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 technolo-

gies, 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, MCQST, 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