QI 7: Atom and Ion Qubits (joint session QI/Q)

Time: Monday 17:00–18:45 Location: HS II

Invited Talk QI 7.1 Mon 17:00 HS II

Trapped-ion quantum computers based on chip-integrated microwave control — •Christian Ospelkaus — Institut für Quantenoptik, Leibniz Universität Hannover, Germany — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

We pursue the implementation of quantum gates using chip-integrated microwave conductors rather than the widely used laser beams for scalability, gate fidelity and chip-level integration of functionality. Previous demonstrations of this method have used a single carefully crafted two-qubit gate combined with single-qubit addressing pulses. Here we show for the first time the execution of arbitrary algorithms on a pair of qubits by implementing the cycle benchmarking protocol and thus a universal computation register. To further integrate the control of the qubits at the chip structure, we demonstrate the generation of the microwave control signals qubits using a cryogenic DDS chip that can be directly integrated with the trap chip. Recent advances in the fabrication of scalable trap structures will be presented, in particular the implementation of through-substrate vias (TSVs) and hybrid integration methods. We present two cryogenic quantum computer demonstrator setups that are currently under construction, combining the computation register with storage and preparation/readout registers and interconnected through an X-junction.

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QI 7.2 Mon 17:30 HS II

Scalable, high-fidelity all-electronic control of trapped-ion qubits — Clemens Löschnauer, Jacopo Mosca Toba, Amy Hughes, Steven King, •Marius Weber, Raghavendra Srinivas, Roland Matt, Rustin Nourshargh, David Allcock, Chris Ballance, Clemens Matthiesen, Maciej Malinowski, and Thomas Harty — Oxford Ionics, Oxford, United Kingdom

The central challenge of quantum computing is implementing high-fidelity quantum gates in a scalable fashion. Our all-electronic qubit control architecture combines laser-free gates with local tuning of electric potentials to enable site-selective single- and two-qubit operations in multi-zone quantum processors. Chip-integrated antennas deliver control fields common to all qubits, while voltages applied to local tuning electrodes adjust the position and motion of ions in each zone, thus enabling local coherent control. We experimentally implement low-noise, site-selective single- and two-qubit control in a microfabricated 7-zone ion trap, demonstrating 99.99916(7)% fidelity for single-qubit gates, and two-qubit Bell state generation with 99.97(1)% fidelity. These results validate the path to directly scaling these techniques to large-scale quantum computers based on electronically controlled trapped-ion qubits.

QI 7.3 Mon 17:45 HS II

Implementation of Quantum Token Protocol with Trapped Ions — •Manika Bhardwaj[1], Jan Thieme[1], Bernd Bauerhenne[1], Moritz Göb[1], Bo Deng[1,2], and Kilian Singer[1] — [1]Experimental Physics I, Institute of Physics, University of Kassel, Heinrich-Plett-Straße 40, 34132 Kassel — [2]Institute of Applied Physics, University of Bonn, Wegelerstraße 8, 53115 Bonn

We present a novel quantum token protocol [1] with trapped ions. This quantum token protocol is based on ensembles exploiting the quantum projection noise. Trapped ions are suitable for implementing a robust quantum token protocol due to their long coherence times and single-shot readout. Specifically, we aim to utilise the $4^2S_{1/2} - 3^2D_{5/2}$ transition of $^{40}Ca^+$ ions for this purpose. The protocol requires preparing the ions in a superposition state, where uniform state preparation across the ensemble is critical for obtaining protocol fidelity. To address potential variations in state preparation due to inhomogeneous control parameters, we will employ tailored composite pulses [2].

[1] K. Singer, C. Popov, and B. Naydenov, Verfahren zum Erstellen eines Quanten-Datentokens (DE 10 2022 107 528 A1) DE-Patent (2023).

[2] G. T. Genov, M. Hain, N. V. Vitanov, and T. Halfmann, PRA 101, 013827 (2020).

QI 7.4 Mon 18:00 HS II

Correction formulas for the Mølmer-Sørensen gate under strong driving — Susanna Kirchhoff[1,2], Frank Wilhelm-Mauch[1,2], and •Felix Motzoi[1,3] — [1]Forschungszentrum Juelich (PGI 8 and 12) — [2]Saarland University — [3]University of Cologne

The Mølmer-Sørensen gate is a widely used entangling gate for ion platforms with inherent robustness to trap heating. The gate performance is limited by coherent errors, arising from the Lamb-Dicke (LD) approximation and sideband errors. Here, we provide explicit analytical formulas for errors up to fourth order in the LD parameter, by using the Magnus expansion to match numerical precision, and overcome significant, orders-of-magnitude underestimation of errors by previous theory methods. We show that fourth order Magnus expansion terms are unavoidable, being in fact leading order in LD, and are therefore critical to include for typical experimental fidelity ranges. We show how these errors can be dramatically reduced compared to previous theory by using analytical renormalization of the drive strength, by calibration of the Lamb-Dicke parameter, and by the use of smooth pulse shaping.

arXiv:2404.17478

QI 7.5 Mon 18:15 HS II

Distributed quantum computing between two trapped-ion processors — Dougal Main, Peter Drmota, •David P. Nadlinger, Ellis M. Ainley, Ayush Agrawal, Bethan C. Nichol, Raghavendra Srinivas, Gabriel Araneda, and David M. Lucas — Dept. of Physics, University of Oxford, Oxford, U.K.

Modular, hybrid quantum systems, where matter qubits are linked via photonic interconnects, hold vast potential across a wide gamut of applications including quantum communication, large-scale computing, and quantum-enhanced metrology. In this talk, I describe an elementary two-node quantum network where $^{88}Sr^+$ acts as the optical interface to generate remote Bell pairs with state-of-the-art performance (fidelities of $\sim 97.0\%$ at rates 100 s^{-1}). By co-trapping $^{43}Ca^+$ ions, which provide a long-lived memory undisturbed by any network activity (remote Bell state coherence times >10 s), we demonstrate the first distributed quantum computation across two optically linked quantum processors using deterministic, repeatable quantum gate teleportation [1]. To illustrate the postselection-free execution of consecutive remote two-qubit gates, we benchmark distributed iSWAP- and SWAP-class circuits along with two-qubit instances of Grover's search algorithm. Finally, we examine how emitter motion impacts atom–photon entanglement generation through phase uncertainty, recoil, and coupling efficiency, proposing an intuitive framework applicable to both conventional optics and waveguide-based systems.

[1] D. Main et al., "Distributed Quantum Computing across an Optical Network Link", Nature (accepted, arXiv:2407.00835)

QI 7.6 Mon 18:30 HS II

Optimizing the circularization of Rydberg atoms — •Matthias Hüls[1,2], Robert Zeier[1], Eloisa Cuestas[1], Felix Motzoi[1,2], and Tommaso Calarco[1,2,3] — [1]Forschungszentrum Jülich GmbH, Quantum Control (PGI-8), Jülich, Germany — [2]University of Cologne, Institute for Theoretical Physics, Köln, Germany — [3]Università di Bologna, Dipartimento di Fisica e Astronomia, Bologna, Italy

Atoms in Circular Rydberg states, with a large principal quantum number n and maximal magnetic quantum number $m = n - 1$, exhibit long state lifetimes and strong, long-range interactions. This renders them a promising platform for quantum simulation and quantum sensing. Yet their preparation is complex and includes a multi-state transfer through a large Rydberg state manifold of dimension n^2 driven by the interaction with radio frequency (RF) pulses. Pulse shapes that achieve the latter with a high fidelity can be designed using optimal control techniques and have enabled a fast and precise circularization of non-interacting atoms in the experiment [1]. With the aim of constructing pulses suitable to circularize arrays of interacting Rydberg atoms, we extend this previous efforts by additional field terms and optimization methods. Further, we study how interactions between atoms affect the performance of current optimized pulses. We therefore build a simulation of the experiment and subsequently use it to optimize RF pulse shapes. [1] Larrouy A, Patsch S, Richaud R, Raimond J-M, Brune M, Koch CP, Gleyzes S. Fast navigation in a large Hilbert space using quantum optimal control. PRX.10:021058 (2020)