Quantum Information Division
Fachverband Quanteninformation (QI)

Otfried Gühne
Universität Siegen
Walter-Flex-Str. 3
57068 Siegen
otfried.guehne@uni-siegen.de

Guido Burkard
Universität Konstanz
Universitätsstraße 10
78464 Konstanz
guido.burkard@uni-konstanz.de

Overview of Invited Talks and Sessions

(Lecture halls H8 and H9; Poster P2)

Invited Talks

QI 1.1	Mon	9:30–10:00	H8	**Coherence of spin qubits in planar germanium** — •Nico Willem Hendrickx
QI 2.1	Mon	9:30–10:00	H9	**Measuring the thermodynamic cost of timekeeping** — •Yelena Guryanova
QI 2.6	Mon	11:15–11:45	H9	**Finite-size effects in quantum thermodynamics** — •Kamil Korzekwa
QI 3.1	Mon	15:00–15:30	H8	**Generalized randomized benchmarking with short random quantum circuits** — Markus Heinrich, •Martin Kliesch, Ingor Roth
QI 5.1	Tue	9:30–10:00	H8	**Towards universal quantum computation and simulation with NV centre in diamond** — •Vadim Vorobyov
QI 6.1	Tue	9:30–10:00	H9	**Towards an Artificial Muse for new Ideas in Quantum Physics** — •Mario Krenn
QI 8.1	Wed	15:00–15:30	H9	**Exploring Quantum Materials with Quantum Sensors** — •Uri Vool
QI 10.1	Thu	9:30–10:00	H9	**Entanglement Transition in the Projective Transverse Field Ising Model** — •Hans Peter Büchler
QI 13.1	Fri	9:30–10:00	H8	**Scalable control of superconducting qubits** — •Stefan Filipp
QI 14.1	Fri	9:30–10:00	H9	**Testing quantum theory with generalized noncontextuality** — •Markus P. Müller, Andrew J. P. Garner

Invited Talks of the joint Symposium Entanglement Distribution in Quantum Networks (SYED)

See SYED for the full program of the symposium.

SYED 1.1	Wed	9:30–10:00	H1	**A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson
SYED 1.2	Wed	10:00–10:30	H1	**Quantum key distribution with highly entangled photons from GaAs quantum dots** — •Armando Rastelli, Santanu Manna, Saimon Covre da Silva, Gabriel Undeutsch, Christian Schimpf
SYED 1.3	Wed	10:30–11:00	H1	**Entanglement distribution with minimal memory requirements using time-bin photonic qudits** — •Johannes Borregaard
SYED 1.4	Wed	11:15–11:45	H1	**Quantum photonics: interference beyond HOM and quantum networks** — •Stefanie Barz
SYED 1.5	Wed	11:45–12:15	H1	**Photonic cluster-state generation for memory-free quantum repeaters** — •Tobias Huber

Sessions

QI 1.1–1.11	Mon	9:30–12:45	H8	**Implementations: Spin Qubits, Atoms, and Photons**
QI 2.1–2.10	Mon	9:30–12:45	H9	**Quantum Thermodynamics and Open Quantum Systems**
QI 3.1–3.10	Mon	15:00–18:00	H8	**Certification and Benchmarking of Quantum Systems**
QI 4.1–4.41	Mon	18:00–20:00	P2	**Poster: Quantum Information**
QI 5.1–5.9	Tue	9:30–12:15	H8	**Implementations: Solid state systems**
QI 6.1–6.11	Tue	9:30–12:45	H9	**Quantum Information: Concepts and Methods**
QI 7.1–7.10	Wed	15:00–17:45	H8	**Quantum Communication and Networks**
QI 8.1–8.9	Wed	15:00–17:45	H9	**Quantum Sensors and Metrology**

QI 9.1–9.10	Thu	9:30–12:15	H8	**Quantum Correlations**
QI 10.1–10.9	Thu	9:30–12:15	H9	**Quantum Simulation and Many-Body Systems**
QI 11	Thu	14:00–15:00	H8	**Members' Assembly**
QI 12.1–12.12	Thu	15:00–18:15	H8	**Quantum Computing and Algorithms**
QI 13.1–13.11	Fri	9:30–12:45	H8	**Implementations: Superconducting Qubits**
QI 14.1–14.10	Fri	9:30–12:30	H9	**Quantum Foundations**

Members' Assembly of the Quantum Information Division

Donnerstag, 8. September 2022 14:00–15:00 H8

More information will be sent to the members of the division by e-mail.

QI 1: Implementations: Spin Qubits, Atoms, and Photons

Time: Monday 9:30–12:45 Location: H8

Invited Talk QI 1.1 Mon 9:30 H8

Coherence of spin qubits in planar germanium — •Nico Willem Hendrickx — IBM Research Zurich, Switzerland

The prospect of building quantum circuits using advanced semiconductor manufacturing techniques position quantum dots as an attractive platform for quantum information processing. Initial demonstrations of one and two-qubit logic have been performed in gallium arsenide and later silicon. However, until recently, interconnecting larger spin qubit systems has remained a challenge.

Over the past years, hole states in strained germanium quantum wells have emerged as a host for spin qubits. These states have favourable properties for defining extended spin qubit arrays. The small effective mass relaxes constraints on lithography, the low degree of disorder enables reproducible quantum dots, the lack of a valley degeneracy ensures an well-defined qubit state and the strong spin-orbit coupling allows for local and electrical qubit control.

Over the past years, this platform has rapidly evolved from materials growth to supporting multi-qubit logic. I will first give an overview of the development of this system, starting from material growth to recent results on operating a highly-connected two-dimensional qubit array. Next, we will discuss the impact of noise on the qubit coherence, as well as strategies to mitigate this. We study the magnetic field dependence of various qubit properties in order to find sweet spots for operation. Finally, we will discuss strategies, challenges, and opportunities in scaling these systems up as a step towards the realisation of scalable qubit tiles for fault-tolerant quantum processors.

QI 1.2 Mon 10:00 H8

Spin relaxation times of single-electrons in bilayer graphene quantum dots — •Katrin Hecker[1,2], Luca Banszerus[1,2], Samuel Möller[1,2], Eike Icking[1,2], Kenji Watanabe[3], Takashi Taniguchi[3], Christian Volk[1,2], and Christoph Stampfer[1,2] — [1]2nd Institute of Physics, RWTH Aachen University, Germany — [2]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Germany — [3]National Institute for Materials Science, Japan

Thanks to its weak spin-orbit coupling and low nuclear spin density, bilayer graphene (BLG) promises long spin relaxation and coherence times, making this material a potentially interesting platform for spin based solid state quantum computation. Although the electrostatic confinement of single electrons in BLG quantum dot (QD) devices has been demonstrated, and their single particle spectrum has been studied in detail [1], their relaxation dynamics remain so far mostly unexplored [2]. Here, we report on measurements of the spin relaxation times (T1) of single-electron spin states in a BLG QD. Using pulsed gate spectroscopy, we extract T1 times exceeding 0.2ms at out-of-plane magnetic fields below 2T. The measured values for T1 show a strong dependence on the spin splitting and increase by about two orders of magnitude when decreasing the magnetic field from 2-3T, suggesting that T1 could be significantly larger at low magnetic fields [3].

[1] A. Kurzmann et al., Phys. Rev. Lett. 123, 026803 (2019).
[2] L. Banszerus et al., Phys. Rev. B 103, L081404 (2021).
[3] L. Banszerus et al., arXiv 2110.13051 (2021).

QI 1.3 Mon 10:15 H8

Microwave spectroscopy of rare earth spin ensembles at zero magnetic field — •Ana Strinic[1,2], Kirill G. Fedorov[1,2], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik-Department, Technische Universität München, Garching, Germany — [3]Munich Center for Quantum Science and Technologies, Munich, Germany

Operating at microwave frequencies and in the absence of external magnetic fields, superconducting circuits show exceptional potential for the development of quantum processors. Realizing a quantum memory, which operates in the microwave regime and in the vicinity of zero magnetic field, would allow for a direct interface to such quantum processors. In this regard, rare earth doped crystals are highly attractive, as they exhibit long optical and spin coherence times and possess transitions in the microwave frequency range [1,2]. In order to identify transitions, which form a suitable quantum memory scheme, we have performed microwave spectroscopy on a $^{167}Er{:}^{7}LiYF_4$ crystal in a magnetically shielded environment. The experimental findings of the spectroscopy study are then compared to simulations of the spin Hamiltonian. [1] N. Kukharchyk et al. New J. Phys. **20**, 023044 (2018) [2] J.V. Rakonjac et al. Phys. Rev. B **101**, 184430 (2020)

QI 1.4 Mon 10:30 H8

Nuclear Spin Quantum Memory in Silicon Carbide — •Benedikt Tissot[1], Michael Trupke[2,3], Philipp Koller[2], Thomas Astner[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria — [3]Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria

Transition metal (TM) defects in silicon carbide (SiC) are a promising platform for applications in quantum technology. Some TM defects, e.g. vanadium, emit in one of the telecom bands, but the large ground state hyperfine manifold poses a problem for applications which require pure quantum states. We develop a driven, dissipative protocol to polarize the nuclear spin, based on a rigorous theoretical model of the defect. We further show that nuclear-spin polarization enables the use of well-known methods for initialization and long-time coherent storage of quantum states. The proposed nuclear-spin preparation protocol thus marks the first step towards an all-optically controlled integrated platform for quantum technology with TM defects in SiC.

QI 1.5 Mon 10:45 H8

Cavity-mediated quantum gates between driven remote spin qubits — •Florian Kayatz, Jonas Mielke, and Guido Burkard — University of Konstanz, Konstanz D-78457, Germany

The implementation of two-qubit gates between distant qubits is of fundamental importance for quantum computing architectures involving many qubits. Considering cold ions confined in a linear trap, the Cirac-Zoller gate (CZ-gate) [1,2] constitutes such a two-qubit gate by exploiting the coupling of the ions through the collective quantized ion motion.

Here, we theoretically demonstrate a CZ-like gate between two spin qubits realized in gate defined semiconductor double quantum dots. In the envisioned system both spin qubits are coupled to a microwave resonator mode that has a similar function as the collective ion motion in the original CZ-gate. Recently, strong spin-photon coupling has been demonstrated [3] and, thus, allows for coherent population exchange between the spin qubit and the resonator mode. Thereby, two of the three main steps in the CZ-gate protocol can be realized. We describe in detail how the remaining step that requires the generation of a phase depending on the state of the second qubit and the resonator photon number can be implemented by driving the second DQD-system.

[1] Cirac, J. I. and Zoller, P., PRL **74**, 4091 (1995)
[2] Schmidt-Kaler et al., Nature **422**, 408-411 (2003)
[3] Mi et al., Nature **555**, 7698 (2018)

15 min. break

QI 1.6 Mon 11:15 H8

Coherence improvements at a higher-order sweet spot in double quantum dots — •Morten I. K. Munk[1,2], Martin Leijnse[1], and Peter Samuelsson[2] — [1]NanoLund and Division of Solid State Physics, Lund University, Lund, Sweden — [2]NanoLund and Division of Mathematical Physics, Lund University, Lund, Sweden

One of the main limiting factors for designing a useful qubit is its dephasing time. In order to improve this, qubits are often operated at optimal points, or so-called "sweet spots", but in recent years, several systems have been proposed which can be tuned to higher-order sweet spots. These qubits often fail in practice, due for example to coupling to leakage states or a lack of protection against other relevant noise sources. In this work we propose a straightforward way of achieving a third-order sweet spot in a double quantum dot with two electrons in the singlet sector. This experimentally feasible qubit has the combined advantages of being operated at strong tunneling strengths, where leakage states are well separated from the qubit states, as well as being possible to construct in a way in which there are no relevant unprotected noise channels. We investigate the decoherence rate due to pure dephasing for a broad range of system parameters and for different noise spectral densities. It is found, in general, that higher-order sweet spots allow for substantially increased dephasing times, suggesting a guiding principle in optimizing the coherence properties of charge qubits in double quantum dots and related systems.

QI 1.7 Mon 11:30 H8

Quantum-optical Characterization of Single-photon Sources based on Chlorine-doped ZnSe/ZnMgSe Nanopillars — •Christine Falter, Yurii Kutovyi, Nils von den Driesch, Thorsten Brazda, Detlev Grützmacher, and Alexander Pawlis — Peter Grünberg Institute PGI-9, Forschungszentrum Jülich GmbH

The realization of optical quantum computers and secure quantum communication networks requires the development of efficient and scalable sources of single, indistinguishable photons that can be integrated onto photonic chips. Here we report on a novel type of single-photon source (SPS) device based on individual Cl donors in ZnSe/ZnMgSe quantum well nanopillars. On top of each nanopillar a solid immersion lens is fabricated, employing the photoresist previously used to define the nanopillars. For optimized conditions the external quantum efficiency is increased by up to one order of magnitude. Excitation-power-dependent photoluminescence measurements confirm that the emission stems from a true two-level system and the single photon purity of the source is verified by measuring the second order correlation function. Finally, we investigate the grade of sequential indistinguishability of subsequent single-photons from our devices by Hong-Ou-Mandel type experiments. This work paves the way for efficient generation of polarization entanglement between two sufficiently indistinguishable photons. Consequently, future applications of these SPSs are envisioned in all-optical based quantum cryptography or to interconnect distant nodes in quantum networks.

QI 1.8 Mon 11:45 H8

A Reversible Classical Half-Adder Implemented with Trapped Ion Qubits — •Patrick Huber[1], Sagar Pratapsi[2,3], Patrick Barthel[1], Sougato Bose[4,5], Yasser Omar[2,3,6], and Christof Wunderlich[1] — [1]Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Germany — [2]Physics of Information and Quantum Technologies Group, Instituto de Telecomunicações, Portugal — [3]Instituto Superior Técnico, U. Lisbon, Portugal — [4]Department of Physics and Astronomy, University College London, London WC1E 6BT, UK — [5]Department of Electronic & Electrical Engineering, University College London, WC1E 7JE London, UK — [6]Portuguese Quantum Institute, Portugal

We experimentally realise a Toffoli gate and a Half-Adder circuit suitable for classical computation, using qubits encoded into trapped $^{171}\mathrm{Yb}^{+}$ ions. The microwave-controlled qubits are coupled by an all-to-all $\sigma_z\sigma_z$ interaction. A comprehensive analysis is given of the energy required to operate the gates, both from first principles and by experimental measurements. This allows for identifying decisive improvements that could lead to energetically efficient classical computation. Our analysis indicates that a novel planar ion trap-setup will already be 10^5 times more efficient.

QI 1.9 Mon 12:00 H8

Improving quantum state detection with adaptive sequential observations — Shawn Geller[1,2], Daniel Cole[1], Scott Glancy[1,2], and •Emanuel Knill[1,2] — [1]National Institute of Standards and Technology, Boulder, CO, USA — [2]University of Colorado at Boulder, Boulder, CO USA

For many quantum systems intended for information processing, one detects the logical state of a qubit by integrating a continuously observed quantity over time. For example, ion and atom qubits are typically measured by driving a cycling transition and counting the number of photons observed from the resulting fluorescence. Instead of recording only the total observed count in a fixed time interval, one can observe the photon arrival times and get a state detection advantage by using the temporal structure in a model such as a Hidden Markov Model. We study what further advantage may be achieved by applying pulses to adaptively transform the state during the observation. We give a three-state example where adaptively chosen transformations yield a clear advantage, and we compare performances on an ion example, where we see improvements in some regimes.

QI 1.10 Mon 12:15 H8

Quantum Information Transfer in a Chain of Trapped Ions — •Theeraphot Sriarunothai, Patrick Barthel, Patrick Huber, Gouri S. Giri, and Christof Wunderlich — Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Germany

We explore a quantum teleportation scheme with four trapped $^{171}\mathrm{Yb}^{+}$ ions in a non-segmented linear Paul trap, each radiofrequency-controlled ion representing one qubit. The $\sigma_z\sigma_z$ interaction between qubits is mediated by Magnetic Gradient Induced Coupling (MAGIC) [1]. The 4×4 interaction matrix of the qubit-system is measured and, taking advantage of all-to-all connectivity, is used to create Bell states between pairs of nearest neighbours and second-nearest neighbours, respectively. Furthermore, it is demonstrated how, while creating an entangled pair, another qubit serves as a decoupled quantum memory. This memory qubit is protected from decoherence with the same dynamical decoupling sequence as the one applied to perform the Bell-state operations. We developed and implemented a blueprint to demonstrate quantum state transfer using a quantum teleportation scheme. First experimental results on teleportation indicate the transfer of a superposition state from one end to another end of a quantum register. The method and techniques developed here can be applied to a larger system, for example, a full quantum byte or across quantum registers.

[1] Ch. Piltz et al., Science Advances **2**, e1600093 (2016).

QI 1.11 Mon 12:30 H8

Dressed $^{171}\mathrm{Yb}^{+}$ Hyperfine Qubits in a Multi-layer Planar Ion Trap — •Elham Esteki[1], Bogdan Okhrimenko[1], Friederike Giebel[2,3,4], Eike Iseke[2,3,4], Konstantin Thronberens[3,4], Nila Krishnakumar[2,4], Jacob Stupp[2,3], Amado Bautista Salvador[2,3,4], Christian Ospelkaus[2,3,4], Ivan Boldin[1], and Christof Wunderlich[1] — [1]Dept. Physik, Nat.-Techn. Fak., Universität Siegen, 57068 Siegen — [2]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [3]Laboratory for Nano - and Quantum Engineering, Schneiderberg 39, 30167 Hannover — [4]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Dressed qubit states – the eigenstates of the Hamiltonian of a qubit subject to a near-resonant driving field – can be used to store and process quantum information instead of bare state qubits. We present a microfabricated ion trap chip, designed for the realization of quantum information processing based on radiofrequency-dressed qubits using hyperfine states of $^{171}\mathrm{Yb}^{+}$ ions [1]. The ion trap chip consists of multiple layers [2], one of which includes an integrated microwave resonator. It creates a gradient of the microwave magnetic field amplitude which is needed for the realization of qubit addressing and qubit-qubit coupling. We experimentally characterize this novel ion trap chip and demonstrate preparation and detection of RF-dressed qubits, as well as single-qubit- and two-qubit operations.

[1] S. Wölk, Ch. Wunderlich, New J.Phys. **19**, 083021 (2017).
[2] A. Bautista-Salvador et al., New J. Phys. **21**, 043011 (2019).

QI 2: Quantum Thermodynamics and Open Quantum Systems

Time: Monday 9:30–12:45 Location: H9

Invited Talk QI 2.1 Mon 9:30 H9

Measuring the thermodynamic cost of timekeeping — •Yelena Guryanova — Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria

All clocks, in some form or another, use the evolution towards higher entropy states to quantify the passage of time. Because of the statistical nature of the second law and corresponding entropy flows, fluctuations fundamentally limit the performance of any clock. This suggests a deep relation between the increase in entropy and the quality of clock ticks. Indeed, minimal models for autonomous clocks in the quantum realm revealed that a linear relation can be derived, where for a limited regime entropy linearly increases with the accuracy. Does a linear relation persist as we move toward a more classical system? We answer this in the affirmative by presenting the first experimental investigation of this thermodynamic relation in a nanoscale clock. We stochastically drive a nanometer-thick membrane and read out its displacement with a radio-frequency cavity, allowing us to identify the ticks. We show theoretically that the maximum possible accuracy for this classical clock is proportional to the entropy created per tick, similar to the known limit for a weakly coupled quantum clock but with a different proportionality constant. We measure both the accuracy and the entropy. Once non-thermal noise is accounted for, we find that there is also a linear relation between accuracy and entropy.

QI 2.2 Mon 10:00 H9

Thermodynamics of Permutation-Invariant Quantum Many-Body Systems: A Group-Theoretical Framework — •Benjamin Yadin[1], Benjamin Morris[2,3], and Kay Brandner[2,3] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, United Kingdom — [3]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham NG7 2RD, United Kingdom

Classical thermodynamics originally described ensembles of many particles controlled collectively without addressing individual particles. However, quantum phenomena such as entanglement may lead to very different collective behaviour. We study non-identical particles that interact identically with their environment and control systems. Such collective dynamics are generally generated by a Hamiltonian invariant under particle permutations.

We develop a general framework for such systems, finding a quantum state space containing additional non-classical degrees of freedom. While the permutation symmetry prevents full thermalisation, we prove that a sufficiently complex bath interaction enables maximum possible thermalisation. For systems initialised out of equilibrium with the bath, we calculate steady-state properties and determine the performance of a heat engine model. Compared with previous models using SU(2) spin interactions, we show that SU(d)-based couplings for d-dimensional particles can lead to thermodynamical advantages.

QI 2.3 Mon 10:15 H9

Geometric structure of thermal cones — •Alexssandre de Oliveira Junior, Jakub Czarkowski, Karol Zyczkowski, and Kamil Korzekwa — Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-348 Kraków, Poland.

The second law of thermodynamics imposes a fundamental asymmetry in the flow of events. The so-called thermodynamic arrow of time introduces an ordering on the space of states that can be distinguished according to the system's evolution as past, incomparable, and future thermal cones. In this work, we analyse the structure of the thermodynamic arrow of time within a resource-theoretic framework, where one investigates the accessibility of quantum state transformations under thermodynamic constraints. Specifically, for a d-dimensional classical state interacting with a heat bath at a fixed temperature T, we found the necessary and sufficient conditions to construct its incomparable and past thermal cones. By introducing a new thermodynamic monotone, the volume of the future thermal cone, we provide a detailed analysis of the behaviour of the thermal cones. In a general context, while the future thermal cone can be seen as a generalisation of the Hardy-Littlewood-Polya theorem, the past and incomparable region can be interpreted as its extensions. Moreover, our results also apply to other majorisation-based resource theories, such as entanglement, since in the limit of infinite temperature, the partial order that emerges is the same (precisely: the opposite) as defined on the set of bipartite pure entangled states by local operations and classical communication

QI 2.4 Mon 10:30 H9

Continuous measurement feedback for adaptive qubit thermometry — •Julia Boeyens and Stefan Nimmrichter — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Siegen 57068, Germany

Bayesian estimation was recently applied to quantum thermometry since it allows for better estimation accuracy when data is limited and admits adaptive estimation schemes. Here, we apply the Bayesian framework to the setting of continuous temperature measurement. We model a qubit probe, subject to continuous monitoring interacting with a bosonic bath of unknown temperature. The Kushner-Stratonovich equation from classical filtering theory is simulated to find the posterior distribution. Bayesian estimation is then used to infer the temperature from this probability distribution using. This is compared to the discrete analogue, collisional thermometry . An adaptive strategy for improved accuracy is described where Hamiltonian parameters of the qubit can be changed continuously by measurement feedback.

QI 2.5 Mon 10:45 H9

Quantum trajectories beyond weak coupling — •Brecht Donvil[1] and Paolo Muratore Ginanneschi[2] — [1]Institute for Complex Quantum Systems, Albert-Einstein-Allee 11, D-89069, Ulm — [2]University of Helsinki, Department of Mathematics and Statistics P.O. Box 68 FIN-00014, Helsinki, Finland

Master equations are one of the main avenues to study open quantum systems. In situations where the interaction between a dedicated system and its environment is weak, the master equation is of the Lindblad form. In this case, the solution of the master equation can be "unraveled in quantum trajectories" i.e. represented as an average over the realizations of a Markov process in the Hilbert space of the system. Quantum trajectories of this type are both an element of quantum measurement theory as well as a numerical tool for systems in large Hilbert spaces.

In this talk, I show that I show how this procedure can be generalized to arbitrary trace-preserving master equations with time-local dissipation rates. In contrast to the conventional setting, these rates can take also negative values, thus mimicking back-flow of information. Such master equations typically arrive from exactly solvable models or time convoluntionless perturbation theory. The crucial ingredient for our unraveling is to weigh averages by a probability pseudo-measure which we call the "influence martingale". The influence martingale satisfies a $1d$ stochastic differential equation enslaved to the ones governing the quantum trajectories. The influence martingale thus extends the existing theory without increasing the computational complexity.

15 min. break

Invited Talk QI 2.6 Mon 11:15 H9

Finite-size effects in quantum thermodynamics — •Kamil Korzekwa — Jagiellonian University, Kraków, Poland

The necessity to go beyond classical thermodynamics is usually motivated by the fact that at the nanoscale quantum effects, like coherence and entanglement, start playing an important role. However, in the quantum regime one also deals with systems composed of a finite number n of particles, whereas the theory of thermodynamics is traditionally constrained to the study of macroscopic systems with $n \to \infty$, whose energy fluctuations are negligible compared to their average energy. In this talk I will address this problem and describe recent developments allowing one to go beyond the thermodynamic limit and rigorously investigate thermodynamic transformations of finite-size systems. I will explain why such transformations are generally irreversible and consume free energy, and how this affects the performance of thermodynamic protocols. A new version of the famous fluctuation-dissipation theorem will also be presented, linking the minimal amount of free energy dissipated in the process to the amount of free energy fluctuations present in the initial state of the system.

Moreover, I will discuss a novel resource resonance phenomenon, which allows one to significantly reduce dissipation for transformations between states whose fluctuations are properly tuned. Finally, I will also explain how quantum coherence may bring states closer to resonance effectively decreasing the dissipation of free energy.

QI 2.7 Mon 11:45 H9

Work fluctuations and entanglement in quantum batteries — •Satoya Imai, Otfried Gühne, and Stefan Nimmrichter — Universität Siegen Department Physik Emmy-Noether-Campus Walter-Flex-Straße 3 57068 Siegen Germany

We consider quantum batteries given by composite interacting quantum systems in terms of the thermodynamic work cost of local random unitary processes. We characterize quantum correlations by monitoring the average energy change and its fluctuations in the high-dimensional bipartite systems. We derive a hierarchy of bounds on high-dimensional entanglement (the so-called Schmidt number) from the work fluctuations and thereby show that larger work fluctuations can verify the presence of stronger entanglement in the system. Finally, we develop two-point measurement protocols with noisy detectors that can estimate work fluctuations, showing that the dimensionality of entanglement can be probed in this manner.

QI 2.8 Mon 12:00 H9

Large fluctuations of qubit decoherence under $1/f$ noise of a sparse bath of two-level fluctuators — •Mohammad Mehmandoost and Viatcheslav Dobrovitski — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands

We theoretically study the qubit decoherence caused by $1/f$ noise of a sparse bath of Two-Level Fluctuators (TLFs) in the Ramsey and Hahn echo experiments. We focus on the role of bath density d, defined as the ratio of the number of TLFs n to the logarithmic frequency range $\ln(\gamma_M/\gamma_m)$, on the qubit decoherence. The first spectral density of $1/f$ noise produced by sparse bath samples, small d, are roughly similar. The qubit decoherence in this regime is, however, not fully characterized by the noise first spectral density. We therefore use the exact expressions describing the qubit decoherence coupled to a sample TLF bath. Using Monte Carlo simulations, we show that the qubit decoherence is subject to large sample-to-sample fluctuations in sparse baths of fixed density d. This highlights the necessity to adopt a statistical approach to characterize the qubit decoherence in this regime. We also found that the qubit decoherence under $1/f$ noise of sparse TLF baths is governed by only a few TLFs. We show that if these TLFs are removed, the coherence times are substantially improved. We hope the latter finding opens up a way to improve the coherence times of the state-of-the-art qubits affected by $1/f$ noise.

QI 2.9 Mon 12:15 H9

Entanglement Preservation in Open Quantum System — •Mei Yu, Stefan Nimmrichter, and Otfried Gühne — Universität Siegen, Siegen, Germany

It's widely known that the entanglement will decay when system is exposed to the environment. In this paper, we study how to keep the entanglement against destructive effect from environment at different temperatures. Within the spin gases model, we firstly investigate the entangling ability of two-qubit gate in Markovian and non-Markovian dephasing environment. Then, we implement the specific reset operation on two-qubit system at stochastic times in order to keep entanglement in steady state. The steady-state entanglement behavior is analysed in both cases of Markvovian and non-Markovian dephasing noise with different temperatures. Excepting for considerable entanglement value, the difference between Markovian and non-Markovian effect can be observed directly.

QI 2.10 Mon 12:30 H9

Quantum thermodynamics of rare earth spin ensembles embedded into Y_2SiO_5 — Andreas Meyer[1,2], Rudolf Gross[1,2,3], and •Nadezhda P. Kukharchyk[1,3] — [1]Walther-Meissner-Institut, Bavarian Academy of Sciences, Garching, Germany — [2]Physics Department, Technical University of Munich, Garching, Germany — [3]Munich Center for Quantum Science and Technologies, Munich, Germany

Interest in the field of quantum thermodynamic has emerged recently supported by advances in quantum information field. While quantum systems themselves require an optimized approach for characterisation of entropy and work, also the temperature range at which such systems operate is highly sensitive to even small excitation. The rare earth spin ensembles belong to those systems, which are in the focus of quantum thermodynamics. When these ensembles are cooled down to millikelvin temperatures, even short controlling pulses result in a strong perturbation of thermal equilibrium in the host crystal, which reveals itself in the observed dynamics of the excited spin ensemble [1]. In this talk, we will discuss the dynamics of the non-equilibrium state within the Y_2SiO_5 crystal, as well as its impact on the relaxation and decoherence processes within the rare earth spin ensembles. The analytical modelling of the heat dynamics will be compared to the experimental finding of the coherence study of $^{167}Er{:}Y_2SiO_5$ at millikelvin temperatures.

1. N. Kukharchyk et al, "Enhancement of optical coherence in $^{167}Er{:}Y_2SiO_5$ crystal at millikelvin temperatures", arXiv: 1910.03096

QI 3: Certification and Benchmarking of Quantum Systems

Time: Monday 15:00–18:00 Location: H8

Invited Talk QI 3.1 Mon 15:00 H8

Generalized randomized benchmarking with short random quantum circuits — Markus Heinrich[1], •Martin Kliesch[1], and Ingor Roth[2] — [1]Heinrich Heine University Düsseldorf, Germany — [2]Technology Innovation Institute, Abu Dhabi, United Arab Emirates

The characterization of the quality of quantum gate implementations is among the most important certification tasks in the quantum sciences. State preparation and measurement errors render this task a challenge, in particular for large qubit numbers. Randomized benchmarking (RB) is among the most popular approaches to address this challenge. Rigorous theoretical guarantees for RB methods rely on sequences of unitary operations each of which is drawn uniformly from a group, often the Clifford group. Due to compiling, such RB strategies effectively require the implementation of quantum circuits with an unfavourable scaling of the circuit depth with the number of qubits. In practice, this scaling results in a restriction to a few qubits.

This talk starts with an introduction to RB, a generalized version thereof and a review of the idea of drawing the unitaries from a generating gate set of the group rather than from its uniform distribution in order to reduce the required circuit depths. Then we show analytically how this changes the exponential decay behaviour observed in RB. In particular, shorter circuits can result in decays that are a combination of the usual RB decay plus a decay corresponding to mixing properties (spectral gap of the moment operator) of the gate set. In this way, we shine new light on the important question of how quantum gates can be certified using short circuits.

QI 3.2 Mon 15:30 H8

Compressive gate set tomography — •Raphael Brieger[1], Ingo Roth[2], and Martin Kliesch[1] — [1]Quantum technology, Heinrich Heine University Düsseldorf, Germany — [2]Quantum Research Centre, Technology Innovation Institute, Abu Dhabi, UAE

Flexible characterization techniques that identify and quantify experimental imperfections under realistic assumptions are crucial for the development of quantum computers. Gate set tomography is a characterization approach that simultaneously and self-consistently extracts a tomographic description of the implementation of an entire set of quantum gates, as well as the initial state and measurement, from experimental data. Obtaining such a detailed picture of the experimental implementation is associated with high requirements on the number of sequences and their design, making gate set tomography a challenging task even for only two qubits. In this work, we show that low-rank approximations of gate sets can be obtained from significantly fewer gate sequences and that it is sufficient to draw them randomly. To this end, we formulate the data processing problem of gate set tomography as a rank-constrained tensor completion problem. We provide an algorithm to solve this problem while respecting the usual positivity and normalization constraints of quantum mechanics by using second-order geometrical optimization methods on the complex Stiefel manifold. Besides the reduction in sequences, we demonstrate numerically that the algorithm does not rely on structured gate sets or an elaborate circuit design to robustly perform gate set tomography and is therefore more broadly applicable than traditional approaches.

QI 3.3 Mon 15:45 H8

Spin squeezing inequalities meet randomized measurements — •Jan Lennart Bönsel, Satoya Imai, Ye-Chao Liu, and Otfried Gühne — University of Siegen, Siegen, Germany

Due to the recent advances in quantum control, large quantum systems containing thousands of atoms can nowadays be prepared in the lab. Here, the characterization of quantum correlations is of special interest. For systems where the individual atoms are difficult to address, the measurement of collective angular momentum observables and the evaluation of the corresponding spin squeezing inequalities are a possibility to characterize entanglement and its usefulness for metrology.

In this contribution, we first study the number of quantum state samples that are necessary to verify entanglement with a certain confidence. For this purpose, we compare different estimators of spin squeezing parameters. We characterize the probability that the estimator deviates from its mean using simulations as well as analytical bounds derived from concentration inequalities, like Cantelli's and Hoeffding's inequality. Second, we analyse if it is possible to obtain a good estimate from fewer measurements made only on a randomly chosen subset of the atoms.

QI 3.4 Mon 16:00 H8

Machine learning approaches to Optimal Gate Sequences for Quantum State Tomography under Noise — •Violeta N. Ivanova-Rohling[1,2,3], Niklas Rohling[1], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz — [2]Zukunftskolleg, University of Konstanz, D-78457 Konstanz — [3]Department of Mathematical Foundations of Computer Sciences, IMI, Bulgarian Academy of Sciences

For limited scenarios, depending on projector rank and system size, optimal measurement schemes for efficient quantum state tomography (QST) are known. In the case of errorless non-degenerate measurements, using mutually unbiased bases yields the optimal QST scheme [1]. However, in the general case, the optimal measurement scheme for efficient QST is not known and, may need to be numerically approximated. Here, we investigate the effect of noise on the optimal QST measurement sets using two noise models: the depolarizing channel, and over- and under-rotation in two-qubit gates [2]. Furthermore, we apply reinforcement learning for optimizing the effective times each quantum gate is switched on in a set of gate sequences which – combined with an elementary projective measurement – realizes a QST quorum. We extend the model by including errors from single-qubit gates and allow for longer gate sequences than necessary for realizing arbitrary measurements aiming at higher noise resilience overall.

[1] Wootters, Fields, Ann. Phys. 191, 363 (1989)
[2] Ivanova-Rohling, Rohling, Burkard, arXiv:2203.05677

QI 3.5 Mon 16:15 H8

Verifying arbitrary entangled state with homogeneous local measurements — •Ye-Chao Liu[1,2], Yinfei Li[2], Jiangwei Shang[2], and Xiangdong Zhang[2] — [1]Universität Siegen, Siegen, Germany — [2]Beijing Institute of Technology, Beijing, China

Quantum state verification is the task that uses only local measurements to judge whether one unknown state is the pure state that we desire. Recently, with the rapid growth in the size of manipulated quantum systems, such a fundamental task attracts more and more attention due to the weakness of the standard tomography method in the efficiency, and many entangled states can be verified efficiently or even optimally. However, how to design a verification protocol for an arbitrary entangled state is still an open problem. In this paper, we present a systematic framework to solve the problem by considering the locality of what we call choice-independent measurement protocols, whose operators can be achieved directly when it is homogeneous. Taking several kinds of entangled states as examples, we demonstrate the concrete processes and results of the design method under the most common Pauli projections. Moreover, our framework can tackle the local protocol design of other tasks, like entanglement witness, which is also an important problem. Finally, all these tasks can be converted into corresponding parameter estimation tasks, whose local protocols can be always easily achieved by our methods.

15 min. break

QI 3.6 Mon 16:45 H8

Dynamical Uncertainty Propagation with Noisy Quantum Parameters — •Felix Motzoi[1], Mogens Dalgaard[2], and Carrie Weidner[3] — [1]Forschungszentrum Juelich — [2]Aarhus University — [3]Bristol University

Many quantum technologies rely on high-precision dynamics, which raises the question of how these are influenced by the experimental uncertainties that are always present in real-life settings. A standard approach in the literature to assess this is Monte Carlo sampling, which suffers from two major drawbacks. First, it is computationally expensive. Second, it does not reveal the effect that each individual uncertainty parameter has on the state of the system. In this talk, we evade both these drawbacks by incorporating propagation of uncertainty directly into simulations of quantum dynamics, thereby obtaining a method that is orders of magnitude faster than Monte Carlo simulations and directly provides information on how each uncertainty parameter influences the system dynamics. Additionally, we compare our method to experimental results obtained using the IBM quantum computers.

Dalgaard et al., Phys. Rev. Lett. 128, 150503 (2022)

QI 3.7 Mon 17:00 H8

Error mitigation - handling noisy quantum hardware — •Kathrin König and Thomas Wellens — Fraunhofer IAF, Freiburg, Germany

Currently available quantum computing hardware suffers from errors due to environmental influences, nearest-neighbour interactions and imperfect gate operations. To achieve robust quantum computing, there are techniques like error mitigation by zero-noise extrapolation [1]. To reduce the impact of gate errors on observable expectation values, arbitrary noise can also be converted into stochastic Pauli errors by so called noise tailoring [2]. We elaborate on the implementation of error mitigation on a superconducting quantum computer and its impact on the computation of expectation values.

[1] He, A. et al., *Zero-noise extrapolation for quantum-gate error mitigation with identity insertions*, Phys. Rev. A 102, 012426 (2020)
[2] Wallman, J. J.; Emerson. J., *Noise tailoring for scalable quantum computation via randomized compiling*, Phys.Rev. A 94, 052325 (2016)

QI 3.8 Mon 17:15 H8

Break-even point of the quantum repetition code — Áron Rozgonyi and •Gábor Széchenyi — Eötvös University, Budapest

Repetition code is not a real quantum error correction code in the sense, that it cannot protect the logical information against any Pauli error. However, for simplicity repetition code is widely investigated theoretically and used for benchmarking state-of-the-art quantum devices. In our work, we analyze the efficiency of the phase-flip code as a quantum memory in presence of relaxation and dephasing. We take into account noisy two-qubit gates suffering from depolarizing and coherent error. We determine the parameter regime, where the repetition code performs better than an idle qubit.

QI 3.9 Mon 17:30 H8

Benchmarking quantum error correcting codes on near-term devices — •Regina Finsterhoelzl and Guido Burkard — Department of Physics, University of Konstanz

We evaluate the performance of small error-correcting codes which we implement on hardware platforms of very different connectivity and coherence: On a superconducting processor and on a spintronic quantum register consisting of a color center in diamond. Taking the hardware-specific errors and connectivity into account, we investigate the dependence of the resulting logical error rate on the platform features such as the native gates, the native connectivity, gate times, and coherence times. Using a standard error model parametrized for the given hardware, we simulate the performance and benchmark these predictions with experimental results when running the code on a real quantum device. The results indicate that for small codes, the hexagonal layout of the superconducting processor proves advantageous, yet for larger codes with multi-qubit controlled operations, the star-like connectivity of the color centers enables lower error rates.

QI 3.10 Mon 17:45 H8

Quantum Lifelong Learning — •Lukas Sigl[1,2], Tatjana

Wilk[2], Anna Donhauser[3,2], Stefan Küchemann[3,2], Bernhard Kraus[1], Jan von Delft[3,2], Jochen Kuhn[3,2], and Alexander Holleitner[1,2] — [1]TU Munich, Germany — [2]MCQST, Germany — [3]LMU Munich, Germany

Quantum technologies comprise rapidly growing scientific fields with great potential for applications in industry. The current challenge for Germany and Europe is to educate a sufficiently large number of students in quantum technologies and to transfer knowledge as well as technological expertise from the research laboratories to the industrial sector.[1] A key role is played by the specialists and executives of the high-tech industry, who have to recognize and implement the specific potential of quantum technologies for the respective company. We present our Munich project Quantum LifeLong Learning (QL3), a targeted education and training program of the Munich universities in the field of quantum technologies according to a university certificate and ECTS system with the target group of specialists and executives in industry. We acknowledge financial support by the Bundesministerium für Bildung und Forschung (BMBF) of Germany.

References: 1. C.D. Aiello, et al. Achieving a quantum smart workforce. Quantum Science and Technology 6, 030501 (2021)

QI 4: Poster: Quantum Information

Time: Monday 18:00–20:00 Location: P2

QI 4.1 Mon 18:00 P2

Toward Digital-Analog Simulations using Superconducting Qubits and Resonators — •Riccardo Roma[1], Frank Wilhelm-Mauch[1,2], and Dmitry Bagrets[2,3] — [1]Theoretical Physics, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Forschungszentrum Jülich GmbH, Germany — [3]Institut für Theoretische Physik, Universität zu Köln, Zülpicher Straße 77, 50937 Köln, Germany

We propose a novel architecture for processors based on superconducting qubits coupled to resonators for digital-analog simulations of bosonic-fermionic systems. More in detail we present some preliminary results of the numerical analysis of a system composed of a pair of superconducting qubits, each coupled to an ancillary qubit via a resonator, interacting with a cross-resonance gate.

QI 4.2 Mon 18:00 P2

Electronic Structure Simulations for Batteries and Fuel Cells Using a Quantum Computer — •Konstantin Lamp[1,2], Alejandro D. Somoza[1], Felix Rupprecht[1], Marina Walt[3], Nicolas Vogt[3], Giorgio Silvi[3], and Birger Horstmann[1,2] — [1]German Aerospace Center, Wilhelm-Runge Straße 10, 89081 Ulm — [2]Helmholtz Institute Ulm, Helmholtzstraße 11, 89081 Ulm — [3]HQS Quantum Simulations GmbH, Haid-und-Neu-Strasse 7, 76131 Karlsruhe

In the context of modern energy devices like batteries and fuel cells a description of challenging molecular structures is vital for the advancement of these technologies. However, classical algorithms for the simulation of such systems suffer from an exponential growth in required resources, which may be avoided by exploiting the correspondence between chemical orbitals and qubits of a quantum computer.

In this work, we show a variety of hybrid quantum algorithms for electronic structure calculations performed on the IBM System One quantum computer with state-of-the-art techniques of error mitigation and noise characterization. In particular, we focus on a class of hybrid algorithms that leverage additional measurements on the quantum processor without an increase in the complexity of the quantum circuits, like VQSE [Phys.Rev.X 10, 011004] and an extension of the QEOM method [Phys.Rev.Res. 2, 043140]. Furthermore, we investigate techniques like Entanglement Forging [arXiv:2104.10220] that exploit partitions of the initial problem into strongly correlated sectors in order to achieve efficient quantum simulations of larger systems.

QI 4.3 Mon 18:00 P2

Quantum simulation of the transverse field Ising models — •Sumeet Sumeet and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg, Department of Physics, Staudtstraße 7, 91058 Erlangen, Germany

With the advancements in quantum technologies, it has become inevitable to investigate the potential existence of quantum advantages for quantum many-body systems. One of the most paradigmatic model is the transverse field Ising model (TFIM) that can be simulated on a quantum computer to compute properties such as the ground-state energy. This problem, when tackled on a classical computer, leads to an exponential surge in the cost of computation with increasing system size. Classical-quantum hybrid algorithms such as the Variational Quantum Eigensolver (VQE) algorithm, is considered reasonably good for obtaining the ground-state energy of quantum many-body systems in the current NISQ era. Here we explore various ansaetze, focusing mainly on the Hamiltonian variational ansatz, for calculating the ground-state energy of one-dimensional TFIMs. We devise strategies to compute the ground-state energy for relatively large spin systems leveraging the power of quantum computers. In addition to that, we explore the quantum advantage and access the resource requirement for a quantum computer to evaluate the properties of systems in difficult regions around the quantum phase transition, which is a computationally difficult problem for a classical computer. Further, we extend our considerations to explore geometrically frustrated TFIMs using quantum simulation.

QI 4.4 Mon 18:00 P2

Estimating the entangling power of a two-qubit gate from measurement data: artificial neural networks and randomized measurements versus standard tomography methods — •Salwa Shaglel — Universität Siegen, Siegen, Germany

Quantum logic gates are the building blocks of quantum circuits and algorithms, where the generation of entanglement is essential to perform quantum computations. The amount of entanglement that a unitary quantum gate can produce from product states can be quantified by the so-called entangling power, which is a function of the gate's unitary or Choi matrix representation.

I introduce two efficient approaches to the practical problem of estimating the entangling power of an unknown two-qubit gate from measurement data. The first approach is using a deep neural network trained with noisy data simulating the outcomes of prepare-and-measure experiments on random gates. The training data is restricted to 48 measurement settings, which is significantly less than the 256 dimensions of the ambient space of 16x16 Choi matrices and very close to the minimum number of settings that guarantees the recovery of a two-qubit unitary gate using the compressed sensing technique at an acceptable error rate. The second approach to determine the entangling power is based on the second moments of correlation functions obtained from locally randomized measurements. The two approaches do not make any prior assumptions about the quantum gate, and they also avoid the need for standard reconstruction tools based on full quantum process tomography, which is prone to systematic errors.

QI 4.5 Mon 18:00 P2

Frequency-degenerate Josephson mixer for quantum illumination — •Fabian Kronowetter[1,2,3], Florian Fesquet[1,2], Maria-Teresa Handschuh[1,2], Kedar Honasoge[1,2], Yuki Nojiri[1,2], Michael Renger[1,2], Achim Marx[1], Frank Deppe[1,2,4], Rudolf Gross[1,2,4], and Kirill G. Fedorov[1,2] — [1]Walther-Meißner-Institut, BAdW, 85748 Garching, Germany — [2]Physik-Department, TUM, 85748 Garching, Germany — [3]Rohde & Schwarz GmbH, 81671 Munich, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

In quantum illumination, the joint measurement of the signal and idler beams enables a quantum advantage in target detection, as compared to the ideal classical radar. This advantage is predicted to exist for the case of weak quantum signals propagating in a bright thermal background, where the latter potentially contains a weakly reflecting target. The joint measurement exploits non-classical correlations between the signal and idler modes. A promising detector concept allowing for a theoretical 3 dB quantum advantage implements this joint measurement by exploiting a frequency-degenerate Josephson mixer (JM). The circuit of this JM consists of two 180° hybrid ring beam splitters and two flux-driven Josephson parametric amplifiers. We present the first successful operation of the frequency-degenerate JM with Gaussian states and, thus, demonstrate an important milestone for the realization of the microwave quantum radar.

QI 4.6 Mon 18:00 P2

Fabrication of low-loss Josephson parametric circuits — •Kedar E. Honasoge[1,2], Yuki Nojiri[1,2], Daniil E. Bazulin[1,2], Leon Koch[1,2], Thomas Luschmann[1,2], Niklas Bruckmoser[1,2], Maria-Teresa Handschuh[1], Florian Fesquet[1,2], Michael Renger[1,2], Fabian Kronowetter[1,2,4], Achim Marx[1], Stefan Filipp[1,2,3], Rudolf Gross[1,2,3], and Kirill G. Fedorov[1,2] — [1]Walther-Meißner-Institut, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MC-QST), 80799 Munich, Germany — [4]Rohde & Schwarz GmbH, Munich, Germany

Interest in quantum-limited amplification based on Josephson superconducting circuits has increased drastically in the past decade due to the rapidly advancing field of quantum information processing. In this context, a key challenge lies in realizing low-loss superconducting devices by minimizing energy dissipation. We achieve this goal by employing various cleaning steps during fabrication of superconducting circuits. Respectively, we fabricate Josephson parametric amplifiers with internal quality factors in excess of 10^4. We characterize bandwidth, gain, noise, dynamic range, and other properties of the realized devices. Based on these investigations, we derive useful criteria for development of more intricate Josephson parametric circuits, such as Josephson parametric converters.

QI 4.7 Mon 18:00 P2

Perspectives of microwave quantum key distribution — •Florian Fesquet[1,2], Fabian Kronowetter[1,2,4], Michael Renger[1,2], Kedar Honasoge[1,2], Yuki Nojiri[1,2], Maria-Teresa Handschuh[1,2], Achim Marx[1,2], Rudolf Gross[1,2,3], and Kirill. G. Fedorov[1,2] — [1]Walther- Meißner-Institut, 85748 Garching, Germany — [2]Physik-Department, TUM, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [4]Rohde & Schwarz GmbH, 81671 Munich, Germany

One of the cornerstones of quantum communication is an unconditionally secure distribution of classical keys between remote parties. This can be achieved by exploiting quantum features of electromagnetic waves, such as entanglement or the no-cloning theorem. However, these quantum resources are known to be susceptible to noise and losses, which are omnipresent in open-air communication scenarios. Here, we theoretically investigate the perspectives of continuous-variable open-air quantum key distribution (QKD) at microwave frequencies. We demonstrate that continuous-variable QKD with propagating microwaves can be unconditionally secure at room temperatures at distances up to 200 meters. Furthermore, we show that microwave QKD provides the potential to outperform conventional QKD protocols at telecom wavelengths for certain weather conditions

QI 4.8 Mon 18:00 P2

Simulating quantum repeaters with experimentally relevant parameters — •Julius Wallnöfer[1], Fabian Wiesner[1], Frederik Hahn[1], Nathan Walk[1], and Jens Eisert[1,2] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, 14109 Berlin, Germany

The quantum repeater protocol is a well established standard for distributing entanglement over long distances. However, there are a number of open questions when considering setups that go beyond the standard scenarios and error models. We have developed a numerical simulation platform for quantum repeaters to explore in multiple directions:

(i) With experiments of small scale quantum repeaters becoming a reality, it is of high interest to explore detailed error models that are close the real situations found in the experiment. Our simulation allows us to not only compare setups with different parameters, but also to assess the effect of improving certain aspects has on e.g. the achievable key rate.

(ii) We explore conceptual questions in larger scale quantum repeaters outside of standard situations - especially in asymmetric setups where e.g. the length or quality of quantum channels is not identical. Furthermore, we investigate strategies for quantum repeaters when considering entanglement purification and multi-mode memories.

QI 4.9 Mon 18:00 P2

Rare earth ion materials in micro-cavities as optically addressable qubits for quantum information — •Jannis Hessenauer[1], Christina Ioannou[1], Kumar Senthil Kuppusamy[1], Mario Ruben[1], Diana Serrano[2], Philippe Goldner[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Université PSL, Chimie ParisTech, CNRS, Paris, France

Rare earth ions retain long optical and spin coherence times in solid state hosts and are therefore a promising realization of optically addressable spin qubits. Due to the dipole forbidden nature of the optical transitions, an efficient spin-photon interface for quantum information technology requires the coupling of single ions to an optical cavity to enhance the transitions via the Purcell effect. Recently, rare earth ions in molecular crystals have demonstrated outstanding coherence properties, while also promising a large parameter space for optimization by chemically engineering of the host molecule. We characterize the optical properties of molecular materials at low temperature using techniques such as photoluminescence spectroscopy, absorption spectroscopy and spectral hole burning. Furthermore, we present our progress towards integrating Yb^{3+}-doped materials into stable high finesse fiber-based Fabry-Pérot cavities.

QI 4.10 Mon 18:00 P2

Circular Bragg gratings for Integrated Enhancement of Quantum Emitters — •Dario Mekle, Jonas Grammel, and David Hunger — Physikalisches Institut, Karlsruher Institut für Technologie

Surface-emitting center-disk cavities, composed of circular Bragg gratings have been successfully employed for distributed feedback lasers and quantum emitter applications based on nitrogen vacancy centers and semiconductor quantum dots.

We aim to transfer this approach to achieve greater collection efficiencies of rare earth ion based emitters in the form of nanocrystals and molecules. The collection efficiency is improved through the use of cavity induced Purcell enhancement and by utilizing directional field emission patterns. A finite element analysis is used to perform geometric parameter optimizations of circular Bragg cavities consisting of PMMA (or similar polymers) and air layers.

The simulation predicts a Purcell factor of more than 140, significantly higher than previously published results. We report on progress in fabricating the simulated structures using electron beam lithography on gold substrates.

QI 4.11 Mon 18:00 P2

Enhancing the optical emission of erbium dopants in silicon with photonic crystals — •Florian Burger[1,2], Lorenz Weiss[1,2], Andreas Gritsch[1,2], Stephan Rinner[1,2], Johannes Früh[1,2], and Andreas Reiserer[1,2] — [1]Max Planck Institute of Quantum Optics, Garching bei München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), LMU Munich, Germany

Silicon photonics has developed into a mature technology platform that allows for rapid development cycles using standardized tools. Integrating coherent optical emitters into silicon chips would pave the way towards large-scale quantum networks. In this context, we explore the use of erbium dopants which feature both long spin coherence times and coherent optical transitions in the telecom C band, where the loss in optical fibers is minimal. Using low-loss nanowire waveguides, we performed resonant spectroscopy and were able to confirm the integration of erbium dopants at well-defined lattice sites, with narrow inhomogeneous linewidths of approximately 1 GHz and homogeneous linewidths of less than 20 kHz at temperatures below 8 K. As the practical use of the investigated transitions is hampered by their long excited-state lifetime, we plan to enhance the emission with tailored photonic nanostructures. To this end, we have designed and fabricated nanophotonic cavities, offering strong narrow-band Purcell enhancement, as well as photonic-crystal waveguides with moderate broadband Purcell enhancement. We will present details about the design and fabrication of these structures, and give an outlook on the control of single erbium dopants in silicon.

QI 4.12 Mon 18:00 P2

Cavity-enhanced spectroscopy of molecular quantum emitters — •Evgenij Vasilenko, Weizhe Li, Nicholas Jobbitt, Senthil Kuppusamy, Mario Ruben, and David Hunger — Kalrsruhe Institute of Technology (KIT)

Rare earth ions in solid-state hosts are a promising candidate for optically addressable spin qubits, owing to their excellent optical and spin coherence times. Recently, also rare earth ion-based molecular complexes have shown excellent optical coherence properties [1]. Due to the long optical lifetime of the optical transition $^5D_0$-$^7F_0$, an efficient spin-photon interface for quantum information processing requires the coupling of single ions to a microcavity. Open-access Fabry-Pérot fiber cavities have been demonstrated to achieve high quality factors and low mode volumes, while simultaneously offering large tunability and efficient collection of the cavity mode [2]. Since the used molecular quantum emitters require a cryogenic environment, the demands on mechanical stability of the cavity setup have a high priority. To tackle these challenges, we report on the development of a monolithic type of cavity assembly, sacrificing some lateral scanning ability for the purpose of significantly increasing the passive stability. We integrate molecules into the cavity in the form of a crystalline thin film on a macroscopic mirror and identify a sub-nanometer local surface roughness, sufficient to avoid excessive scattering loss. We report on first studies of cavity-enhanced emission spectroscopy.

[1] Serrano et al., to appear in Nature, arXiv:2105.07081
[2] Hunger et al., New J. Phys 12, 065038 (2010)

QI 4.13 Mon 18:00 P2

Finite-range multiplexing in tripartite quantum networks — •Julia Alina Kunzelmann, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf

Due to the interaction between qubits and their environment, long-distance communication still poses a challenge. To overcome this problem, quantum repeaters are used, in which the repeater rate can be maximized by utilizing multiplexing. In previous work (Abruzzo et al. (2014)), a finite-range multiplexing protocol for two parties was investigated. We extend this protocol to three parties and it turns out that also in the tripartite network, full-range multiplexing does not provide substantial advantages over finite-range multiplexing. We also analyze decoherence of quantum memories and various strategies to lower the experimental requirements. To achieve this, different three-dimensional matching strategies are analyzed.

QI 4.14 Mon 18:00 P2

Integrated Photonic Information Processing for Quantum Networks — •Jeldrik Huster[1], Simon Abdani[1], Jonas Zatsch[1], Christian Schweikert[2], Rouven Klenk[2], and Stefanie Barz[1] — [1]Institute for Functional Matter and Quantum Technologies & IQST, University of Stuttgart, 70569 Stuttgart, Germany — [2]Institute of Electrical and Optical Communications Engineering, University of Stuttgart, 70569 Stuttgart, Germany

The steady progression of photonic quantum systems allows the realisation of quantum computation, communication and networked applications. Key in pursuit of scalable photonic quantum technology are integrated devices operating in the telecom regime, due to their small footprint, high phase stability and low loss connectivity. Particularly, the generation of multipartite entangled states is of special interest. These states are the basis for measurement-based quantum computing and multiparty key exchange. Here, we present our recent progress on silicon-photonic quantum circuits operating at the single-photon level. The circuits consist of tuneable beam splitters, phase shifters and highly efficient grating couplers. They are powered by spontaneous parametric down conversion sources and used in combination with superconducting single-photon detectors. We show the characterisation of integrated devices and a pathway to generate complex entangled sates in an integrated manner.

QI 4.15 Mon 18:00 P2

Entanglement distribution over a cryogenic microwave link — •Simon Gandorfer[1,2], Michael Renger[1,2], Wun Kwan Yam[1,2], Florian Fesquet[1,2], Kedar Honasoge[1,2], Fabian Kronowetter[1,2,3], Yuki Nojiri[1,2], Maria-Teresa Handschuh[1,2], Achim Marx[1], Rudolf Gross[1,2,4], and Kirill G. Fedorov[1,2] — [1]Walther-Meißner-Institut, 85748 Garching, Germany — [2]Physik-Department, TUM, 85748 Garching, Germany — [3]Rohde & Schwarz GmbH & Co. KG, 81671 Munich, Germany — [4]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

In the context of rapid progress in quantum technologies, the realization of hardware platforms for quantum communication networks is of utmost importance. Quantum local area networks connecting remote superconducting quantum nodes are crucial for the implementation of distributed quantum computing architectures. In this regard, we demonstrate a 6.5 m cryogenic link connecting two dilution cryostats via a cold network node. The respective microwave quantum communication channel is realized with superconducting microwave coaxial cables cooled to temperatures below 100 mK. By using this system, we demonstrate a successful distribution of squeezed states and two-mode entanglement between the remote dilution fridges and validate robustness of the quantum state transfer up to channel temperatures of 1 K.

QI 4.16 Mon 18:00 P2

Efficient spin-photon interface for NV centers in diamond — •Jeremias Resch[1], Kerim Köster[1], Maximillian Pallmann[1], Julia Heupel[2], Cyril Popov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie (KIT) — [2]Universität Kassel

In order to achieve spin-photon-based quantum computers, we require excellent control of the qubit spin states, in addition to long coherence times of the nuclear spin states. By combining several computing nodes, and linking them to a global register via optical networks, scalability is achieved. A crucial component of this optical network is an efficient, coherent single-photon source. Coupling colour centers in diamond, such as the nitrogen-vacancy or tin-vacancy centers, to a microcavity is a promising approach in order to achieve efficient single-photon sources. In our experiment, we integrate a diamond membrane into an open access fiber-based Fabry-Perot microcavity to attain emission enhancement into a single well-defined mode. We present our fully tunable, cryogenic cavity platform operating in a closed-cycle cryostat, and we achieve a sub-picometer mechanical stability during quiet periods. We observe cavity-enhanced fluorescence spectra of an ensemble of shallow-implanted nitrogen-vacancy centers in diamond, showing Purcell-enhancement of the zero-phonon line.

QI 4.17 Mon 18:00 P2

Designing a microwave antenna for spectroscopy of nitrogen vacancy centers in a fiber-based cavity — •Matthias Klausmann, Maximilian Pallmann, Jeremias Resch, and David Hunger — Karlsruher Institut für Technologie

Overcoming losses in long distance fiber-based quantum networks is one of the big challenges in the field of quantum communication, which requires the development of a quantum repeater. Color centers in diamond are a promising platform for realizing the needed spin-photon interfaces due to the possibility of optical readout and initialization. The optical readout of coherent photons can be enhanced by integrating the diamond in a cavity by exploiting the Purcell-effect. In addition, the coherent control of the electron spin of the color center and nearby nuclear spins is necessary for such a device.

In our experiment, we look for different designs of microwave antennas to manipulate the electron spin of nitrogen vacancy centers in a fiber-based Fabry-Pérot micro-cavity with regard that this can also be used under cryogenic conditions. Testing the antenna designs is performed in a room-temperature confocal microscope setup. We observe large ensembles of shallow implanted nitrogen-vacancy centers but also single centers at a depth of a few micrometers below the diamond surface. With our antennas we are able to perform pulsed optically detected magnetic resonance, Rabi and Echo measurements. Using this measurement protocols, the hyperfine interaction between the electron spin and the nuclear spin of the hosting nitrogen atom as well as the interaction with a nearby 13C nuclear spin can be resolved.

QI 4.18 Mon 18:00 P2

Microwave quantum teleportation over thermal channels — •Wun Kwan Yam[1,2], Michael Renger[1,2], Simon Gandorfer[1,2], Florian Fesquet[1,2], Kedar Honasoge[1,2], Fabian Kronowetter[1,2,3], Yuki Nojiri[1,2], Maria-Teresa Handschuh[1,2], Achim Marx[1], Rudolf Gross[1,2,4], and Kirill G. Fedorov[1,2] — [1]Walther-Meißner-Institut, BAdW, 85748 Garching, Germany — [2]Physik-Department, TUM, 85748 Garching, Germany — [3]Rohde & Schwarz GmbH & Co. KG, 81671 Munich, Germany — [4]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Microwave quantum communication enables quantum local area networks between superconducting quantum processors and, thereby, paves the way towards distributed quantum computing. Quantum teleportation belongs to the most relevant quantum communication protocols. It permits efficient and unconditionally secure transfer of quantum states. Recent experimental demonstration of quantum teleportation with propagating microwaves [1] motivates the investigation of its resilience against experimental imperfections. To this end, we analyze the effect of thermal noise in the analog feedforward channel. We show that quantum teleportation implements an error correction scheme for loss and noise in the feedforward signal. Furthermore, we consider realistic operating parameters and find that the teleportation fidelity can exceed the no-cloning threshold for finite energy codebooks.

[1] K. G. Fedorov et al., "Experimental quantum teleportation of propagating microwaves", Sci. Adv. 7, eabk0891 (2021)

QI 4.19 Mon 18:00 P2

Quantum Polyspectra - Grand Unified Theory of Continuous Quantum Measurements — •Markus Sifft and Daniel Hägele — Ruhr University Bochum, Faculty of Physics and Astronomy, Experimental Physics VI (AG), Germany

The evaluation of continuous quantum measurements is a challenge in research areas like circuit quantum electrodynamics, spin noise spectroscopy, and quantum sensing. Measurement records can exhibit as diverse results as quantum jumps, mainly Gaussian noise, or even stochastic peaks from detectors with single photon resolution. Until now, specialized theories were used to model and eventually evaluate such measurement records. The poster reports on our recent progress in unifying all continuous measurement schemes into one theory. The theory is based on the measurement record, its power spectrum, and its third and fourth order generalizations, so-called polyspectra. Expressions for quantum polyspectra can be derived without approximation from the stochastic master equation [1]. System parameters follow from fitting quantum polyspectra to measured spectra [2]. This approach allows for a systematic evaluation of quantum measurements including coherent quantum dynamics, environmental damping, and measurement backaction at arbitrary measurement strength (Zeno-physics). We present and interpret quantum polyspectra of conventional spin noise spectroscopy, quantum transport through quantum dots, and spin noise spectroscopy in the single-photon regime.

[1] Hägele et al., PRB 98, 205143 (2018), [2] Sifft et al., PRR 3, 033123 (2021)

QI 4.20 Mon 18:00 P2

Multipartite High-dimensional Quantum Steering — •Sophie Egelhaaf and Roope Uola — Department of Applied Physics, University of Geneva, 1211 Geneva, Switzerland

Bipartite low dimensional entanglement has been studied extensively. However, many findings cannot be extrapolated to multiple parties and moreover, increasing the dimensions of the systems adds complexity to the entanglement structure.

We are interested in characterising the degree of high-dimensional entanglement, specifically focusing on various multipartite quantum steering scenarios. One such example is a triangle network with only one trusted party, or more generally a line network with some trusted parties. We investigate what can be deduced about the strength of entanglement between the different nodes of the network in such scenarios. We are especially interested in entanglement dimensionality, i.e. the question of how many degrees of freedom can be certified to be entangled, for which we provide analytical bounds.

QI 4.21 Mon 18:00 P2

Gate-error characterization via long-sequence quantum process tomography — •Andreas Ketterer and Thomas Wellens — Fraunhofer Institut für Angewandte Festkörperphysik (IAF), Tullastr. 72, 79108 Freiburg, Germany

Currently available quantum computing hardware realizes networks of tens of super-conducting qubits with the possibility of controlled nearest-neighbor interactions. However, the inherent noise and decoherence effects of such quantum chips considerably alter basic gate operations and lead to imperfect outputs of the targeted quantum computation. We show how to characterize such quantum gate errors in detail using a combination of quantum process and gate set tomography in order to estimate a complete set of single- and two-qubit gate operations. Key ingredients of our approach are the efficient characterization of a universal single qubit gate set via gate-set tomography and the subsequent reconstruction of one additional two-qubit entangling gate using a long-sequence version of quantum process tomography. The latter involves repeated applications of the respective target gate in combination with appropriately chosen single-qubit operations in order to assure a precise estimation of all involved error parameters. Lastly, we demonstrate the devised protocol by implementing it on IBMQ hardware and briefly discuss the impact of crosstalk effects on near-term quantum algorithms.

QI 4.22 Mon 18:00 P2

Solvable projected entangled pair states for ternary unitary quantum gates — •Richard Maximilian Milbradt[1], Christopher Assmus[1], and Christian Bernhard Mendl[1,2] — [1]Technical University of Munich, Department of Informatics, Boltzmannstraße 3, 85748 Garching, Germany — [2]Technical University of Munich, Institute for Advanced Study, Lichtenbergstraße 2a, 85748 Garching, Germany

Recently we introduced the so-called ternary unitary quantum gates. These are four-particle gates acting in 2+1-dimensions and are unitary in time and both spatial dimensions. Now we generalise the concept of solvable MPS[Phys. Rev. B 101, 094304 (2020)] to two spatial dimensions with cylindrical boundary conditions. We show that such *solvable PEPS* can be identified with matrix product unitaries. In the resulting tensor network for evaluating equal-time correlation functions, the bulk ternary unitary gates cancel out, and we delineate and implement a numerical algorithm for computing such correlations.

QI 4.23 Mon 18:00 P2

Towards digital-analog quantum computing with superconducting qubits — Julia Lamprich[1], Nicola Wurz[1], •Stefan Pogorzalek[1], Manish Thapa[1], Vicente Pina-Canelles[1], Antti Vepsäläinen[2], Miha Papič[1], Jayshankar Nath[1], Florian Vigneau[1], Daria Gusenkova[1], Ping Yang[1], Hermanni Heimonen[2], Hsiang-Sheng Ku[1], Adrian Auer[1], Johannes Heinsoo[2], Frank Deppe[1], and Inés de Vega[1] — [1]IQM Quantum Computers, Nymphenburgerstr. 86, 80636 Munich, Germany — [2]IQM Quantum Computers, Keilaranta 19, FI-02150 Espoo, Finland

Digital-Analog Quantum Computing (DAQC) is a novel approach to quantum computing. Here, one variant is banged DAQC where single qubit gates are applied on top of an analog (entangling) evolution. We have investigated the experimental and fundamental challenges in realizing banged DAQC for the example of preparing a Bell state. The main challenge in banged DAQC is the correct execution of single qubit gates under simultaneous qubit-qubit interaction. The latter is induced by a flux-tunable coupler element, which allows for the accumulation of conditional phase during the analog block. In addition, banged DAQC is compared to an alternative approach called stepwise DAQC, where the single qubit gates are executed only when the qubits do not interact. For both approaches, the relevant error sources are identified and fidelities are compared to the purely digital case.

We acknowledge support from the German Federal Ministry of Education and Research via the projects DAQC (13N15686) and Q-Exa (13N16062).

QI 4.24 Mon 18:00 P2

Thermo-optical properties of superconducting thin films for waveguide-integrated single-photon detectors. — •Anthony Chukwunonso Ogbuehi[1,2], Pierre Piel[1,2], Martin Wolff[1,2], Matthias Häussler[1,2], Carsten Schuck[1,2], and Ursula Wurstbauer[1,2] — [1]Institute of Physics, Münster University, Germany — [2]Center for Soft Nanoscience SoN, Münster University, Germany

Integrated quantum photonics relies on the generation, manipulation, and measurement of single quantum states of light. The latter can be achieved with superconducting nanowire single-photon detectors (SNSPD) embedded into photonic integrated circuits [1]. While SNSPDs show attractive detection efficiency and high timing accuracy [2], it remains largely unknown how detector performance characteristics are connected to superconducting material properties. Here we study the temperature-dependent dielectric function of niobium-titanium nitride (NbTiN) thin films above and below the critical temperature by means of spectroscopic ellipsometry by varying a number of parameters. Material optimization guided by spectroscopic ellipsometry provides a novel approach for both getting new insight into key parameters of the detection process and improving single-photon detector benchmarks, benefitting a wide range of integrated quantum technology applications.

[1] S. Ferrari et al., Nanophotonics 7, 1725 (2018) [2] M. A. Wolff et al., Appl. Phys. Lett. 118, 154004 (2021).

QI 4.25 Mon 18:00 P2

Quantum Possibilistic Paradoxes and Logical Contextuality — •Leonardo Santos — Universität Siegen, Siegen, Germany

Contextuality and nonlocality are nonclassical properties exhibited by quantum statistics whose implications profoundly impact both the foundations and applications of quantum theory. In this contribution we provide some insights into logical contextuality and inequality-free proofs. The former concept can be understood as the possibility version of contextuality, while the latter refers to proofs of quantum contextuality or nonlocality that are not based on violations of some noncontextuality (or Bell) inequality. By *possibilistic* we mean a description in terms of possibilities for the outcomes, which are Boolean variables assuming value 1 when the corresponding probability is strictly larger than zero and 0 otherwise. In this work we built a bridge between these two concepts from what we call possibilistic paradoxes, which are sets of possibilistic conditions whose occurrence implies contextuality and nonlocality. As the main result, we demonstrate the existence of possibilistic paradoxes whose occurrence is a necessary and sufficient condition for logical contextuality in a very important class of scenarios. Finally, we discuss some interesting consequences arising from the completeness of these possibilistic paradoxes.

QI 4.26 Mon 18:00 P2

Generating Entangled States on IBM Quantum — Sebastian Brandhofer[1], Jelena Mackeprang[2], •Daniel Bhatti[2], Ilia Polian[1], and Stefanie Barz[2] — [1]Institute of Computer Architecture and Computer Engineering & IQST, University of Stuttgart, Germany — [2]Institute for Functional Matter and Quantum Technologies & IQST, University of Stuttgart, Germany

Commercially available quantum computers have reached the NISQ era and already can be employed to run basic quantum algorithms. One of the most important resources for quantum computations are entangled multi-qubit quantum states. Therefore, it is necessary to produce these states deterministically and with a high fidelity. Based on the specific physical architectures of different IBM quantum computers we produce graph states and GHZ states with the help of CPHASE and CNOT gates, respectively, and assess the quality of the state preparation. To optimize the resulting state fidelities, we develop and implement a classical optimization algorithm that considers various error characteristics of the qubits and the two-qubit gates.

QI 4.27 Mon 18:00 P2

Quantum circuits for the preparation of spin eigenfunctions on quantum computers — •Alessandro Carbone[1,2], Davide Emilio Galli[2], Mario Motta[3], and Barbara Jones[3] — [1]Theory and Simulations of Materials (THEOS), and National Centre for Computational Design and Discovery of Novel Materials (MARVEL), École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland — [2]Dipartimento di Fisica, Università degli Studi di Milano, via Celoria 16, 20133 Milano, Italy — [3]IBM Quantum, IBM Research Almaden, 650 Harry Road, San Jose, CA 95120, USA

The preparation of accurate and efficient approximations for Hamiltonian eigenstates on quantum computers is a crucial step for building the quantum advantage when studying many-body quantum systems. If we can describe molecules or materials with a coarse-grained spin Hamiltonian, spin eigenfunctions can be a useful starting point for simulations which aim to understand their electronic structure. In particular the purpose of this work is to delve into the description of the quantum circuits which prepare total spin eigenfunctions in the case of spin-1/2 systems. We investigate the balance between generality, accuracy, and computational cost in the encoding of spin eigenfunctions by quantum circuits without ancillary qubits, by pursuing two approaches: an exact recursive construction of spin eigenstates, and a heuristic variational construction of approximate spin eigenstates. We have tested the described quantum circuits on the available IBM (classical) simulators and quantum devices in the cases of 3-spin and 5-spin systems.

QI 4.28 Mon 18:00 P2

Performances and limitations of variational quantum algorithms under realistic noise models — •Marco Schumann, Frank Wilhelm-Mauch, and Alessandro Ciani — Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, 52425 Jülich, Germany

As the field of quantum computing progresses, an intriguing question is if the currently available NISQ devices can deliver a quantum advantage for practical applications, like Variational Quantum Algorithms (VQAs). Due to the lack of error correction, noise limits the performance of these algorithms. Recently it was shown that a quantum state undergoing a variational quantum circuit with general Pauli noise approaches the completely mixed state with increasing circuit depth. In this ongoing project, we study the question of how variational quantum circuits behave under more realistic noise models, like dephasing or amplitude damping noise. We use the Quantum Approximate Optimization Algorithm (QAOA), which is a specific VQA, to solve combinatorial optimization problems. Considering the problem of MaxCut on different d-regular graphs with different qubit numbers, we run the circuit for many instances of randomly chosen circuit parameters. We find that for weak amplitude damping or dephasing noise the average purity of the output state of the circuit approaches the purity of the completely mixed state while the variance of the purity approaches zero with increasing circuit depth. The decrease of the average purity is well described by an exponential decay, where the decay rate is approximately linear in the noise strength.

QI 4.29 Mon 18:00 P2

A multi-qubit Bloch vector representation of density matrices in Julia — •Qunsheng Huang and Christian Mendl — Technische Universität München. Fakultät für Informatik. Boltzmannstraße 3. 85748 Garching

In the Bloch sphere picture, one finds the coefficients for expanding a single-qubit density operator in terms of the identity and Pauli matrices. A generalization to n qubits via tensor products represents a density operator by a real vector of length 4^n, conceptually similar to a statevector.

The tensor structure leads to computationally efficient algorithms for applying circuit gates and performing few-qubit quantum operations. In view of variational circuit optimization, we study backpropagation through a quantum circuit and gradient computation based on this representation, and generalize our analysis to the Lindblad equation for modeling the (non-unitary) time evolution of a density operator.

QI 4.30 Mon 18:00 P2

Efficient energy estimation for variational quantum algorithms using ShadowGrouping — •Alexander Gresch and Martin Kliesch — Quantum Technology Research Group, Heinrich Heine University, Düsseldorf

Hybrid variational quantum algorithms (VQAs) are one of the main candidates for relevant applications of quantum computation in the near future. However, due to the hybrid quantum-classical nature of VQAs, a large number of repeated energy measurements for various trial states is needed. Each of these states requires an estimate $\hat{E}$ of the target energy E.

In our work, we aim to find the optimal strategy with single-qubit measurements that yields the highest provable accuracy given a total measurement budget. To this end, we derive a new upper bound to the failure probability $\mathbb{P}[|\hat{E}-E] > \epsilon]$ for a given tolerable accuracy ϵ, which improves upon previous bounds obtained in the context of derandomized classical shadows. Moreover, we combine strategies that measure groups of commuting Hamiltonian terms with that framework. This combination results in a measurement allocation scheme which we call *ShadowGrouping*. Numerically, we demonstrate that ShadowGrouping outperforms state-of-the-art methods in estimating the electronic ground-state energies of various small molecules. Hence, this work provides a promising way to approach the measurement bottleneck of VQAs.

QI 4.31 Mon 18:00 P2

Single Photon Sources at Telecom Wavelengths — •Jonas Grammel[1], Dario Mekle[1], András Laukó[1], Thomas Herzog[2], Simone Luca Portalupi[2], Peter Michler[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart

Semiconductor single photon sources are fundamental building blocks for quantum information applications. The current limitations of such quantum dot sources are the emitting wavelength and insufficient collection efficiency in fiber-based implementations. In the project *Telecom Single Photon Sources* we aim to realize high brightness, fiber coupled sources of single and indistinguishable photons at the telecom wavelength for the upcoming realization of fiber-based quantum networks. We employ open cavities realized with fiber-based mirrors, in combination with InGaAs quantum dots emitting in the telecom O-band and C-band. To achieve Fourier-limited photons we utilize the lifetime reduction of the emitters via the Purcell effect. We optimize the mode matching between the cavity mode and the guided fiber mode by introducing a fiber-integrated mode-matching optics that can basically reach near-unity collection efficiency. Fundamentally new is also the combination of Fabry-Perot micro-cavity modes with lateral micro and nano structures to reduce the cavity mode volume and thereby boost the emission enhancement and efficiency of the single photon emitters.

QI 4.32 Mon 18:00 P2

Towards downscaling of inter-electode spacing in PDMR for quantum sensing applications — •Jan Heiden, Marcel Schrodin, and Wolfgang Wernsdorfer — KIT, Karlsruhe, Germany

Photoelectric Detection of Magnetic Resonances (PDMR) states a novel technique for the detection of electronic spin-states in nitrogen vacancy centers (NV centers). Contrary to the currently established optical detection (ODMR), which measures the spin-dependent fluorescence of the negatively charged NV- center, the new method relies on the selectivity of the photocurrent induced by the ionizing conversion between NV0 and NV-. Therefore, gold electrodes are deposited directly onto the diamond surface with current inter-electrode distances of down to 2 um.

Besides improved selectivity, PDMR promises enhanced spatial resolution, purely dependent on the process of micro-fabrication. Further advantages arise from the separation of excitation and signal processing paths towards integration of optical systems into on-chip electronic environments.

The work presented focuses on proceeding the down-scaling of the inter-electrode spacing towards the nanometer regime for diamond-spin based quantum information applications at milikelvin temperatures.

QI 4.33 Mon 18:00 P2

Addressing of superconducting qubit in rectangular waveguide. — •Romain Albert[1], Maximilian Zanner[1], Eric Rosenthal[2], Silvia Casulleras[1], Mathieu L. Juan[3], Konrad Lehnert[2], Oriol Romero-Isart[1], and Gerhard Kirchmair[1] — [1]University of Innsbruck, Innsbruck, Austria — [2]JILA - University of Colorado, Boulder, United States — [3]Université de Sherbrooke, Sherbrooke, Canada

Superconducting qubits embedded into microwave waveguides have shown great potential for analog quantum simulation. Such systems present a unique combination of short-range direct qubit interactions and long-range waveguide mediated interactions which make it possible to model a wide variety of Hamiltonians. However, it is challenging to address individual qubits in such systems, as they are often separated by less than the wavelength of their control field. One possible solution is to use the non-linear dispersion of the waveguide to focus frequency chirped pulses to a specific location and it was shown theoretically that such a pulse can be used to selectively control a qubit[1]. We experimentally demonstrate this control using transmon qubits embedded in a rectangular waveguide.

[1] Casulleras, Silvia, et al. "Remote individual addressing of quantum emitters with chirped pulses." Phys Rev Let (2021)

QI 4.34 Mon 18:00 P2

Reduction of frequency spread in superconducting quantum coherent circuits — •Tammo Sievers[1,2,3], Leon Koch[1,2,3], Niklas Bruckmoser[1,2,3], Yuki Nojiri[1,2,3], Thomas Luschmann[1,2,3], Kirill Fedorov[1,2,3], and Stefan Filipp[1,2,3] — [1]Physik- Department, Technische Universität München, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST)

Superconducting quantum circuits form the basis of emerging applications in quantum computing and other quantum technologies. A prominent example is the transmon qubit, a superconducting Josephson junction shunted with a large capacitance. To become practically useful, reliable fabrication methods are required to produce highperformance transmon qubits with lifetimes exceeding several hundred μs and well-controlled parameters, such as the junction frequency. Here, we present our results of different fabrication methods to reduce frequency variations of Manhattan-style Al-AlOx-Al Josephson junctions. To compare the influence of the investigated fabrication techniques, we measure the room temperature resistivity of Josephson junctions and use the Ambegaokar-Baratoff relation in order to quantify the critical current spread of the junctions.

QI 4.35 Mon 18:00 P2

Minimization of Loss Channels in Superconducting Resonators — •Niklas Bruckmoser[1,2], Leon Koch[1,2], Leonhard Hölscher[1,2], David Bunch[1,2], Tammo Sievers[1,2], Kedar E. Honasoge[1,2], Yuki Nojiri[1,2], Thomas Luschmann[1,2], Kirill G. Fedorov[1,2], and Stefan Filipp[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik-Department, Technische Universität München, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), München, Germany

Realizing a fault-tolerant quantum computer is the goal of an evergrowing number of publicly funded and commercial research and development activities. Amongst many potential platforms, quantum computers based on superconducting quantum circuits with Josephson junctions are a promising candidate. However, the fidelity of superconducting qubits is limited by decoherence due to noise arising from various sources, in particular the local environment of the qubit. Driven by the development of partially noise-protected qubit designs, related lifetimes increased significantly from several nanoseconds to a few hundred microseconds. Nonetheless, it is crucial to gain an even better understanding of the origin of loss channels to further improve the qubit coherence by tailored design and fabrication processes. Here, we demonstrate a process for fabricating coplanar waveguide resonators and qubits based on niobium thin films sputtered on silicon substrates. We achieve qubit lifetimes up to 150 μs by systematically analyzing fabrication steps, such as surface treatment and thin film deposition.

QI 4.36 Mon 18:00 P2

Reduction of frequency spread in superconducting quantum circuits — •Tammo Sievers[1,2,3], Leon Koch[1,2,3], Niklas Bruckmoser[1,2,3], Yuki Nojiri[1,2,3], Thomas Luschmann[1,2,3], Kedar E. Honasoge[1,2,3], Kirill G. Fedorov[1,2,3], and Stefan Filipp[1,2,3] — [1]Physik- Department, Technische Universität München, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST)

Superconducting quantum circuits form the basis of emerging applications in quantum computing and other quantum technologies. A prominent example is the transmon qubit, a superconducting Josephson junction shunted with a large capacitance. As quantum processors scale to larger sizes, avoiding frequency collisions becomes a formidable task. Here, we present our results on different fabrication methods to reduce frequency variations of Manhattan-style Al-AlOx-Al Josephson junctions. To compare the influence of the investigated fabrication techniques, we measure the room temperature resistivity of Josephson junctions and use the Ambegaokar-Baratoff relation in order to quantify the critical current spread of the fabricated junctions.

QI 4.37 Mon 18:00 P2

Optimizing Fabrication Parameters for Superconducting Coplanar Waveguide Resonators — •David Bunch[1,2,3], Leon Koch[1,2,3], Niklas Bruckmoser[1,2,3], Kedar E. Honasoge[1,2], Yuki Nojiri[1,2,3], Thomas Luschmann[1,2,3], Tammo Sievers[1,2,3], Kirill G. Fedorov[1,2], and Stefan Filipp[1,2,3] — [1]Physik-Department, Technische Universität München, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST)

Superconducting circuits are a promising platform for the implementation of a universal quantum computer. However, the coherence times of superconducting qubits that make up such systems are limited by material losses, leading to errors in quantum gates. In particular, the coherence time is predominantly limited by coupling to unwanted two level systems (TLS) located at material interfaces. Identifying fabrication techniques, materials, and thin-film dielectrics that reduce losses is essential to achieve scalable architectures for superconducting quantum computing. To evaluate the efficacy of different fabrication techniques we measure the quality factor of superconducting microwave resonators. We present results on optimal sputtering parameters for enhancing the internal quality factor of superconducting coplanar waveguide resonators and investigate the effects of different etching processes, cleaning methods, and surface treatments on these resonators. We validate our results by fabricating qubits with high coherence times.

QI 4.38 Mon 18:00 P2

Nb/AlOx/Nb-trilayer based Dimer Josephson Junction Array Amplifiers — Fabian Kaap[1], Sergey Lothkov[1], Christoph Kissling[1], Victor Gaydamachenko[1], Marat Khabipov[1], Mark Bieler[1], and •Lukas Grünhaupt[1,2] — [1]Physikalisch-Technische Bundesanstalt, Department Quantum Electronics, 38116 Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt, Quantum Technology Competence Center, 38116 Braunschweig, Germany

Josephson parametric amplifiers are crucial components for superconducting quantum circuits as they enable high fidelity readout of qubits by improving the signal-to-noise ratio. Among them, Dimer Josephson Junction Array Amplifiers (DJJAA) [1] have shown promise as user-friendly devices with gain on the order of 20 dB, low added noise, saturation powers larger than approximately -110 dBm, and non-degenerate amplification over a bandwidth of up to ~10 MHz. Due to the use of dc-SQUIDS and multiple dimer modes the operating frequency can be tuned in the range of 2-10 GHz. Using results obtained on DJJAAs with Al/AlOx/Al Josephson junctions as a baseline, we present our progress towards realizing DJJAAs with Nb/AlOx/Nb-trilayer Josephson junctions. We will discuss the circuit design, our fabrication processes, and show preliminary cryogenic measurements of the device.

[1] P. Winkel et al., Phys. Rev. Applied 13, 024015 (2020)

QI 4.39 Mon 18:00 P2

High-fidelity gates and readout for scalable multi-qubit superconducting quantum processors — •Florian Wallner[1,2], Malay Singh[1,2], Gleb Krylov[1,2], Ivan Tsitsilin[1,2], Gerhard Huber[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Niklas Glaser[1,2], Christian Schweizer[1,2], and Stefan Filipp[1,2,3] — [1]Physik- Department, Technische Universität München, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, German — [3]Munich Center for Quantum Science and Technology (MCQST)

To reach the goal of implementing an error-corrected quantum computer, qubits with long coherence times need to be manipulated in real time with high fidelity, followed by a fast and accurate readout. Currently, the main challenge for all hardware platforms is to scale up the number of qubits while at the same time maintain high quality gate operations.
Here, we report on our recent advances to build superconducting multi-qubit devices. Through a dedicated fabrication process we reach coherence times of up to 150 μs. We show single-qubit characterization measurements of gates and high fidelity dispersive readout. By applying this method to multi-qubit systems, we achieve simultaneous multiplexed readout of several qubits coupled to the same feed line. Furthermore, we demonstrate first randomized benchmarking results for single- and two-qubit gates. In addition we give an outlook on our efforts to build multi-qubit devices and qubits on alternative architectures that promise substantial longer coherence times.

QI 4.40 Mon 18:00 P2

Improving the Sørensen-Mølmer gate using analytical optimal control — •Susanna Kirchhoff[1,2], Frank K. Wilhelm[1,2], and Felix Motzoi[3] — [1]Forschungszentrum Jülich, Quantum Computing Analytics (PGI 12), D-52425 Jülich, Germany — [2]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany — [3]Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), D-52425 Jülich, Germany

The Sørensen-Mølmer gate is an entangling gate for ion qubits [1]. The entangled state is obtained by the application of a bichromatic light beam which collectively drives the ions. This leads to an entangling gate if certain conditions on gate time, drive frequency and amplitude are fulfilled. These conditions can be derived from the propagator. However, the gate is not perfect. In [1] the authors apply the Lamb-Dicke approximation and neglect some fast rotating terms as well as the single qubit rotation before calculating the propagator. This leads to gate errors. We investigate how the approximations affect the gate fidelity and explore methods to avoid those errors and make the gate more robust against heating.

[1] Sørensen and Mølmer: Entanglement and quantum computation with ions in thermal motion. In: Physical Review A 62.2 (2000)

QI 4.41 Mon 18:00 P2

Spin defects in hBN as promising temperature, pressure and magnetic field quantum sensor — •Paul Konrad[1], Andreas Gottscholl[1], Andreas Sperlich[1], Igor Aharonovich[2], and Vladimir Dyakonov[1] — [1]Experimental Physics 6, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]School of Mathematics and Physical Sciences, University of Technology Sydney, Ultimo, NSW 2007, Australia

Colour centres in solid-state materials show great potential in quantum information technology and sensing applications. The lately discovered negatively charged boron vacancy (V_B^-) in hexagonal boron nitride (hBN)[1] has shown the defect to be host to a spin-triplet ground state with spin-dependent photoluminescence. The system can be exploited in terms of its application as temperature, magnetic field, and pressure sensor [2,3] which extends the already known applications of e.g. NV-centers in diamond not only due to its 2D character but also by highly improved temperature sensing especially at low temperatures.

Yet, the irradiation protocol is still unoptimized and achieving high contrast optically detected magnetic resonance (ODMR) on increasingly thinner flakes remains a challenge. We are on our way to tackle aforementioned challenges by performing measurements on V_B^- created by various types of irradiation and achieve tremendous improvement of ODMR contrast on flakes of down to 80nm thickness.

[1] Gottscholl et al., *Nat. Mat.*, **19**, 5, 540 (2020).
[2] Gottscholl et al., *Sci. Adv.*, **7** (14), eabf3630 (2021).
[3] Gottscholl et al., *Nat. Commun.*, **12**, 4480 (2021).

QI 5: Implementations: Solid state systems

Time: Tuesday 9:30–12:15 Location: H8

Invited Talk QI 5.1 Tue 9:30 H8

Towards universal quantum computation and simulation with NV centre in diamond — •Vadim Vorobyov — 3rd Physical Institute, University of Stuttgart

NV centre in diamond is a mature platform for quantum technologies having applications ranging from quantum sensing to quantum communication and quantum information processing. Numerous implementation of NV centres in coupe with relative simplicity of the experiment enabled implementation of the NV magnetometry within complementary analysis methods such as X ray spectrometers and high pressure diamond anvil cells scanning probe experiments enabled discovery of 2D antiferromagnetic domain walls and single layer magnetism in layered magnetic materials proving its firm niche among nanoscale quantum sensors.

For quantum information processing a well addressable, readable interacting qubits are essential. NV centre - as optically readable single electron spin forms an interface to nearby nuclear spin baths, allowing to realize a star shape central spin model. In this work we discuss the computational potential of such system and compare it to planar architecture adapted by superconducting qubit systems.

We perform a randomised benchmarking of a room temperature operational system and benchmark important building blocks for quantum information processing: QFT and Toffoli gates on a qubits and discuss their possible applications in quantum sensing.

QI 5.2 Tue 10:00 H8

Probing the quantum noise of metals and spin liquids with NV center spin qubits — Jun Yong Khoo[1,5], Falko Pientka[2,5], Patrick A. Lee[3], and •Inti Sodemann Villadiego[4,5] — [1]Institute of High Performance Computing, Agency for Science, Technology, and Research, Singapore — [2]Institut fur Theoretische Physik, Goethe-Universitat Frankfurt a.M. — [3]Department of Physics, Massachusetts Institute of Technology, Cambridge Massachusetts, USA — [4]Institut fur Theoretische Physik, Universitat Leipzig — [5]Max-Planck-Institut fur Physik komplexer Systeme

Finding tailored probes that allow to identify the presence of exotic fractionalized states in quantum materials is a major open challenge. Recently, spin qubits based on NV centers are emerging as a new tool to investigate the magnetic noise emanating from complex correlated materials.

Here we study the magnetic noise emerging from a U(1) spin liquid state with a spinon Fermi surface. We show that at low frequencies the noise from this state has the same distance and frequency dependence as a metal but is reduced by a dimensionless pre-factor controlled by the diamagnetic susceptibilities of emergent fractionalized particles in this state. We estimate that the regime to detect this behavior can be comfortably accessed by the typical NV center splittings of a few GHz and estimate that the expected T1 times for an NV center placed above candidate materials, such as the organic dmit and ET salts, monolayer 1T-TaS2/Se2, would range from several tens to a few hundred milliseconds.

QI 5.3 Tue 10:15 H8

Fidelities of quantum algorithms for a spin register in diamond in presence of magnetic impurities. — •Dominik Maile, Jürgen Stockburger, and Joachim Ankerhold — Institut für komplexe Quantensysteme, Universität Ulm, Germany

The Nitrogen Vacancy Center in diamond coupled to addressable surrounding nuclear spins forms a versatile building block for future quantum technologies. We theoretically study quantum information protocols of a small spin register built out of this constituents in presence of a common bath of impurity spins. Using a cluster correlation expansion, we predict the coherence and relaxation properties as well as the fidelities for different quantum algorithms. Further, we study the influence of the volume density and the geometry of the spin bath consisting of substitutional nitrogen atoms. Our investigations yield insight how to efficiently use such a platform for quantum information purposes in presence of unavoidable magnetic impurities.

QI 5.4 Tue 10:30 H8

Nitrogen vacancy centers in diamond membranes coupled to an optical microcavity — •Maximilian Pallmann[1], Kerim Köster[1], Jonathan Körber[3], Julia Heupel[2], Rainer Stöhr[3], Timon Eichhorn[1], Larissa Kohler[1], Cyril Popov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität Kassel — [3]Universität Stuttgart

Color centers in diamond centers are very promising candidates for applications in quantum communication and metrology. The nitrogen vacancy center (NV) stands out due to its exceptional spin coherence properties. On the other hand, it suffers from rather bad optical properties due to significant phonon coupling, and only 3% of the emitted light belongs to the Zero phonon line (ZPL). This can be overcome by coupling the emitters to optical cavities, making use of the Purcell effect.

In our experiment, we integrate a diamond membrane to an open access fiber-based Fabry-Perot microcavity [1] to attain emission enhancement into a single well-collectable mode as well as spectral filtering. We investigate the influence of the diamond membrane on the optical properties of the cavity.

We present Purcell-enhanced ensemble-fluorescence of shallow-implanted NV centers and observe cavity-induced collective effects that lead to a bunching behavior in the emission.

[1] Heupel,Pallmann,Körber.Micromachines 2020, 11, 1080;

QI 5.5 Tue 10:45 H8

Cavity-free microwave spectral hole burning in ^{166}Er:Y_2SiO_5 below 1K — Anton Mladenov[1], Natalia Pankratova[2], Dmitriy Sholokhov[1], Vladimir Manucharyan[2], Pavel Bushev[1,3], and •Nadezhda Kukharchyk[1,4,5] — [1]Experimental physics, University of Saarland, Saarbruecken, Germany — [2]Department of Physics, Joint Quantum Institute and Center for Nanophysics and Advanced Materials, University of Maryland, College Park, USA — [3]JARA-Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, Jülich, Germany — [4]Walther-Meißner-Institut, Bavarian academy of sciences, Garching, Germany — [5]Munich Center for Quantum Science and Technologies, Munich, Germany

Deterministic narrow spectral hole burning on a microwave transition would allow for realization of microwave atomic frequency combs (mwAFC). On the way towards realisation an mwAFC, we present our recent results in spectral hole burning in Er:Y_2SiO_5 crystal in cavity-free regime at the variation of magnetic field and at temperatures below 1 K.

15 min. break

QI 5.6 Tue 11:15 H8

Modelling and engineering cQED devices via effective Hamiltonians — •Boxi Li[1,2], Tommaso Calarco[1,2], and Felix Motzoi[1] — [1]Forschungszentrum Jülich, D-52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, D-50937 Cologne, Germany

Deriving effective Hamiltonian models plays an essential role in quantum theory, with particular emphasis in recent years on control and engineering problems. To develop fast, high-fidelity operations on cQED devices, there are also increasing demands on modelling tools that go beyond the strong perturbative regime and accurately capture the dynamics.

To this goal, we present two symbolic methods for computing effective Hamiltonian models. The first method makes use of the Jacobi iteration and works without the assumptions of perturbation theory while retaining convergence. In the perturbation regime, it reduces to a variant of the Schrieffer-Wolff method, which takes advantage of a recursive structure and exponentially decreases the number of terms in the high-order expansion. Both methods consist of algebraic expressions and can be easily automated for symbolic computation.

Based on these methods, we perform (semi-)analytical calculations that compute the effective Hamiltonian. We investigate both the ZZ and the cross-resonance interaction in the quasi-dispersive regimes. By choosing a proper frame transformation, we show that one can develop control pulses to suppress noises such as leakage and dynamical ZZ crosstalk, improving upon the conventional perturbative calculation.

QI 5.7 Tue 11:30 H8

Demonstration of an integrated optomechanical microcavity with a suspended frequency-dependent photonic crystal reflector — •Sushanth Kini M[1], Anastasiia Ciers[1], Juliette Monsel[1], Cindy Peralle[2], Shu Min Wang[1], Philippe Tassin[2], and Witlef Wieczorek[1] — [1]Dept of Microtechnology and Nanoscience, Chalmers University, Göteborg, Sweden — [2]Dept of Physics, Chalmers University, Göteborg, Sweden

Optical microcavities confine the light field on sub-wavelength length scales leading to stronger light-matter interactions. Using microcavities in cavity optomechanics, which explores the interaction between an optical cavity and mechanical motion, one drastically increases the optomechanical interaction. In our work, we use this concept in on-chip optomechanical microcavities fabricated from AlGaAs heterostructures. In our realization, the mechanically-compliant element is a suspended photonic crystal (PhC) reflector slab, whose distance to a distributed Bragg reflector (DBR) mirror is less than the optical wavelength. We demonstrate a precise control over the microcavity resonance wavelength by varying the PhC hole radius, notably keeping cavity length constant. Importantly, we demonstrate that the frequency dependence of the optical reflectivity of the PhC slab modifies the optomechanical effects compared to a conventional optomechanical system. In the future, this integrated optomechanical microcavity platform offers novel capabilities in manipulating mechanical motion, such as offering more efficient cooling schemes or the capability to generate mechanical squeezing in the ultra-strong coupling regime.

QI 5.8 Tue 11:45 H8

Quantum reservoir computing with coupled cavity arrays — •Frederik Lohof, Niclas Götting, and Christopher Gies — Institute for Theoretical Physics, University of Bremen, Bremen

Arrays of coupled cavities with embedded semiconducting quantum dots are a potential platform for the realization of a photonic quantum reservoir computer. The quantum reservoir paradigm is intriguing as it can be realized with preexisting technology and does not rely on fine-tuning of the system parameters as it is the case with gate-based quantum computing. Crucially, the performance of a quantum reservoir relies on a sampling of the exponentially increasing phase-space dimension. We provide theoretical benchmarks on how the topology of a quantum reservoir influences the reservoir's performance and discuss prospects for implementing quantum reservoir computing on a platform of arrays of semiconducting microcavities.

QI 5.9 Tue 12:00 H8

Ultra-stable open micro-cavity platform for closed cycle cryostats — •Michael Förg[1,2], Jonathan Noé[1,2], Manuel Nutz[1,2], Theodor W. Hänsch[1,3], and Thomas Hümmer[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität Munich, Germany — [2]Qlibri GmbH, Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

High-finesse, open-access, mechanical tunable, optical micro-cavities offer a compelling system to enhance light matter interaction in numerous systems, e.g. for quantum repeaters, single-photon sources, quantum computation and spectroscopy of nanoscale solid-state systems. Combining a scannable microscopic fiber-based mirror and a macroscopic planar mirror creates a versatile experimental platform.

A large variety of solid-state quantum systems can be brought onto the planar mirror, analyzed, addressed individually, and (strongly) coupled to the cavity. 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.

QI 6: Quantum Information: Concepts and Methods

Time: Tuesday 9:30–12:45 Location: H9

Invited Talk QI 6.1 Tue 9:30 H9

Towards an Artificial Muse for new Ideas in Quantum Physics — •Mario Krenn — Max Planck Institute for the Science of Light (MPL), Erlangen, Germany

Artificial intelligence (AI) is a potentially disruptive tool for physics and science in general. One crucial question is how this technology can contribute at a conceptual level to help acquire new scientific understanding or inspire new surprising ideas. I will talk about how AI can be used as an artificial muse in quantum physics, which suggests surprising and unconventional ideas and techniques that the human scientist can interpret, understand and generalize.

[1] Krenn, Kottmann, Tischler, Aspuru-Guzik, Conceptual understanding through efficient automated design of quantum optical experiments. Physical Review X 11(3), 031044 (2021).

[2] Krenn, Pollice, Guo, Aldeghi, Cervera-Lierta, Friederich, Gomes, Häse, Jinich, Nigam, Yao, Aspuru-Guzik, On scientific understanding with artificial intelligence. arXiv:2204.01467 (2022).

[3] Krenn, Zeilinger, Predicting research trends with semantic and neural networks with an application in quantum physics. PNAS 117(4), 1910-1916 (2020).

QI 6.2 Tue 10:00 H9

Learning variable quantum processes — Marco Fanizza[1], Yihui Quek[2], and •Matteo Rosati[3] — [1]FT: IFQ, Universitat Autonoma de Barcelona, 08193 Bellaterra (Barcelona) Spain — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [3]Electrical Engineering and Computer Science, Technische Universität Berlin, 10587 Berlin, Germany

Much of the current research on characterizing quantum processes via statistical learning theory assumes a highly controlled learning setting. Typically, the learner is allowed to use the unknown process as a black-box that may be applied to well-crafted inputs. In this work, we relax this assumption. How hard is it to learn a quantum process observed 'in-the-wild', without control over the inputs? This is the case, for instance, in learning astronomical processes induced by random celestial events, Hamiltonians at variable temperature and biological processes triggered by mechanisms which we can observe but not control. We reformulate this problem as one where a learner has access to a source that outputs classical-quantum states $\sum_x p(x)|x\rangle\langle x| \otimes \psi(x)$ where ψ is the unknown process mapping an input classical random variable x to an output quantum state. The goal is to learn ψ. When ψ is drawn from a class of functions C, we show that the complexity of this task scales polynomially in a combinatorial dimension of C (a measure of its effective size) that we define, and further give algorithms that achieve this complexity. We show, for the first time to our knowledge, that quantum states and processes can be learned efficiently even when identical repetitions of the same experiment are not possible.

QI 6.3 Tue 10:15 H9

Shortening Quantum Convolutional Neural Networks to Constant Depth — •Nathan McMahon, Petr Zapletal, and Michael Hartmann — Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

The quantum convolutional neural network (QCNN) is a quantum circuit that detects symmetry protected topological (SPT) phases, with its construction drawing from ideas of renormalisation theory. In this talk I will discuss a special class of these circuits that are equivalent to constant depth quantum circuits, local measurements, and classical post-processing, including an earlier example from Cong et al for a Z2 x Z2 SPT phase detection circuit. We modify this circuit and demonstrate how to shorten it to constant depth, while improving both the time complexity and signal fidelity.

Surprisingly, while the quantum component circuit is constant depth on N-qubits, we still observe a provably exponential (in N) sample complexity speed up compared to only local Pauli measurements and post-processing of the input state. To understand how this happens we demonstrate that a reduced complexity of the input state leads to a guaranteed reduction in the sample complexity speedup.

We finally consider how to explain the effectiveness of the QCNN as a phase recognition algorithm through quantum fidelity approaches to phase transitions. We do this by deriving a sufficient condition for the layers of the QCNN for its output to perform phase recognition. In the process, also making a tantalising connection between the renormalisation group and optimisation.

QI 6.4 Tue 10:30 H9

Quantum Convolutional Neural Network as a Phase Detection Circuit on the Toric Code — •Leon Sander, Nathan McMahon, and Michael Hartmann — Chair of Theoretical Physics, Friedrich-Alexander-Universität Erlangen Nürnberg, Germany

Understanding macroscopic behaviour of quantum materials is an interesting challenge in the field of quantum technologies. This macroscopic behaviour can be evaluated by the examination of quantum phases. Consequently, recognising the phase of a given input state is an important problem, which is often solved by measuring the corresponding order parameter. However, previous work by Cong et al. and Hermann et al. suggests quantum convolutional neural networks (QCNN) are an alternative method of phase detection that can also improve sampling efficiency near the phase boundary compared to direct measurements.

We construct a QCNN designed to act as a phase recognition circuit that determines whether certain magnetic/Ising type perturbations are sufficient to induce a phase transition in the toric code. The choice to study this quantum error correcting code can be motivated as it promises to reveal connections between quantum information and quantum phase transitions.

QI 6.5 Tue 10:45 H9

Evaluating the power and performance of sigmoid quantum perceptrons. — •Samuel Wilkinson and Michael Harman — Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstr. 7, 91058 Erlangen, Germa

Quantum neural networks (QNN) have been proposed as a promising architecture for quantum machine learning. There exist a number of different quantum circuit designs being branded as QNNs, however no clear candidate has presented itself as more suitable than the others. Rather, the search for a "quantum perceptron" – the fundamental building block of a QNN – is still underway.

One candidate is quantum perceptrons designed to emulate the nonlinear activation functions of classical perceptrons. Such sigmoid quantum perceptrons (SQPs) inherent the universal approximation property that guarantees that classical neural networks can approximate any continuous function. However, this does not guarantee that QNNs built from SQPs will have any quantum advantage over their classical counterparts. Here we critically investigate both the capabilities and performance of SQP networks by computing general measures of the dimension and capacity of the network, as well as its performance on real learning problems. The results are compared to those obtained for other candidate networks which lack activation functions. It is found that simpler, easier-to-implement parametric quantum circuits actually perform better than SQPs. This indicates that the universal approximation theorem, which a cornerstone of the theory of classical neural networks, is not a relevant criterion for QNNs.

15 min. break

QI 6.6 Tue 11:15 H9

An algorithm to factorize quantum walks into shift and coin operations — •Christopher Cedzich[1], Tobias Geib[2], and

Reinhard F. Werner[2] — [1]Quantum Technology Group, Heinrich Heine Universität Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover

Quantum walks provide a basic architecture for implementing quantum information processing and computing. It is therefore important to resolve a given task into available operations, i.e., to "compile" a targeted program. We provide such a method, showing that an arbitrary one-dimensional quantum operation can be resolved into a protocol of two basic operations: A fixed conditional shift that transports particles between cells and suitable coin operators that act locally in each cell. This allows to tailor quantum walk protocols to any experimental setup by rephrasing it on the cell structure determined by the experimental limitations.

QI 6.7 Tue 11:30 H9

Improved Bell state measurement — •Simone D'Aurelio, Matthias Bayerbach, and Stefanie Barz — Institute for Functional Matter and Quantum Technologies & IQST, University of Stuttgart, 70569 Stuttgart, Germany

Bell-state measurements play an important role in many quantum technologies, e.g. in quantum repeaters, certain quantum communication protocols and photonic quantum computing. However, using linear-optics only, such a Bell-state measurement has a success probability of 50%. Here, we show the implementation of a novel scheme that allows overcoming this limit.

We give details on the experimental setup. We show how we generate Bell-states in a linear Mach-Zehnder-like scheme as well as how we create ancilliary N00N states from single photons. Both states interfere in a linear-optical setup and photon-number measurements at the output allow determining the respective Bell state.

QI 6.8 Tue 11:45 H9

Preparation of maximally entangled states with digital-analog quantum computing — •Nicola Wurz[1], Julia Lamprich[1], Manish Thapa[1], Vicente Pina Canelles[1], Stefan Pogorzalek[1], Antti Vepsäläinen[2], Miha Papic[1], Jayshankar Nath[1], Florian Vigneau[1], Daria Gusenkova[1], Ping Yang[1], Hermanni Heimonen[2], Hsiang-Sheng Ku[1], Adrian Auer[1], Johannes Heinsoo[2], Frank Deppe[1], and Inés de Vega[1] — [1]IQM Quantum Computers, Munich, Germany — [2]IQM Quantum Computers, Espoo, Finland

Digital-Analog Quantum Computing (DAQC) is a novel approach, which combines digital single qubit gates with analog multi-qubit blocks. The DAQC concept distinguishes between stepwise and banged DAQC, where the single qubit gates are placed in between analog blocks or applied simultaneously with the analog (entangling) evolution, respectively. We have identified relevant sources of error for both DAQC protocols. When preparing a maximally entangled two-qubit state using either stepwise or banged DAQC, we reach similar fidelities as in the purely digital case. The multi-qubit version of the implemented circuit allows us to create GHZ states by parallelizing several two-qubit interactions. For the case of three qubits, we have investigated infidelities arising due to the multi-qubit nature of the interaction, including parasitic and higher order couplings.

We acknowledge support from the German Federal Ministry of Education and Research via the projects DAQC (13N15686) and Q-Exa (13N16062).

QI 6.9 Tue 12:00 H9

Momentum-Space Entanlgement and the Wilsonian Effective Action — •Matheus Henrique Martins Costa[1,2], Gastao Inacio Krein[2], Flavio de Souza Nogueira[1], and Jeroen van den Brink[1] — [1]Institute for Theoretical Solid State Physics - IFW Dresden, Dresden, Germany — [2]Instituto de Física Teórica - Universidade Estadual Paulista, Sao Paulo, Brazil

The entanglement between momentum modes of a quantum field theory at different scales is not as well studied as its counterpart in real space, despite the natural connection with the Wilsonian idea of integrating out the high-momentum degrees of freedom. Here, we push such connection further by developing a novel method to calculate the Rényi and entanglement entropies between slow and fast modes which is based on the Wilsonian effective action at a given scale and apply it to the perturbative regime of some scalar theories, comparing the lowest-order results with those from the literature and giving them an interpretation in terms of Feynman diagrams. Our results open the way for further work in exploring the relation between renormalization and entanglement and the role of the latter in phase transitions.

QI 6.10 Tue 12:15 H9

Holographic code in the laboratory — •Gerard Anglès Munné[1], Valentin Kasper[2], and Felix Huber[1] — [1]Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-348 Kraków, Poland. — [2]Institut de Ciències Fotòniques (ICFO), Mediterranean Technology Park, 08860 Castelldefels, Barcelona, Spain

We propose a method to prepare the holographic pentagon code in the laboratory. The code states can be described by graph states whose interactions patterns are optimized for experimental purposes. Taking a small instance of the holographic code on 12 qubits, we show how to do encoding and decoding. Furthermore, we demonstrate how to test the holographic property - any bulk part is determined by its nearby boundary - through a partial recovery procedure.

QI 6.11 Tue 12:30 H9

Universal ground state entanglement entropy in strongly biased bipartite systems — •Ohad Shpielberg — University of Haifa, Haifa, Israel

Consider the AB bipartite system with a single conserved quantity, say a particle number. The particle bias R is defined as the expectation of the particle number in subsystem A over the expectation in subsystem B. At the limit of large R, the ground state entanglement entropy is shown to universally scale like $\log R/R$, independent of the Hamiltonian details. A $1/\sqrt{R}$ universal power law is obtained for multiple conserved quantities. Moreover, the analysis shows a similar universal structure of the Rényi entropy.

This universal behavior could be exploited to optimize entanglement-assisted control over large many body systems, using systems with a small degree of freedom. Alternatively, one can use the different scaling of the entanglement entropy to detect hidden conserved quantities.

Part of the announced results are available at Phys. Rev. A 105, 042420 (2022).

QI 7: Quantum Communication and Networks

Time: Wednesday 15:00–17:45 Location: H8

QI 7.1 Wed 15:00 H8

Quantum networks and symmetries — •Kiara Hansenne[1], Zhen-Peng Xu[1], Tristan Kraft[2], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Siegen, Germany — [2]Institute for Theoretical Physics, University of Innsbruck, 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. Here 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 or fermionic symmetry can not be generated in networks; moreover, cluster and graph states are not accessible. Our methods can be used to design certification methods for the functionality of specific links in a network and have implications for the design of future network structures.

QI 7.2 Wed 15:15 H8

Secure Anonymous Conferencing in Quantum Networks — •Federico Grasselli[1], Gláucia Murta[1], Jarn de Jong[2], Frederik Hahn[3], Dagmar Bruss[1], Hermann Kampermann[1], and Anna Pappa[2,4] — [1]Heinrich-Heine-Universität Düsseldorf — [2]Technische Universität Berlin — [3]Freie Universität Berlin — [4]Fraunhofer Institut for Open Communication Systems

Users of quantum networks can securely exchange classical messages via quantum conference key agreement (CKA), which requires the users' identities to be publicly known. In numerous scenarios, however, communicating users demand anonymity with respect to the other network users, the network manager and even between themselves.

We introduce a security framework for anonymous conference key agreement with different levels of anonymity, generalizing the security of quantum key distribution (QKD). We present efficient and noise-tolerant protocols exploiting multipartite Greenberger-Horne-Zeilinger (GHZ) states and prove their security against general quantum attacks in the finite-key regime. We analyze their performance in noisy and lossy quantum networks and compare with protocols that only use bipartite entanglement to achieve the same functionalities. Our simulations show that GHZ-based protocols can outperform protocols based on bipartite entanglement and that the advantage increases for protocols with stronger anonymity requirements.

Our work advocates the use of multipartite entanglement for cryptographic tasks involving several users and enables the implementation of quantum communication protocols beyond QKD and CKA.

QI 7.3 Wed 15:30 H8

Prepare-and-measure conference key agreement protocol based on single-photon interference — •Giacomo Carrara, Federico Grasselli, Gláucia Murta, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Germany

Quantum Key Distribution (QKD) and its multipartite counterpart, Conference Key Agreement, (CKA) are fundamental cryptographic tasks, where two or more parties try to establish a common, secret key. The so-called Twin-Field Quantum Key Distribution (TF-QKD) setup recently received great attention as it only requires lasers and linear optical devices. TF-QKD has been generalized to many parties, where a CKA protocol based on single-photon interference has been proposed [F. Grasselli *et al*, 2019, New J. Phys., **21** 123002]. This multipartite protocol, however, has a big drawback: it does not have a prepare-and-measure formulation and thus lacks a simple, practical implementation. In this work we propose a CKA protocol that allows for a prepare-and-measure implementation, where the parties are required only to produce weak coherent pulses. We provide for this protocol a security analysis based on the decoy state method and analyze how the protocol performs compared to the well-known repeaterless bound, considering different network architectures.

QI 7.4 Wed 15:45 H8

Experimental anonymous conference key agreement using linear cluster states — •Lukas Rückle, Jakob Budde, and Stefanie Barz — Institute for Functional Matter and Quantum Technologies and IQST, University of Stuttgart, 70569 Stuttgart

Quantum networks allow for secure communication between more than just two parties. One example is the conference key agreement, where multiple parties exchange a secure key. Interestingly, quantum networks can provide another security feature: protecting the identity of the participants. Here, we realize such anonymous quantum conference key agreement in a linear network architecture using photonic cluster states. We show how different parties of the network can exchange a key anonymously by extracting a smaller GHZ state from the cluster state. We further study how noise affects the finite and asymptotic key rate and show that we achieve a positive asymptotic key rate.

QI 7.5 Wed 16:00 H8

Average waiting times for entanglement links in multiplexed 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 combine the elementary links to a long-distance link.

Since the generation of an elementary link is probabilistic and quantum memories have a limited storage time, the generation of a long-distance link is probabilistic, too [1]. One possibility to speed up the generation of a long-distance link is a multiplexed system, in which there is more than one elementary link between two nodes [2]. In this contribution, we will present estimates and bounds on waiting times in such a system. Our results rely on an analytical treatment of the underlying stochastic process, as well as numerical investigations using the matrix product state formalism.

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

QI 7.6 Wed 16:15 H8

Fiber communication with collective quantum measurements: a machine learning perspective with applications — •Matteo Rosati[1] and Janis Nötzel[2] — [1]Electrical Engineering and Computer Science, Technische Universität Berlin, 10587 Berlin, Germany — [2]1Emmy-Noether Gruppe Theoretisches Quantensystemdesign Lehrstuhl für Theoretische Informationstechnik Technische Universität München.

The transmission rate of classical bits on optical fiber is ultimately governed by the Holevo capacity. Achieving such rate requires writing information into coherent states of light and then performing a collective quantum measurement on multiple received signals at once, known as quantum joint-detection receiver (QJDR).

We find that the realization of a QJDR would enable two key advantages in current communication networks: (i) an estimated 55% decrease in energy consumption of optical amplifiers; (ii) an unbounded logarithmic growth of the channel capacity with the signal pulse rate, as opposed to the bounded rate attained by conventional detectors.

We then develop a machine learning framework to discover approximate implementations of the QJDR with a state-of-the-art photonic circuit. We compute the theoretical learning complexity of such photonic circuits, showing that it is polynomial in the number of optical modes, and introduce a simple algorithm to optimize them. Finally, we show that our algorithm is able to discover decoder setups that are both realizable at the state of the art and can attain a decoding success rate as high as 93% of the optimal QJDR.

15 min. break

QI 7.7 Wed 16:45 H8

A Graphical Formalism for Entanglement Purification — •Lina Vandré and Otfried Gühne — Universität Siegen, Germany

Hypergraph states form an interesting family of multi-qubit quantum states which are useful for quantum error correction, non-locality and measurement-based quantum computing. They are a generalisation of graph and cluster states. The states can be represented by hypergraphs, where the vertices and hyperedges represent qubits and entangling gates, respectively.

For quantum information processing, one needs high-fidelity entangled states, but in practice most states are noisy. Purification protocols address this problem and provide a method to transform a certain number of copies of a noisy state into single high-fidelity state. There exists a purification protocol for hypergraph states [1]. In my talk, I will first reformulate the purification protocol in a graphical manner, which makes it intuitively understandable. Based on this, I will propose systematic extensions, which naturally arise from the graphical formalism.

[1] T. Carle et al., Phys. Rev. A 87, 012328 (2013))

QI 7.8 Wed 17:00 H8

Quantum memories for space: from ideas to experimental roadmap — •Mustafa Gündoğan, Martin Jutisz, Elisa Da Ros, and Markus Krutzik — Humboldt-Universität zu Berlin, Berlin, Germany

Quantum communication is usually limited to around a few hundred kilometers due to the exponential losses in optical fibers. Quantum repeaters (QR) based on the heralded storage of entangled states have been proposed to overcome this direct transmission limit. However, they are still limited to around a few thousand kms. On the other hand, space-based quantum links where channel loss scales mainly polynomially offer another solution to this problem. In this case, however, the communication distance is limited to the line-of-sight distance of the satellite which is around 2000 km for low earth orbit. In order to reach truly global distances, we have recently proposed an architecture that combines the above two approaches [1]: a quantum repeater operating in space. We show that this scheme provides a three orders of magnitude faster entanglement distribution rate across global distances than ground-based and hybrid space-ground architectures.

In this talk, after summarizing our findings and presenting a comparison of our scheme with already existing architectures I will finish with presenting our experimental work towards building space-compatible quantum memories with warm and cold atomic gases.

[1] M. Gündoğan *et. al.*, npj Quantum Information **7**, 128 (2021)

(This work has been supported by DLR through the funds provided by BMWi: 50WM1958, 50WM2055 and 50RP2090.)

QI 7.9 Wed 17:15 H8

Employing Atomically-thin Single-Photon Sources in Quantum Communication — •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

Confined excitons in monolayers of transition metal dichalcogenides (TMDCs) emerged as a novel type of quantum emitter showing appealing prospects for large-scale and low-cost device integration for quantum information technologies. Here, we pioneer the practical suitability of TMDC devices in quantum communication by evaluating the performance of a single-photon source (SPS) based on a strain engineered WSe_2 monolayer for applications in quantum key distribution (QKD) [1]. Employed in a QKD-testbed emulating the BB84 protocol we achieve raw key rates of up to 66.95 kHz and antibunching values down to 0.034 - competitive with QKD experiments using semiconductor quantum dots or color centers in diamond [2]. Furthermore, we exploit routines for the performance optimization developed in our group. Our work thus sets the direction for wider applications of emerging materials in quantum information processing.

[1] T. Gao, M. v. Helversen, C. Anton-Solanas, C. Schneider, and T. Heindel, Atomically-thin Single-photon Sources for Quantum Communication, arXiv:2204.06427 (2022)
[2] D. Vajner et al., Adv. Quantum Technol. 2100116 (2022).

QI 7.10 Wed 17:30 H8

Restoring quantum communication efficiency over high loss optical fibres — •Francesco Anna Mele — Scuola Normale Superiore, Pisa, Italy

In the absence of quantum repeaters, quantum communication proved to be nearly impossible across optical fibres longer than approximately 20 km due to the drop of transmissivity below the critical threshold of 1/2. However, if the signals fed into the fibre are separated by a sufficiently short time interval, memory effects must be taken into account. In this talk we show that by properly accounting for these effects it is possible to devise schemes that enable unassisted quantum communication across arbitrarily long optical fibres at a fixed positive qubit transmission rate. We also demonstrate how to achieve entanglement-assisted communication over arbitrarily long distances at a rate of the same order of the maximum achievable in the unassisted noiseless case.

This talk is based on https://arxiv.org/abs/2204.13128 and https://arxiv.org/abs/2204.13129 .

QI 8: Quantum Sensors and Metrology

Time: Wednesday 15:00–17:45 Location: H9

Invited Talk QI 8.1 Wed 15:00 H9

Exploring Quantum Materials with Quantum Sensors — •Uri Vool — Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

In recent years, improvements in crystal growth and sample fabrication have given us access to an expanding variety of quantum materials which exhibit exotic macroscopic phenomena directly tied to the strong quantum effects in their microscopic structure. These are exciting for basic research and potential technology applications, but there are still fundamental open questions about the structure of such systems, and the ability to control their quantum effects.

Meanwhile, there has been rapid growth in the ability to control coherent quantum effects in various solid state systems, from atomic defects to macroscopic electromagnetic circuits. These quantum systems can be efficiently manipulated and tuned while maintaining high coherence, making them leading quantum computing platforms. These advantages also make them excellent quantum sensors, and their operation at cryogenic temperatures and material compatibility make them especially suited for exploring quantum materials.

This talk will present several recent and ongoing experiments using coherent quantum systems for material exploration. We will focus on two experimental techniques: 1. Nitrogen-vacancy centers as cryogenic scanning probes for imaging hydrodynamic electron flow. 2. Hybrid superconducting circuits as probes of the superconducting structure in novel materials. Finally, we will discuss the prospective of this approach for material exploration and quantum technology.

QI 8.2 Wed 15:30 H9

Fractional Josephson effect induced by weak measurement — •Mohammad Atif Javed, Jakob Schwibbert, and Roman-Pascal Riwar — Forschungszentrum Jülich, Peter Grünberg Institute (PGI-2), 52425, Jülich, Deutschland

The fractional Josephson effect is commonly directly linked to the presence of Majorana- and parafermions, which are important candidates to implement (universally) protected quantum gates in superconducting quantum hardware. However, these exotic particles still seem notoriously challenging to realize in experiment, and difficult to unambiguously identify via transport measurements. Moreover, a proper understanding of the topological transport properties requires a generalization to an open quantum system context.

Here, we study a standard quantum dot in proximity to two conventional superconducting contacts, including a weak transport measurement and a nonequilibrium quasiparticle source. The non-hermitian system dynamics are analysed by means of exceptional points, leading to a braiding of the complex eigenspectrum. Based on this analysis, we show that this system exhibits an open system version of a fractional Josephson effect, in spite of using only conventional materials.

QI 8.3 Wed 15:45 H9

Defects in semi-conductors for Quantum Applications — •SAJID ALI, Fabian Bertoldo, Simone Manti, and Kristian Thygesen — CAMD, Computational Atomic-Scale Materials Design, Department of Physics, Technical University of Denmark, 2800 Kgs. Lyngby Denmark

Discovery of single photon emission (SPE) from 2D materials has opened a new arena of research because of the unique electric, magnetic and optical properties possessed by these SPE*s systems. Based on these superiror properties, such systems provide very attractive platform that can help to realize, control, manipulate and measure individual quantum states. The defect systems with similar properties must be explored in other 2D materials, as this will broaden the range of materials available for such applications, consequently revolutionising this field. In the present work we have shortlisted/ the defect systems with optimal properties for various quantum applications e.g. qubits, quantum key distribution, brain magnetometers etc., based on our screening study of intrinsic point defects in dynamically and thermodynamically stable and non-magnetic host systems from C2DB database . We study various aspects and properties of these defect systems e.g. photoluminescence (PL) line shape, Transition dipole moment, Radiative recombination rates, Inter-system crossing rates, Hyperfine coupling parameters, Zero field splitting, Spin-Coherence times etc. We identify a set of defect systems, with ideal properties, which can be exploited for various quantum technologies.

QI 8.4 Wed 16:00 H9

Iterative adaptive spectroscopy with a two-level nanomechanical platform — •Avishek Chowdhury[1], Anh Tuan Le[1], Hugo Ribeiro[3], and Eva M. Weig[1,2] — [1]Department of Electrical and Computer Engineering, Technical University of Munich, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799, Munich, Germany — [3]Department of Physics and Applied Physics,University of Massachusetts Lowell, Lowell, MA 01854, USA

We develop an iterative, adaptive frequency sensing protocol based on Ramsey interferometry of a two-level system. Our scheme allows one to estimate unknown frequencies with a high precision from short, finite signals. It avoids several issues related to processing of decaying signals and reduces the experimental overhead related to sampling. High precision is achieved by enhancing the Ramsey sequence to prepare with high fidelity both the sensing and readout state and by using an iterative procedure built to mitigate systematic errors when estimating frequencies from Fourier transform. Furthermore, we implement the protocol to demonstrate a proof-of-principle study on a classical two-level nanomechanical platform. We demonstrate that the protocol can detect the coupling between two normal modes with an accuracy higher than their individual dissipation rate. Moreover, the protocol can detect small DC fluctuation of the surrounding electrical field around our nanomechanical oscillator.

QI 8.5 Wed 16:15 H9

Quantum enhancement of multiphoton absorption signals in nonlinear interferometers — •Shahram Panahiyan[1,2] and Frank Schlawin[1,2] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

SU(1,1)-interferometers are novel nonlinear interferometers [1] in which optical parametric amplifiers create quantum states of light by squeezing and anti-squeezing the light fields [2]. By taking advantage of these quantum states of light, SU(1,1)-interferometers have been employed for spectroscopy [3], imaging [4], quantum state engineering, and quantum information purposes.

Motivated by these applications, we study the precision of multiphoton absorption measurements in a nonlinear SU(1,1)-interferometer. We analyze multiphoton absorption signals, characterize the absorption as a function of nonlinear order, and derive sensitivity bounds from the Fisher Information. We show that the precision of multiphoton absorption measurements can be enhanced compared to classical measurement strategies. Finally, we highlight that this enhancement is robust against experimental imperfections in detection devices.

[1] M. V. Chekhova and Z. Y. Ou, Adv. Opt. Photon. 8, 104 (2016).

[2] S. Panahiyan, C. S. Muñoz, M. V. Chekhova, F. Schlawin, [arXiv:2205.10675].

[3] K. E. Dorfman, Light: Science & Applications 9, 123 (2020).

[4] M. Manceau et al., Phys. Rev. Lett. 119, 223604 (2017).

15 min. break

QI 8.6 Wed 16:45 H9

Multicopy metrology with many-particle quantum states — •Róbert Trényi[1,2,3], Árpád Lukács[1,4,3], Paweł Horodecki[5,6], Ryszard Horodecki[5], Tamás Vértesi[7], and Géza Tóth[1,2,8,3] — [1]Dept. of Theoretical Physics, U. of the Basque Country UPV/EHU, Bilbao, Spain — [2]DIPC, San Sebastián, Spain — [3]Wigner Research Centre for Physics, Budapest, Hungary — [4]Dept. of Mathematical Sciences, Durham University, United Kingdom — [5]International Centre for Theory of Quantum Technologies, University of Gdansk, Gdansk, Poland — [6]Faculty of Applied Physics and Mathematics, National Quantum Information Centre, Gdansk University of Technology, Gdansk, Poland — [7]Institute for Nuclear Research, Debrecen, Hungary — [8]IKERBASQUE, Bilbao, Spain

We consider quantum metrology with several copies of bipartite and multipartite quantum states. We characterize the metrological usefulness by determining how much the state outperforms separable states. We identify a large class of entangled states that become maximally useful for metrology in the limit of infinite number of copies. The maximally achievable metrological usefulness is attained exponentially fast in the number of copies. We show that, on the other hand, pure entangled states with even a small amount of white noise do not become maximally useful even in the limit of infinite number of copies. We also make general statements about the usefulness of a single copy of pure entangled states. We show that the multiqubit states presented in Hyllus et al. [Phys. Rev. A 82, 012337 (2010)], which are not useful, become useful if we embed the qubits locally in qutrits.

QI 8.7 Wed 17:00 H9

Quantum metrology in the non-asymptotic regime — •Johannes Jakob Meyer[1], Sumeet Khatri[1], Philippe Faist[1], Daniel Stilck-França[2], Giacomo Guarnieri[1], and Jens Eisert[1,3,4] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Univ Lyon, ENS Lyon, UCBL, CNRS, Inria, LIP, F-69342, Lyon Cedex 07, France — [3]Fraunhofer Heinrich Hertz Institute, 10587 Berlin, Germany — [4]Helmholtz-Zentrum Berlin für Materialien und Energie, 14109 Berlin, Germany

The main concern of quantum metrology is to determine how we can achieve the best possible precision in estimating parameters of physical processes. One of the main tools used in the field is the Quantum Cramér-Rao bound. However, it is a relation that is only tight and meaningful asymptotically and, conversely, too optimistic for finite numbers of experimental repetitions. We analyze how a change of perspective to an operationally motivated measure of estimation success can be used to achieve more meaningful bounds. We show that the measure can be evaluated using a semidefinite program and detail how it can be used to establish minimax guarantees against any prior distribution of the underlying parameter. We focus on the analysis of group-covariant estimation on pure states, which is relevant because of its relation to phase estimation. We prove that the optimal measurement in this setting is given by the pretty good measurement and exhibit a construction of a probe state that numerically saturates the optimal asymptotic minimax rate.

QI 8.8 Wed 17:15 H9

Gradient Magnetometry with Atomic Ensembles — •Iagoba Apellaniz[1], Iñigo Urizar-Lanz[1], Zoltán Zimborás[1,2,3], Philipp Hyllus[1], and Géza Tóth[1,2,4] — [1]Department of Physics, University of the Basque Country UPV/EHU, P. O. Box 644, E-48080 Bilbao, Spain — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [3]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary — [4]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain

We study gradient magnetometry with ensembles of atoms with arbitrary spin. We calculate precision bounds for estimating the gradient of the magnetic field based on the quantum Fisher information. For states that are sensitive to homogeneous fields, a simultaneous measurement is needed, as the homogeneous field must also be estimated.

We present a method to calculate precision bounds for gradient estimation with two spatially separated atomic ensembles. We also consider a single atomic ensemble with an arbitrary density profile, where the atoms cannot be addressed individually, and which is a very relevant case for experiments.

[1] I. Apellaniz *et al.*, Phys. Rev. A, **97** 053603 (2018)

[2] G. Vitagliano *et al.*, arXiv:2104.05663 (2021)

QI 8.9 Wed 17:30 H9

Ultra-low perturbation quantum measurements via random-time sampling — •Markus Sifft and Daniel Hägele — Ruhr

University Bochum, Faculty of Physics and Astronomy, Experimental Physics VI (AG), Germany

Random-time sampling of a quantum system is introduced as a new approach to continuous quantum measurements with prospects for ultra-low-perturbation measurements [1]. Random sampling is, e.g., naturally realized in an optical spin noise experiment when weak probe-laser light exhibits random single-photon events in the detector [2]. Our theory shows that a direct evaluation of these detector click events yields power spectra that are equivalent but not identical to those of the usual Gaussian continuous measurement regime [3]. Surprisingly, this holds true even for average sampling rates much lower than the typical frequency range of the measured quantum dynamics. The third-order quantum polyspectrum (bispectrum) also contains the same information as its continuous counterpart. System characterization can, therefore, be performed using the analytic form of the quantum polyspectra [4]. Many applications of random- time sampling are envisioned for high-resolution spectroscopy, circuit quantum electrodynamics, quantum sensing, and quantum measurements in general.

[1] https://arxiv.org/abs/2109.05862, [2] G. M. Müller et al., Physica E 43, 569 (2010), [3] M. Sifft et al., Phys. Rev. Res. 3, 033123 (2021) [4] D. Hägele et al., Phys. Rev. B 98, 205143 (2018)

QI 9: Quantum Correlations

Time: Thursday 9:30–12:15 Location: H8

QI 9.1 Thu 9:30 H8

Dimension-free entanglement detection in multipartite Werner states — •Felix Huber[1], Igor Klep[2], Victor Magron[3], and Jurij Volčič[4] — [1]Institute of Theoretical Physics, Jagiellonian University, 30-348 Kraków, Poland — [2]Faculty of Mathematics and Physics, University of Ljubljana, Slovenia — [3]LAAS-CNRS & Institute of Mathematics from Toulouse, France — [4]Department of Mathematical Sciences, University of Copenhagen, Denmark

Werner states are multipartite quantum states that are invariant under the diagonal conjugate action of the unitary group. We give a complete characterization of their entanglement that is independent of the underlying local Hilbert space: for every entangled Werner state there exists a dimension-free entanglement witness. The construction of such a witness is formulated as an optimization problem. To solve it, two semidefinite programming hierarchies are introduced. The first one is derived using real algebraic geometry applied to positive polynomials in the entries of a Gram matrix, and is complete in the sense that for every entangled Werner state it converges to an entanglement witness. The second one is based on a sum-of-squares certificate for the positivity of trace polynomials in noncommuting variables, and is a relaxation that involves smaller semidefinite constraints.

QI 9.2 Thu 9:45 H8

Constructing entanglement witnesses based on the Schmidt decomposition of operators — •Sophia Denker[1], Chengjie Zhang[2], Ali Asadian[3], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]School of Physical Science and Technology, Ningbo University, Ningbo, 315211, China — [3]Department of Physics, Institute for Advanced Studies in Basic Sciences (IASBS), Gava Zang, Zanjan 45137-66731, Iran

Characterizing entanglement is an important issue in quantum information, as entanglement is considered to be a resource for quantum key distribution or quantum metrology. One useful tool to detect and quantify entanglement are witness operators. A standard way to design entanglement witnesses for two or more particles is based on the fidelity of a pure quantum state; in mathematical terms this construction relies on the Schmidt decomposition of vectors. In this contribution, we present a method to build entanglement witnesses based on the Schmidt decomposition of operators. Our scheme works for the bipartite and the multipartite case and is found to be strictly stronger than the concept of fidelity-based witnesses. We discuss various examples and demonstrate that our approach can also be used to quantify quantum correlations as well as characterize the dimensionality of entanglement.

QI 9.3 Thu 10:00 H8

Nonlinear Entanglement Detection from Immanant Inequalities — •Albert Rico and Felix Huber — Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-348 Kraków, Poland

We develop a method for nonlinear entanglement detection which is based on inequalities for immanants. This allows to use multipartite witnesses to detect bipartite states in a non-conventional way. We give examples and compare their effectiveness to the standard usage of witnesses. We show that this type of nonlinear entanglement detection can outperform its linear version, and how the detection can be performed in the laboratory through randomized measurements.

QI 9.4 Thu 10:15 H8

The shape of higher-dimensional state space: Bloch ball analog for a qutrit — Christopher Eltschka[1], Marcus Huber[2,3], Simon Morelli[2,3], and •Jens Siewert[4,5] — [1]Institut für Theoretische Physik, Universität Regensburg, Regensburg, Germany — [2]IQOQI Vienna, Vienna, Austria — [3]Atominstitut TU Wien, Vienna, Austria — [4]University of the Basque Country UPV/EHU and EHU Quantum Center, Bilbao, Spain — [5]Ikerbasque, Basque Foundation for Science, Bilbao, Spain

The Bloch ball as a geometric representation of the state space for qubits is an ubiquitous tool to gain deeper insight and intuitive understanding of quantum-mechanical phenomena. Unfortunately, even for the next more complex system, the qutrit, such a geometric representation (rather than cross sections or projections) is not known. In order to serve as a model for higher-dimensional state space, it should display a number of desirable properties, such as different surface parts corresponding to pure or mixed states, convexity, inner and outer sphere with the corresponding radii, pure states should form a connected set, etc. [1]. We show that, based on the Bloch representation of qutrit states, such a model can be constructed that captures many of the geometric features discussed in Ref. [1].

[1] I. Bengtsson, S. Weis, K. Zyczkowski, Geometry of the Set of Mixed Quantum States: An Apophatic Approach. In: P. Kielanowski et al (eds) Geometric Methods in Physics. Trends in Mathematics (Birkhäuser, Basel, 2013).

QI 9.5 Thu 10:30 H8

Nearly optimal separability certification of quantum states — •Ties-Albrecht Ohst[1], Chau Nguyen[1], Otfried Gühne[1], and Xiao-Dong Yu[2] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen — [2]Department of Physics, Shandong University, Jinan

Entanglement describes the possibility of local parties sharing a joint global system state that cannot be expressed as a probabilistic mixture of locally prepared states. The question on whether some given state is entangled or separable, on the contrary, is generically difficult to answer. We present an algorithm for the quantum separability problem for intermediate dimensions with evidences of being nearly optimal. The basic idea of our considerations can in general be described by a systematic search for separable decompositions of a given state by polytope approximations to a local system. As a benchmark we can compute the separability thresholds for known bound entangled states of two coupled qutrits with an accuracy that has not been achieved before. Also, for bi-partite systems of higher dimension we can certify the separability of states reliably which follows from the comparison with data by known entanglement criteria. For three coupled qubit systems, our ideas allow for an efficient distinction between different separability classes that lie at the heart of the theory of multi-partite entanglement. We developed an algorithm for the search among all fully bi-separable states to find the one whose entanglement robustness is as large as possible. Quite interestingly, the obtained states show a deep connection to the post measurement states in the teleportation protocol.

QI 9.6 Thu 10:45 H8

Hilbert-Schmidt geometry of two-qubit correlations — •Santiago Llorens[1] and Jens Siewert[2,3] — [1]Grup d'Informació Quàntica, Universitat Autònoma de Barcelona, Barcelona, Spain — [2]University of the Basque Country and EHU Quantum Center, Bil-

bao, Spain — [3]Ikerbasque, Basque Foundation for Science, Bilbao, Spain

The Bloch representation of quantum states endows the state space with a natural Euclidean geometry via the Hilbert-Schmidt scalar product. Based on this, a Bloch ball-type global view of the state space for a qutrit was found recently. This imposes the question whether an analogous method exists for the simplest quantum correlations – those in a system of two qubits. From such a visualization one may expect a better understanding of the links between the algebraic correlation constraints and their geometric background. We show that indeed the 2-sector (aka as the correlation tensor) of two-qubit states allows for a geometric representation of the algebraic constraints to the entries of the Bloch vector. In this context we provide novel insight into the relation between entanglement quantifiers and characteristic parameters of the Bloch representation of bipartite systems.

15 min. break

QI 9.7 Thu 11:15 H8

Schmidt number witnesses for high-dimensional quantum states in photonic temporal mode setups — •Nikolai Wyderka[1], Giovanni Chesi[2], Hermann Kampermann[1], and Dagmar Bruss[1] — [1]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany — [2]Istituto Nazionale di Fisica Nucleare Sezione di Pavia, Via Agostino Bassi 6, I-27100 Pavia, Italy

Photonic temporal modes offer a robust and efficient toolbox for high-dimensional quantum information applications. In order to characterize the experimentally generated quantum states, we aim to use witnesses to certify their Schmidt numbers as a robust entanglement measure. To that end, we develop an iterative algorithm that yields Schmidt number witness candidates that require only a few of those measurements inherent to the temporal mode framework using quantum pulse gates. Finally, we use the numerical candidates to derive a proper Schmidt number witness for states close to the maximally entangled state.

QI 9.8 Thu 11:30 H8

Complete hierarchy for high-dimensional steering certification — •Carlos de Gois, Martin Plávala, and Otfried Gühne — Naturwissenschaftlich Technische Fakultät, Universität Siegen

Steerability can be employed as a semi-device independent test of the Schmidt number. As such, it is a promising component in quantum informational protocols that make use of entanglement dimension certification. Recently proposed and experimentally demonstrated for the special case in which the assemblage is prepared from two choices of measurements, high-dimensional steering is so far lacking a general certification procedure. Herein, we provide necessary and, at a limit, sufficient conditions to certify the entanglement dimension of a steering assemblage. These conditions are stated in terms of a hierarchy of semidefinite programs, which can also be used to compute the steering dimension robustness.

QI 9.9 Thu 11:45 H8

Distance-based resource quantification for sets of quantum measurements — •Lucas Tendick, Martin Kliesch, Hermann Kampermann, and Dagmar Bruss — Institute for Theoretical Physics, Heinrich Heine University Düsseldorf, D-40225 Düsseldorf, Germany

The advantage that quantum systems provide for certain quantum information processing tasks over their classical counterparts can be quantified within the general framework of resource theories. Certain distance functions between quantum states have successfully been used to quantify resources like entanglement and coherence. Perhaps surprisingly, such a distance-based approach has not been adopted to study resources of quantum measurements, where other geometric quantifiers are used instead. Here, we define distance functions between sets of quantum measurements and show that they naturally induce resource monotones for convex resource theories of measurements. By focusing on a distance based on the diamond norm, we establish a hierarchy of measurement resources and derive analytical bounds on the incompatibility of any set of measurements. We show that these bounds are tight for certain projective measurements based on mutually unbiased bases and identify scenarios where different measurement resources attain the same value when quantified by our resource monotone. Our results provide a general framework to compare distance-based resources for sets of measurements and allow us to obtain limitations on Bell-type experiments.

QI 9.10 Thu 12:00 H8

On entanglement swapping and teleportation with local hidden variables — •Eugen Muchowski — Primelstrasse 10, 85591 Vaterstetten

A model with local hidden variables is presented, which describes phenomena such as entanglement swapping and teleportation and also reproduces the quantum mechanical expectation values for the measurement of entangled photons. It refutes Bell's theorem and at the same time expands our physical understanding of entangled states since it can also explain the phenomena mentioned above.

QI 10: Quantum Simulation and Many-Body Systems

Time: Thursday 9:30–12:15 Location: H9

Invited Talk QI 10.1 Thu 9:30 H9

Entanglement Transition in the Projective Transverse Field Ising Model — •Hans Peter Büchler — Institut für theoretische Physik III, Universität Stuttgart

Discrete quantum trajectories of systems under random unitary gates and projective measurements have been shown to feature transitions in the entanglement scaling that are not encoded in the density matrix. Here we present the projective transverse field Ising model, a stochastic model with two noncommuting projective measurements and no unitary dynamics, and demonstrate the appearance of an entanglement transition. This transition is connected to quantum error correction, and we demonstrate the most efficient decoding of stored quantum information. Especially, we show that the ability to retrieve stored quantum information can serve as an experimental tool to detect such entanglement phase transitions.

QI 10.2 Thu 10:00 H9

Efficient Quantum Computation of Floquet Hamiltonians — •Benedikt Fauseweh[1] and Jian-Xin Zhu[2,3] — [1]Institute for Software Technology, German Aerospace Center (DLR), Germany — [2]Theoretical Division, Los Alamos National Laboratory, USA — [3]Center for Integrated Nanotechnologies, Los Alamos National Laboratory, USA

The Floquet formalism describes the control over quantum systems using external periodic fields. With recent advances in ultrafast spectroscopy of solid-state systems, Floquet engineering, that is, a targeted design of quantum systems driven by laser pulse, has led to an increasing interest in computational methods that can simulate light-matter interactions. Although the perturbative regime, in which the fundamental driving frequency is much larger than the energy bandwidth of the quantum system, shows interesting phenomena, it is the non-perturbative regime that presents the most exciting opportunity to study the interplay with strong correlations and which remains largely unexplored. Here we describe hybrid quantum algorithms that make use of quantum computers to tackle this problem. The required quantum resources are within reach for current day NISQ devices and allow the efficient computation of Floquet Hamiltonians. We demonstrate applications of these algorithms and discuss their performance for small scale driven quantum systems.

This work was carried out under the auspices of the U.S. DOE NNSA (Contract No. 89233218CNA000001) and was supported by the LANL LDRD Program.

QI 10.3 Thu 10:15 H9

Noise-utilizing quantum simulation of a system coupled to a structured bath — •Juha Leppäkangas, Nicolas Vogt, Kirsten Bark, Keith Fratus, Jan-Michael Reiner, Sebastian Zanker, and Michael Marthaler — HQS Quantum Simulations GmbH, Haid-und-Neu-Strasse 7, 76131 Karlsruhe, Germany

We consider noisy gate-based quantum computers for the purpose of simulating the spin-boson model. We establish a bosonic bath by an ensemble of qubits with finite coherence times. The energy-level broadening of qubits is mapped to broadening of the simulated bath spectral function. We study how desired forms of the spectral density can be constructed by optimizing simulated spin-bath couplings and bath energies. We study the effect of different gate decompositions and system connectivity on the quality of the mapping to the desired form. In the ideal situation, the spin-bath couplings can be decomposed using only variable angle two-qubit gates, such as a variable Mølmer-Sørensen gate. In other cases, qubit noise can get mapped to two-body noise in the simulated spin-bath system, which does not have exact correspondence in the spin-boson model. We show a numeric comparison of the quality of the mapping for various decompositions. Furthermore we compare the full inclusion of the two-body noise terms with an approximate mapping of the effects on the spectral density of the simulated spin-boson problem.

QI 10.4 Thu 10:30 H9

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

The generation of spatially distributed entanglement is important for the realization of quantum information protocols and quantum computing, leading to new fields of research like quantum machine learning. 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 10.5 Thu 10:45 H9

Probing confinement in a $\mathbb{Z}_2$ lattice gauge theory on a quantum computer — •Julius Mildenberger[1], Wojciech Mruczkiewicz[2], Jad Halimeh[3,4], Zhang Jiang[2], and Philipp Hauke[1] — [1]INO-CNR BEC Center and Department of Physics, University of Trento, Italy — [2]Google Quantum AI, Venice, CA, USA — [3]Department of Physics and ASC, Ludwig-Maximilians-Universität München, Germany — [4]MCQST, Munich, Germany

Digital quantum simulators provide a table-top platform for addressing salient questions in particle and condensed-matter physics. A particularly rewarding target is given by lattice gauge theories. Their constituents, e.g., charged matter and the electric gauge field, are governed by local gauge constraints, which are highly challenging to engineer and lead to intriguing yet not fully understood features such as confinement of particles. We simulate confinement dynamics in a $\mathbb{Z}_2$ LGT on a superconducting quantum chip. The charge–gauge-field interaction is synthesized using only 6 native two-qubit gates, enabling us to reach simulation times of up to 25 Trotter steps. We observe how tuning a term that couples only to the electric field confines the charges, a manifestation of the tight bond that the local gauge constraint generates between both. Moreover, we study a different mechanism, where a modification of the gauge constraint from $\mathbb{Z}_2$ to $U(1)$ symmetry freezes the system dynamics. Our work showcases the strong restriction that the underlying gauge constraint imposes on the dynamics of an LGT, illustrates how gauge constraints can be modified and protected, and paves the way for studying other models with many-body interactions.

15 min. break

QI 10.6 Thu 11:15 H9

Quantum Information Scrambling in Thermalizing Spin Chains with Nonlocal Interactions — •Darvin Wanisch[1,2,3] and Stephan Fritzsche[1,2,3] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Motivated by recent works on information scrambling in spin systems with nonlocal interactions, and their potential of sharing features of quantum gravity, we study scrambling in different variants of the Ising model. Our results demonstrate that out-of-time-order correlators (OTOCs) might not be sufficient to properly characterize information scrambling in the presence of nonlocal interactions. In particular, two models that exhibit a highly nonlinear lightcone can vary widely in their thermalization timescale. More elaborate measures of operator growth can distinguish these two scenarios and reveal very different operator dynamics. Moreover, we find a distinct analogy between the growth of a local operator under time-evolution and the entanglement entropy following a quantum quench. Our work gives new insights into scrambling properties of systems that are within reach of state-of-the-art experimental platforms and complements results on the possibility of observing features of quantum gravity in the laboratory.

QI 10.7 Thu 11:30 H9

Quantum simulation of $\mathbb{Z}_2$ lattice gauge theories with dynamical matter from two-body interactions in $(2+1)$D — •Lukas Homeier[1,2,3], Annabelle Bohrdt[3,4], Simon Linsel[1,2], Eugene Demler[5], Jad C. Halimeh[1,2], and Fabian Grusdt[1,2] — [1]LMU Munich, Germany — [2]MCQST, Munich, Germany — [3]Harvard University, Cambridge (MA), USA — [4]ITAMP, Cambridge (MA), USA — [5]ETH Zurich, Switzerland

Gauge fields coupled to dynamical matter are a universal framework in many disciplines of physics, ranging from particle to condensed matter physics, but remain poorly understood at strong couplings. Through the steadily increasing control over numerically inaccessible Hilbert spaces, analog quantum simulation platforms have become a powerful tool to study interacting quantum many-body systems. Here we propose a scheme in which a $\mathbb{Z}_2$ gauge structure emerges from local two-body interactions and one-body terms in two spatial dimensions. The scheme is suitable for Rydberg atom arrays and enables the experimental study of both $(2+1)$D $\mathbb{Z}_2$ lattice gauge theories coupled to dynamical matter ($\mathbb{Z}_2$ mLGTs) and quantum dimer models on the honeycomb lattice, for which we derive effective Hamiltonians. We discuss ground-state phase diagrams of the experimentally relevant effective $\mathbb{Z}_2$ mLGT for $U(1)$ and quantum-$\mathbb{Z}_2$ matter featuring deconfined phases. Our proposed scheme allows to experimentally study not only longstanding goals of theoretical physics, such as Fradkin and Shenker's [PRD 19, 1979] conjectured phase diagram, but also go beyond regimes accessible with current numerical techniques.

QI 10.8 Thu 11:45 H9

Digital quantum simulation of the BCS model with a central-spin-like quantum processor — •Jannis Ruh, Regina Finsterhoelzl, and Guido Burkard — University of Konstanz, Konstanz, Germany

The simulation of quantum systems is one of the most promising applications of quantum computers. We present a quantum algorithm to perform digital quantum simulations of the Bardeen-Cooper-Schrieffer (BCS) superconductivity model on a quantum register with a star shaped connectivity map, as it is, e.g., featured by color centers in diamond. We show how to effectively translate the problem onto the quantum computer and implement the algorithm using only the native interactions between the qubits. Furthermore, we use the algorithm to simulate the dynamics of the BCS model by subjecting its mean-field ground state to a time-dependent perturbation. The quantum simulation algorithm is studied using a classically simulated quantum computer.

QI 10.9 Thu 12:00 H9

Characterizing quantum correlations among magnons in antiferromagnets
— •Vahid Azimi Mousolou[1,2], Yuefei Liu[3], Anders Bergman[1], Anna Delin[3], Olle Eriksson[1,4], Manuel Pereiro[1], Danny Thonig[4], and Erik Sjöqvist[1] — [1]Uppsala University, Uppsala, Sweden — [2]University of Isfahan, Isfahan, Iran — [3]KTH Royal Institute of Technology, Stockholm, Sweden — [4]Örebro University, Örebro, Sweden

Quantum magnonics provides promising hybrid platforms for accessing unique quantum phenomena and using them to realize stable and energy-efficient nanoscale quantum technologies. Clearly, quantum correlations are the major non-classical resources in such quantum systems. Here we discuss how an antiferromagnetic coupling generates experimentally detectable bipartite continuous variable magnon-entanglement [1, 2]. We present feasible experimental setups based on hybrid magnon+X systems to quantify the demonstrated magnon-entanglement through an uncertainty relation.

[1] V. Azimi-Mousolou, et al., Hierarchy of magnon mode entanglement in antiferromagnets, Phys. Rev. B 102, 224418 (2020).
[2] V. Azimi-Mousolou, et al., Magnon-magnon entanglement and its quantification via a microwave cavity, Phys. Rev. B 104, 224302 (2021).

QI 11: Members' Assembly

Time: Thursday 14:00–15:00 Location: H8

All members of the Quantum Information Division are invited to participate.

QI 12: Quantum Computing and Algorithms

Time: Thursday 15:00–18:15 Location: H8

QI 12.1 Thu 15:00 H8

Partitioning methods for solving optimization problems on NISQ-devices — •Federico Dominguez[1], Kaonan Campos Micadei[1], Christian Ertler[1], and Wolfgang Lechner[1,2] — [1]Parity QC Germany GmbH, Munich, Germany — [2]Institute for Theoretical Physics, LFUI, and Parity QC GmbH, Innsbruck, Austria

Partitioning methods are hybrid quantum-classical algorithms aimed at overcoming the memory limitations of current quantum devices. These methods decompose large problems into smaller pieces suitable for running on small quantum devices. The partial solutions to the problem are recombined using classical algorithms that can deal with both the error from the partition approximation and the intrinsic errors of the NISQ devices.

In this work, we solve optimization problems by developing partitioning methods based on the Parity encoding [1,2] and we benchmark the results using simulated quantum annealing. The Parity transformation is capable of encoding all-to-all graphs, hypergraphs, and side conditions of optimization problems using only local qubit interactions and allowing for a high gate parallelizability and hence scalability [3,4]. The resulting locality property is especially suited for the partitioning approach. The performance of our method shows that large optimization problems can be efficiently run on small quantum devices. [1] Lechner, W. et al. (2015). Science advances,1(9), e1500838. [2] Ender, K. et al. (2021).arXiv preprint arXiv:2105.06233. [3] Lechner, W. (2020). IEEE Transactions on Quantum Engineering,1, 1-6. [4] Drieb-Schön, M. et al. (2021). arXiv preprint arXiv:2105.06235.

QI 12.2 Thu 15:15 H8

Calculation of Correlated Electronic States on Noisy Intermediate Scale Quantum Computers — •Jannis Ehrlich[1], Daniel Urban[1], and Christian Elsässer[1,2] — [1]Fraunhofer-Institut für Werkstoffmechanik IWM, Freiburg, Germany — [2]Freiburger Materialforschungszentrum, Universität Freiburg, Germany

The numerical description of correlated electrons on conventional computers is limited to small system sizes. For the exact diagonalization approach, for example, all configurations in the many-particle space have to be considered, and their number grows exponentially with the number of one-particle states. This limitation can be overcome by simulating the correlated electrons with one of the artificial quantum systems that recently became available through the advance in quantum computing technologies. On such systems, each one-particle state can be represented by one qubit, which can be entangled with each other to generate superpositions. Thus, a linear scaling in the number of qubits is sufficient to cover the full many-particle space. Here, we describe strongly correlated systems within the dynamical mean-field theory (DMFT) and investigate its possible realization on a quantum computer. As a proof of concept, we study the simplified version of two-site DMFT both, by using simulators and an IBMQ quantum computer. We show that a solution of this model can be obtained using the quantum-classical variational quantum eigensolver (VQE). As the quality of the results is limited by the noise level of current quantum computers (NISQ type), we further investigate how different error mitigation strategies can improve the results.

QI 12.3 Thu 15:30 H8

Optimal gradient estimation for variational quantum algorithms — •Lennart Bittel, Jens Watty, and Martin Kliesch — Heinrich Heine Universität, Düsseldorf

Variational quantum algorithms (VQAs) are a leading approach for achieving a practically relevant near-term quantum advantage. A bottleneck of this approach is the estimation of derivatives of a given energy functional w.r.t. the parameters of the underlying variational quantum circuit. The parameter shift rule and its extensions allow for such and estimation without systematic errors. However, due to the measurement shot noise, they can have a large statistical error. As a consequence, many measurement rounds are required, which result in non-optimal VQA run-times.

In this work, we reduce this measurement overhead by using a Bayesian estimation framework. For this, we use prior knowledge about the circuit to then determine optimal measurement settings that minimize the expected statistical and systematic errors simultaneously. With accurate priors, this approach can significantly outperform traditional methods. We test our estimation algorithm numerically for a common quantum approximate optimization algorithm (QAOA). For a desired estimation accuracy we can reduce the number of measurements by an order of magnitude compared to traditional estimation methods. This also leads to significantly improved convergence times for the gradient descent algorithm.

QI 12.4 Thu 15:45 H8

Synthesis of and compilation with time-optimal multi-qubit gates — •Pascal Bassler[1], Matthias Zipper[1], Christopher Cedzich[1], Patrick Huber[2], Michael Johanning[2], Markus Heinrich[1], and Martin Kliesch[1] — [1]Heinrich Heine University Düsseldorf, Germany — [2]University of Siegen, Germany

We develop a method to synthesize a class of entangling multi-qubit gates for a quantum computing platform with fixed Ising-type interaction with all-to-all connectivity. The only requirement on the flexibility of the interaction is that it can be switched on and off for individual qubits. Our method yields a time-optimal implementation of the multi-qubit gates. We numerically demonstrate that the total multi-qubit gate time scales approximately linear in the number of qubits. Using this gate synthesis as a subroutine, we provide compilation strategies for important use cases: (i) we show that any Clifford circuit on n qubits can be implemented using at most n multi-qubit gates without requiring ancilla qubits, (ii) we decompose the quantum Fourier transform in a similar fashion, (iii) we compile a simulation of molecular dynamics into native gates, and (iv) we propose a method for the compilation of diagonal unitaries with time-optimal multi-qubit gates, as a step towards general unitaries. As motivation, we provide a detailed discussion on a microwave controlled ion trap architecture with magnetic gradient induced coupling (MAGIC) for the generation of the Ising-type interactions.

QI 12.5 Thu 16:00 H8

Estimating molecular forces and other energy gradients efficiently on a quantum computer — •Michael Streif[2], Thomas O'Brien[1], Nicholas C. Rubin[1], Raffaele Santagati[2], Yuan Su[1], William J. Huggins[1], Joshua J. Goings[1], Nikolaj Moll[2], Elica Kyoseva[2], Matthias Degroote[2], Christofer S. Tautermann[3], Joonho Lee[1,4], Dominic W. Berry[5], Nathan Wiebe[6,7], and Ryan Babbush[1] — [1]Google Research, USA — [2]Quantum Lab, Boehringer Ingelheim, Germany — [3]Boehringer Ingelheim Pharma GmbH & Co KG, Germany — [4]Department of Chemistry, Columbia University, USA — [5]Department of Physics and Astronomy, Macquarie University, Australia — [6]Department of Computer Science, University of Toronto, Canada — [7]Pacific Northwest National Laboratory, USA

The calculation of energy derivatives underpins many fundamental properties for molecular systems, such as dipole moments or molecular forces. Nevertheless, most methods for quantum chemistry on quantum computers have focused on electronic structure calculations, even though energy derivatives are fundamental for many practical applications. Here, I will introduce quantum algorithms for the calculation of energy derivatives on noisy intermediate scale (NISQ) and fault tolerant (FTQC) quantum computers, with substantially reduced cost compared to previous methods. Our results suggest that the calculation of molecular forces has a similar cost to estimating energies. However, since molecular dynamics (MD) simulations typically require millions of force calculations, current known methods for MD on quantum computers are impractical and new approaches need to be found.

QI 12.6 Thu 16:15 H8

Towards the Simulation of Large Scale Protein-Ligand Interactions on NISQ-era Quantum Computers — •Nikolaj Moll[1], Fionn D. Malone[2], Robert M. Parrish[2], Alicia R. Welden[2], Thomas Fox[3], Matthias Degroote[1], Elica Kyoseva[1], Raffaele Santagati[1], and Michael Streif[1] — [1]Quantum Lab, Boehringer Ingelheim, 55218 Ingelheim, Germany — [2]QC Ware Corporation, Palo Alto, CA, 94301, USA — [3]Medicinal Chemistry, Boehringer Ingelheim Pharma GmbH & Co. KG, 88397 Biberach, Germany

Most quantum computing research for quantum chemistry applications has focused on the calculation of ground state energies, while in the pharmaceutical industry, one is often more interested in gaining insight into the interaction of drugs and proteins. The interaction energy together with entropic contributions allows the determination of the efficacy of a potential drug. Here we explore the use of symmetry-adapted perturbation theory (SAPT) as a simple means to compute interaction energies between two molecular systems with a hybrid method combing NISQ-era quantum and classical computers. From the one- and two-particle reduced density matrices of the monomer wavefunctions obtained by the variational quantum eigensolver (VQE), we compute SAPT contributions to the interaction energy. At first order, this energy yields the electrostatic and exchange contributions for non-covalently bound systems. Ideal statevector simulations show that the SAPT(VQE) interaction energy components display orders of magnitude lower absolute errors than the corresponding VQE total energies which sub kcal/mol accuracy in the SAPT interaction energies.

15 min. break

QI 12.7 Thu 16:45 H8

Resilience of quantum approximate optimization against correlated errors — Joris Kattemölle and •Guido Burkard — Universität Konstanz, Konstanz, Deutschland

The Quantum Approximate Optimization Algorithm (QAOA) has the potential of providing a quantum advantage in large-scale optimization problems, as well as in finding the ground state of spin glasses. This algorithm is especially suited for Noisy Intermediate Scale Quantum (NISQ) devices because of its noise resilience. So far, this noise resilience has only been studied under the assumption of uncorrelated noise. However, in recent years, it has become increasingly clear that the noise impacting NISQ devices is significantly correlated. In this work, we introduce a model for both spatially and temporally (non-Markovian) correlated errors that allows for the independent variation of the marginalized local error probability and the correlation strength. Using this model, we study the effects of noise correlations on QAOA by full density matrix simulation. We find evidence that the performance of QAOA improves as the strength of noise correlations is increased at fixed marginalised local error probability. This shows that, as opposed to algorithms for fully error-corrected quantum computers, noise correlations need not be detrimental for NISQ algorithms such as QAOA, and may actually improve the performance thereof.

QI 12.8 Thu 17:00 H8

Exploiting symmetry in variational quantum machine learning — Johannes Jakob Meyer[1], Marian Mularski[1,2], Elies Gil-Fuster[1,3], •Antonio Anna Mele[1], Francesco Arzani[1], Alissa Wilms[1,2], and Jens Eisert[1,3,4] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Porsche Digital GmbH, 71636 Ludwigsburg, Germany — [3]Fraunhofer Heinrich Hertz Institute, 10587 Berlin, Germany — [4]Helmholtz-Zentrum Berlin für Materialien und Energie, 14109 Berlin, Germany

Variational quantum machine learning is an extensively studied NISQ application. The success of variational quantum learning models crucially depends on finding a suitable parametrization of the model that encodes an inductive bias relevant to the learning task. However, little is known about guiding principles for constructing suitable parametrizations. We explore when and how symmetries of the learning problem can be exploited to construct quantum learning models with outcomes invariant under the symmetry of the learning task. Using tools from representation theory, we show how a standard gateset can be transformed into an equivariant one that respects the symmetries of the problem through a process of symmetrization. We benchmark the proposed methods on two toy problems that feature a non-trivial symmetry and observe a substantial increase in generalization performance. As our tools can also be applied in a straightforward way to other variational problems with symmetric structure, we show how equivariant gatesets can be used in variational quantum eigensolvers.

QI 12.9 Thu 17:15 H8

Preparation of Hardware-Efficient Graph States on IBM QX — •Sebastian Brandhofer[1], Jelena Mackeprang[2], Daniel Bhatti[2], Ilia Polian[1], and Stefanie Barz[2] — [1]Institute of Computer Architecture and Computer Engineering & IQST, University of Stuttgart, Germany — [2]Institute for Functional Matter and Quantum Technologies & IQST, University of Stuttgart, Germany

Near-term quantum computers are characterized by heterogeneous errors that occur at a high rate, a short decoherence time, and a limited number of qubits. Preparing a quantum state on these near-term quantum computers must be performed with these limitations in mind. Especially, when preparing highly entangled multi-qubit quantum states one would like to reach quantum state fidelities as high as possible. For this, the quantum state preparation algorithm needs to be adapted to the specific quantum hardware and the respective limitations. In this work, a method is proposed for determining the optimal preparation algorithm of a specific class of graph states. The proposed method is based on one of the winning submissions to the 2020 IBM Quantum's Open Science Prize - Graph State Challenge.

QI 12.10 Thu 17:30 H8

A single T-gate makes distribution learning hard — Marcel Hinsche[1], Marios Ioannou[1], •Alexander Nietner[1], Jonas Haferkamp[1], Yihui Quek[1], Dominik Hangleiter[2], Jean-Pierre Seifert[3], Jens Eisert[1,4,5], and Ryan Sweke[1] — [1]FU Berlin, 14195 Berlin, Germany — [2]University of Maryland, MD 20742, USA — [3]TU Berlin, 10587 Berlin, Germany — [4]Helmholtz-Zentrum Berlin, 14109 Berlin, Germany — [5]Fraunhofer Heinrich Hertz Institute, 10587 Berlin, Germany

The task of probabilistic modelling is at the core of many practical applications. As such, the efficient learnability of natural classes of probability distributions is a question of both fundamental and practical interest. The output distributions of local quantum circuits is a particularly interesting class of distributions, of key importance both to quantum advantage proposals and a variety of quantum machine learning algorithms. In this work, we provide an extensive characterization of the learnability of the output distributions of local quantum circuits. We prove that the density modelling problem can be solved efficiently in case of Clifford circuits, while adding a single T gate renders the task computationally hard. Evidently, the simulability of this class does not imply its learnability. Next we show that the generative modelling task is hard for depth $n^{\Omega(1)}$ universal local quantum circuits for both, classical and quantum algorithms. Finally we obtain a similar hardness result already for depth $\omega(\log(n))$ local Clifford circuits when restricting to practically relevant learning algorithms, such hybrid-quantum classical algorithms.

QI 12.11 Thu 17:45 H8

Avoiding barren plateaus via transferability of smooth solutions in Hamiltonian Variational Ansatz — Antonio Anna Mele[1,2], Glen Bigan Mbeng[3], Giuseppe Ernesto Santoro[2], Mario Collura[2], and •Pietro Torta[2] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]SISSA, Via Bonomea 265, I-34136 Trieste, Italy — [3]Universität Innsbruck, Technikerstraße 21 a, A-6020 Innsbruck, Austria

A large ongoing research effort focuses on Variational Quantum Algorithms (VQAs), representing leading candidates to achieve computational speed-ups on current quantum devices. The scalability of VQAs to a large number of qubits, beyond the simulation capabilities of classical computers, is still debated. Two major hurdles are the proliferation of low-quality variational local minima, and the exponential vanishing of gradients in the cost function landscape, a phenomenon referred to as barren plateaus. Here we show that, by employing iterative search schemes one can effectively prepare the ground state of paradigmatic quantum many-body models, circumventing also the barren plateau phenomenon. This is accomplished by leveraging the transferability to larger system sizes of iterative solutions, displaying an intrinsic smoothness of the variational parameters, a result that does not extend to other solutions found via random-start local optimization. Our scheme could be directly tested on near-term quantum devices, running a refinement optimization in a favorable local landscape with non-vanishing gradients.

QI 12.12 Thu 18:00 H8

Hay from the haystack: explicit examples of exponential quantum circuit complexity — •Yifan Jia and Michael M. Wolf — Department of Mathematics, Technische Universität München, Germany

The vast majority of quantum states and unitaries have circuit complexity exponential in the number of qubits. In a similar vein, most of them also have exponential minimum description length, which makes it difficult to pinpoint examples of exponential complexity. In this work, we construct examples of constant description length but exponential circuit complexity. We provide infinite families such that each element requires an exponential number of two-qubit gates to be generated exactly from a product and where the same is true for the approximate generation of the vast majority of elements in the family. The results are based on sets of large transcendence degree and discussed for tensor networks, diagonal unitaries and maximally coherent states.

QI 13: Implementations: Superconducting Qubits

Time: Friday 9:30–12:45 Location: H8

Invited Talk QI 13.1 Fri 9:30 H8

Scalable control of superconducting qubits — •Stefan Filipp — Walther-Meissner-Institut, 85748 Garching — TU Munich, Physics-Department, 85748 Garching

The rapid development of quantum technologies in the recent past has led to the realization of first quantum computer prototypes that promise to outperform conventional computers in specific types of problems. However, before practical real-life problems can be solved efficiently on quantum computers we have to still tackle numerous challenges not only to enhance the coherence, but also the control of qubits. To improve the fidelity of single qubit operations we utilize closed-loop optimization methods based on high duty-cycle measurements. With piecewise-constant pulse parameterizations we are able to demonstrate short, 4ns single-qubit pulses with high fidelity and low leakage. We further explore architectures that contain 'hidden' qubits, which are not directly addressable, and experimentally demonstrate full control and measurement capabilities of such a hidden qubit. I will then discuss the impact of such restricted control capabilities on the performance of specific qubit coupling networks. I will further preview promising future directions such as the use of adiabatic gates for quantum feed-forward neural networks and multi-qubit gate operations for the efficient implementation of quantum algorithms as part of the newly formed Munich Quantum Valley, a cross-disciplinary initiative to realize a full-stack quantum computer.

QI 13.2 Fri 10:00 H8

Test and diagnostics speed up for characterizing few-qubit superconducting quantum processors — •Thorsten Last, Garrelt Alberts, Adam Lawrence, Kelvin Loh, Viacheslav Ostroukh, and Adriaan Rol — Orange Quantum Systems B.V., Lorentzweg 1, 2628 CJ Delft, NL

The combined challenge of increasing the qubit count on a quantum processor and a requirement to further reduce the qubit's error rates require novel approaches in test and qubit diagnostics. An important aspect to improve the situation is an acceleration of the development cycle for quantum processors [1]. Here we present benchmarking and diagnostic tools based on the recently established open-source platform Quantify [2] to perform end-to-end data analytics. Structured (human-assisted) characterization and a gradual enhancement of automation already led to a reduction of time for basic qubit diagnostics from months to days. The diagnostic tools for characterizing small scale superconducting quantum processors are available as software packages or fully integrated into room temperature electronic control racks. They are organized in complexity classes ranging from hardware verification, and basic single-qubit analytics up to the level of algorithmic benchmarking. Besides quantum processor diagnostics these tools are also used for full-stack system verification through experiment. [1] G.J.N. Alberts, et al., EPJ Quantum Technol. 8: 18 (2021). [2] https://quantify-quantify-core.readthedocs-hosted.com/en/0.5.3_a/

QI 13.3 Fri 10:15 H8

How to correctly account for time-varying fluxes in superconducting circuits — •Ahmed Kenawy[1], Fabian Hassler[2], David DiVincenzo[1], and Roman Riwar[1] — [1]Peter Grünberg Institute, Theoretical Nanoelectronics, Forschungszentrum Jülich — [2]JARA-Institute for Quantum Information, RWTH Aachen University

Time-varying fluxes are a ubiquitous tool to control superconducting hardware. Surprisingly, however, the existing literature has never fully accounted for the electro-motive force induced by the magnetic field. Here, we propose a general recipe to construct a low-energy Hamiltonian, taking as input only the circuit geometry and the solution of the external magnetic fields. We apply this recipe to the example of a dc SQUID and show that the assignment of individual capacitances to each Josephson junction is possible only if we permit those capacitances to be negative, time-dependent, or even momentarily singular. Such anomalous capacitances lead, among others, to a strong enhancement of qubit relaxation rates. Then, we tackle the problem of driven topological quantum circuits, focusing on two weakly coupled Kitaev chains and study how the electro-motive force modifies the time-dependent fractional Josephson effect.

QI 13.4 Fri 10:30 H8

Majorana fermions revealing the true nature of quantum phase slip junctions — •Christina Koliofoti and Roman-Pascal Riwar — Forschungszentrum Jülich, Peter Grünberg Institut (PGI-2), 52425 Jülich, Deutschland

Quantum circuit theory is a powerful and ever-evolving tool to predict the dynamics of superconducting circuits. In its language, quantum phase slips are famously considered to be the exact dual to the Josephson effect. However, if taken at face value, this duality stipulates that charge must be continuous. We propose a charge-quantization conserving description of quantum phase slips and show that this seemingly minute change gives rise to some very different predictions. When shunting a quantum phase slip junction with a topological Josephson junction, the new description leads to a complete dissappearance of the Hofstadter butterfly spectrum. For topologically trivial circuits we argue that adhering to charge quantization renders realizations of the Gottesman-Kitaev-Preskill code impossible.

QI 13.5 Fri 10:45 H8

Tunable-coupler mediated controlled-controlled-phase gate with superconducting qubits — •Niklas J Glaser[1,2], Federico Roy[1,3], and Stefan Filipp[1,2,4] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, 85748 Garching, Germany — [3]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany

Applications for noisy intermediate scale quantum computing devices rely on the efficient entanglement of many qubits to reach a potential quantum advantage. Although entanglement is typically generated using two-qubit gates, direct control of strong multi-qubit interactions can improve the efficiency of the process. We investigate a system of three superconducting transmon-type qubits coupled via a single flux-tunable coupler. Tuning the frequency of the coupler by adiabatic flux pulses enables us to control the conditional energy shifts between the qubits and directly realize multi-qubit interactions. To accurately adjust the resulting controlled relative phases, we describe a gate protocol involving refocusing pulses and adjustable interaction times. This enables the implementation of the full family of pairwise controlled-phase (CPHASE) and controlled-controlled-phase (CCPHASE) gates. Numerical simulations result in fidelities around 99% and gate times below 300 ns using currently achievable system parameters and decoherence rates.

15 min. break

QI 13.6 Fri 11:15 H8

Coupler-mediated unconditional reset of fixed-frequency superconducting qubits — •Gerhard Huber[1,2], Federico Roy[1,2], and Stefan Filipp[1,2,3] — [1]Walther-Meißner-Institut, Bayrische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany

Advances in superconducting qubit fabrication procedures have led to energy relaxation times regularly exceeding 100 μs. Therefore, passive reset via relaxation has become unpractical, and an active reset protocol is required to achieve high repetition rate of quantum algorithms. Previous unconditional qubit reset schemes have relied on flux tunable qubits or multiple transitions over higher qubit states. We extend a previous reset scheme using flux tunable qubits to fixed frequency transmon qubits with tunable couplers. The reset pulse consists of a single parametric flux pulse on the coupler to transfer qubit excitations to a quickly decaying resonator. Our protocol does not rely on additional control lines and can be implemented on current multi-qubit architectures. Further, it can be extended to architectures where a single coupler allows for reset of multiple qubits. We present preliminary numerical and experimental results for this reset protocol demonstrating its potential usefulness.

QI 13.7 Fri 11:30 H8

Analysis of calibration techniques for single-qubit gates on a superconducting quantum computer — •Kathrin König[1], Naoki Kanazawa[2], and Shota Nakasuji[3] — [1]Fraunhofer IAF, Freiburg, Germany — [2]IBM Research, Tokyo, Japan — [3]University of Tokyo, Tokyo, Japan

Inexact calibrated gates and environmental influences lead to imperfect outcomes of a quantum computation. We investigate two calibration techniques on an IBM quantum computer. The state-of-the art calibration uses an empirical formula to update the optimal control parameter. The compared new technique can directly estimate the parameter at arbitrary precision. We confirmed that the new technique shows higher precision with comparable accuracy.

QI 13.8 Fri 11:45 H8

Pulse class meta-optimization of continous quantum gates in transmon systems — •Francesco Preti — Forschungszentrum Jülich, Jülich, Germany

Reducing the circuit depth of quantum circuits is a crucial bottleneck to enabling quantum technology. This depth is inversely proportional to the number of available quantum gates that have been synthesized. Moreover, quantum gate synthesis and control problems exhibit a vast range of external parameter dependencies, both physical and application-specific. We address the possibility of learning families of optimal control pulses in transmon systems, which depend adaptively on various parameters, in order to obtain a global optimal mapping from the space of potential parameter values to the control space, and hence continuous classes of gates. Our proposed method is tested on different experimentally relevant quantum gates and proves capable of producing high-fidelity pulses even in presence of multiple variables or uncertain parameters with wide ranges.

QI 13.9 Fri 12:00 H8

Magnetic field dependence of the quasiparticle parity lifetime in 3D transmons with thin-film $Al - AlO_x - Al$ Josephson junctions — •Jonas Krause[1], Lucas Jannsen[1], Christian Dickel[1], Elmore Vaal[1], Michel Vielmetter[1], Jurek Frey[2], Felix Motzoi[3], Shai Machness[2], Kelvin Loh[4], Michiel Adriaan Rol[4], Gianluigi Catelani[5], and Yoichi Ando[1] — [1]Physics Institute II, University of Cologne — [2]Quantum Computing Analytics (PGI 12), Forschungszentrum Jülich — [3]Institute of Quantum Control (PGI-8), Forschungszentrum Jülich — [4]Orange Quantum Systems — [5]JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich

Magnetic-field resilient superconducting circuits enable quantum sensing applications, hybrid quantum computing architectures, as well as studying flux noise and quasiparticle loss. Placing a thin-film aluminum transmon in a 3D copper cavity, we can measure its quasiparticle parity lifetime over a large range of magnetic fields, with inplane fields approaching 1T. The magnetic field reduces the Josephson Energy E_J, while the charging energy E_C is virtually unaffected. The transmon exhibits a parity-dependent frequency splitting. We are working on optimal control techniques for fast parity-selective gates which together with single-shot readout allow measuring the parity lifetime. The magnetic-field dependence of the parity lifetime is of interest for future topological qubits, which rely on combining superconductors with magnetic fields; additionally, it could improve the understanding quasiparticle loss in conventional superconducting qubits.

QI 13.10 Fri 12:15 H8

Towards cQED experiments with in-situ fabrication of topological insulator Josephson junctions — •Lucas Janssen, Jonas Krause, Christian Dickel, Alexey Taskin, Roozbeh Yazdampanah Ravari, Anjana Uday, Gertjan Lippertz, and Yoichi Ando — AG Ando, PH2, Universität zu Köln, Germany

Circuit quantum electrodynamics experiments with topological insulator (TI) Josephson junctions (JJs) are a promising path towards finding and studying Majorana zero modes. However, the fabrication of TI JJs is challenging. For our topological insulator, we use MBE grown ternary TI (BiSb)_2Te_3. The interface between the proximitising superconductor and the TI film is critically important for the quality of the JJ, which in turn is vital for microwave performance. Hence, we have been fabricating TI JJs with in-situ deposited niobium. However, etching the niobium to define a JJ has proven challenging. We are exploring a combination of titanium and aluminium as an alternative superconductor. An alternative to this etching step is stencil mask technology. We will present our progress in JJ fabrication and possibly first cQED measurements.

QI 13.11 Fri 12:30 H8

Mitigation of quasiparticle loss in superconducting qubits by phonon scattering — Arno Bargerbos[1], Lukas J. Splitthoff[1], Marta Pita-Vidal[1], Jaap J. Wesdorp[1], Yu Liu[2], Peter Krogstrup[3], Leo P. Kouwenhoven[1], Christian K. Andersen[1], and •Lukas Grünhaupt[1,4] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands — [2]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark — [3]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Most error correction schemes for future quantum processors rely on the assumption that errors are uncorrelated. However, in superconducting devices this assumption is drastically violated in the presence of ionizing radiation, which creates bursts of high energy phonons in the substrate. A mitigation technique is to place large volumes of metal on the device, capable of reducing the phonon energy to below the superconducting gap of the qubits. To investigate the effectiveness of this method we fabricate a device with four nominally identical nanowire-based transmon qubits and replace one half of the niobium titanium nitride ground plane with aluminum (Al), which has a much lower superconducting gap. We inject phonons into the substrate by voltage biasing a galvanically isolated Josephson junction and we find protection due to the Al by a factor of 2-4 in terms of qubit lifetime and excited state population. Furthermore, we turn the Al normal with a magnetic field, finding no marked change in the phonon-protection.

QI 14: Quantum Foundations

Time: Friday 9:30–12:30 Location: H9

Invited Talk QI 14.1 Fri 9:30 H9

Testing quantum theory with generalized noncontextuality — •Markus P. Müller[1,2,3] and Andrew J. P. Garner[1] — [1]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria — [2]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria — [3]Perimeter Institute for Theoretical Physics, 31 Caroline Street North, Waterloo, ON N2L 2Y5, Canada

It is a fundamental prediction of quantum theory that states of physical systems are described by complex vectors or density operators on a Hilbert space. However, many experiments admit effective descriptions in terms of other state spaces, such as classical probability distributions or quantum systems with superselection rules. Here, we ask which probabilistic theories could reasonably be found as effective descriptions of physical systems if nature is fundamentally quantum. To this end, we employ a generalized version of noncontextuality: processes that are statistically indistinguishable in an effective theory should not require explanation by multiple distinguishable processes in a more fundamental theory. We formulate this principle in terms of embeddings and simulations of one probabilistic theory by another, show how this concept subsumes standard notions of contextuality, and prove a multitude of fundamental results on approximate embeddings. We show how results on Bell inequalities can be used for the robust certification of generalized contextuality, and use this to propose a novel type of experimental test of quantum theory.

QI 14.2 Fri 10:00 H9

Proposal for demonstrating hidden nonlocality without assumptions — •Jonathan Steinberg, H. Chau Nguyen, and Matthias Kleinmann — University of Siegen, Siegen, Germany

A quantum state with hidden nonlocality does not violate any Bell inequality unless its hidden nonlocality is activated using local filters. This phenomenon has been demonstrated in experiments, however only when special Bell inequalities are considered [Kwiat et al., Nature 409, 1014 (2001)], or under the assumption that the quantum state is constrained to a special form which has a known local hidden variable [Opt. Express 28, 13638 (2020)]. Developing a general method for constructing local models for bipartite systems of a qubit and a qudit, we propose a protocol which allows one to conclusively demonstrate hidden nonlocality which is free from assumptions on both, the form of Bell inequalities and the special form of the state. By an optimization over the states and measurement directions we obtain that the required precision is within reach of near future experiments.

QI 14.3 Fri 10:15 H9

Non-locality with overlapping marginals — •Moisés Bermejo Morán — Jagiellonian University, Krakow, Poland

We investigate how non-locality can be shared in multi-partite physical systems. Going beyond the standard scenario with disjoint subsystems, we focus on the case where the subsystems participating in the Bell inequality can have overlap. The analytical methods are limited in generality and the standard numerical tools do not effectively provide good bounds when measurements with overlapping support are involved. We overcome these limitations by considering the Navascués-Pironio-Acín hierarchy for finite-dimensional systems, for a fixed dimension. Finding the optimal value via convex combinations of random states and PVMs. These allow us to find non-trivial monogamy bounds in simple scenarios.

QI 14.4 Fri 10:30 H9

Optimal convergence rate in the quantum Zeno effect for open quantum systems in infinite dimensions — •Tim Möbus and Cambyse Rouzé — Technical University Munich, Germany

In open quantum systems, the quantum Zeno effect consists in frequent applications of a given quantum operation, e.g. a measurement, used to restrict the time evolution (due e.g. to decoherence) to states that are invariant under the quantum operation. In an abstract setting, the Zeno sequence is an alternating concatenation of a contraction operator (quantum operation) and a strongly continuous contraction semigroup (time evolution) on a Banach space. In this paper, we prove the optimal convergence rate of order $1/n$ of the Zeno sequence by proving explicit error bounds. For that, we derive a new Chernoff-type lemma, which we believe to be of independent interest. Moreover, we generalize the Zeno effect in two directions: We weaken the assumptions on the generator, which induce a Zeno dynamics generated by an unbounded generator and we improve the convergence to the uniform topology. Finally, we provide a large class of examples arising from our assumptions.

QI 14.5 Fri 10:45 H9

Gravitational redshift induces quantum interference — •David Edward Bruschi[1] and Andreas Wolfgang Schell[2,3] — [1]Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, Jülich, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

We use quantum field theory in curved spacetime to show that gravitational redshift induces a unitary transformation on the quantum state of propagating photons. This occurs for realistic photons characterized by a finite bandwidth, while ideal photons with sharp frequencies do not transform unitarily. We find that the transformation is a mode-mixing operation, and we devise a protocol that exploits gravity to induce a Hong-Ou-Mandel-like interference effect on the state of two photons. Testing the results of this work can provide a demonstration of quantum field theory in curved spacetime.

15 min. break

QI 14.6 Fri 11:15 H9

Dynamical Theories in Phase-Space: The Almost Hydrogen Atom — •Martin Plávala and Matthias Kleinmann — Universität Siegen, Siegen, Deutschland

We construct a large class of operational theories of hydrogen atom that includes both classical and quantum theory as special cases. We show that one can formulate a well-defined theory of stationary bound states even without uniquely defined time-evolution and we prove that the ground state energy is finite only if the theory exhibits preparation uncertainty relation between position and momentum observables. We perturb the Hamiltonian by including external magnetic field, which leads to breaking of the degeneracy of the energy spectrum; in this setting we show that the magnetic quantum number is bounded by the principal quantum number, similarly as in quantum theory. We also perturb the Hamiltonian by nonstationary electric field and we show that this leads to excitations of the atom. Finally we investigate scattering theory where we show that Rutherford formula for scattering holds in all investigated operational theories.

QI 14.7 Fri 11:30 H9

Uncertainty relations with the variance and the quantum Fisher information — •Géza Tóth[1,2,3,4] and Florian Fröwis[5] — [1]Theoretical Physics and EHU Quantum Center, 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]Group of Applied Physics, University of Geneva, CH-1211 Geneva, Switzerland

We present several inequalities related to the Robertson-Schrödinger uncertainty relation. In all these inequalities, we consider a decomposition of the density matrix into a mixture of states, and use the fact that the Robertson-Schrödinger uncertainty relation is valid for all these components. By considering a convex roof of the bound, we obtain an alternative derivation of the relation in Fröwis et al. [Phys. Rev. A 92, 012102 (2015)], and we can also list a number of conditions that are needed to saturate the relation. We present a formulation of the Cramér-Rao bound involving the convex roof of the variance. By considering a concave roof of the bound in the Robertson-Schrödinger uncertainty relation over decompositions to mixed states, we obtain an improvement of the Robertson-Schrödinger uncertainty relation. We consider similar techniques for uncertainty relations with three variances. Finally, we present further uncertainty relations that provide lower bounds on the metrological usefulness of bipartite quantum states in two-mode and two-spin systems.

QI 14.8 Fri 11:45 H9

Geometry of expectation values of non-commuting observables — •Konrad Szymanski — Universität Siegen, Siegen, Deutschland

Non-commutativity lies at the heart of quantum theory and provides a rich set of mathematical and physical questions. Here, I address this topic through the concept of the Joint Numerical Range (JNR) – the set of simultaneously attainable expectation values for multiple quantum observables, which in general need not commute. I discuss mathematical and physical implications of the geometry of JNR: classification of the possible shapes of the set, as well as development of novel uncertainty relations, entanglement and Schmidt rank witnesses, and detection of vanishing energy gap.

QI 14.9 Fri 12:00 H9

Measurement-based models of friction and dissipative collapse — •Michael Gaida and Stefan Nimmrichter — Universität Siegen

Collapse models are objective modifications of quantum theory that aim to solve the measurement problem. One of the most studied models is the Continuous Spontaneous Localisation (CSL) model and its dissipative extension. We present a protocol based on randomly occurring Gaussian position measurements and unitary feedback operations that reproduces the single particle dynamics of dissipative CSL. Inspired by this protocol, we introduce a class of measurement-based models, implementing classical friction forces. We find that the specific model for linear Stokes friction reproduces the single-particle dissipative CSL master equation, as well.

QI 14.10 Fri 12:15 H9

Transcendental properties of entropy-constrained sets — •Vjosa Blakaj[1,2] and Michael Wolf[1,2] — [1]Technical University of Munich — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

For information-theoretic quantities with an asymptotic operational characterization, the question arises whether an alternative single-shot characterization exists, possibly including an optimization over an ancilla system. If the expressions are algebraic and the ancilla is finite, this leads to semialgebraic level sets. In this work, we provide a criterion for disproving that a set is semialgebraic based on an analytic continuation of the Gauss map. Applied to the von Neumann entropy, this shows that its level sets are nowhere semialgebraic in dimension $d > 2$, ruling out algebraic single-shot characterizations with finite ancilla (e.g., via catalytic transformations). We show similar results for related quantities, including the relative entropy, and discuss under which conditions entropy values are transcendental, algebraic, or rational.