Q 29: Implementations: Ions and Atoms (joint session QI/Q)

Time: Wednesday 11:00–13:00 Location: F428

Invited Talk Q 29.1 Wed 11:00 F428

Experimental quantum error correction with trapped ions — •Philipp Schindler — University of Innsbruck

For large-scale quantum computing, effective quantum error correction will be mandatory. Current, small-scale experiments can be used to validate assumptions on the physical errors in the system that are required for fault-tolerant operation. I will report on our experimental efforts towards fault-tolerant quantum information processing in our trapped-ion platform. In particular, I will discuss the implementation of a fault tolerant universal set of logical operations. The results from these experiments are used to inform the development of large scale ion-trap quantum devices.

Q 29.2 Wed 11:30 F428

Towards an entangling gate between bosonic qubits in trapped ions — •Stephan Welte, Martin Wagener, Moritz Fontbote-Schmidt, Hendrik Timme, Luca Hermann, Ralf Berner, Edgar Brucke, Paul Röggla, Ivan Rojkov, Florentin Reiter, and Jonathan Home — ETH Zurich, Zurich, Switzerland

Encoding quantum information in a harmonic oscillator provides a resource-efficient platform for quantum error correction. A promising code is Gottesman-Kitaev-Preskill (GKP) encoding [1], which has been realized both in trapped ions [2, 3] and superconducting qubits [4]. State preparation, single qubits rotations, readout, and error correction have been realized in both architectures. However, a universal two-qubit gate has not yet been realized. We will describe our work on such an entangling gate between GKP qubits prepared in the motional modes of calcium ions in a Paul trap. The modes are coupled via the Coulomb interaction approximating a beam splitter interaction. Together with squeezing operations, this interaction can realize the desired universal gate. In theoretical work, we investigate this gate for experimentally realistic parameters and finite energy states. In parallel, we are developing an apparatus for an experimental implementation, including the fabrication of a novel ion trap and the implementation of individual addressing with tightly focused laser beams.

[1] D. Gottesman, A. Kitaev, and J. Preskill. PRA 64, 012310 (2001) [2] C. Flühmann et al. Nature 566, 513(2019) [3] B. de Neeve et al. Nat. Phys. 18, 296 (2022) [4] V. Sivak et al. arXiv 2211.09116 (2022)

Q 29.3 Wed 11:45 F428

A universal two-qubit computational register for trapped-ion quantum processors — •Nicolas Pulido-Mateo[1,2], Hardik Mendpara[1,2], Markus Duwe[1,2], Giorgio Zarantonello[1,2,3], Amado Bautista-Salvador[1,2], Ludwig Krinner[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA

Here we report on the realization of a two qubit universal computational register compatible with the QCCD architecture [1]. Single qubit gates are performed by addressing each ion individually via a micromotion sideband [2]. The entangling operation is implemented using an MS-type interaction, where we measure an infidelity that approaches 10^{-3} [3] when using partial state tomography. To characterize the single qubit gates we use a randomized benchmarking protocol [4] and obtain an infidelity of $3.8(4) \times 10^{-3}$. We perform a characterization of the register by means of the cycle benchmarking protocol [5] obtaining, as a preliminary result, a composite process fidelity of 96.6(4) %. Finally we use simulation software for quantum open systems to model possible error sources and calculate an error budget.

[1] D. Kielpinski *et al.*, Nature **417**, 709 (2002).
[2] U. Warring *et al.*, Phys. Rev. Lett. **17**, 173002 (2013)
[3] M. Duwe *et al.*, Quantum Sci. Technol. **7**, 045005 (2022)
[4] C. Piltz *et al.*, Nature Communications **5**, 4679 (2014).
[5] A. Erhard *et al.*, Nat. Commun. **10**, 5347 (2019)

Q 29.4 Wed 12:00 F428

Coherent Control of Trapped Ion Qubits with Localized Electric Fields — •Raghavendra Srinivas[1,2], Clemens Löschnauer[1], Maciej Malinowski[1], Amy Hughes[1], Rustin Nourshargh[1], Vlad Negnevitsky[1], David Allcock[1,3], Steven King[1], Clemens Matthiesen[1], Thomas Harty[1], and Chris Ballance[1,2] — [1]Oxford Ionics — [2]University of Oxford — [3]University of Oregon, Eugene

We present a new method for coherent control of trapped ion qubits in separate interaction regions of a multi-zone trap by simultaneously applying an electric field and a spin-dependent gradient. Both the phase and amplitude of the effective single-qubit rotation depend on the electric field, which can be localised to each zone. We demonstrate this interaction on a single ion using both laser-based and magnetic field gradients in a surface-electrode ion trap, and measure the localisation of the electric field.

[1] arXiv:2210.16129

Q 29.5 Wed 12:15 F428

Entangling scheme for Rydberg ion crystals using electric kicks in radial direction — •Han Bao[1], Jonas Vogel[1], Alexander Schulze-Makuch[1], Ulrich Poschinger[1], and Ferdinand Schmidt-Kaler[1,2] — [1]QUANTUM, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, D-55128 Mainz, Germany

Due to the strong dipole interaction between Rydberg atoms, fast entangling gates have been achieved both in neutral atoms [1] and trapped ions [2]. A second unique feature of Rydberg states is their high electric polarizability. For trapped ions, Rydberg states electric polarizability may lead to a change of the secular frequency [3]. Such state dependent secular frequency can establish entanglement [4]. Here, we show that using electric kicks in the radial direction demands a 100 times lower voltage, thus much more feasible for an experimental realization. Accordingly, as lower motional are transiently excited only, the scheme becomes more robust. We also show scaling the method up for larger ions crystals, using a complex sequence of electric kicks, such that finally the motion state is recovered back.

We discuss the status of the experimental realization the electric kick entanglement generation.

[1]Levine et al., *Phys. Rev. Lett.* **123**, 170503 (2019)
[2]Zhang et al., *Nature* **580**, 345 (2020)
[3]Schmidt-Kaler et al., *New J. Phys.* **13**, 075014 (2011)
[4]Vogel et al., *Phys. Rev. Lett.* **123**, 153603 (2019)

Q 29.6 Wed 12:30 F428

Coherent transfer of transverse optical momentum to the motion of a single trapped ion — •Felix Stopp[1], Maurizio Verde[1], Milton Katz[2], Martín Drechsler[2], Christian Schmiegelow[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]CONICET, Instituto de Física de Buenos Aires (IFIBA), Universidad de Buenos Aires, Buenos Aires, Argentina

A structured light beam is carrying orbital angular momentum and we demonstrate the excitation of the center of mass motion of a single atom in the transverse direction to the beam's propagation. This interaction is achieved with a vortex beam carrying one unit of orbital angular momentum and one unit of spin angular momentum. Using a singly charged $^{40}Ca^{+}$ ion, cooled near the ground state of motion in the three-dimensional harmonic potential of a Paul trap, we probe the sidebands of the $S_{1/2}$ to $D_{5/2}$ transition near 729 nm to quantify the momentum transfer. Exchange of quanta in the perpendicular direction to the beam's wave vector k is observed in case of centered a vortex shaped beam, while parasitic carrier excitation is reduced by a factor 40. This is in sharp contrast to the vanishing spin-motion coupling at the center of Gaussian beam. We characterize the coherent interaction by an effective transverse Lamb-Dicke factor $\eta_{\perp}^{\mathrm{exp}} = 0.0062(5)$ which is in agreement with our theoretical prediction $\eta_{\perp}^{\mathrm{theo}} = 0.0057(1)$ [1]. Finally we discuss the application of our finding for quantum information processing with trapped ion crystals.

[1] accepted Paper 22 November 2022: Phys. Rev. Lett.

Q 29.7 Wed 12:45 F428

Lasersystem for Control of Magnsium Atoms — •Tobias Spanke, Lennart Guth, Philip Kiefer, Lucas Eisenhart, Deviprasath Palani, Apurba Das, Florian Hasse, Jörn Denter, Mario Niebuhr, Ulrich Warring, and Tobias Schätz — Physikalisches Institut, Albert-Ludwigs-Universität, Freiburg

Trapped ions present a promising platform for quantum simulations. Versatile and robust laser systems with narrow bandwidth and high power and intensity stability are required for reliable control of this platform. The latest systems for Mg^+, Be^+ ions are based on vertical external cavity surface emitting lasers (VECSEL)[1] in the near-infrared. We are testing new compact cooling systems with impact on short-term frequency stability using commercially available PC parts. With the goal of measuring magnesium ions at a frequency stability of 200 kHz ($\lambda \approx 1120$ nm, P=2 W) with high accuracy. We aim at further development of the VECSEL into a compact, stable and user-friendly "turnkey" system.

[1]Burd, S. et al.(2016), VECSEL systems for generation and manipulation of trapped magnesium ions, Optica Vol. 3, Issue 12, pp. 1294-1299 (2016)