QI 18: Quantum Technologies: Trapped Ions (joint session Q/QI)

Time: Wednesday 11:00–13:00 Location: F342

QI 18.1 Wed 11:00 F342

Non-commuting dynamics in light-ion-interactions on an ion-trap system — •Sebastian Saner[1], Oana Bazavan[1], Donovan Webb[1], Gabriel Araneda[1], Mariella Minder[1], David Lucas[1], Raghavendra Srinivas[1], and Chris Ballance[1,2] — [1]University of Oxford, Oxford, UK — [2]Oxford Ionics, Oxford, UK

The interaction Hamiltonian that governs the dynamics between trapped ions and laser light [1] is well studied and understood in the limit of low laser powers, leading to simple dynamics. However, at high powers, off-resonant coupling to multiple carrier and motional transitions is not negligible, leading to more complex and richer dynamics, with Hamiltonians exhibiting non-commuting terms.

In quantum computing with trapped ions, fast and versatile interactions that require high laser powers are important. It is of interest to either suppress those off-resonant terms or harness them in a controlled way. In this talk, we present our experimental work on utilising non-commuting terms to create two-qubit entanglement [2]. Furthermore, we evaluate how to apply this idea in the context of hybrid spin-motion systems. Secondly, we will show how we employ a phase stable optical lattice to coherently suppress a non-commuting error source that appears in the conventional Molmer-Sorensen interaction. This approach has the potential to allow for fast and high-fidelity entangling gates which are not limited by scattering errors.

[1]: Wineland et al., J. Res. Natl. Inst. Stand. Technol. 103(3), 259-328, 1998

[2]: Bazavan, Saner et al., arXiv:2207.11193, 2022

QI 18.2 Wed 11:15 F342

Optimization methods for RF junctions in register-based surface-electrode ion traps — •Florian Ungerechts[1], Rodrigo Munoz[1], Axel Hoffmann[1,2], Brigitte Kaune[1], Teresa Meiners[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Register-based ion traps are among the leading approaches for scalable quantum processors. A fundamental component of these are RF junctions that allow the ions to move between the specialized zones of the quantum processor via ion transport. We discuss the design choices and optimization methods of such a junction and present an optimized symmetric RF X-junction feasible for through-junction ion transport of single $^{9}Be^{+}$ ions and multilayer microfabrication.

QI 18.3 Wed 11:30 F342

Simultaneous super- and subradiant light emission of two stored ion in free space — •Stefan Richter[1], Sebastian Wolf[2], Joachim vom Zanthier[1], and Ferdinand Schmidt-Kaler[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany

Modification of spontaneous decay in space and time is a central topic of quantum physics. It has been predominantly investigated in cavity quantum electrodynamic systems. Altered spontaneous decay may equally result from correlations among the emitters in free space, as observed in super- and subradiance. Yet, preparation of an entangled quantum state and the resulting modified emission pattern has not been observed so far due to the lack of ultra-fast multi-pixelated cameras. Using two trapped ions in free space, we prepare their state via projective measurements and observe their corresponding collective photon emission. Depending on the direction of detection of the first photon, we record fundamentally different emission patterns, including super- and subradiance [1]. Our results demonstrate that the detection of a single photon may fundamentally determine the subsequent collective emission pattern of an atomic array, here represented by its most elementary building block of two atoms stored in an ion trap.

[1] arXiv:2202.13678

QI 18.4 Wed 11:45 F342

Quantum repeater node with two $^{40}Ca^{+}$ ions — •Max Bergerhoff, Omar Elshehy, Stephan Kucera, Matthias Kreis, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

The quantum repeater cell according to [1] is a fundamental building block for large distance quantum networks. It serves for overcoming the exponential scaling of fiber transmission, by the division of a transmission fiber in two asynchronously driven segments and the use of quantum memories. Recent realizations with single atoms [2] in a cavity and ions in a large cavity [3] already demonstrate the advantage of this protocol. Here we report on the implementation of a free-space quantum repeater cell with two $^{40}Ca^{+}$ ions in the same trap that act as memories.

We demonstrate ion-photon entanglement according to [4] by controlled emission of single photons from the individually addressed ions. The entanglement is swapped onto the photons via the Mølmer-Sørensen gate [5]. We discuss the rate scaling due to the asynchronous sequence and the fidelity of the final photon-photon state.

[1] D. Luong et al., Appl. Phys. B 122, 96 (2016)
[2] S. Langenfeld et al., Phys. Rev. Lett. 126, 30506 (2021)
[3] V. Krutyanskiy et al. arXiv preprint arXiv:2210.05418 (2022)
[4] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[5] K. Mølmer and A. Sørensen, Phys. Rev. Lett 82, 1835-8 (1999)

QI 18.5 Wed 12:00 F342

Spin-dependent coherent light scattering from linear ion crystal — •Maurizio Verde[1], Benjamin Zenz[1], Stefan Richter[2], Zyad Shehata[2], Ferdinand Schmidt-Kaler[1], and Joachim von Zanthier[2] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]Institut für Optik, Information und Photonik, Universität Erlangen, Erlangen, Germany

Linear crystals of ultracold ions are emerging platforms for quantum simulator thanks to their unique properties of long coherence times and high-fidelity optical manipulation. In this perspective, the development of new detection techniques based on photo-correlation measurements is of central interest in order to access structural and dynamical information. Following the ideas reported in [1] on light-crystal coherent scattering, we explored extensions of these phenomena and here we report on a new detection scheme to unveil the spin texture for linear chains of $^{40}Ca^{+}$ ions. First, we initialize the crystal in the desired spin configuration, then we use the narrow transitions at 729nm and 854nm to perform spin-dependent coherent scattering and measure the background-free $g^{(1)}$ photo-correlation function by recording light near 393nm in the far field. The laser beam geometry is chosen to minimize the single-ion recoil and therefore the corresponding Debye-Waller factor. We use a high spatio-temporal resolution MCP camera and reveal from the spatial interference pattern the spin texture of the crystal. We discuss the efficiency of our new method for detecting magnetic phases and phase transitions.

[1]Wolf et al., Phys. Rev. Lett. 116, 183002 (2016)

QI 18.6 Wed 12:15 F342

Sideband Thermometry on Ion Crystals — •Ivan Vybornyi[1], Laura Dreissen[2], Daniel Vadlejch[2], Tanja Mehlstäubler[2], and Klemens Hammerer[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover, Appelstraße 2,30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100,308116 Braunschweig, Germany

Crystals of ultracold trapped ions reach sizes of hundreds of individual particles and require high level of control over their motional temperature to account for the second-order Doppler shift in clocks and implement high-fidelity quantum gates in quantum computers. The existing thermometry tools fail to provide an accurate temperature estimation for large ground-state cooled crystals, either focusing only on the symmetric c.o.m. mode of motion or neglecting the involved spin-spin correlations between the ions.

To resolve the thermometry large-N bottleneck, we consider crystal many-body dynamics arising when motional sideband transitions are driven in a near ground-state regime, which is a widely used approach in thermometry of a single ion. To gain some valuable insights on the sideband thermometry method, we also address the single ion case and study it from the Fisher Information prospective.

Extending the approach further, we account for entanglement created between the ions in a crystal to derive a new reliable temperature estimator, insensitive to the number of ions, and field-test in experiments with 4- and 19-ion crystals done by colleagues from PTB and Innsbruck.

QI 18.7 Wed 12:30 F342

Mixed qubit types in registers of trapped barium ions — •Fabian Pokorny, Andres Vazquez-Brennan, Jamie Leppard, Ana Sotirova, and Chris Ballance — Department of Physics, University of Oxford, United Kingdom

Registers of mixed qubit types are a promising approach for scaling trapped-ion quantum computers. The insensitivity of one qubit type to the others' light fields eliminates scattering errors and enables advanced qubit control schemes.

Barium-ion qubits are uniquely suited for realising this approach. Their long-lived metastable states allow for the implementation of different qubit types using just one atomic species, which, combined with atomic transitions in the visible range, significantly reduces experimental complexity [1]. In our experiment we use $^{137}Ba^{+}$, whose nuclear spin of 3/2 provides magnetic-field insensitive 'clock' qubits in both the stable ground-state manifold and the long-lived metastable $5D_{5/2}$ manifold. The ground and metastable level qubits are connected via a pair of 'clock' transitions, and both qubit types can be driven using a two-photon Raman process with 532 nm light and low scattering error.

We show an all-fiber Raman system capable of single-ion addressing in a large qubit register and further demonstrate simultaneous manipulation of ground-state and metastable-state qubits. These are prerequisites for working with long registers of mixed qubit types and for realising partial projective measurements and mid-circuit measurements.

[1] D. Allcock et al., Applied Physics Letters, vol. 119, 2021.

QI 18.8 Wed 12:45 F342

Introducing a surface ion trap with integrated photonics for Yb+ ions — •Markus Kromrey[1], Elena Jordan[1], Guochun Du[1], Carl-Frederik Grimpe[1], Gillenhaal Beck[2], Karan Metha[5], and Tanja Mehlstäubler[1,3,4] — [1]Physikalisch Technische Bundesanstalt, Braunschweig, Deutschland — [2]Eidgenössische Technische Hochschule Zürich, Zürich, Schweiz — [3]Laboratorium für Nano- und Quantenengineering, Hannover, Deutschland — [4]Leibniz Universität Hannover, Hannover, Deutschland — [5]Cornell University, Ithaca, USA

One of the main obstacles to the scalability of ion trap applications such as quantum computing and quantum sensing is the miniaturization and scalability of the optics required to provide the trapped ions with the light necessary to manipulate them. In this talk, we will present a surface ion trap with integrated optics that requires much less space than classical setups. Integrated optics also offer routes to eliminating important technical noise sources present in conventional setups. The integrated optics deliver all the lasers required for a Yb 172 clock experiment to the ion. One of the main features of the trap is a grating coupler that provides the ion with light in a Hermite-Gaussian mode to excite the narrow Yb 172 octupole transition.