QI 41: Quantum Computing and Simulation II (joint session Q/QI)

Time: Friday 11:00–13:00 Location: AP-HS

Invited Talk QI 41.1 Fri 11:00 AP-HS

Towards Quantum Simulation with Qudits — •Martin Ringbauer — Universität Innsbruck, Institut für Experimentalphysik, Technikerstraße 25, 6020 Innsbruck

Current quantum computers and simulators are almost exclusively built for binary information processing, yet, nature rarely gives us two-level systems. This is true for our quantum information carriers, as well as for the systems we want to simulate with our quantum devices. I will discuss the opportunities and challenges of using the inherent multilevel Hilbert space of trapped ions for quantum computing information processing. This will be exemplified by recent experimental results for qudit-enhanced QIP, as well as native qudit quantum simulations.

QI 41.2 Fri 11:30 AP-HS

Tuning the qubit-qubit interaction for multi-qubit quantum gates — •Patrick H. Huber, Dorna Niroomand, Markus Nünnerich, Patrick Barthel, and Christof Wunderlich — Walter-Flex-Straße 3, 57072 Siegen

Internal hyperfine states of ions trapped in a common potential provide long-lived qubits that can be coupled via the ions' Coulomb interaction. A set of such qubits, analogous to a classical register, can be referred to as a quantum register. The Magnetic Gradient Induced Coupling (MAGIC) approach to quantum computing with trapped ions can provide an always-on, all-to-all Ising-type interaction between radio frequency-controlled qubits in such a quantum register [1,2]. The interaction strength is determined by the trapping potential and the applied magnetic field gradient. Here we present a novel method that allows for the tuning of the qubits' interaction without changing the trapping potential nor the magnetic field while simultaneously preserving the qubits' coherence. This method uses pulsed dynamical decoupling and is demonstrated experimentally in a quantum register of four laser-cooled $^{171}\mathrm{Yb}^+$ qubits. It is used to synthesize an arbitrary coupling matrix within a quantum register and to generate non-interacting subregisters. Thus, this method opens up novel ways for efficiently synthesizing quantum algorithms on a trapped ion quantum computer. [1] A. Khromova *et al.*, Phys. Rev. Lett. 108, 220502 (2012). [2] P. Baßler *et al.*, Quantum 7, 984 (2023).

QI 41.3 Fri 11:45 AP-HS

Fast radio frequency-driven entangling gates for trapped ions — •Markus Nünnerich, Patrick Huber, Dorna Niroomand, and Christof Wunderlich — Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Gemany

Entangling gates are a fundamental component of any quantum processor, ideally operating at high speeds in a robust and scalable manner. Here, we experimentally investigate a novel radio frequency (RF)-driven two-qubit gate with trapped and laser cooled $^{171}\mathrm{Yb}^+$ ions exposed to a static magnetic gradient field of 19 T/m that induces an effective qubit-qubit interaction (Magnetic Gradient Induced Coupling, MAGIC). The hyperfine states $|0\rangle \equiv |^2\mathrm{S}_{1/2}, \mathrm{F}=0, \mathrm{m_F}=0\rangle$ and $|1\rangle \equiv |^2\mathrm{S}_{1/2}, \mathrm{F}=1, \mathrm{m_F}=-1\rangle$ are used as qubits. We generate Bell states by applying continuously two RF driving fields, each one of them on resonance to one of the two qubit transitions. The phase of these driving fields is varied periodically yielding effectively a sequence of back-to back dynamical decoupling pulses. By adjusting the Rabi frequency induced by the driving fields, the effective coupling of the qubits to the ions' motional state is changed, and the entangling gate speed can be varied between ≈ 4 ms and $\approx 300\mu$s. Higher gate speeds are advantageous for achieving faster and deeper quantum algorithms. In currently used micro-structured traps with larger magnetic field gradients, gate speeds on par with laser-driven gates in trapped ions are expected.

QI 41.4 Fri 12:00 AP-HS

Coherent control of trapped-ion qubits and qumodes via phase-stable optical addressing — •Kai Shinbrough[1], Donovan J. Webb[1], Iver R. Øvergaard[1], Oana Băzăvan[1], Sebastian Saner[1], Gabriel Araneda[1], Raghavendra Srinivas[1,2], and Christopher J. Ballance[1,2] — [1]University of Oxford, Oxford, UK — [2]Oxford Ionics, Oxford, UK

Control over the phase of optical addressing beams in the trapped-ion platform allows for precise control of the coupling between spin and motional states of the ion. This control serves as a resource for fast, high-fidelity multi-qubit entangling gates, as well as for continuous variable quantum information processing using the motional state qumodes of single ions and ion chains. Here we report on a suite of qubit-qubit, qubit-qumode, and qumode-qumode interactions enabled by this phase control, including two-qubit gates faster than the speed limit imposed by off-resonant carrier coupling [1], non-Gaussian operations performed on the ion motional state [2,3] (which, along with a complete set of Gaussian operations, satisfy the Lloyd-Braunstein criterion for universal quantum computation [4]), and progress toward a linear chain of $^{40}\mathrm{Ca}^+$ ions with individually addressed standing waves.

[1] S. Saner, O. Băzăvan, *et al.*, Phys. Rev. Lett. **131**, 220601 (2023).
[2] O. Băzăvan, S. Saner, *et al.*, arXiv:2403.05471 (2024).
[3] S. Saner, O. Băzăvan, *et al.*, arXiv:2409.03482 (2024).
[4] S. Lloyd, S. L. Braunstein, Phys. Rev. Lett. **82**, 1784 (1999).

QI 41.5 Fri 12:15 AP-HS

Integrated micromagnets for trapped ion quantum science — •Benjamin Bürger, Patrick Huber, and Christof Wunderlich — Universität Siegen, Walter-Flex-Straße 3, 57072 Siegen

We present the design and implementation of quasi-two-dimensional (2D) micromagnets tailored to generate an inhomogeneous static magnetic field. This field, when integegrated into a micro-structured ion trap, enables frequency-selective addressing of ions through radio frequency radiation (RF) and conditional quantum dynamics with trapped ions. We will integrate the magnet design into a planar Paul trap that is split into two types of regions: An interaction zone and a cooling/readout zone. The micromagnets are meticulously designed to produce high field gradients while maintaining a low absolute field strength, effectively minimizing decoherence induced by magnetic field noise within the qubit interaction zones. In the cooling/readout zones, the magnets are designed to generate a small homogeneous magnetic field to facilitate efficient Doppler cooling on larger strings. Furthermore, the magnetic field orientation is optimized to support both σ and π polarized RF-driven transitions in $^{171}\mathrm{Yb}^+$ ions facilitating efficient cooling on the magnetic-field-insensitive π transition and utilizing the σ transition for gate operations.

QI 41.6 Fri 12:30 AP-HS

Towards a cryogenic trapped ion quantum demonstrator using cryogenic control electronics — •Dorna Niroomand[1], Daniel Busch[1], Kais Rejaibi[1], Ernst A Hackler[1], Rodolfo M Rodriguez[1], Patrick Huber[1], Garima Saraswat[2], Michael Johanning[2], and Christof Wunderlich[1] — [1]Department of Physics, School of Science and Technology University of Siegen, 57068 Siegen, Gemany — [2]eleQtron, 57072 Siegen, Germany

Trapped ion quantum computing platforms in cryogenic vacuum have the advantage of rapidly achieving ultra-high vacuum. This allows long ion storage times even in the relatively shallow trapping potential of surface-electrode Paul traps. In addition, it offers more flexibility in exchanging trap chips, making it feasible to study multiple generations of traps with different structure and experimental specifications. Here, I will discuss the progress towards building and operating a cryogenic (4 K) quantum demonstrator that includes low-noise cryogenic electronics to precisely control trapping potentials and enable shuttling of ions (BMBF-funded project ATIQ). En route towards scalable trapped ion quantum processors, multiple generations of microfabricated surface-electrode traps with integrated magnets and cryogenic control electronics will be investigated in this platform.

QI 41.7 Fri 12:45 AP-HS

Cooling a quantum annealer with a quantum field — •Raphael Menu and Giovanna Morigi — Universität des Saarlandes, Saarbrücken

We analyse the Landau-Zener dynamics of a qubit, which is simultaneously coupled to a dissipative auxiliary system. By tuning the coupling, the qubit dynamics ranges from a dephasing master equation to a strongly coupled qubit-auxiliary system, which is effectively a non-Markovian reservoir for the qubit. We determine the quantum trajectories in the different regimes and analyse the distribution of each trajectory in terms of the time-dependent probability of a diabatic transition. Depending on the strength of the coupling, we observe multipeaked configurations, which undergo transitions to narrow distributions. These transitions are signaled by a higher probability that a jump occurs. The behavior of the probability of a quantum jump as a function of the coupling and of the time of the sweep, in turn, allows us to shed light on the stages of the dynamics when the environment is detrimental and when instead it corrects diabatic transition. It shows, in particular, that memory effects can be beneficial in cooling a quantum system.