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Fachverband Quanteninformation (QI)

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Overview of Invited Talks and Sessions

(Lecture halls H3, H4 and H5; Poster P)

Invited Talks

QI 1.1	Mon	10:45–11:15	H4	**TBA** — •Christine Silberhorn
QI 1.2	Mon	11:15–11:45	H4	**TBA** — •Jonathan Home
QI 3.1	Mon	14:00–14:30	H4	**Quantum Non-Locality in Networks** — •Nicolas Gisin
QI 3.2	Mon	14:30–15:00	H4	**Quantum Foundations Meets Causal Inference** — •Robert W. Spekkens
QI 4.1	Tue	14:00–14:30	H3	**Principles of quantum functional testing** — Nadia Milazzo, Olivier Giraud, •Daniel Braun
QI 4.6	Tue	15:30–16:00	H3	**Noncommuting conserved quantities in thermodynamics** — •Nicole Yunger Halpern
QI 5.1	Tue	14:00–14:30	H4	**Recent progress with superconducting fluxonium qubit** — •Vladimir Manucharyan
QI 5.2	Tue	14:30–15:00	H4	**Quantum information processing with semiconductor technology: from qubits to integrated quantum circuits** — •Menno Veldhorst
QI 6.1	Wed	10:45–11:15	H3	**Stabilization and operation of a Kerr-cat qubit in a nonlinear superconducting resonator** — •Alexander Grimm
QI 6.2	Wed	11:15–11:45	H3	**The 3rd quantum revolution: Quantum Algorithmic Experiments.** — •Dorit Aharonov
QI 9.1	Thu	10:45–11:15	H4	**The true Heisenberg limit in optical interferometry** — •Rafal Demkowicz-Dobrzanski
QI 9.2	Thu	11:15–11:45	H4	**On the quantum limits of field sensing** — •Morgan Mitchell
QI 11.1	Thu	14:00–14:30	H4	**Numerical Security Analyis for Quantum Key Distribution and Application to Optical Protocols** — •Norbert Lütkenhaus
QI 11.2	Thu	14:30–15:00	H4	**Photonic graph states for quantum communication and quantum computing** — •Stefanie Barz
QI 12.1	Fri	10:45–11:15	H3	**Emergent Hilbert-space fragmentation in tilted Fermi-Hubbard chains** — •Monika Aidelsburger
QI 12.2	Fri	11:15–11:45	H3	**An entanglement-based perspective on quantum many-body systems** — •Norbert Schuch
QI 14.1	Fri	14:00–14:30	H3	**Quantum computing: scaling from university lab to industry** — •Jan Goetz, IQM Team
QI 14.2	Fri	14:30–15:00	H3	**Gate Based Quantum Computing at Volkswagen** — •Martin Leib
QI 14.3	Fri	15:00–15:30	H3	**TBA** — •Sarah Sheldon

Sessions

QI 1.1–1.6	Mon	10:45–12:45	H4	**Implementations: Atoms, Ions and Photons**
QI 2.1–2.8	Mon	10:45–12:45	H5	**Quantum Computing and Algorithms I**
QI 3.1–3.6	Mon	14:00–16:00	H4	**Quantum Information and Foundations I**
QI 4.1–4.6	Tue	14:00–16:00	H3	**Quantum Thermodynamics and Open Quantum Systems**
QI 5.1–5.6	Tue	14:00–16:00	H4	**Implementations: Solid State Systems**
QI 6.1–6.6	Wed	10:45–12:45	H3	**Quantum Computing and Algorithms II**
QI 7.1–7.7	Wed	10:45–12:30	H4	**Quantum Information: Applications**
QI 8.1–8.27	Wed	16:30–18:30	P	**Quantum Information: Poster (joint session QI/Q)**

QI 9.1–9.6	Thu	10:45–12:45	H4	**Quantum Metrology**
QI 10.1–10.7	Thu	10:45–12:30	H5	**Certification and Benchmarking of Quantum Systems**
QI 11.1–11.6	Thu	14:00–16:00	H4	**Quantum Communication**
QI 12.1–12.6	Fri	10:45–12:45	H3	**Quantum Simulation and Many-Body Systems**
QI 13.1–13.7	Fri	10:45–12:30	H4	**Quantum Information and Foundations II**
QI 14.1–14.3	Fri	14:00–15:30	H3	**Quantum Computing in Industry**

QI 1: Implementations: Atoms, Ions and Photons

Time: Monday 10:45–12:45 Location: H4

Invited Talk QI 1.1 Mon 10:45 H4
TBA — •Christine Silberhorn — Universität Paderborn, Fakultät für Naturwissenschaften, Department Physik - Angewandte Physik, 33095 Paderborn, Germany

TBA

Invited Talk QI 1.2 Mon 11:15 H4
TBA — •Jonathan Home — ETH Zürich, Department of Physics, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

TBA

QI 1.3 Mon 11:45 H4
Superconducting Nb-based plasmonic perfect absorbers for tunable near- and mid-IR photodetection — •Philipp Karl[1], Sandra Mennle[1], Monika Ubl[1], Ksenia Weber[1], Mario Hentschel[1], Philipp Flad[1], Jing-Wei Yang[2,3], Yu-Jung Lu[2,3], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Research Center for Applied Sciences, Academia Sinica, Taipei 11529, Taiwan — [3]Department of Physics, National Taiwan University, Taipei 10617, Taiwan

Quantum technologies require the provision of high-quality and efficient photodetectors, as well as the ability to detect single photons, which can be provided by superconducting nanowire single photon detectors. To reach near-100% absorption with our structures we are utilizing resonant plasmonic perfect absorber effects. This is aided by the angle insensitivity and the high resonant absorption cross section and of plasmonic resonances, which enable ultra-small active areas and short recovery times. In this work, we present simulations as well as measurements of tunable superconducting niobium based plasmonic perfect absorber structures with near-100% absorption efficiency in the infrared spectral range and use the tunable plasmonic resonance to create a polarization dependent photodetector. To demonstrate the resonant plasmonic behavior, which manifests itself through a polarization dependence detector response, we investigated the detector structure with an external light source, as well as with a directly coupled single mode fiber.

QI 1.4 Mon 12:00 H4
Towards a fault-tolerant universal set of microwave driven quantum gates with trapped ions — •Nicolas Pulido[1,2], Markus Duwe[1,2], Hardik Mendpara[1,2], Amado Bautista[1,2], Giorgio Zarantonello[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]National Institute of Standards and Technology, Boulder, Colorado 80303

A fully operational quantum computer will require a complete set of quantum gates, with sufficiently low gate-errors to allow fault tolerance [1]. Here, we consider the implementation of single- and two-qubit gates using microwaves [2] as a scalable alternative to the more widely spread optical addressing techniques, which are typically limited by photon scattering. The control fields are generated by microwave conductors embedded directly into the trap structure. We obtain a preliminary infidelity of 10^{-4} for single-qubit gates and approaching 10^{-3} for two-qubit operations using this fully integrated approach. The two-qubit gates are shown to be robust with respect to motional quantum bus noise as a result of a tailored amplitude modulation protocol [3].

[1] E. Knill et al., Nature 434, 39-44 (2005)
[2] C. Ospelkaus et al., Phys. Rev. Lett. 101 090502 (2008)
[3] G. Zarantonello et al., Phys. Rev. Lett. 123 260503 (2019)

QI 1.5 Mon 12:15 H4
Tunable magnetic quadrupole for MAGIC-based quantum information processing in a planar electrode ion trap — •Ivan Boldin, Elham Esteki, Bogdan Okhrimenko, and Christof Wunderlich — University of Siegen, Siegen, Germany

Magnetic gradient induced coupling (MAGIC) is an approach to quantum information processing with trapped ions, where all coherent operations with qubits are carried out with microwave-frequency electromagnetic fields. This approach requires a strong static magnetic field gradient along the chain of trapped ions. Such a static gradient can either be created by electric currents or by permanent magnets. Electric currents are tunable, but it is hard to reduce the current noise to a sufficiently low level. Permanent magnets can provide a strong field gradient with low noise, but the field cannot be tuned. We have come up with a solution to the abovementioned challenge: a system that is free from electrical currents during quantum logic operations, and which creates a fully tunable strongly inhomogeneous magnetic field. This is achieved by the use of a permanent magnet quadrupole made of moderate coercivity material (AlNiCo) that can be magnetized (and demagnetized) by short current pulses. We present the results of experimental characterization of our novel type of magnetic quadrupole. Using trapped Yb ions as a magnetic field sensor, we demonstrate a maximum gradient of 116 T/m and the tunability of the field. In addition, we present the results of the investigation of the coherence properties of the trapped-ion based qubits, depending on the magnetic field gradient.

QI 1.6 Mon 12:30 H4
Real-time capable CCD-based individual trapped-ion qubit measurement — •Sebastian Halama[1], Timko Dubielzig[1], Niklas Orlowski[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische-Bundesanstalt, Bundesallee 100,0 38116 Braunschweig, Germany

We report on the individual detection of $^{9}Be^{+}$ qubit states undergoing coherent excitation using an EMCCD camera. The ions are trapped in a cryogenic surface-electrode ion trap with integrated microwave conductors [1] for near-field quantum control. This kind of trap promises good scalability to a higher number of qubits [2]. Together with the individual real-time detection this is a key requirement for many-body quantum simulation and also error-correction protocols in quantum information processing [3]. We discuss known error sources during state preparation and measurement in the order of 0.5 % and comment on the sources and the amount of crosstalk in our detection system. We briefly present the used imaging system and compare the qubit state detection performance of the EMCCD camera with a PMT.

[1] Dubielzig et. al., Rev. Sci. Instr. **92**, 043201 (2021)
[2] Kielpinski et. al., Nature **417**, 709 (2002)
[3] Nielsen and Chuang, Quantum Computation and Quantum Information, Cambridge (2000)

QI 2: Quantum Computing and Algorithms I

Time: Monday 10:45–12:45 Location: H5

QI 2.1 Mon 10:45 H5
Training variational quantum algorithms is NP-hard — •Lennart Bittel and Martin Kliesch — Heinrich-Heine-Universität, Düsseldorf, Deutschland

Variational quantum algorithms (VQAs) are proposed to solve relevant computational problems on near term quantum devices. Popular versions are variational quantum eigensolvers (VQEs) and quantum approximate optimization algorithms (QAOAs) that solve ground state problems from quantum chemistry and binary optimization problems, respectively. They are based on the idea to use a classical computer to train a parameterized quantum circuit. We show that the corresponding classical optimization problems are NP-hard. Moreover, the hardness is robust in the sense that for every polynomial time algorithm, there exists instances for which the relative error resulting from the classical optimization problem can be arbitrarily large, assuming P =/= NP. Even for classically tractable systems, composed of only logarithmically many qubits or free fermions, we show that the optimization is NP-hard. This elucidates that the classical optimization is intrinsically hard and does not merely inherit the hardness from the ground state problem. Our analysis shows that the training landscape can have many far from optimal persistent local minima. This means gradient and higher order decent algorithms will generally converge to far from optimal solutions.

QI 2.2 Mon 11:00 H5

Linear growth of quantum circuit complexity — •Jonas Haferkamp[1], Philippe Faist[1], Naga Kothakonda[1], Jens Eisert[1], and Nicole Yunger Halpern[2] — [1]Freie Universität Berlin — [2]Harvard-Smithsonian, ITAMP

Quantifying quantum states' complexity is a key problem in various subfields of science, from quantum computing to black-hole physics. We prove a prominent conjecture by Brown and Susskind about how random quantum circuits' complexity increases. Consider constructing a unitary from Haar-random two-qubit quantum gates. Implementing the unitary exactly requires a circuit of some minimal number of gates - the unitary's exact circuit complexity. We prove that this complexity grows linearly in the number of random gates, with unit probability, until saturating after exponentially many random gates. Our proof is surprisingly short, given the established difficulty of lower-bounding the exact circuit complexity. Our strategy combines differential topology and elementary algebraic geometry with an inductive construction of Clifford circuits.

QI 2.3 Mon 11:15 H5

Understanding Variational Quantum Learning Models — Matthias C. Caro[1,2], Jens Eisert[3,4], Elies Gil-Fuster[3], •Johannes Jakob Meyer[3,5], Maria Schuld[6], and Ryan Sweke[3] — [1]Department of Mathematics, Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany — [4]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany — [5]QMATH, University of Copenhagen, Copenhagen, Denmark — [6]Xanadu, Toronto, ON, M5G 2C8, Canada

Finding practically relevant applications for noisy intermediate-scale quantum devices is an active frontier of quantum information research. Using them to execute parametrized quantum circuits used as learning models is a possible candidate. We show that the possible output functions of such learning models can be elegantly expressed by generalized trigonometric polynomials, whose available frequencies are determined by the spectra of the Hamiltonians used for the data encoding [1]. This approach allows for an intuitive understanding of quantum learning models and underlines the important role of data encoding in quantum machine learning. Building on this, we exploit this natural connection to give generalization bounds which explicitly take into account how a given quantum learning model is encoding the data [2]. These bounds can act as a guideline to select and optimize quantum learning models in a structural risk minimization approach. Based on [1] arXiv:2008.08605 and [2] arXiv:2106.03880.

QI 2.4 Mon 11:30 H5

Generalization in quantum machine learning from few training data — •Matthias C. Caro[1,2], Hsin-Yuan Huang[3,4], Marco Cerezo[5,6], Kunal Sharma[7,8], Andrew Sornborger[9,10], Lukasz Cincio[5], and Patrick J. Coles[5] — [1]Department of Mathematics, TU Munich, Garching, Germany — [2]MCQST, Munich, Germany — [3]IQIM, Caltech, Pasadena, CA, USA — [4]Department of Computing and Mathematical Sciences, Caltech, Pasadena, CA, USA — [5]Theoretical Division, LANL, Los Alamos, NM, USA — [6]Center for Nonlinear Studies, LANL, Los Alamos, NM, USA — [7]QuICS, University of Maryland, College Park, MD, USA — [8]Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA USA — [9]Information Sciences, LANL, Los Alamos, NM, USA — [10]Quantum Science Center, Oak Ridge, TN, USA

Modern quantum machine learning (QML) methods involve variationally optimizing a parameterized quantum circuit on training data, and then make predictions on testing data. We study the generalization performance in QML after training on N data points. We show: The generalization error of a quantum circuit with T trainable gates scales at worst as $\sqrt{T/N}$. When only $K \ll T$ gates have undergone substantial change in the optimization process, this improves to $\sqrt{K/N}$.

Core applications include significantly speeding up the compiling of unitaries into polynomially many native gates and classifying quantum states across a phase transition with a quantum convolutional neural network using a small training data set. Our work injects new hope into QML, as good generalization is guaranteed from few training data.

QI 2.5 Mon 11:45 H5

Quantum Autoencoders for Error Correction — •David Locher[1], Lorenzo Cardarelli[2], and Markus Müller[1,2] — [1]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [2]Peter Grünberg Institute, Theoretical Nanoelectronics, Forschungszentrum Jülich, D-52425 Jülich, Germany

The operation of reliable large-scale quantum computers will foreseeably require quantum error correction procedures, in order to cope with errors that dynamically occur during storage and processing of fragile quantum information. Classical machine learning approaches, e.g. neural networks, have been proposed and successfully used for flexible and scalable strategies for quantum error correction. Complementary to these efforts, we investigate the potential of quantum machine learning for quantum error correction purposes. Specifically, we show how quantum neural networks, in the form of quantum autoencoders, can be trained to learn optimal strategies for active detection and correction of errors, including possibly correlated bit-flip and depolarizing noise, as well as qubit loss. We highlight that the denoising possibilities of quantum autoencoders are not limited to the protection of specific states but extend to entire logical codespaces. In addition, we show that quantum neural networks can discover new encodings, optimally adapted to the underlying noise.

QI 2.6 Mon 12:00 H5

Gottesman-Kitaev-Preskill bosonic error correcting codes: a lattice perspective — Jonathan Conrad, •Francesco Arzani, and Jens Eisert — Freie Universität Berlin, Arnimallee 14, 14195 Berlin

Bosonic error correcting codes (ECC) protect the state of a finite-dimensional quantum system by embedding it in the infinite-dimensional Hilbert space of an ensemble of harmonic oscillators. Gottesman-Kitaev-Preskill (GKP) codes are a class of bosonic ECC that rely on translation symmetries of the code-states to detect and correct common errors affecting physical realizations of harmonic oscillators (e.g. photon loss in electromagnetic modes). For example, imposing the correct symmetries on a single oscillator restricts the state-space to that of a qubit. To achieve better noise resilience, the code can be concatenated with a qubit-level ECC. This allows to directly apply the machinery developed for qubits. However, the translation symmetries also establish a formal connection with lattices, which is not fully exploited by usual approaches to concatenated codes (CC). Furthermore, CC are special cases, which are not guaranteed to be optimal given the underlying bosonic nature of the system.

We examine general GKP codes, including concatenated GKP codes, through the lens of lattice theory to understand the structure of this class of stabilizer codes. We derive formal bounds on code parameters, show how different decoding strategies are related and point to natural resource savings that have remained hidden in previous approaches.

QI 2.7 Mon 12:15 H5

Scalable approach to many-body localization via quantum data — •Alexander Gresch, Lennart Bittel, and Martin Kliesch — Quantum Technology Group, Heinrich Heine University Düsseldorf

We are interested in how quantum data can allow for practical solutions to otherwise difficult computational problems. Such a notoriously difficult phenomenon from quantum many-body physics is the emergence of many-body localization (MBL). So far, is has evaded a comprehensive analysis. In particular, numerical studies are challenged by the exponential growth of the Hilbert space dimension. As many of these studies rely on exact diagonalization of the system's Hamiltonian, only small system sizes are accessible.

In this work, we propose a highly flexible neural network based learning approach that, once given training data, circumvents any computationally expensive step. In this way, we can efficiently estimate common indicators of MBL such as the adjacent gap ratio or entropic quantities. Moreover, our estimator can be trained on data from various system sizes at once which grants the ability to extrapolate from smaller to larger ones. We hope that our approach can be applied to large-scale quantum experiments to provide new insights into quantum many-body physics.

QI 2.8 Mon 12:30 H5

Fermion Sampling — Michal Oszmaniec[1], Ninnat Dangniam[1], Mauro Morales[2], and •Zoltan Zimboras[3,4] — [1]Center for Theoretical Physics, Polish Academy of Sciences — [2]University of Technology Sydney, Australia — [3]Wigner Research Centre for Physics, Budapest, Hungary — [4]BME-MTA Lendület Quantum Information Theory Research Group, Budapest, Hungary and Mathematical Institute, Budapest University of Technology and Economics, Budapest, Hungary

In this talk, we present a quantum advantage scheme which is a fermionic analogue of Boson Sampling: Fermion Sampling with magic input states. We argue that this scheme merges the strengths of Random Circuit Sampling and Boson Sampling. On the one hand side, we provide hardness guarantees for this scheme which is at a comparable level to that of the state-of-the-art hardness guarantees for Random Circuit Sampling, surpassing that of Boson Sampling. On the other hand, we argue that there are verification schemes of Fermion Sampling circuits that are stronger than those for Random Circuit Sampling. We also discuss the experimental feasibility of our scheme.

QI 3: Quantum Information and Foundations I

Time: Monday 14:00–16:00 Location: H4

Invited Talk QI 3.1 Mon 14:00 H4

Quantum Non-Locality in Networks — •Nicolas Gisin — University of Geneva, Switzerland — Schaffhausen Institute of Technology, SIT-Geneva, Switzerland

Quantum non-locality, i.e. the violation of some Bell inequality, has proven to be an extremely useful concept in analyzing entanglement, quantum randomness and cryptography, among others. In particular, it led to the fascinating field of device-independent quantum information processing.

Historically, the idea was that the particles emitted by various quantum sources carry additional variables, known as local hidden variables. The more modern view, strongly influenced by computer science, refers to these additional variables as shared randomness. This, however, leads to ambiguity when there is more than one source, as in quantum networks. Should the randomness produced by each source be considered as fully correlated, as in most common analyses, or should one analyze the situation assuming that each source produces independent randomness, closer to the historical spirit?

The latter is known, for the case of n independent sources, as n-locality. For example, in entanglement swapping there are two sources, hence *quantumness* should be analyzed using 2-locality (or, equivalently, bi-locality). The situation when the network has loops is especially interesting. Recent results for triangular networks will be presented.

Invited Talk QI 3.2 Mon 14:30 H4

Quantum Foundations Meets Causal Inference — •Robert W. Spekkens — Perimeter Institute, Waterloo, Canada

Can the effectiveness of a medical treatment be determined without the expense of a randomized controlled trial? Can the impact of a new policy be disentangled from other factors that happen to vary at the same time? Questions such as these are the purview of the field of causal inference, a general-purpose science of cause and effect, applicable in domains ranging from epidemiology to economics. Researchers in this field seek in particular to find techniques for extracting causal conclusions from statistical data. Meanwhile, one of the most significant results in the foundations of quantum theory—Bell's theorem—can also be understood as an attempt to disentangle correlation and causation. Recently, it has been recognized that Bell's 1964 result is an early foray into the field of causal inference and that the insights derived from more than 50 years of research on his theorem can supplement and improve upon state-of-the-art causal inference techniques. In the other direction, the conceptual framework developed by causal inference researchers provides a fruitful new perspective on what could possibly count as a satisfactory causal explanation of the quantum correlations observed in Bell experiments. Efforts to elaborate upon these connections have led to an exciting flow of techniques and insights across the disciplinary divide. This talk will explore what is happening at the intersection of these two fields.

QI 3.3 Mon 15:00 H4

Symmetries in quantum networks — •Kiara Hansenne[1], Zhen-Peng Xu[1], Tristan Kraft[1,2], and Otfried Guehne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Germany — [2]Institut für Theoretische Physik, Universität Innsbruck, Austria

Quantum networks are promising tools for the implementation of long-range quantum communication. The characterization of quantum correlations in networks and their usefulness for information processing is therefore central for the progress of the field, but so far only results for small basic network structures or pure quantum states are known. In this contribution, we show that symmetries provide a versatile tool for the analysis of correlations in quantum networks. We provide an analytical approach to characterize correlations in large network structures with arbitrary topologies. As examples, we show that entangled quantum states with a bosonic symmetry can not be generated in networks; moreover, cluster and graph states are not accessible either. Our results allow us to design certification methods for the functionality of specific links and have direct implications for the design of future network structures.

QI 3.4 Mon 15:15 H4

Self-testing maximally-dimensional genuinely entangled subspaceswithin the stabilizer formalism — •Owidiusz Makuta and Remigiusz Augusiak — Center for Theoretical Physics, Polish Academy of Sciences, Warsaw, Poland

The main goal of our work is to identify the largest genuinely entangled stabilizer subspaceand to show that such a subspace can be self-tested. To this end, we first introduce a frameworkallowing to efficiently check whether a given stabilizer subspace is genuinely entangled. Building on it, wethen determine the maximal dimension of genuinely entangled subspaces that can be constructed within thestabilizer subspaces and provide an exemplary construction of such maximally-dimensional subspaces for anynumber of qubits. Third, we construct Bell inequalities that are maximally violated by any entangled state fromthose subspaces and thus also any mixed states supported on them, and we show these inequalities to be usefulfor self-testing. Interestingly, our Bell inequalities allow for identification of higher-dimensional face structuresin the boundaries of the sets of quantum correlations in the simplest multipartite Bell scenarios in which everyobserver performs two dichotomic measurements.

QI 3.5 Mon 15:30 H4

Measurement classicality in the prepare and measure scenario — •Carlos de Gois[1], George Moreno[2], Ranieri Nery[2], Samuraí Brito[2], Rafael Chaves[2], and Rafael Rabelo[1] — [1]"Gleb Wataghin" Physics Institute, University of Campinas — [2]International Institute of Physics, Federal University of Rio Grande do Norte

Quantum communication is expected to become a widespread technology. In that regard, dense coding, random access coding, and quantum key distribution are some of the most outstanding communication protocols where quantum systems provide advantage over their classical counterparts. These will arguably be building blocks for the so-called quantum internet, and recent experiments prove they are feasible in practice. Prepare and measure scenarios — the central theme in this presentation — are a useful abstraction within which a common basis for many such protocols can be found. In these scenarios, an objective of primal importance is determining which preparations and measurements can or cannot lead to nonclassical behaviors, and what are the quantum features that enable nonclassicality to happen. Focusing on the measurements, we provide a general method that can certify, through a sufficient condition, if a given set of measurements are classical (i.e., they never lead to nonclassicality), no matter what quantum preparations they may act upon. As an application, we demonstrate the existence of a large set of incompatible measurements that are nevertheless classical, thus showing incompatibility is insufficient for nonclassicality in the prepare and measure scenario.

Ref.: PRX Quantum 2, 030311 (2021)

QI 3.6 Mon 15:45 H4

Bound entanglement from randomized measurements —

Satoya Imai[1], •Nikolai Wyderka[2], Andreas Ketterer[3,4], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany — [2]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, D-40225 Düsseldorf, Germany — [3]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany — [4]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany

In scenarios with limited control over multipartite quantum states, randomized measurements provide a powerful tool to characterize quantum correlations. To that end, we analyze the moments of the resulting probability distribution in a systematic way and show (near-)optimal criteria to detect entanglement in different scenarios of bipartite and tripartite systems. In particular, we analyze the geometry of the space of higher-dimensional bipartite quantum systems in order to derive explicit criteria that are able to detect bound entanglement, a very weak form of entanglement, in this setting.

QI 4: Quantum Thermodynamics and Open Quantum Systems

Time: Tuesday 14:00–16:00 Location: H3

Invited Talk QI 4.1 Tue 14:00 H3

Principles of quantum functional testing — Nadia Milazzo[1,2], Olivier Giraud[2], and •Daniel Braun[1] — [1]Institute for theoretical physics, University Tübingen — [2]LPTMS, Université Paris-Saclay

With increasing complexity of quantum-information-processing devices, testing their functionality becomes a pressing and difficult problem. In contrast to quantum-process tomography, quantum functional testing refers to the decision problem of accepting or rejecting a device based on specifications provided by the producer and limited experimental evidence. The decision should be reached as quickly as possible, yet with as high confidence as possible. Here we review and propose several tools and principles for quantum functional testing, ranging from the formalism of truncated moment sequences, over coherent enhancement of deterministic errors, to automated experimental design for maximum information gain and non-greedy Bayesian parameter estimation. We demonstrate their usefulness at the hand of frequently encountered quantum states and channels.

QI 4.2 Tue 14:30 H3

Necessary structure of a thermodynamic bath for entanglement generation via bath engineering — •Steffen Wilksen, Frederik Lohof, and Christopher Gies — Institut für Theoretische Physik, Universität Bremen, Otto-Hahn-Allee, 28334 Bremen

Interaction of a quantum mechanical system with the environment is usually considered to be an obstacle when preparing entangled states, because this interaction induces decoherence and destroys the entanglement. This does not have to be the case, as coupling the system to a carefully engineered thermal bath can help to create entanglement and even stabilize it indefinitely.

First we consider a non-interacting two-qubit Hamiltonian, where the entanglement is solely created by the system-bath interaction. Specifically, we look at the strength of entanglement as a function of different system parameters. We then generalize our results for a Hamiltonian of arbitrary size and examine the requirements of the Hamiltonian and thermal bath to create entangled states. In particular, we find necessary conditions for the structure of the system-bath interaction that give rise to the occurrence of bath mediated entanglement generation.

QI 4.3 Tue 14:45 H3

Thermodynamic information erasure with computational limitations — •Naga B. T. Kothakonda[1,2], Jonas Haferkamp[2,3], Nicole Yunger Halpern[4], Jens Eisert[2,3], and Philippe Faist[2] — [1]University of Cologne — [2]Freie Univ. Berlin — [3]HZB Berlin — [4]Harvard Univ., MIT, Univ. of Maryland

The role of information entropy in thermodynamics is epitomized by the example of Landauer erasure: To reset a quantum state ρ to a standard pure state, there is a minimum dissipation of $kT\ln(2)\,H(\rho)$, where $H(\rho)$ is the information entropy of the quantum state. Here, we determine the energy cost of resetting a quantum state on a memory register to a standard state under an additional computational restriction: The agent cannot apply more than a given number of unitary gates from a given gate set. The cost is given by a new entropy measure, the *complexity-effective entropy*, which accounts for the complexity of the state. The effective entropy is consistent with known results in the regime where the agent can perform arbitrarily many gates. The effective entropy provides a direct link between complexity and entropy, by quantifying the trade-off between complexity cost and work cost for Landauer erasure. On a conceptual level, the effective entropy generalizes the approach in statistical mechanics whereby a system is studied via the properties of its local observables. Along with our recent results on the linear growth of complexity in random circuits, we believe that the effective entropy can be a powerful tool to understand the physical properties of quantum systems that are chaotic, as well as in quantum gravity, where complexity is believed to play a major role.

QI 4.4 Tue 15:00 H3

Controlled Dephasing and Unequal Time Correlations in Rydberg Qubits — •Andre Salzinger[1], Kevin Geier[2], Titus Franz[1], Sebastian Geier[1], Robert Ott[3], Annika Tebben[1], Clement Hainaut[1], Gerhard Zürn[1], Martin Gärttner[1], Philipp Hauke[2], and Matthias Weidemüller[1] — [1]Physikalisches Institut Heidelberg — [2]University of Trento — [3]Institut für Theoretische Physik Heidelberg

Engineering open system dynamics relies on implementing restrictions on the degrees of freedom of a larger system. We present experimental results for simple Qubit rotations subjected to random phase walks, which are sampled from 1D Brownian motion. The observed ensemble and realization average follows a Lindblad description with a decay parameter given by the variance of sampled phase walks. We show how this technique can be used to extract unequal-time correlation functions in the driven two-level system by coupling to an ancilla level, and how this procedure can be extended to colored noise and larger spin systems.

QI 4.5 Tue 15:15 H3

Entanglement and work fluctuations in composite quantum systems — •Satoya Imai, Otfried Gühne, and Stefan Nimmrichter — Universität Siegen Department Physik Emmy-Noether-Campus Walter-Flex-Straße 3 57068 Siegen Germany

We investigate the role of quantum correlations in the thermodynamics of composite quantum systems by comparing the work cost of unitary operations for separable and entangled states. In a limited control scenario, quantum correlations between interacting, high-dimensional two-particle systems can be characterized by monitoring the average energy change and its fluctuations due to random local or global unitary operations. These operations can represent isentropic strokes as part of a thermodynamic protocol. We derive a hierarchy of bounds based on the Schmidt rank of the quantum state and thereby show that higher work fluctuations can verify the presence of stronger entanglement in the system.

Invited Talk QI 4.6 Tue 15:30 H3

Noncommuting conserved quantities in thermodynamics — •Nicole Yunger Halpern — National Institute of Standards and Technology, College Park, Maryland, USA — Joint Center for Quantum Information and Computer Science, College Park, Maryland, USA — Institute for Physical Science and Technology, College Park, Maryland, USA

In statistical mechanics, a small system exchanges conserved quantities—heat, particles, electric charge, etc.—with a bath. The small system may thermalize to the canonical ensemble, the grand canonical ensemble, etc. The conserved quantities are represented by operators usually assumed to commute with each other. But noncommutation distinguishes quantum physics from classical. What if the operators fail to commute? This question of truly nonclassical thermodynamics has gained substantial attention in quantum-information-theoretic thermodynamics recently. I will discuss recent advances and what noncommutation of conserved quantities may buy for a thermodynamic agent, including the possibility of hindering thermalization to preserve information in memories. Applications include atomic, molecular, and optical physics; condensed matter; and potentially lattice gauge theories.

References:

1) NYH, Beverland, and Kalev, Phys. Rev. E 101, 042117 (2020).
2) NYH and Majidy, arXiv:2103.14041 (2021).
3) NYH, Faist, Oppenheim, and Winter, Nat. Comms. 7, 12051 (2016).

QI 5: Implementations: Solid State Systems

Time: Tuesday 14:00–16:00 Location: H4

Invited Talk QI 5.1 Tue 14:00 H4

Recent progress with superconducting fluxonium qubit — •Vladimir Manucharyan — University of Maryland, College Park, USA

Fluxonium consists of a superconducting loop interrupted by over 100 Josephson junctions, strips of insulating material a few nanometers thick sandwiched between superconducting layers. Consequently, the loop has an exceptionally large value inductance, which makes fluxonium distinct and useful. Having so many junctions per qubit has been generally viewed as a liability for establishing long coherence times. Yet, we observed coherence in excess of 1 millisecond and conclude that even longer coherence time should be possible by upgrading our fabrication procedures to the state of the art. The exceptional combination of fluxonium's high coherence and strong anharmonicity can be utilized for improving the fidelity of logical gates and constructing analog simulators of strongly interacting quantum spin models.

Invited Talk QI 5.2 Tue 14:30 H4

Quantum information processing with semiconductor technology: from qubits to integrated quantum circuits — •Menno Veldhorst — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, 2600 GA Delft, The Netherlands

Quantum computation with quantum dots has now been studied for more than two decades after the original proposal by Loss and DiVincenzo. Developments have been across the full-stack. Materials science progressed from GaAs heterostructures, to silicon, and most recently to strained germanium. These advances led to demonstrations of single qubit gates with fidelities close to 99.99%, high-fidelity two-qubit gates, and culminated in the realization a four-qubit quantum processor where qubits are positioned in a 2x2 array.

In this talk I will present the past achievements made with semiconductor qubits, highlight the current state-of-the-art, and provide a perspective on future efforts toward scaling to large-scale quantum computing. In particular I will focus on our efforts on germanium quantum technology, show implementations of rudimentary algorithms and initial error correction schemes such as the phase-flip code. Taken together, this talk provides an introduction to the field and motivates why semiconductor qubits are one of the most promising platforms for quantum technology.

QI 5.3 Tue 15:00 H4

Crosstalk analysis for single-qubit and two-qubit gates in spin qubit arrays — •Irina Heinz and Guido Burkard — University of Konstanz, Konstanz, Germany

Scaling up spin qubit systems requires high-fidelity single-qubit and two-qubit gates. Gate fidelities exceeding 98% were already demonstrated in silicon based single and double quantum dots, whereas for the realization of larger qubit arrays crosstalk effects on neighboring qubits must be taken into account. We analyze qubit fidelities impacted by crosstalk when performing single-qubit and two-qubit operations on neighbor qubits with a simple Heisenberg model. Furthermore we propose conditions for driving fields to robustly synchronize Rabi oscillations and avoid crosstalk effects. In our analysis we also consider next to nearest neighbor crosstalk and show that double synchronization leads to a restricted choice for the driving field strength, exchange interaction, and thus gate time. Considering realistic experimental conditions we propose a set of parameter values to perform a nearly crosstalk-free CNOT gate and so open up the pathway to scalable quantum computing devices.

QI 5.4 Tue 15:15 H4

Evaluating Atomically Thin Quantum Emitters for Quantum Key Distribution — •Timm Gao[1], Martin v. Helversen[1], Carlos Anton-Solanas[2], Christian Schneider[2], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany

Single photon sources are considered key building blocks for future quantum communication networks. In recent years, atomic monolayers of transition metal dichalcogenides (TMDCs) emerged as a promising material platform for the development of compact quantum light sources. In this work, we evaluate for the first time the performance of a single photon source based on a strain-engineered WSe_2 monolayer [1] for quantum key distribution (QKD). Employed in a QKD-testbed emulating the BB84 protocol, we analyze the single-photon purity in terms of $g^{(2)}(0)$ and secret key rates as well as quantum bit error rates to be expected in full implementations of QKD. Furthermore, we exploit routines for the performance optimization previously applied to quantum dot based single-photon sources [2]. Our work represents a major step towards the application of TMDC-based devices in quantum technologies.

[1] L. Tripathi et al., ACS Photonics 5, 1919-1926 (2018)
[2] T. Kupko et al., npj Quantum Inform. 6, 29 (2020)

QI 5.5 Tue 15:30 H4

Nuclear Spin Readout in a Cavity-Coupled Hybrid Quantum Dot-Donor System — •Jonas Mielke[1], Jason R. Petta[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, Konstanz D-78457, Germany — [2]Department of Physics, Princeton University, Princeton, New Jersey 08544, USA

Nuclear spins show long coherence times and are well isolated from the environment, which are properties making them promising for quantum information applications. Here, we present a method for nuclear spin readout by probing the transmission of a microwave resonator. We consider a single electron in a silicon quantum dot-donor device interacting with a microwave resonator via the electric dipole coupling and subjected to a homogeneous magnetic field and a transverse magnetic field gradient. In our scenario, the electron spin interacts with a ^{31}P defect nuclear spin via the hyperfine interaction. We theoretically investigate the influence of the P nuclear spin state on the microwave transmission through the cavity and show that nuclear spin readout is feasible with current state-of-the-art devices. Moreover, we identify optimal readout points with strong signal contrast to facilitate the experimental implementation of nuclear spin readout.

QI 5.6 Tue 15:45 H4

Ancilla assisted discrete quantum time crystal with nitrogen-vacancy center in diamond — •Jianpei Geng, Vadim Vorobyov, Durga Dasari, and Jörg Wrachtrup — 3. Physics Institute, University of Stuttgart, Stuttgart 70569, Germany

Time crystal is a phase of matter of which the time-translation symmetry is spontaneously broken. Though continuous quantum time crystal is controversial, discrete quantum time crystal has been experimentally demonstrated in various systems. The interplay of periodic driving, disorder, and interaction plays an essential role in stabilizing the time crystal phase against perturbations. Here we extend the study to even non-interacting systems and show how a non-interacting system could be stabilized to the time-crystal phase by coupling to an ancillary system. We show that the coupling between the system and the ancilla, even if just an ancilla qubit, could introduce an effective interaction in the system, and thus enables the emergence of the time-crystal phase. We demonstrate the time-crystal signature of non-interacting nuclear spins by simulation and experiment on nitrogen-vacancy center in diamond.

QI 6: Quantum Computing and Algorithms II

Time: Wednesday 10:45–12:45 Location: H3

Invited Talk QI 6.1 Wed 10:45 H3

Stabilization and operation of a Kerr-cat qubit in a nonlinear superconducting resonator — •Alexander Grimm — Paul Scherrer Institute, Villigen, Switzerland

Quantum two-level systems are routinely used to encode qubits, but tend to be inherently fragile leading to errors in the encoded information. Quantum error correction (QEC) addresses this challenge by encoding effective qubits into more complex quantum systems.

A qubit that is intrinsically protected against a subset of quantum errors can be encoded into superpositions of two opposite-phase oscillations in a resonator, so-called Schrödinger-cat states. This "cat qubit" has the potential to significantly reduce the complexity of QEC. However, the practical operation of a cat qubit faces several challenges: The oscillations are highly excited states of the resonator and need to be stabilized in order to maintain the protection. At the same time, the system has to be compatible with fast gate operations and an efficient measurement of the encoded information.

In this talk, I will review some key concepts of QEC and situate our approach within the field. Then, I will present recent experimental results on the stabilization and operation of an error-protected cat qubit through the interplay between Kerr nonlinearity and single-mode squeezing in a superconducting microwave resonator. I will conclude with an outlook on different applied and fundamental research directions enabled by this experiment.

Invited Talk QI 6.2 Wed 11:15 H3

The 3rd quantum revolution: Quantum Algorithmic Experiments. — •Dorit Aharonov — Hebrew University of Jerusalem, Israel

Following the second quantum revolution, which had completely undermined how we think of algorithms, the last decade gave birth to a third quantum revolution - which has changed the way we think of physical experiments. I will demonstrate this with some examples of how quantum computational ideas such as quantum error correction and quantum algorithms can be used to enhance conventional quantum experiments, to achieve increased efficiency and precision in sensing, metrology, and more. I will then describe my recent attempt together with Jordan Cotler and Xiaoliang Qi to generalize these developments and provide a universal mathematical model for quantum experiments, which we call Quantum algorithmic measurements (QUALMs). In this framework, we show that certain experimental tasks (such as determining the time reversal symmetry of a many body quantum system), can be performed exponentially more efficiently if enhanced with even simple quantum computational abilities. Improvements on our initial protocols were recently implemented experimentally on Google's Sycamore. These and other results which I will mention, suggest that quantum experiments constitute a new playground in which quantum-computational advantages can be exhibited.

QI 6.3 Wed 11:45 H3

Dynamical subset sampling of quantum error correcting circuits — •Sascha Heussen[1,2], Manuel Rispler[1,2], and Markus Müller[1,2] — [1]Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany — [2]Institute for Theoretical Nanoelectronics (PGI-2), Forschungszentrum Jülich, 52428 Jülich, Germany

Quantum error correcting stabilizer codes enable protection of quantum information against errors during storage and processing. Efficiently simulating faulty gate operations poses numerical challenges beyond circuit depth or large numbers of qubits. More efficient simulation of non-deterministic quantum error correcting protocols, such as Shor-type error correction or flag-qubit based fault-tolerant circuits where intermediate measurements and classical feedback determine the actual circuit sequence to perform the protocol, becomes feasible via dynamical subset sampling. As an importance sampling technique, dynamical subset sampling allows to effectively make use of computational resources to only sample the most relevant sequences of quantum circuits in order to estimate a protocol's logical failure rate with well-defined error bars instead of post-selecting on classical measurement data. We outline the method along with two examples that demonstrate its capabilities to reach a given target variance on the logical failure rate with five orders of magnitude fewer samples than Monte Carlo simulation. Our method naturally allows for efficient simulation of realistic multi-parameter noise models describing faulty quantum processor architectures, e.g. based on trapped ions.

QI 6.4 Wed 12:00 H3

Pauli channels can be estimated from syndrome measurements in quantum error correction — •Thomas Wagner, Dagmar Bruss, Hermann Kampermann, and Martin Kliesch — Heinrich-Heine-Universität Düsseldorf

Large scale quantum computation requires quantum error correction. The performance can be significantly improved if detailed information about the noise is available, allowing to optimize both codes and decoders. It has been proposed to estimate error parameters from the syndrome measurements done anyway during quantum error correction. While these measurements preserve the encoded quantum state, it is currently not clear how much information about the noise can be extracted in this way. So far, apart from the limit of vanishing error rates, rigorous results have only been established for some specific codes.

In this work, we rigorously resolve the question for arbitrary stabilizer codes. We prove that a surprisingly high amount of information can be extracted from the syndromes. The main result is that a stabilizer code can be used to estimate Pauli channels with correlations across a number of qubits given by the pure distance. This result does not rely on the limit of low error rates, and applies even if high weight errors occur frequently. Our proof combines Boolean Fourier analysis, combinatorics, elementary algebraic geometry and iterated Schur complements. It is our hope that this work opens up interesting applications, such as the online adaptation of a decoder to time-varying noise.

QI 6.5 Wed 12:15 H3

Cheap Readout Error Mitigation on Expensive NISQ devices — •Ákos Budai[1,2,3], András Pályi[1,3], and Zoltán Zimborás[2,3] — [1]Department of Theoretical Physics and MTA-BME Exotic Quantum Phases Research Group, Budapest University of Technology and Economics, Hungary — [2]Wigner RCP, Hungarian Academy of Sciences — [3]Nokia Bell Labs, (Budapest, Hungary)

Noisy Intermediate-Scale Quantum (NISQ) devices are already available today for public use. These prototype quantum processors do not have enough qubits needed for implementing useful quantum error correction codes. Instead, different error mitigation schemes turned out to be efficient tools for improving the functionality of NISQ devices. In most superconducting prototype quantum computers, the readout error dominates the errors of individual gates. The level of improvement gained by readout error mitigation (REM) depends on the error probabilities and number of shots available. In this work, we quantify the efficiency of REM for a specific simple quantum protocol (parameter estimation), and combine analytical and numerical techniques to find the optimal division of available shots between the REM task and the quantum protocol itself. This task is of direct financial relevance, since certain quantum computer providers bill after the number of shots executed.

QI 6.6 Wed 12:30 H3

Microwave individual qubit addressing of $^{9}Be^{+}$ in a two-ion crystal — •Hardik Mendpara[1,2], Markus Duwe[1,2], Nicolas Pulido[1,2], Amado Bautista[1,2], Giorgio Zarantonello[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100,38116 Braunschweig — [3]National Institute of Standards and Technology, Boulder, Colorado 80303

Single-qubit rotations and two-qubit entangling gates form a universal set of quantum operations capable of implementing any quantum algorithm. With multiple trapped ions, a key prerequisite for single-qubit rotations is the capability to reliably address individual qubits. Instead of the more wide-spread laser based approach, we implement quantum operations using microwaves. In this work, we report on microwave individual-ion addressing, and on the implementation of randomized benchmarking [1]. Together with the entangling gate, this enables controlled sequences of single- and two-qubit gates [2]. This makes it possible to perform benchmarking algorithms to better characterize the performance of two-qubit entangling gates [3,4].

[1] U. Warring *et al.*, Phys. Rev. Lett. **110**,173002 (2013)
[2] G. Zarantonello *et al.*, Phys. Rev. Lett. **123**, 260503 (2019)
[3] A. Erhard *et al.*, Nat. Commun. **10**, 5347 (2019)
[4] J. Gaebler *et al.*, Phys. Rev. Lett. **109**, 179902 (2012)

QI 7: Quantum Information: Applications

Time: Wednesday 10:45–12:30 Location: H4

QI 7.1 Wed 10:45 H4

qopt: An experiment-oriented Qubit Simulation and Quantum Optimal Control Package — •Julian Teske and Hendrik Bluhm — JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, 52074 Aachen, Germany

Realistic modelling of qubit systems including noise and constraints imposed by control hardware is required for performance prediction and control optimization of quantum processors. We introduce qopt, a software framework for simulating qubit dynamics and robust quantum optimal control considering common experimental situations. To this end, we model open and closed qubit systems with a focus on the simulation of realistic noise characteristics and experimental constraints. Specifically, the influence of noise can be calculated using Monte Carlo methods, effective master equations or with the efficient filter function formalism, which enables the investigation and mitigation of auto-correlated noise. In addition, limitations of control electronics including finite bandwidth effects can be considered. The calculation of gradients based on analytic results is implemented to facilitate the efficient optimization of control pulses. The software is published under an open source license, well-tested and features a detailed documentation.

QI 7.2 Wed 11:00 H4

Cyclic cooling of quantum systems at the saturation limit — •Durga Dasari[1], Sadegh Raeisi[2], and Joerg Wrachtrup[1] — [1]3. Physics Institute, University of Stuttgart, Stuttgart, GERMANY — [2]Department of Physics, Sharif University of Technology, Tehran, IRAN

The achievable bounds of cooling quantum systems, and the possibility to violate them is not well-explored experimentally. For example, among the common methods to enhance spin polarization (cooling), one utilizes the low temperature and high-magnetic field condition or employs a resonant exchange with highly polarized spins. The achievable polarization, in such cases, is bounded either by Boltzmann distribution or by energy conservation. Heat-bath algorithmic cooling schemes (HBAC), on the other hand, have shown the possibility to surpass the physical limit set by the energy conservation and achieve a higher saturation limit in spin cooling. Despite, the huge theoretical progress, and few principle demonstrations, neither the existence of the limit nor its application in cooling quantum systems towards the maximum achievable limit have been experimentally verified. Here, we show the experimental saturation of the HBAC limit for single nuclear spins, beyond any available polarization in solid-state spin system, the Nitrogen-Vacancy centers in diamond. We benchmark the performance of our experiment over a range of variable reset polarizations (bath temperatures), and discuss the role of quantum coherence in HBAC.

QI 7.3 Wed 11:15 H4

Superradiant many-qubit absorption refrigerator — Michal Kloc[1], Kurt Meier[1], Kimon Hadjikyriakos[2], and •Gernot Schaller[3] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [2]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328, Dresden, Germany

We show that the lower levels of a large-spin network with a collective anti-ferromagnetic interaction and collective couplings to three reservoirs may function as a quantum absorption refrigerator. In appropriate regimes, the steady-state cooling current of this refrigerator scales quadratically with the size of the working medium, i.e., the number of spins. The same scaling is observed for the noise and the entropy production rate.

[1] arXiv:2106.04164

QI 7.4 Wed 11:30 H4

The Dicke Model as an Associative Quantum Neural Network — •Lukas Bödeker[1], Eliana Fiorelli[1,2], and Markus Müller[1,2] — [1]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [2]Peter Gruenberg Institute, Theoretical Nanoelectronics, Forschungszentrum Juelich, D-52425 Juelich, Germany

Nowadays Classical Artificial Neural Networks (NNs) show their great power and versatility in information processing tasks. Early instances of NNs are given by Associative NNs, that have the ability to retrieve a stored state, starting from a compromised initial one. Such dynamics can be engineered via a stochastic evolution, where stored configurations are minima of an energy landscape. One of the first examples of associative NNs is the Hopfield NN, which is an Ising-type system featuring all-to-all interactions. Motivated by the fast progress in controlling quantum systems, as well as in quantum computation, a question that is currently explored is whether a Hopfield-type associative memory could be hosted in quantum systems. The goal is to understand whether quantum effects can be advantageous to store information. To this end, we consider the multi-mode Dicke model, in which a bosonic bath mediates an effective all-to-all spin interaction. The latter can be exploited to store information associatively, by setting the spin boson couplings accordingly. We analyse the storage properties of this system and further aim at investigating the maximum capacity i.e. the maximum number of stored states given a certain system size, generalising the classical approach introduced by Gardner.

QI 7.5 Wed 11:45 H4

Hyperfine Structure of Transition Metal Defects in SiC — •Benedikt Tissot and Guido Burkard — Universtität Konstanz

Transition metal (TM) defects in silicon carbide (SiC) are a promising platform in quantum technology, especially because some TM defects emit in the telecom band. We develop a theory for the interaction of an active electron in the *D*-shell of a TM defect in SiC with the TM nuclear spin and derive the effective hyperfine tensor within the Kramers doublets formed by the spin-orbit coupling. Based on our theory we discuss the possibility to exchange the nuclear and electron states with potential applications for nuclear spin manipulation and long-lived nunclear-spin based quantum memories.

QI 7.6 Wed 12:00 H4

Quantum polyspectra for modeling and evaluating quantum measurements: A unifying approach to the strong and weak measurement regime — •Markus Sifft[1], Annika Kurzmann[2], Jens Kerski[2], Rüdiger Schott[3], Arne Ludwig[3], Andreas D. Wieck[3], Axel Lorke[2], Martin Geller[2], and Daniel Hägele[1] — [1]Ruhr University Bochum, Faculty of Physics and Astronomy, Experimental Physics VI (AG), Germany — [2]Faculty of Physics and CENIDE, University of Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany — [3]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum, Germany

Quantum polyspectra of up to fourth order are introduced for modeling and evaluating quantum measurements. As an example, experimental time-traces of the occupation dynamics of a single quantum dot are evaluated via simultaneously fitting their 2nd-, 3rd-, and 4th-order spectra. Moreover, the evaluation of time-traces via quantum polyspectra is demonstrated to be feasible also in the weak measurement regime even when quantum jumps can no longer be identified from time-traces and methods related to the full counting statistics cease to be applicable. Quantum polyspectra thus constitute a unifying approach to the strong and weak regime of quantum mea- surements in general with possible applications in diverse fields as nano-electronic, circuit quantum electrodynamics, spin noise spectroscopy, or quantum optics.

QI 7.7 Wed 12:15 H4

Towards satellite-suited noise-free quantum memories — •Luisa Esguerra[1,2], Leon Messner[1,2], Elizabeth Robertson[1,2], Mustafa Gündoğan[1,3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin, Germany. — [2]TU Berlin, Institut für Optik und Atomare Physik, Hardenbergstr. 36, 10623 Berlin, Germany. — [3]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, Berlin 12489, Germany.

The use of memory-assisted quantum repeaters on satellites as transmission links between the nodes of a quantum network could push the current distance limit for quantum key distribution QKD [1]. We have realised a technologically simple, satellite-suited quantum memory in Caesium vapour, based on electromagnetically induced transparency (EIT) on the D1 line, similar to [2]. We have achieved light storage at the single-photon level with end-to-end efficiencies up to 11%, which correspond to internal memory efficiencies of up to 44%. We also achieve a maximal signal-to-noise level of unity for input signal pulses containing $\bar{\mu}_1 = 0.029$ photons. Furthermore, we have determined the limiting noise source at this level to be spontaneous Raman scattering processes in the Lambda-system.

[1] M. Gündoğan et al., arXiv:2006.10636 (2020)
[2] J. Wolters, et al., PRL 119, 060502 (2017)

QI 8: Quantum Information: Poster (joint session QI/Q)

Time: Wednesday 16:30–18:30 Location: P

QI 8.1 Wed 16:30 P

Does a disordered isolated Heisenberg spin system thermalize? — •Titus Franz[1], Adrien Signoles[2], Renato Ferracini Alves[1], Clément Hainaut[1], Sebastian Geier[1], Andre Salzinger[1], Annika Tebben[1], Shannon Whitlock[3], Gerhard Zürn[1], Martin Gärttner[4], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, 69120 Heidelberg, Germany — [2]Pasqal, 91120 Palaiseau, France — [3]IPCMS and ISIS, University of Strasbourg and CNRS, 67000 Strasbourg, France — [4]Kirchhoff-Institut für Physik, Universität Heidelberg, 69120 Heidelberg, Germany

The far-from equilibrium dynamics of generic disordered systems is expected to show thermalization, but this process is yet not well understood and shows a rich phenomenology ranging from anomalously slow relaxation to the breakdown of thermalization. While this problem is notoriously difficult to study numerically, we can experimentally probe the relaxation dynamics in an isolated spin system realized by a frozen gas of Rydberg atoms. By breaking the symmetry of the Hamiltonian with an external field, we can identify characteristics of the long time magnetization, including a non-analytic behavior at zero field. These can be understood from mean field, perturbative, and spectral arguments. The emergence of these distinctive features seem to disagree with Eigenstate Thermalization Hypothesis (ETH), which indicates that either a better theoretical understanding of thermalization is required or ETH breaks for the here studied quench in a disordered spin system.

QI 8.2 Wed 16:30 P

How Quantum Evolution with Memory is Generated in a Time-Local Way — •Konstantin Nestmann[1,2], Valentin Bruch[1,2], and Maarten R. Wegewijs[1,2,3] — [1]RWTH Aachen — [2]JARA-FIT — [3]Peter Grünberg Institut

Two widely used approaches to the dynamics of open quantum systems with strong dissipation and memory are the Nakajima-Zwanzig and the time-convolutionless quantum master equation. The first one uses a *time-nonlocal* memory kernel $\mathcal{K}$, whereas the second achieves the same using a *time-local* generator $\mathcal{G}$. Here we show that the two are connected by a simple yet general fixed-point relation: $\mathcal{G} = \hat{\mathcal{K}}[\mathcal{G}]$ [1].

This result provides a deep connection between these two entirely different approaches with applications to strongly interacting open quantum systems [2]. In particular, it explicitly relates two widely used but *distinct* perturbative expansions [3], quantitatively connects the *distinct* non-perturbative Markov approximations they define, and resolves the puzzling issue how these manage to converge to exactly the same stationary state.

Furthermore, our fixed-point equation naturally leads to an iterative procedure to compute the time-local generator directly from the memory kernel producing non-Markovian approximations which are guaranteed to be accurate both at short and long times.

[1] Phys. Rev. X **11**, 021041 (2021)
[2] arXiv:2104.11202
[3] arXiv:2107.08949

QI 8.3 Wed 16:30 P

Tailored Optical Clock Transition in $^{40}Ca^+$ — •Lennart Pelzer[1], Kai Dietze[1], Johannes Kramer[1], Fabian Dawel[1], Ludwig Krinner[1,2], Nicolas Spethman[1], Victor Martinez[2], Nati Aharon[3], Alex Retzker[3], Klemens Hammerer[2], and Piet Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, — [3]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Israel

Optical clocks based on single trapped ions are often impeded by long averaging times due to the quantum projection noise limit. Longer probe time would improve the statistical uncertainty, but currently, phase coherence of clock laser systems is limiting probe times for most clock candidates. We propose pre-stabilization of the laser to a larger $^{40}Ca^+$ ion crystal, offering a higher signal-to-noise ratio. We engineer an artificial optical clock transition with a two stage continuous dynamical decoupling scheme, by applying near-resonant rf dressing fields. The scheme suppresses inhomogeneous tensor shifts as well as the linear Zeeman shift, making it suitable for multi-ion operation. This tailored transition has drastically reduced magnetic-field sensitivity. Even without any active or passive magnet-field stabilization, it can be probed close to the second-long natural lifetime limit of the $D_{5/2}$ level. This ensures low statistical uncertainty. In addition, we show a significant suppression of the quadrupole shift on a linear five-ion crystal by applying magic angle detuning on the rf-drives.

QI 8.4 Wed 16:30 P

Experimental exploration of fragmented models and non-ergodicity in tilted Fermi-Hubbard chains — •Clara Bachorz[1], Sebastian Scherg[1,2], Thomas Kohlert[1,2], Pablo Sala[3], Frank Pollmann[3], Bharath Hebbe Madhusudhana[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]LMU Munich, Germany — [2]Max-Planck institut fur Quantenoptik, Garching, Germany — [3]TUM Munich, Germany

Thermalization of isolated quantum many-body systems is deeply related to redistribution of quantum information in the system. A question of fundamental importance is when do quantum many-body systems fail to thermalize, i.e., feature non-ergodicity. A test-bed for the study of non-ergodicity is the tilted Fermi-Hubbard model, which is directly accessible in experiments with ultracold atoms in optical lattices. Here we experimentally study non-ergodic behavior in this model by tracking the evolution of an initial charge-density wave [1]. In the limit of large tilts, we identify the microscopic processes which the observed dynamics arise from. These processes constitute an effective Hamiltonian and we experimentally show its validity [2]. This effective Hamiltonian features the novel phenomenon of Hilbert space fragmentation. For intermediate tilts, while these effective models are no longer valid, we show that the features of fragmentation are still vaguely present in the dynamics. Finally, we explore the relaxation dynamics of the imbalance in a 2D tilted Fermi-Hubbard system.

[1.] Sebastian Scherg et al. arXiv:2010.12965
[2.] Thomas Kohlert et al. arXiv:2106.15586

QI 8.5 Wed 16:30 P

Quantifying necessary quantum resources for nonlocality — •Lucas Tendick, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Nonlocality is one of the most important resources for quantum information protocols. The observation of nonlocal correlations in a Bell experiment is the result of appropriately chosen measurements and quantum states. We study quantitatively which quantum resources within the state and measurements are needed to achieve a given degree of nonlocality by exploiting the hierarchical structure of the resources. More explicitly, we quantify the minimal purity to achieve a certain Bell value for any Bell operator. Since purity is the most fundamental resource of a quantum state, this enables us also to quantify the necessary coherence, discord, and entanglement for a given violation of two-qubit correlation inequalities. Our results shine new light on the CHSH inequality by showing that for a fixed Bell violation an increase in the measurement resources does not always lead to a decrease of the minimal state resources.

QI 8.6 Wed 16:30 P

Floquet Hamiltonian Engineering of an Isolated Many-Body Spin System — •Sebastian Geier[1], Nithiwadee Thaicharoen[1,2], Clément Hainaut[1], Titus Franz[1], Andre Salzinger[1], Annika Tebben[1], David Grimshandl[1], Gerhard Zürn[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Research Center for Quantum Technology, Faculty of Science, Chiang Mai University 239 Huay Kaew Road, Muang, Chiang Mai, 50200, Thailand

Controlling interactions is the key element for quantum engineering of many-body systems. Using time-periodic driving, a naturally given many-body Hamiltonian of a closed quantum system can be transformed into an effective target Hamiltonian exhibiting vastly different dynamics. We demonstrate such Floquet engineering with a system of spins represented by Rydberg states in an ultracold atomic gas. Applying a sequence of spin manipulations, we change the symmetry properties of the effective Heisenberg XYZ Hamiltonian. As a consequence, the relaxation behavior of the total spin is drastically modified. The observed dynamics can be qualitatively captured by a semi-classical simulation. Synthesising a wide range of Hamiltonians opens vast opportunities for implementing quantum simulation of non-equilibrium dynamics in a single experimental setting.

QI 8.7 Wed 16:30 P

Detecting Genuine Multipartite Entanglement Using Quantum Teleportation — •Sophie Egelhaaf, Harry Giles, and Paul Skrzypczyk — University of Bristol, Bristol, UK

In the standard quantum teleportation protocol one party is given an unknown quantum state that is teleported to another party, using a shared entangled state, a Bell state measurement and classical communication. In this work, we consider adding a third party, whose role is to act as a 'gatekeeper', either allowing or blocking the teleportation between the other two parties.

We show that the capabilities of the gatekeeper depend upon the type of multipartite entanglement they share with the other two parties. In particular, we show that a sufficiently ideal performance can only be achieved if the shared state is genuine multipartite entangled.

QI 8.8 Wed 16:30 P

Coupling Erbium Dopants to Silicon Nanophotonic Structures — Andreas Gritsch[1], Lorenz Weiss[1], •Johannes Früh[1], Stephan Rinner[1], Florian Burger[1], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität, München, Germany

Erbium dopants are promising candidates for the implementation of large-scale quantum networks since they can combine second-long ground state coherence with coherent optical transitions at telecommunication wavelength. Among the potential host crystals for erbium, silicon stands out because it allows for the scalable fabrication of nanophotonic devices based on established processes of the semiconductor industry. In contrast to observations of previous studies, we have shown that erbium ions implanted into silicon nanostructures can be integrated at well-defined lattice sites with narrow inhomogeneous (~1 GHz) and homogeneous (<0.1 GHz) linewidths [1]. By optimizing the sample preparation, we have recently improved the homogeneous linewidth down to 20 kHz. As the long lifetime of the optically excited state (~0.25 ms) would limit the achievable rates, we designed and fabricated photonic crystal cavities which may reduce the lifetime by more than three orders of magnitude. This will allow us to control individual dopants, making our system a promising candidate for the implementation of distributed quantum information processing.

[1] L. Weiss, A. Gritsch, B. Merkel, and A. Reiserer, Optica, 8, 40-41(2021)

QI 8.9 Wed 16:30 P

Site-specific Rydberg excitation in a multi-site quantum register of neutral atoms — •Tobias Schreiber, Dominik Schäffner, Jan Lautenschläger, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Applications in quantum technologies, such as quantum information science and metrology, demand for scalable platforms of identical quantum systems. Additionally, precise spatial control and fast switching of quantum states and of qubit coupling constitute milestones for quantum computing and simulation.

We present a micro-optical platform for defect-free assembled 2D clusters of more than 100 single-atom quantum systems [1] and demonstrate site-resolved excitations into various Rydberg states [2]. Together with fast addressing of individual array sites at a microsecond timescale, we gain real-time control over interactions between next neighbors in the quantum register. This allows the demonstration of Rydberg blockade with tunable blockade strength dependent on the respective state and atom separation. In combination with long coherence times for the prepared hyperfine states of the atoms, this technique leads the way to quantum computing and simulation with neutral atoms in our experimental setup.

[1] D. Ohl de Mello et. al., Phys. Rev. Lett. **122**, 203601 (2019).
[2] M. Schlosser et. al., J. Phys. B: At. Mol. Opt. Phys. **53** 144001 (2020).

QI 8.10 Wed 16:30 P

Characterising which causal structures might not support a classical explanation based on any underlying physical theory — •Shashaank Khanna and Matthew Pusey — Department of Mathematics, University of York, Heslington, UK

A causal relationship can be described using the formalism of Generalised Bayesian Networks. This framework allows the depiction of cause and effect relations (causal scenarios) effectively using generalised directed acyclic graphs (GDAGs). A GDAG is "not interesting" if the causal relations existing can be explained classically regardless of the underlying physical theory. Henson, Lal and Pusey (HLP) have proposed a sufficient condition to check whether a causal scenario is "not interesting". With their methods and some more developments the problem of identifying "interesting" causal structures has been solved for GDAGs of 6 nodes. But the problem of identifying "interesting" causal scenarios for GDAGs of 7 nodes is still open. We propose a new graphical theorem (and call it the E-separation theorem) to check several of the GADGs of 7 nodes which couldn't be checked by HLP's condition. Finally we also use "fine-grained" entropic inequalities to check whether the remaining GDAGs (of 7 nodes) are interesting or not.

QI 8.11 Wed 16:30 P

Average waiting times for entanglement links in quantum networks — •Lisa Weinbrenner, Lina Vandré, and Otfried Gühne — Universität Siegen, Deutschland

In quantum communication protocols using noisy channels the error probability typically scales exponentially with the length of the channel. To reach long-distance entanglement distribution, one can use quantum repeaters. These schemes involve first a generation of elementary bipartite entanglement links between two nodes and then measurements to join the elementary links. Since the generation of an elementary link is probabilistic and quantum memories have a limited storage time, the generation of a long-distance entangled link is probabilistic, too [1].

While the average waiting time for the generation of such a link in the case of just two elementary links is well understood [2], there is no analytical expression known for more than two links. The aim of this contribution is to explore estimations on the average waiting time for a long-distance entangled link for arbitrary network sizes.

[1] S. Khatri et al., Phys. Rev. Research 1, 023032 (2019)
[2] O. A. Collins et al., Phys. Rev. Lett 98, 060502 (2007)

QI 8.12 Wed 16:30 P

A perceptron quantum gate for quantum machine learning — •Patrick Huber[1], Erik Torrontegui[2], Johann Haber[3], Patrick Barthel[1], Juan Jose Garcia Ripoll[2], and Christof Wunderlich[1,3] — [1]Universität Siegen, Walter-Flex-Straße 3, 57068

Siegen — [2]Instituto de Física Fundamental IFF-CSIC - Calle Serrano 113b, 28006 Madrid, Spain — [3]eleQtron GmbH, Martinshardt 19, 57074 Siegen

As quantum computing advances towards the implementation of noisy intermediate-scale quantum computers (NISQs), the number of applications and scientific use cases keep growing. A recent addition is machine learning. We demonstrate the implementation of a perceptron on an ion-based quantum computer comprised of three qubits, a bias qubit, a control qubit, and a target qubit, the latter of which encodes the output state of the perceptron. The system uses magnetic gradient induced coupling (MAGIC) which allows for the control of the qubits by microwave radiation. The magnetic gradient also induces an Ising-like interaction between individual ions. This property is exploited in order to implement the perceptron. We demonstrate both the working of the basic perceptron quantum gate as predicted in [1], and show that by successive application of the perceptron more sophisticated multi-qubit quantum gates can be implemented easily and straightforwardly.

[1] Unitary quantum perceptron as efficient universal approximator, E. Torrontegui and J. J. García-Ripoll EPL, 125 3 (2019) 30004 DOI: https://doi.org/10.1209/0295-5075/125/30004

QI 8.13 Wed 16:30 P

Spatial entanglement dynamics between two quantum walkers with symmetric and anti-symmetric coins — •Ibrahim Yahaya Muhammad[1], Tanapat Deesuwan[1], Sikarin Yoo-Kong[2], Suwat Tangwancharoen[1], and Monsit Tanasittikosol[1] — [1]Department of Physics, Faculty of Science, King Mongkut's University of Technology Thonburi, Bangkok, Thailand — [2]The Institute for Fundamental Study (IF), Naresuan University, Phitsanulok, Thailand

We investigate the dynamics of the spatial entanglement between two initially independent walkers that individually and identically perform discrete-time quantum walk with symmetric and anti-symmetric initial coin states. The numerical results show that the spatial entanglement between the two walkers behaves similarly to the dynamics of an underdamped oscillator. By considering the symmetry associated with the setting and post-selecting the states of the two coins accordingly, we show both numerically and analytically that, for the anti-symmetric initial coin state, the entanglement dynamics corresponding to all the "triplet" results are constant, and the damping behaviour only shows up in the "singlet" result. On the other hand, for the symmetric initial coin state, the relationships between the entanglement dynamics and the post-selecting results are the other way around. Moreover, we obtain the relationship between the period of oscillation (T) and the coin operator parameter (θ) for the damping case as $\mathrm{T} = \pi/\theta$. Our findings reveal some interesting aspects of symmetry and quantum walks, which may be useful for applications in quantum communication and other quantum technology.

QI 8.14 Wed 16:30 P

Vibrationally-decoupled cryogenic surface-electrode ion trap for scalable quantum computing and simulation — •Niklas Orlowski[1], Timko Dubielzig[1], Sebastian Halama[1], Chloe Allen-Ede[1], Niels Kurz[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We present an overview of the necessary experimental infrastructure to perform experiments with an integrated microwave near-field surface-electrode ion trap at cryogenic temperatures for quantum logic applications [1]. We describe the measures to isolate the ions from environmental influences, like vibrational decoupling and XUHV-conditions. We discuss the loading scheme involving lasers for ablation and ionization as well as Doppler cooling, repumping and detection of $^9\mathrm{Be}^+$-ions. State preparation and manipulation procedures with precisely timed and tuned microwave and laser pulses are presented. Finally, we report on thermal stabilization as required for reproducible radial sideband spectroscopy. The achieved stability of the radial sideband modes will allow for implementation of microwave sideband-cooling and microwave quantum gates [2].

[1] Dubielzig et al. RSI **92.4** (2021): 043201
[2] Zarantonello et al. PRL **123**, 260503

QI 8.15 Wed 16:30 P

Retrieval of single photons from solid-state quantum transducers — •Tom Schmit[1], Luigi Giannelli[1,2,3], Anders S. Sørensen[4], and Giovanna Morigi[1] — [1]Theoretical Physics, Department of Physics, Saarland University, 66123 Saarbr+cken, Germany — [2]Dipartimento di Fisica e Astronomia "Ettore Majorana", Universit\a di Catania, Via S. Sofia 64, 95123 Catania, Italy — [3]INFN, Sez. Catania, 95123 Catania, Italy — [4]enter for Hybrid Quantum Networks (Hy-Q), Niels Bohr Institute,University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark

Quantum networks using photonic channels require control of the interactions between the photons, carrying the information, and the elements comprising the nodes. In this work, we theoretically analyse the spectral properties of an optical photon emitted by a solid-state quantum memory, which acts as a converter of a photon absorbed in another frequency range. We determine explicitly the expression connecting the stored and retrieved excitation taking into account possible mode and phase mismatching of the experimental setup. The expression we obtain describes the output field as a function of the input field for a transducer working over a wide range of frequencies, from optical-to-optical to microwave-to-optical. We apply this result to analyse the photon spectrum and the retrieval probability as a function of the optical depth for microwave-to-optical transduction. In the absence of losses, the efficiency of the solid-state quantum transducer is intrinsically determined by the capability of designing the retrieval process as the time-reversal of the storage dynamics.

QI 8.16 Wed 16:30 P

On the Advantage of Sub-Poissonian Single Photon Sources in Quantum Communication — •Daniel Vajner, Timm Gao, and Tobias Heindel — Institute of Solid State Physics, Technical University Berlin, 10623 Berlin

Quantum Communication in principle enables a provably secure transmission of information. While the original protocols envisioned single photons as the quantum information carrier [1], nowadays implementations and commercial realizations make use of attenuated laser pulses. There are, however, a number of advantages of using single photon sources. They are not limited by the Poisson statistics and suffer less under finite-key length corrections [2]. In addition, the second order interference visibility of true single photons can exceed the classical value of 50% which will be benefitial for all quantum information processing schemes, as well as measurment device independent QKD schemes, that rely on Bell state measurements of photons from different sources [3]. Given recent advances in the development of engineered semiconductor QD-based light sources, harnessing these advantages is within reach. We present an overview of different scenarios in which employing single photon sources improves the communication rate and distance.

[1] Bennett et al. *Proceedings of the IEEE International Conference on Computers, Systems and Signal Processing* (1984)
[2] Cai et al. *New Journal of Physics* 11.4 (2009): 045024
[3] Mandel, L. *Physical Review A* 28.2 (1983): 929

QI 8.17 Wed 16:30 P

Multi-rail optical memory in warm Cs vapor — •Leon Messner[1,2,3], Luisa Esguerra[2,3], Mustafa Gündoğan[1,2], and Janik Wolters[2,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin, Germany — [3]Technische Universität Berlin, Institut für Optik und Atomare Physik, Str. des 17 Juni 135, 10623 Berlin, Germany

Mapping quantum states of light onto long-lived matter excitations is considered an important step in the realization of optical quantum communication and computation architectures [1]. In quantum communication the manifold approaches to this task are subsumed under the topic of quantum memories [2]. Multiplexing of these memories helps to achieve higher communication rates per link and is especially important on links that exhibit high loss [3].

We present a multi-rail EIT memory [4] within a single Cs vapor cell at room temperature. By deflecting the co-propagating signal and control beams, multiple non-interacting volumes within a single Cs vapor cell are addressed. Storing to and retrieving from randomly selected rails is then demonstrated by changing the AOM driving frequency.

[1] Kimble, H., Nature **453**, 1023 (2008)
[2] Heshami, K. et al., JModOpt **63**, 2005 (2016)
[3] Gündoğan, M. et al., arXiv:2006.10636 (2020)
[4] Wolters, J. et al., PRL, **119**, 060502 (2017)

QI 8.18 Wed 16:30 P

Toward a Photon-Photon Quantum Gate Based on Cavity Rydberg EIT — Thomas Stolz, •Hendrik Hegels, Bianca Röhr, Maximilian Winter, Ya-Fen Hsiao, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann Str. 1, 85748 Garching, Germany

All realizations of optical photon-photon quantum gates to date suffer from low efficiency [1]. Theory suggests that this limitation can be overcome using Rydberg electromagnetically induced transparency (EIT) in an optical cavity of moderate finesse [2]. We have set up a new vacuum system, which houses a cavity, in which an ultracold atomic ensemble is held in an optical dipole trap. The ensemble is cooled in multiple stages to a temperature of $0.2\,\mu$K. This low temperature is needed to achieve a long coherence time [3]. We report on the observation of cavity Rydberg EIT. This is a promising step on the way to a future realization of a photon-photon gate.

[1] K. Kieling et al. NJP 12, 013003 (2010), B. Hacker et al. Nature 536, 193 (2016), D. Tiarks et al. Nat. Phys. 15, 124 (2019).
[2] Y. Hao et al. Sci. Rep. 5, 10005 (2015), S. Das et al. PRA 93, 040303 (2016).
[3] S. Schmidt-Eberle et al. PRA 101, 013421 (2020).

QI 8.19 Wed 16:30 P

Towards Cavity-Enhanced Spectroscopy of Single Europium Ions in Yttria Nanocrystals — Timon Eichhorn[1], •Sören Bieling[1], Christian Rentschler[2], Shuping Liu[3], Alban Ferrier[3], Philippe Goldner[3], and David Hunger[1] — [1]Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]CFEL/DESY, 22607 Hamburg, Germany — [3]Chimie Paris Tech, 75231 Paris, France

A promising approach for realizing scalable quantum registers lies in the efficient optical addressing of rare-earth ion spin qubits in a solid state host. Within the EU Quantum Flagship project SQUARE we study Eu^{3+} ions doped into Y_2O_3 nanoparticles (NPs) as a coherent qubit material and work towards efficient single ion detection by coupling their emission to a high-finesse fiber-based Fabry-Pérot microcavity. A beneficial ratio of the narrow homogeneous line to the inhomogeneous broadening of the ion ensemble at temperatures below 10K makes it possible to spectrally address and readout single ions. The coherent control of the single ion $^5D_0-^7F_0$ transition then permits optically driven single qubit operations on the Europium nuclear spin states. A Rydberg-blockade mechanism between ions within the same nanocrystal permits the implementation of a two-qubit CNOT gate to entangle spin qubits and perform quantum logic operations. Theoretical simulations of the single and two-qubit gate operations predict fidelities of up to 98.2% and 96.5%, respectively, with current material properties. We report on our progress to experimentally implement this scheme.

QI 8.20 Wed 16:30 P

Controlling single erbium dopants in a Fabry-Perot resonator — •Alexander Ulanowski[1], Benjamin Merkel[1], and Andreas Reiserer[1,2] — [1]MPI of Quantum Optics, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität München, München, Germany

Erbium dopants exhibit unique optical and spin coherence lifetimes and show great promise for long-distance quantum networks, as their emission lies in the minimal-loss window of optical fibers. To achieve an efficient spin-photon interface for single dopants, we integrate thin host crystals into cryogenic Fabry-Perot resonators. With a Finesse of $1.2 \cdot 10^5$ we can demonstrate up to 58(6)-fold Purcell enhancement of the emission rate, corresponding to a two-level cooperativity of 530(50). Our approach avoids interfaces in the proximity of the dopants and therefore preserves the optical coherence up to the lifetime limit. [1]

Using this system, we resolve individual Erbium dopants which feature an ultra-low spectral diffusion of less than 100 kHz, being limited by the nuclear spin bath. This should facilitate frequency-multiplexed spin-qubit readout, control and entanglement, opening unique perspectives for the implementation of quantum repeater nodes.

[1] B. Merkel, A. Ulanowski, and A. Reiserer, Phys. Rev. X 10, 041025 (2020)

QI 8.21 Wed 16:30 P

A multi-site quantum register of neutral atoms with single-site controllability — •Lars Pause, Tilman Preuschoff, Stephan Amann, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Assembled arrays of neutral atoms are a versatile platform for quantum techologies. As effectively non-interacting particles with identical intrinsic properties they also feature switchable interactions when excited to Rydberg states. This makes neutral atoms well suited for quantum simulation, computation, and metrology.

We present our unique micro-optical implementation of triangular arrays of optical tweezers. Combined with a digital micromirror device (DMD), site-selective manipulation of the trapping potentials is possible while utilizing the robust architecture of microlens-based systems. The addition of a single movable optical tweezer enables atom sorting for achieving defect-free structures of individual atoms. We also discuss recent work with microlens arrays fabricated by femtosecond direct laser writing [1].

In addition, we present our open-source digital controllers for laser frequency and intensity stabilization [2]. Using the STEMlab (originally Red Pitaya) platform we achieve a control bandwidth of up to 1.25 MHz resulting in a laser line width of 52(1) kHz (FWHM) and intensity control to the $1 \cdot 10^{-3}$ level.

[1] D. Schäffner et. al., Opt. Express **28**, 8640-8645 (2020).
[2] T. Preuschoff et. al., Rev. Sci. Instrum. **91**, 083001 (2020).

QI 8.22 Wed 16:30 P

Ultra-stable open micro-cavity platform for closed cycle cryostats — •Michael Förg[1,2], Jonathan Noé[1,2], Manuel Nutz[1,2], Theodor Hänsch[2], and Thomas Hümmer[1,2] — [1]Qlibri project, Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany — [2]Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany

We present a fully 3D-scannable, yet highly stable micro-cavity setup, which features a stability on the sub-pm scale under ambient conditions and unprecedented stability inside closed-cycle cryostats. An optimized mechanical geometry, custom built stiff micro-positioning, vibration isolation and fast active locking enables quantum optics experiments even in the strongly vibrating environment of closed-cycle cryostats. High-finesse, open-access, mechanical tunable, optical micro-cavities offer a compelling system to enhance light matter interaction. Combining a scannable microscopic fiber-based mirror and a macroscopic planar mirror creates a versatile experimental platform. A variety of solid-state quantum systems can be brought onto the planar mirror, addressed individually, and (strongly) coupled to the cavity. With mechanical tuning of the cavity length, the resonance frequency can be adapted to the quantum system. However, the flexibility of the mechanical degrees of freedom bears also downsides. Inside close-cycle cryostats, fluctuations of the cavity length on the picometer scale are often enough to prevent the use of high-finesse cavities for quantum optics experiments. Our system enables the use of a flexible micro-cavity system for quantum applications even in this adversarial environment.

QI 8.23 Wed 16:30 P

Engineering of Vibrational dynamics in a two-dimensional array of trapped ions — •Deviprasath Palani, Philip Kiefer, Lennart Guth, Florian Hasse, Robin Thomm, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, University of 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 by tuning motional frequencies and mode orientations [3]. Our setup consists of an 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 1D arrangements. We demonstrate its tuning in real-time and show interference of large coherent states [4] and employ modulation of the local trapping potentials to realize phonon-assisted tunneling between adjacent sites [5]. Furthermore, with an identical prototype setup, we investigate methods such as surface cleaning to decrease noise field contributions [6].

[1] K. R. Brown et al., Nature 471 (2011). [2] T. Schaetz et al., N. J. Phys. 15, 085009 (2013). [3] M.Mielenz et al., Nat. Com. 7, 11839 (2016). [4] Hakelberg, F. et al. Phys. Rev. Lett. 123, 100504 (2019). [5] Kiefer, P. et al. Phys. Rev. Lett. 123, 213605 (2019). [6] U. Warring et al., Adv. Quantum Technol. 2020, 1900137.

QI 8.24 Wed 16:30 P

Characteristic dynamics of the bosonic quantum east model — •Andreas Geissler and Juan Garrahan — School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK

Kinetically constrained models like the East model are among the simplest systems to give insight into the dynamics of glass formers. In these models local spin flips are only possible if neighboring spins satisfy a condition, for example in the East model if the neighbor to the left points up. Here, we consider a bosonic quantum version of the East model using the Holstein-Primakoff-transformation. A comparison of exact diagonalzation and the flucuation operator expansion reveals a ground state phase diagram reminiscent of the spin half case. Using a Gross-Pitaevskii like limit for large spin we are able to perform dynamics for large system sizes. These reveal different dynamical regimes. We use open boundary conditions with the first site fixed to any non-zero occupation. We then observe two types of chaotic behavior in the active regime, depending on the energy of the local generator, and nontrivial localization dynamics in the inactive regime.

[1] M.C. Banuls et al., PRL, 123, 200601 (2019)

QI 8.25 Wed 16:30 P

Optimized diamond inverted nanocones for enhanced color center to fiber coupling — •Cem Güney Torun[1], Philipp-Immanuel Schneider[2,3], Martin Hammerschmidt[2,3], Sven Burger[2,3], Tommaso Pregnolato[1,4], Joseph. H. D. Munns[1], and Tim Schröder[1,4] — [1]Integrated Quantum Photonics, Humboldt-Universität zu Berlin, Berlin — [2]JCMwave GmbH, Berlin — [3]Zuse Institute Berlin (ZIB), Berlin — [4]Diamond Nanophotonics, Ferdinand-Braun-Institut, Berlin

Fiber coupling of the emission from color centers in diamond, a promising candidate for quantum nodes, is challenging due to the mode mismatches and reduced light outcoupling caused by the total internal reflections. Nanostructures are popular tools utilized to overcome these challanges. Nevertheless, while the fiber coupling properties are crucial for a single mode of indistinguishable photons, this performance of nanostructures is rarely investigated. Here, we simulate the emission of color centers and overlap of this emission with the fundamental fiber modes for a novel nanostructure called **inverted nanocone**. Using different figures of merit, the parameters are optimized to maximize fiber coupling efficiency, free-space collection efficiency or emission rate enhancement. The optimized inverted nanocones show promising results, with 66% fiber coupling or 83% free-space collection efficiency at the tin-vacancy center zero-phonon line wavelength of 619 nm. For maximum emission rate into a fiber mode, a design with a Purcell factor of 2.34 is identified. Moreover, these designs are analyzed for their broadband performance and robustness against fabrication errors.

QI 8.26 Wed 16:30 P

Construction of a reliable laser light source for resonant excitation of tin-vacany centers — •Franziska M. Herrmann[1], Joseph H.D. Munns[1], and Tim Schröder[1,2] — [1]Integrated Quantum Photonics, Institut für Physik, Humboldt-Universität zu Berlin, Berlin — [2]Diamond Nanophotonics, Ferdinand-Braun-Institut, Berlin

Tin-vacancy colour centres in diamond are promising candidates for nodes in quantum networks, due to their suitable optical and spin properties. However, with a zero phonon line wavelength of 619 nm, resonant excitation cannot be achieved easily by commercially available and affordable laser systems. At 1238 nm however, suitable narrowband lasers are available and the targeted 619 nm can be reached by frequency doubling. The conversion is achieved based on second harmonic generation in an MgO:PPLN crystal pumped with infrared laser light. Here we introduce the setup and investigate the stability and tunability of this laser system and demonstrate how several PID controlled feedback loops can ensure usability for future quantum control applications.

QI 8.27 Wed 16:30 P

Shorcuts to adiabaticity with quantum non-demolition measurements — •Raphael Menu and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, German

The realization of quantum adiabatic dynamics is at the core of implementations of adiabatic quantum computers. One major issue is to efficiently compromise between the long time scales required by the adiabatic protocol and the detrimental effects of the environment, which set an upper bound to the time scale of the operation. In this work we propose a protocol which achieves fast adiabatic dynamics by coupling the system to an external environment by the means of a quantum-non-demolition (QND) Hamiltonian. We analyse the infidelity of adiabatic transfer for a Landau-Zener problem in the presence of QND measurement, where the qubit couples to a meter which in turn quickly dissipates. We analyse the protocol's fidelity as a function of the strength of the QND coupling and of the relaxation time of the meter. In the limit where the decay rate of the ancilla is the largest frequency scale of the dynamics, the QND coupling induces an effective dephasing in the adiabatic basis. Optimal conditions for adiabaticity are found when the coupling with the meter induces dissipative dynamics which suppresses unwanted diabatic transitions.

QI 9: Quantum Metrology

Time: Thursday 10:45–12:45 Location: H4

Invited Talk QI 9.1 Thu 10:45 H4

The true Heisenberg limit in optical interferometry — •Rafal Demkowicz-Dobrzanski — University of Warsaw, Poland

The concept of the Heisenberg limit represents the ultimate bound on estimation precision in quantum enhanced optical interferometry and in quantum metrology in general. In the context of optical interferometry it refers to the inverse-proportionality scaling of the phase estimation precision as a function of the number of photons used in the experiment—a quadratic improvement over the shot noise scaling. Even though at a first glance there should be no ambiguity as to the actual form of the limit, it comes in different variants depending on whether: (i) definite or indefinite photon number states are considered, (ii) reference beam is explicitly taken into account or not, (iii) multiple-repetition or single-shot scenarios are considered. This results in Heisenberg limits that differ by constant factors and a reasonable question to ask is: 'which one is the actual operationally meaningful one?'.

This issue has an even more dramatic turn in case of multiple-arm interferometry where multiple relative phases are to be estimated simultaneously. In this case the actual scaling of the Heisenberg limit, in terms of the number of phases being estimated, may differ depending on the approach.

Invited Talk QI 9.2 Thu 11:15 H4

On the quantum limits of field sensing — •Morgan Mitchell — ICFO - The Institute of Photonic Sciences, Barcelona, Spain

We discuss the nature and status of "energy resolution" limits in magnetic field sensing. Unlike better-known quantum limits, energy resolution limits constrain directly the sensitivity, with no reference to particle number or any other resource. Today's best-developed magnetometer technologies are known to be limited to an energy resolution per bandwidth of about $\hbar$. We discuss the possibility that this is a universal sensing limit, and describe proposed sensing methods that could surpass the $\hbar$ level.

Reference: Mitchell, Morgan W. and Palacios Alvarez, Silvana, "Colloquium: Quantum limits to the energy resolution of magnetic field sensors," Rev. Mod. Phys. **92**, 021001 (2020). `https://doi.org/10.1103/RevModPhys.92.021001`

QI 9.3 Thu 11:45 H4

Activating hidden metrological usefulness — •Géza Tóth[1,2,3,4], Tamás Vértesi[5], Paweł Horodecki[6,7], and Ryszard Horodecki[6,8] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), E-20080 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [4]Wigner Research Centre for Physics, H-1525 Budapest, Hungary — [5]Institute for Nuclear Research, Hungarian Academy of Sciences, H-4001 Debrecen, Hungary — [6]International Centre for Theory of Quantum Technologies, University of Gdańsk, PL-80308

Gdańsk, Poland — [7]Faculty of Applied Physics and Mathematics, National Quantum Information Centre, Gdańsk University of Technology, PL-80233 Gdańsk, Poland — [8]Institute of Theoretical Physics and Astrophysics, National Quantum Information Centre, Faculty of Mathematics, Physics and Informatics, University of Gdańsk, PL-80308 Gdańsk, Poland

We consider entangled states that cannot outperform separable states in any linear interferometer. Then, we show that these states can still be more useful metrologically than separable states if several copies of the state are provided or an ancilla is added to the quantum system. We present a general method to find the local Hamiltonian for which a given quantum state performs the best compared to separable states.

QI 9.4 Thu 12:00 H4

Time-energy uncertainty relation for noisy quantum metrology — •Philippe Faist[1], Mischa P. Woods[2], Victor V. Albert[4], Joseph M Renes[2], Jens Eisert[1], and John Preskill[3,5] — [1]Freie Universität Berlin — [2]ETH Zurich, Switzerland — [3]Caltech, Pasadena, USA — [4]JCQCI, NIST and University of Maryland, USA — [5]AWS Center for Quantum Computing, USA

Quantum metrology has many applications to science and technology, including the detection of very weak forces and precise measurement of time. To sense time, one prepares an initial state of a clock system, allows the system to evolve as governed by a Hamiltonian H, and then performs a measurement to estimate the time elapsed. Here, we introduce and study a fundamental trade-off which relates the amount by which the application of a noise channel reduces the accuracy of a quantum clock to the amount of information about the energy of the clock that leaks to the environment. We prove that Bob's loss of quantum Fisher information about the elapsed time is equal to Eve's gain of quantum Fisher information about a complementary energy parameter. We also prove a similar, but more general, trade-off that applies when Bob and Eve wish to estimate the values of parameters associated with two non-commuting observables. We derive the necessary and sufficient conditions for the accuracy of the clock to be unaffected by the noise, which are weaker than the Knill-Laflamme error-correction conditions. We discuss applications of the trade-off relation to sensing using a quantum many-body probe subject to erasure or amplitude-damping noise.

QI 9.5 Thu 12:15 H4

Metrological complementarity reveals the Einstein-Podolsky-Rosen paradox — •Benjamin Yadin[1,2], Matteo Fadel[3], and Manuel Gessner[4] — [1]School of Mathematical Sciences, University of Nottingham, Nottingham, UK — [2]Wolfson College, University of Oxford, Oxford, UK — [3]Department of Physics, University of Basel, Basel, Switzerland — [4]Laboratoire Kastler Brossel, ENS-Université PSL, CNRS, Sorbonne Université, Collège de France, Paris, France

The Einstein-Podolsky-Rosen (EPR) paradox plays a fundamental role in our understanding of quantum mechanics, and is associated with the possibility of predicting the results of non-commuting measurements with a precision that seems to violate the uncertainty principle. This apparent contradiction to complementarity is made possible by nonclassical correlations stronger than entanglement, called steering. Quantum information recognises steering as an essential resource for a number of tasks but, contrary to entanglement, its role for metrology has so far remained unclear. Here, we formulate the EPR paradox in the framework of quantum metrology, showing that it enables the precise estimation of a local phase shift and of its generating observable. Employing a stricter formulation of quantum complementarity, we derive a criterion based on the quantum Fisher information that detects steering in a larger class of states than well-known uncertainty-based criteria. Our result identifies useful steering for quantum-enhanced precision measurements and allows one to uncover steering of non-Gaussian states in state-of-the-art experiments.

QI 9.6 Thu 12:30 H4

Bayesian Quantum Thermometry — •Julia Boeyens[1], Stefan Nimmrichter[1], and Stella Seah[2] — [1]University of Siegen, Siegen 57068, Germany — [2]University of Geneva, 1211 Geneva, Switzerland

Most theoretical treatments of temperature estimation in quantum systems have focused on systems in thermal equilibrium in the asymptotic limit of many measurements. In this limit, the thermal Cramér-Rao bound applies, and the optimal measurement strategy can be found by maximizing the Fisher information, either locally for each possible temperature or over a desired temperature range [1]. It has also been shown that driving systems out of thermal equilibrium by means of repeated finite-time collisions with non-thermal probes can boost temperature sensitivity beyond the Cramér-Rao bound in the limit of many repetitions [2]. However, in practical implementations, only scarce data may be available and the Bayesian method of parameter estimation is more appropriate [3]. Here, we study non-informative Bayesian thermometry with a minimal restriction on the allowed temperature range and with a limited number of qubit probes in and out of thermal equilibrium. We compare different estimates for the temperature and the associated error and work out the most faithful estimation strategy. We demonstrate how non-equilibrium thermometry improves measurement precision at high temperatures already for a few hundred qubit probes.

[1] M. Mehboudi, A. Sanpera, L.A. Correa; J. Phys. A 52, 303001 (2019) [2] S. Seah et al; Phys. Rev. Lett. 123, 180602 (2019) [3] J. Rubio, J. Anders, L.A. Correa; arXiv:2011.13018

QI 10: Certification and Benchmarking of Quantum Systems

Time: Thursday 10:45–12:30 Location: H5

QI 10.1 Thu 10:45 H5

Machine-learning framework for customized optimal quantum state tomography — •Violeta Ivanova-Rohling[1,2,3], Guido Burkard[1], and Niklas Rohling[1] — [1]Department of Physics, University of Konstanz, Germany — [2]Zukunftskolleg, University of Konstanz — [3]Department of Mathematical Foundations of Computer Sciences, Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Sofia, Bulgaria

Fastest quantum state tomography (QST) schemes which reach a desired precision are of high practical relevance. Rarely, analytical solutions are known, e.g. non-degenerate projective measurements whose eigenbases form a complete set of mutually unbiased bases (MUBs) [1]; mutually unbiased subspaces (MUSs) constructed from a complete set of MUBs if measuring one out of N qubits [2]. Our flexible scheme finds numerically an optimized QST measurement set given the system's specifications, e.g. for a qubit-qutrit system (e.g. NV center in diamond), a QST measurement set closely approximating MUSs [3]. Furthermore, machine learning approaches now for individual rank-1 measurements in eight dimensions [4] outperform standard numerical methods yielding high-performing measurement sets with complex structure and symmetries. Funded by Zukunftskolleg (U. Konstanz) and Bulgarian National Science Fund, contract No KP-06-PM 32/8

[1] Wootters, Fields, Ann. Phys. 191, 363 (1989).
[2] Bodmann, Haas, Proc. Amer. Math. Soc. 146, 2601 (2018).
[3] Ivanova-Rohling, Burkard, Rohling, arXiv:2012.14494.
[4] Ivanova-Rohling, Rohling, Cyb. Inf. Technol. 20 (6), 61 (2020).

QI 10.2 Thu 11:00 H5

Optimal quantum state tomography measurement set under noise — Violeta Ivanova-Rohling[1,2,3], •Niklas Rohling[1], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, Germany — [2]Zukunftskolleg, University of Konstanz — [3]Department of Mathematical Foundations of Computer Sciences, Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Sofia, Bulgaria

Quantum state tomography (QST) is an essential yet time-consuming tool for the verification of a quantum device. An informaion-theory-based quality measure for QST measurement sets allowed Wootters and Fields to prove that a set of n+1 mutually unbiased bases is ideal for QST in an n-dimensional system with non-degenerate measurements [1]. The same quality measure can be used to obtain a numerically optimized QST measurement set for degenerate measurements, e.g. for measurements projecting on one-dimensional [2] or n/2-dimensional subspaces [3]. Here, we add a noise-dependent correction factor to the quality measure. We find optimal QST measurement schemes for two qubits measured in a standard basis preceded by a gate sequence including noisy two-qubit gates.

Funded by Zukunftskolleg (U. Konstanz) and Bulgarian National Science Fund,contract No KP-06-PM 32/8.

[1] Wootters, Fields, Ann. Phys. 191, 363 (1989).
[2] Ivanova-Rohling, Rohling, PRA 100, 032332 (2019).
[3] Ivanova-Rohling, Burkard, Rohling, arXiv:2012.14494.

QI 10.3 Thu 11:15 H5

Wigner state and process tomography on near-term quantum devices — •Amit Devra[1,2], Niklas J. Glaser[3,4], and Steffen J. Glaser[1,2] — [1]Technische Universität München, Department of Chemistry, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany — [3]Technische Universität München, Department of Physics, 85748 Garching, Germany — [4]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Germany

We present a scanning-based tomography approach in the context of finite-dimensional Wigner representations on near-term quantum devices. These representations completely characterize and visualize operators using shapes assembled from linear combinations of spherical harmonics [1]. The shapes can also be experimentally recovered by measuring the expectation value of rotated axial tensor operators. Here, we present the translation of a nuclear magnetic resonance (NMR) based experimental approach for state tomography [2] and known quantum propagators (gates) [3] for general quantum computers based on projective measurements and showcase results of simulations and experiments on the IBM quantum experience platform.

References: 1. A. Garon, R. Zeier, and S. J. Glaser, Phys. Rev. A 91, 042122 (2015). 2. D. Leiner, R. Zeier, and S. J. Glaser, Physical Review A 96, 063413 (2017). 3. D. Leiner and S. J. Glaser, Physical Review A 98, 012112 (2018).

QI 10.4 Thu 11:30 H5

Gate set tomography via Riemannian optimization — •Raphael Brieger[1], Martin Kliesch[1], and Ingo Roth[2] — [1]Institute for Theoretical Physics, Heinrich Heine University Düsseldorf, Germany — [2]Quantum research centre, Technology Innovation Institute, Abu Dhabi, UAE

Flexible characterization techniques that quantify and identify noise under realistic assumptions are crucial for the development of near term quantum computers. 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 subject to physicality constraints, such as complete positivity, can naturally be cast as an optimization problem on the complex Stiefel manifold. We develop a second order manifold optimization algorithm that allows us to perform GST accurately from random circuit data. In contrast to traditional approaches our algorithm does not need a structured gate set and an elaborate circuit design to perform GST, while matching the performance of state of the art methods. Furthermore, it can naturally include low-rank constraints on the gate set in order to reduce the scaling problems inherent in quantum process tomography.

QI 10.5 Thu 11:45 H5

Certifying multiparticle entanglement with randomized measurements — •Andreas Ketterer[1], Satoya Imai[2], Nikolai Wyderka[3], and Otfried Gühne[2] — [1]University of Freiburg, Freiburg, Germany — [2]University of Siegen, Siegen, Germany — [3]Heinrich Heine University Düsseldorf, Düsseldorf, Germany

We consider statistical methods based on finite samples of locally randomized measurements in order to certify different degrees of multiparticle entanglement in intermediate-scale quantum systems. We first introduce hierarchies of multi-qubit criteria satisfied by states which are separable with respect to partitions of different size, involving only second moments of the underlying probability distribution. Then, we analyze in detail the statistical error of the estimation in experiments and show how to infer the statistical significance based on large deviation bounds. In this way we are able to characterize the measurement resources required for the certification of multiparticle correlations, as well as to analyze given experimental data.

QI 10.6 Thu 12:00 H5

Generalizing optimal Bell inequalities — •Fabian Bernards and Otfried Gühne — Universität Siegen, Siegen, Germany

Bell inequalities are central tools for studying nonlocal correlations and their applications in quantum information processing. Identifying inequalities for many particles or measurements is, however, difficult due to the computational complexity of characterizing the set of local correlations. We develop a method to characterize Bell inequalities under constraints, which may be given by symmetry or other linear conditions. This allows to search systematically for generalizations of given Bell inequalities to more parties. As an example, we find all possible generalizations of the two-particle inequality by Froissart [Il Nuovo Cimento B64, 241 (1981)], also known as I3322 inequality, to three particles. For the simplest of these inequalities, we study their quantum mechanical properties and demonstrate that they are relevant, in the sense that they detect nonlocality of quantum states, for which all two-setting inequalities fail to do so.

QI 10.7 Thu 12:15 H5

When can a quantum measurement be regarded as happened? — •Zhen-Peng Xu, Jonathan Steinberg, Hai Chau Nguyen, and Otfried Guehne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, 57068 Siegen, Germany

Whether measurements in quantum mechanics can be regarded as absolute events is at the center of the debates in the foundation of quantum mechanics, which have been recently shown to be deeply linked to the concept of Wigner friends as well as that of Bell nonlocality. We argue that, the subtlety is not at the interaction between the measurement device and the system, rather at how the outcomes are perceived. In particular, we show that even regarding measurements of which the outcomes are already partially read as absolutely happens, when combined with the assumptions of the so-called locality and no superdeterminism, is also incompatible with quantum mechanics at its universal validity. This shares also the spirit in Lüders rule of measurements in quantum mechanics, as well as Peres' argument for contextuality.

QI 11: Quantum Communication

Time: Thursday 14:00–16:00 Location: H4

Invited Talk QI 11.1 Thu 14:00 H4

Numerical Security Analysis for Quantum Key Distribution and Application to Optical Protocols — •Norbert Lütkenhaus — Institute for Quantum Computing, University of Waterloo, Canada

The security analysis of Quantum Key Distribution (QKD) protocols reveals the achievable secrete key rate as a function of observable parameters, such as loss and noise parameters. Calculating the secret key rate is equivalent to solving a convex optimization problem. While for highly symmetric protocols that optimization protocol can be solved analytically, in general it is of advantage to resort to numerical approaches.

We will review the progress of this research agenda accessible to a broader audience to show how researchers with different backgrounds can contribute. The resulting toolbox is available as open source code [1]. I will show some applications, including finite size analysis and the use for optical protocols, such as the Discrete Modulated Continuous Variable QKD protocol. Our approach also allows the evaluation of side-channels that result from device imperfections, including a tight analysis of combinations of such imperfections.

[1] https://openqkdsecurity.org

Invited Talk QI 11.2 Thu 14:30 H4

Photonic graph states for quantum communication and quantum computing — •Stefanie Barz — Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Germany — Centre for Integrated Quantum Science and Technologies, University of Stuttgart, Germany

Multipartite entanglement and, in particular, graph states are useful resources both for quantum computing and quantum communication, especially in networked settings. In this talk, I will show a few examples where multipartite entanglement offers an advantage over classical or bipartite approaches. In particular, I will present how photonic graph states can serve as a resource for computation and, vice versa, how computation can be used as a tool to test certain states. Furthermore, I will show how graph states offer an advantage for communication protocols, in particular in networked settings and where one aims at keeping the identity of the communicating parties private. I will present implementations of these concepts and discuss challenges in scaling up photonic quantum technologies.

QI 11.3 Thu 15:00 H4

Anonymous Quantum Conference Key Agreement — •Frederik Hahn[1], Jarn de Jong[2], and Anna Pappa[2] — [1]Freie Universität Berlin, Berlin, Deutschland — [2]Technische Universität Berlin, Berlin, Deutschland

Conference Key Agreement (CKA) is a cryptographic effort by multiple parties to create a shared secret key. In future quantum networks, generating secret keys in an anonymous manner is of enormous importance for parties who wish to keep their shared key secret while protecting their own identities. We present a CKA protocol using multipartite entangled GHZ states that is provably anonymous in realistic adversarial scenarios. The existence of secure and anonymous protocols based on multipartite entangled states provides a new insight into their potential as resources and paves the way for further applications.

DOI:https://doi.org/10.1103/PRXQuantum.1.020325

QI 11.4 Thu 15:15 H4

Resource analysis for quantum-aided Byzantine agreement — •Zoltán Guba[1], István Finta[2,3], Ákos Budai[1,2,4], Lóránt Farkas[2], Zoltán Zimborás[4,5], and András Pályi[1] — [1]Department of Theoretical Physics and MTA-BME Exotic Quantum Phases Research Group, Budapest University of Technology and Economics, Hungary — [2]Nokia Bell Labs, Budapest, Hungary — [3]Óbuda University, Budapest, Hungary — [4]Wigner Research Centre for Physics, Budapest, Hungary — [5]BME-MTA Lendület Quantum Information Theory Research Group, Budapest, Hungary and Mathematical Institute, Budapest University of Technology and Economics, Budapest, Hungary

In distributed computing, a byzantine fault is a condition where a component shows different symptoms to different components of the system. Consensus among the correct components in the presence of byzantine faults can be reached by appropriately crafted communication protocols. Quantum-aided protocols built upon distributed entangled quantum states are worth considering, as they are more resilient than traditional ones. Based on earlier ideas, we introduce a parameter-dependent family of quantum-aided weak broadcast protocols. We analyze the resource requirements as functions of the protocol parameters, and locate the parameter range where these requirements are minimal. Following earlier work demonstrating the suitability of noisy intermediate-scale quantum (NISQ) devices for the study of quantum networks, we show how to prepare our resource quantum state on publicly available IBM quantum computers.

QI 11.5 Thu 15:30 H4

Squeezing-enhanced communication without a phase reference — Marco Fanizza[1], •Matteo Rosati[2], Michalis Skotiniotis[2], John Calsamiglia[2], and Vittorio Giovannetti[1] — [1]NEST, Scuola Normale Superiore and Istituto Nanoscienze-CNR, I-56126 Pisa, Italy — [2]Física Teòrica: Informació i Fenòmens Quàntics, Departament de Física, Universitat Autònoma de Barcelona, 08193 Bellaterra (Barcelona) Spain

We study the problem of transmitting classical information using quantum Gaussian states on a family of phase-noise channels with a finite decoherence time, such that the phase-reference is lost after m consecutive uses of the transmission line. This problem is relevant for long-distance communication in free space and optical fiber, where phase noise is typically considered as a limiting factor. We show that the optimal Gaussian encoding is generated by a Haar-random passive interferometer acting on pure product states. We upper- and lower-bound the optimal coherent-state rate and exhibit a lower bound to the squeezed-coherent rate that, for the first time to our knowledge, surpasses any coherent encoding for m=1 and provides a considerable advantage with respect to the coherent-state lower bound for m>1. This advantage is robust with respect to moderate attenuation, and persists in a regime where Fock encodings with up to two-photon states are also suboptimal. Finally, we show that the advantage carries over to the private capacity of the channel and that the use of part of the energy to establish a reference frame is sub-optimal even at large energies.

QI 11.6 Thu 15:45 H4

Evaluating a Plug&Play Telecom-Wavelength Single-Photon Source for Quantum Key Distribution — Timm Gao[1], •Lucas Rickert[1], Felix Urban[1], Jan Grosse[1], Nicole Srocka[1], Sven Rodt[1], Anna Musiał[2], Kinga Żołnacz[3], Paweł Mergo[4], Kamil Dybka[5], Wacław Urbańczyk[3], Grzegorz Sek[2], Sven Burger[6], Stephan Reitzenstein[1], and Tobias Heindel[1] — [1]Institute of Solid State Physics, Technical University Berlin, 10623 Berlin, Germany — [2]Department of Experimental Physics, Wrocław University of Science and Technology, 50-370 Wrocław, Poland — [3]Department of Optics and Photonics, Wrocław University of Science and Technology, 50-370 Wrocław, Poland — [4]Institute of Chemical Sciences, Maria Curie Sklodowska University, 20-031 Lublin, Poland — [5]Fibrain Sp. z o.o., 36-062 Zaczernie, Poland — [6]Zuse Institute Berlin, 14195 Berlin, Germany

We report on quantum key distribution (QKD) tests using a 19-inch benchtop single-photon source at 1321 nm based on a fiber-pigtailed quantum dot (QD) integrated into a Stirling cryocooler. Emulating the polarization-encoded BB84 protocol, we achieve an antibunching of $g^{(2)}(0) = 0.10 \pm 0.01$, a raw key rate of up to 4.72 ± 0.13 kHz, and a maximum tolerable loss of 23.19 dB exploiting optimized temporal filters in the asymptotic limit [1]. Our study represents an important step forward in the development of fiber-based quantum-secured communication networks exploiting sub-Poissonian quantum light sources.

[1] T. Kupko et al., arXiv.2105.03473 (2021)

QI 12: Quantum Simulation and Many-Body Systems

Time: Friday 10:45–12:45 Location: H3

Invited Talk QI 12.1 Fri 10:45 H3

Emergent Hilbert-space fragmentation in tilted Fermi-Hubbard chains — •Monika Aidelsburger — Fakultät für Physik, Ludwig-Maximilians-Universität Munich, Germany — Munich Center for Quantum Science and Technology (MCQST) Munich, Germany

Well-controlled synthetic quantum systems, such as ultracold atoms in optical lattices, offer intriguing possibilities to study complex many-body problems relevant to a variety of research areas, ranging from condensed matter to statistical physics. In particular, out-of-equilibrium phenomena constitute natural applications of quantum simulators, which have already successfully demonstrated simulations in regimes that are beyond reach using state-of-the-art numerical techniques. This enables us to shed new light on fundamental questions about the thermalization of isolated quantum many-body systems. While generic models are expected to thermalize according to the eigenstate thermalization hypothesis (ETH), violation of ETH is believed to occur mainly in two types of systems: integrable models and manybody localized systems. In between these two extreme limits, there is, however, a whole range of models that exhibit more complex dynamics, for instance, due to an emergent fragmentation of the many-body Hilbert space. A versatile platform that paves the way towards studying this rich variety of (weak) ergodic-breaking phenomena is the 1D Fermi-Hubbard model with a strong linear potential (tilt).

Invited Talk QI 12.2 Fri 11:15 H3

An entanglement-based perspective on quantum many-body systems — •Norbert Schuch — University of Vienna, Austria

Quantum many-body systems exhibit a wide range of exciting and unconventional phenomena, such as order outside the conventional framework of symmetry breaking (“topological order”) which is accompanied by excitations with exotic properties (“anyons”), and the ability to store and process quantum information. All these phenomena are deeply rooted in the complex global quantum entanglement present in these systems. In my talk, I will explain how Quantum Information Theory, and in particular the theory of entanglement, provides us with a comprehensive perspective on these systems, which reconciles their global entanglement with the locality inherent to the physical laws, using the language of tensor networks. I will discuss how this allows us to obtain a full picture of how symmetries and entanglement interplay, and how it provides us both with a mathematical framework to analytically study exotic topologically ordered quantum systems, and with a wide range of numerical tools which allow to probe their unconventional physics at a microscopic level.

QI 12.3 Fri 11:45 H3

Benchmarking an efficient approximate method for localized 1D Fermi-Hubbard systems on a quantum simulator — •Bharath Hebbe Madhusudhana[1,2], Sebastian Scherg[1,2], Thomas Kohlert[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]Fakultat fur Physik, LMU Munich, Germany — [2]Max-Planck-Institut fur Quantenoptik, Garching, Germany

Understanding the applications of NISQ-era quantum devices is a topical problem. While state-of-the art neutral atom quantum simulators have made remarkable progress in studying many-body dynamics, they are noisy and limited in the variability of initial state and the observables that can be measured. Here we show that despite these limitations, quantum simulators can be used to develop new numerical techniques to solve for the dynamics of many-body systems in regimes that are practically inaccessible to established numerical techniques [1]. Considering localized 1D Fermi-Hubbard systems, we use an approximation ansatz to develop a new numerical method that facilitates efficient classical simulations in such regimes. Since this new method does not have an error estimate and is not valid in general, we use a neutral-atom Fermi-Hubbard quantum simulator with L_exp = 290 lattice sites to benchmark its performance in terms of accuracy and convergence for evolution times up to 700 tunnelling times. We then use this method to make a prediction of the behaviour of interacting dynamics for spin imbalanced Fermi-Hubbard systems, and show that it is in quantitative agreement with experimental results.

[1.] Bharath Hebbe Madhusudhana et. al. arXiv:2105.06372

QI 12.4 Fri 12:00 H3

Randomizing multi-product formulas for improved Hamiltonian simulation — •Paul K. Fährmann[1], Mark Steudtner[1], Richard Küng[2], Mária Kieferová[3], and Jens Eisert[1,4] — [1]Freie Universität Berlin — [2]Johannes Kepler Universität Linz — [3]University of Technology Sydney — [4]Helmholtz-Zentrum Berlin

Quantum simulation suggests a path forward for the efficient simulation of problems in condensed-matter physics, quantum chemistry and materials science. While most quantum simulation algorithms are deterministic, a recent surge of ideas has shown that randomization can greatly benefit algorithmic performance. This work introduces a scheme for quantum simulation uniting the advantages of randomized compiling on the one hand and higher-order multi-product formulas as they are used for example in linear-combination-of-unitaries (LCU) algorithms on the other hand. In doing so, we propose a framework of randomized sampling that is expected to be useful for programmable quantum simulators and present two new multi-product formula algorithms tailored to it. Our framework greatly reduces the circuit depth, circumventing the need for oblivious amplitude amplification required for standard LCU methods, rendering it especially useful for near-term quantum computing. Our algorithms achieve a simulation error that shrinks exponentially with the circuit depth. We prove rigorous performance bounds and concentration of the randomized sampling procedure. Furthermore, we demonstrate the functioning for several physically meaningful examples of Hamiltonians for which the method provides a favorable scaling in the effort.

QI 12.5 Fri 12:15 H3

Distributed Multipartite Entanglement Generation in Coupled Cavities — •Marc Bostelmann, Frederik Lohof, and Christopher Gies — Institute for Theoretical Physics, University of Bremen, Germany

Generation of spatially distributed entanglement is important for the realization of quantum information protocols and quantum computing. Coupled cavities offer a platform to create this kind of entanglement between spatially separated qubits [1]. By carefully tailoring excitations with external light pulses we theoretically examine the generation of entangled states, such as GHZ or Dicke states. Starting with a system of two qubits for generating bipartite entanglement, we extend the discussion to the multipartite case, exploiting symmetries of the system. Bridging the gap to experimental realizations, we study robustness of the generated entangled states to dissipation and asymmetry in the system. [1] Aron et al., PRA, 90, 062305 (2014).

QI 12.6 Fri 12:30 H3

From non-Hermitian linear response to dynamical correlations and fluctuation–dissipation relations in quantum many-body systems — •Kevin T. Geier[1,2] and Philipp Hauke[1] — [1]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, 38123 Povo, Italy — [2]Institute for Theoretical Physics, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

Dynamical correlations encode a plethora of fundamental properties in quantum many-body systems. An outstanding role is played by the fluctuation–dissipation relation (FDR), which connects the intrinsic fluctuations of a system in thermal equilibrium across the entire frequency spectrum with the energy dissipated in response to a perturbation. Out of equilibrium, independent measurements of both sides of the FDR could serve as an unbiased probe of thermalization in closed quantum systems. Yet, while the dissipation side is commonly probed in linear response experiments, it is by far more challenging to access the fluctuation side experimentally. Here, we show that the linear response to a non-Hermitian perturbation can be used to measure unequal-time anti-commutators, giving direct access to the fluctuation side of the FDR [1]. We present specific protocols to realize the required non-Hermitian dynamics in cold-atom systems, which we illustrate through numerical simulations of a Bose–Hubbard system. Our framework provides a general and flexible way to characterize dynamical correlations in strongly correlated matter on a variety of platforms. [1] K. T. Geier and P. Hauke, arXiv:2104.03983 [cond-mat.quant-gas].

QI 13: Quantum Information and Foundations II

Time: Friday 10:45–12:30 Location: H4

QI 13.1 Fri 10:45 H4

Genuine multipartite entanglement is not a precondition for secure conference key agreement — •Giacomo Carrara, Dagmar Bruss, Hermann Kampermann, and Gláucia Murta — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Entanglement plays a crucial role in the security of quantum key distribution. A secret key can only be obtained by two parties if there exists a corresponding entanglement-based description of the protocol in which entanglement is witnessed, as shown by Curty et al (2004). Here we investigate the role of entanglement for the generalization of quantum key distribution to the multipartite scenario, namely conference key agreement. In particular, we ask whether the strongest form of multipartite entanglement, namely genuine multipartite entanglement, is necessary to establish a conference key. We show that, surprisingly, a non-zero conference key can be obtained even if the parties share biseparable states in each round of the protocol. Moreover we relate conference key agreement with entanglement witnesses and show that a non-zero conference key can be interpreted as a non-linear entanglement witness that detects a class of states which cannot be detected by usual linear entanglement witnesses.

QI 13.2 Fri 11:00 H4

An algorithm for maximizing the geometric measure of entanglement — •Jonathan Steinberg and Otfried Gühne — Universität Siegen, Siegen, Deutschland

The characterization of multipartite entanglement is an important subject in order to make quantum advantages accessible for applications. One proper multipartite entanglement measure, i.e., a measure that does not rely on averages of bipartite entanglement, is the geometric measure. In this work we propose an algorithm which aims to find maximally entangled states with respect to the geometric measure. As it turns out, the algorithm's update rule constitutes a gradient descent, providing fast convergences and applicability to large systems. Surprisingly, we find that the maximally entangled states for a n-partite qudit system is in the case of existence always given by an AME(n,d) state, except for n=3, where the w-state maximizes the measure. However, for those cases where AME states do not exist, we present a family of states, called maximally marginal symmetric, that maximizes the geometric measure. Further we discuss how the algorithm could be utilized to find new AME states as AME(8,4).

QI 13.3 Fri 11:15 H4

Quantum correlations in time — •Tian Zhang[1], Oscar Dahlsten[1,2], and Vlatko Vedral[1,3,4] — [1]Clarendon Laboratory, University of Oxford, Oxford OX13PU, UK — [2]Institute for Quantum Science and Engineering, Department of Physics, Southern University of Science and Technology (SUSTech), Shenzhen 518055, China — [3]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543 — [4]Department of Physics, National University of Singapore, Singapore 117542

We investigate quantum correlations in time in different approaches. We assume that temporal correlations should be treated in an even-handed manner with spatial correlations. We compare the pseudo-density matrix formalism with several other approaches: indefinite causal structures, consistent histories, generalised quantum games, out-of-time-order correlations(OTOCs), and path integrals. We establish close relationships among these space-time approaches in non-relativistic quantum theory, resulting in a unified picture. With the exception of amplitude-weighted correlations in the path integral formalism, in a given experiment, temporal correlations in the different approaches are operationally equivalent.

QI 13.4 Fri 11:30 H4

Some quantum measurements with three outcomes can reveal nonclassicality where all two-outcome measurements fail to do so — •Hai Chau Nguyen and Otfried Gühne — Department of Physics, University of Siegen

Measurements serve as the intermediate communication layer between the quantum world and our classical perception. So, the question of which measurements efficiently extract information from quantum systems is of central interest. Using quantum steering as a nonclassical phenomenon, we show that there are instances where the results of all two-outcome measurements can be explained in a classical manner, while the results of some three-outcome measurements cannot. This points to the important role of the number of outcomes in revealing the nonclassicality hidden in a quantum system. Moreover, our methods allow us to improve the understanding of quantum correlations by delivering novel criteria for quantum steering and improved ways to construct local hidden variable models.

QI 13.5 Fri 11:45 H4

On Quantum Sets of Non-Contextuality Inequalities — •Lina Vandré[1] and Marcelo Terra Cunha[2] — [1]Universität Siegen, Germany — [2]Universidade Estadualde Campinas, Brazil

Bell inequalities and other non-contextuality (NC) inequalities are fundamental for quantum information processing. The underlying scenarios can be represented by exclusivity graphs [1]. While a Bell or NC scenario has a unique graph, the same graph can correspond to different scenarios. Originally there is no distinction between parties. In Ref. [2], the approach got modified by using coloured graphs to represent scenarios of multiple parties. In general, coloured graphs describes the underlying Bell or NC scenarios more precisely. The mathematical properties of the graph are then used for finding the classical and the quantum bound of the inequality. Also the complete set of behaviours allowed by classical probability theory as well as the quantum set can be characterised using these methods.

In this contribution I will discuss the coloured graph approach to the CHSH inequality and provide a method to characterise the corresponding quantum set. Moreover, I introduce a family of subgraphs of the CHSH graph which have the same underlying non-coloured graph (shadow) as the CHSH graph but represent different Bell or NC scenarios. I will compare the quantum sets of different graphs from this family and show how changes in the graph influence the underlying scenario and the quantum set [3].

[1] Phys. Rev. Lett. 112, 040401 (2014) [2] J. Phys. A: Math. Theor. 47, 4240214 (2014) [3] arXiv:2105.08561

QI 13.6 Fri 12:00 H4

Relative entropic uncertainty relation for scalar quantum fields — Stefan Floerchinger, Tobias Haas, and •Markus Schröfl — Institut für Theoretische Physik, Universität Heidelberg, Heidelberg, Germany

Entropic uncertainty is a well-known concept to formulate uncertainty relations for continuous variable quantum systems with finitely many degrees of freedom. Typically, the bounds of such relations scale with the number of oscillator modes, preventing a straight-forward generalization to quantum field theories. In this work, we overcome this difficulty by introducing the notion of a functional relative entropy and show that it has a meaningful field theory limit. We present the first entropic uncertainty relation for a scalar quantum field theory and exemplify its behavior by considering few particle excitations.

QI 13.7 Fri 12:15 H4

Operational Theories in Phase Space: Toy Model for the Harmonic Oscillator — •Martin Plávala and Matthias Kleinmann — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, 57068 Siegen, Germany

We construct a toy model for the harmonic oscillator that is neither classical nor quantum. The model features a discrete energy spectrum, a ground state with sharp position and momentum, an eigenstate with non-positive Wigner function as well as a state that has tunneling properties. The underlying formalism exploits that the Wigner–Weyl approach to quantum theory and the Hamilton formalism in classical theory can be formulated in the same operational language, which we then use to construct toy model with well-defined phase space. The toy model demonstrates that operational theories are a viable alternative to operator-based approaches for building physical theories.

QI 14: Quantum Computing in Industry

Time: Friday 14:00–15:30 Location: H3

Invited Talk QI 14.1 Fri 14:00 H3

Quantum computing: scaling from university lab to industry — •Jan Goetz and IQM Team — IQM Quantum Computers

Quantum computing has made its way from purely theoretical concepts in the 1980s through scientific breakthroughs in academia to full industrial efforts nowadays. A typical path, especially in Europe where large tech corporates like in the US or China are missing, is to create university spinouts to commercialize the technology. In this talk, I will discuss the question of what is necessary to create such deep tech companies out of academia on the example of IQM. I will introduce the European strategy for quantum computing which highlights the concept of quantum accelerators, where quantum computers are connected to supercomputing infrastructure. In addition, I will introduce concepts on how industry can be engaged even though commercial quantum advantage has still not been reached.

Invited Talk QI 14.2 Fri 14:30 H3

Gate Based Quantum Computing at Volkswagen — •Martin Leib — Data:Lab Volkswagen AG, Munich, Germany

In this talk I will be presenting a compilation of recent projects on the application of and research in gate based quantum computing at Volkswagen Data:Lab.

First, I'll be presenting our newest results concerning our Quantum Optimisation framework where we show how to get rid of the outer learning loop of the Quantum Approximate Optimisation Algorithm (QAOA) as well as a flexible method to investigate analytically the performance of QAOA. All this is presented with an optimisation example from VW's production lines.

Second, I'll be providing first results on an adaption of the QAOA to the realm of quantum machine learning, specifically generative learning.

Invited Talk QI 14.3 Fri 15:00 H3

TBA — •Sarah Sheldon — IBM Quantum, Almaden Research Center, San Jose, CA 95120, USA

TBA