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Overview of Invited Talks and Sessions

(Lecture halls BEY/0137, BEY/0245, and BEY/0E17; Poster P4)

Invited Talks

QI 2.1	Mon	9:30–10:00	BEY/0245	**Advances in Frequency-Multiplexed Readout and Subsequent Qubit-State Reset** — •Benjamin Lienhard, Shivang Arora, Emily Guo, Priyanka Yashwantrao, Patryk Dabkowski, Stefan Filipp
QI 4.1	Mon	15:00–15:30	BEY/0245	**Reducing Noise, Complexity, and Optimization Barriers in Quantum Simulations of Strongly Correlated Systems** — •Werner Dobrautz
QI 6.1	Tue	9:30–10:00	BEY/0245	**Erbium dopants for quantum networks** — •Andreas Reiserer
QI 11.1	Wed	9:30–10:00	BEY/0245	**Nb-trilayer Josephson junction based parametric amplifiers for microwave frequency signals** — •Lukas Grünhaupt
QI 15.7	Thu	11:30–12:00	BEY/0137	**Robust shadow tomography: from quantum simulation to high-energy physics** — •Hai-Chau Nguyen
QI 16.1	Thu	9:30–10:00	BEY/0245	**Measurement-free universal fault-tolerant quantum computation** — •Friederike Butt, Ivan Pogorelov, Alex Steiner, Marcel Meyer, Thomas Monz, Markus Müller, Robert Freund
QI 18.1	Thu	15:00–15:30	BEY/0245	**Multipartite Quantum states from guided-wave structures** — •Virginia D'Auria, Adrien Bensemhoun, Silvia Cassina, Carlos Gonzalez-Arciniegas, Mohamed Fauzi Melalkia, Giuseppe Patera, Jonathan Faugier-Tovar, Quentin Wilmar, Ségolène Olivier, Alessandro Zavatta, Anthony Martin, Jean Etesse, Laurent Labonté, Sébastien Tanzilli
QI 21.1	Fri	9:30–10:00	BEY/0245	**Non-Hermitian topology and directional amplification** — •Clara Wanjura

Sessions

QI 1.1–1.11	Mon	9:30–12:45	BEY/0137	**Quantum Computing and Algorithms I**
QI 2.1–2.10	Mon	9:30–12:45	BEY/0245	**Implementations I**
QI 3.1–3.12	Mon	15:00–18:30	BEY/0137	**Quantum Simulation**
QI 4.1–4.11	Mon	15:00–18:30	BEY/0245	**Quantum Manybody Systems (joint session QI/TT)**
QI 5.1–5.10	Tue	9:30–12:30	BEY/0137	**Quantum Computing and Algorithms II**
QI 6.1–6.10	Tue	9:30–12:45	BEY/0245	**Implementations II**
QI 7.1–7.6	Tue	9:30–11:00	BEY/0E17	**Quantum Thermodynamics**
QI 8.1–8.6	Tue	14:00–15:30	BEY/0137	**Implementations III**
QI 9.1–9.6	Tue	14:00–15:30	BEY/0245	**Decoherence and Open Systems I**
QI 10.1–10.11	Wed	9:30–12:45	BEY/0137	**Quantum Information: Concepts and Methods I**
QI 11.1–11.10	Wed	9:30–12:45	BEY/0245	**Implementations IV**
QI 12.1–12.10	Wed	15:00–18:00	BEY/0137	**Quantum Foundations**
QI 13.1–13.10	Wed	15:00–18:00	BEY/0245	**Quantum Control**
QI 14.1–14.28	Wed	18:00–21:00	P4	**Quantum Information Poster Session**
QI 15.1–15.9	Thu	9:30–12:30	BEY/0137	**Quantum Information: Concepts and Methods II**

QI 16.1–16.10	Thu	9:30–12:45	BEY/0245	**Quantum Software**
QI 17.1–17.8	Thu	15:00–17:30	BEY/0137	**Decoherence and Open Systems II**
QI 18.1–18.9	Thu	15:00–18:00	BEY/0245	**Quantum Communication**
QI 19	Thu	18:00–19:00	BEY/0245	**Members' Assembly**
QI 20.1–20.8	Fri	9:30–12:00	BEY/0137	**Metrology and Sensing**
QI 21.1–21.10	Fri	9:30–12:45	BEY/0245	**Quantum Information: Concepts and Methods III**

Members' Assembly of the Quantum Information Division

Thursday 18:00–19:00 BEY/0245

QI 1: Quantum Computing and Algorithms I

Time: Monday 9:30–12:45 Location: BEY/0137

QI 1.1 Mon 9:30 BEY/0137

The Complexity of Simulating Inertially Coupled Bosonic Hamiltonians — •Refik Mansuroglu[1], Lilith Zschetzsche[1], and Norbert Schuch[1,2] — [1]University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria — [2]University of Vienna, Faculty of Mathematics, Oskar-Morgenstern-Platz 1, 1090 Vienna, Austria

The computational complexity of simulating physically natural quantum systems is a central question at the interface of quantum physics and computer science. While recent work has established the BQP-completeness of simulating an exponential number of coupled classical oscillators [Babbush et al.], the complexity of more general bosonic dynamics has remained unresolved. Here we prove that simulating inertially coupled bosonic systems, a broad class that includes quantum harmonic oscillators as a special case, is BQP-complete. In the Hamiltonian framework, we consider the problem of deciding whether the expectation value of an R-local observable is polynomially separated from zero, given only polynomially many nonzero initial amplitudes $q_j(0)$ and $p_j(0)$. We show that the Hamiltonians governing continuous-time quantum walks can be expressed as inertially coupled bosonic systems, thereby unifying two paradigms of quantum dynamics within a single complexity-theoretic classification.

QI 1.2 Mon 9:45 BEY/0137

Equivalence of Quantum Walk and Coupled Classical Oscillator Simulation — •Lilith Zschetzsche[1], Refik Mansuroglu[1], András Molnár[1,2], and Norbert Schuch[1,2] — [1]University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Wien, Austria — [2]University of Vienna, Faculty of Mathematics, Oskar-Morgenstern-Platz 1, 1090 Vienna, Austria

We present direct and physically well-motivated reductions between the simulation of quantum walk Hamiltonians and the simulation of exponentially many coupled classical oscillators, problems that are known to be BQP-complete. Mapping the complex amplitudes of the quantum walk to the displacements and conjugate momenta of the classical oscillators allows us to identify the equations of motions of the quantum walk with those of the harmonic oscillators. That is, we construct a classical Hamiltonian of harmonic oscillators from a quantum walk Hamiltonian (and vice versa), such that energy terms for oscillators and vertex populations of the quantum walk are identified as measurement outcomes on the time-evolved state. Given the BQP-completeness of one of those problems, our reduction can be seen as an alternative proof for BQP-hardness of the other, although the reduction reaches beyond BQP-complete versions of the problem.

QI 1.3 Mon 10:00 BEY/0137

Block encoding and QSVT for solving differential equations — •Abhishek Setty — Forschungszentrum Jülich, Germany — University of Cologne, Germany

We present a unified framework for efficient block encoding of arbitrary sparse matrices, addressing the key barriers to practical quantum algorithms: multi-controlled gate overhead, amplitude reordering, and hardware connectivity. Our method combines a combinatorial-optimization strategy for control-qubit assignment with coherent permutation operators, yielding explicit gate-level constructions with reduced depth. Building on this, we outline a quantum linear systems pathway for solving differential equations within the QSVT paradigm. We demonstrate this on a complex linear system and extend it to CFD problems, including the heat equation and Carleman-linearized Burgers equation. These results highlight both the potential and limitations of current methods, underscoring the need for efficient estimation of minimum singular value, depth-reduction techniques, and benchmarks against classical reachability. This pathway lays a foundation for advancing quantum linear system methods toward large-scale applications.

QI 1.4 Mon 10:15 BEY/0137

Exploring Variational Entanglement Hamiltonians — •Yanick S. Kind[1,2] and Benedikt Fauseweh[1,2] — [1]TU Dortmund, Dortmund, Germany — [2]German Aerospace Center, Cologne, Germany

Recent advances in analog and digital quantum-simulation platforms have enabled exploration of the spectrum of entanglement Hamiltonians via variational algorithms. We investigate the convergence properties of a variational algorithm and benchmark the results against numerically exact calculations. By interpreting the cost function as an integral, we employ an iterative quadrature scheme, reducing the measurement overhead by several orders of magnitude. We further demonstrate that a modified Bisognano-Wichmann ansatz allows better convergence in lattice models and provides a diagnostic for quantum phase transitions. Finally, we show that a lower cost function does not necessarily lead to a lower trace distance. However, it still faithfully reproduces degeneracies in the entanglement spectrum, which are essential for topological applications. Y. S. Kind, B. Fauseweh, arXiv:2505.10530, 2025

QI 1.5 Mon 10:30 BEY/0137

The sub-Riemannian geometry of measurement based quantum computation — •Lukas Hantzko — Leibniz Universität, Hannover, DE

The computational power of symmetry-protected phases of matter can be accessed through local measurements, but what is the most efficient way of doing so? In this work, we show that minimizing operational resources in measurement-based quantum computation (MBQC) on subsystem symmetric resource states amounts to solving a sub-Riemannian geodesic problem between the identity and the target logical unitary. This reveals a geometric structure underlying MBQC and offers a principled route to optimize quantum processing in computational phases.

QI 1.6 Mon 10:45 BEY/0137

Entanglement-informed construction of variational quantum circuits — Alina Joch[1,2], Götz Uhrig[1], and •Benedikt Fauseweh[1,2] — [1]Condensed Matter Theory, TU Dortmund University, Otto-Hahn-Straße 4, 44227 Dortmund, Germany — [2]Institute of Software Technology, German Aerospace Center (DLR), 51147 Cologne, Germany

The variational quantum eigensolver is a promising tool for simulating ground states of quantum many-body systems on noisy quantum computers. Its effectiveness relies heavily on the ansatz, which must be both hardware-efficient for implementation on noisy hardware and problem-specific to avoid local minima and convergence problems. Here, we explore entanglement-informed ansatz schemes that naturally emerge from specific models, aiming to balance accuracy with minimal use of two-qubit entangling gates. We investigate quasi-1D Hamiltonians focusing on entanglement barriers and long-range interactions. We find that including the entanglement structure in the parameterized quantum circuit reduces the resources necessary to achieve a given accuracy. A better assessment is obtained by analyzing how the ansatz captures the entanglement spectrum. Our comprehensive analysis provides a new perspective on the design of ansätze based on the expected entanglement structure of the approximated state.

Quantum Sci. Technol. 10 035032 (2025)

30min. break

QI 1.7 Mon 11:30 BEY/0137

Measurement-driven Quantum Approximate Optimization — •Tobias Stollenwerk[1] and Stuart Hadfield[2,3] — [1]Institute for Quantum Computing Analytics (PGI-12), Jülich Research Centre, Wilhelm-Johnen-Straße, 52428 Jülich, Germany — [2]Quantum Artificial Intelligence Lab (QuAIL), NASA Ames Research Center, Moffett Field, CA 94035, USA — [3]USRA Research Institute for Advanced Computer Science (RIACS), Mountain View, CA 94043, USA

Algorithms based on non-unitary evolution have attracted much interest for ground state preparation on quantum computers. In this work we specialize and extend one recently proposed approach that employs mid-circuit measurements and control to the setting of constrained and unconstrained combinatorial optimization. For this we compare and contrast both penalty-based and feasibility-preserving approaches, elucidating the significant advantages of the latter approach. We show how to select parameters such that the success probability of each measurement step is bounded away from 1/2. Our approach is general and may be applied to easy-to-prepare initial states as a standalone algorithm, or deployed as a quantum postprocessing stage. We then propose a more sophisticated variant of our algorithm that adaptively applies a mixing operator or not, based on the measurement outcomes seen so far, as to speeds up the algorithm and helps the system evolution avoid slowing down or getting stuck suboptimally. In particular, we show that mixing operators from QAOA can be imported directly, both for the necessary eigenstate scrambling operator and for initial state preparation, and discuss quantum resource tradeoffs.

QI 1.8 Mon 11:45 BEY/0137

Greens Function on Quantum Computers: Error Mitigation and application in Dynamical Mean Field Theory — •Jannis Ehrlich[1], Aljoscha F. Baumann[1], Daniel F. Urban[1,2], and Christian Elsässer[1,2] — [1]Fraunhofer-Institut für Werkstoffmechanik IWM, Freiburg, Germany — [2]Freiburger Materialforschungszentrum, Universität Freiburg, Germany

Dynamical Mean Field Theory (DMFT) has become a powerful tool for investigating the physics of materials that exhibit strong electronic correlations, like high-temperature superconductivity or metal-insulator transitions. The numerically challenging part is the calculation of the Greens function (GF) of the underlying Anderson impurity auxiliary model due to the explicit treatment of electron interactions, which is also directly connected to the energy of the system and the spectral function.
We present a time-evolution approach for extracting the GF by simulating the quantum system on a quantum computer and show its performance for the auxiliary Anderson impurity model of DMFT on real quantum processors with systems of increasing sizes. We further investigate the relevance of accuracy in the ground-state preparation and demonstrate possibilities to reduce and mitigate errors of current quantum devices.

QI 1.9 Mon 12:00 BEY/0137

Generation of Fermionic Gaussian States: Optimal and Approximate Matchgate Circuits — •Marc Langer[1,2], Raúl Morral-Yepes[1,2], Adam Gammon-Smith[3,4], Frank Pollmann[1,2], and Barbara Kraus[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK — [4]Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, University of Nottingham, Nottingham, NG7 2RD, UK

Fermionic Gaussian states (FGS), and the related matchgates, play an important role in the study of various phenomena. Despite being able to represent highly entangled states, they are still tractable on classical computers. A naturally arising question is how to optimally create such states, for instance when using matchgate circuits acting on product states. In this work, we present algorithms for explicitly constructing such circuits that provably yield the minimal number of gates. Our techniques furthermore allow us to characterize which states can be represented exactly with a low depth matchgate circuit. Some applications of these results include approximate state preparation, robust disentangling algorithms and classical simulation methods.

QI 1.10 Mon 12:15 BEY/0137

Adaptive, efficient and provable energy estimation on noisy intermediate-scale quantum computers — •Bruno Murta[1], Alexander Gresch[2], and Martin Kliesch[1] — [1]TUHH - Hamburg University of Technology — [2]eleQtron GmbH

Estimating the energy of a prepared quantum state from measurements is a central subroutine in quantum simulation algorithms. In a noisy intermediate-scale quantum (NISQ) setting, this estimation must be carried out with shallow readout circuits. In this work, we introduce an energy estimation framework that both tightens theoretical guarantees and reduces the cost of measuring molecular and solid-state Hamiltonians on NISQ devices. Our protocol exploits empirical (co)variance information gathered during measurement collection to adapt the estimation to the specific state, interpolates between qubit-wise and global commutativity to provide a trade-off between circuit depth and shot efficiency, and is supported by rigorous error bounds. Numerical benchmarks on molecular and lattice models indicate that the resulting scheme achieves a significant suppression of shot noise for a fixed measurement budget, while keeping quantum resources compatible with current NISQ hardware.

QI 1.11 Mon 12:30 BEY/0137

A Constant Measurement Quantum Algorithm for Graph Connectivity — •Maximilian Balthasar Mansky[1], Chonfai Kam[2], and Claudia Linnhoff-Popien[1] — [1]LMU Munich — [2]Palermo University

We introduce a novel quantum algorithm for determining graph connectedness using a constant number of measurements. The algorithm can be extended to find connected components with a linear number of measurements. It relies on non-unitary abelian gates taken from ZX calculus. Due to the fusion rule, the two-qubit gates correspond to a large single action on the qubits. The algorithm is general and can handle any undirected graph, including those with repeated edges and self-loops. The depth of the algorithm is variable, depending on the graph, and we derive upper and lower bounds. The algorithm exhibits a state decay that can be remedied with ancilla qubits. We provide a numerical simulation of the algorithm.

QI 2: Implementations I

Time: Monday 9:30–12:45 Location: BEY/0245

Invited Talk QI 2.1 Mon 9:30 BEY/0245

Advances in Frequency-Multiplexed Readout and Subsequent Qubit-State Reset — •Benjamin Lienhard[1,2], Shivang Arora[1,2], Emily Guo[1,2], Priyanka Yashwantrao[1,2], Patryk Dabkowski[1,2,3], and Stefan Filipp[1,2] — [1]Technical University of Munich, Garching 85748, Germany — [2]Walther-Meißner-Institut, Garching 85748, Germany — [3]Zurich Instruments, 8005 Zürich, Switzerland

In scalable, resource-efficient quantum processors with large numbers of superconducting qubits, readout performance often becomes a key limitation for overall system fidelity. Achieving fast, high-fidelity simultaneous measurement—critical for quantum error correction—typically relies on frequency-multiplexed readout to reduce resource overhead. However, crosstalk and other nonidealities pose significant challenges for conventional signal processing and state discrimination. Emerging machine learning (ML) approaches provide efficient, low-complexity mappings from measurement signals to qubit states, reducing error rates and enabling real-time scalability. In this talk, I will present recent advances in ML-based readout and reset techniques, along with their implementation on dedicated hardware. By combining scalable algorithms with compact, ML-driven discriminators deployed on FPGAs, we can address the readout bottleneck and substantially improve both fidelity and speed.

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QI 2.2 Mon 10:00 BEY/0245

Environment-assisted Cross-Resonance gate — •Radhika Hemant Joshi[1], Alwin van Steensel[1], Julian Rapp[2], and Mohammad Ansari[1] — [1]Peter Grunberg Institute, PGI-2, Forschungszentrum Julich, 52428 Julich, Germany — [2]Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany

Superconducting qubits have emerged to become a promising platform for quantum computing [1]. A cross-resonance (CR) gate is a particularly important two-qubit gate, which enables CNOT operation. In CR gate, two qubits, the so-called control and target, are coupled and the control qubit is driven at frequency of the target qubit [2,3]. However, the operation of these gates is affected by their environment[4]. To quantify this effect, we consider a Cross-Resonance (CR) gate connected to external reservoirs and evaluate the entangling interaction.

[1] J. Clarke, F. Wilhelm, Superconducting quantum bits, Nature453, 1031-1042 (2008)
[2] Xuexin Xu, M.H. Ansari, ZZ freedom in two qubit gates, Phys.Rev. Applied 15, 064074(2021), arXiv:2009.00485
[3] Xuexin Xu, M. Ansari, Parasitic-Free Gate: An Error-Protected Cross-Resonance Switch in Weakly Tunable Architectures, Phys.Rev.

Applied 19, 024057, arXiv:2212.05519
[4] Radhika H. Joshi, Mohammad H. Ansari, Environment-assisted Cross-Resonance gate, in preparation.

QI 2.3 Mon 10:15 BEY/0245

Robust universal gate set for neutral-atom qudits — Amir Burshtein[1], •Shachar Fraenkel[1], Moshe Goldstein[1], and Ran Finkelstein[1,2] — [1]School of Physics and Astronomy, Tel Aviv University, Tel Aviv 6997801, Israel — [2]The Center for Nanoscience & Nanotechnology, Tel Aviv University, Tel Aviv 6997801, Israel

Quantum devices comprised of native qudits, instead of qubits, offer promising advantages for quantum simulation and fault-tolerant quantum computation, yet efficient schemes for the control and entanglement of qudits in quantum hardware remain scarce. In particular, no experimental demonstration of multi-qudit control has been achieved to date in neutral-atom arrays. We propose a universal control scheme for qudits encoded in ground and metastable states of neutral atoms. Within this scheme, single-qudit gates are implemented efficiently via the simultaneous driving of multiple transition frequencies. For entangling operations, we provide a recipe implementing any symmetric controlled-phase gate (e.g., controlled-Z) for any qudit dimension d. The recipe relies on a global drive, a key requirement for high experimental fidelity, and involves pulses that simultaneously drive two different Rydberg transitions, which we prove to be the minimal number generally necessary for realizing such global-drive phase gates. This underlines a more general need for adjusting the notion of a universal gate set to the practical limitations of the hardware of interest. The gates we design are easy to calibrate and robust to realistic experimental imperfections, as we demonstrate via extensive noise simulations.

Reference: arXiv:2508.16294

QI 2.4 Mon 10:30 BEY/0245

Hyperfine spectroscopy of rare-earth ions in $CaWO_4$ using broadband electron spin resonance — •Georg Mair[1,2], Ana Strinić[1,2,3], Achim Marx[1], Kirill Fedorov[1,2,3], Hans Huebl[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]School of Natural Sciences, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 München, Germany

The spin states of rare-earth ions doped into crystals provide a promising platform for quantum memories, owing to their long coherence times and frequency compatibility with superconducting quantum circuits. We investigate dilute ensembles of erbium and ytterbium ions in $CaWO_4$ crystals at millikelvin temperatures using broadband electron spin resonance spectroscopy based on superconducting coplanar waveguides. This approach enables the precise detection of zero-field and low-field spin transition spectra. Hyperfine and quadrupolar interactions emerging from the nuclear spins of ^{167}Er, ^{171}Yb, and ^{173}Yb give rise to a rich microwave spectrum below 4 GHz, from which we identify Zero First-Order Zeeman (ZEFOZ) shift transitions. By measuring coherence properties of individual hyperfine spin transitions, we find Hahn echo coherence times of tens of microseconds to milliseconds. Our broadband spectroscopy approach thus enables not only the fitting of full spin Hamiltonians, but also the identification and validation of long-lived spin transitions.

QI 2.5 Mon 10:45 BEY/0245

shaping free electron wavepackets with plasmonic near-field — •Fatemeh Chahshouri[1] and Nahid Talebi[1,2] — [1]Institute of Experimental and Applied Physics, Kiel University, 24098 Kiel, Germany — [2]Kiel, Nano, Surface, and Interface Science * KiNSIS, Kiel University, 24098 Kiel, Germany

Free-electron interactions with light and matter have long served as a cornerstone for exploring the quantum and ultrafast dynamics of material excitation. Here, we investigate how the plasmonic near-fields of gold nanorods and dimers modulate slow-electron wavepackets and result in controlled elastic and inelastic interactions beyond the nonrecoil approximation. We first show that tailoring the geometry, polarization, and near-field topology of the nanorod, together with adjusting the phase offset between sequential near-field components through phase-locked gating, enables deterministic control over momentum transfer to the electron, including both inelastic longitudinal energy exchange and transverse recoil of the electron beam. We then study electron shaping under rotating plasmonic fields generated either by two orthogonally polarized pulses with controlled phase delay or by circularly polarized light with defined handedness, which leads to angular-momentum transfer and a strong handedness-dependent electron modulation in both real- and reciprocal space. These results underscore the versatility of engineered plasmonic near-fields for shaping free-electron beams and open new opportunities for ultrafast interferometry and quantum-coherent electron microscopy.

30min. break

QI 2.6 Mon 11:30 BEY/0245

A Free-Electron-Driven Quantum Light Source — •Armin Feist[1,2], Guanhao Huang[3,4], Germaine Arend[1,2], Yujia Yang[3,4], Jan-Wilke Henke[1,2], Zheru Qiu[3,4], Hao Jeng[1,2], Arslan Sajid Raja[3,4], Rudolf Haindl[1,2], Rui Ning Wang[3,4], Tobias J. Kippenberg[3,4], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, DE — [2]4th Physical Institute, University of Göttingen, DE — [3]Institute of Physics, EPFL, Lausanne, CH — [4]Center for Quantum Science and Engineering, EPFL, Lausanne, CH

Tailored nonclassical light is essential for photonic quantum technologies, yet generating complex optical states remains challenging. Inelastic free-electron scattering offers a promising new method for creating parametric and wavelength-tunable quantum light, particularly through coherent cathodoluminescence.

Here, we present a novel platform that efficiently couples free-electron beams to silicon nitride integrated photonics [1], enabling the generation of electron-photon pair states [2]. By post-selecting electrons with quantized energy loss, we can herald nonclassical single and multi-photon states [2,3]. This establishes a versatile source of tailored quantum light, potentially leading to a new class of hybrid quantum technology that combines electrons and photons.

[1] J.-W. Henke *et al.*, Nature **600**, 653 (2021) [2] A. Feist *et al.*, Science **377**, 777 (2022) [3] G. Arend *et al.*, Nat. Phys. **21**, 1855 (2024)

QI 2.7 Mon 11:45 BEY/0245

Fast Monitoring of Qubit T1 Fluctuations from Single-Shot Readout — •Julian Englhardt[1,2], Emily Wright[1,2], Niklas Glaser[1,2], Leon Koch[1,2], Christian Schneider[1,2], Benjamin Lienhard[1,2], Max Werninghaus[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Department of Physics — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften

Temporal fluctuations in energy relaxation times (T1) on superconducting qubits can occur on fast and irregular timescales. A quantitative understanding of the underlying relaxation dynamics is important for improving qubit stability and therefore advancing the development of fault-tolerant superconducting quantum processors. We employ a new method by monitoring the qubit continuously and determining the average decay and excitation rates. Simulations suggest that the decay constant can be extracted on timescales significantly shorter than conventional T1 measurements, allowing for monitoring of relaxation dynamics two orders of magnitude faster than conventional approaches. Preliminary experimental results demonstrate the feasibility of this technique and its potential for identifying fast fluctuations in qubit performance. As we extract the information directly from single-shot data, we do not require any additional classical logic beyond active reset, making the method easily integrable into existing setups. We acknowledge financial support from GeQCoS, MUNIQC-SC, MC-QST, OpenSuperQPlus100, Munich Quantum Valley, and Deutsche Forschungsgemeinschaft (DFG, German Research Foundation).

QI 2.8 Mon 12:00 BEY/0245

Towards measurement based quantum computation with multipods — Claire Benjamin[1,2], Dániel Varjas[3,4], Gábor Széchenyi[5,6], Judit Romhányi[1], and •László Oroszlány[2,6] — [1]Department of Physics and Astronomy, University of California, Irvine — [2]Department of Physics of Complex Systems, Eötvös Loránd University — [3]Department of Theoretical Physics, Institute of Physics, Budapest University of Technology and Economics — [4]Institute for Theoretical Solid State Physics, IFW Dresden and Würzburg-Dresden Cluster of Excellence; — [5]Department of Materials Physics, ELTE Eötvös Loránd University — [6]HUN-REN Wigner Research Centre for Physics

We propose a Hubbard-star construction at half filling as a route to realizing Affleck-Kennedy-Lieb-Tasaki (AKLT) physics. By connecting star-shaped clusters of quantum dots, we derive low-energy effective

Hamiltonians that reproduce the S=1 and S=3/2 AKLT models. Using exact diagonalization and quasi-degenerate perturbation theory, we identify the coupling regimes in which these models emerge. Since AKLT ground states are known resources for measurement-based quantum computation, our scheme offers a feasible path toward quantum computational phases in recently fabricated, highly tunable quantum dot arrays.

QI 2.9 Mon 12:15 BEY/0245

Local isotopic enrichment of ^{28}Si for quantum applications — •Lukas Prager[1], Ewelina Gacka[1], Priyal Dadhich[1], Stefan Findeisen[2], Nico Klingner[1], and Gregor Hlawacek[1] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Bautzner Landstr. 400, 01328 Dresden, Germany — [2]Department of Mechanical Engineering, HZDR, Bautzner Landstr. 400, 01328 Dresden, Germany

Donor spin qubits in silicon are a promising candidate in the search for a qubit that can be fabricated in a scalable way while exhibiting long coherence times. Achieving minimal decoherence requires a magnetic moment-free environment, called *spin vacuum*, which, in case of silicon, necessitates the suppression of the nuclear spin-bearing isotope ^{29}Si (4.7%). We perform this task by ^{28}Si focused ion beam (FIB) implantation with energies larger than 45 keV to implant more atoms than removing by sputtering. The usage of a FIB offers a time efficient and spatially resolved way to achieve the necessary fluences ($>10^{19}$ ions/cm^2), while the spatial confinement leaves the surrounding semiconductor materials and devices untouched. Our aim is to ultimately achieve remaining concentrations of ^{29}Si that are lower than centrifuge-based approaches ($<$10 ppm). The resulting spin vacuum areas are one of the fundamental building blocks of a scalable qubit platform based on bismuth donor spin qubits embedded into silicon. The bismuth atoms will be precisely implanted in a deterministic way. Besides that, our device will feature qubits coupled via mechanical modes and single electron transistor governed readout.

QI 2.10 Mon 12:30 BEY/0245

A heat-resilient hole spin qubit in silicon — Victor Champain[1], Gabriele Boschetto[2], Heimanu Niebojewski[2], Benoit Bertrand[2], Lorenzo Mauro[2], Marion Bassi[1], Vivien Schmitt[1], Xavier Jehl[1], Simon Zihlmann[1], Romain Maurand[1], Yann-Michel Niquet[3], •Clemens Winkelmann[1], Silvano De Franceschi[1], Biel Martinez[2], and Boris Brun[1] — [1]Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG-Pheliqs, Grenoble, France — [2]Univ. Grenoble Alpes, CEA, Leti, F-38000 Grenoble, France — [3]Univ. Grenoble Alpes, CEA, IRIG-MEM-L Sim, Grenoble, France

Recent advances in scaling up spin-based quantum processors have revealed unanticipated issues related to thermal effects. Microwave pulses required to manipulate and read the qubits are found to overheat the spins' environment, which unexpectedly induces Larmor frequency shifts, reducing thereby gate fidelities. In this study, we shine light on these elusive thermal effects, by experimentally characterizing the temperature dependence of the Larmor frequency for a single hole spin in silicon. Our results unambiguously reveal an electrical origin underlying the thermal susceptibility, stemming from the spin-orbit-induced electric susceptibility. We perform an accurate modeling of the spin electrostatic environment and gyromagnetic properties, allowing us to pinpoint electric dipoles as responsible for these frequency shifts, that unfreeze as the temperature increases. Surprisingly, we find that the thermal susceptibility can be tuned with the magnetic field angle and can even cancel out, unveiling a sweet spot where the hole spin is rendered immune to thermal effects. arXiv:2509.15823

QI 3: Quantum Simulation

Time: Monday 15:00–18:30 Location: BEY/0137

QI 3.1 Mon 15:00 BEY/0137

Real-Time Dynamics in a (2+1)-D Gauge Theory: The Stringy Nature on a Superconducting Quantum Simulator — Jesús Cobos[1], Joana Fraxanet[2], César Benito[3], Francesco di Marcantonio[1], Pedro Rivero[2], Kornél Kapás[4], •Miklós Antal Werner[4], Örs Legeza[4,5,6,7], Alejandro Bermudez[3], and Enrique Rico[1,8,9,10] — [1]EHU QC, Bilbao, Spain — [2]IBM Quantum, New York, USA — [3]UAM-CSIC, Madrid, Spain — [4]Wigner RCP, Budapest, Hungary — [5]Dynaflex LTD, Budapest, Hungary — [6]TUM IAS, Garching, Germany — [7]Parmenides St., Pöcking, Germany — [8]DIPC, San Sebastián, Spain — [9]IKERBASQUE, Bilbao, Spain — [10]CERN, Geneva, Switzerland

We probe string modes of motion with dynamical matter in a digital quantum simulation of the $\mathbb{Z}_2$-Higgs model with an optimized embedding into a heavy-hex organized superconducting quantum processor with up to 144 qubits. Using local gauge symmetries, we implement various error suppression, mitigation, and correction strategies to enable high control of electric strings connecting dynamical charges and to observe longitudinal oscillations and transverse bending at the endpoints of the string, which are precursors to hadronization and rotational spectra of mesons. To validate our error-aware protocols, we employ extensive tensor network simulations: the relevant parameter regimes of the model are determined by large-scale DMRG simulations. The dynamics are classically simulated by the basis update and Galerkin (BUG) method, and the agreement with hardware results is remarkable.

QI 3.2 Mon 15:15 BEY/0137

Braiding of Majorana zero modes on the digital IBM quantum processor — •Stefan Schmitz[1,2], Kevin Lively[3], Maike Drieb-Schön[4], Tim Bode[1], Benedikt Fauseweh[3,5], and Dmitry Bagrets[1,2] — [1]Peter Grünberg Institute, Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany — [3]Institute for Software Technology, German Aerospace Center (DLR), 51147 Cologne, Germany — [4]Institute for Theoretical Physics, University of Innsbruck, 6020 Innsbruck, Austria — [5]Department of Physics, TU Dortmund University, 44227 Dortmund, Germany

The search for elusive Majorana fermions in solid-state devices has occupied the scientific community for more than a decade. Their unambiguous detection is expected to rely on a braiding protocol that can verify their non-Abelian statistics. We have emulated one variant of this protocol using digital quantum simulations performed on IBM quantum processors. Remarkably, only 12 Trotter steps are sufficient to reproduce a theoretically predicted Majorana braiding operation with a fidelity exceeding 99.9 % in the absence of decoherence and noise. In experiment, this upper bound can not be reached due to the lack of topological protection for the virtual Majoranas. However, we show that applying error mitigation techniques can restore experimental fidelity to values close to the ideal limit.

QI 3.3 Mon 15:30 BEY/0137

How compactness curbs entanglement growth in bosonic systems — •Stefan Aimet[1], Philipp Schmoll[1], Jens Eisert[1], and Spyros Sotiriadis[2] — [1]Freie Universität Berlin, Dahlem Center for Complex Quantum Systems and Institut für Theoretische Physik, 14195 Berlin, Germany — [2]Institute of Theoretical and Computational Physics, University of Crete, 71003 Heraklion, Greece

Zero modes, degrees of freedom with vanishing frequency, play a crucial role in the non-equilibrium dynamics of bosonic systems. In Gaussian models, such zero modes are known to drive unbounded, logarithmic growth of entanglement entropy. We show that this divergence is not an inherent feature of zero modes per se, but arises only for non-compact zero modes whose continuous spectrum and non-normalisable eigenstates allow unbounded position-space spreading and momentum-space dephasing. By contrast, compact zero modes occurring in compact bosonic systems behave fundamentally differently: spreading and dephasing are eventually halted, and compactness caps the entanglement entropy at a finite value. We demonstrate this mechanism using a minimal toy model comparing two coupled harmonic oscillators with two coupled quantum rotors, and show that the same underlying physics carries over to many-body settings by comparing an N-site compact rotor chain with the non-compact harmonic chain. Finally, we relate these insights to ultracold-atom realisations of compact quantum field theories, clarifying when the compact free boson (Tomonaga-Luttinger liquid) description is required and when the commonly used non-compact massless Klein-Gordon model fails.

QI 3.4 Mon 15:45 BEY/0137

A Parametrically-Driven High-Q Multimode Cavity for Analog Quantum Simulations — •Johannes Schading[1], Ian Yang[1], Joao C. Pinto Barros[2], Thea Budde[2], Raquel Garcia-Belles[3], Alexander Anferov[3], Yiwen Chu[3], Marina Marinkovic[2], and Alexander Grimm[1] — [1]Bosonic Quantum Information Group (LNQ/CPS), Paul Scherrer Institute, Switzerland — [2]High Performance Computational Physics Group, ETH Zürich, Switzerland — [3]Hybrid Quantum Systems Group, ETH Zürich, Switzerland

Analog quantum simulations offer a powerful route to study real-time dynamics in systems such as lattice gauge theories or quantum synchronization of nonlinear oscillators. However, these simulations require interaction strengths to exceed decoherence rates by a large margin. Our approach to address this challenge is to encode the system degrees of freedom in high-Q bosonic modes and activating strong parametric interactions in an all-to-all-connected multimode architecture coupled to a superconducting qubit. By applying a microwave drive, we use a qubit-mediated fourth-order parametric process to realize a three-bosonic-mode interaction with a hopping rate of $J/2\pi > 50$ kHz, significantly larger than typical decay rates in high-purity aluminum cavities [1]. Our multimode architecture allows for in-situ connectivity that enables simulations of high-dimensional systems, such as a (2+1)D lattice formulation of the Schwinger model. In this talk, I will discuss our progress towards implementing analog quantum simulations with parametrically-activated bosonic-mode interactions.

[1] Chakram, S. *et al.* *Physical Review Letters* **127**, 107701 (2021).

QI 3.5 Mon 16:00 BEY/0137

Effective Hamiltonians for Measurement Protocols in Quantum Circuits — •Manuel Freudig[1], Davide Bincoletto[2], Francesco Diotallevi[1], Leander Reascos[1], Mónica Benito[1], and Jakob Kottmann[2] — [1]Institute of Physics, University of Augsburg, Augsburg, Germany — [2]Institute for Computer Science, University of Augsburg, Augsburg, Germany

A significant drawback for the realization of Variational Quantum Eigensolvers (VQEs), is the overhead due to measurement repetitions. Addressing this bottleneck, an iterative measurement protocol, designed for molecular Hamiltonians, was introduced [1]. It relies on cheaply measuring commuting groups of operators, while the residual (non-commuting) elements are grouped in a different basis and then measured. Our work proposes an enhanced measurement strategy by integrating the iterative measurement protocol [1] with perturbative and non-perturbative techniques for the derivation of effective Hamiltonians [2,3]. This combination aims to further reduce measurement overhead and increase the accuracy of the approximated expectation value, providing a more viable path for practical VQE implementations.

[1] Bincoletto, D.; Kottmann, J. S.; arXiv:2504.03019. [2] Li, B.; Calarco, T.; Motzoi, F.; PRX Quantum 3, 030313. [3] Schrieffer, J. R.; Wolff, P. A.; Phys. Rev. 149, 491-492.

QI 3.6 Mon 16:15 BEY/0137

Hamiltonian simulation with explicit formulas for Digital-Analog Quantum Computing — Mikel Garcia de Andoin[1,2], Thorge Müller[3], and •Gonzalo Camacho[3] — [1]University of the Basque Country UPV/EHU, Leioa, Spain — [2]EHU Quantum Center, Leioa, Spain — [3]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Köln, Germany

In Hamiltonian simulation, modifying a given source Hamiltonian is often required to engineer a desired target Hamiltonian. In this work, we provide an exact solution for the problem of expressing arbitrary target two-body Hamiltonians as the sum of local unitary transformations of an arbitrary source Ising Hamiltonian, with the total number of required terms being at most quadratic in system size. This allows us to design an efficient digital-analog compilation protocol for Hamiltonian simulation that avoids employing numerical optimization over a large parameter space, minimizes computational resources and allows for further scaling.

30min. break

QI 3.7 Mon 17:00 BEY/0137

Barren-plateau free variational quantum simulation of Z2 lattice gauge theories — •Fariha Azad[1], Matteo Inajetovic[1], Stefan Kühn[2], and Anna Pappa[1] — [1]Electrical Engineering and Computer Science Department, Technische Universität Berlin, 10587 Berlin, Germany — [2]Deutsches Elektronen-Synchrotron DESY, Platanenallee 6, 15738 Zeuthen, Germany

In this work, we design a variational quantum eigensolver (VQE) suitable for investigating ground states and static string breaking in a Z2 lattice gauge theory (LGT). We consider a two-leg ladder lattice with Kogut-Susskind staggered fermions and verify the results of the VQE simulations using tensor network methods. We find that for varying Hamiltonian parameter regimes and in the presence of external charges, the VQE is able to arrive at the gauge-invariant ground state without explicitly enforcing gauge invariance through penalty terms. Additionally, experiments showing string breaking are performed on the IBM quantum platform. Thus, VQEs are seen to be a promising tool for Z2 LGTs, and could serve as a stepping stone toward studies of other gauge groups. We find that the scaling of gradients with the number of qubits is favorable for avoiding barren plateaus. Furthermore, strategies that avoid barren plateaus arise naturally as features of LGTs, such as choosing the initialization by setting the Gauss law sector and restricting the Hilbert space to the gauge-invariant subspace.

QI 3.8 Mon 17:15 BEY/0137

Efficient Quantum and Classical Simulation of the Non-Uniform Wave Equation — •Kevin Lively, Vittorio Pagni, and Gonzalo Camacho — Deutsches Zentrum für Luft- und Raumfahrt, Quantum Computing Applications, Sankt Augustin

We present an efficient algorithm based on the construction of a unitary quantum circuit for simulating the non-uniform wave equation in one, two or three dimensions. We utilize the first-order-in-time-derivative form of the wave equation alongside Pauli four-vectors to embed and manipulate vector quantities in a language which translates naturally to quantum simulation. We exploit this to create an efficient quantum-inspired classical tensor-network algorithm to inject and propagate waveforms through inhomogeneous media far beyond the memory limitations of naive finite difference methods. We explore applications of this algorithm in real world data-sets of complex media.

QI 3.9 Mon 17:30 BEY/0137

Quantum Simulation of Electron-Phonon Interactions in Circuit QED — •Riccardo Roma[1,2], Tim Bode[1], Dmitriy S. Shapiro[1], Alessandro Ciani[1], Dmitry Bagrets[1,3], and Frank Wilhelm-Mauch[1,2] — [1]Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany — [3]Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany

Electron-phonon interaction is a fundamental process in condensed-matter physics, responsible for a variety of phenomena ranging from polaron formation in semiconductors and molecules to charge-density waves, (high-temperature) superconductivity or the Hubbard-Holstein (HH) and the Yukawa-Sachdev-Ye-Kitaev (YSYK) models.

Leveraging physical resonators for emulating bosonic degrees of freedom allows to circumvent the considerable overhead associated with their encoding in qubits. It also avoids the necessity of truncating the bosonic Fock space, which is an inherent limitation of current qubit encodings.

We extend the standard gate set available for superconducting qubits by entangling gates between a transmon and a microwave resonator, showing how this can be achieved experimentally via flux tuning or microwave driving. We then derive the digital simulation circuits for the HH and YSYK models. Our work concludes with a minimal electron-phonon model for which we demonstrate a Dicke-type superradiant transition that is robust to noise and thus experimentally feasible.

QI 3.10 Mon 17:45 BEY/0137

Discrete local dynamics in globally driven dual-species Rydberg atom arrays — Francesco Cesa[3,4], Andrea di Fini[1,2], •David Korbany[1,2], Roberto Tricarico[3,4], Hannes Pichler[3,4], Hannes Bernien[3,5,6], and Lorenzo Piroli[1,2] — [1]DIFA, Universit'a di Bologna — [2]INFN, Sezione di Bologna — [3]IQOQI Innsbruck — [4]Institute for Theoretical Physics, University of Innsbruck — [5]Pritzker School of Molecular Engineering, University of Chicago — [6]Institute for Experimental Physics, University of Innsbruck

We present a simple construction to implement a family of one- and two-dimensional discrete dynamics using dual-species Rydberg atom arrays. The discrete dynamics that we consider are special examples of quantum cellular automata (QCA) and include the exact Floquet dynamics of the kicked Ising model, as well as the Trotterized evolution of translation-invariant nearest-neighbor Hamiltonians. In our scheme, one of the two species of atoms represents the physical qubits, while the other species plays an auxiliary role, mediating the interactions. Our construction only requires global driving, with no local addressing of the qubits, and assumes an ideal blockade regime. Importantly, when the inter-species interactions are dominant over the intra-species one, we give a simple argument showing that, both in the one- and two-dimensional case, the deviations from the ideal blockade regime are at least as small as for established single-species implementations in one-dimensional arrays. Finally, we illustrate applications of our constructions in the study of chaotic features of QCA dynamics. Our results may be relevant for near-term experimental implementations.

QI 3.11 Mon 18:00 BEY/0137

Extracting transport properties using zero noise extrapolations of noisy quantum dynamics — •Hansveer Singh[1], Pieter Claeys[1], Sarang Gopalakrishnan[2], and Anushya Chandran[3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, DE — [2]Princeton University, Princeton, New Jersey USA — [3]Boston University, Boston, Massachusetts, USA

We examine extrapolating transport coefficients of quantum systems subjected to weak noise. Though noise generally breaks conservation laws of a quantum system, we show for weak noise strengths it is still possible to define an effective notion of transport. For chaotic diffusive quantum systems, we provide a protocol to extrapolate diffusion constants and argue that the effective diffusion constant in the weak noise limit can be decomposed into two parts: an analytic function of the noise strength and a function determined by non-linear corrections to diffusive hydrodynamics. We support our findings with tensor network simulations of a dissipative version of the staggered field spin-1/2 XXZ chain.

QI 3.12 Mon 18:15 BEY/0137

Scrambling the Information of Transmons using Interaction by Metamaterials — •Arne Schlabes and Mohammad Ansari — Forschungszentrum Jülich

Transmission lines made of capacitors in series and inductors to the ground form so called metamaterials with inverse dispersion relations. These Left-Handed materials allow for a multi-mode interaction of transmons coupled to the resonator. We use flux tunable qubits and parametric driving to excite resonator mode states. This occupation can be spread controllably from the resonator to a qubit and back to other resonator states. With this we realize a scrambling of information which started locally in one resonator state but is then encoded non-locally in multiple states. The precise composition of the final state depends on the parameters used to encode it, without them the initial state can not be recovered.

QI 4: Quantum Manybody Systems (joint session QI/TT)

Time: Monday 15:00–18:30 Location: BEY/0245

Invited Talk QI 4.1 Mon 15:00 BEY/0245

Reducing Noise, Complexity, and Optimization Barriers in Quantum Simulations of Strongly Correlated Systems — •Werner Dobrautz — Center for Advanced Systems Understanding (CASUS), Görlitz, Germany — Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Dresden, Germany — Center for Scalable Data Analytics and Artificial Intelligence (ScaDS.AI) Dresden/Leipzig, Dresden, Germany — Technical University Dresden, Dresden, Germany

Near-term quantum hardware poses severe constraints for quantum chemistry and quantum many-body simulations due to noise, limited coherence, and challenging optimization landscapes. We present a unifying set of algorithmic strategies to address these bottlenecks, combining transcorrelated Hamiltonians, spin-adapted representations, and advanced variational optimization techniques. By embedding electronic correlations directly into the Hamiltonian, transcorrelated methods yield compact, noise-resilient quantum circuits and improved convergence for both molecular systems and lattice models. Spin-adapted formulations further reduce Hilbert space complexity and enable efficient simulations of correlated spin systems. To enhance robustness and trainability, we introduce multireference error mitigation strategies and qBang, a momentum-aware variational optimization scheme that effectively navigates flat and ill-conditioned energy landscapes. Together, these approaches establish a scalable and hardware-aware framework for accurate quantum simulations of strongly correlated systems on current and near-term quantum devices.

QI 4.2 Mon 15:30 BEY/0245

Hybrid superconducting devices — •Anamaria Ghihor[1], Yejin Lee[1], Haolin Jin[1], Markus König[1], Andreas Leithe-Jasper[1], Roemer Hinlopen[1,2], Carsten Putzke[2], Philip Moll[2], Uri Vool[1], and Eteri Svanidze[1] — [1]MPI CPfS - Nothnitzer Str. 40, Dresden, Germany — [2]MPI MPSD - Luruper Chaussee 149, Hamburg, Germany

Superconducting resonators are highly tunable, low-loss coherent macroscopic devices, making them ideal for quantum technology and sensing applications. Recently, these resonators have been paired with van der Waals (vdW) materials to explore their microwave losses, dielectric properties and kinetic inductance. However, creating a hybrid device that only integrates a superconducting resonator with a vdW flake limits the range of materials that can be used. To overcome this limitation, we fabricate a lamella using a focused ion beam (FIB), effectively replicating the flake. This approach offers the added benefit of precise dimensional control, something that is difficult to achieve with exfoliated flakes. The lamella can then be attached in situ to the resonator using a micro-manipulator. In this talk we will show preliminary hybrid devices with lamella developed from conventional and unconventional superconductors.This approach greatly expands the range of materials that can be explored and enables detailed studies of their superfluid density.

QI 4.3 Mon 15:45 BEY/0245

Hybrid Monte Carlo enhanced by exact diagonalization: simulating interacting Hubbard systems — •Martina Gisti[1], Finn Temmen[2], Thomas Luu[1], David Luitz[2], and Johann Ostmeyer[3] — [1]Institute of Physics, University of Bonn, Nußallee 12, 53115 Bonn — [2]Forschungszentrum Jülich GmbH Wilhelm-Johnen-Straße 52428 Jülich — [3]Helmholtz Institute for Radiation and Nuclear Physics, University of Bonn

We present a hybrid simulation framework that integrates the hybrid Monte Carlo method with exact diagonalization techniques to study Hubbard chains coupled through many-body interactions. Within a path integral formulation, thermal expectation values are expressed and evaluated exactly along the chains. We study the impact of the hybrid method on persistent challenges in the application of stochastic simulations, such as the sign problem and ergodicity violations. The approach mitigates the sign problem that hampers conventional simulations, providing a feasible path for studying strongly correlated quantum systems beyond one dimension.

QI 4.4 Mon 16:00 BEY/0245

Topological properties of coupled superconducting chains in the presence of interactions — •Frederick Del Pozo — aboratoire Kastler Brossel, Sorbonne Universite, CNRS, ENS-PSL Research University, Coll'ege de France; 4 Place Jussieu, 75005 Paris, France

We investigate the topological and critical properties of coupled and interacting superconducting wires.

As a prototype of superconductors with topological order, the Kitaev chain model is a perfect testing ground for novel theoretical and numerical tools, including the density-matrix-renormalization-group (DMRG) algorithm and bi-partite entanglement entropy.

In the following talk we report on the results of several recent works, which have lead to a deeper understanding of the topological and critical properties of coupled and interacting Kitaev chains, also in the presence of real-space disorder. We reveal that the usual topological invariant, defined in the absence of interactions, remains a sensible marker for the topology when two wires are brought into close proximity of each other where interaction effects and inter-wire hopping processes become relevant. We also reveal the appearance of a many-body entangled ground state, and interaction reinforced critical region in the wires' phase diagram.

Our results highlight the rich physics present in quasi one-dimensional quantum systems, and motivates the further research into properties relevant for applications in superconducting qubits and topological quantum computation protocols.

QI 4.5 Mon 16:15 BEY/0245

Quantum Assisted Ghost Gutzwiller Ansatz — •PV Sriluckshmy, Francois Jamet, and Fedor Simkovic — IQM Quantum Computers, Georg-Brauchle-Ring 23-25, 80992 Munich, Germany

The ghost Gutzwiller ansatz (gGut) technique was shown to achieve accuracy comparable to dynamical mean-field theory at a much lower computational cost. However, gGut is limited by the bottleneck of computing the density matrix. We develop a hybrid quantum-classical gGut technique that computes ground state properties of embedding Hamiltonians on a quantum computer using the quantum-selected configuration interaction (QSCI) algorithm. We find that the ground states of interest become sufficiently sparse as the number of ghost orbitals increases. We investigate QSCI's performance using local unitary cluster Jastrow (LUCJ) ansatz with circuit cutting on IQM's quantum hardware for up to 24 qubits. Our converged gGut calculations correctly capture the metal-to-insulator phase transition in the Fermi-Hubbard model. This was achieved using quantum samples to build a basis with as little as 1% of the total CI states.

30min. break

QI 4.6 Mon 17:00 BEY/0245

Measurement-Based Quantum Computation in Symmetry-Enriched Topological Phases — •Paul Herringer[1,2,3], Vir B. Bulchandani[4,5], Younes Javanmard[1], David T. Stephen[6,7], and Robert Raussendorf[1,3] — [1]Leibniz Universität Hannover, Hannover, Germany — [2]University of British Columbia, Vancouver, Canada — [3]Stewart Blusson Quantum Matter Institute, Vancouver, Canada — [4]Rice University, Houston, USA — [5]National University of Singapore, Singapore — [6]University of Colorado Boulder, Boulder, USA — [7]California Institute of Technology, Pasadena, USA

We present the first examples of topological phases of matter with uniform power for measurement-based quantum computation. This is possible thanks to a new framework for analyzing the computational properties of phases of matter that is more general than previous constructions, which were limited to short-range entangled phases in one dimension. We show that ground states of the toric code in an anisotropic magnetic field yield a natural, albeit non-computationally-universal, application of our framework. We then present a new model with topological order whose ground states are universal resources for MBQC. Both topological models are enriched by subsystem symmetries, and these symmetries protect their computational power. Our framework greatly expands the range of physical models that can be analyzed from the computational perspective.

QI 4.7 Mon 17:15 BEY/0245

Many-body localization in the Sherrington-Kirkpatrick model — •Gergo Dénes[1], Balázs Hetényi[1], Márton Kormos[1], Angelo Valli[1], Pascu Moca[1,2], and Gergely Zaránd[1] — [1]Department of Theoretical Physics, Institute of Physics, Budapest University of Technology and Economics, Muegyetem rkp. 3., H-1111 Budapest, Hungary — [2]Department of Physics, University of Oradea, Str. Universitatii nr. 1 Oradea, 410087, Romania

The Sherrington-Kirkpatrick (SK) model has been extensively studied for more than 50 years [1]. In the context of optimization problems, it represents one of the most difficult paradigmatic optimization problems, the MAXCUT problem. Its quantum extension, the transverse field SK model (TFSK model) is therefore a paradigmatic model for the Quantum Adiabatic Optimization Approach (QAOA).

We performed extensive finite-size numerical simulations of the TFSK model at different transverse field strengths to extract various many-body localization (MBL) indicators, such as inverse participation ratio, Shannon entropy, and level spacing ratio. Our numerical and analytical analysis suggest the presence of an MBL transition as a function of the transverse field at certain energy densities, different from the spin-glass transition, and in contrast to the findings of Ref. [2]. In the MBL phase, states do not seem to be exponentially localized, rather, our data suggest the presence of power-law MBL.

[1] M. Mezard, G. Parisi, M. A. Virasoro Spin Glass Theory and Beyond, ISBN: 978-9971-5-0116-7 (1986).

[2] S. Mukherjee, S. Nag, A. Garg, Phys. Rev. B 97, 144202 (2018).

QI 4.8 Mon 17:30 BEY/0245

Typical entanglement entropy of anyon chains — Yale Yauk[1,2], •Alexander Hahn[1,3,2], and Lucas Hackl[4,5] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, D-85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstraße 4, D-80799 Munich, Germany — [3]Technical University of Munich, TUM School of Natural Sciences, Physics Department, D-85748 Garching, Germany — [4]School of Mathematics and Statistics, The University of Melbourne, Parkville, VIC 3010, Australia — [5]School of Physics, The University of Melbourne, Parkville, VIC 3010, Australia

Random-state entanglement serves as a key probe of quantum chaos, thermalization, and information scrambling, but its behavior in topologically ordered systems remains unclear. Here we study the statistical properties of bipartite entanglement in one-dimensional anyon chains, where the Hilbert space is constrained by the fusion rules. In such systems, the conventional trace must be replaced by the quantum trace, requiring a consistent redefinition of density matrices and entanglement measures that incorporates topological data. We compute the average bipartite entanglement entropy and its variance for both open and periodic boundary conditions. The resulting average anyonic entanglement entropy reproduces the Page curve exactly, revealing that topological constraints modify the normalization but not the universal form of typical entanglement. Despite topological charge conservation, the average entanglement shows no symmetry-related correction of the kind that appears in systems with Lie group symmetries.

QI 4.9 Mon 17:45 BEY/0245

Thermal Entanglement and Out-of-Equilibrium Thermodynamics in 1D Bosonic Systems — •Julia Mathe, Nicky Kai Hong Li, Pharnam Bakhshinezhad, and Giuseppe Vitagliano — TU Wien, Atominstitut, Stadionallee 2, 1020 Vienna, Austria

We investigate entanglement in- and out-of equilibirum in harmonic chains, with direct relevance to low-energy descriptions of paradigmatic models, like 1D Bose-Einstein condensates. Working in a regime where all states are Gaussian, we employ the logarithmic negativity and the covariance matrix criterion (CMC) as known entanglement quantifiers. For thermal states, we extensively characterize entanglement and its scaling behaviour, including in the massless (critical) limit. We extract the optimal entanglement witness coming from the CMC and uncover a simple mode-resolved structure underlying the entanglement-to-separability transition. At finite temperature, the optimal witnesses are diagonal in the normal-mode basis, allowing to characterize entanglement from a few normal mode uncertainties, which are physically related to static susceptibilities. We then investigate out-of-equilibrium dynamics arising from a time-dependent coupling and analyze entanglement growth, suppression, and transport. Based on this, we construct a full Gaussian framework for studying entanglement in thermodynamic cycles. Our results give a unified and physically intuitive picture of how entanglement emerges and evolves in 1D Gaussian many-body systems and show that thermal separability and entanglement are mainly governed by the low-energy (infrared) sector that also underlies the continuum field-theory description.

QI 4.10 Mon 18:00 BEY/0245

Symmetry-preserving warm starts for variational ground state preparation — •Ivana Miháliková — Matej Bel University, Národná ulica 12, Banská Bystrica, 97401, Slovakia — Institute of Physics, Slovak Academy of Sciences, Bratislava 84511, Slovakia

Enforcing physical symmetries can dramatically simplify ground-state preparation in the variational quantum eigensolver (VQE). This work considers a 12-spin all-to-all neutrino-inspired model and a 4×3 Heisenberg lattice. In both systems, simple product states are projected onto symmetry subspaces with fixed total spin J and J_z (and, for the Heisenberg lattice, translation and mirror symmetries), then refined using swap-based entangling layers that generate only symmetry-compatible correlations. The resulting warm starts lie well within previously established worst-case upper bounds on the energy error normalized by system size and interaction-graph degree, showing that symmetry-aware initialization can substantially outperform generic guarantees. For the Heisenberg lattice, the symmetry-preserving construction reduces the relevant search space from 4096 basis states to just 9 symmetry-compatible states and increases the effective spectral gap from about 7 to about 28 energy units. Within a VQE setting this yields a smoother optimization landscape and faster convergence with shallow circuits. In practice, the neutrino-inspired model reaches

$\sim$ 98.8% fidelity within the $J = 0$ subspace, and the Heisenberg lattice exceeds 98.0% fidelity once translation and mirror symmetries are enforced.

QI 4.11 Mon 18:15 BEY/0245

An emerging generator of rotations for a 1- or many-particle Hofstadter problem on a lattice pierced by magnetic field — •Arabi Seshappan[1,2], Tangi Morvan[2], Alberto Nardin[2], and Leonardo Mazza[2] — [1]Department of Physics, University of California, Merced, CA 95343, USA — [2]Université Paris-Saclay, CNRS, LPTMS, 91405, Orsay, France

Topological quantum computation is an exciting direction for development of fault-tolerant qubits—a quintessential example being manipulation of excitations in fractional quantum Hall (FQH) systems. As recent cold-atom and photonic experiments have realized few-particle FQH states in small lattices, and theoretical results have shown spectra of specific lattice sizes to exhibit exactly flat-bands in momentum space, we have theoretically studied similar FQH lattices for 1- and many-particle bosonic cases. Our construction is that of a two-dimensional (2D) square lattice, with nearest-neighbor hopping, pierced by a perpendicular, uniform magnetic field. We vary the magnetic field such that, for lattice edge length L, the flux per plaquette ranges between $\alpha = 1/L$ and $\alpha = 1/4$, and analyze the resultant spectra. We have found that, for low energy levels, measurements of density are an excellent proxy for defining a gauge-invariant generator of rotations (GIGR) and can make order in the spectra. This removes any need for assumption of circular droplet invariance, and provides a useful characterization technique for cold-atom experiments.

QI 5: Quantum Computing and Algorithms II

Time: Tuesday 9:30–12:30 Location: BEY/0137

QI 5.1 Tue 9:30 BEY/0137

Transcorrelated Method with Quantum Computing : Quasi-Hermitian Hamiltonian Simulation — •Cheng-Lin Hong[1,2] and Werner Dobrautz[1,2,3,4] — [1]Center for Advanced Systems Understanding, 02826 Görlitz, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [3]Center for Scalable Data Analytics and Artificial Intelligence Dresden/Leipzig, 01069 Dresden, Germany — [4]Technical University Dresden, 01069 Dresden, Germany

A major challenge in quantum chemistry on quantum computers is the large number of qubits required to achieve accurate results near the complete basis set (CBS) limit. The transcorrelated (TC) method addresses this issue by using a non-unitary similarity transformation to incorporate electron-correlation effects, such as the cusp condition, directly into the Hamiltonian. This method accelerates convergence toward the CBS limit even with smaller basis sets, thereby reducing the number of qubits required. However, the non-unitary nature of the transformation leads to a non-Hermitian Hamiltonian, whose structure and its corresponding physical quantities depend sensitively on the chosen Jastrow factor. The choice of the Jastrow factor governs the final form of this Hamiltonian and its corresponding physical quantities.

We investigate such non-Hermitian transcorrelated Hamiltonians in a quantum-computing context. We analyze how different single-parameter Jastrow factors affect the structure of the final qubit Hamiltonian and evaluate the quantum resources required to solve them. Finally, we employ perturbation theory to derive an approximate solution for these non-Hermitian transcorrelated systems.

QI 5.2 Tue 9:45 BEY/0137

Optimal Embedded Ising Problem — •Elisabeth Lobe — German Aerospace Center (DLR), Braunschweig, Germany

Suitable Ising problems for quantum annealers need to be formulated such that they respect the specific hardware restrictions and at the same time represent the original problems which shall actually be solved. This requires to find an embedding into the hardware graph and choose the parameters of the embedded Ising problem in accordance with the precision of the machine. We have developed a method to provide provably equivalent embedded Ising problems with optimal parameters for a given arbitrary Ising problem and a corresponding embedding. The thus formulated optimal embedded Ising problems are compared to the state-of-the-art embedding transformation implemented in the D-Wave API. We investigate the Ising formulations in different scenarios to evaluate the performance of both methods. We show that our method provides better embedded Ising Problems in terms of coefficient distributions and more stable solution quality.

QI 5.3 Tue 10:00 BEY/0137

Verifiable End-to-End Delegated Variational Quantum Algorithms — •Matteo Inajetovic[1], Petros Wallden[2], and Anna Pappa[1] — [1]Technische Universität Berlin, Berlin, Germany — [2]Quantum Software Lab, School of Informatics, University of Edinburgh, Edinburgh, UK

Variational quantum algorithms (VQAs) have emerged as promising candidates for solving complex optimization and machine learning tasks on near-term quantum hardware. However, executing quantum operations remains challenging for small-scale users because of several hardware constraints, making it desirable to delegate parts of the computation to more powerful quantum devices. In this work, we introduce a framework for delegated variational quantum algorithms (DVQAs), where a client with limited quantum capabilities delegates the execution of a VQA to a more powerful quantum server. In particular, we introduce a protocol that enables a client to delegate a variational quantum algorithm to a server while ensuring that the input, the output and also the computation itself remain secret. Additionally, if the protocol does not abort, the client can be certain that the computation outcome is indeed correct. Our approach first proposes a verifiable protocol for delegating the quantum computation at each optimization step of a VQA, and then combines the iterative steps into an error-resilient optimization process that offers end-to-end verifiable algorithm execution, paving the way for practical quantum cloud computing applications.

QI 5.4 Tue 10:15 BEY/0137

Quantum algorithm for one quasi-particle excitations in the thermodynamic limit via cluster-additive block-diagonalization — •Sumeet Sumeet, Max Hörmann, and Kai Phillip Schmidt — Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany

We present a hybrid quantum-classical algorithm for computing one quasi-particle excitation energies in the thermodynamic limit by combining the variational quantum eigensolver (VQE) with numerical linked-cluster expansions (NLCEs) [1], extending our NLCE+VQE approach for ground states [2] to excitations. We minimize variance (or trace) cost functions with VQE to block-diagonalize the Hamiltonian, then extend to the thermodynamic limit with NLCE. The central challenge is ensuring cluster additivity for degenerate subspaces, essential for NLCE convergence. We address this by integrating the projective cluster-additive transformation (PCAT) with VQE: PCAT constructs the cluster-additive unitary from a polynomial number of measurements on the quantum device. Benchmarking on the transverse-field Ising model demonstrates NLCE convergence with circuit depth scaling linearly with system size. We analyze cost function robustness for models with broken symmetry. The PCAT post-processing framework applies to any quantum eigenstate preparation method, demonstrated via VQE and adiabatic sweeps on real quantum hardware. [1] Sumeet, M. Hörmann, and K. P. Schmidt, arXiv:2511.06623 (2025).
[2] Sumeet, M. Hörmann, and K. P. Schmidt, Phys. Rev. B 110, 155128 (2024).

QI 5.5 Tue 10:30 BEY/0137

Scalable Generic State Preparation through Tensor Cross Interpolation and Binary Trees — •Vittorio Pagni[1,2], Kevin Lively[1], Peter Ken Schuhmacher[1], and Michael Felderer[1,2] — [1]Institute of Software Technology German Aerospace Center (DLR) Sankt Augustin, Germany — [2]University of Cologne, Cologne, Germany

Efficient preparation of generic quantum states remains a major computational bottleneck in many quantum protocols. We introduce a deterministic and scalable method that employs tensor cross interpolation to construct a tensor-train representation of high-dimensional, queryable functions beyond what can be stored directly in memory and maps it onto a sequence of single-qubit and controlled rotations.

This mapping is achieved through an intermediate binary-tree representation, which systematically exploits the underlying data structure to minimize circuit depth under various connectivity constraints. The approach offers a transparent and structured alternative to variational methods.

QI 5.6 Tue 10:45 BEY/0137

Quantum-inspired space-time PDE solver and dynamic mode decomposition — •Raghavendra Dheeraj Peddinti[1], Stefano Pisoni[1,2], Narsimha Rapaka[3], Mohamed K. Riahi[3], Egor Tiunov[1], and Leandro Aolita[1] — [1]Quantum Research Center, Technology Innovation Institute, Abu Dhabi, UAE — [2]Hamburg University of Technology, Institute for Quantum Inspired and Quantum Optimization, Germany — [3]Emirates Nuclear Technology Center, Khalifa University of Science and Technology, Abu Dhabi, UAE

Numerical solutions of partial differential equations (PDEs) are central to the understanding of dynamical systems. Space-time methods that treat the combined space-time domain simultaneously offer better stability and accuracy than standard time-stepping schemes. Interestingly, data-driven approaches, such as dynamic mode decomposition (DMD), also employ a combined space-time representation. However, the curse of dimensionality often limits the practical benefits of space-time methods. In this work, we investigate quantum-inspired methods for space-time approaches, both for solving PDEs and for making DMD predictions. We achieve this goal by treating both spatial and temporal dimensions within a single matrix product state (MPS) encoding. First, we benchmark our MPS space-time solver for both linear and nonlinear PDEs, observing that the MPS ansatz accurately captures the underlying spatio-temporal correlations while having significantly fewer degrees of freedom. Second, we develop an MPS-DMD algorithm for accurate long-term predictions of nonlinear systems, with runtime scaling logarithmically with both spatial and temporal resolution.

30min. break

QI 5.7 Tue 11:30 BEY/0137

Probabilistic imaginary-time evolution on the ion-trap quantum computer — •Satoshi Ejima[1,2], Kazuhiro Seki[2], Benedikt Fauseweh[1,3], and Seiji Yunoki[2,4] — [1]German Aerospace Center (DLR), Cologne, Germany — [2]RIKEN, Wako, Japan — [3]TU Dortmund University, Dortmund, Germany — [4]RIKEN, Kobe, Japan

Imaginary-time evolution (ITE) is a classical method for projecting ground states of quantum many-body systems. Probabilistic imaginary-time evolution (PITE) adapts this idea to quantum hardware, providing a pathway to low-energy state preparation. We formulate PITE within a state-vector simulation framework and use it to optimize initial algorithm parameters.

We benchmark the approach on the spin-1/2 Heisenberg chain and the transverse-field Ising model (TFIM). With optimized parameters, the success probability quickly approaches unity within only a few iterations, and the energy expectation converges to the exact ground-state value.

Finally, we implement PITE for the TFIM on a trapped-ion device. Although hardware noise distorts raw outcomes, a simple global depolarizing model significantly improves agreement with ideal, noise-free behavior.

Reference: *Phys. Rev. Research* **7**, 043182 (2025).

QI 5.8 Tue 11:45 BEY/0137

From gradients to curvature: tensor-network Hessian-vector products for second-order Riemannian quantum circuit compression — •Isabel Nha Minh Le[1,2], Roeland Wiersema[3], and Christian B. Mendl[1,2,4] — [1]Technical University of Munich, School of Computation, Information and Technology, Boltzmannstraße 3, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstrasse 4, 80799 Munich, Germany — [3]Center for Computational Quantum Physics, Flatiron Institute, 162 Fifth Avenue, New York, NY 10010, USA — [4]Technical University of Munich, Institute for Advanced Study, Lichtenbergstraße 2a, 85748 Garching, Germany

Riemannian optimization, combined with tensor network techniques, has shown strong potential for quantum circuit compression. However, existing approaches either rely solely on first-order gradient information [1] or are restricted to symmetry-invariant systems [2]. We introduce a tensor-network-based framework for efficiently computing second-order derivatives on Riemannian manifolds. By integrating these curvature estimates with in- and out-of-distribution generalization strategies from quantum machine learning [3], we develop a scalable second-order Riemannian optimization method for compressing quantum circuits.

[1] Quantum 9, 1833 (2025).
[2] J. Phys. A: Math. Theor. 57 135303 (2024).
[3] arXiv preprint arXiv:2409.16346 (2024).

QI 5.9 Tue 12:00 BEY/0137

Identifying optimal non-classicality witnesses — •Martina Jung[1], Suchitra Krishnaswamy[2], Jan Sperling[2], Timon Schapeler[3], Tim Bartley[3], Annabelle Bohrdt[4], and Martin Gärttner[1] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University, Jena, Germany — [2]Institute for Photonic Quantum Systems, Theoretical Quantum Science, Paderborn University, Germany — [3]Department of Physics, Paderborn University, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), München, Germany

Non-classicality, defined and understood in the quantum optical sense, acts as a resource for photon-based quantum technologies. Therefore, certifying the non-classicality of a quantum state is crucial to gauging its potential for quantum advantage. However, traditional non-classicality witnesses often fail in realistic scenarios involving finite-resolution photon detectors and limited statistics.

Here, we train a variational model using finitely many snapshots, measured with different detection schemes, to learn an optimal non-classicality witness for a given set of physically relevant states. The model is both device-agnostic and interpretable; the optimal witness can be extracted once the model has been trained. Training the model on experimental data measured with (i) a superconducting nanowire single-photon detector and (ii) a time-bin multiplexing detection scheme demonstrates the versatility of the approach, paving the way for efficient non-classicality certification in the lab.

QI 5.10 Tue 12:15 BEY/0137

A hybrid learning agent approach for solving the flight trajectory optimization — •Marcel Schindler[1], Rouven Kanitz[2], and Sabine Wölk[1] — [1]Institute of quantum technologies, DLR, Ulm, Germany — [2]Institute of air transport, DLR, Hamburg, Germany

It is believed that combinatorial optimization is to be among the first applications where quantum computers can demonstrate a practical advantage over classical systems. One such problem is the flight trajectory optimization, which aims to find the optimal path between two airports for an aircraft under given conditions. Due to non-local constraints of the flight path, the problem is part of complexity class NP-hard and becomes difficult to solve for classical algorithms. To address this, we employ a reinforcement learning algorithm in which the learning process of an agent is sped up by using a quantum communication channel.

QI 6: Implementations II

Time: Tuesday 9:30–12:45 Location: BEY/0245

Invited Talk QI 6.1 Tue 9:30 BEY/0245

Erbium dopants for quantum networks — •Andreas Reiserer — Technical University of Munich, TUM Center for Quantum Engineering (ZQE), Am Coulombwall 3A, 85748 Garching, Germany

Despite decade-long research into different physical systems, demonstrating a scalable platform for quantum networks and distributed quantum information processing remains an outstanding challenge. In this context, our group investigates the use of erbium dopants in silicon and silicate crystals. This platform offers unique potential for up-scaling: First, erbium dopants can exhibit second-long coherence in a temperature range accessible with 4He cryocoolers. Second, the optical transition of erbium is among the narrowest spectral features ever measured in a solid. Thus, frequency-multiplexed addressing of individual dopants gives access to an unprecedented qubit density. Finally, by embedding the dopants into slow-light waveguides or optical resonators with a high quality factor, the optical lifetime can be reduced via the Purcell effect. This has enabled lifetime-limited photon emission in the telecommunications C-band, where optical fiber losses are minimal. Furthermore, it has paved the way for the optical spin readout of erbium dopants and for spectroscopy of their surrounding nuclei. Taken together, our results thus establish erbium dopants as a promising new hardware platform that may facilitate the implementation of scalable quantum networks and repeaters based on single emitters at telecommunications wavelengths.

QI 6.2 Tue 10:00 BEY/0245

Shadow Wall Epitaxy: All-in-situ fabrication of ZnSe-based Quantum Devices — •Christine Falter[1,2], Yurii Kutovyi[1,2], Nils von den Driesch[1,2], Denny Dütz[2,3], Lars R. Schreiber[2,3], and Alexander Pawlis[1,2] — [1]Peter Grünberg Institute, Forschungszentrum Jülich GmbH, 52428 Jülich, Germany — [2]JARA-FIT, Jülich Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany — [3]JARA-Institute for Quantum Information, RWTH Aachen University, 52074 Aachen, Germany

The wide band-gap semiconductor ZnSe offers a wide range of unique optical and electrical properties, which make it a promising candidate for a variety of quantum devices. In standard fabrication schemes, device performance is often limited by surface states and defects introduced during ex-situ applied processing steps. With this in mind, we have developed a Shadow Wall technique for molecular beam epitaxy (MBE), which allows for all-in-situ device fabrication making all post processing steps obsolete. The technique relies on the pre-patterning of vertical walls on the substrate and the precise alignment of material fluxes during deposition. Using our technique we have realized an all-in-situ ZnSe-based field effect transistor (FET). In our contribution, we demonstrate the MBE growth of high quality ZnSe layers on pre-patterned substrates, the optimization of the electronic band-structure and the electrical characterization of the final device. The optimization of the ZnSe FET platform is a first step towards the realization of qubits based on gate defined quantum dots in ZnSe.

QI 6.3 Tue 10:15 BEY/0245

Harnessing the non-Abelian Berry phase for universal control of zero-field spin qubits — •Baksa Kolok[1,2], Csongor Hunyady[1], and András Pályi[1,2] — [1]Department of Theoretical Physics, Institute of Physics, Budapest University of Technology and Economics — [2]HUN-REN-BME-BCE Quantum Technology Research Group, Budapest University of Technology and Economics

Spin qubits in semiconductor quantum dots achieve their longest coherence times at zero magnetic field when nuclear spins are suppressed, making zero-field operation attractive. It also promises reduced control complexity by removing the need for magnets and enabling electrical, baseband manipulation. In this talk, I present a control framework that realizes universal quantum computation in sparse quantum-dot arrays operating entirely at zero magnetic field. Initialization and readout rely on singlet-triplet energy separation and Pauli spin blockade. Single-qubit gates emerge geometrically: when a qubit is shuttled around closed loops in the array, it accumulates a non-Abelian Berry phase that implements a deterministic SU(2) rotation. Although the number of accessible loops, and thus the native gate set, is discrete, we show that in generic devices two loops already provide full single-qubit controllability. Moreover, the same pair of loops suffices for complete quantum process tomography, enabling characterization of decoherence in zero-field architectures. Combined with exchange-based entangling gates, these results position sparse quantum-dot arrays as a promising platform for high-coherence, all-electric quantum computation without magnetic fields or microwave pulses.

QI 6.4 Tue 10:30 BEY/0245

Modelling readout of spin qubits using a single electron transistor — •Domonkos Svastits[1,2], Sudipto Das[1], Aritra Sen[1], and András Pályi[1,3] — [1]Budapest University of Technology and Economics, Budapest, Hungary — [2]Qutility @ Faulhornlabs, Budapest, Hungary — [3]HUN-REN-BME-BCE Quantum Technology Research Group, Budapest, Hungary

Spin qubits in semiconductor quantum dots are a promising platform for scalable quantum computing. However, current qubit operations remain too noisy for practical applications, with qubit readout often being the noisiest operation. Readout typically uses Pauli blockade spin-to-charge conversion combined with charge sensing. In this work, we present a microscopic model of charge sensing implemented by a single-electron transistor (SET), intended to guide improvements in spin-qubit readout, focusing on an n-type Silicon double quantum dot equipped with a micromagnet. Our model provides a microscopic, dynamical description of the measurement process. We show the measurement induces unwanted back-action in the form of incoherent transitions between qubit energy eigenstates, similar to predictions for a QPC (D. Svastits et al., arXiv:2505.15878 [quant-ph]). We also calculate how the measurement rate, i.e. the speed of the measurement, depends on the qubit Hamiltonian. We find that the parameter dependence of readout infidelity, post-measurement state mixedness and leakage are well explained by the transition rates and the measurement rate. Finally, we propose experimentally practical strategies to increase the measurement rate while suppressing the transition rates.

QI 6.5 Tue 10:45 BEY/0245

Ge-based qubit heterostructure: A 3-in-1 photoelectron spectroscopy study — •Andreas Fuhrberg[1], Maximilian Oezkent[2], Kevin-P. Gradwohl[2], Sergii Chernov[4], Volkmar Koller[4], Christoph Schlueter[4], Hans-Joachim Elmers[3], and Martina Müller[1] — [1]Universität Konstanz — [2]IKZ, Berlin — [3]Universität Mainz — [4]DESY, Hamburg

Semiconductor spin qubits are a key component in quantum information processing. Ge-based hole spin qubits have also proven to be a suitable system for realizing spin qubits. Strain-induced $Ge_{0.8}Si_{0.2}$/Ge/$Ge_{0.8}Si_{0.2}$ heterostructures are a common way to build such components. At both interfaces, holes are confined by a strain-induced valence band offset (VBO) - an essential device parameter.
A set of three synchrotron-based photoemission experiments are performed to investigate the interfaces of Ge-based qubit heterostructures by varying the thickness of (i) the central Ge-layer and (ii) $Ge_{0.8}Si_{0.2}$ overlayer. Using hard X-ray momentum microscopy (MM), the valence band along the symmetry points Γ, X and L is characterized, and the VBO near both interfaces is quantized. MM reveals an increased energy shift of ≈ 50 meV between the heavy/light hole band and the spin-orbit band for (i) Ge and (ii) $Ge_{0.8}Si_{0.2}$ bands near the respective interface. An MM-based diffraction experiments and hard X-ray photoelectron spectroscopy further analyse the interface structure and chemistry. Together, this three-in-one photoelectron spectroscopy technique provides a nearly full characterization of the Ge-hole spin qubits main structure and supports the qubit optimization process.

30min. break

QI 6.6 Tue 11:30 BEY/0245

The flopping-mode exchange-only spin qubit — •Simon Stastny[1] and Guido Burkard[2] — [1]Universität Konstanz, Konstanz, Germany — [2]Universität Konstanz, Konstanz, Germany

Electron or hole spin qubits in quantum dots coupled to a microwave cavity are an established platform to realize spin qubits. One promising qubit is the exchange-only spin qubit, that allows for full baseband control, without magnetic fields. In this work we propose a spin qubit, that couples exchange-only qubit states to a cavity by adding a charge degree of freedom to the established three dot exchange-only qubit. The proposed qubit is a generalized flopping mode qubit: It comprises four quantum dots with three electrons, operating near the $(0,1,1,1) \leftrightarrow (1,0,1,1) \leftrightarrow (1,1,0,1)$ charge transition. The qubit as well as its resulting transversal and longitudinal spin photon couplings allow for full baseband control. the couplings and quasi static noise of the qubit are analyzed. We find dephasing times exceeding the estimated gates times, thus the proposed qubit is a promising system to realize baseband-controlled resonator-mediated (longitudinal) two qubit gates.

QI 6.7 Tue 11:45 BEY/0245

Reinforcement learning entangling operations on spin qubits — •Mohammad Abedi[1,2] and Markus Schmitt[1,3] — [1]PGI-8 (Quantum Control), Forschungszentrum Jülich, Wilhelm-Johnen-Straße, 52428, Jülich — [2]Fakultät für Physik, Universität Regensburg, Universitätsstraße 31, D-93051, Regensburg — [3]Fakultät für Informatik und Data Science, Universität Regensburg, Universitätsstraße 31, D-93040, Regensburg

High-fidelity control of one- and two-qubit gates past the error correction threshold is an essential ingredient for scalable quantum computing. We present a reinforcement learning (RL) approach to find entangling protocols for semiconductor-based singlet-triplet qubits in a double quantum dot. Despite the presence of realistically modelled experimental constraints, such as various noise contributions and finite rise-time effects, we demonstrate that an RL agent can yield performative protocols, while avoiding the model-biases of traditional gradient-based methods. We optimise our RL approach for different regimes and tasks, including training from simulated process tomography reconstruction of unitary gates, and investigate the nuances of RL agent design.

QI 6.8 Tue 12:00 BEY/0245

Spin Qubit Leapfrogging: Dynamics of shuttling electrons on top of another — •Nicklas Meineke and Guido Burkard — Faculty of Physics, University of Konstanz, 78464 Konstanz, Germany

In recent years spin shuttling has distinguished itself as a promising candidate for achieving high fidelity medium range interactions between spin qubits and presents a powerful tool for enabling scalable semiconductor spin quantum computing architectures in the future.

Modelling the process of a shuttled spin qubit encountering a stationary quantum dot, we investigate the dynamics of the (1,1)-(0,2) charge transition in a silicon double quantum dot with non-vanishing inter-valley coupling. This enables us to describe the process of the mobile electron leapfrogging over the stationary one i.e. transitioning from a (1,1,0)- to a (0,1,1)-charge state, occupying a (0,2,0) state inbetween. Here the triplets will occupy a valley excited state to circumvent Pauli-Spin-Blockade leading to a S*T0 splitting approximately equal to the valley splitting in the stationary dot. Consequently this protocol will implement an entangling gate, which can be tuned by waiting in this configuration. For the gate to be noise-resistant and controllable the valley splitting at the location of the middle dot needs to be very low. Therefore this opens up the possibility to make practical use and isolate low-valley splitting hotspots on a wafer, which would otherwise act as error sources.

QI 6.9 Tue 12:15 BEY/0245

Highly crystalline superconducting resonators grown on reconstructed sapphire via Thermal Laser Epitaxy and Molecular Beam Epitaxy — •Thomas J. Smart[1], Marc Neis[2], Roudy Hanna[1,2], Marcello Gaurdascione[2], Michael Schleenvoigt[1], Joscha Domnick[1], Benjamin Bennemann[1], Janine Lorenz[3], Jin Hee Bae[1], Abdur R. Jalil[1], Pavel A. Bushev[2], Felix Lüpke[3], Peter Schüffelgen[1], Detlev Grützmacher[1], and Rami Barends[2] — [1]Peter Grünberg Institute of Semiconductor Nanoelectronics (PGI-9), Forschungszentrum Jülich & Jülich Aachen Research Alliance; 52425, Jülich, Germany — [2]Peter Grünberg Institute of Functional Quantum Systems (PGI-13), Forschungszentrum Jülich, Campus-Boulevard 79, 52074, Aachen, Germany — [3]Peter Grünberg Institute of Quantum Nanoscience (PGI-3), Forschungszentrum Jülich, 52425, Jülich, Germany

In the ongoing search for optimizing quantum computing hardware, many alternative superconducting materials are being investigated, including nitrogen-based compounds with large superconducting band gaps, high Tc values, and resistance to oxidation. Concurrently, thermal reconstruction of substrates via Thermal Laser Epitaxy enables enhanced epitaxial growth and pristine interface quality. We demonstrate the growth of highly crystalline TiN on reconstructed sapphire via Molecular Beam Epitaxy, subsequently fabricated into superconducting resonators. These resonators produce internal quality factors greater than 2e6 at single-photon values, among the highest recorded for crystalline TiN on sapphire.

QI 6.10 Tue 12:30 BEY/0245

Characterization of driven unwanted state transitions in superconducting circuits — •Sumeru Hazra, Wei Dai, Daniel. K. Weiss, Pavel D. Kurilovich, Thomas Connolly, Harsh K. Babla, Shraddha Singh, Vidul R. Joshi, Andy Z. Ding, Pranav D. Parakh, Jaya Venkatraman, Xu Xiao, Luigi Frunzio, and Michel H. Devoret — Department of Applied Physics, Yale University, New Haven, CT, USA

Microwave drives are essential for the control and readout of superconducting quantum circuits. Ideally, strong drive increases the speed and fidelity of such operations, however, in practice, strong drives also induce unwanted state transitions that corrupt these operations. In this talk, I will present a comprehensive investigation of drive-induced transitions in a fixed-frequency qubit subjected to microwave tones over a broad 9 GHz range. By combining a pump-probe spectroscopy with driven Hamiltonian simulations, we identify the physical origins of these transitions and group them into three mechanisms: (i) Resonant interactions with parasitic two-level systems activated by drive-induced ac-Stark shifts, (ii) Intrinsic multi-photon transitions out of the computational subspace, and (iii) Inelastic scattering processes where the qubit exchanges energy with spurious electromagnetic modes or TLS defects. I will show that Floquet steady-state simulations, supplemented with finite-element electromagnetic modeling, accurately predict all transitions that do not involve TLSs. These results establish a unified framework for predicting and eliminating drive-induced unwanted transitions.

QI 7: Quantum Thermodynamics

Time: Tuesday 9:30–11:00 Location: BEY/0E17

QI 7.1 Tue 9:30 BEY/0E17

Probes of Full Eigenstate Thermalization in Ergodicity-Breaking Quantum Circuits — •Gabriel O. Alves, Felix Fritzsch, and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany

The eigenstate thermalization hypothesis (ETH) is the leading interpretation in our current understanding of quantum thermalization. Recent results uncovered strong connections between quantum correlations in thermalizing systems and the structure of free probability theory, leading to the notion of full ETH. However, most studies have been performed for ergodic systems and it is still unclear whether or how full ETH manifests in ergodicity-breaking models. We fill this gap by studying standard probes of full ETH in ergodicity-breaking quantum circuits, presenting numerical and analytical results for interacting integrable systems. These probes can display distinct behavior and undergo a different scaling than the ones observed in ergodic systems. For the analytical results we consider an interacting integrable dual-unitary model and present the exact eigenstates, allowing us to analytically express common probes for full ETH. We discuss the underlying mechanisms responsible for these differences and show how the presence of solitons dictates the behavior of ETH-related quantities in the dual-unitary model. We show numerical evidence that this behavior is sufficiently generic away from dual-unitarity when restricted to the appropriate symmetry sectors.

QI 7.2 Tue 9:45 BEY/0E17

Exploring Noisy Quantum Thermodynamical Processes via Global Depolarizing Approximation — Jian Li[1], Xiaoyang Wang[2], Marcus Huber[1], Nicolai Friis[1], and •Pharnam Bakhshinezhad[1] — [1]Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria — [2]RIKEN Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS), Wako 351-0198, Japan

Noise is an unavoidable challenge for quantum thermodynamical protocols in deep circuits [1]. To overcome the difficulty of analytically characterizing cumulative, gate-dependent errors, we introduce the Global Depolarizing Approximation (GDA), a scalable framework. The GDA approximates complex local noise channels with a single, system-wide depolarizing channel, requiring only a moderate circuit depth that approximates a unitary 2-design [2].

Applying the GDA to the Two-Sort Algorithmic Cooling (TSAC) protocol [3], we derive a novel analytical expression for its asymptotic cooling limit under realistic noise. This analysis reveals a fundamental noise-induced trade-off: the ideal exponential gain from increasing the qubit number is counteracted by an exponential increase in noise accumulation, which dictates an optimal qubit number and a sharp upper bound on the achievable cooling performance. We validate the GDA's accuracy against detailed physical noise simulations for both TSAC and Dynamic Cooling (DC) protocols [4]. Our framework offers a powerful tool for quantifying the thermodynamic cost of imperfect control in noisy quantum systems.

QI 7.3 Tue 10:00 BEY/0E17

Exact heat currents for multi-bath open quantum systems — •Matteo Garbellini[1], Valentin Link[2], and Walter Strunz[1] — [1]Institut für Theoretische Physik, Technische Universität Dresden, Dresden, Germany — [2]Technische Universität Berlin, Berlin, Germany

I present a numerically exact method for computing stationary heat currents in small quantum systems coupled to multiple bosonic reservoirs at different temperatures. Our approach leverages the recently introduced uniTEMPO method [1], which efficiently generates compressed auxiliary environments for non-Markovian Gaussian baths. Building upon this, we are able to efficiently compute heat currents into the reservoirs in both transient and steady-state regimes.

We apply our method to a single qubit strongly coupled to two baths and analyze how different coupling operators and the structure of the environments affect heat transport. Finally, we apply the method to quantum refrigeration. For a three-level system coupled to two reservoirs, we find that although autonomous global refrigeration does not occur, a frequency-resolved analysis reveals local cooling of specific environmental modes, suggesting a route to exploiting this localized effect with additional weakly coupled modes.

[1] V. Link, H.-H. Tu, and W. T. Strunz, Phys. Rev. Lett. 132, 200403 (2024)

QI 7.4 Tue 10:15 BEY/0E17

Local energy assignment for two interacting quantum thermal reservoirs — •Alessandra Colla[1,2], Bassano Vacchini[2], and Andrea Smirne[2] — [1]Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Dipartimento di Fisica “Aldo Pontremoli”, Università degli Studi di Milano, Via Celoria 16, I-20133 Milan, Italy

Understanding how to assign internal energy, heat, and work in quantum systems beyond weak coupling remains a central problem in quantum thermodynamics, particularly as the difference between competing definitions becomes increasingly relevant. In this work [1], we identify two common sets of definitions for first law quantities that are used in the literature to describe the thermodynamics of quantum systems coupled to thermal environments. Both are conceptually non-symmetric, treating one part of the bipartition (the “system”) differently from the other (the “bath”). We analyze these in a setting where such roles are not easily assigned, namely two large sets of thermal harmonic oscillators interacting with each other. We further compare them with a third set of definitions based on a local, conceptually symmetric open-system approach (“minimal dissipation”) and discuss their quantitative and structural differences. We observe that all three sets of definitions differ substantially even in the dispersive regime, and that the minimal dissipation approach features distinct work peaks that increase with coupling strength.

[1] A. Colla, B. Vacchini and A. Smirne, New Journal of Physics 10.1088/1367-2630/ae24a0 (2025)

QI 7.5 Tue 10:30 BEY/0E17

Symmetry-Aware Cooling Protocols for High-Fidelity Initialization of Many-Body Spin Networks — •Durga Dasari[1], Saikat Sur[2], and Gershon Kurizki[3] — [1]3. Physics Institute, University of Stuttgart, Stuttgart, GERMANY — [2]Institute of Mathematical Sciences, Chennai, India — [3]Weizmann Institute of Science, Israel

Interacting quantum spin networks are central to many-body quantum simulations, sensing, and quantum computation, all of which demand a highly polarized initial state. However, cooling such networks to their ground state is impeded by interaction-induced correlations and symmetry-protected subspaces. Resetting a mixed many-body state to the computational-zero state thus remains an open challenge. We present a universal cooling strategy that couples the network collectively to an ancilla spin that periodically dumps entropy into an ultracold bath. Using graph-theoretic analysis of the network*capturing connectivity, symmetry sectors, and correlation flow*we bypass the intractability of full quantum dynamics. This analysis reveals a unique coherent control sequence that deliberately breaks graph-imposed symmetry constraints and unlocks otherwise inaccessible cooling pathways. The resulting protocol provides a general and experimentally realistic route to high-fidelity purification of complex spin networks.

QI 7.6 Tue 10:45 BEY/0E17

Local and global thermodynamics of pure decoherence processes — •Irene Ada Picatoste[1], Alessandra Colla[2], and Heinz-Peter Breuer[1] — [1]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Dipartimento di Fisica Aldo Pontremoli, Università degli Studi di Milano, via Celoria 16, I-20133 Milan, Italy

We study the thermodynamics of pure decoherence processes in open quantum systems coupled to a thermal reservoir. We perform a comparison between two viewpoints: a local approach [1] which is based on the system's degrees of freedom alone, and global approaches [2, 3] which require knowledge about the degrees of freedom of the bath. We also employ a specific model and, in calculating entropy production, internal energy, heat and work, we find substantial differences between the formulations. Concretely, in the global approaches we observe a large heat exchange, that refers in this particular case to the rearranging of the energy in the degrees of freedom of the reservoir, rather than to energy entering or leaving the system [4].

[1] A. Colla and H.-P. Breuer, Phys. Rev. A 105, 052216 (2022).

[2] M. Esposito, K. Lindenberg, and C. V. den Broeck, New J. Phys. 12, 013013 (2010).
[3] G. T. Landi and M. Paternostro, Rev. Mod. Phys. 93, 035008 (2021).
[4] I. A. Picatoste, A. Colla, and H.-P. Breuer, Phys. Rev. A 112, 022210 (2025).

QI 8: Implementations III

Time: Tuesday 14:00–15:30 Location: BEY/0137

QI 8.1 Tue 14:00 BEY/0137

Proposal of multi-mode couplers for all-to-all connectivity and long distance couplings for superconducting qubits — •Zhongyi Jiang[1,2], Mira Sharma[2], Simon Geisert[3], Sören Ihssen[3], Ioan Pop[3,4,5], and Mohammad Ansari[1] — [1]Peter Grünberg Institute PGI-12, Forschungszentrum Jülich, Jülich 52425, Germany — [2]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [3]IQMT, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [4]PHI, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [5]Physics Institute 1, Stuttgart University, 70569 Stuttgart, Germany

The low connectivity in superconducting systems has become a crucial bottleneck for scaling up superconducting QPU and implementing error correction. Building on our previous theory of multi-mode couplers, we propose a coupler and QPU design with superconducting qubits that support native all-to-all connectivity and long distance couplings. In our design, each module consists of a central multi-mode coupler with qubits around it. The central coupler provides all-to-all coupling within the module. Between the modules, central couplers are coupled via a bus coupler. The central couplers and the bus coupler together provide long-distance coupling among qubits in different modules. We give theory analysis and numerical simulations for such a QPU design. We believe this gives a feasible path for scaling up superconducting qubits.

QI 8.2 Tue 14:15 BEY/0137

Accelerated CZ gates on Tunable Fluxonium architecture — •Aneesh Anand Kamat[1,2], Dimitrios Georgiadis[1,3], Francisco Cárdenas-López[1], and Felix Motzoi[1,3] — [1]Peter Grünberg Institute, Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany — [3]Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany

Fluxonium qubits offer superior coherence for large-scale superconducting processors, but their protected nature complicates standard entangling schemes due to smaller matrix elements. The Fluxonium-Transmon-Fluxonium (FTF) architecture leverages a flux-tunable Transmon coupler to mediate interaction, enabling stronger effective couplings for fast gates. We analyze the error budget for a flux-controlled CZ gate in the FTF architecture by characterizing the dominant leakage channels for experimentally realized systems, and developing the strategies to remove them using quantum optimal control.

QI 8.3 Tue 14:30 BEY/0137

Realising Superconducting Qubit Architectures using Scalable Flip-Chip Integration — •Anirban Bhattacharjee[1,2], Lea Richard[1,2], Julius Feigl[1,2], Ivan Tsitsilin[1,2,3], Niklas Bruckmoser[1,2], Johannes Schirk[1,2], João Romeiro[1,2], David Bunch[1,2], Leon Koch[1,2,3], Haiyang Hu[1,2], Lasse Södergren[1,2], Christian Schneider[1,2], Max Werninghaus[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [3]Peak Quantum GmbH, Garching, Germany

Flip-chip integration technologies have emerged as a promising approach to scale superconducting qubits. This enables flexible signal routing and minimizes crosstalk. Separating the qubit chip from the control chip, consisting of microwave signal lines, allows tackling fabrication challenges independently. In this work, we use high quality indium bumps for inter chip bonding and polymer spacers to achieve precise control of inter chip spacing and alignment. We demonstrate qubits exhibiting average relaxation times of $T_1 = 102 \pm 13\mu s$ and microwave resonators with quality factors of $Q_{int} \geq 10^6$, demonstrating that our techniques do not degrade the resonator or qubit performance. We also report our ongoing work in realizing high fidelity two-qubit gates using a tunable coupler architecture, an essential step towards scaling up superconducting quantum processors using flip-chip technologies.

QI 8.4 Tue 14:45 BEY/0137

Inherent crosstalk in superconducting circuits — •Balázs Gulácsi and Guido Burkard — University of Konstanz, Konstanz, Germany

Crosstalk refers to unwanted qubit addressing. This is particularly detrimental for scaling quantum information systems because unintended interactions limit overall performance. For superconducting qubits, tunable couplings and frequency tunability achieved through externally applied magnetic fluxes enable high-fidelity entangling gates; however, they also introduce crosstalk through flux linkage. In this work, we are investigating the impact of time-dependent external-flux-aware circuit quantization on superconducting qubit couplings. We find that non-trivial couplings emerge between capacitively linked qubits when the magnetic flux threading one qubit's loop varies in time, in a manner analogous to Faraday's law of induction. These effects influence the performance of parametrically activated two-qubit gates and enable flux noise to propagate even to fixed-frequency transmons.

QI 8.5 Tue 15:00 BEY/0137

Ultrafast Single Qubit Gates through Multi-Photon Transition Removal — •Yuan Gao[1,2], Asier Galicia[1,2], José Da Costa Jesus[3,4], Yebin Liu[1], Yorgo Haddad[1,2], Dmitriy Volkov[1,2], Jéferson Guimarães[1,2], Harsh Bhardwaj[1,2], Markus Jerger[1], Marc Neis[1,2], Boxi Li[3], Francisco Cárdenas-López[3], Felix Motzoi[3,4], Pavel Bushev[1], and Rami Barends[1,2] — [1]Institute for Functional Quantum System (PGI-13), Forschungszentrum Jülich, Jülich, Germany — [2]Department of Physics, RWTH Aachen University, Aachen, Germany — [3]Institute for Quantum Control (PGI-8), Forschungszentrum Jülich, Jülich, Germany — [4]Institute for Theoretical Physics, University of Cologne, Cologne, Germany

Qubits typically have multilevel structures making them prone to unwanted transitions from fast gates. Previous works focus on suppressing leakage by mitigating the first to second excited state transition, overlooking multi-photon transitions, and achieving faster gates with further reductions in leakage has remained elusive. Here, we demonstrate single qubit gates with a total leakage error consistently below 2.0×10^{-5}, and obtain fidelities above 99.98% for pulse durations down to 6.8 ns for both X and $X/2$ gates. This is achieved by removing direct transitions beyond nearest-neighbor levels using a double recursive implementation of the Derivative Removal by Adiabatic Gate (DRAG) method, which we name the R2D method. We also introduce an approach for amplifying leakage error that can precisely quantify leakage rates below 10^{-6}. The presented approaches can be readily applied to other qubit types as well.

QI 8.6 Tue 15:15 BEY/0137

Analytical blueprint for 99.999% single-qubit gate fidelities via multi-photon error suppression on present hardware — •José Diogo Da Costa Jesus[1,2], Boxi Li[1,2], Francisco Cárdenas-López[1], and Felix Motzoi[1,2] — [1]Forschungszentrum Jülich — [2]University of Cologne

To attain high-fidelity single-qubit gates on a quantum processor, precise control of the quantum system is required. Nevertheless, such operations suffer from a plethora of errors arising from residual couplings to higher levels, resulting in leakage and phase errors that limit gate accuracy and make this task significantly challenging. Here, we demonstrate that single-qubit gate errors on the order of 10^(-5) can be achieved by introducing simple control methods based on multi-derivative pulse shaping, termed R1D and R2D, which correct the leading sources of error and enable gate infidelities below 10^(-5) for a 7ns pi-rotation in a superconducting ladder system. Moreover, we show that for a gate duration below ten nanoseconds, modeling the ladder as a three-level system does not provide an adequate descrip-

tion, because multi-photon transitions involving the third excited state become a major source of error. Based on this formalism, we also obtain analytical expressions for the drive amplitude and drive detuning allowing further error suppression and simplifying the calibration process. These results demonstrate that analytical pulse-shaping techniques can substantially improve single-qubit gate performance.

QI 9: Decoherence and Open Systems I

Time: Tuesday 14:00–15:30 Location: BEY/0245

QI 9.1 Tue 14:00 BEY/0245

Asymptotic Exceptional Steady States in Dissipative Dynamics — •Yu-Min Hu[1] and Jan Carl Budich[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]Institute of Theoretical Physics, Technische Universität Dresden and Würzburg-Dresden Cluster of Excellence ct.qmat, 01062 Dresden, Germany

Spectral degeneracies in Liouvillian generators of dissipative dynamics generically occur as exceptional points, where the corresponding non-Hermitian operator becomes non-diagonalizable. Steady states, i.e., zero-modes of Liouvillians, are considered a fundamental exception to this rule since a no-go theorem excludes non-diagonalizable degeneracies there. Here, we demonstrate that the crucial issue of diverging timescales in dissipative state preparation is largely tantamount to an asymptotic approach towards the forbidden scenario of an exceptional steady state in the thermodynamic limit. With case studies ranging from NP-complete satisfiability problems encoded in a quantum master equation to the dissipative preparation of a symmetry-protected topological phase, we reveal the close relation between the computational complexity of the problem at hand and the finite-size scaling towards the exceptional steady state, exemplifying both exponential and polynomial scaling. Formally treating the weight W of quantum jumps in the Lindblad master equation as a parameter, we show that exceptional steady states at the physical value W=1 may be understood as a critical point hallmarking the onset of dynamical instability.

QI 9.2 Tue 14:15 BEY/0245

Dissipation as a resource: non-Markovian pathways to autonomous steady-state entanglement in photonic platforms — •Karol Kawa[1], Katarzyna Roszak[1], Radim Filip[2], and Tomáš Novotný[3] — [1]FZU – Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic — [2]Palacký University Olomouc, Olomouc, Czech Republic — [3]Charles University, Prague, Czech Republic

Decoherence is usually cast as the nemesis of entanglement in open quantum systems. Here we overturn that narrative and show that environmental engineering can, by itself, generate and stabilize entanglement. We analyze two bosonic modes, each coupled to an independent, uncorrelated thermal bath, and explore two complementary routes toward autonomous entanglement: (i) direct mode*mode coupling and˜(ii) dissipation-induced single-mode squeezing followed by passive linear optics. Going beyond previous Markov-limit studies that dismissed the possibility of steady-state entanglement by neglecting anomalous coupling terms, we perform a full non-equilibrium treatment that embraces non-Markovian noise and counter-rotating interactions. Logarithmic negativity reveals a robust, sizable entanglement in both scenarios. Our results depict an experimentally realistic blueprint compatible with contemporary photonic circuitry to transform unavoidable dissipation into a functional resource. By revealing how tailored system-bath couplings autonomously drive quantum correlations, this work enriches the toolbox of reservoir engineering and advances the quest for scalable, self-contained quantum technologies.

QI 9.3 Tue 14:30 BEY/0245

Emergent decoherent histories from first principles — •Philipp Strasberg — Instituto de Fisica de Cantabria (IFCA), Santander, Spain

I overview recent progress about the emergence of decoherent histories from first principles, i.e., without the use of ensembles or approximations to the Schroedinger dynamics —akin to approaches in pure state statistical mechanics. After briefly reviewing the importance of decoherent histories to understand a unitarily evolving quantum Universe, I show that generic (non-integrable) many-body systems are characterized by an exponential suppression of interference effects (as a function of the particle number of the system) whereas integrable systems are characterized by a much weaker form of decoherence. I conclude with an outlook about how (long) (de/re)coherent histories shape the structure of the Multiverse, a hitherto unappreciated phenomenon.

QI 9.4 Tue 14:45 BEY/0245

Random matrix perspective on probabilistic error cancellation — •Leonhard Moske[1], David Luitz[1], Pedro Ribeiro[2], Tomaž Prosen[3], Sergiy Denysov[4], and Karol Zyczkowski[5,6] — [1]Institute of Physics, University of Bonn, Germany — [2]CeFEMA-LaPMET, Departamento de Fisica, Instituto Superior Tecnico, Universidade de Lisboa, Portugal — [3]Faculty of Mathematics and Physics, University of Ljubljana, Slovenia — [4]Department of Computer Science, OsloMet, Oslo Metropolitan University, Norway — [5]Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, Poland — [6]Center for Theoretical Physics, Polish Academy of Sciences, Poland

Probabilistic error cancellation is an attempt to reverse the effect of dissipative noise channels on quantum computers by applying unphysical channels after the execution of a quantum algorithm on noisy hardware. We investigate on general grounds the properties of such unphysical quantum channels by considering a random matrix ensemble modeling noisy quantum algorithms. We show that the complex spectra of denoiser channels inherit their structure from random Lindbladians. Additional structure imposed by the locality of noise channels of the quantum computer emerges in terms of a hierarchy of timescales.

QI 9.5 Tue 15:00 BEY/0245

Quantum Memory in Strongly Coupled Systems via Time-Evolving Matrix Product Operators — •Ilja List, Konrad Mickiewicz, Matteo Garbellini, Charlotte Bäcker, and Walter Strunz — Dresden University of Technology, Dresden, Germany

The steady exchange of information and energy between system and environment in open quantum systems introduces noise and dissipation into the dynamics. In the interest of modelling realistic quantum systems, it is crucial to investigate systems strongly coupled to the environment. In such non-Markovian quantum dynamics, the origin of memory effects requires a strict classification as classical or quantum. Using the paradigmatic spin-boson model, we examine numerically the behavior of open quantum systems via local quantum memory criteria based on process tensors [1]. To this end, we use the recently introduced method uniTEMPO [2] to construct the process tensors. We focus on the long-range multi-time correlations of non-Markovian open quantum systems for increasing coupling strength, and investigate the detection of quantum memory near the quantum phase transition.

[1] C. Bäcker, V. Link, and W. T. Strunz. Phys. Rev. Res. 5bfc-znkj (2025)
[2] V. Link, H.-H. Tu, and W. T. Strunz, Phys. Rev. Lett. 132, 200403 (2024)

QI 9.6 Tue 15:15 BEY/0245

Signatures of correlated noise in cavity QED — •Nadine Lenke and Guido Burkard — Department of Physics, University of Konstanu, 78457 Konstanz, Germany

Noise effects limit the performance of quantum computation drastically. While the effects of noise are examined in various publications a detailed theoretical description of the influence of noise correlations is missing. In this work we examine the effects of noise correlations in cavity QED. Our underlying system consists of two qubits, which are coupled to the same cavity but not directly to each other. Both qubits are affected by longitudinal noise impacting their energy separation. The effects from noise correlations are indirectly examined with the transmission through the cavity. We compare the influences of white noise and quasi-static noise in the transient regime by applying input-output theory. We find that after averaging over many measurements, the noise correlation spectral density $S_{12}(\omega)$ can be extracted from the cavity transmission amplitude A. We compare its dependence on $S_{12}(\omega)$ for the two noise models. We conclude that in both cases a

higher noise correlation spectral density leads to a decreasing A. In the quasi-static noise case the reduction of the cavity transmission amplitude is weaker. We find that in special parameter settings and for certain initial conditions it is possible to extract the noise correlation spectral density for general types of noise from the second derivative of A with respect to the sensitivities to the noise on the two qubits. The recreation of $S_{12}(\omega)$ can be achieved by writing this quantity as a sum of convolutions and by applying the convolution theorem.

QI 10: Quantum Information: Concepts and Methods I

Time: Wednesday 9:30–12:45 Location: BEY/0137

QI 10.1 Wed 9:30 BEY/0137

Deciding finiteness of Hamiltonian algebras I — •David Edward Bruschi, Tim Christoph Heib, and Robert Zeier — Forschungszentrum Jülich, Jülich, Germany

The ability to exactly obtain the dynamics of a physical system is a core goal of most areas of modern physics. Full knowledge of the state of a system at all times would be of greatest advantage for a myriad of tasks of current interest, such as quantum simulation, computing, and control. Quantum dynamics are characterized by the non-commutativity of operators in the Hamiltonian, which in turn implies that analytical solution are, in general, impossible to obtain. A standard way to approach this problem is to use of ad-hoc solutions or numerical techniques. While this allows for a better understanding of the physical processes of interest, such understanding remains only partial, and the question of how to obtain full control over the dynamics remains open.

We introduce a novel approach to determine the dimensionality of a Hamiltonian Lie algebra of interacting bosonic systems by appropriately classifying the space of its generating terms, thereby dividing the space of arbitrary linear Hermitian operators into classes with a meaningful physical interpretation. A first main result on the constraints that must be fulfilled by Hamiltonians without drift in order for the Hamiltonian Lie algebra to be finite-dimensional is obtained. Extension of this work to the classification of such algebras for one self-interacting bosonic mode is also provided. Our work has important implications for theoretical (quantum) physics as well as the theory Lie algebras.

QI 10.2 Wed 9:45 BEY/0137

Deciding finiteness of bosonic dynamics II — •Tim Heib — Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, 52425 Jülich, Germany — Theoretical Physics, Universität des Saarlandes, 66123 Saarbrücken, Germany

Determining the exact dynamics of a given system is paramount in most areas of physics, especially in quantum mechanics. A well-known method for systematically solving these dynamics by factorizing the time-evolution operator into a finite product of exponentials is the Wei-Norman method.

Recently, a new approach has been proposed to investigate the classes of Hamiltonians for which this method is applicable. This involves analyzing the dimensionality of Hamiltonian Lie algebras by appropriately characterizing their generating terms. In our work, we generalize previous results by significantly extending their applicability to a broader class of physically relevant bosonic Hamiltonians. We reduce the complexity of verifying finiteness conditions from quadratic to linear, and we also introduce a visual algorithm to implement the corresponding procedure. Furthermore, we identify a universal Lie algebraic structure encompassing all finite-dimensional algebras within this framework. Our contributions represent a substantial step toward a comprehensive classification of Hamiltonian Lie algebras, with potential impact for practical applications in quantum technologies.

QI 10.3 Wed 10:00 BEY/0137

Identification of unital channels without mixed-unitary representation — •Charlotte Bäcker and Walter Strunz — Dresden University of Technology, Dresden, Germany

Unital quantum channels are characterized by their property of leaving the maximally mixed state invariant. Among these channels are mixed-unitary channels, which can be represented as a probabilistic mixture of unitary operations. For qubits (d = 2), any unital channel is also mixed-unitary, however this does not hold for d > 2. A well-known, open NP-hard problem is to distinguish between these two classes of channels in higher-dimensional quantum dynamics. This question is relevant not only from a theoretical perspective but also for applications in quantum technology (e.g., error correction). In this talk, we will present a new method to identify non-mixed-unitary channels using tools from quantum memory theory. After introducing the relevant concepts, we will demonstrate how this method allows for a more sensitive characterization, illustrated by specific examples.

QI 10.4 Wed 10:15 BEY/0137

Understanding Quantum Reservoir Computing through the lens of Krylov Complexity — •Saud Cindrak, Lina Jaurigue, and Kathy Lüdge — Technische Universität Ilmenau, Ilmenau, Deutschland

Recent years have seen growing interest in using information-theoretic and dynamical measures to characterize quantum systems. Krylov complexity, in particular, quantifies how an operator or state spreads within a Krylov basis and distinguishes integrable from chaotic dynamics.

Here we show that time-evolved states and operators generate the same Krylov space, leading to a natural formulation of time-dependent Krylov spaces. Instead of relying on Krylov complexity, we introduce an effective phase-space dimension on the Krylov space that does not inherently assign larger complexity to states deeper in the Krylov chain. We term this measure Krylov observability (for operators) and Krylov expressivity (for states).

We then compare Krylov observability with the data generalizability of a quantum reservoir computer, quantified by its information processing capacity (IPC), and find that the two exhibit almost identical behavior. Lastly, we introduce a quantum Zeno time for operators and use it to further clarify the behavior of Krylov observability up to the Heisenberg time obtained from level statistics.

[1] S. Čindrak, L. Jaurigue, K.Lüdge, Phys. Rev. Res. 7, L042039
[2] S. Čindrak, L. Jaurigue, K.Lüdge, Phys. Rev. Res. 7, 043190
[3] S. Čindrak, L. Jaurigue, K.Lüdge, J. High Energ. Phys 2024, 83

QI 10.5 Wed 10:30 BEY/0137

Characterizing Criteria of Non-Markovian Dynamics and Quantum Memory — •Nick Maryshchak, Charlotte Bäcker, and Walter Strunz — Dresden University of Technology, Dresden, Germany

The occurrence of non-Markovianity in the dynamics of open quantum systems gives rise to the classification of memory phenomena. While in classical dynamics, non-Markovian processes are well defined, there is no unique quantum analogue. Several concepts of quantum non-Markovianity have been proposed, based for example on divisibility of the quantum map or on distinguishability of quantum states. We examine the fraction of non-Markovian dynamics in regard to different criteria in the state space of time-discrete dynamics. A growing debate is whether these memory effects are of truly quantum origin. In the subclass of non-Markovian dynamics, we examine different proposed witnesses for quantum memory and their relation among themselves.

QI 10.6 Wed 10:45 BEY/0137

Use of Neural Networks to Reconstruct Information on NV-Center Spin Registers — •Alessia Camuti Borani[1], Matthias Müller[2], and Tommaso Calarco[1,2,3] — [1]Università di Bologna — [2]Forschungszentrum Jülich — [3]Universität zu Köln

The presentation will focus on the use of Neural Networks to reconstruct information about spin states in NV-center platforms from computational-basis measurement outcomes. Neural Networks can in fact serve as a more efficient alternative to standard reconstruction protocols, thanks to their ability to detect patterns in data.

The quantum platform we simulate consists of the electronic spin of a Nitrogen-Vacancy (NV) defect in diamond, used for initialization and readout, together with the surrounding nuclear carbon spins, which serve as the actual qubits.

In the first part of the talk, we will discuss results on full-state tomography of spin states in NV-center registers using Neural Networks. We will compare the performance obtained when feeding the network with Pauli-basis measurement outcomes to that of a randomized protocol, in which randomly selected gates are applied prior to measurement. In the second part of the talk, we will instead present results on the reconstruction of observables of NV-center systems, rather than full density matrices.

30min. break

QI 10.7 Wed 11:30 BEY/0137

Entanglement quantification with randomized measurements is maximally difficult — Julian Eisfeld and •Nikolai Wyderka — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf, Germany

The certification of quantum systems is essential for emerging quantum technologies, particularly in quantum communication, networks, and distributed computing, where maintaining a common reference frame across distant nodes poses significant challenges. Reference frame independent approaches, such as randomized measurement schemes, offer a promising route by reducing experimental demands while granting access to basis-independent quantities, including entanglement. However, the efficiency of such schemes in measuring local invariants has remained unclear.

In this contribution, we determine the minimal number of measurement settings required to access all two-qubit invariants using randomized measurement schemes. We further demonstrate that entanglement certification necessarily involves the most demanding invariants, establishing it as a maximally difficult task. Our results reveal a fundamental hierarchy among invariants, with direct implications for experimental feasibility and theoretical understanding of quantum certification. Finally, we extend our analysis beyond bipartite systems by applying it to the Kempe invariant in three-qubit systems, providing a first step toward uncovering similar hierarchies in higher dimensions.

QI 10.8 Wed 11:45 BEY/0137

The three kinds of three-qubit entanglement — •Szilárd Szalay — Wigner Research Centre for Physics, Budapest, Hungary

We construct an important missing piece in the entanglement theory of pure three-qubit states, which is a polynomial measure of W entanglement, working in parallel to the three-tangle, which is a polynomial measure of GHZ entanglement, and to the bipartite concurrence, which is a polynomial measure of bipartite entanglement. We also show that these entanglement measures are ordered, the bipartite measure is larger than the W measure, which is larger than the GHZ measure. It is meaningful then to consider these three types of three-qubit entanglement, which are also ordered, bipartite is weaker than W, which is weaker than GHZ, in parallel to the order of the three equivalence classes of entangled three-qubit states.

QI 10.9 Wed 12:00 BEY/0137

Gaussian fermionic embezzlement of entanglement — •Alessia Kera, Lauritz van Luijk, Alexander Stottmeister, and Henrik Wilming — Institute for Theoretical Physics, Leibniz University Hanover, Hanover, Germany

Embezzlement of entanglement allows to extract arbitrary entangled states from a suitable embezzling state using only local operations while perturbing the resource state arbitrarily little. A natural family of embezzling states is given by ground states of non-interacting, critical fermions in one spatial dimension. This raises the question of whether the embezzlement operations can be restricted to Gaussian operations whenever one only wishes to extract Gaussian entangled states.

In our work we showed that this is indeed the case and proved that the embezzling property is in fact a generic property of fermionic Gaussian states. Our results provide a fine-grained understanding of embezzlement of entanglement for fermionic Gaussian states in the finite-size regime and thereby bridge finite-size systems to abstract characterizations based on the classification of von Neumann algebras. To prove our results, we established novel bounds relating the distance of covariances to the trace-distance of Gaussian states, which may be of independent interest.

QI 10.10 Wed 12:15 BEY/0137

The relative entropy of magic and its nonadditivity — •Carolin Deckers, Justus Neumann, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf, Germany

The resource theory of magic is a theoretical framework that quantifies the non-stabilizer quantum resource "magic", which is crucial for universal quantum computation. To quantify the amount of magic in states or operations, measures such as the relative entropy of magic have been introduced. The relative entropy of magic is a subadditive measure. Previous results [R. Rubboli, R. Takagi, and M. Tomamichel, Quantum 8, 1492 (2024)] have shown that this measure is additive for a special class of states. We show that for n-qubit product states, the relative entropy of magic is not additive if the states do not belong to that special class and fulfill an additional condition.

QI 10.11 Wed 12:30 BEY/0137

Characterizing covariance matrix and entanglement with finite Fourier transformed Observables — •Dimpi Thakuria[1], Konrad Szymański[2], Shuheng Liu[1], and Giuseppe Vitagliano[1] — [1]Atominstitut, Technische Universität Wien, Stadionallee 2, 1020 Vienna, Austria — [2]Research Center for Quantum Information, Slovenská Akadémia Vied, Dúbravská cesta 9, 84511 Bratislava, Slovakia

In Quantum physics, a covariance matrix provides us a means to certify a physically valid quantum system (through its positive semidefiniteness). It constrains the allowed quantum states and fully characterizes the Gaussian states. In continuous variable systems the covariance matrix is known to capture key properties like entanglement, squeezing, the purity of the states etc.. In this work we explore these concepts in the context of the discrete phase-space observables in finite-dimension, focusing on canonical position/momentum observables linked by finite Fourier transforms. Our approach is complementary to the typical way of using finite-dimensional Heisenberg-Weyl framework (especially discrete-displacement operators) for studying such systems. We characterize the allowed states via characterization of the invariants : the trace and the determinant of the covariance matrix. We also study the structure of the allowed covariance matrix transformations in the discrete phase-space, as well as the underlying Hilbert space. Our insights help us to discuss applications like entanglement detection in finite-dimensional systems, akin to covariance matrix criteria in continuous-variable systems.

QI 11: Implementations IV

Time: Wednesday 9:30–12:45 Location: BEY/0245

Invited Talk QI 11.1 Wed 9:30 BEY/0245

Nb-trilayer Josephson junction based parametric amplifiers for microwave frequency signals — •Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Parametric amplifiers have become a widely-used tool in cryogenic setups processing faint microwave signals. Such signals, with powers as low as femtowatts, are used, e.g., to read out solid state qubits or are hypothesized as signatures of dark matter. A large variety of superconducting parametric amplifiers exists, which can be broadly divided into two groups: devices based on resonators with typical bandwidth on the order of a few MHz and traveling-wave parametric amplifiers (TWPAs) providing bandwidths larger than 1 GHz. In addition to their bandwidth, dynamic range and added noise are the main parameters engineered in such devices, leading to a plethora of parametric amplifier implementations. At PTB we are exploring a range of superconducting parametric amplifiers harnessing the nonlinearity provided by Nb-trilayer Josephson junctions or by the kinetic inductance of granular aluminium thin films. In this talk I will discuss our recent results on rf-SQUID TWPAs [1] and present our implementation of dimer Josephson junction array amplifiers.

[1] V. Gaydamachenko & C. Kissling, L. Grünhaupt, Phys. Rev. Appl. 23, 064053 (2025)

QI 11.2 Wed 10:00 BEY/0245

Double-pumped Bogoliubov parametric amplifier using a superconducting Bose-Hubbard dimer — •Najmeh Etehadi Abari[1], Nicolas Zapata[1], Ioan Pop[1,2], and Anja Metelmann[1,3] — [1]Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Physics Institute 1, Stuttgart University, 70569, Stuttgart, Germany — [3]Institut de Sciences et d'Ingénierie Supramoléculaires,(ISIS, UMR7006), University of Strasbourg and CNRS, 67000 Strasbourg, France

Quantum limited standing-wave amplifiers in superconducting circuits are key tools for quantum-device readout, relying on Josephson junction or high kinetic inductance nonlinearities to convert pump energy into signal gain[1,2]. However, their performance is typically limited by operation near dynamic instability, restricting bandwidth. We discuss a class of standing-wave parametric amplifiers known as Bogoliubov amplifiers [3], which leverage double-pump drives to operate far from the instability region, thereby overcoming the intrinsic gain-bandwidth limitation. We demonstrate this concept on a Bose-Hubbard dimer formed by two coupled Kerr resonators [4], showing that double-pump driving enables tunable gain, bandwidth, and noise performance. This establishes Bogoliubov amplifiers as a promising platform for scalable qubit readout and precision quantum measurements. [1] P. Winkel, et al., Phys. Rev. Appl. 13.2 (2020). [2] D. J. Parker, et al., Phys. Rev. Appl. 17.3 (2022). [3] A. Metelmann, et al., arXiv:2208.00024 (2022). [4] N. Zapata, et al., Phys. Rev. Lett. 133. 26 (2024).

QI 11.3 Wed 10:15 BEY/0245

Universal Pulses for Superconducting Qudit Ladder Gates — Boxi Li[1,2], Francisco Cárdenas-López[1], Andrian Lupascu[3], and •Felix Motzoi[1,2] — [1]Forschungzentrum Jülich, Institute of Quantum Control — [2]Universität zu Köln — [3]University of Waterloo, Institute for Quantum Computing

In this work (PRX Quantum 6, 03035), we present a universal pulse construction for generating rapid, high-fidelity unitary rotations between adjacent qudit levels, thereby providing a prescription for any gate in SU(d). Control errors in these operations are effectively analyzed within a four-level subspace, including two leakage levels with approximately opposite detuning. By identifying the optimal degrees of freedom, we derive concise analytical pulse schemes that suppress multiple control errors and outperform existing methods. Remarkably, our approach achieves consistent coherent error scaling across all levels, approaching the quantum speed limit independently of parameter variations between levels. Numerical validation on transmon circuits demonstrates significant improvements in gate fidelity for various qudit sizes aiming for 10^-4 error. This method provides a scalable solution for improving qudit control and can be broadly applied to other quantum systems with ladder structures or operations involving multiple ancillary levels.

QI 11.4 Wed 10:30 BEY/0245

Superconducting Gralmonium Qubit Resilient to High Magnetic Fields — •Janic Beck[1], Simon Günzler[1], Dennis Rieger[1], Nicolas Gossling[1], Nicolas Zapata[1], Mitchell Field[1], Simon Geisert[1], Andreas Bacher[1], Judith Hohmann[1], Martin Spiecker[1], Wolfgang Wernsdorfer[1], and Ioan Pop[1,2] — [1]PHI, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]PI 1, Stuttgart University, 70569 Stuttgart, Germany

Superconducting qubits can be used as information engines to probe and manipulate microscopic degrees of freedom (DOF), whether intentionally designed or naturally occurring in their environment. In the case of magnetically susceptible DOF, the external magnetic field used to polarize them presents a challenge for superconductors and Josephson junctions. Here we demonstrate the operation of a granular aluminum nanojunction fluxonium qubit (Gralmonium), resilient to in-plane magnetic fields beyond one Tesla. By employing a gradiometric fluxonium design, we enhance the qubit's insensitivity to global magnetic flux fluctuations. The energy relaxation (T1 = 8 μs) and coherence (T2E = 2.5 μs) are unaffected by the magnetic field and we observe only minor changes in the qubit spectrum, caused by percent level gap suppression. The gradiometric gralmonium's field resilience highlights its potential for hybrid quantum architectures that combine superconducting qubits with spin systems.

QI 11.5 Wed 10:45 BEY/0245

Spin Environment of a Superconducting Qubit in High Magnetic Fields — •Simon Günzler[1], Janic Beck[1], Dennis Rieger[1], Nicolas Gosling[1], Nicolas Zapata[1], Mitchell Field[1], Simon Geisert[1], Andreas Bacher[1], Judith K. Hohmann[1], Martin Spiecker[1], Wolfgang Wernsdorfer[1], and Ioan M. Pop[1,2] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Stuttgart University, Stuttgart, Germany

We leverage the magnetic field resilience of a granular aluminum nanojunction fluxonium qubit (Gralmonium) with a gradiometric design to uncover a paramagnetic spin-1/2 ensemble, which is the dominant Gralmonium loss mechanism when the electron spin resonance matches the qubit. We also report a suppression of fast flux noise measured in Spin-Echo experiments in magnetic fields exceeding 0.4 Tesla, which suggests the freezing of surface spins. In addition to these environments, by employing an active state stabilization sequence of the qubit, we hyperpolarize long-lived two-level systems (TLS), previously speculated to also be of magnetic origin. Surprisingly, the coupling to this TLS environment remains unaffected by magnetic fields, leaving the question of their origin open. These results demonstrate the gradiometric Gralmonium's potential for hybrid quantum architectures combining superconducting qubits with spins.

30min. break

QI 11.6 Wed 11:30 BEY/0245

High-Coherence Superconducting Qubits on Wafer-Scale — •Julius Feigl[1,2], Niklas Bruckmoser[1,2], Leon M. Koch[1,2,3], David Bunch[1,2], Léa Richard[1,2], Christian Gnandt[1,2], Ivan Tsitsilin[1,2,3], Anirban Bhattacharjee[1,2], Haiyang Hu[1,2], Vera P. Bader[1,2], Lasse Södergren[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [3]Peak Quantum GmbH, Garching, Germany

Scaling superconducting quantum processors requires fabrication processes that maintain high qubit coherence across increasingly complex multi-qubit chips. While substantial progress has been achieved for isolated, single-qubit devices, preserving these coherence levels in multi-qubit architectures remains challenging due to added fabrication steps and potential loss mechanisms. In particular, as system performance is frequently limited by the least coherent qubit, understanding coherence variations across a wafer is crucial. Therefore, we present coherence measurements from twelve transmon qubits across two chips fabricated on a 100 mm wafer. The qubits exhibit an average relaxation time of $T_1 = 236 \pm 14\,\mu$s, with the lowest device having a relaxation time of $111 \pm 30\,\mu$s. We further examine the influence of fabrication processes required for large-scale integration, such as air bridges and indium bumps, on coherence. These lead to a reduction in coherence time, providing insight into the impact of additional processing required for large-scale superconducting quantum processors.

QI 11.7 Wed 11:45 BEY/0245

A charge-basis tomographic protocol for superconducting qubits — •Elena Lupo[1], Daniel Long[2], Daniel Dahan[3], Konstantin Yavilberg[3], Malcolm R. Connolly[2], Eytan Grosfeld[3], and Eran Ginossar[4] — [1]Forschungszentrum Jülich, 52428 Jülich, Germany — [2]Imperial College London, SW7 2AZ London, UK — [3]Ben-Gurion University of the Negev, 84105 Beer-Sheva, Israel — [4]University of Surrey, GU2 7XH Guildford, UK

The use of accurate models and parameters in superconducting circuits is essential for the understanding and control of quantum states. While conventional spectroscopic techniques allow the extraction of excited-state populations, transition frequencies, and decay rates, information about quantum coherence can only be obtained through phase-sensitive methods such as quantum state tomography, which is usually performed in the system's energy basis. Here we introduce a complementary tomographic protocol for the reconstruction of the ground state of a superconducting circuit with a generic Josephson junction potential [1]. The state reconstruction is done in the basis of its relative charge across the junction - a representation that can provide new insights into the quantum circuit and can assist in validating its Hamiltonian model. The method combines the flux-tuning of a split Josephson junction and adiabatic evolution to achieve the desired density matrix reconstruction of the circuit's ground state. Further possible applications of this method include the study of hybrid superconductor-semiconductor junctions [2]. [1] Lupo et al, arXiv: 2502.07748; [2] Dahan et al, arXiv: 2502.07684.

QI 11.8 Wed 12:00 BEY/0245

Magnetic-Field and Temperature Limits of a Kinetic-Inductance Traveling-Wave Parametric Amplifier — Lucas M. Janssen[1], Farzad Faramarzi[2], Henry G. LeDuc[2], Sahil Patel[3,2], Gianluigi Catelani[4,5], Peter K. Day[2], Yoichi Ando[1], and •Dickel Christian[1] — [1]Physics Institute II, University of Cologne, Germany — [2]Jet Propulsion Laboratory, Caltech, USA — [3]Department of Applied Physics and Materials Science, Caltech, USA — [4]JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, Germany — [5]Quantum Research Center, TII, Abu Dhabi, UAE

Kinetic-inductance traveling-wave parametric amplifiers (KI-TWPAs) offer broadband near-quantum-limited amplification with high saturation power. In this work [1], we study how magnetic field and temperature affect the performance of a KI-TWPA based on a thin-NbTiN inverse microstrip with a Nb ground plane. This KI-TWPA can provide substantial signal-to-noise ratio improvement (ΔSNR) up to in-plane magnetic fields of 0.35 T and out-of-plane fields of 50 mT, considerably higher than what has been demonstrated with TWPAs based on Josephson junctions [2]. We also find that the gain does not degrade when the temperature is raised to 3 K (limited by the Nb ground plane) while ΔSNR decreases with temperature consistently with expectation. The operability of KI-TWPAs in high magnetic fields opens the door to a wide range of applications in spin qubits, spin ensembles, topological qubits, low-power NMR, and the search for axion dark matter.

[1] Janssen et al., PR Appl. 2024 [2] Janssen et al., arXiv:2509.15043

QI 11.9 Wed 12:15 BEY/0245

Toward Chemically Resilient Superconducting Qubit Fabrication — •Niklas Bruckmoser[1,2], Leon M. Koch[1,2,3], Thomas Brenninger[2], Ivan Tsitsilin[1,2,3], Amanda Scoles[1,2], David Bunch[1,2], Julius Feigl[1,2], Lea Richard[1,2], Christian Gnandt[1,2], Christian M.F. Schneider[1,2], Vera P. Bader[1,2], Haiyang Hu[1,2], Lasse Södergren[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, BAdW, Germany — [3]Peak Quantum GmbH, Germany

As superconducting quantum processors scale up, there is an increasing need for fabrication methods that combine low loss with high yield. One promising strategy is the implementation of subtractive processes that also withstand aggressive interface cleaning, particularly by replacing aluminum with chemically resilient materials. In this talk, we demonstrate a fully subtractive process for niobium-based air bridges that are used as interconnects as well as vacuum-gap capacitors. Rigorous surface cleaning allows us to achieve mean internal quality factors of coplanar waveguide resonators exceeding $Q_{\text{int}} = 7.9 \times 10^6$ in the single-photon limit, with no detectable added loss from air bridges. By integrating large vacuum-gap capacitors into transmon qubits, we observe median lifetimes above $T_1 = 50\ \mu$s.

Building on this platform, we share our first exploratory efforts toward the implementation of chemically resilient Josephson junctions. At this early stage, we focus on challenges and discuss pathways to achieve a scalable, high-yield, and low-loss fabrication process.

QI 11.10 Wed 12:30 BEY/0245

TiN superconducting resonators: influence of sputter conditions on Qi(T) and TLS-based loss modeling — •Benedikt Schoof[1], Moritz Singer[1], Harsh Gupta[1], Simon Lang[2], and Marc Tornow[1,2] — [1]TUM CIT, 85748 Garching, Germany — [2]EMFT, 80686 Munich, Germany

We investigate how reactive sputter conditions affect the internal quality factor as a function of temperature (Qi(T)) of TiN coplanar-waveguide resonators. TiN films were grown on high-ohmic silicon (100) under varied substrate temperature (RT to 500 C), pressure (2 mbar to 18 mbar) and N2/Ar gas flow ratio (0.0 to 1.0). Electrical characterization yielded resistivity values in the range of 100 microOhm cm to 100 milliOhm cm and Tc values from 0.5 K to 5.1 K, which together with XPS, XRD and ToF-SIMS data were correlated with the Qi(T) data extracted from CPW resonators fabricated from these films. We find that films sputtered at elevated substrate temperature exhibit higher Qi (0.8e6) in the single-photon regime at 100 mK and are well described by a standard additive loss model with a single two-level-system (TLS) component. In contrast, room-temperature sputtered films require two distinct TLS contributions to reproduce the full Qi(T) dependence, indicating multiple dielectric defect populations or enhanced interfacial disorder introduced during low-temperature growth. Tc shows only a weak correlation with Qi, confirming that superconducting transition metrics alone do not capture the relevant microwave loss mechanisms. Our results provide quantitative guidance for optimizing TiN resonators for superconducting-qubit applications.

QI 12: Quantum Foundations

Time: Wednesday 15:00–18:00 Location: BEY/0137

QI 12.1 Wed 15:00 BEY/0137

On the Dynamics of Local Hidden-Variable Models — •Nick von Selzam[1,2] and Florian Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg

Bell nonlocality is an intriguing property of quantum mechanics with far reaching consequences for information processing, philosophy and our fundamental understanding of nature. However, nonlocality is a statement about static correlations only. It does not take into account dynamics, i.e. time evolution of those correlations. Consider a dynamic situation where the correlations remain local for all times. Then at each moment in time there exists a local hidden-variable (LHV) model reproducing the momentary correlations. Can the time evolution of the correlations then be captured by evolving the hidden variables? In this light, we define dynamical LHV models and motivate and discuss a wide range of physical and mathematical assumptions. Based on a simple counter example we conjecture that such LHV dynamics does in general not exist. This is further substantiated by a rigorous no-go theorem. Our results suggest a new type of dynamical nonlocality expressed by the quantum time evolution of local correlations.

QI 12.2 Wed 15:15 BEY/0137

Today's Experiments Suffice to Verify the Quantum Essence of Gravity — •Martin Plávala — Institut für Theoretische Physik, Leibniz Universität Hannover, 30167 Hannover, Germany

The gravity-mediated entanglement experiments employ concepts from quantum information to argue that if gravitational interaction creates entanglement between two systems, then gravity cannot be described by a classical system. However, the proposed experiments remain beyond out current technological capability, with optimistic projections placing the experiment outside of short-term future. Here we leverage quantum information techniques to argue that current matter-wave interferometers are sufficient to indirectly prove that gravitational interaction creates entanglement between two systems. Specifically, we prove that if we experimentally verify the Schrödinger equation for a single delocalized system interacting gravitationally with an external mass, then the time evolution of two delocalized systems will lead to gravity-mediated entanglement. Our findings indicate that the experimental verification of the quantum essence of gravity is on the horizon.

QI 12.3 Wed 15:30 BEY/0137

Paradox-free classical non-causality and unambiguous nonlocality without entanglement are equivalent — Hippolyte Dourdent[1], Kyrylo Simonov[2], •Andreas Leitherer[1], Emanuel-Cristian Boghiu[2], Ravi Kunjwal[3], Saronath Halder[4], Remigiusz Augusiak[4], and Antonio Acín[1,5] — [1]ICFO-Institut de Ciències Fotòniques — [2]Fakultät für Mathematik, Universität Wien — [3]Aix-Marseille University, CNRS, LIS — [4]Center for Theoretical Physics, Polish Academy of Sciences — [5]ICREA - Institució Catalana de Recerca i Estudis Avançats

Definite causal order is an intuitive assumption which can, however, be violated without introducing paradoxes such as the grandfather antinomy. Interestingly, it is not necessary to invoke quantum or more exotic physics: process functions generalize classical deterministic communication by relaxing the assumption of a fixed causal structure between local operations. Previous work demonstrated that for three-parties, non-causal process functions can distinguish qubit product bases that cannot be realized by local operations and classical communication - a phenomenon known as quantum nonlocality without entanglement (QNLWE). We significantly elevate this result for any dimension and any number of parties, establishing an equivalence between the unique fixed-point condition characterizing process functions and a simple "unambiguity" condition, requiring that local parties perform local disjoint operations. We refine previous characterizations of process functions and demonstrate how to construct non-causal process functions from unambiguous QNLWE product bases and vice versa.

QI 12.4 Wed 15:45 BEY/0137

Generalised Quantum Dynamics under Operational Constraints — •Joel Huber and Matthias Kleinmann — Universität Siegen

Generalised phase space theories can be considered to study potential deviations from quantum time evolution given by the Schrödinger equation. In the phase space formulation, quantum dynamics is governed by the Moyal bracket. We consider generalisations thereof and impose operational conditions – such as probability positivity – to characterise consistent dynamics. We show how (generalised) quantum dynamics impacts the momentum and position distributions in the presence of a cubic potential, and argue that this effect is experimentally accessible. The consistency of a proposed evolution depends critically on both the bracket structure and the underlying state space. We analyse scenarios where the state space contains Gaussian states or the first excited state of the harmonic oscillator. In the case of ideal preparation of these states, phase space dynamics is strongly constrained and quantum dynamics is found to be the only consistent time-reversible evolution, at least to the order that can be probed in a cubic potential.

QI 12.5 Wed 16:00 BEY/0137

Phase space tableau simulation for quantum computation — •Selman Ipek[1], Cihan Okay[2], Atak Talay Yücel[3], Cagdas Ozdemir[4], and Farzad Shahi[2] — [1]Institut Für Theoretische Physik, Leibniz Universität Hannover — [2]Department of Mathematics, Bilkent University — [3]Department of Computer Engineering, Bilkent University — [4]Department of Physics, Bilkent University

We introduce a novel tableau-based classical simulation method for quantum computation, formulated within the phase space framework of the extended stabilizer theory of closed non-contextual operators. This method enables the efficient classical simulation of a broader class of quantum circuits beyond the stabilizer formalism. We implement the simulator and benchmark its performance on basic quantum algorithms, including the hidden shift and Deutsch-Jozsa algorithms.

QI 12.6 Wed 16:15 BEY/0137

Witnessing nonstabilizerness with Bell inequalities — Rafael Macêdo[1,2], •Patrick Andriolo[2,3,4], Santiago Zamora[1,2], Davide Poderini[2,5], and Rafael Chaves[2,6] — [1]Departamento de Física Teórica e Experimental, Universidade Federal do Rio Grande do Norte, 59078-970 Natal-RN, Brazil — [2]International Institute of Physics, Federal University of Rio Grande do Norte, 59078-970, Natal, Brazil — [3]Physics Institute, University of São Paulo, Rua do Matão, 1371, São Paulo, Brazil — [4]Atominstitut, Technische Universität Wien, Stadionallee 2, 1020 Vienna, Austria — [5]Università degli Studi di Pavia, Dipartimento di Fisica, QUIT Group, via Bassi 6, 27100 Pavia, Italy — [6]School of Science and Technology, Federal University of Rio Grande do Norte, 59078-970 Natal, Brazil

Non-stabilizerness is a fundamental resource for quantum computation, enabling quantum algorithms to surpass classical capabilities. Despite its importance, characterizing this resource remains challenging due to the intricate geometry of stabilizer polytopes and the difficulty of simulating non-stabilizer states. In this work, through device-independent considerations, we reveal an unexpected connection between non-stabilizerness and Bell inequalities. Although certain stabilizer states can already achieve maximal violations of specific Bell inequalities, we demonstrate that appropriately constructed Bell inequalities can nevertheless serve as witnesses of non-stabilizerness, revealing when a state lies beyond the stabilizer set. This uncovers a novel relationship between the device-independent framework and quantum computation. Phys. Rev. A 112, L050401.

30min. break

QI 12.7 Wed 17:00 BEY/0137

Beyond Mermin: Multipartite Bell Inequalities with Many Measurement Settings — •Fynn Otto[1], Junxiang Huang[2], Carlos de Gois[1,3,4], Xiao Yuan[2], and Otfried Gühne[1] — [1]Universität Siegen, Siegen, Germany — [2]Peking University, Beijing, China — [3]Inria de Saclay, Palaiseau, France — [4]École polytechnique, Palaiseau, France

Nonlocal correlations in multipartite quantum systems are typically probed through Bell inequalities with only a few measurement settings, limiting the sensitivity of existing tests. Here we introduce a generalization of the Mermin inequality to an arbitrarily large number of measurement settings per party. This family of inequalities is maximally violated by Greenberger-Horne-Zeilinger states and substantially lowers the noise thresholds required to certify nonlocality and nonlocality depth. We further derive Bell inequalities capable of detecting genuine multipartite entanglement in broad classes of graph states. Finally, we discuss prospects for experimental implementations of these inequalities in state-of-the-art quantum platforms. Together, these advances expand the toolbox for probing the structure of quantum correlations and strengthen practical routes toward certifying entanglement in complex quantum systems.

QI 12.8 Wed 17:15 BEY/0137

A Causal-Modelling Reconstruction of Quantum Mechanics That Comes With its Own Interpretation — •Joppe Widstam — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We reconstruct quantum mechanics from intuitive causal-modelling principles for time-symmetric physics. In this reconstruction, the quantum state is a mere convenient mathematical object for agents able to control the initial conditions and who are able to choose what observable to measure.

QI 12.9 Wed 17:30 BEY/0137

The Quantum Rashomon Effect: A Strengthened Frauchiger-Renner Argument — •Jochen Szangolies — Deutsches Zentrum für Luft- und Raumfahrt, Köln

The Frauchiger-Renner argument aims to show that 'quantum theory cannot consistently describe the use of itself': in many-party settings where agents are themselves subject to quantum experiments, agents may make predictions that contradict observations. Here, we introduce a simplified setting using only three agents, that is independent of the initial quantum state, thus eliminating in particular any need for entanglement, and furthermore does not need to invoke any final measurement and resulting collapse. Nevertheless, the predictions and observations made by the agents cannot be integrated into a single, consistent account. We propose that the existence of this sort of Rashomon effect, i.e. the impossibility of uniting different perspectives, is due to failing to account for the limits put on the information available about any given system as encapsulated in the notion of an epistemic horizon.

QI 12.10 Wed 17:45 BEY/0137

Multiple solutions of the classical shooting problem: consistent histories and decoherence — •Julian Rettenberger-Zweck and Juan-Diego Urbina — Institut für theoretische Physik, Universität Regensburg, Regensburg, Germany

The *consistent histories* approach to quantum mechanics [1] provides a framework for defining whether a sequence of events occurring at different times—a *history*—exhibits emergent classical behavior. Specifically, a set of histories is called consistent if the off-diagonal elements of the decoherence functional, which quantify the interference between histories, vanish in an appropriate limit, leaving only the (properly normalized) classical probabilities on the diagonal [2]. The semiclassical (Van Vleck–Gutzwiller) propagator [3] consists of a coherent sum over all classical paths—or, in the language of consistent histories, all classical histories satisfying the specified boundary conditions—which enables a direct calculation of the decoherence functional. In this way, we explicitly evaluate the decoherence functional for two simple systems: the particle on a circle and the particle in a box, confirming the suppression of interference between distinct classical histories as well as the effect of decoherence within a Caldeira–Leggett approach [4].

[1] R. B. Griffiths, *J. Stat. Phys.* 36, 219 (1984).
[2] H. F. Dowker and J. J. Halliwell, *Phys. Rev. D* 46, 1580 (1992).
[3] M. C. Gutzwiller, *Chaos in Classical and Quantum Mechanics*, Springer, New York (1990).
[4] A. O. Caldeira and A. J. Leggett, *Physica A* 121, 587 (1983).

QI 13: Quantum Control

Time: Wednesday 15:00–18:00 Location: BEY/0245

QI 13.1 Wed 15:00 BEY/0245

A Statistical-Physics Approach to Quantum Control Landscape Exploration — •Malte Krug and Jürgen Stockburger — Institute for Complex Quantum Systems, Ulm, Germany

Conventional approaches to quantum optimal control rely on local optimizers that return a single high-fidelity pulse but offer little insight into the global structure of the cost landscape. A new method is presented, motivated by a statistical-physics inspired approach to stochastic control theory [1], that maps the quantum optimal control problem to an exploration of a high-dimensional landscape using ideas from protein-folding methods [2]. Instead of a single pulse, the method generates a distribution of control trajectories, represented by a Markov chain whose stationary distribution reflects the dominant regions of the cost landscape. This ensemble captures globally competitive pulses, reveals the diversity of near-optimal solutions, and allows for characterization of the local landscape through soft and stiff directions around optimal pulses. Moreover, the sampled trajectories provide high-quality initial guesses for conventional optimization methods, strongly biased toward the most promising regions of the landscape.

[1] Kappen, H. J.,*Phys. Rev. Lett.* 95, 200201 (2005).
[2] Trebst, S. & Troyer, M., in: *Computer Simulations in Condensed Matter Systems*, eds. Ferrario, M., Ciccotti, G. & Binder, K., Springer (2006).

QI 13.2 Wed 15:15 BEY/0245

Closed-Loop Control with Tailored Benchmarking Protocols — •Matthias Müller — Forschungszentrum Jülich

Quantum technology is a fast-emerging field with both scientific and technological importance. The performance relies on unique features like superposition and entanglement and depends on sophisticated mechanisms of control to perform the desired tasks. Quantum Optimal Control (QOC) has proven to be a powerful tool to accomplish this task. I will give a brief overview on the CRAB algorithm for QOC [1] and the optimal-control software QuOCS [2], and then talk about recent work on closed-loop control [3,4,5] for one- and two-qubit gates.

[1] M. M. Müller et al., Rep. Prog. Phys. 85 076001 (2022) [2] M. Rossignolo et al. Comp. Phys. Comm. 291, 108782 (2023) [3] N. Oshnik et al., Phys. Rev. A 106, 013107 (2022) [4] P. Vetter et al., npj Quantum Information 10 (1), 96 (2024) [5] A. Marcomini et al., in preparation (2025)

QI 13.3 Wed 15:30 BEY/0245

Efficient pulse-sequence optimization method for quantum control under realistic hardware constraints — Marco Dall'Ara[1,2], Florentin Reiter[1], Thomas Wellens[1], Martin Koppenhöfer[1], and •Walter Hahn[1] — [1]Fraunhofer Institute for Applied Solid State Physics IAF, Freiburg, Germany — [2]Dipartimento di Fisica e Astronomia G. Galilei & Padua Quantum Technologies Research Center, Università degli Studi di Padova, Padova, Italy

We propose a simple yet efficient pulse-sequence optimization method for controlling quantum systems. The ansatz leads to an efficient exploration of the unitary space without over-parameterization, even when the pulse amplitudes are restricted to a few discrete values suitable for quantum devices. Bandwidth and power limitations of experimental settings can be straightforwardly included with only minor computational overhead. We numerically validate the method by applying it to (i) unitary synthesis of a three-qubit gate and (ii) ground-state preparation on a globally-driven Rydberg-atom platform, and (iii) state transfer in an Ising spin chain. For all problems considered, our method approaches an information-theoretic lower bound on the number of parameters and exhibits advantages when compared to commonly used quantum control algorithms.

QI 13.4 Wed 15:45 BEY/0245

Optimal Control for Open Quantum System in Circuit Quantum Electrodynamics — •Francisco Cardenas-Lopez[1] and Xi Chen[2] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]Instituto de Ciencia de Materiales de Madrid (CSIC), Cantoblanco, E-28049 Madrid, Spain

We propose a quantum optimal control framework based on the Pontryagin Maximum Principle to design energy- and time-efficient pulses for open quantum systems. By formulating the Langevin equation of a dissipative LC circuit as a linear control problem, we derive optimized pulses with exponential scaling in energy cost, outperforming conventional shortcut-to-adiabaticity methods such as counter-diabatic driving. When applied to a resonator dispersively coupled to a qubit, these optimized pulses achieve an excellent signal-to-noise ratio comparable to longitudinal coupling schemes across varying critical photon numbers. Our results provide a significant step toward efficient control in dissipative open systems and improved qubit readout in circuit quantum electrodynamics.

QI 13.5 Wed 16:00 BEY/0245

Learning to Steer Quantum Mmany-Body Dynamics with Tree Optimization — Jixing Zhang[1], Bo Peng[2], Yang Wang[1], •Cheuk Kit Cheung[1], Guodong Bian[3], Andrew Edmonds[4], Matthew Markham[4], Zhe Zhao[2], Durga Dasari[1], Ruoming Peng[1], Ye Wei[2], and Jörg Wrachtrup[1] — [1]3rd Institute of Physics, University of Stuttgart, Allmandring 13, Stuttgart, 70569, Germany — [2]Department of Data Science, City University of Hong Kong, Hong Kong, China — [3]School of Chemistry, University of Birmingham, B15 2TT, Edgbaston Birmingham, UK — [4]Element Six Global Innovation Centre, Fermi Avenue, Harwell Oxford, Didcot, Oxfordshire OX11 0QR, United Kingdom

Achieving practical quantum technologies requires high-quality control over complex quantum systems, but progress is hindered by exponentially growing state spaces and experimental challenges. We present an AI framework that learns to design optimized pulse sequences for many-body spin control, offering a powerful alternative to conventional theory-driven methods. The framework combines tree search, neural network filtering, and numerical simulation guidance to navigate highly nonlinear optimization landscapes using minimal resources. It identifies high-performing, non-intuitive sequences that established methods struggle to find. Experiments in a diamond spin ensemble show the best AI-designed sequences achieved spin coherence times exceeding 200 microseconds, a 100% improvement over state-of-the-art baselines. This work highlights AI's potential to steer complex many-body dynamics, marking a decisive shift toward data-driven sequence design.

QI 13.6 Wed 16:15 BEY/0245

Efficient analytical gradient evaluation for locally-interacting large multi-qubit platforms — •Alessandro Ciani[1], Ashutosh Mishra[1,2], Elena Lupo[1], and Frank Wilhelm-Mauch[1,2] — [1]Forschungszentrum Jülich, Jülich, Germany — [2]Universität des Saarlandes, Saarbrücken, Germany

We present a general framework for the computation of derivatives of time-ordered propagators in quantum optimal control, for both closed and open quantum systems, with respect to any general pulse parameterization, by deriving the formal solution from first principles. We obtain a series expansion for the gradients of the propagator, and utilize locality constraints to efficiently compute the derivatives. Further, we demonstrate that such a method can be used to efficiently compute gradients in large multi-qubit platforms, without running necessarily into the problem of storing the whole quantum state, whose size grows exponentially with the number of qubits. Our approach, can be viewed in terms of the recently introduced Pauli propagation framework applied to the computation of gradients in optimal control tasks. Finally, we show that our method is capable of accurately estimating the gradients, with much reduced memory and runtime compared to direct numerical evaluation.

30min. break

QI 13.7 Wed 17:00 BEY/0245

Analytical flux-tuned iSWAP pulse suppressing leakage channels — •Dimitrios Georgiadis[1,2], Boxi Li[1], Francisco Cardenas Lopez[1], and Felix Motzoi[1,2] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, 50937 Cologne, Germany

Achieving fast, high-fidelity qubit gates remains one of the major challenges in quantum computing, and despite recent progress, enhancing the efficiency of superconducting two-qubit gates still presents complications. In this work we investigate optimal control methods in order to improve the fidelity of two qubit gates in a flux tunable architecture based on a tunable coupler. We emphasize the importance of suppression of various leakage channels and we demonstrate simulations with analytical optimal control methods, (DRAG) and (DRAG-like), on the external flux on the tunable coupler, achieving further improved fidelities for an iSWAP gate. Finally, we propose a generalized pulse-shaping approach for the external flux, leading to significant leakage suppression across different circuit parameters.

QI 13.8 Wed 17:15 BEY/0245

Autonomous reachability of quantum states on random graphs — •Konrad Szymański[1], Tomasz Andrzejewski[2], Yuri Minoguchi[2], and Phila Rembold[2] — [1]Research Center for Quantum Information, Bratislava, Slovakia — [2]Atominstitut, TU Wien, Vienna, Austria

We study a particle hopping on a graph under a Hamiltonian with fixed but tunable couplings (no time-dependent control). We ask: which states can be reached from a given initially localized state via such autonomous dynamics? The Hamiltonian is a linear combination of generators corresponding to graph edges, with weights chosen freely but held constant during evolution. We develop three criteria to determine whether a given state is reachable from another. The first is analytical: if a certain matrix constructed from expectation values of the two states is strictly positive definite, the target state is certified unreachable from the initial one. The remaining two rely on numerical optimization over overlaps in the Hamiltonian eigenspaces and Krylov subspace structure. Applying these tools to random graph ensembles, we characterize how the fraction of Haar-random pure states that are unreachable from a localized initial state depends on graph connectivity.

QI 13.9 Wed 17:30 BEY/0245

Coherent control in V-type system: Simulation insights using intense two-dimensional coherent spectroscopy — •Rishabh Tripathi, Krishna Maurya, and Rohan Singh — Indian Institute of Science Education and Research (IISER) Bhopal, Bhopal, India

Our study investigates coherent control in V-type three-level systems using high-intensity, ultrafast laser pulses, explored through two-dimensional coherent spectroscopy (2DCS). Employing numerical solutions of the optical Bloch equations, we analyze the response of a V-type system to Gaussian pulses of 10 fs and 120 fs. The research reveals that shorter pulses induce uniform Rabi oscillations, whereas longer pulses result in complex quantum interference and state-specific population dynamics. This distinction underscores the pivotal role of pulse duration and spectral properties in modulating quantum interactions. Our 2DCS simulations, utilizing phase-cycling methods, provide insight into the system's spectral response in both perturbative and non-perturbative regimes. These simulations reveal the manipulation of spectral peak amplitudes and phases by adjusting the pulse areas, demonstrating control over the system.

This work contributes to the understanding of light-matter interactions in quantum systems and highlights the potential of tailored laser pulses for advanced coherent control, with implications for atomic vapors, semiconductor nanostructures, and photonics research.

QI 13.10 Wed 17:45 BEY/0245

Applications of dynamical decoupling to qubit noise suppression — •Chun Kit Dennis Law[1], Francisco Andrés Cárdenas-López[2], and Felix Motzoi[3] — [1]Peter Grünberg Institute, Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), D-52425 Jülich, Germany — [2]Peter Grünberg Institute, Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), D-52425 Jülich, Germany — [3]Peter Grünberg Institute, Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), D-52425 Jülich, Germany

Noises are one of the major sources of the high error rates in the operation of modern quantum devices. Dynamical decoupling are some of the earliest experimentally demonstrated and least resource-intensive methods to suppress errors. We construct a many-level quantum system and isolate the lowest two energy levels for information processing. Upon the introduction of noise, we investigate how effective the XY4 sequence is by studying the associated leakage and the fidelity concerning the lowest two energy levels. Time permitting, we also investigate the effects of modifying the pulse shape by DRAG (derivative removal by adiabatic gate), which has been successfully applied to superconducting qubits to reduce leakage and phase errors.

QI 14: Quantum Information Poster Session

Time: Wednesday 18:00–21:00 Location: P4

QI 14.1 Wed 18:00 P4

An Efficient Error Correction Protocol Variant for Field Tests of Continuous-Variable Quantum Key Distribution — Lukas Eisemann[1,2], •Stefan Richter[1,2], Hüseyin Vural[1,2], Ömer Bayraktar[1,2], Kevin Jaksch[1,2], and Christoph Marquardt[1,2] — [1]Chair of Optical Quantum Technologies, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7 / A3, Erlangen — [2]Max Planck Institute for the Science of Light, Staudtstr. 2, Erlangen

Continuous-variable quantum key distribution (CV-QKD) requires near-optimally efficient information reconciliation (IR) to achieve high secret key rates (SKR) and transmission distances. Here, we present a novel and improved variant of a recently introduced IR-protocol, which is based on multiple decoding attempts (MDA). We evaluate our method on simulated data sets and employ it in the IR step for our fiber-based discrete-modulated CV-QKD system, which we deployed during a large-scale public technology demonstration in Berlin. In each instance, we observe meaningful key rate improvements over both the ubiquitous single decoding attempt protocol and the original MDA implementation, even at a fixed decoding complexity. We also discuss some of the practical challenges associated with CV-QKD deployments in real networks outside of a lab context, arguing that the adaptability of our method makes it well-suited to solve them, providing implementation benefits in the process.

QI 14.2 Wed 18:00 P4

Entanglement with a mode observable via a tunable interaction with a qubit — •Malgorzata Strzalka[1,2], Radim Filip[3], and Katarzyna Roszak[1] — [1]FZU - Institute of Physics of the Czech Academy of Sciences,. — [2]Faculty of Mathematics and Physics, Charles University. — [3]Department of Optics, Palacký University.

We propose a qubit-environment entanglement (QEE) detection scheme for time dependent pure dephasing Hamiltonians. We study the entanglement for a transmon qubit interacting with an environment of microwave cavity photons. The QEE detection schemes that were previously developed for interactions that lead to pure decoherence of the qubit are based on measurements and operations performed only on the qubit alone [1]. Yet they could not be used in the studied scenario because of inherent symmetries in the Hamiltonian. We show that it is possible to override this problem by using different Hamiltonias in the preparation and the measurement stage. We take advantage of the possibility of tuning of the qubit-environment coupling to detect entanglement. Qubit-oscillator entanglement is seen to play a essential role in developing bosonic quantum technology. We previously studied the evolution of QEE for the same system [2] and now we present how the developed detection scheme can signify this type of entanglement. The scheme can be also used for other systems, where the decoherence is predominantly pure dephasing.

[1] M. Strzalka and K. Roszak, Phys. Rev. A 104, 042411 (2021).
[2] M. Strzalka et al. Phys. Rev. A 109, 032412 (2024).

QI 14.3 Wed 18:00 P4

Non-perturbative approach to entanglement harvesting — •Fabian Ganzer, Mei Yu, and Walter Strunz — Institute for Theoretical Physics, TU Dresden

It has been shown that two localized quantum systems like qubits or atoms can harvest entanglement from a quantum vacuum field through local interactions [1]. This phenomenon is often interpreted as a buildup of quantum correlations that can be established faster than with the speed of light due to a vacuum field. To date, however, most investigations have relied on perturbative approaches, leaving the genuine non-perturbative dynamics largely unexplored. In this work, we study entanglement harvesting using the non-perturbative numerical uniTEMPO method [2], enabling us to access both the weak- and strong-coupling regimes. Our results demonstrate that reliable statements about entanglement harvesting require both, a non-perturbative method and a careful analysis of correlations, particularly quantum correlations.

[1] C. Sabín, J. J. García-Ripoll, E. Solano, and J. León, Dynamics of entanglement via propagating microwave photons, Phys. Rev. B 81, 184501 (2010)
[2] V. Link, H.-H. Tu and W. T. Strunz, Open quantum system dynamics from infinite tensor network contraction, Phys. Rev. Lett. 132, 200403 (2024)

QI 14.4 Wed 18:00 P4

Simulating and Utilizing Dissipative Non-Equilibrium Physics on NISQ Devices — •Rochus Lechler[1], Pascal Stadler[2], Jan Reiner[2], Dominik Maile[1], Michael Marthaler[2], and Joachim Ankerhold[1] — [1]Institute for Complex Quantum Systems, Ulm University, Ulm — [2]HQS Quantum Simulations GmbH, Karlsruhe

Driven dissipative quantum many-body systems hold a variety of interesting phenomena like dissipative quantum phase transitions and non-equilibrium steady states. Typically, the full theoretical understanding of these phenomena is hindered by complex dynamics in large Hilbert spaces. Within this context, quantum simulation is a promising alternative bridging the gap between theory and experiment. Our project aims at finding efficient ways to simulate dissipative and driven many-body systems on NISQ devices. To this end, we make use of a software package provided by HQS Quantum Simulations capable of simulating complex open quantum systems. The key idea of this approach is to view quantum hardware itself as being a driven dissipative many-body system. More specifically, we utilize the noise on the hardware to engineer the required decoherence processes for the system under study. Building up on recent theoretical advances we show how to reduce the resources needed for these simulations.

QI 14.5 Wed 18:00 P4

Entanglement generation in quantum networks driven by multi-mode squeezed radiation — •Miguel Angel Palomo Marcos[1,2], Franz Pöschl[1,2], and Peter Rabl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, D-85748 Garching, Germany — [2]School of Natural Sciences, Technische Universität München, D-85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, D-80799 Munich, Germany

The development of scalable and efficient entanglement generation schemes is of central importance for the practical realization of quantum computing. Conventional approaches suffer from cumulative gate errors and decoherence, which have motivated the search for more scalable and robust protocols. Here we propose and analyze a quantum network, where a set of distant qubits is illuminated by multi-mode squeezed radiation. The dissipative dynamics drives the system into a stationary entangled state. We discuss different phase space techniques to numerically simulate this system for a large number of qubits and photonic modes and characterize the resulting entanglement generation properties for different parameter regimes.

QI 14.6 Wed 18:00 P4

Non-Markovian bound-state formation in a giant atom with two coupling points — •Mei Yu[1], Stefan Nimmrichter[2], and Walter Strunz[1] — [1]TUD Dresden University of Technology, — [2]University of Siegen

Superconducting qubits coupled to meandering transmission lines or to surface acoustic waveguides can realize giant artificial atoms, whose interaction with the waveguide occurs at multiple, spatially separated coupling points. Such a geometry introduces well-controlled propagation delays between the coupling points and thereby enables strongly non-Markovian dynamics with memory effects beyond the atomic lifetime [1, 2]. In this work, we investigate the relaxation dynamics of a single giant atom coupled to a one-dimensional acoustic waveguide through two coupling points in the strong-coupling regime. We show that interference between the delayed feedback channels leads to the formation of a bound state embedded in the continuum of waveguide modes, which in turn results in partial population trapping within the giant atom.

[1] L. Guo, A. Grimsmo, A. F. Kockum, M. Pletyukhov, and G. Johansson, Giant acoustic atom: A single quantum system with a deterministic time delay, Phys. Rev. A 95, 053821 (2017).
[2] G. Andersson, B. Suri, L. Guo, T. Aref, and P. Delsing, Non-exponential decay of a giant artificial atom, Nature Physics 15, 1123 (2019).

QI 14.7 Wed 18:00 P4

Entanglement distillation of microwave entangled states

— •Ivan Solomakhin[1,2], Simon Gandorfer[1,2], Maria-Teresa Handschuh[1,2], Jasmine Frijters[1,2], Wun Kwan Yam[1,2], Achim Marx[1,2], and Kirill G. Fedorov[1,2,3] — [1]Walther-Meißner- Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]School of Natural Sciences, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Quantum entanglement is a crucial resource in continuous-variable quantum protocols, such as quantum teleportation and quantum key distribution. However, as the communication distance and complexity increase, losses due to unavoidable imperfections along the signal path lead to the degradation of shared entanglement and diminish the protocol performance. This challenge motivates the development and optimization of entanglement distillation strategies. Here, we investigate experimental implementations of entanglement distillation based on photon-subtraction techniques in application to two-mode squeezed, path-entangled microwave states. We employ superconducting Josephson amplifiers for the generation of two-mode squeezed states. Photon subtraction is realized by using a single-photon microwave detector composed of a transmon qubit in a multimode cavity. We analyze the resulting improvement in entanglement and discuss its implications for quantum communication and quantum networks in the microwave regime.

QI 14.8 Wed 18:00 P4

Noise mitigation in microwave quantum key distribution using single-photon detection — •Jasmine Frijters[1,2], Ivan Solomakhin[1,2], Simon Gandorfer[1,2], Wun Kwan Yam[1,2], Maria-Teresa Handschuh[1,2], Achim Marx[1], and Kirill G. Fedorov[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Quantum key distribution (QKD) is a cryptographic protocol that allows for the unconditionally secure exchange of secret keys between two parties. While QKD implementations in the optical domain are rapidly developing toward practical applications, we analyse a continuous-variable microwave QKD protocol that utilizes single-photon detection to increase the secure transmission distance in both direct and reverse reconciliation schemes. In view of current experimental capabilities for microwave QKD, we predict an increase of up to 80% in secure transmission distance and estimate a key distribution of more than 300 m.

QI 14.9 Wed 18:00 P4

Bounds on quantum conference key agreement in networks with bipartite links — •Justus Neumann, Anton Trushechkin, Hermann Kampermann, and Dagmar Bruss — Heinrich Heine Universität Düsseldorf

Quantum conference key agreement allows several users to establish a shared secret key. A common approach is to use multipartite entangled states like Greenberger-Horne-Zeilinger states, but these are difficult to create in real networks. We instead consider a more practical setting where only two-party entangled states are available between network nodes, and users can only perform local measurements followed by classical communication, without quantum memory. We study the general conference key agreement problem and derive a fundamental upper bound on the achievable key rate. We prove that, in any network composed only of bipartite sources, one cannot outperform a simple strategy: perform ordinary two-party quantum key distribution between one user and each of the others, and then merge the pairwise keys into a common conference key. This shows that complex multipartite strategies offer no rate advantage in such networks.

QI 14.10 Wed 18:00 P4

Entanglement of Electron and Nuclear Spins in Diamond — •Magnus J. R. Platena, Marius M. Strassner, Tim C. Duka, and Martin S. Brandt — Walter Schottky Institut, TU München, Am Coulombwall 4, 85748 Garching

Entanglement is one of the most surprising and counterintuitive phenomena of quantum physics. Nitrogen-vacancy (NV) centers in diamond provide a platform for studying this phenomenon at room temperature, a unique advantage of this solid-state system. The goal of this work is to demonstrate and quantify the entanglement of electron spins and ^{15}N nuclear spins in ensembles of NV centers via optically detected magnetic resonance. In a first step, we characterize isotopically engineered diamonds as a function of ^{15}N concentration, electron irradiation, and annealing and reproduce the published dependence of T_2 and T_2^* on nitrogen concentration. With the help of electron nuclear double resonance, we entangle the two spins and quantify the entanglement via quantum state tomography and application of the Peres criterion.

QI 14.11 Wed 18:00 P4

Differential magnetometry with partially flipped Dicke states — •Iagoba Apellaniz[1,2], Manuel Gessner[3], and Géza Tóth[1,2,4,5,6] — [1]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P. O. Box 644, ES-48080 Bilbao, Spain — [2]EHU Quantum Center, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain — [3]Departament de Física Teòrica, IFIC, Universitat de València, CSIC, Carrer del Dr. Moliner 50, 46100 Burjassot (València), Spain — [4]Donostia International Physics Center DIPC, Paseo Manuel de Lardizabal 4, San Sebastián, E-20018, Spain — [5]IKERBASQUE, Basque Foundation for Science, E-48009 Bilbao, Spain — [6]HUN-REN Wigner Research Centre for Physics, P.O. Box 49, H-1525 Budapest, Hungary

Dicke states on two ensembles can be sensitive to magnetic gradients by locally rotating the spins on one well. We determine bounds for the precision for gradient metrology in the three orthogonal directions as a function of the sensitivities of the homogenous field. The resulting partially flipped Dicke state saturates these bounds. Exploiting entanglement between the two ensembles, this state achieves roughly twice the precision attainable by the best bipartite separable state, which is a product of local Dicke states. For small ensembles, we explicitly identify measurement operators saturating the quantum Cramér-Rao bound, while for larger ensembles, we propose simpler schemes. The gradient is estimated from second moments of local angular momentum operators. Our results demonstrate how metrological properties of Dicke states can be exploited for quantum-enhanced estimation.

QI 14.12 Wed 18:00 P4

Calculation of Binding Energies for a Total of 25 Nuclei Between 2 and 12 nucleon Nuclei Using the Quantum Computer VQE Algorithm — •Taylan BAŞKAN and Ahmet Hakan YILMAZ — Faculty of Sciences, Department of Physics, Karadeniz Technical University, Trabzon, 61080 Turkey

In this study, the binding energies of the first 25 nuclear nuclei were calculated using a quantum computer simulator provided by IBM. These 25 nuclei include nuclei with a nucleon number of 12 and their isotopes, from hydrogen to oxygen. The VQE (variational quantum eigensolver) algorithm was used in the calculation process. The Hamiltonian designed for this purpose was designed to cover all nuclei. This developed a basic approach encompassing light nuclei and generated a model for estimating binding energies. The binding energies of the nuclei were obtained with an average deviation of 17% from known experimental values. For the VQE algorithm, a pre-written Hamiltonian was mapped to the quantum computer and determined by selecting ansatz and minimizing eigenvalues.

QI 14.13 Wed 18:00 P4

Quantum error mitigation on a bosonic quantum processing unit — •Corvin Lenz[1], Tanay Roy[2], Yao Lu[2], and Peter Orth[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Superconducting Quantum Materials and Systems Division, Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

Bosonic processing units offer a scalable platform for continuous-variable quantum computation, but their interaction with noisy ancillary systems introduces significant errors that must be mitigated for reliable performance.

In this work, we simulate a bosonic qudit dispersively coupled to a two-level transmon, controlled via pulse-based external drives. Using process tomography on a synthesized, universal gate set, we characterize gate-dependent error channels arising from transmon-induced noise. We then apply probabilistic error cancellation (PEC) as an error mitigation technique, which reduces the impact of noise without relying on full fault-tolerant schemes.

Our results demonstrate a substantial improvement in individual gate performances, highlighting the effectiveness of PEC for error mitigation.

QI 14.14 Wed 18:00 P4

Efficient Spin-Adapted QPE Initial State Preparation —
•Hampus Brunander[1,2] and Werner Dobrautz[1,2,3,4] — [1]Center for Advanced Systems Understanding, 02826 Görlitz, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [3]Center for Scalable Data Analytics and Artificial Intelligence Dresden/Leipzig, 01069 Dresden, Germany — [4]Technical University Dresden, 01069 Dresden, Germany

The performance of quantum algorithms for strongly correlated electronic systems hinges on the overlap between the initial trial wavefunction and the ground state. However, a critical trade-off exists: the circuit cost of state preparation must not outweigh the algorithmic advantage. We address this by identifying regimes where problem-specific preparations yield high overlaps with minimal circuit depth. By adapting classical spin-group approaches, we utilize Localized Orbitals (LOs) to identify the optimal spin-coupling ordering. This chemically motivated approach constructs a dominant spin-adapted state that maximizes overlap while ensuring a compact, hardware-efficient implementation. We demonstrate that this strategy significantly improves fidelity for challenging systems, such as the stretched nitrogen dimer and iron-sulfur clusters.

QI 14.15 Wed 18:00 P4

Superconducting Digital-Analog Circuits for Quantum Approximate Optimization —
•Siyu Wang and Mohammad H. Ansari — Forschungszentrum Juelich, 52425 Juelich, Germany

Digital-analog quantum algorithms such as the digital-analog Quantum Approximate Optimization Algorithm (DA-QAOA) offer a scalable approach to quantum optimization by combining digital gate-based control with native analog evolution. In this work, we aim to explore a quantum processor architecture that supports DA-QAOA using the multi-mode superconducting resonator as the analog interaction resource.

The structure leverages the finite-mode resonator to enable effective ZZ-type interactions between different pairs of qubits without requiring tunable couplers. Single-qubit gates are applied digitally via dedicated drive lines, enabling a clear separation between analog and digital layers. This approach naturally realizes qubit interactions, thus eliminating the need for SWAP operations that are typically required in digital only architectures with limited connectivity, thereby reducing the circuit depth. The goal is to identify a layout and interaction scheme that preserves the essential properties of DA-QAOA while remaining fabrication-friendly and scalable to larger systems.

Our findings provide a design framework for implementing variational quantum algorithms in NISQ hardware using fewer resources.

QI 14.16 Wed 18:00 P4

Mitigating Noise in Quantum-Classical Electronic Band Structure Calculations —
•Vojtěch Vašina[1,2] and Martin Friák[1] — [1]Institute of Physics of Materials, Czech Academy of Sciences, Brno, Czech Republic — [2]Brno University of Technology, Institute of Material Sciences and Engineering

Computational materials science is currently facing a significant scalability issue. Simulating large condensed matter systems requires immense computational resources because the computational complexity grows exponentially as the size of the system increases. Quantum computers are emerging as a possible solution to overcome this problem because they theoretically offer up to an exponential speedup for certain problems. Current Noisy Intermediate-Scale Quantum (NISQ) computers are too noisy to provide results that are sufficiently accurate so classical and quantum algorithms are combined into so-called quantum-classical hybrid algorithms to overcome high levels of noise. In our study, we focused on computing the electronic band structure of diamond as this problem is well known and can be accurately solved on classical computers allowing us to compare those results to results obtained from the Variational Quantum Deflation (VQD) algorithm. We specifically investigate different error suppression and error mitigation techniques because the fidelity of results sensitively depends on them. The quantum parts of the VQD algorithm were executed on real quantum computers provided by IBM.

QI 14.17 Wed 18:00 P4

Effects of geometry on the error threshold of the toric code —
•Daniel Lessing, Calvin Kraemer, Jan Alexander Koziol, Anja Langheld, and Kai Phillip Schmidt — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen, Germany

The Random-Bond Ising Model can serve as a theoretical model for determining the error threshold of the toric code. This threshold is the maximum physical error rate tolerable for fault-tolerant quantum computation. We employ Monte Carlo Integration combined with finite-size scaling to map the RBIM's phase boundary for different temperatures and antiferromagnetic bond concentrations, which correspond to the different error rates in the toric code. The intersection of this phase boundary with the Nishimori line directly defines the critical error threshold for the toric code. Our investigation determines how this critical error threshold is influenced by varying the underlying geometry of the lattice.

QI 14.18 Wed 18:00 P4

Effect of Long-range Crosstalk Errors on the Surface Code —
•Solomon Birhanu Samuel[1] and Janos Karoly Asboth[1,2,3] — [1]Department of Theoretical Physics, Institute of Physics, Budapest University of Technology and Economics, Muegyetem rkp. 3., H-1111 Budapest, Hungary — [2]HUN-REN Wigner Research Centre for Physics, H-1525 Budapest, P.O. Box 49., Hungary — [3]HUN-REN-BME-BCE Quantum Technology Research Group, Muegyetem rkp. 3., H-1111 Budapest, Hungary

Crosstalk errors (due to unintended interactions between qubits and coupling between different circuit elements) pose a challenge to quantum error correction. They are often assumed to only affect nearest or next-nearest neighbor qubits[1], but experiments on some superconducting quantum processors[2] show that they can occur between more distant qubits as well. In this work, we study the effect of longer-range crosstalk errors on the surface code using numerical models (Clifford simulation) with realistic parameters of superconducting chips. We use Pauli error models to simulate the effect of the crosstalk both on the threshold and the logical error rate below threshold.

[1] Zhou, Zeyuan, Andrew Ji, and Yongshan Ding. "Surface Code Error Correction with Crosstalk Noise." arXiv preprint arXiv:2503.04642 (2025).

[2] Kosen, Sandoko, et al. "Signal crosstalk in a flip-chip quantum processor." PRX Quantum 5.3 (2024): 030350.

QI 14.19 Wed 18:00 P4

Hybrid Quantum-Classical Walks with Applications to Machine Learning —
•Adrián Marín Boyero[1], Daniel Manzano Diosdado[1], and Carlos Cano Gutiérrez[2] — [1]Department of Electromagnetism and Condensed Matter Physics, Avenida de la Fuente Nueva, 18071 Granada, University of Granada, Granada, Spain — [2]Institute Carlos I for Theoretical and Computational Physics, Avenida de la Fuente Nueva, 18071 Granada, University of Granada, Granada, Spain

Complex systems can often be described as networks, where nodes represent elements and edges represent interactions. Classical Random Walks (CRWs) are widely used for machine learning tasks on such structures. In this work, we introduce a Hybrid Quantum-Classical Walk (HQCW) model based on a modified Lindblad equation. This framework interpolates between quantum coherence and classical jumps through a parameter $\alpha \in [0, 1]$, generating node-visit trajectories whose statistics recover the Lindblad dynamics. The trajectories are generated with a Monte Carlo method known as Quantum Jumps, which reproduces the statistics of the underlying open system evolution. We use these trajectories for Graph Representation Learning and show that HQCWs break node ranking degeneracies, correctly recover communities, and separate node clusters in synthetic networks, even at low embedding dimension d. Performance peaks in a near-classical regime ($\alpha \approx 0.8$), capturing the global graph structure effectively. Our results highlight HQCWs as a scalable quantum-inspired tool for network analysis and machine learning.

QI 14.20 Wed 18:00 P4

GRAPE with feedback: the method and the Python package
— •Pavlo Bilous[1] and Florian Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

Quantum control with feedback is an essential component of modern quantum technology applications. While open-loop control tasks are usually solved using gradient methods like GRadient Ascent Pulse Engineering (GRAPE), it was until recently not clear how feedback from measurements in the control process can be integrated in these methods. Here, we discuss the "Feedback GRAPE" method introduced recently in Ref. [1] where feedback is combined with GRAPE

using machine learning techniques. Given the potential use of "Feedback GRAPE" for the community, we developed an efficient GPU-accelerated Python package implementing the approach. Here we discuss our codes and showcase them on three main closed-loop tasks: state preparation with feedback, state purification and state stabilization. Using the presented examples as the starting point, the users can conveniently apply our package for their problem at hand.

[1] R. Porotti, V. Peano, and F. Marquardt, PRX Quantum 4, 030305 (2023).

QI 14.21 Wed 18:00 P4

Characterization of spin-relaxation dynamics of rare earth ions in $CaWO_4$ — •Sebastian Dominguez-Calderon[1,2], Georg Mair[1,2], Arjun Bhasker[1,2], Robert Pant[1,2], Hans Huebl[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, D-85748 Garching, Germany — [2]School of Natural Sciences, Technische Universität München, D-85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, D-80799 Munich, Germany

Rare-earth spin ensembles doped into bulk crystals, such as $CaWO_4$, are promising candidates for quantum memory devices operating at microwave frequencies and compatible to superconducting quantum technologies. To further improve this technology, it is of pivotal importance to understand the mechanisms which affect information lifetimes. In the present work, we investigate spin interactions in ensembles of rare-earth (RE) ions in $CaWO_4$ via superconducting coplanar waveguides at millikelvin temperatures. Using spatially separated transmission lines, as well as pump-probe detection schemes, we aim to understand the ensemble's spin diffusion, suspected to be dominated by spin-spin as well as spin-phonon interactions. Characterization of the diffusion will give insights into different relaxation channels for RE:$CaWO_4$ that would aid the design of future quantum memory devices.

QI 14.22 Wed 18:00 P4

Qubit analogues in exciton-polariton condensates with optical manipulation — •Roman Lebs[1], Jan Wingenbach[1,2], Hendrik Rose[2], and Stefan Schumacher[1,2] — [1]Physics Department and CeOPP, Paderborn University, Germany — [2]PhoQS, Paderborn University, Germany

Exciton-polariton condensates provide a promising platform for quantum information processing, offering long coherence times, robust information storage and operation up to room temperature. Here we build upon earlier demonstrations of vortex-based information encoding (Ma et al., Nat. Commun. 11, 897, 2020), split ring qubit analogues (Xue et al., Phys. Rev. Research 3, 013099, 2021), and recent progress toward polaritonic qubit prototypes in annular traps (Barrat et al., Science Advances 10, eado4042, 2024), investigating a polariton condensate as a fully optically controllable qubit analogue. The condensate dynamics are modelled using the nonlinear Gross-Pitaevskii equation and numerically solved with PHOENIX, a highly optimized CUDA accelerated solver for two-dimensional nonlinear Schrödinger equations (Wingenbach et al., Comput. Phys. Commun. 315, 109689, 2025), which enables efficient and high-resolution simulations. We show that all points of the Bloch sphere can be reached by encoding the $|0\rangle$ and $|1\rangle$ states as localized spatial profiles with distinct phases. A simple pump geometry, combining a ring pump and a Gaussian pump applied on the ring, allows precise control of trajectories on the Bloch sphere. We also outline how this scheme can be extended toward coupled condensates in multi qubit architectures.

QI 14.23 Wed 18:00 P4

Si/SiGe interfaces for scalable qubit devices - a depth resolved HAXPES study — •Nathalie Niederbudde[1], Andreas Fuhrberg[1], Denny Dütz[2], Andrej Gloskovskii[3], Christoph Schlueter[3], Lars R. Schreiber[2], and Martina Müller[1] — [1]Universität Konstanz — [2]RWTH Aachen University — [3]DESY, Hamburg, Germany

An ongoing challenge in quantum physics research is optimizing the performance of silicon-based spin qubits. These devices use the intrinsic spin of electrons as logic states. The electron location is electrostatically controlled by biased gate pattern on top of the device. A common spin qubit platform compatible with industrial processes is based on SiGe/Si/SiGe heterostructures, where the electron is trapped in the strained Si layer. To achieve reliable control of the trapping potential, defects occurring mainly at the Si-capping layer and the amorphous gate-oxide must be explored, studied and minimized.

This study investigates an Al_2O_3/Si/SiGe-qubit structure using hard X-ray photoelectron spectroscopy (HAXPES) with synchrotron radiation of 2.8 & 6 keV at beamline P22, DESY. The influence of thermal annealing typical for device fabrication on the Si capping layer is analysed. Si oxide formation is observed independently of annealing, with a thicker oxide layer forming in the annealed sample and an additional shift in binding energies. Additional oxidation states are found close to the Si/Al_2O_3 interface. Although the entire Si layer is thought to be oxidized, no Ge oxide was detected. This study improves our understanding of the influence of qubit preparation processes.

QI 14.24 Wed 18:00 P4

Industrially fabricated and isotopically enriched Si/SiGe Quantum Dots for coherent spin qubit control — •Dominic Barthlott[1], Viktor Adam[1], Daniel Sitter[1], Daniel Schroller[1], Clement Godfrin[2], and Wolfgang Wernsdorfer[1] — [1]Physikalisches Institut (PHI), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [2]Interuniversity Microelectronics Centre (imec), Leuven, Belgium

Spin qubits represent a promising quantum-computing platform due to their combination of long coherence times and compatibility with established, industry-supported semiconductor fabrication techniques. Enrichment with ^{28}Si isotopes can increase the coherence time of the qubit by reducing the amount of naturally occurring ^{29}Si which has a non-zero nuclear spin. Hence, we are investigating this effect by comparing enriched to non-enriched samples fabricated using industry-level processes. The devices consist of two quantum dots and one single-electron transistor (SET) which is used for charge sensing, thereby detecting electron tunnel events in the quantum dots. By adjusting the gate voltages, the system can be tuned to its ground-state charge configuration, allowing individual electrons to be loaded into each quantum dot. After this initialization, two individual qubits are defined and can be coherently driven. Their performance is concluded by carrying out standard benchmark protocols, including T_1 relaxation measurements or Ramsey and Hahn-echo sequences for T_2 determination.

QI 14.25 Wed 18:00 P4

Induced quantum dot microscopy of germanium and graphene quantum devices — •Patrick Raif[1,2], Aurèle Kamber[1], Luca Forrer[1,2], Christian Olsen[1], Martino Poggio[1,2], Andrea Hofmann[1,2], and Floris Braakman[1,2] — [1]Department of Physics, Basel, Switzerland — [2]Swiss Nanoscience Institute, Basel, Switzerland

Quantum dots are fundamental building blocks for semiconductor-based qubits [1], which are a promising platform for quantum computation due to the high compatibility with currently existing manufacturing technology and the potential for scaling up. In recent years, planar Ge/SiGe heterostructures have been established as a leading material for such devices, in particular for the implementation of spin qubits [2].

However, even the highest quality qubit devices show significant variations of important parameters like coherence times, pinch-off voltages, tunnel barrier heights, Landé g-factors, spin-orbit lengths, and valley splittings. These variations represent a serious obstacle for scaling up as they necessitate tuning of the individual quantum dots.

To map out the spatial variations we will apply newly developed scanning probe microscopy techniques using cantilevers that are patterned with multiple gates via electron-beam lithography [3] by inducing quantum dots in a quantum well underneath the cantilever.

[1] G. Burkard, et al., *Rev. Mod. Phys.* **95**, 025003 (2023). [2] G. Scappucci, et al., *Nat. Rev. Mat.* **6**, 926-943 (2021). [3] L. Forrer, et al., *AIP Advances* **13**, 035208 (2023).

QI 14.26 Wed 18:00 P4

Exploration of exotic dielectric barrier materials for quantum computing — •Leqi Zhou[1], Thomas J. Smart[1], Christine Falter[1,2], Josua Thieme[1,2], Joscha Domnick[1], Benjamin Bennemann[1,2], Detlev Grützmacher[1], Peter Schüffelgen[1], and Alexander Pawlis[1,2] — [1]Peter Gruenberg Institute, Forschungszentrum Juelich GmbH, Juelich, Germany — [2]JARA-Fundamentals of Future Information Technology, Juelich-Aachen Research Alliance, Aachen, Germany

A majority of the modern research performed on superconducting quantum systems uses Al2O3 as the dielectric barrier material of interest. However, there has been renewed interest in alternatives to Al2O3 as a barrier material, due to the formation of two-level systems (TLSs) which can impede device performance. Within this work, we explore the deposition of alternative dielectric materials, such as AlN and TiO2. These films, grown via different epitaxy techniques are then electrically characterized to determine their resistive and capacitive properties. By optimizing the growth processes, based on these electrical measurements, we aim to implement these alternative dielectric materials into Josephson Junctions to test their suitability for future quantum computing systems.

QI 14.27 Wed 18:00 P4

Low-overhead Liouvillian Learning of Superconducting Qubit Arrays via Simultaneous Weak Measurements — •Markus Sifft, Armin Ghorbanietemad, and Daniel Hägele — Ruhr University Bochum, Faculty of Physics and Astronomy, Germany

Building on quantum polyspectra for higher-order noise analysis [1,2], we present a low-overhead protocol to reconstruct the Liouvillian of an open system from continuous weak multi-detector measurements of qubits. From a parameterized Liouvillian and measurement operators, we use closed-form expressions for multi-channel polyspectra up to fourth order, which compactly encode coherent dynamics and dissipation. Fitting theory to measured spectra allows us to extract key Hamiltonian and dissipative parameters of superconducting-qubit processors, including qubit frequencies, coherent couplings, crosstalk, drive leakage, and effective temperatures, even with background noise and in the ultra-weak measurement regime. A Fisher-information-based figure of merit quantifies identifiability and optimizes drive frequencies, amplitudes, measurement strengths, and operating temperature. The framework scales to many detectors and qubits, yields error bars and measurement-time estimates, and, compared to standard pulsed characterization, enables spectroscopy-style characterization from a single continuous experiment. All ingredients are implemented in our open-source QuantumCatch [3] and SignalSnap [4] libraries. [1] Hägele, Phys. Rev. B 98, 205143 (2018) [2] M. Sifft et al., arXiv:2505.01231 (2025) [3] github.com/markussifft/quantumcatch [4] github.com/ArminGEtemad/SignalSnap-PyTorch

QI 14.28 Wed 18:00 P4

Making entanglement witnesses robust to measurement errors — •Elisa Monchietti and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

In recent years, a variety of methods have been developed to characterise quantum entanglement, among which entanglement witnesses are one of the most widely studied tools. A major limitation of these operators, however, is their high sensitivity to measurement imperfections, which can lead to false positives in the detection of entangled states. In realistic experimental scenarios, even with advanced error-mitigation techniques, measurement errors arising from device imperfections and external noise cannot be completely eliminated. In this work, we aim to characterise quantum correlations in a more realistic framework by explicitly accounting for imprecise measurements. To this end, we investigate correction terms that can be incorporated to compensate for the effects of measurement misalignment and device imperfections. In particular, we study the existence and construction of entanglement witnesses for multiqubit systems that remain robust against misalignment errors.

QI 15: Quantum Information: Concepts and Methods II

Time: Thursday 9:30–12:30 Location: BEY/0137

QI 15.1 Thu 9:30 BEY/0137

Quantum dynmics induced by Pauli strings — •Roberto Gargiulo[1,2] and Robert Zeier[1] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]University of Cologne, Institute for theoretical physics (THP), 50937 Cologne, Germany

General quantum dynamics in qubit systems are described by independently controlled Hamiltonians consisting of sums of Pauli strings (i.e. tensor products of Pauli operators). We consider the case where each independently controlled Hamiltonian is given by a single Pauli string. We provide a unified description of the resulting dynamics relying on inherent symmetries and generated Lie algebras. This allows us to describe dynamical properties in terms of simple invariants and to detail possible free-fermionic mappings. We expand and extend recent work [1-3] which enables us to re-interpret them in a general framework. Our description addresses various questions of controllability, computational power, and many-body properties, especially in the context of Heisenberg picture and operator subspaces.

[1] Chapman et al. Quantum 4, 278 (2020)
[2] Kökcü et al., arXiv:2409.19797
[3] Aguilar et al. arXiv:2408.00081

QI 15.2 Thu 9:45 BEY/0137

Robust certification of non-projective measurements — •Raphael Brinster[1], Peter Tirler[2], Shishir Khandelwal[3], Michael Meth[2], Hermann Kampermann[1], Dagmar Bruss[1], Rainer Blatt[2,4], Martin Ringbauer[2], Armin Tavakoli[3], and Nikolai Wyderka[1] — [1]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf — [2]Institut für Experimentalphysik, Universität Innsbruck — [3]Physics Department and NanoLund, Lund University, — [4]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, Innsbruck

Determining the conditions under which the most general class of quantum measurements (positive operator-valued measures (POVMs)), outperform projective measurements remains a challenging and largely unresolved problem. Of particular interest are projectively simulable POVMs which offer no advantage over projective schemes, as they can be realized through probabilistic mixtures of projective measurements. Characterizing the boundary between simulable and non-simulable POVMs is, however, a difficult task, and existing tools either fail to scale efficiently, provide limited experimental feasibility or work only for specific POVMs. Here, we introduce a general method to certify non-simulability of a POVM by constructing non-simulability witnesses and demonstrate how to make them robust against state preparation errors in experiments.

QI 15.3 Thu 10:00 BEY/0137

Entanglement detection close to Dicke states with many-body correlations — •Géza Tóth[1,2,3,4], Martin Quensen[5,6], Mareike Hetzel[5,6], Luis Santos[5], Augusto Smerzi[7,8,9], Luca Pezzè[7,8,9], and Carsten Klempt[5,6] — [1]Theoretical Physics and EHU Quantum Center, University of the Basque Country UPV/EHU, 48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), 20018 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, 48009 Bilbao, Spain — [4]HUN-REN Wigner Research Centre for Physics, 1525 Budapest, Hungary — [5]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [6]Institut für Satellitengeodäsie und Inertialsensorik (DLR-SI), Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), 30167 Hannover, Germany — [7]Instituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche (INO-CNR), 50125 Firenze, Italy — [8]European Laboratory for Nonlinear Spectroscopy (LENS), 50019 Sesto Fiorentino, Italy — [9]Quantum Science and Technologies in Arcetri (QSTAR), 50125 Firenze, Italy

We will review methods for detecting multipartite entanglement in an ensemble of spin-1/2 atoms with collective measurements. We will introduce entanglement criteria based on the measurement of many-body correlations, such as the parity. Interestingly, such criteria can detect a larger entanglement depth in some practical situations than previous methods. In an experimental application, our criteria require a single-particle resolution in measuring the particle number.

QI 15.4 Thu 10:15 BEY/0137

Higher-dimensional information lattice: Quantum state characterization through inclusion-exclusion local information — •Claudia Artiaco — Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany

The information lattice provides a universal characterization of quantum many-body states through local information. Local information quantifies the total amount of correlations in a region on a given scale that cannot be found in any smaller subregion. This framework allows us to define the intrinsic correlation length scales of many-body states. Moreover, within the information lattice, the total information in a system becomes akin to a hydrodynamic quantity with well-defined local densities and local currents, which allow us to characterize quench dynamics and develop efficient approximate methods for the time evolution of large-scale many-body systems.

However, the original information lattice is strictly valid only for one-dimensional states, and its key properties, such as locality and the conservation of local information under unitary dynamics, do not easily extend to higher dimensions. In this talk, I will discuss these challenges and introduce a higher-dimensional generalization of the information lattice based on the inclusion-exclusion principle. I will show how this approach enables the characterization of two-dimensional states in different universality classes, including Anderson localized states, gapped states with critical boundaries, and ground states of the toric code in various geometries. I will further demonstrate how topological features can be interpreted in terms of inclusion-exclusion local information.

QI 15.5 Thu 10:30 BEY/0137

Remote quantum certification from prepare-measure correlations: theory and experiment — •Albert Rico[1], Javier Fernandez[2], Anna Sanpera[2], Some Sankar[2], and Adam Valles[2] — [1]University of Siegen — [2]Universitat Autonoma de Barcelona

For the practical implementation of quantum protocols, it is essencial to verify the presence of quantumness from classically observable data, under realistic assumptions. In a recent work, we demonstrated how this can be done in theory and experiment from the correlations between the inputs and outputs of a prepare-measure quantum setup, under the assumption that our quantum devices are limited in operational dimension and memory. Our contributions are: (1) we derive an inequality for the classical dimension needed to reproduce anti-correlated probability distributions; (2) we show that this inequality can be saturated, and this event displays quadratic quantum advantage with respect to classical siulation; (3) we prove that there is a unique strategy saturating the inequality, and thus find a method to self-test SIC-POVMs; (4) we engineer a certification protocol with low experimental error; and (5) we perform this method experimentally with orbital angular momentum with noise tolerance, thus certifying quantumness in practice. In this talk we will summarize the main ingredients of prepare-measure setup under consideration, sketch the results presented, and explain their implications in practical remote quantum certification for distant communication protocols.

QI 15.6 Thu 10:45 BEY/0137

Computable measures of fermionic non-Gaussianity — Poetri Sonya Tarabunga[1,2], Bernhard Jobst[1,2], Sheng-Hsuan Lin[3], Marc Langer[1,2], •Raúl Morral-Yepes[1,2], Barbara Kraus[1,2], and Frank Pollmann[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MC-QST), Schellingstr. 4, 80799 München, Germany — [3]Quantinuum, Leopoldstrasse 180, 80804 Munich, Germany

Quantum many-body states generally cannot be efficiently simulated on classical computers. However, certain classes of states with special structure admit efficient representations and simulations. Among these, fermionic Gaussian states are fully characterized by their two-point correlation functions. In this work, we investigate two measures of fermionic non-Gaussianity, which quantify how close a given state is to being Gaussian: the occupation number entropy, defined in terms of the eigenvalues of the correlation matrix, and the natural orbital Rényi entropy, given by the participation entropy in the basis that diagonalizes the correlation matrix. We present efficient methods to compute these quantities and analyze their connection to classical simulability and the complexity of state preparation. Additionally, we prove the monotonicity of these measures under specific conditions. Finally, we demonstrate their behavior in several models.

30min. break

Invited Talk QI 15.7 Thu 11:30 BEY/0137

Robust shadow tomography: from quantum simulation to high-energy physics — •Hai-Chau Nguyen — University of Siegen, Siegen, Germany

Starting with a brief introduction to shadow tomography, we show that it can be reformulated in terms of generalised measurements. On the one hand, this allows for taking into account the measurement errors in the implementation of shadow tomography in a canonical way. On the other hand, the symmetry of a shadow tomography protocol can be investigated in parallel with the symmetry of its associated generalised measurement, revealing its robustness against even complex measurement noise. We then show that measurement errors in shadow tomography can be efficiently mitigated even when they are correlated. This can be achieved by effectively symmetrising the shadow tomography protocol through simple controlled randomised (qu)bit flips, which provides a simple and robust protocol in comparison to those that are more demanding, such as protocols based on sampling Clifford gates. While the theory of shadow tomography and its technical developments were motivated by applications in quantum simulators, we emphasise its more general conceptual implications. In particular, we demonstrate a natural application of shadow tomography in the characterisation of relativistic spin-spin correlations of output particles in high-energy physics experiments. As a concrete example, we discuss how shadow tomography can shed light on conceptual aspects of the recent experiments demonstrating top-quark entanglement at ATLAS and CMS.

QI 15.8 Thu 12:00 BEY/0137

Detection of many-body entanglement partitions in a quantum computer — Albert Rico[1,2], Dmitry Grinko[3,4,5], •Robin Krebs[6], and Lin Htoo Zaw[7] — [1]Quantum information Group, Autonomous University of Barcleona, Spain — [2]Theoretische Quantenoptik, Universität Siegen, Germany — [3]QuSoft, Amsterdam, Netherlands — [4]Institute for Logic, Language and Computation, University of Amsterdam, Netherlands — [5]Korteweg-de Vries Institute for Mathematics, University of Amsterdam, Netherlands — [6]Quantum Computing, Technische Universität Darmstadt, Germany — [7]Centre for Quantum Technologies, National University of Singapore, Singapore

We present a method to detect entanglement partitions of multipartite quantum systems, by exploiting their inherent symmetries. Structures like genuinely multipartite entanglement, m-separability and entanglement depth are detected as special cases. This formulation enables us to characterize all the entanglement partitions of all three- and four-partite states and witnesses with unitary and permutation symmetry. In particular, we find and parametrize a complete set of bound entangled states therein. For larger systems, we provide a large family of analytical witnesses detecting many-body states of arbitrary size where none of the parties is separable from the rest. This method relies on weak Schur sampling with projective measurements, and thus can be implemented in a quantum computer. Beyond physics, our results apply to mathematics: we establish new inequalities between matrix immanants, and characterize the set of such inequalities for matrices of size three and four.

QI 15.9 Thu 12:15 BEY/0137

k-body correlations of graph states — •Mengying Hu[1,2], Elisa Monchietti[2], Ismaël Septembre[2], Kenneth Goodenough[2], Raphaël Mothe[2], and Otfried Gühne[2] — [1]School of Mathematical Sciences, Hebei Normal University, Shijiazhuang 050024, China — [2]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Germany

Graph states play a key role in quantum information processing tasks, for instance quantum computing and quantum error correction. Understanding their intrinsic structure is fundamental for assessing their usefulness in computational or informational tasks. In particular, graph states are stabilizer states, meaning they can be uniquely defined by the group of local Pauli operators stabilizing them. Here, we study the groups that arise after deleting certain subsets of qubits from the stabilizer group, which we use to capture the k-body correlations of graph states, and we use these correlations as invariants to distinguish graph states up to local unitaries.

QI 16: Quantum Software

Time: Thursday 9:30–12:45 Location: BEY/0245

Invited Talk QI 16.1 Thu 9:30 BEY/0245

Measurement-free universal fault-tolerant quantum computation — •Friederike Butt[1,2], Ivan Pogorelov[3], Alex Steiner[3], Marcel Meyer[3], Thomas Monz[3,4], Markus Müller[1,2], and Robert Freund[3] — [1]Institute for Theoretical Nanoelectronics (PGI-2), Forschungszentrum Jülich — [2]Institute for Quantum Information, RWTH Aachen University — [3]Universität Innsbruck, Institut für Experimentalphysik, Innsbruck — [4]Alpine Quantum Technologies GmbH, Innsbruck

The ability to perform quantum error correction (QEC) and robust gate operations on encoded qubits opens the door to demonstrations of quantum algorithms. Contemporary QEC schemes typically require mid-circuit measurements with feed-forward control, which are challenging for qubit control, often slow, and susceptible to relatively high error rates. I will present protocols and the experimental realization of a universal toolbox of fault-tolerant logical operations without mid-circuit measurements on a trapped-ion quantum processor. This includes modular logical state teleportation between two four-qubit error-detecting codes without measurements during algorithm execution, as well as a fault-tolerant universal gate set on an eight-qubit error-detecting code hosting three logical qubits, based on state injection, which can be executed by coherent gate operations only. This toolbox can then be used to realize Grover's quantum search algorithm fault-tolerantly on three logical qubits encoded in eight physical qubits, with the implementation displaying clear identification of the desired solution states.

QI 16.2 Thu 10:00 BEY/0245

A Framework for Spectator Error Mitigation in Surface-Code Hamiltonian Modeling — •Xuexin Xu[1], Mohammad H. Ansari[1], and John M. Martinis[2] — [1]PGI-2, Forschungszentrum Juelich, Juelich, 52428, Germany — [2]Qolab, Madison, Wisconsin, 53706, USA

Realistic surface-code architectures rely on precisely engineered single and two-qubit gates across large-scale quantum lattices. Yet subtle whispers from spectator qubits those surrounding but not directly involved in a target operation can disturb intended surface-code Hamiltonian and degrade logical fidelity. We analyze the origin and effects of spectator-induced errors in lattices and propose a mitigation scheme based on the inherent symmetry of spectator qubits. Through numerical simulations and perturbative analysis, we show that our method gently suppresses parasitic effects while boosting the performance of intended two-qubit gates. This approach offers a scalable and systematic path to enhance gate fidelity and tame crosstalk, bringing surface-code quantum processors closer to practical, reliable operation.

QI 16.3 Thu 10:15 BEY/0245

Handling Quantum Errors under Realistic Noise Models of Trapped Ion Quantum Devices — •Niko Trittschanke[1,2], Daniel Borcherding[2], and Robert Raussendorf[1,3] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]QUDORA Technologies GmbH — [3]Stewart Blusson Quantum Matter Institute, University of British Columbia

Quantum computers are poised to grant an advantage over classical computers for some specific problems. These applications will require fully fault-tolerant quantum computers in order to produce significant results. However, due to the overhead of gates and qubits required by quantum error correction, fault-tolerant computation is out of scope for current devices. This necessitates the development of lightweight yet effective strategies to handle errors in noisy quantum devices. We investigate a $[[2m, 2m-2, 2]]$ error-detection code based on the 'Iceberg code' by applying it to realistic quantum simulations of the Schwinger model. Using an accurate noise model for the two-qubit entangling gate based on the upcoming trapped ion architecture of QUDORA, we simulate the dynamics of the particle number density on a noisy emulator. We demonstrate that the Iceberg code is able to substantially reduce the errors in this simulation, if correctly tuned. To that end, we propose a workflow to optimize the Iceberg code by selecting an optimal number of stabilizer measurements for a given problem. These results show that noisy intermediate-scale quantum computing can extensively be improved by carefully choosing low-overhead error-handling methods.

QI 16.4 Thu 10:30 BEY/0245

Probabilistic error cancellation for single-mode Gottesman-Kitaev-Preskillev-Preskill codes — Alessandro Ciani[1] and •Victoria Wadewitz[1,2] — [1]Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Theoretical Physics, Universität des Saarlandes, 66123 Saarbrücken, Germany

To solve practical problems on a quantum computer, fault-tolerant quantum error correction schemes are necessary to overcome noise from imperfections in physical components. The Gottesman-Kitaev-Preskill (GKP) code achieves this by encoding finite-dimensional logical space within the continuous variables of bosonic modes, offering a pathway to scalable, fault-tolerant quantum computing. However, it is not feasible to eliminate errors entirely, so they must be mitigated. In this work, we study a quantum error mitigation method known as probabilistic error cancellation (PEC) in the context of GKP codes. We compare Steane-type and teleportation-based GKP error correction, and calculate sampling overheads for square and hexagonal GKP codes. The PEC sampling probabilities are derived using a stabilizer subsystem decomposition for GKP codes. Considering noise from finite squeezing of the data and the two ancilla modes, as well as other contributions like pure loss and Gaussian random displacement, we examine the relationship between the overhead and the noise. Our results cover single- and two-GKP-qubit Clifford gates. Preliminary analysis suggests that, when combined with error mitigation techniques, teleportation-based GKP error correction outperforms Steane-type GKP error correction.

QI 16.5 Thu 10:45 BEY/0245

Real-time adaptive quantum error correction by model-free multi-agent learning — •Manuel Guatto[1,2], Francesco Preti[1], Michael Schilling[1,2], Tommaso Calarco[1,2,3], Francisco Cardenas-Lopez[1], and Felix Motzoi[1,2] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, D-50937 Cologne, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

Can Quantum Error Correction (QEC) adapt in real time to changing noise? We show that it can. We introduce a two-level reinforcement-learning framework that learns QEC from scratch and adapts it on the fly. At the first level, a model-free multi-agent RL system automatically discovers full QEC cycles*encoding, stabilizer measurements, and recovery*using only orthogonality constraints and no prior knowledge of the device. Using the stabilizer formalism, we demonstrate that it can generate new QEC codes tailored to multi-level quantum architectures. At the second level, we present BRAVE (Bandit Retraining for Adaptive Variational Error correction), an efficient algorithm that continuously retunes the variational layer to track time-dependent noise with minimal retraining. Combined, these methods yield more than an order-of-magnitude improvement in logical fidelity under time-varying bit- and phase-flip noise compared to standard QEC schemes.

30min. break

QI 16.6 Thu 11:30 BEY/0245

Continuous vs. Pauli Noise: Impact on Small-Scale Quantum Codes — •Yunos El Kaderi[1,2], Andreas Honecker[1], and Iryna Andriyanova[2] — [1]LPTM CNRS UMR 8089, CY Cergy Paris University, France — [2]ETIS CNRS UMR 8051, CY Cergy Paris University, France

Noise remains the main limit to reliable quantum computation. Standard Pauli models treat faults as discrete events, but real devices exhibit small, coherent shifts in gate rotations that accumulate over time [1,2]. These shifts follow directional patterns linked to axis and angle drift, which are well described by von Mises–Fisher statistics [3].

We study a continuous coherent-noise model built from these rotational laws and apply it to memory circuits based on the $[[5, 1, 3]]$ and $[[7, 1, 3]]$ stabilizer codes. We compare its logical performance with that of a matched-entropy Pauli channel, so both models share the same binary-symmetric uncertainty at readout. This isolates how the *shape* of noise, not only its strength, affects logical error rates.

We also introduce an approximate method that propagates small coherent errors through Clifford circuits without full Monte Carlo.

[1] S. Sheldon *et al.*, Phys. Rev. A 93, 012301 (2016)
[2] E. Huang *et al.*, Phys. Rev. A 99, 022313 (2019)
[3] G. Ragazzi *et al.*, Phys. Rev. A 110, 052425 (2024)

QI 16.7 Thu 11:45 BEY/0245

Encoding Numerical Data for Generative Quantum Machine Learning — •Michael Krebsbach[1], Hagen-Henrik Kowalski[2], Florentin Reiter[1], Ali Abedi[2], and Thomas Wellens[1] — [1]Fraunhofer IAF, Tullastraße 72, 79108 Freiburg — [2]Bundesdruckerei GmbH, Kommandantenstraße 18, 10969 Berlin

Generative quantum machine learning has the potential to model probability distributions that are out of reach for their classical counterparts. Due to the binary nature of samples drawn from a quantum computer, many of the generative models described in the literature focus on binary data. The transition from binary to real-world data, which is typically numerical, necessitates an additional encoding step that can obscure structure in the data and hinder effective learning.

In this talk, we present our investigation into binary encodings and their effect on the training process of generative quantum machine learning algorithms. We identify situations in which the conventional approach is limited, and propose strategies that circumvent these limitations at essentially no additional cost. We test these strategies on a range of datasets and provide numerical evidence that they provide an average-case improvement over the conventional approach.

QI 16.8 Thu 12:00 BEY/0245

Machine Learning methods for Entanglement Detection in High Dimensional Systems — •Yasmin Bougammoura[1], Martin Plávala[1], Fabio Anselmi[2], and Fabio Benatti[2] — [1]Institute of Theoretical Physics - Leibniz University Hannover, Germany — [2]University of Trieste, Italy

A universal approach to entanglement detection can be cast as a semidefinite program (SDP), but this formulation becomes computationally inefficient as the dimension of the system grows. Since entanglement detection for systems of dimension $d \geq 6$ is already an NP-hard task, this motivates the search for practical numerical strategies. Although current machine learning models reach high accuracy values, they do not provide robust and verifiable separability criteria. We propose two simple approaches: i. using automatic differentiation to approximate a given quantum state, and ii. training an artificial neural network to construct a certifiable entanglement witness W for a given entangled quantum state. The former efficiently approximates separable states; the latter achieves an improvement of two orders of magnitude in the dimension of the optimisation problem, which increases exponentially with the number of qubits. In terms of computational resources, the neural network model runs on a local machine with 16 GB RAM for a system of 8 qubits, whereas the SDP formulation is limited to a system of only 4 qubits.

QI 16.9 Thu 12:15 BEY/0245

Reducing the cost of gate-set tomography of superconducting quantum processors — •Martin Koppenhöfer, Michael Krebsbach, and Thomas Wellens — Fraunhofer-Institut für Angewandte Festkörperphysik IAF, Tullastraße 72, 79108 Freiburg, Deutschland

Gate errors remain one of the biggest obstacles on the road towards scalable quantum processors. Obtaining a precise understanding of these errors and of their origin is a necessary step for hardware improvements and error mitigation. In principle, gate-set tomography protocols allow one to obtain a detailed, self-consistent picture of quantum processors including state-preparation and measurement steps. However, a drawback of these protocols is that they become computationally very costly when multi-qubit gates are analyzed, leading to a very large set of germ circuits as well as an exponential growth of the initial states that need to be prepared and measurements that need to be performed.

In this talk, we present a modified approach to gate-set tomography that exploits different gate fidelities for single- and two-qubit gates to reduce the number of germ circuits and fiducial states. For two-qubit gate-set tomography, this approach reduces the number of required experiments by more than an order of magnitude and thus speeds up gate-set tomography protocols. We demonstrate this new technique on a superconducting quantum processor.

QI 16.10 Thu 12:30 BEY/0245

Detecting genuine multipartite entanglement in multi-qubit devices with restricted measurements — •Nicky Kai Hong Li[1,2], Xi Dai[3,4], Manuel Muñoz-Arias[5], Kevin Reuer[3,4], Marcus Huber[1,2], and Nicolai Friis[1] — [1]Atominstitut, Technische Universität Wien, Stadionallee 2, 1020 Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria — [3]Department of Physics, ETH Zurich, CH-8093 Zurich, Switzerland — [4]Quantum Center, ETH Zurich, CH-8093 Zurich, Switzerland — [5]Institut Quantique and Département de Physique, Université de Sherbrooke, Sherbrooke J1K 2R1 QC, Canada

Detecting genuine multipartite entanglement (GME) is a state-characterization task that benchmarks coherence and experimental control in quantum systems. Existing GME tests often require joint measurements on many qubits, posing experimental challenges for systems like time-bin qubits and microwave photons from superconducting circuits. Here we introduce GME and k-inseparability criteria applicable to any state, which only require measuring $O(n^2)$ out of 2^n $\leqslant m$-body stabilizers of n-qubit target graph states, with m at most twice the graph's maximum degree. For cluster or ring-graph states, only constant-weight stabilizers are needed. Using SDP, we further reduce both the number and weight of required stabilizers. Analytical and numerical results show that our criteria are noise-robust and can infer state infidelity from certified k-inseparability in microwave photonic graph states generated under realistic conditions.

QI 17: Decoherence and Open Systems II

Time: Thursday 15:00–17:30 Location: BEY/0137

QI 17.1 Thu 15:00 BEY/0137

A mathematical justification to apply the secular approximation to the Redfield equation — •Niklas Jung[1,2], Francesco Rosati[1,2], Gabriel Rath[1,2], Frank Wilhelm[1,2], and Peter Schuhmacher[3] — [1]Theoretical Physics, Saarland University, Campus, 66123 Saarbruecken, Germany — [2]Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Juelich, 52425 Juelich, Germany — [3]Department of High Performance Computing, Institute of Software Technology, German Aerospace Center (DLR), Rathausallee 12, 53757 Sankt Augustin, Germany

In this work, we prove that the solutions of the master equation obtained by applying the secular approximation are also obtained by an approximation of the same order as the one performed to obtain the Redfield equation. We hereby provide a mathematical justification for the secular approximation. We show that the result of applying the secular approximation is obtained naturally by applying a self-consistency argument. This shows that the resulting master equation is also in the same equivalence class of approximations as the Redfield master equation.

QI 17.2 Thu 15:15 BEY/0137

Quantum Zeno effect versus adiabatic quantum computing and quantum annealing — Naser Ahmadiniaz[1], Dennis Kraft[1], Gernot Schaller[1], and •Ralf Schuetzhold[1,2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany — [2]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany

For the adiabatic version of Grover's quantum search algorithm as proposed by Roland and Cerf, we study the impact of decoherence caused by a rather general coupling to some environment. For quite generic conditions, we find that the quantum Zeno effect poses strong limitations on the performance (quantum speed-up) since the environment effectively measures the state of the system permanently and thereby inhibits or slows down quantum transitions. Generalizing our results, we find that analogous restrictions should apply universally to adiabatic quantum algorithms and quantum annealing schemes which are based on isolated Landau-Zener type transitions at avoided level crossings (similar to first-order phase transitions). As a possible resort, more gradual changes of the quantum state (as in second-order phase transitions) or suitable error-correcting schemes such as the spin-echo method may alleviate this problem. https://doi.org/10.48550/arXiv.2509.04057

QI 17.3 Thu 15:30 BEY/0137

Cat state preparation and stabilization in open quantum systems — •Suocheng Zhao[1], Sofia Qvarfort[2,3], and Anja Metelmann[1,4,5] — [1]IQMT, KIT, 76344 Eggenstein-Leopoldshafen, Germany — [2]Nordita, KTH Royal Institute of Technology and Stockholm University, SE-106 91 Stockholm, Sweden — [3]Department of Physics, Stockholm University, AlbaNova University Center, SE-106 91 Stockholm, Sweden — [4]TKM, KIT, 76131 Karlsruhe, Germany — [5]ISIS, University of Strasbourg and CNRS

Cat states are a valuable resource for quantum metrology applications, promising to enable sensitivity down to the Heisenberg limit. Moreover, Schrödinger cat states, based on a coherent superposition of coherent states, show robustness against the bit-flip error making them a promising candidate for bosonic quantum codes. Despite these advantages, cat states are generally difficult to generate, and their practical usefulness is fundamentally challenged by environmental noise, which degrades both their preparation and subsequent performance. In this talk, I present three complementary strategies for mitigating the impact of noise, illustrated through the preparation and protection of cat states: (1) accelerating state preparation to outrun noise accumulation using self- and cross-Kerr interactions, as well as quantum optimal control, (2) squeezing the cat states to enhance their intrinsic robustness against noise, and (3) engineering tailored dissipative processes that drive the system toward cat states, and counteract noise to extend their lifetime. Together, these approaches pave the way for deploying cat states in practical quantum technologies.

QI 17.4 Thu 15:45 BEY/0137

Exact Floquet dynamics of strongly damped driven quantum systems — •Konrad Mickiewicz[1], Valentin Link[2], and Walter T. Strunz[1] — [1]Institut für Theoretische Physik, Technische Universität Dresden, D-01062, Dresden, Germany — [2]Institut für Physik und Astronomie, Technische Universität Berlin, D-10623, Berlin, Germany

We introduce an approach for efficiently simulating strongly damped, periodically driven quantum systems [1] using a translationally invariant matrix product operator representation of the influence functional [2]. This allows us to construct a numerically exact Floquet propagator that captures non-Markovian open system dynamics, serving as a dissipative analogue to the Floquet Hamiltonian of isolated periodically driven systems. We apply our method to investigate deviations from equilibrium in spin-boson models by studying the asymptotic reservoir heating. Additionally, we demonstrate that local driving of two qubits can stabilize a transient, environmentally induced buildup of entanglement. Our approach enables a direct analysis of both stationary and transient dynamics in strongly damped, driven quantum systems within a consistent theoretical and computational framework. [1] K. Mickiewicz, V. Link, and W. T. Strunz, arXiv:2511.08754 (2025) [2] V. Link, H.-H. Tu, and W. T. Strunz, Phys. Rev. Lett. 132, 200403 (2024)

QI 17.5 Thu 16:00 BEY/0137

Exceptional Points and Optimized Encoding under Continuous Measurement — •Yves Rottstaedt[1], Andrei Pavlov[2], Alexander Shnirman[2], Yuval Gefen[3], and Bernd Rosenow[1] — [1]Universität Leipzig, Leipzig, Germany — [2]Karlsruhe Institut für Technologie, Karlsruhe, Germany — [3]Weizmann Institute of Science, Rechovot, Israel

We study a system of three qubits subject to blind continuous stabilizer measurements and stochastic bit-flip errors. The resulting open-system dynamics are governed by a non-Hermitian Liouvillian superoperator, which exhibits an exceptional point (EP) at a specific critical error rate: two eigenvalues coalesce and their eigenmodes merge into a single vector, forming a nontrivial Jordan chain. Motivated by this structure, we construct a logical-qubit basis directly from the Liouvillian eigenmodes, thereby incorporating both measurement-induced dissipation and error processes into the encoded subspace. By analyzing the Jordan chain at the EP, we identify dynamical features that enhance logical-state stability over short and intermediate times. We then optimize the logical basis to reproduce these EP-induced properties for arbitrary error rates, effectively extending the favorable dynamical behavior beyond the singular point.

QI 17.6 Thu 16:15 BEY/0137

Closed-Form approximation of Kraus operators for GKSL dynamics in the weak-noise regime — •Shahrukh Chishti[1,2], Francisco Cardenas-Lopez[1], and Felix Motzoi[1,2] — [1]Forschungszentrum Juelich GmbH, Peter Gruenberg Institute, Quantum Control (PGI-8), 52425 Juelich, Germany — [2]Institute for Theoretical Physics, University of Cologne, D-50937 Cologne, Germany

Quantum system interacts unavoidably with the surrounding environment leading to decoherence and thermalization. The dynamics of an open quantum system is equivalently represented with the GKSL equation or the Kraus operators that includes the effects of the environment. For a general noise channel, it is difficult to obtain the Kraus operators from the Lindbladian and vice-versa. We derive a closed-form approximation of the Kraus operators for the GKSL dynamics by employing two approximations; first, weak noise limit of the dynamical map and then discretizing this map via a Riemann summation. Further, this technique could be extended to higher orders in evolution and time-dependent Hamiltonians. These results provide insight into the interaction between noise and coherent dynamics.

30min. break

QI 17.7 Thu 17:00 BEY/0137

Non-perturbative switching rates in bistable open quantum systems: from driven Kerr oscillators to dissipative cat qubits — •Leon Carde[1], Ronan Gautier[1], Nicolas Didier[1], Alexandru Petrescu[2], Joachim Cohen[1], and Alexander McDonald[3] — [1]Alice&Bob, Paris, France — [2]Mines ParisTech, Paris, France — [3]University of Sherbrooke, Sherbrooke, Canada

In this work, we use path integral techniques to predict the switching rate in a single-mode bistable open quantum system. While analytical expressions are well-known to be accessible for systems subject to Gaussian noise obeying classical detailed balance, we generalize this approach to a class of quantum systems, those which satisfy the recently-introduced notion of hidden time-reversal symmetry. .In particular, in the context of quantum computing, we obtain analytical estimates of bit-flip error rates in cat-qubit architectures. We confirm these findings by comparing our results to numerically exact diagonalization of the Linbladian. Our results provide a path towards exploring switching phenomena in multistable open quantum systems

QI 17.8 Thu 17:15 BEY/0137

Conserved quantities enable the quantum Mpemba effect in weakly open systems — •Iris Ulcakar[1,2], Gianluca Lagnese[1], Rustem Sharipov[2], and Zala Lenarcic[1] — [1]"Jozef Stefan" Institute, Ljubljana, Slovenia — [2]Faculty of Mathematics and Physics, University of Ljubljana, Slovenia

Observation of the quantum Mpemba effect has spurred much interest in its enabling conditions and its relation to the classical counterpart. Here, we consider weakly open many-body quantum systems initialized in different thermal states and examine when the initially farther state relaxes to the (non-equilibrium) steady state faster. We claim that the number of conserved quantities in the unitary part plays a crucial role: the Mpemba effect is possible only when the Hamiltonian commutes with other extensive operators or is integrable. The reason lies in the dynamical evolution happening in spaces of different dimensions. When energy is the only approximately conserved quantity, dissipation pushes the dynamics within a single-parameter manifold of different thermal states. In contrast, for Hamiltonians with several conserved quantities, the dynamics drift in the multi-dimensional space of generalized Gibbs ensembles, whose distance to the steady state is less trivial. We provide numerical results for large system sizes using tensor networks and free-fermion techniques, thereby supporting our claim.

QI 18: Quantum Communication

Time: Thursday 15:00–18:00 Location: BEY/0245

Invited Talk QI 18.1 Thu 15:00 BEY/0245

Multipartite Quantum states from guided-wave structures — •Virginia D'Auria[1], Adrien Bensemhoun[1], Silvia Cassina[2], Carlos Gonzalez-Arciniegas[3], Mohamed Fauzi Melalkia[1], Giuseppe Patera[4], Jonathan Faugier-Tovar[5], Quentin Wilmar[5], Ségolène Olivier[5], Alessandro Zavatta[6], Anthony Martin[1], Jean Etesse[1], Laurent Labonté[1], and Sébastien Tanzilli[1] — [1]University Côte d'Azur, Institut of Physics of Nice, Nice, FR — [2]University of Insubria, Como, IT — [3]University of Virginia, Charlottesville, VA, US — [4]University of Lille, Lille, FR — [5]CEA-LETI, Grenoble, FR — [6]Istituto Nationale di Ottica, Florence, IT

Our experimental work demonstrates multipartite quantum correlation in bright frequency combs out of a microresonator integrated on silicon nitride operating above its oscillation threshold. Multipartite features, going beyond so far reported two-mode correlation, naturally arise due to a cascade of non-linear optical processes, making a single-color laser pump sufficient to initiate their generation. Our results show the transition from two-mode to multipartite correlation.

QI 18.2 Thu 15:30 BEY/0245

Microwave quantum communication over thermal quantum networks — •Wun Kwan Yam[1,2], Simon Gandorfer[1,2], Maria-Teresa Handschuh[1,2], Achim Marx[1], Rudolf Gross[1,2,3], and Kirill G. Fedorov[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Quantum communication in the microwave regime is set to play an important role in distributed quantum computing and hybrid quantum networks. In a step towards practical quantum networks, we demonstrate quantum teleportation of microwave coherent states over a thermal quantum network composed of two spatially-separated dilution refrigerators, achieving teleportation fidelities of 72.3 % at channel temperatures of 1 K and 59.9 % at 4 K. Furthermore, we theoretically analyze quantum communication of discrete-variable qubit states using a continuous-variable two-mode squeezing resource state, paving the way towards hybrid quantum communication protocols. Our results show the experimental feasibility of distributed superconducting architectures and motivate further investigations of noisy quantum networks in various frequency regimes.

QI 18.3 Thu 15:45 BEY/0245

Entanglement distribution in hybrid-variable microwave networks — •Simon Gandorfer[1,2], Ivan Solomakhin[1,2], Maria-Teresa Handschuh[1,2], Joan Agustí[1,2], Achim Marx[1], Peter Rabl[1,2,3], Rudolf Gross[1,2,3], and Kirill G. Fedorov[1,2,3] — [1]Walther-Meißner- Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]School of Natural Sciences, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Distributing entanglement between distant nodes of a large-scale quantum network is a fundamentally important milestone for quantum information processing. In particular, quantum entanglement is crucial for quantum teleportation protocols or logical quantum gates with remote qubits. In our experiment, we investigate remote entanglement of discrete-variable qubits by using contiunuos-variable entangled signals. The latter is represented by the two-mode squeezed microwaves generated with Josephson parametric circuits, while the former are given by superconducting transmons in 3D cavities. We observe a build-up of entanglement between the qubits due to their interaction with the common, quantum-correlated, reservoir. The corresponding entanglement conversion between continuous- and discrete-variables allows for promising and robust, hybrid-variable, quantum microwave networks. Finally, we discuss possible extensions and applications of our findings for distributed quantum computing architectures.

QI 18.4 Thu 16:00 BEY/0245

Quantum Key Distribution without Hidden Message Transmission — •Yien Liang, Anton Trushechkin, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf, Germany

Steganography is the practice of hiding secret information within irrelevant information. A way to hide information within a valid digital signature is to take advantage of the random number required by a digital signature protocol, the adversary can maliciously choose a number that hides information instead of randomly choosing one. Such steganography technique is called subliminal channel [1]. A quantum key distribution (QKD) protocol involves communicating a large set of random random numbers, which can be used to establish a subliminal channel. The participants of a QKD protocol can intentionally hide information within the public announcement which is undetectable by any third party. Malicious QKD devices could also use a subliminal channel as a covert channel [2] to leak information to a third party. In our contribution, we propose a modified QKD protocol which is information-theoretic secure against eavesdropping and provable (more-than-one-bit-)subliminal-channel-free. We also generalize our results to quantum conference key agreement protocols.

[1] Simmons G J. Advances in cryptology: proceedings of crypto 83. Boston, MA: Springer US, 1984: 51-67. [2] Curty M, Lo H K. npj Quantum Information, 2019, 5(1): 14.

QI 18.5 Thu 16:15 BEY/0245

Verified delegated quantum computation requires techniques beyond cut-and-choose — •Fabian Wiesner and Anna Pappa — Technische Universität Berlin, Einsteinufer 17, 10587 Berlin, Germany

Delegated quantum computation enables a client with limited quantum capabilities to outsource computations to a more powerful quantum server while preserving correctness and privacy. Verification is crucial in this setting to ensure that the untrusted quantum server performs the computation honestly and returns correct results. A common verification method is the quantum cut-and-choose technique. Inspired by classical verification methods for two-party computation, the client uses the majority of the delegated rounds to test the server's honesty, while keeping the remaining ones for the actual computation. Combining this technique with other methods, such as quantum error correction, could help achieve negligible cheating probabilities for the server; however, such methods can impose significant overheads, making implementations unfeasible for the near-term future. In this work, we investigate whether cut-and-choose can yield efficient and secure verifiable quantum computation without additional costly techniques. We find that verifiable delegated quantum computation protocols relying solely on cut-and-choose techniques cannot be secure and efficient at the same time.

30min. break

QI 18.6 Thu 17:00 BEY/0245

Deployed BBM92 quantum key distribution using frequency-converted entangled photons emitted by a quantum dot — •Benjamin Breiholz[1], Michal Vyvlecka[1], Raphael Joos[1], Aurélien Marmasse[1], Ilenia Neureuther[1], Timo Schnieber[1], Anna Frederike Köhler[1], Tim Strobel[1], Tobias Bauer[2], Marlon Schäfer[2], Nand Lal Sharma[3], Caspar Hofmann[3], Simone Luca Portalupi[1], Christoph Becher[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, 70569 Stuttgart, Germany — [2]Fachrichtung Physik, 66123 Saarbrücken, Germany — [3]Institute for Integrative Nanosciences, 01069 Dresden, Germany

We implemented an entanglement-based BBM92 quantum key distribution (QKD) protocol over approximately 700 m across the university campus buildings using the existing deployed fiber network. The entangled-photon pair at wavelength of 780 nm was emitted by an epitaxially grown droplet-etched GaAs quantum dot (QD) embedded in a dielectric antenna. The QD was excited via two-photon excitation using a pulsed laser that emits 10 ps pulses at 779 nm with a 380 MHz repetition rate. To minimize losses in silica fibers, we employed bidirectional, polarization-conserving quantum frequency conversion to shift the QD emission to a telecom wavelength. We achieved stable QKD operation for more than 10 hours, with a raw key rate exceeding 200 Hz and a quantum bit error rate below 4.5 %. After error correction and privacy amplification, we distilled a secure key at a rate of 100 Hz.

QI 18.7 Thu 17:15 BEY/0245

GHz-clocked Single-photon Quantum Key Distribution in the Telecom C-band — •Koray Kaymazlar[1], Mareike Lach[1], Robert B. Behrends[1], Lucas Rickert[1], Martin von Helversen[1], Jochen Kaupp[2], Yorick Raum[2], Tobias Huber Loyola[2,3], Sven Höfling[2], Andreas Pfenning[2], and Tobias Heindel[4] — [1]Institute of Physics and Astronomy, Technische Univeristät Berlin — [2]Technische Physik, Physikalisches Institut and Würzburg-Dresden Cluster of Excellence — [3]Karlsruher Institut für Technologie, Institute of Photonics and Quantum Electronics — [4]Department for Quantum Technology, Univeristät Münster

High speed operation is one of the most desired properties for implementations of quantum key distribution (QKD). This requires however the generation and state-preparation of photonic qubits at high speed. Here, we report on a QKD system based on the BB84 protocol that operates at GHz clock-rates using a highly Purcell-enhanced single-photons source emitting in the telecom C-band. We use a laser with a repetition rate of 2.5 GHz to pump the quantum dot source and prepare the polarization states fot the protocol using a customized fiber-based electro-optic modulator (EOM) controlled by an arbitrary waveform generator (AWG) using the trigger output of the pump laser as common clock. Our results show that our system performs the BB84 protocol succesfully with a quantum bit error ratio (QBER) around 5 % at these unprecendeted high clock-rates.

QI 18.8 Thu 17:30 BEY/0245

Multiplexed multipartite quantum repeater rates in the stationary regime — •Anton Trushechkin, Julia Kunzelmann, Nikolai Wyderka, Hermann Kampermann, and Dagmar Bruss — Heinrich Heine University Düsseldorf, Faculty of Mathematics and Natural Sciences, Institute for Theoretical Physics III, Universitätsstr. 1, Düsseldorf 40225

We consider a multipartite quantum repeater creating GHZ states between several parties from bipartite entanglement links. Each bipartite link is characterised by a success probability, i.e., probability of successful establishment of bipartite entanglement per round. We are interested in GHZ generation rate in such repeater on long times, i.e., in the stationary regime. On an abstract level, the mathematical description is also equivalent to the usual bipartite quantum repeater chain between two parties and the corresponding bipartite entanglement generation rate. We also consider the case of memory multiplexing and study its effect on the generation rate. We derive closed-form expressions for the stationary generation rate depending on the number of parties (or the segments in a chain of bipartite repeaters) and the multiplexing number.

QI 18.9 Thu 17:45 BEY/0245

Anonymous and private parameter estimation in networks of quantum sensors — Jarn De Jong[1], Santiago Scheiner[2], Naomi R. Solomons[2], •Ziad Chaoui[1], Damian Markham[2], and Anna Pappa[1] — [1]Technische Universität Berlin, Einsteinufer 19, 10587 Berlin, Germany — [2]LIP6, CNRS, Sorbonne Université, 4 place Jussieu, F-75005 Paris, France

Anonymity and privacy are two key properties of modern communication networks. In quantum networks, distributed quantum sensing has emerged as a powerful use case, with applications to clock synchronization, detecting gravitational effects, and more. In this work, we develop a new protocol that, for the first time, combines the different cryptographic properties of anonymity and privacy for the task of distributed parameter estimation. That is, we present a protocol that allows a selected subset of network participants to anonymously collaborate in estimating the average of their private parameters. Crucially, this is achieved without disclosing either the individual parameter values or the identities of the participants, neither to each other nor to the broader network.

QI 19: Members' Assembly

Time: Thursday 18:00–19:00 Location: BEY/0245

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

QI 20: Metrology and Sensing

Time: Friday 9:30–12:00 Location: BEY/0137

QI 20.1 Fri 9:30 BEY/0137

Nitrogen Vacancy center based gradiometry: Towards unshielded magnetic biosensing applications — •Magnus Benke, Jixing Zhang, Michael Kübler, Yihua Wang, and Jörg Wrachtrup — 3rd Physics Insitute, University of Stuttgart, Stuttgart

Magnetometers based on Nitrogen Vacancy (NV) centers in diamond offer high sensitivities and spatial resolution, as well as a broad dynamic range. These properties allow for unshielded measurements by combining two or more sensors into a gradiometric array to suppress common-mode noise. In this work we present a DC-broadband gradiometer, comprised of two magnetometers using a CW-ODMR (Continuous-Wave Optically Detected Magnetic Resonance) measurement scheme. With this array we were able to effectively reduce an artificial background signal by 45 times without attenuating an applied test signal. For further detailed analysis of the noise floor, we equipped the sensors with flux concentrators to identify the different noise contributions in the signal.

QI 20.2 Fri 9:45 BEY/0137

Model-free error mitigation in NV center magnetometry — •Dennis Herb[1], Miriam Resch[1], Mirko Rossini[1], Joachim Ankerhold[1,2], and Dominik Maile[1] — [1]Institute for Complex Quantum Systems, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), Ulm-Stuttgart, Germany

Quantum sensing is an emerging field with the potential to outperform classical methods in both precision and spatial resolution. However, the sensitivity of the underlying quantum platform also makes them highly susceptible to their environmental noise. To address this issue, techniques from the field of quantum error mitigation have been used to improve measurement results from noisy device signals via post-processing. We present a novel mitigation technique for quantum sensors to efficiently reverse the effects of any noise source that can be described by a completely positive trace preserving map. The method neither requires tomography of the final density matrix after the sensing protocol nor an underlying noise-model. It leverages the knowledge acquired by a pre-characterization step of the device to automatically adapt to the complexity of the dissipative evolution and to indicate which sensing times τ are best suited for the most accurate results. This method represents a further step toward perfecting a new family of sensors with the smallest scale of resolution, enabling measurements at the molecular scale.

QI 20.3 Fri 10:00 BEY/0137

Part 1: Optically Addressable Molecular Spins at 2D surfaces — •Yan Tung Kong, XuanKai Zhou, Cheuk Kit Cheung, Ruoming Peng, and Jörg Wrachtrup — 3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany

Optically addressable surface spins constitute a long-sought goal in quantum sensing, offering a pathway to probe quantum phenomena with atomic-scale precision. Here, we introduce a novel architecture in which pentacene spin molecules are anchored onto two-dimensional hexagonal boron nitride (hBN) and self-align with the underlying lattice. This configuration yields robust optically detected magnetic resonance (ODMR) signals from 4 K to room temperature. We further demonstrate ensemble spin sensing of Fe3GaTe2 (FGT), as well as controlled positioning of Pc molecules. This work represents the first demonstration of a surface molecular spin sensor that integrates long

coherence, optical addressability, and interfacial functionality, thereby enabling quantum sensing capabilities beyond those of conventional solid-state spin systems.

QI 20.4 Fri 10:15 BEY/0137

Part 2: Optically Addressable Molecular Spins at 2D surfaces — •Xuankai Zhou[1], Yan-Tung Kong[1], Cheuk Kit Cheung[1], Ruoming Peng[1], and Jörg Wrachtrup[1,2] — [1]3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany

Surface spins with coherent control hold the potential to quantum sensing revolution by nanoscale magnetic imaging. On the pentacene-hBN hybrid platform, we demonstrate distinguished coherence engineering alongside versatile functional sensing. By employing isotope purification and dynamical decoupling, the spin-coherence time is extended to $T_2 > 30$ μs and $T_{2,DD} > 300$ μs, already approaching the intrinsic triplet state lifetime limit. Meanwhile, it is also available for the platform to sense nearby proton nuclear signals and magnetic responses of two-dimensional magnets beneath hBN layer. This work represents the first demonstration of surface molecular spin sensor, integrating long coherence, optical addressability and interfacial functionality, thereby enabling quantum sensing beyond conventional solid-state spins.

QI 20.5 Fri 10:30 BEY/0137

Iterative optimization in quantum metrology and entanglement theory using semidefinite programming — Árpád Lukács[1,2,3], •Róbert Trényi[2,3,4,5], Tamás Vértesi[6], and Géza Tóth[3,4,2] — [1]Dept. of Math. Sci., Durh. Univ., UK — [2]HUN-REN Wigner RCP, Budapest, Hungary — [3]Dept. of Th. Phys., UPV/EHU, Bilbao, Spain — [4]EHU Quantum Center, UPV/EHU, Bilbao, Spain — [5]Dept. of Th. Phys., Univ. of Szeged, Hungary — [6]HUN-REN Inst. for Nucl. Research, Debrecen, Hungary

Metrological performance of a quantum state is measured by how much it can outperform all separable states in a metrological task. We present efficient optimization techniques to maximize this performance by searching for the optimal local Hamiltonian generating the unitary dynamics for a given bipartite initial state. We show that this is equivalent to maximizing the Quantum Fisher Information over a specific set of local Hamiltonians. This task is very difficult, as it involves maximizing a convex function over a convex set. We reformulate the problem in a bilinear way and optimize it using an iterative seesaw method, where each optimization step is solved via semidefinite programming. We further show that the same optimization framework can be adapted to problems in entanglement theory, such as identifying bound entangled states that maximally violate the Computable Cross Norm-Realignment criterion. Finally, we provide examples where two copies of a quantum state outperform a single copy, demonstrating metrological activation for certain small systems.

QI 20.6 Fri 10:45 BEY/0137

Localization and coherent control of 25 nuclear spins in Silicon Carbide — •Pierre Kuna[1], Erik Hesselmeier-Hüttman[1], Phillip Schillinger[1], Felix Gloistein[1], Viktor Ivády[2], Wolfgang Knolle[3], Jawad Ul-Hassan[4], Vadim Vorobyov[1], and Jörg Wrachtrup[1,5] — [1]3rd Institute of Physics, University of Stuttgart, Stuttgart, Germany — [2]Eötvös Loránd University, Hungary — [3]Department of Sensoric Surfaces and Functional Interfaces, Leibniz-Institute of Surface Engineering (IOM), Leipzig, Germany — [4]Department of Physics, Chemistry and Biology, Linköping University, Linköping, Sweden — [5]Max Planck Institute for solid state physics, Stuttgart, Germany

Nuclear spins coupled to optically addressable defects provide long-lived quantum memories[1] and scalable resources for quantum algorithms. For the V2 center in 4H-SiC, leveraging this potential requires precise knowledge of the surrounding nuclear-spin environment to refine DFT models and enable advanced multi-qubit algorithms[3,4].

We report ångström-level 3D localization of 25 naturally occurring 29Si and 13C spins around a single V2 center. Using correlation-spectroscopy SEDOR, Our work establishes a new state of the art in controlling nuclear spin cluster in 4H-SiC. By selecting multi-spin chains up to length four, we access and characterize new nuclear spins and reconstruct their couplings to the central electron and neighboring nuclei.

[1] M. Zhong, Nature 517, 177 (2015) [2] Abobeih, M.H., Nature 606, 884*889 (2022) [3] J. Randall*et al..Science374,1474-1478(2021)

30min. break

QI 20.7 Fri 11:30 BEY/0137

Charge sensing back-action on spin qubit readout using a micromagnet — •Sudipto Das[1], Domonkos Svastits[1,2], Aritra Sen[1], and Andras Palyi[1,3] — [1]Budapest University of Technology and Economics, Budapest, Hungary — [2]Qutility @ Faulhorn Labs, Budapest, Hungary — [3]HUN-REN-BME-BCE Quantum Technology Research Group, Budapest, Hungary

This work presents a theoretical framework for the charge-sensing readout of semiconductor spin qubits in double quantum dots. We explain the readout based on Pauli blockade spin-to-charge conversion and subsequent charge sensing via quantum point contact using the Qubit Measures Qubit model [1]. Our analysis focuses on n-type Silicon double quantum dots with micromagnets enabling resonant single-qubit control, explicitly accounting for the inhomogeneous micromagnet field and its modulation by charge-sensor shot noise.

Within this model, we quantify key readout errors-fidelity loss due to Zeeman-field modulation, mixedness of the post-measurement state, and leakage caused by perpendicular field fluctuations. We also incorporate the noise from charge sensors to understand its effect on readout. By studying their dependence on device parameters, including the orientation of the external magnetic field, we offer insights into readout performance optimization and readout sweet spots.

[1] D. Svastits, B. Hetényi, G. Széchenyi, J. Wootton, D. Loss, S. Bosco, and A. Pályi, Readout sweet spots for spin qubits with strong spin-orbit interaction, arXiv:2505.15878.

QI 20.8 Fri 11:45 BEY/0137

Quantitative inspection of quantum chips using SQUID-on-tip atomic force microscopy — •Daan B. Boltje[1], Jessalyn DeVine[1], Dalal Benali[1], Matthijs Rog[2], Tycho Blom[2], Milan P. Allan[3], Alessandro Bruno[4], Kaveh Lahabi[1,2], and Johannes Jobst[1] — [1]QuantaMap B.V., Leiden, The Netherlands. — [2]LION, Leiden University, The Netherlands. — [3]Faculty of Physics, LMU Munich, Germany. — [4]QuantWare B.V., Delft, The Netherlands.

The performance of quantum chips and the physics of quantum materials in general and are often dominated by local properties and or defects. Understanding those local properties requires microscopy that operates at cryogenic temperatures and that does not disturb the highly sensitive quantum effects it aims to reveal. In this talk, we will show measurements obtained with a tuning-fork, atomic force microscope (AFM) that integrates a nano-SQUID sensor on the tip. This design enables extremely short sensor-chip distances and robust height feedback in tapping-mode to prevent crashes, which would damage the SQUID sensor as well as the chip under study. It offers a non-invasive, purely electronic readout and magnetic sensitivity in and out-of plane. Frequency multiplexing permits simultaneous imaging of chip topography, magnetic fields, current flow and thermal dissipation on the nanoscale. We will show experiments from this novel microscope on magnetic and superconducting nanostructures of spin qubits and transmon quantum chips. We demonstrate how insights from this SQUID microscopy into material properties and local effects can be used to improve the quantum chips. [1] M. Rog et al. arXiv:2508.21575 (2025)

QI 21: Quantum Information: Concepts and Methods III

Time: Friday 9:30–12:45 Location: BEY/0245

Invited Talk QI 21.1 Fri 9:30 BEY/0245

Non-Hermitian topology and directional amplification — •Clara Wanjura — Max Planck Institute for the Science of Light, Staudtstraße 2, Erlangen

Topology has been a major research theme in condensed matter physics and is associated with a number of remarkable phenomena such as robust edge states. More recently, topology started to be investigated in systems experiencing gain and loss, sparking the field of non-Hermitian topology. However, for a long time, a clear observable signature of non-Hermitian topology had been lacking.

We recently closed this gap and showed that non-trivial, non-Hermitian topology is in one-to-one correspondence with the phenomenon of directional amplification in one-dimensional driven-dissipative systems, e.g., cavity arrays. Directional amplification allows to selectively amplify signals depending on their propagation direction and has attracted much attention as key resource for applications, such as quantum information processing. We experimentally demonstrated this connection between non-Hermitian topology and directional amplification in a cavity optomechanical system as well as realised a sensor based on non-Hermitian topology for which the sensitivity is exponentially enhanced with increasing system size.

Our work opens up new routes for the design of multimode robust directional amplifiers and novel topological sensors that can be integrated in scalable platforms such as superconducting circuits, cavity optomechanical systems, plasmonic waveguides and nanocavity arrays.

QI 21.2 Fri 10:00 BEY/0245

Graph-State Gates as Scrambling Primitives: Entanglement Growth and Complexity in Quantum Circuits — •Zahra Raissi[1], Himanshu Sahu[2], Mario Flory[3], and Aranya Bhattacharya[4] — [1]Paderborn University, Germany — [2]Perimeter Institute, Canada — [3]Jagiellonian University, Poland — [4]University of Bristol, UK

Understanding how quantum information spreads in many-body systems is central to quantum simulation, error correction, and quantum network design. In this work, we investigate structured random circuits built from graph-state gates, where small multi-qubit graph states are repeatedly embedded into a one-dimensional Clifford circuit at random locations. Each gate acts on a fixed number of qubits but carries an internal graph structure, allowing us to disentangle the role of local graph geometry from that of global circuit architecture.

Within this model, we use stabilizer methods to compute bipartite entanglement entropies, height functions, and light-cone diagnostics based on both Pauli spreading and out-of-time-order correlators (OTOCs). We find that the entanglement growth rate and saturation time are strongly correlated with two graph-theoretic features: a local light-cone capacity (degree and connectivity) and a cross-entanglement capacity (edge cuts/height). This reveals a hierarchy of graph-state gates according to their entangling and scrambling power. Our results provide a graph-theoretic design principle and a concrete ranking for selecting small graph blocks that optimize entanglement generation and operator spreading in Clifford quantum circuits.

QI 21.3 Fri 10:15 BEY/0245

Analysis of multi-detector quantum measurements via their cross-correlation polyspectra — •Armin Ghorbanietemad, Markus Sifft, and Daniel Hägele — Ruhr University Bochum, Faculty of Physics and Astronomy, Experimental Physics VI, Germany

Recent work has shown that higher-order spectra of continuous quantum measurement records provide characteristic fingerprints of stochastic system dynamics. These polyspectra capture essential features of measurement processes in platforms as diverse as nanotransport, single-photon emission from quantum dots, and spin-noise spectroscopy [1 - 3]. This makes them a more versatile analysis tool than traditional approaches such as full counting statistics or Langevin-based methods. The framework naturally incorporates measurement-induced damping, detector backaction, and the quantum Zeno effect. Key system parameters can be extracted by comparing experimental polyspectra with their analytical counterparts [2].

Here, we extend our single-detector theory to the case of multiple observables monitored simultaneously. We derive general expressions for spectra up to fourth order, apply the formalism to a coupled quantum system, and present a GPU-accelerated implementation that enables efficient computation of cross-correlation polyspectra from arbitrary Liouvillians.

[1] Hägele et al., PRB 98, 205143 (2018)
[2] Sifft et al., PRR 3, 033123 (2021)
[3] Sifft et al., PRA 109, 062210 (2024)

QI 21.4 Fri 10:30 BEY/0245

Characterizing genuine multipartite high-dimensional entanglement with the partition rank — •Sophia Denker[1], Ismaël Septembre[1], Robin Krebs[2], and Otfried Gühne[1] — [1]Universität Siegen, Siegen, Germany — [2]Technische Universität Darmstadt, Darmstadt, Germany

Entanglement is an important resource in quantum information as it has been demonstrated to bring advantages in several applications. In fact, these advantages are even higher when going to larger systems, i. e. increasing the number of particles or their local dimensions. However, with increasing system size also the characterization and quantification of quantum entanglement becomes more complex.

We introduce a new measure for the entanglement dimensionality of multiparticle states, based on the partition rank. The partition rank is given by the number of biseparable terms, needed to decompose a multipartite quantum state. Different from the Schmidt decomposition the terms appearing here are allowed to be separable with respect to different bipartitions, making this approach a truly multipartite quantification. We translate the problem of finding the closest state with a certain partition rank to the problem of finding the closest product state, which is known as the geometric measure of entanglement. This translation allows us to tackle this new problem with well-established methods. Along the way, we identify quantum states which are maximally entangled with respect to this measure and further show that our methods could make a contribution towards solving an open problem in mathematics, related to the partition rank.

QI 21.5 Fri 10:45 BEY/0245

Analyzing Classical vs Quantum Temporal Correlations in Discrete-Time Counting Processes — •Bita Olamaei, Pharnam Bakhshinezhad, and Giuseppe Vitagliano — Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, 1020 Vienna, Austria

We consider the problem of characterizing temporal sequences or outcomes arising from a quantum finite-state automaton process. This approach can be also seen as a relaxation of the original idea of Leggett and Garg of distinguishing classical from quantum temporal correlations based on macrorealist hidden-variable theories. The latter correspond essentially to automata with only one available state [1]. We focus on discrete-time counting processes and characterize the strength of temporal correlations via the probability of the "tick" event or via the Fano factor, that have been shown to have a nontrivial memory cost [2]. In particular, we look for the quantum d-state automaton model that can saturate the memory cost of the counting process, achieving either maximal probability of tick or maximal Fano factor, thereby characterizing the nature of the resource that, in particular, allows to surpass the performance of the analogous classical d-state automaton model.

[1]- C. Budroni and G. Vitagliano, Leggett-Garg macrorealism and temporal correlations, Phys. Rev. A. 107. 040101 (2023) [2]- C. Budroni, G. Vitagliano, and M. P. Woods, Ticking-clock performance enhanced by nonclassical temporal correlations, Phys. Rev. Res. 3, 033051 (2021)

30min. break

QI 21.6 Fri 11:30 BEY/0245

Measurement-induced transitions in fermionic systems — •Ihor Poboiko, Igor Gornyi, and Alexander D. Mirlin — Karlsruhe Institute of Technology, Karlsruhe, Germany

We develop a theory of measurement-induced phase transitions (MIPT) for d-dimensional lattice free fermions subject to random projective measurements of local site occupation numbers. In the limit of rare measurements, $\gamma \ll J$ (where γ is measurement rate per site and J is hopping constant), we derive a non-linear sigma model (NLSM) as an effective field theory of the problem. On the Gaussian level, valid in the limit $\gamma/J \to 0$, this model predicts "critical" (i.e. logarithmic enhancement of area law) behavior for the entanglement entropy. However, one-loop renormalization group analysis shows that for $d = 1$, the logarithmic growth saturates at a finite value $(J/\gamma)^2$ even for rare measurements, implying existence of a single area-law phase. The crossover between logarithmic growth and saturation, however, happens at an exponentially large scale, $\ln(l_{corr}) \sim J/\gamma$, thus making it easy to confuse with a transition in a finite-size system. Furthermore, utilizing ε-expansion, we demonstrate that the "critical" phase is stabilized for $d > 1$ with a transition to the area-law phase at a finite value of γ/J. The analytical calculations are supported by and are in excellent agreement with the extensive numerical simulations for $d = 1, 2$.

QI 21.7 Fri 11:45 BEY/0245

Efficient Entanglement Quantification with a Graph Neural Network — •Susanna Bräu, Martina Jung, and Martin Gärttner — Institut für Festkörpertheorie und Optik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena

Entanglement is a fundamental feature of quantum mechanics, yet quantifying it - using measures such as entanglement entropy - generally requires reconstruction of the full quantum state. However, this is infeasible for larger systems, limiting the accessible system sizes. In this work, we predict quantum correlation measures for many-body spin systems from measurement snapshots with a supervised machine learning approach, avoiding full quantum state tomography. Our approach uses a permutation-invariant graph neural network (GNN), which scales linearly with the system size. To improve the scaling with the number of snapshots, we implemented a mini-set architecture, that divides the input into smaller subsets processed in parallel. This modified architecture enables entanglement prediction for larger data sets, potentially allowing for more accurate predictions than the traditional architecture without increasing the number of parameters in the network significantly. Furthermore, we aim to extend the approach from quantum many-body systems to continuous variable systems.

QI 21.8 Fri 12:00 BEY/0245

Chaotic melting of superconducting quantum chips: Quantum chaos in effective Hamiltonians — •Lucas Resch and Juan Diego Urbina — University of Regensburg

Superconducting qubits, in particular transmons, are at the forefront of quantum computing research [1]. Recent studies have revealed signatures of chaos near the ground state in these systems, challenging the conventional view that chaotic behavior emerges only at high energies [2]. In this work, we analyze spectral statistics, the inverse participation ratio, and the Lyapunov exponent to characterize this chaotic regime. Our results indicate that the observed chaotic features can be attributed to virtual interactions between computational states within an effective low-energy subspace and non-computational states outside it. This reinterpretation clarifies the origin of chaos in transmon-based architectures and provides a framework for understanding its implications for quantum control and device performance.

References

[1] J. M. Gambetta et al., *Building logical qubits in a superconducting quantum computing system,* npj Quantum Information 3, 2 (2017). [2] S. Börner et al., *Classical chaos in quantum computers,* Phys. Rev. Research 6, (2024).

QI 21.9 Fri 12:15 BEY/0245

Stabilizing Rényi entropy and entanglement distributions in unitary random circuits — Dominik Szombathy[1,2], Angelo Valli[1], Catalin Pascu Moca[3], Janos Asboth[1], Lorant Farkas[2], Tibor Rakovszky[1], and •Gergely Zarand[1] — [1]Budapest University of Technology and Economics, Budapest (Hungary) — [2]Nokia Bell Labs, Budapest (Hungary) — [3]University of Oradea, Oradea (Romania)

Entanglement and nonstabilizerness (or ”magic”) are instrumental in characterizing quantum complexity. While entanglement is related to the ”quantumness” of a state, it is not exhaustive, as Clifford circuits generate highly entangled states but can be efficiently simulated classically. This lack of complexity is encoded in their peculiar spectral properties. Stabilizer Rényi entropy quantifies non-Clifford resources required to prepare a quantum state and is pivotal for achieving quantum advantage. These resources are related, yet their interplay is largely unexplored. We characterize entanglement and magic generation through their distributions, obtained by numerically sampling Clifford+T and Haar-random unitary circuits. For N qubits, the distributions are highly concentrated around typical values of entanglement (N/2 plus a quantum correction) and magic (N-2), which are not independent. However, we demonstrate that their fluctuations are asymptotically independent: both the covariance and mutual information of the joint entanglement-magic distribution vanish exponentially with system size.

Szombathy et al. PRR 7, 043080 (2025); PRR 7, 043072 (2025)

QI 21.10 Fri 12:30 BEY/0245

Quantitative bound entanglement in the Horodecki two-qutrit states — Gael Sentis[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, Bilbao, Spain — [3]Ikerbasque, Basque Foundation of Science, Bilbao, Spain

In 1999, Horodecki *et al.* [1] introduced a one-parameter family of two-qutrit states that has since become an archetypal example of entangled states with a positive partial transpose (PPT). PPT states are typically highly mixed, and their entanglement is widely regarded as rather weak. Yet the actual degree of this weakness has remained unclear. In Ref. [2], we provided a numerically exact solution for the linear entropy of the Horodecki two-qutrit PPT-entangled states. However, this result has limited practical relevance, as linear entropy is not commonly used in entanglement quantification, and no approximate analytical expression is known. In the present contribution, we investigate whether an exact formula for the concurrence of this emblematic family of states can be obtained.

[1] P. Horodecki, M. Horodecki, and R. Horodecki, Phys. Rev. Lett. **82**, 1056 (1999).

[2] G. Sentís, C. Eltschka, and J. Siewert, Phys. Rev. A **94**, 020302(R) (2016).