Q 19: Quantum Technologies – Ion Traps

Time: Tuesday 11:00–13:00 Location: P 5

Q 19.1 Tue 11:00 P 5

OPEN-2QS: towards long observation timescales in trapped ion systems — •Larisa Thorne and Ferdinand Schmidt-Kaler — QUANTUM, Johannes Gutenberg University Mainz, Department of Physics, Staudingerweg 7, Germany

Current state-of-the-art quantum simulators are limited by their short observation times. The OPEN-2QS platform leverages the advantages of Rydberg ions [1] with those of Penning trap configurations [2] to allow significantly longer observation times, up to 7 orders of magnitude longer than microscopic timescales [3]. This will allow us to pursue fundamental research questions previously inaccessible, such as characterizing collective dynamics beyond the decoherence timescale, and exploring non-equilibrium phenomena, particularly those in open many-body quantum systems. In this presentation, I will give an overview of the R&D program at Mainz, including the design of a Penning trap suited to confinement of $^{40}Ca^{+}$ Rydberg ions, and updates on the status of the requisite cryogenic components.

[1] A. Mokhberi et al, Adv. Atom. Mol. Opt. Phys. Vol. 69, pp. 233-306 (2020)
[2] A. Polloreno et al, arXiv:2203.05196 (2022)
[3] C. Chen et al, Nature 616, 691 (2023)

Q 19.2 Tue 11:15 P 5

Trapped ion crystal setup for efficient recording of photon correlations — •Benjamin Zenz[1], Roman Rosenfeld[1], Corina Revora[3], Christian T. Schmiegelow[3], and Ferdinand Schmidt-Kaler[1,2] — [1]QUANTUM, Institut für Physik, 55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, 55099 Mainz, Germany — [3]Departamento de Física, Buenos Aires, Argentina

Trapped ions provide an exceptionally well-controlled quantum system with truly identical particles confined in deep potentials and manipulated with extraordinary precision. Each ion acts as a single-photon emitter allowing us to investigate collective light*matter interactions at the most fundamental level. In the past, we observed interference in both first- and second-order photon correlation functions, revealing spin-textures [1], spatially dependent bunched and antibunched photon statistics [2], superradiance and subradiance as well as measurement induced entanglement [3].

In this talk, I present our new experimental platform which combines, a multisegmented trap for the versatile control of the emitter positions. Furthermore, the setup features high-numerical-aperture detection from opposite directions, enabling efficient exploration of spatiotemporal photon correlations emitted from ion crystals of 50 and more ions. I report the system characterization along recent data and sketch future experiments.

[1] Verde, et al. Phys. Rev. A; 112, 043719 (2025)
[2] Wolf, et al. Phys. Rev. Lett.; 124, 063603 (2020)
[3] Richter, et al. Phys. Rev. Research; 5, 013163 (2023)

Q 19.3 Tue 11:30 P 5

Framework for optimization of Paul trap design and control voltages for X-junction shuttling — •Andreas Conta, Ulrich Poschinger, Santiago Bogino, and Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz

Trapped-ion quantum computing is a promising architecture for large-scale quantum computing. We aim to scale up the shuttling-based [1] approach. This requires complex multi-segmented traps that include junctions [2]. We present our comprehensive framework for optimization of trap designs and control voltages waveforms, with the goal of shuttling a linear crystals an X-junction. Commercially available tools are used to create parameterised models of traps and potentials of the electrodes. Our custom Segmented Ion Trap CONtrol System (SITCONS) then performs a multipole expansion, thereby enabling the calculation of control voltages using quadratic programming. We analyse the influence of different trap designs and electrode shapes on the shuttling through an X-junction.

[1] Ruster et al., Phys. Rev. A 90, 033410 (2014)
[2] Delaney et al., Phys. Rev. X 14, 041028 (2024)

Q 19.4 Tue 11:45 P 5

Characterization of a commercial 3D ion trap — •Martin Hesse[1], Ranjit K. Singh[1,2], Ole Ketterkat[1], Jannik Mattil[1], André P. Kulosa[1], Ulf Hinze[3], Nicolas Spethmann[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany — [3]Laser nanoFab GmbH, Hannover, Germany

The Quantum Technology Competence Center (QTZ) was established at the Physikalisch-Technische Bundesanstalt (PTB) to support German industry in transitioning quantum technology (QT) from research into application.

Ion traps have evolved from fundamental research objects to an industrial product for QT applications ranging from quantum sensing to quantum simulation and computation. Within the QTZ user facility "Ion Traps", we offer access to a testbed for the standardized characterization of ion traps from industry and academia.

Here, we report about the characterization of a commercial, segmented 3D Paul trap. The electrode chips are made of Rogers material. The assembled ion trap is contacted to a carrier board which contains flexible electronic SMD-based filters to suppress electromagnetic noise coupling to the ion. We present the ion trap characterization routines to run automated to ensure repeatable measurements, which is - aside a reproducible environment - the key essential for a standardized characterization of ion traps.

Q 19.5 Tue 12:00 P 5

Characterization of Inner Control Electrode Shapes for Multi-Layer Surface-Electrode Ion Traps — •Florian Ungerechts[1], Rodrigo Munoz[1], Janina Bätge[1], Masum Billah[1], Giorgio Zarantonello[1,2], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]QUDORA Technologies GmbH — [3]Physikalisch-Technische Bundesanstalt

Trapped ions are a leading platform for quantum information processing. Scalable architectures, such as the Quantum Charged Coupled Device (QCCD) architecture, enable all-to-all connectivity between atomic ion qubits in dedicated registers and can be implemented on microfabricated surface-electrode traps. The development of novel fabrication techniques over the past years has transformed the design of surface-electrode ion traps into increasingly complex multi-layer structures. Yet, the control electrodes remain mostly unchanged. For three-dimensional traps and single-layer surface traps, the control electrodes are rectangular due to geometrical constraints. However, this does not imply that it is the ideal shape for control electrodes in modern multi-layer surface traps. Thus, we compare various shapes for inner control electrodes and evaluate their performance in terms of ion shuttling and radial shim compensation.

Q 19.6 Tue 12:15 P 5

Enhancing Trapped Ion Quantum Processor Scalability via Integrated Photonics and Microwave Technology — •Mohammad Masum Billah[1,2], Florian Ungerechts[1], Rodrigo Munoz[1], Phil Nuschke[1], Janina Bätge[1], Axel Hoffmann[1,4], Giorgio Zarantonello[1,3], Celeste Torkzaban[1], and Christian Ospelkaus[1,2,5] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover — [3]QUDORA Technologies GmbH — [4]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover — [5]Physikalisch- Technische Bundesanstalt

Scalability is a critical requirement for performing meaningful computations with trapped-ion quantum processors. Microfabricated surface-electrode ion traps have demonstrated considerable potential to implement the scalable Quantum Charged Coupled Device (QCCD) architecture. However, reliance on free-space laser delivery poses a substantial challenge to expanding these systems. In our research, we explore laser-free gate operations using oscillating microwave magnetic field gradient for chip-integration of the gate mechanism. To achieve comprehensive scalability, photonics integration is essential for delivering, preparation and detection light via optical waveguides and grating out-couplers directly from the trap surface. Our study focuses on optimizing the placement of integrated light sources considering key factors such as light polarization and phase, opto-electrical effects, impacts on the trapping potential, optical crosstalk, thus addressing key challenges to facilitate scalable trapped-ion quantum computing.

Q 19.7 Tue 12:30 P 5

Advancements in ion trap quantum computing with multiple ion species — •David C. Stuhrmann[1], Sascha Agne[2], Najwa Al-Zaki[1], Erik Dunkel[1], Radhika Goyal[1], Tobias Pootz[1], Kevin Rempel[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

In the context of scalable quantum computing hardware with high-fidelity qubits, surface electrode ion traps are one of the most promising platforms. The long coherence times and very high fidelities of hyperfine qubits have been demonstrated on small numbers of ions. The ongoing challenge lies in scaling up the systems in terms of size, a process which necessitates improvements in hardware, as well as in experimental techniques. Building on the expertise of our existing room temperature experiments with near field microwave qubit interactions we present the next generation of cryogenic experiments. Our upgraded laser systems and the use of multiple ion species (Beryllium, Calcium, Strontium) position us for the adoption of integrated optics and sympathetic cooling. New ion trap geometries can be efficiently evaluated and include the ability to shuttle ions to dedicated zones to raise the number of addressable ions. The subsequent step is to establish automated calibration and monitoring procedures to optimize the device's uptime and remote connectivity for future applications.

Q 19.8 Tue 12:45 P 5

Parallelising electronic qubit control for trapped-ion quantum computing — •Dougal Main, Jacopo Mosca Toba, Hannah Knaack, Susanna Todaro, Amy Hughes, Lukas Spiess, Justin Niedermayer, Clemens Matthiesen, Steven King, and Oxford Ionics team — Oxford Ionics, Oxford, United Kingdom

We present our vision for large-scale, parallel control of trapped-ion qubits using chip-integrated electric and magnetic fields. Our architecture enables efficient parallelisation of gate operations and shuttling of ions on a surface-electrode trap chip with junctions, implementing a quantum charge-coupled device that is scalable and high-fidelity at the same time. We outline how single- and two-qubit gates can be performed in parallel, and show data from demonstrator devices.