xie[1,2,3], Frank Deppe[1,2,3,4], Qi-ming Chen[1,2], Michael Fischer[1,2,3], Michael Renger[1,2], Stefan Pogorzalek[1,2], Kirill G. Fedorov[1,2], Matti Partanen[1], Achim Marx[1], and Rudolf Gross[1,2,3,4] — [1]Walther- Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

We realize a quantum memory by coupling a transmon qubit to a rectangular 3D cavity resonator [1]. Exploiting the multimode structure of the 3D cavity enables us to use a single resonator for storage and readout purposes, thereby significantly enhancing scalability. We accurately characterize the loss of quantum information during the storage and retrieval process by performing quantum process tomography on our memory system and find a corrected process fidelity of 88%. Finally, we employ optimal control with DRAG-like pulses in an attempt to suppress state leakage and, thus, improve our memory protocol.

We acknowledge support by the Germany's Excellence Strategy EXC-2111-390814868, Elite Network of Bavaria through the program ExQM, and the European Union via the Quantum Flagship project QMiCS (Grant No. 820505). [1] E. Xie *et al.*, Appl. Phys. Lett. **112**, 202601 (2018).

FM 84.4 Thu 16:30 Tents

Towards techniques for on-chip pump filtering of light sources — •Julian Brockmeier[1], Jan Philipp Höpker[1], Maximilian Protte[1], Harald Herrmann[2], Christof Eigner[2], Christine Silberhorn[2], and Tim Bartley[1] — [1]Mesoskopische Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Integrierte Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Integrated sources of quantum light are increasingly used in many quantum photonic technologies. Many of these sources are optically driven, based on a nonlinear process such as spontaneous parametric down-conversion (SPDC) or four-wave mixing (SFWM). It is also desirable to place detectors on the same chips as the sources, to reduce overall losses and latency of the photonic circuits. However, the strong pump must be separated from the single-photon level quantum light prior to detection. This is a challenging task due to the huge difference in relative power levels, as well as the requirement of low-loss on the quantum light. We present several schemes using titanium in-diffused lithium niobite waveguides which may offer progress towards the goal of on-chip pump filtering, based on both waveguide design, dispersion engineering and high-speed response of superconducting integrated detectors.

FM 84.5 Thu 16:30 Tents

Polarization-preserving quantum frequency conversion for entanglement distribution in quantum networks — •Matthias Bock[1], Stephan Kucera[1], Robert Garthoff[2], Tim van Leent[2], Kai Redeker[2], Pascal Eich[1], Matthias Kreis[1], Wenjamin Rosenfeld[2,3], Tobias Bauer[1], Harald Weinfurter[2,3], Juergen Eschner[1], and Christoph Becher[1] — [1]Universität des Saarlandes, Campus E2.6, Saarbrücken, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Entanglement between a stationary quantum system and a photonic flying qubit is an essential ingredient of a quantum-repeater network. Most stationary quantum bits, however, have transition wavelengths in the blue, red or near-infrared spectral regions, whereas long-range fiber-communication requires wavelengths in the low-loss telecom regime. A proven tool to interconnect flying qubits at visible/NIR wavelengths to the telecom bands is quantum frequency conversion.

Here we will show an efficient and low-noise polarization-preserving frequency converter connecting 854 nm – a transition wavelength in a single trapped $^{40}Ca^{+}$-ion – to the Telecom O-band at 1310 nm. This enables the observation of ion-telecom-photon entanglement as well as an ion-to-telecom-photon state transfer. Moreover we will present a complete QFC system designed as telecom interface for an elementary Rubidium-atom based quantum network link. As a first result, the entanglement between a single Rb-atom and a telecom photon transmitted through an optical fiber of 10 km length is shown.

FM 84.6 Thu 16:30 Tents

Building Blocks for Practical Single-Photon QKD — •Lucas Rickert[1], Timm Kupko[1], Martin v. Helversen[1], Alexander Schlehahn[1], Sven Rodt[1], Christian Schneider[2], Sven Höfling[2,3], Stephan Reitzenstein[1], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Technische Physik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [3]SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, United Kingdom

We will present our recent progress in the development of practical devices for quantum communication employing quantum light sources. The first device is a plug-and-play single-photon source (SPS) based on semiconductor quantum dots, integrated in a compact Stirling cryocooler for user-friendly operation. We address efficient direct coupling of electrically operable quantum light sources to optical single-mode fibers, representing one crucial step towards applications. The second device constitutes a receiver module designed for polarization-encoded QKD. We show that temporal filtering of single-photon pulses can be used for a performance optimization of QKD systems implemented with realistic quantum-light sources. Finally, we demonstrate real-time security monitoring using our receiver-module by evaluating $g^{(2)}(0)$ inside the quantum channel.

The results presented here are an important contribution towards the development of QKD-secured communication networks based on quantum-light sources suitable for practical applications.

FM 84.7 Thu 16:30 Tents

Polarization-Preserving Quantum Frequency Conversion of $^{40}Ca^{+}$-Resonant Photons to the Telecom C-Band — •Tobias Bauer, Matthias Bock, Stephan Kucera, Benjamin Kambs, Jan Arenskötter, Jürgen Eschner, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

In quantum communication networks information is stored in internal states of quantum nodes, which can be realized e.g. in trapped ions like $^{40}Ca^{+}$. By transferring the states onto photons, it is possible to exchange information between these nodes over long distances via optical fiber links. In order to minimize attenuation in fibers, which is particularly high for typical transition frequencies of trapped ions, quantum frequency down-conversion of the transmitted photons to low-loss telecom bands is utilized [1].

We present a scheme for polarization-preserving quantum frequency conversion of $^{40}Ca^{+}$-resonant photons to the telecom C-band. It relies on the difference frequency generation process $854\,\text{nm} - 1904\,\text{nm} = 1550\,\text{nm}$ [2] in a PPLN waveguide, which is arranged in a Sagnac configuration to achieve polarization preservation. We will present the characterization of the converter, in particular of its conversion efficiency and noise count rates.

[1] M. Bock, P. Eich et al., Nat. Commun. 9, 1998 (2018)
[2] V. Krutyanskiy et al., Appl. Phys. B 123:228 (2017).

FM 84.8 Thu 16:30 Tents

Quantum repeater implementation based on a nitrogen-vacancy center in diamond — •Javid Javadzade, Florian Kaiser, Amlan Mukherjee, Erik Hesselmeier, Ilja Gerhardt, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology IQST, Stuttgart, Germany

Distribution of entanglement over large distances is a prerequisite for implementation of high-level quantum information tasks, e.g. quantum cryptography. While there are already commercial solutions for short distance point-to-point quantum links, a scalable approach towards long-distance quantum key distribution (QKD) calls for a quantum repeater based network architecture. By dividing the quantum communication channel in multiple nodes, channel losses are overcome and error correction can be implemented. Here, we outline our research strategy towards implementing an elementary quantum repeater node as a part of the Q.Link.X project, funded through the German BMBF. The repeater node will utilize a single nitrogen-vacancy center in diamond coupled to a nearby 13C nuclear spin, acting as quantum memory [1]. Our protocol is based on entanglement between solid-state spins and photonic time-bin modes. We will present the estimated entanglement rates and discuss further extensions and improvements.

[1] D. Luong et al. Appl. Phys. B, 122, 96 (2016)

FM 84.9 Thu 16:30 Tents

Towards hybrid waveguides in lithium niobate for quantum optical applications — •Maxmilian Protte[1], Lena Ebers[2], Jan Philipp Höpker[1], Basudeb Sain[1], Julian Brockmeier[1], Raimund Ricken[1], Manfred Hammer[2], Christof Eigner[1], Jens Förstner[2], Christine Silberhorn[1], and Tim Bartley[1] — [1]Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Department Elektrotechnik und Informationstechnik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

In recent years there has been a great number of optical devices realized in titanium in-diffused lithium niobate waveguides. One great advantage is the on-chip coupling efficiency (≥ 80%) which results from the good overlap between the fiber mode and the waveguide mode. A significant challenge is efficiently coupling between titanium in-diffused waveguides and material systems with much smaller optical mode dimensions, such as semiconductor waveguides or superconducting detectors. One approach is the use of tapers consisting of a high refractive index material such as silicon, and vertical evanescent coupling between the two waveguide structures. We theoretically and experimentally investigate this approach to increase the detection efficiency of superconducting integrated detectors, which would further increase the versatility of an already promising platform for integrated photonics.

FM 84.10 Thu 16:30 Tents

Characterization and Readout of Multi-Element Superconducting Single Photon Detectors — •Timon Schapeler[1], Johannes Tiedau[2], Vikas Anant[3], Helmut Fedder[4], Christine Silberhorn[2], and Tim Bartley[1] — [1]Mesoskopische Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Integrierte Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [3]Photon Spot, Inc. 142 W Olive Ave, Monrovia, CA 91016, USA — [4]Swabian Instruments GmbH, Frankenstr. 39, 71701 Schwieberdingen, Germany

The detection of single photons is the basis of many applications in quantum photonics. Increasingly, superconducting nanowire single-photon detectors (SNSPDs) are used, due to their high efficiency, low dark count rate and their high repetition rate up to the gigahertz regime. In addition, some photon-number information can be extracted using multi-element devices. We demonstrate one way to characterize the photon statistics arising from four-element SNSPDs in terms of their detection efficiency. By a comparison of experimental data and a theoretical model of a commercial four-pixel device, we were able to account for the individual detection efficiencies of each pixel. Furthermore, we demonstrate a multi-element single-channel readout scheme, based on measuring pulse length of the output of the four-pixel device with each element connected in series. This simplifies the electronic data acquisition of such devices, as well as reduces the electronic heat-load in the cryostat.

FM 84.11 Thu 16:30 Tents

Linear and Nonlinear Characterisation of Cryogenic Waveguides in Lithium Niobate — •Nina Amelie Lange[1], Moritz Bartnick[1], Jan Philipp Höpker[1], Frederik Thiele[1], Raimund Ricken[2], Viktor Quiring[2], Christof Eigner[2], Harald Herrmann[2], Christine Silberhorn[2], and Tim Bartley[1] — [1]Mesoskopische Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Integrierte Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Lithium niobate is a promising platform for integrated quantum photonics. In particular, the outstanding electro-optic properties and the high second-order nonlinearity allow for high-speed modulation, polarisation conversion and sources of quantum light. These properties are well examined at room temperatures. However, many quantum optic devices, especially superconducting detectors, can only operate at cryogenic temperatures. Therefore, the properties of waveguides in lithium niobate must be investigated at temperatures of a few Kelvin. We developed some techniques to perform a linear and a nonlinear characterisation of titanium in-diffused lithium niobate waveguides inside a closed cycle cryostat. These techniques allow us to characterise the waveguide losses and the second harmonic generation at cryogenic temperatures. The examined samples show that losses and nonlinear phasematching bandwidths are not strongly affected in this temperature range. Moreover, these characterisation techniques allow to investigate the pyroelectric properties of lithium niobate.

FM 84.12 Thu 16:30 Tents

Design and impelementation of a segmented ion trap with an integrated fiber cavity — •Omar Elshehy, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Efficient atom-photon interfaces are a basic requirement for any quantum network [1,2]. The efficiency of such interfaces has been shown to increase significantly by the use of cavities [3]. We present a segmented ion trap design for $^{40}Ca^+$ ions with an integrated fiber cavity. The fiber cavity is incorporated into the center electrodes of the trap, which protects the ion from charge accumulation on the fiber mirrors and shields the fibers from lasers. A simulation of the trapping potential shows its tunability for micro-motion compensation and ion-shuttling operations. Moreover, preliminary characterization measurements of coupling efficiency and finesse of the fiber cavity are presented.

[1] C. Kurz et al., Nat. Commun. **5**, 5527 (2014)
[2] M. Bock et al., Nat. Commun. **9**, 1998 (2018)
[3] T. G. Ballance et al., Phys. Rev. A **95**, 033812 (2017)

FM 84.13 Thu 16:30 Tents

Time-multiplexed photonic quantum walks with 4D coins — •Lennart Lorz[1], Evan Meyer-Scott[1], Thomas Nitsche[1], Václav Potocek[2], Aurél Gábris[2], Sonja Barkhofen[1], Igor Jex[2], and Christine Silberhorn[1] — [1]Integrated Quantum Optics, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Brehová 7, 115 19, Praha 1, Czech Republic

Discrete time quantum walks, realized in time-multiplexed architectures, are an essential tool to experimentally study quantum transport phenomena. We have implemented the well-established time-multiplexing scheme in a Michelson interferometer loop, in contrast to the standard Mach-Zehnder setup. By exploiting the two different traveling directions in the loop in addition to the two possible polarizations of the walker, we devise a four dimensional coin space for a one dimensional quantum walk. Making use of the extra degrees of freedom, we are able to generate quantum walks on loop structures of various sizes and topologies, with mixing and non-mixing coins and different input positions and polarizations. By capitalizing on the full dimensionality of the coin, we demonstrate walk evolutions on so-called figure of eight graphs consisting of two loops connected by a central vertex of rank four.

FM 84.14 Thu 16:30 Tents

Efficient single-photon collection for long-distance entanglement of atoms — •Robert Garthoff[1], Tim van Leent[1], Kai Redeker[1], Matthias Seubert[1], Wei Zhang[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Planck- Institut für Quantenoptik, Garching, Germany

Photon mediated entanglement between distributed quantum systems forms the basis of future quantum networks and thus will be essential for secure quantum communication and distributed quantum computing. Currently, efficient collection of photons from the quantum memory limits the generation of remote entanglement in entanglement swapping based schemes.

Here we present the details and experimental results of a new setup with optimized photon collection efficiency from a single Rb-87 atom. Using a custom designed high-NA microscope objectives, corrected for our specific experimental geometry, we observe an increase of the collection efficiency by a factor of 2.5. This now enables an improved rate to achieve remote entanglement by a factor of 6, which in turn forms the crucial ingredient to apply frequency conversion to telecom wavelengths in order to efficiently obtain entanglement between quantum memories on a suburban scale.

[1] W. Rosenfeld, Phys. Rev. Lett. **119**, 010402 (2017).

FM 84.15 Thu 16:30 Tents

Multi-photon Entanglement via Quantum Interference Buffering — Evan Meyer-Scott[1], •Nidhin Prasannan[1], Ish Dhand[2], Christof Eigner[1], Viktor Quiring[1], Sonja Barkhofen[1], Benjamin Brecht[1], Martin B Plenio[2], and Christine Silberhorn[1] — [1]University of Paderborn, 33098 Paderborn, Germany — [2]Institüt für Theoretische Physik and Center for Integrated Quantum Science and Technology(IQST), University of Ulm, 89069 Ulm, Germany

We present an experimental method to generate multi-photon entangled state which utilises quantum buffering and temporal source multiplexing. Our all optical polarization insensitive buffer memory is able to store photonic qubits with good efficiency and state fidelity. Quantum state tomography reveals photonic qubit state fidelity of 99% for 200ns and above 88% for $1\mu s$ storage time. A Sagnac based polarization entangled source is pumped by a femtosecond laser to fire Bell pairs with high entanglement visibility. Combining temporal source multiplexing and memory loop we apply a quantum interference buffering technique to entangle subsequent Bell pairs towards a four photon GHZ state. We achieve a state fidelity above 80% for the GHZ state. Temporal multiplexing of 20 sources shows nine fold increase in four photon generation rates.

FM 84.16 Thu 16:30 Tents

Quantum repeater protocols assisted by single- and two-qubit memory — •Martin Steinel, Matthias Kreis, Jan Arenskötter, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

The generation of entanglement over long distance is a fundamental ingredient in quantum networks that may be employed for quantum key distribution or distributed quantum computing. Because of fiber loss, the transmission efficiency decreases exponentially with distance. To counteract this, quantum repeaters [1] are required. The Lütkenhaus protocol [2] promises to achieve higher entanglement rates by combining quantum repeater methods with quantum memories (QM) in the middle of the link. Focusing on an implementation based on trapped ions as quantum memories [3-5] and an SPDC source of entangled photon pairs [6], we compare protocols for a quantum repeater link using two QMs with protocols using a single QM. We consider efficiency, scalability, and rates in a case study for our existing setup.

[1] H.-J. Briegel et al., Phys. Rev. Lett. **81**, 5932 (1998) [2] D. Luong et al., Appl. Phys. B **122**, 96 (2016) [3] C. Kurz et al., Nat. Commun. **5**, 5527 (2014) [4] C. Kurz et al., Phys. Rev. A **93**, 062348 (2016) [5] M. Bock et al., Nat. Commun. **9**, 1998 (2018) [6] S. Kucera et al., in preparation

FM 84.17 Thu 16:30 Tents

Towards long-time entanglement between a single optically trapped atom and a single photon — •Wei Zhang[1], Tim van Leent[1], Robert Garthoff[1], Kai Redeker[1], Matthias Seubert[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Planck- Institut für Quantenoptik, Garching, Germany

The most fundamental task for a quantum network is to generate atom-photon entanglement with long coherence time.

At present, for atom-photon states of a single optically trapped Rb-87 atom and its emitted photons, there are two decoherence mechanisms. One is motional decoherence in the dipole trap and the other is magnetic decoherence caused by the fluctuation of external magnetic fields. The proposed method is to use a standing-wave dipole trap to confine the atom in space thus reducing motional decoherence. At the same time, this optics can be used to apply stimulated Raman adiabatic passage to coherently transfer the entangled atomic state to the new atomic states which is 500 hundred times less-sensitive to magnetic-field fluctuations.

The coherence time for an atom-photon entangled state is expected to be increased by 2 orders of magnitude, from the (current) 100 microseconds to 10 milliseconds, which would be sufficient for communications over more than 100 km.

FM 84.18 Thu 16:30 Tents

Single-photon source design for quantum telecommunication networks — •Nico Sieber[1,2], Matthias Bayerbach[1,2], and Stefanie Barz[1,2] — [1]Center for Integrated Quantum Science and Technology — [2]Institute for Functional Matter and Quantum Technologies

Photonic devices are key to a large range of quantum technologies, for example quantum communication and wider quantum networks. When transmitting quantum information over long distances, minimizing losses is crucial to any quantum protocols. Thus, the favourable wavelength is in the telecom regime (1550nm). Many quantum protocols thus rely on pure and indistinguishable photons at this wavelength. Here, we demonstrate the generation of single photons at telecom wavelength using type II spontaneous parametric down-conversion (SPDC) in periodically-poled potassium titanyl phosphate (ppKTP) crystals. When being used in quantum network tasks, the probabilistic nature of SPDC fosters the occurrence of multi-photon pair generation leading to reduced fidelities of the tasks to be implemented. Following that, we perform a simulation of this effect on a variety of quantum network tasks.

FM 84.19 Thu 16:30 Tents

Hybrid Devices of Spin-photon Interfaces for Singlet-triplet Quantum Dots — •Zheng Zeng[1], David Fricker[1], Arne Ludwig[2], Marcel Schmidt[2], Chao Zhao[1], Hendrik Bluhm[3], and Beata Kardynał[1] — [1]Peter Grünberg Institute 9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr- Universität Bochum, 44780 Bochum, Germany — [3]JARA-Institute for Quantum Information, RWTH Aachen University, 52074 Aachen, Germany

Connecting quantum processors over long distances using photon qubits would enable more complex quantum computing architectures and quantum networks. Recently a protocol to transfer a quantum state from a photonic qubit to a singlet-triplet spin qubit in GaAs/AlGaAs heterostructure has been theoretically demonstrated. In practice, the coherent transfer is facilitated by a hybrid device where a GaAs/AlGaAs gate-defined double quantum dot (GDQD) is tunnel coupled to a self-assemble quantum dot (SAQD), in which a conversion between a photon state and a spin state takes place. In this contribution we discuss fabrication techniques to achieve the precise alignment of both types of QDs both in energy as well as in space, which is essential for the device operation. We fabricate front- and back-gates to enable tuning the energy levels of the quantum dots. We discuss the method to align the gates of the GDQD to a SAQD. Further we explore methods of QDs growth to minimize the impact on the GDQDs. In particular we compare the performance of strain-free droplet QDs with high quality Stransky-Krastanov QDs in the hybrid devices.

FM 85: Poster: Enabling Technologies: Cavity QED

Time: Thursday 16:30–18:30 Location: Tents

FM 85.1 Thu 16:30 Tents

Cavity-enhanced spectroscopy of a few-ion ensemble in $\mathbf{Eu^{3+}:Y_2O_3}$ — Bernardo Casabone[1,2], Julia Benedikter[2,3,4], Thomas Hümmer[2,3], Franziska Oehl[3], Karmel De Oliviera Lima[5], Theodor W. Hänsch[2,3], Alban Ferrier[5,6], Philippe Goldner[5,6], Hughes De Riedmatten[1,7], •Timon Eichhorn[4], Kelvin Chung[4], and David Hunger[4] — [1]ICFO-Institut de Ciencies Fotoniques — [2]Max-Planck-Institut für Quantenoptik — [3]Fakultät für Physik, Ludwig-Maximilians-Universität — [4]Karlsruher Institut für Technologie — [5]Université PSL, Chimie ParisTech, CNRS — [6]Sorbonne Université — [7]ICREA-Institució Catalana de Recerca i Estudis Avançats

A promising approach for realizing scalable quantum registers lies in the efficient optical addressing of solid state quantum memories. Within the EU Quantum Flagship project SQUARE we tackle this problem by coupling the flourescence of Eu ions in Y_2O_3 nanoparticles (NPs) to a high-finesse fiber-based Fabry-Pérot microcavity. As a first step towards efficient readout of single rare earth ions, we present cavity-enhanced spectroscopy measurements of a few europium-ions as published in New J. Phys. **20** (2018) 095006. In particular, we focus on the coherent transition $^5D_0 -^7F_0$ of Eu^{3+} that has been shown to have narrow optical linewidth in the order of 100 kHz. We determined the number of ions in a NP and observed an increased fluorescence count rate in agreement with the Purcell enhancement of the cavity. An inhomogeneous linewidth of 22 GHz, which is close to bulk value, indicates high crystal quality of the NPs.

FM 85.2 Thu 16:30 Tents

Towards a coherent spin photon interface for quantum

repeaters using NV centers in diamond — •Maximilian Pallmann[1], Rainer Stöhr[2], Eugen Vasilenko[1], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität Stuttgart

Building a long distance quantum network is one of the big challenges in the field of quantum communication, which requires the development of a quantum repeater. A crucial component of this is an efficient, coherent spin photon interface, and coupling single Nitrogen Vacancy centers to a microcavity is a promising approach therefor. In our experiment, we integrate a diamond membrane to an open access fiber-based Fabry-Perot microcavity to increase the weak emission into the Zero Phonon Line (ZPL) of NV centers. Simulations predict the feasibility of a strong enhancement of the ZPL emission efficiency, reaching values of up to 80%. We present a spatially resolved characterization of a coupled cavity-membrane device and report on the current status of the experiment.

FM 85.3 Thu 16:30 Tents

Quantum Fourier Transform in Oscillating Modes — •Qi-Ming Chen[1,2], Frank Deppe[1,2,3], Stefan Pogorzalek[1,2], Michael Renger[1,2], Kirill G. Fedorov[1,2], Matti Partanen[1,2], Achim Marx[1], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

Quantum Fourier transform (QFT) is the key ingredient for many quantum algorithms. Typical applications of QFT, such as phase estimation, require a considerable number of qubits as well as a square number of quantum gates to form a Hilbert space large enough for generating high-precision results. Even though qubit recycling can be used to realize semi-classical FT with a single ancilla qubit in problems related to phase estimation, one pays the price of repeated measurements and feedforward throughout the process. In this work, we map the qubit state onto an oscillating mode with an infinite-dimensional Hilbert space, and implement QFT by means of two coupled oscillating modes with cross-Kerr interaction. This method enables high-dimensional fully-quantum FT with state-of-the-art superconducting quantum circuits.

We acknowledge support by the Germany's Excellence Strategy EXC-2111-390814868, Elite Network of Bavaria through the program ExQM, the European Union via the Quantum Flagship project QMiCS (Grant No. 820505).

FM 85.4 Thu 16:30 Tents

Multimode cavity QED description of photonic Bose-Einstein condensation — •David Steinbrecht[1], Robert Bennett[1,2], and Stefan Yoshi Buhmann[1,2] — [1]University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

Photonic Bose–Einstein condensation is a novel quantum state of light that arises when a laser-driven ensemble of dye molecules thermalises with light inside a cavity [1]. We are developing a first-principles description of the spatiotemporal structure of the phenomenon on the basis of multimode cavity QED. In our model, the molecule–light interactions are described in an open systems approach that quantifies spontaneous decay, cavity losses and intramolecular channels. The spatial mode structure is determined in terms of the electromagnetic Green's tensor [2].

[1] J. Klaers, J. Schmitt, F. Vewinger and M. Weitz, Nature **468**, 545 (2010).

[2] S. Esfandiarpour, H. Safari, R. Bennett, S. Y. Buhmann, J. Phys. B **51**, 094004 (2018).

FM 85.5 Thu 16:30 Tents

An atom-cavity system for high-bandwidth quantum networks — •Maximilian Ammenwerth, Lukas Ahlheit, Wolfgang Alt, Tobias Macha, Pooja Malik, Deepak Pandey, Hannes Pfeifer, Eduardo Urunuela, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115, Bonn, Germany

Miniaturized fiber Fabry-Pérot cavities are robust and integrable atom-light interfaces with emerging applications in fiber-based quantum networks. Their small mode volume allows for the combination of strong light-matter coupling and high input bandwidth [1]. For these *open* resonators, the well-known technique of cavity cooling is not easily accessible. As an alternative, we present degenerate Raman Sideband Cooling, which makes use of Raman transitions driven by the atom-confining dipole trap beams.

We demonstrate the storage of short light pulses by employing a single rubidium atom coupled to the resonator and an assisting control laser [2]. The optimal control pulse is found from a numerical optimisation based on simulating the system dynamics via the Lindblad master equation. A storage efficiency of $(8.2 \pm 0.9)\%$ is found for a coherent wavepacket with a full width at half maximum of 5 ns, a duration well below the atomic decay time. The measured efficiency is in good agreement with the numerical simulation encouraging *hybrid experiments* with semiconductor quantum dots as light sources.

[1] PRL 121, 173603 (2018)
[2] arXiv:1903.10922 (2019)

FM 85.6 Thu 16:30 Tents

A rigid fiber Fabry Pérot cavity for spectroscopic applications — •Carlos Saavedra, Madhavakkannan Saravanan, Wolfgang Alt, Deepak Pandey, Hannes Pfeifer, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115, Bonn, Germany

Optical fiber cavities present a versatile system to confine light in small mode volumes for a broad range of applications, such as cavity QED [1], frequency filtering or spectroscopic applications. We present a monolithic fiber cavity assembly, which offers high passive stability in a compact mount. We outline the general procedure of our rigid cavity fabrication and characterization process [2]. We demonstrate active stabilizion of the length of the cavity using the Pound-Drever-Hall locking technique.

[1] New J. Phys. 12, 065038, (2010)
[2] Appl. Phys. B 122:47, (2016)

FM 85.7 Thu 16:30 Tents

Heteroepitaxial growth of GaP membrane structures on Silicon — •Muhammad Shaharukh[1], Paul Mertin[2], Friedhard Römer[2], Bernd Witzigmann[2], Johann Peter Reithmaier[1], and Mohamed Benyoucef[1] — [1]Institute of Nanostructure Technology and Analytics (INA),CINSaT,University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Computational Electronics and Photonics (CEP), CINSaT, University of Kassel, Germany

The growth of III-V materials on Si is quite challenging due to the lattice mismatch and incompatible thermal expansion coefficients, which leads to a high density of dislocations. Due to the low lattice mismatch, GaP has been shown to overcome these obstacles. GaAs and Si- based photonic crystal (PhC) cavity prevents the use of emitters such as molecules that typically have resonances at visible wavelengths. GaP-based PhC cavity is one of the possible candidates for coupled PhC cavity-molecule systems to generate identical single-emitters for potential applications in scalable solid-state quantum systems.

Here, we report on the growth of GaP on Si substrates as well as GaP-based membrane structures using molecular beam epitaxy. The effects of different growth parameters on the formation of GaP structure where nucleation layer acts as a virtual substrate are investigated. The design and fabrication of GaP-based PhC cavity structures are also discussed. The optical properties of the grown structures are examined by photoluminescence spectroscopy.

This work is supported by the state of Hesse in the frame of LOEWE priority project SMolBits.

FM 85.8 Thu 16:30 Tents

Natural cavities with huge Purcell factors in gold nano sponges — Felix Schwarz[1], Sebastian Bohm[1], •Erich Runge[1], Dong Wang[1], Peter Schaaf[1], Jinhui Zhong[2], Juemin Yi[2], and Christoph Lienau[2] — [1]TU Ilmenau — [2]Universität Oldenburg

Metallurgically produced porous gold nanoparticles, so-called nano sponges, are a cheap and mass-producible system of fascinating quantum mechanical and quantum optical properties. For optimized parameters (filling factor, pore size, pore shapes...)[1] and in any given frequency range, always some local pore configurations will act as natural nano antennae and nano cavities[2] with huge Purcell factors $\gtrsim 7000$. Under illumination, electromagnetic energy is transferred from the wavelength scale via the Mie resonance of the whole nano particle ($\sim$200 nm) into hot-spots of tens of nm size or less[3]. The strongly enhanced electromagnetic fields in the hot spots live rather long and dominate the non-linear properties of the sponge, as has been shown via electron emission in Ref. [2]. Thus, tailored gold nanosponges have the potential to be an enabling technology for the exploitation of QED

effects in mass-produced systems.
[1] Towards optimal disorder in gold nanosponges for long-lived localized plasmonic modes, F. Schwarz, E. Runge, Ann. Phys. (Berlin) 529(12), 1600234 (2017); [2] Long-lived electron emission reveals localized plasmon modes in disordered nanosponge antennas, G. Hergert et al., Light: S&A 6(10), e17075 (2017); [3] Strong spatial and spectral localization of surface plasmons in individual randomly disordered gold nanosponges, J. Zhong et al., Nano Lett. 18 (8), 4957-4964 (2018)

FM 86: Poster: Secure Communication & Computation

Time: Thursday 16:30–18:30 Location: Tents

FM 86.1 Thu 16:30 Tents

Relevance of POVMs for Bell nonlocality — •Lucas Tendick, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

We discuss the relevance of general positive-operator valued measures (POVMs) for Bell nonlocality. Despite the fact that POVMs outperform projective measurements in many other quantum information tasks, about the benefit of POVMs with respect to nonlocality only little is known. We study Bell inequalities which involve up to four outcomes with multiple settings and discuss their properties. Especially the advantage of POVMs compared to projective measurements on qubits in terms of maximal violation and robustness of the inequality is analysed. We discuss both facet and non-facet defining inequalities of the local polytope from the literature, as well as new inequalities found by linear programming. Furthermore, possible connections between Bell inequalities and tasks where an advantage of POVMs is well-known are analysed.

FM 86.2 Thu 16:30 Tents

Tripartite Device-independent Quantum Key Distribution Beyond CHSH Violation — •Timo Holz, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Security proofs for device-independent (DI) quantum key distribution (QKD) rely on a loophole-free violation of Bell inequalities. We introduce a novel Bell inequality including three parties, where each of them measure two dichotomic observables. This Bell inequality functions as a DI witness for genuine tripartite entanglement, given a particular violation is observed. We furthermore present a DIQKD protocol based on the violation of this new Bell inequality. The connection between achievable conference-key rates and the violation of the multipartite Bell inequality is established with the semidefinite programming techniques introduced in Ref. [1]. Thus, our approach goes beyond breaking the multipartite-Bell setting down into an effective bipartite one, violating the Clauser-Horne-Shimony-Holt inequality, and the results of Ref. [2]. We suggest a suitable tripartite QKD protocol and study the effect of different noise models on achievable asymptotic secret-conference-key rates.

[1] L. Masanes et al., Nat. Commun. 2, 238 (2011)
[2] A. Acin et al., Phys. Rev. Lett. 98, 230501 (2007)

FM 86.3 Thu 16:30 Tents

Test of a time-bin entanglement-based QKD system in a commercial optical link. — •Oleg Nikiforov, Erik Fitzke, Daniel Hofmann, Kai Roth, and Thomas Walther — AG Laser und Quantenoptik, Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany

Quantum Key Distribution offers means for cryptographic key exchange, superior in security to the majority of contemporary classical key distribution schemes. We are working on a time-bin entanglement-based system for quantum key distribution. We test its performance in a real-world commercial telecommunication environment of Deutsche Telekom. In this contribution, we discuss the recent progress of our experiment and show first results.

FM 86.4 Thu 16:30 Tents

Fiber-based source for QKD around 1550 nm — •Maximilian Tippmann, Oleg Nikiforov, Erik Fitzke, and Thomas Walther — AG Laser und Quantenoptik, Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany

We develop an all-fiber system for quantum key distribution in a commercial telecom network via energy-time entangled photons. Our source consists of a PPLN crystal pumped by a MOPA with subsequent SHG and can be operated in cw as well as pulsed. A modular setup guarantees robust and flexible operation outside of a controlled lab environment. In the contribution, we discuss the performance of the whole system and its components.

FM 86.5 Thu 16:30 Tents

Photoluminescence excitation spectroscopy of single quantum dots emitting in the 2^{nd} and 3^{rd} telecom windows — •H. Salamon[1], P. Wyborski[1], A. Maryński[1], A. Musiał[1], P. Podemski[1], T. Heusler[2], N. Srocka[2], D. Quandt[2], A. Strittmatter[2], S. Rodt[2], A. Kors[3], J.P. Reithmaier[3], M. Benyoucef[2], S. Reitzenstein[3], and G. Sek[1] — [1]Wrocław University of Science and Technology, Poland — [2]Technical University of Berlin, Germany — [3]University of Kassel, Germany

Photoluminescence excitation spectroscopy (PLE) allows for energy structure determination and energy transfer processes observation in semiconductor structures. Single dot PLE has always been challenging in the spectral range above 1 μm . Here, we present how this technique was adapted to single quantum dots (InGaAs/GaAs and InAs/InP) emitting in the 2^{nd} and 3^{rd} telecom windows, including demonstration of excited states detection in single nanostructures. This kind of quantum dots are promising candidates for non-classical photon sources required for quantum communication and computation applications.

We acknowledge financial support via the "Quantum dot-based indistinguishable and entangled photon sources at telecom wavelengths" project carried out within the HOMING programme of the Foundation for Polish Science co-financed by the European Union under the European Regional Development Fund. This work was also financially supported by the German Federal Ministry of Education and Research (BMBF) within projects Q.com-H and Q.Link.X.

FM 86.6 Thu 16:30 Tents

Spectral Characterization of Photon Pairs for Quantum Key Distribution — •Erik Fitzke, Daniel Hofmann, Till Dolejsky, Oleg Nikiforov, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

We are developing a QKD system with energy-time entangled photon pairs around 1550 nm. The system will later be integrated in a standard telecommunication network. Our system requires characterization of the spectra of the emitted photon pairs and of the influence of transmission through several kilometers of telecommunication fiber. Thus, we compare different methods of analysis such as a grating spectrograph, the arrival time shift due to chromatic dispersion or autocorrelation function measurement. Results of the different approaches with photon pairs from SPDC will be presented.

FM 86.7 Thu 16:30 Tents

Towards efficient single-photon sources at telecom wavelengths — •J. Jasiński[1], N. Srocka[2], W. Rudno-Rudziński[1], P.-I. Schneider[3], S. Burger[3,4], D. Quandt[2], A. Strittmatter[2], S. Rodt[2], A. Musiał[1], S. Reitzenstein[2], and G. Sek[1] — [1]Wrocław University of Science and Technology, Poland — [2]Technical University of Berlin, Germany — [3]JCMwave, Berlin, Germany — [4]Zuse Institute Berlin, Germany

Extraction efficiency is the main limiting factor in applications (e.g. QKD) of single-photon sources at telecom wavelengths required for integration with existing fiber networks. Epitaxial quantum dots (QDs) embedded in the solid-state matrix are very attractive in view of their integration, scalability and compatibility with current semiconductor technology. Here we present epitaxial In0.75Ga0.25As/GaAs QDs grown on a DBR and capped with strain reducing layer. QDs were deterministically embedded into cylindrical photonic mesa structures using in-situ electron beam lithography. The extraction efficiency has been determined based on single QD emission spectrum measured at saturation in a calibrated setup under non-resonant pulsed excitation

using single photon counting modules. Values exceeding 10% have been achieved, but theoretical calculations show possibility of reaching 40% following optimized mesa geometry design.

We acknowledge financial support via the QuanTel project carried out within the HOMING programme of the Foundation for Polish Science co-financed by the EU under the European Regional Development Fund and by the Polish National Agency for Academic Exchange.

FM 86.8 Thu 16:30 Tents

Photonic integrated circuits for satellite quantum communication on a CubeSat — Ömer Bayraktar[1,2], •Jonas Pudelko[1,2], Imran Khan[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, Friedrich-Alexander University Erlangen-Nürnberg, Germany

The limited range of quantum key distribution (QKD) in fiber based systems led to several projects aiming for the development of a satellite based QKD infrastructure. Photonic integrated circuits (PICs) are a convenient way to implement all necessary optical functions, while meeting the stringent demands on size, weight and power in satellite missions.

In this work, we present our payload intended for the demonstration of integrated quantum communication technology in space. It is based on two Indium-Phosphide PICs implementing a source for modulated weak coherent states as well as a quantum random number generator (QRNG) based on homodyne measurements of the quantum mechanical vacuum state. The whole system is implemented on a 10 cm x 10 cm PCB including electronics, making it compatible to the CubeSat standard.

These developments will be tested as a part of the CubeSat mission QUBE.

FM 86.9 Thu 16:30 Tents

True randomness certified from loop-hole free Bell test — •Xing Chen[1], Ilja Gerhardt[1], Jörg Wrachtrup[1], Robert Garthoff[2], Kai Redeker[2], and Wenjamin Rosenfeld[2] — [1]3. Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology, IQST, Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, D-80799 Munich, Germany

The loop-hole free test of Bell's inequality allows us to certify quantum random numbers with a very limited set of prior assumptions [1]. The randomness certified by Bell's theorem was extracted by singlet probability $p(a|x)$ in previous studies, which does not fully extract the device-independent (DI) randomness in the Bell test data. A more precise and smaller upper bound could be deduced by semi-defined-programs, but it is not convenient and not secure for practical use. Here, we develop an analytic upper bound for the joint outcome probability $p(ab|xy)$, so we can extract all the DI randomness from the Bell test data. In a weaker semi-device-independent conditions, with dimension witnesses [2], substantial more randomness can be extracted than in the device-independent cases. We use our models on the loophole free Bell test experiment [3], and certify more randomness than previous models.

[1] S. Pironio, *et al.*, Nature 464.7291 (2010): 1021.
[2] J. Bowles, *et al.*, Physical Review Letters 112.14 (2014):140407.
[3] W. Rosenfeld, *et al.*, Physical Review Letters 119.1 (2017): 010402.

FM 87: Outreach: Public science evening

Time: Thursday 19:30–21:00 Location: Audi Max

Discussion FM 87.1 Thu 19:30 Audi Max

Revolution in der Quantenwelt? — Ottfried Gühne[1], Oliver Benson[2] und Oliver Ambacher[3] — [1]Universität Siegen — [2]Humboldt Universität zu Berlin — [3]Fraunhofer Institut und Universität Freiburg

In der Halbleiter- oder auch in der Lasertechnologie ist die Entwicklung immer neuer Komponenten und Anwendungen ohne ein gutes Verständnis der Quantenphysik seit langem undenkbar. Die technologischen Fortschritte der letzten Jahrzehnte bringen nun aber eine völlig neue Generation von Methoden und Komponenten. Das neue Gebiet der Quanteninformation brachte nicht nur Konzepte für sichere Kommunikation, Quantenteleportation und den Quantencomputer. Es brachte auch ein deutlich besseres Verständnis der Quantenphysik sowie neue Techniken für die experimentelle Umsetzung. Die Referenten geben in Impulsvorträgen einen Überblick über die neuen Konzepte, neue nichtklassische Lichtquellen, den Einsatz von Nanophotonik, sowie die Entwicklung neuer Quantensensoren für die Vermessung von Magnetfeldern mit atomarer Auflösung und beantworten in einer Podiumsdiskussion Ihre Fragen.

FM 88: Plenary Talk: Extreme Entanglement

Time: Friday 8:30–9:30 Location: Audi Max

Plenary Talk FM 88.1 Fri 8:30 Audi Max

What can be done with extreme entanglement? — •Richard Cleve — University of Waterloo, Waterloo, Canada

In 2017, William Slofstra showed that there are correlations (i.e., variants of the Bell inequality) that require an infinite amount of quantum entanglement to produce exactly, and a very large amount of entanglement to approximate. Since this work, there have been interesting advances in a lively exploration of deep connections between different notions of entanglement, the theory of computation, and the theory of operator algebras. I will explain various notions of infinite entanglement and describe some simple operational tasks that require large or infinite entanglement to perform.

FM 89: Introductory Talk: Quantum Light Sources

Time: Friday 9:30–10:30 Location: Audi Max

Introductory Talk FM 89.1 Fri 9:30 Audi Max

Generation of pure quantum light in the solid-state — •Pascale Senellart — Center for Nanoscience and Nanotechnology - CNRS- University Paris Saclay - 10 Bd T. Gobert, 91120, Palaiseau, France

The ability to generate light in pure quantum states is central to the development of quantum-enhanced technologies. Recently, artificial atoms in the form of semiconductor quantum dots have emerged as an excellent platform for quantum light generation [1-2]. By placing the quantum dot in an optical microcavity, pure dephasing phenomena are strongly suppressed and single photon wavepackets with very high quantum purity in the frequency domain are generated. This is demonstrated at unprecedented high efficiency that allows scaling up linear quantum optical technologies [3]. The system is also shown to generate light pulses in a pure quantum superposition in the photon number basis, a feature that has never been demonstrated even with natural atoms. This is obtained through coherent control of the artificial atom transition: a pure quantum superposition of vacuum and one-photon is generated with a full control of their relative populations. Driving the system even stronger, a coherent superposition of vacuum, one- and two-photons is generated—a state that shows phase super-resolving interferometry [4].

[1] N. Somaschi, et al. Nature Photonics, 10, 340 (2016) [2] P Senellart, G Solomon, A White, Nature Nanotechnology 12 (11), (2017) [3] C Antón, et al., arXiv:1905.00936 [4] J. C. Loredo, C. Anton, et. al, arXiv:1810.05170, to appear in Nature Photonics

FM 90: Special Session: Quantum Physics for AI & AI for Quantum Physics

Time: Friday 11:00–13:00 Location: Audi Max

Invited Talk FM 90.1 Fri 11:00 Audi Max

How to use quantum light to machine learn graph-structured data — •Maria Schuld[1,2], Kamil Bradler[1], Robert Israel[1], Daiqin Su[1], and Brajesh Gupt[1] — [1]Xanadu, Toronto, Canada — [2]University of KwaZulu-Natal, Durban, South Africa

A device called a 'Gaussian Boson Sampler' has initially been proposed as a near-term demonstration of classically intractable quantum computation. But these devices can also be used to decide whether two graphs are similar to each other, which is the central challenge when doing machine learning on data represented by graphs, such as molecules and social networks. In this talk, I will show how to construct a graph similarity measure - or 'graph kernel' as it is known in machine learning - using samples from an optical Gaussian Boson Sampler. Combining this with standard machine learning methods allows us to predict features of the graph using example data. I will present promising benchmark results comparing the 'quantum kernel' to 'classical kernels' and motivate theoretically why such a continuous-variable quantum computer can actually extract interesting properties. The work is an example of how to use first-generation quantum technologies for machine learning tasks.

Invited Talk FM 90.2 Fri 11:30 Audi Max

Ensuring safety for AI methods - from basic research to Bosch applications — •David Reeb — Bosch Center for Artificial Intelligence, Renningen, Germany

For industry and business applications - especially for safety critical ones - which involve machine learning, it is imperative to ensure that such data-driven methods perform as promised, despite the fact that only a small part of reality has been seen during training. I will motivate this need via Bosch applications, and then describe theoretical methods to ensure such safety requirements. In particular, I will introduce the framework of Statistical Learning Theory, which provides probabilistic guarantees of this kind, and outline some of its paradigmatic results as well as major open questions. Finally, I will describe how generalization bounds from this theory can be used to devise learning algorithms that yield good safety guarantees. We have employed such a result to train Gaussian Processes - a machine learning method popular in industry - and obtained significantly better generalization guarantees compared to training with conventional methods (arXiv:1810.12263).

Invited Talk FM 90.3 Fri 12:00 Audi Max

Boltzmann machines and tensor networks for simulating quantum many body systems — •Frank Verstrate — Ghent University

I will discuss challenges and opportunities for simulating strongly correlated quantum many body systems using Boltzmann machines and tensor networks.

Invited Talk FM 90.4 Fri 12:30 Audi Max

Response operators in Machine Learning: Response Properties in Chemical Space — •Anders Christensen — Institute of Physical Chemistry and National Center for Computational Design and Discovery of Novel Materials (MARVEL), Department of Chemistry, University of Basel, Klingelbergstrasse 80, CH-4056 Basel, Switzerland

This talk focuses on the use of response operators in machine learning models for properties of chemical compounds. The role of response operators is well-established in quantum chemistry in which they are used to calculate properties of chemical compounds using differential operators. The same response operators commonly used in quantum chemistry are here applied to a new machine learning model in order to increase its accuracy. Prediction errors for corresponding properties reach high accuracies for small training set sizes. For example, the learning rate of dipole moments is improved by a factor 20x compared to a similar model without operators. In addition, the prediction of vibrational normal modes and infrared spectra of small molecules demonstrates the applicability of this approach for chemistry. The presented operator-based approach is general and can in principle be applied to any machine learning model.

FM 91: Special Session: Quantum Information Concepts in Astrophysics

Time: Friday 11:00–13:00 Location: 2004

Invited Talk FM 91.1 Fri 11:00 2004

Information Theoretic Methods in Inflationary Cosmology — •Achim Kempf — University of Waterloo, Canada

At the Planck scale, and close to a big bang, the conventional notions of space-time and matter are widely expected to reach the very limit of their range of applicability. For this reason, the use of quantum information-theoretic tools could be useful in these circumstances: no matter how counter intuitive the phenomena at the Planck scale are, it should always make sense to quantify how much information and how much information processing is involved. I will first review related information-theoretic concepts such as covariant bandlimitation. I will then focus on the prospect that information-theoretically-described Planck scale physics has left an imprint in inflation and that it has, therefore, possibly left an observable imprint in the cosmic microwave background and in structure formation.

Invited Talk FM 91.2 Fri 11:40 2004

Quantum Information and Cosmic Inflation — •Jerome Martin — Institut d'Astrophysique de Paris, 98bis boulevard Arago, 75014 Paris, France

According to the theory of cosmic inflation, the large scale structures observed in our Universe (galaxies, clusters of galaxies, Cosmic Background Microwave - CMB - anisotropy ...) are of quantum mechanical origin. They are nothing but vacuum fluctuations, stretched to cosmological scales by the cosmic expansion and amplified by gravitational instability. At the end of inflation, these perturbations are placed in a two-mode squeezed state with the strongest squeezing ever produced in Nature (much larger than anything that can be made in the laboratory on Earth). In this talk, one studies whether astrophysical observations could unambiguously reveal this quantum origin by borrowing ideas from quantum information theory. One argues that cosmic inflation is not only a successful paradigm to understand the early Universe. It is also the only situation in Physics where one crucially needs General Relativity and Quantum Mechanics to derive the predictions of a theory and, where, at the same time, we have high-accuracy data to test these predictions, making inflation a playground of utmost importance to discuss foundational issues in Quantum Mechanics

Invited Talk FM 91.3 Fri 12:20 2004

Collective excitations as quantum sensors for fundamental physics — •Ivette Fuentes — School of Mathematical Sciences, University of Nottingham, UK

Quantum sensors that are used to measure gravitational fields and detect dark energy typically use single particle interferometric techniques that are limited by the time of flight in the interferometer arm. In this talk I will present a new detection method that uses quantum resonances and the sensitivity of collective excitations (phonons) to gravitational fields. When phonons in a Bose-Einstein condensate are initially prepared in a squeezed state, spacetime distortions can create additional excitations through parametric amplification. This effect can be used to detect gravitational waves at high frequencies. We have also developed a phonon based scheme to estimate spacetime parameters, miniaturize devices to measure gravitational fields and gradients and set further constrains on dark energy models.