Q 39: Quantum Information: Atoms and Ions III

Time: Wednesday 16:30–19:00 Location: E 214

Group Report Q 39.1 We 16:30 E 214

Optical trapping of an ion — •Christian Schneider, Martin Enderlein, Thomas Huber, Stephan Duewel, Robert Matjeschk, Hector Schmitz, and Tobias Schaetz — Max-Planck-Institut für Quantenoptik

After more than 50 years of successfully trapping ions in Paul traps and more than 20 years of confining atoms in optical dipole traps followed by optical lattices, we were able to do the first step to merge these fields by trapping an ion optically. We initialize the system via trapping and laser cooling the ion in our linear Paul trap setup, switch on the optical dipole trap and switch completely off the Paul trap. After a waiting time the Paul trap is switched on and the optical dipole trap switched off again. We check for the presence of the ion via fluorescence. With experimentally measured survival durations (lifetimes) of single ions of the order of milliseconds, the lifetime is limited by optical heating processes of the dipole trap.

In the near future, we aim to realize cooling to increase the life time and to investigate the limitations on the coherence times. Loading two ions and/or one ion and atoms into the identical one-dimensional optical lattice could be explored soon. This approach demonstrates not only the feasibility of optically trapping ions, but also hybrid systems of Paul and optical traps, providing long range interaction, individual addressability and a potentially intriguing interplay between neutral and charged particles.

Q 39.2 We 17:00 E 214

Quantum gate between logical qubits in decoherence-free subspace implemented with trapped ions — •Peter Ivanov, Ulrich Poschinger, Kilian Singer, and Ferdinand Schmidt-Kaler — Institut für Quanteninformationsverarbeitung, Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm, Germany

We propose an efficient technique for the implementation of a geometric phase gate in a decoherence-free subspace with trapped ions. In this scheme, the quantum information is encoded in the Zeeman sublevels of the ground state and two physical qubits are used to make up one logical qubit with ultra long coherence time. The physical realization of a geometric phase gate between two logic qubits is performed with four ions in a linear crystal simultaneously interacting with single laser beam. We investigate in detail the robustness of the scheme with respect to the right choice of the trap frequency and provide a detailed analysis of error sources, taking into account the experimental conditions. Furthermore, possible applications for the generation of cluster states for larger numbers of ions within the decoherence-free subspace are presented.

Q 39.3 We 17:15 E 214

Realization of a quantum walk with one and two trapped ions — •Florian Zähringer[1,2], Gerhard Kirchmair[1,2], Rene Gerritsma[1,2], Enrique Solano[3], Rainer Blatt[1,2], and Christian Roos[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, A-6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, ÖAW, Otto-Hittmair-Platz 1, A-6020 Innsbruck, Austria — [3]Ikerbasque, Basque Foundation for Science, Alameda Urquijo 36, 48011 Bilbao, Spain

We experimentally demonstrate a quantum walk on a line in phase space using one and two trapped ions [1]. A walk with up to 23 steps is realized by subjecting an ion to state-dependent displacement operations interleaved with quantum coin tossing operations. To analyze the ion's motional state after each step we apply a technique that directly maps the probability density distribution onto the ion's internal state. The measured probability distributions and the position's second moment clearly show the non-classical character of the quantum walk. To further highlight the difference between the classical (random) and the quantum walk, we demonstrate the reversibility of the latter. Finally, we extend the quantum walk by using two ions, giving the walker the additional possibility to stay instead of taking a step.

[1] F. Zähringer et al., arXiv: 0911.1876 (2009)

Q 39.4 We 17:30 E 214

Combining dressed states and ion traps for coherent qubits — •Nuala Timoney, Ingo Baumgart, and Christof Wunderlich — Fachbereich Physik, Universität Siegen, 57068 Siegen

Coherence time is an important property of a quantum computer. A weakness of an ion trap quantum computer, is its potential dependence on magnetic field sensitive levels. Ambient magnetic field noise is the cause of the shorter coherence times of magnetic field sensitive levels (5 ms) compared to their field insensitive counterparts (500 ms) as observed in $^{171}Yb^{+}$. A scheme is suggested which is based on using dressed states as qubits, adiabatically turning on the fields before and turning the fields off at the end of the operations.

A three level system of hyperfine states is dressed by microwave photons and prepared in its dark state using STIRAP, Rabi oscillations are observed between the dark and the ground state and a Ramsey time measurement reveals a preliminary coherence time of 6.06 ms. In comparison a simpler two level dressed state scheme, which is based on a magnetic field insensitive transition with a dependence of the transition energy on the Rabi frequency of the dressing field, revealed a preliminary coherence time of 17 ms.

The coherence time measured is presently restricted by technical problems which will be improved in future experiments.

Q 39.5 We 17:45 E 214

Ion-Photon and Photon-Ion Interfaces for Quantum Networks — Felix Rohde[1], Nicolas Piro[1], Carsten Schuck[1], Marc Almendros[1], Jan Huwer[1], Joyee Ghosh[1], Markus Hennrich[1], Albrecht Haase[1], Francois Dubin[1], and •Jürgen Eschner[1,2] — [1]ICFO - Institut de Ciencies Fotoniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain — [2]FR Experimentalphysik, Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken

We report experimental progresses towards the realization of tools for quantum networking with single ions, such as two-photon interference from two remote, bandwidth tunable single photon sources and the generation of polarization correlated photon pairs from a single ion. A possible strategy to create remote entanglement in a quantum network is to generate entangled photon pairs by means of parametric down-conversion and make them interact with distant atoms, thereby transferring entanglement from photonic to atomic qubits. We present the realization of a first step towards such entanglement transfer, the absorption of a single down-conversion photon by a single $^{40}Ca^{+}$ ion, heralded by the partner photon.

Q 39.6 We 18:00 E 214

Trapping of Ytterbium Ions with a Stylus Trap — •Andrea Golla[1,2], Robert Maiwald[1,2], Simon Heugel[1,2], Alessandro Villar[2], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Institut für Optik, Information und Photonik (IOIP), Universität Erlangen-Nürnberg, Staudtstr. 7/B2, 91058 Erlangen — [2]Max-Planck-Institut für die Physik des Lichts (MPL), Günther-Scharowsky-Str. 1/Bau 24, 91058 Erlangen

Recently, a needle like Paul trap with high optical and physical accessibility has been developed and tested using magnesium ions [1]. We want to employ such a stylus trap for localizing a single ion in the focal point of a deep parabolic mirror. In the planned experiment, singly and doubly ionized ytterbium will be coupled to the light field from the nearly full solid angle. Yb^{2+} will be produced by photoionization of trapped and laser cooled Yb^{+}. Here, we report on the successful trapping of single Yb^{+} ions with the stylus trap and discuss the experimental progress.

[1] R. Maiwald *et al.*, Nature Physics **5**, 551-554 (2009)

Q 39.7 We 18:15 E 214

Quantum Gates utilizing the Phonon Modes of an Ion Coulomb Crystal in a Magnetic Field — •Jens Domagoj Baltrusch[1,2], Antonio Negretti[3], Jacob M. Taylor[4], and Tommaso Calarco[3] — [1]Theoretische Physik, Universität des Saarlandes, Germany — [2]Grup d'Òptica, Universitat Autònoma de Barcelona, Bellaterra, Spain — [3]Institut für Quanteninformationsverarbeitung, Universität Ulm, Germany — [4]Joint Quantum Institute, University of Maryland and NIST, College Park, MD, USA

Ion Coulomb crystals rotating in the magnetic field of a Penning trap have been proposed for a scalable implementation of quantum gates [Porras & Cirac PRL96 250501 (2006); Taylor & Calarco PRA78 062331 (2008)]. So far these approaches are quite difficult to implement since they are limited to a crystal rotation frequency of half the cyclotron frequency, which could be as large as hundreds of MHz. However, at lower rotation rates the magnetic field of the trap induces a coupling between the positions and the momenta of the ions. This coupling complicates the calculation of the phonon modes, which are an essential component in the implementation of two-qubit gate operations. We examine a method based on Williamson's theorem [Williamson Amer.J.of Math.58 141 (1963)] to calculate the phonon modes in the case of position-momentum coupling, show numerical results of the determination of the equilibrium positions and the normal modes for different rotation rates of the ion crystal, and discuss the simulation of the necessary gate operations.

Q 39.8 We 18:30 E 214

State-independent experimental test of quantum contextuality with trapped ions — •Gerhard Kirchmair[1,2], Florian Zähringer[1,2], Rene Gerritsma[1,2], Matthias Kleinmann[2], Ottfried Gühne[2,3], Adan Cabello[4], Rainer Blatt[1,2], and Christian F. Roos[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, A-6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation,ÖAW, Otto-Hittmair-Platz 1, A-6020 Innsbruck, Austria — [3]Institut für theoretische Physik, Universität Innsbruck, Technikerstr. 25, A-6020 Innsbruck, Austria — [4]Departamento de Física Aplicada II, Universidad de Sevilla, E-41012 Sevilla, Spain

In this talk, I will present the realization of a recent proposal for a state-independent test of quantum contextuality. I will start with a brief overview of a gate mechanism that allows for entangling ions without ground state cooling and experimental results obtained with two ions. Then, I will present recent experiments in which we apply the gate for a quantum non-demolition measurement of two-ion spin correlations. This technique makes it possible to sequentially measure several compatible observables on a single quantum system and to correlate the measurement results. In this way, we have been able to realize a state-independent test of quantum contextuality. The experimental results [1] demonstrate that the observed correlations cannot be explained by non-contextual hidden variable theories.

[1]Kirchmair G. et.al. *Nature* **460**, 494 (2009)

Q 39.9 We 18:45 E 214

Quantum simulation of the Dirac equation — Rene Gerritsma[1], Gerhard Kirchmair[1], Florian Zähringer[1], Enrique Solano[2], Rainer Blatt[1], and •Christian Roos[1] — [1]Institut für Quantenoptik und Quanteninformation, Otto-Hittmair-Platz 1, 6020 Innsbruck, Österreich — [2]Departamento de Quimica Fisica, Universidad del Pais Vasco - Euskal Herriko Unibertsitatea, 48080 Bilbao, Spain

The Dirac equation is a cornerstone in the history of physics, merging successfully quantum mechanics with special relativity, providing a natural description of the electron spin and predicting the existence of anti-matter. However, the Dirac equation also predicts some peculiar effects such as Klein's paradox and Zitterbewegung, an unexpected quivering motion of a free relativistic quantum particle first examined by Schrödinger. In this talk, we report on a proof-of-principle quantum simulation of the one-dimensional Dirac equation using a single trapped ion, which is set to behave as a free relativistic quantum particle [1]. We measure as a function of time the particle position and study Zitterbewegung for different initial superpositions of positive and negative energy spinor states, as well as the cross-over from relativistic to nonrelativistic dynamics.

[1] R. Gerritsma et al, arXiv:0909.0674, accepted for publication in Nature.