Q 32: Quantum Information: Atoms and Ions 3

Time: Wednesday 14:30–16:15 Location: HÜL 386

Q 32.1 Wed 14:30 HÜL 386

Quantum computation and simulation using dissipation — •Philipp Schindler[1], Julio T. Barreiro[1], Markus Müller[2,3], Daniel Nigg[1], Thomas Monz[1], Michael Chwalla[1,2], Markus Hennrich[1], Christian F. Roos[2], Volckmar Nebendahl[3], Peter Zoller[2,3], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Austria — [3]Institut für Theoretische Physik, Universität Innsbruck, Austria

In quantum information experiments, quantum systems are usually isolated from the environment and their dynamics is controlled coherently. On the other hand, engineering the dynamics of many particles by a controlled coupling to an environment opens new possibilities in quantum information and simulation experiments[1]. We report on several experiments combining the power of multi-qubit quantum gates and dissipative coupling to the environment in a ^{40}Ca^{+} ion trap quantum computer. For example, quantum error correction requires to dissipatively reset ancilla qubits. For this optical pumping is used thus enabling multiple steps of a quantum-error-correction algorithm. We further demonstrate a toolbox for simulating an open quantum system with up to five qubits exemplified by the dissipative preparation of entangled states. This work offers novel prospects for quantum simulation and computation by adding controlled dissipation to coherent operations.

[1] F. Verstraete, et. al., *Nature Phys.* **5**, 633 (2009)

Q 32.2 Wed 14:45 HÜL 386

Quantum information processing with trapped ions at NIST — •Christian Ospelkaus — NIST, 325 Broadway, Boulder, CO, USA — Present address: QUEST, Universität Hannover, Welfengarten 1, 30167 Hannover and PTB, Bundesallee 100, 38116 Braunschweig

Most current schemes for Quantum Information Processing (QIP) with trapped ions implement quantum logic gates through a *laser-induced* spin-dependent interaction between ions held in the *same* trap. We give an overview of the current effort and describe experiments which explore ideas beyond these well-established techniques. In particular, we demonstrate Coulomb coupling between two ions held in individual traps separated by 40 μm. We observe oscillations of energy between the two oscillators at the single quantum level. Beyond the fundamental relevance of this system of coupled quantized mechanical oscillators, these results open new experimental perspectives for quantum simulation, novel entangling schemes for QIP and for precision spectroscopy. In a second experiment, we demonstrate a microwave near-field approach to coherent quantum control of trapped ions. For quantum logic, this approach has several important potential advantages with respect to operation fidelity and reduced complexity. We demonstrate single-qubit rotations with π times of less than 20 ns, driven by microwave currents in the trap electrodes, motional sideband transitions induced by the near-field magnetic field gradient, and sideband cooling. We discuss applications to quantum logic, simulation and spectroscopy. This work has been supported by IARPA, DARPA, NSA, ONR, and the NIST Quantum Information Program.

Q 32.3 Wed 15:00 HÜL 386

High precision measurement techniques for improving the scalability of ion trap quantum computing — •Andreas Walther, Ulrich Poschinger, Frank Ziesel, Max Hettrich, Alex Wiens, Michael Schnorr, Jens Welzel, Kilian Singer, and Ferdinand Schmidt-Kaler — Institute of Physics, University of Mainz, Staudinger Weg 7, 55128 Mainz

Two techniques for advancing the state of quantum computing in ion traps are presented. Both results are important for improving future gate fidelities as well as scalability possibilities of the ion trap quantum computing concept. The first one is a novel homodyne detection of the interference between two parts of an ion wavepacket, where the motional state of the ion is entangled with its spin state. We use this technique to characterize the phase space trajectory of the ion with high enough accuracy to find deviations from the linear approximation to the spin dependent light force, leading to an extension of the current models of the system evoloution.

Secondly, we employ a single ion to measure a magnetic field gradient with a relative sensitivity of $\Delta B/B \sim 10^{-7}$ over a 100 μm distance, which is shown to be quantum shot noise limited. The compensation of gradients helps to increase the coherence time of qubits that are transported for the realization of scalable quantum information processsing.

Q 32.4 Wed 15:15 HÜL 386

Optical Ion Trapping - Cooling and Perspectives — •Martin Enderlein, Thomas Huber, Christian Schneider, Stephan Duewel, Johannes Stroehle, and Tobias Schaetz — Max-Planck-Institut für Quantenoptik, Garching, Germany

Atomic ions stored in a linear Paul trap is one of the experimental quantum systems which is best controllable and suffers least from decoherence, making it particularly suited for quantum information experiments. Recently we were able to demonstrate a proof of principle for a quantum simulator for quantum spin systems by making use of the long-range interaction between ions [1]. The motivation for a quantum simulator is to gain deeper insight into complex quantum dynamics (e.g. of a solid-state system) via experimentally simulating the quantum behaviour of interest in another, better controllable quantum system (e.g. trapped ions). In order to gain genuinely new insights one has to scale these simulations to particle numbers that cannot be handled efficiently on a classical computer. This, however, might not be possible in a linear trap. One approach is to combine the advantages of trapped ions with those of optical lattices. As a first experimental step, we were able to trap an ion in a deep optical dipole trap [2]. In the mean time we have been analyzing the system in more detail and have investigated several laser cooling schemes. These results are the basis for future experiments with the goal of 2D quantum simulations with ions, or ions and atoms, trapped in optical lattices.

[1] A. Friedenauer et al., Nat. Phys. 4 (2008), 757-761
[2] Ch. Schneider et al., Nat. Photonics 4 (2010), 772-775

Q 32.5 Wed 15:30 HÜL 386

Measuring the Magnetic induced J-coupling between two ions — •Anastasiya Khromova, Andrés Felipe Varón, Benedikt Scharfenberger, Christian Piltz, Timm Gloger, and Christof Wunderlich — Fachbereich Physik, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen

Two 171Yb+ ions are electrodynamically trapped in presence of a magnetic gradient field. This magnetic field not only allows to address the ions independently [1] but also accounts for an effective spin-spin coupling [2]. This interaction was measured in a linear Paul trap using spin echo techniques on Doppler-cooled ions.

The magnetic field gradient is produced by means of two permanent magnets with identical poles facing toward each other and reaches up to 17 T/m. Having the axial trap potentials in the range of hundred kilohertz we are able to measure coupling constants of a few tens of hertz. The measured values we obtained are in good agreement with the theoretical expectations.

[1] M. Johanning et al., Phys. Rev. Lett. 102, 073004 (2009).
[2] Chr.Wunderlich, Laser Physics at the Limits, p.261, (Springer, 2002), arXiv:quant-ph/0111158

Q 32.6 Wed 15:45 HÜL 386

Towards quantum simulations in a two-dimensional lattice of ions — •Johannes Stroehle, Christian Schneider, Martin Enderlein, Thomas Huber, Stephan Duewel, and Tobias Schaetz — Max-Planck-Institut für Quantenoptik

Linear Paul traps have demonstrated to be a well-suited tool for quantum simulations [1,2]. General 2D interactions or large-scale systems can hardly be simulated in conventional Paul traps. Surface-electrode traps are a promising candidate to overcome some of these limitations and allow to design arbitrary trapping geometries [3].

We started a collaboration with Roman Schmied (Uni Basel), Didi Leibfried (NIST, Boulder) and Dave Moehring (Sandia National Labs) to investigate the feasibility of a surface-electrode trap providing a lattice of RF traps. We want to report on our progress in setting up a new experiment and visions for quantum simulations. A linear surface-electrode trap from Sandia National Labs has been successfully assembled into a vacuum system to test the integral parts of a new setup. Afterwards, we plan to substitute it by a first lattice trap with three trapping zones arranged in a triangle. The zones will have mutual distances of 40 μm and a height above the surface of 40 μm, which could already allow to achieve a sufficient coupling strength between the ions for first quantum simulation experiments in two dimensions.

[1] A. Friedenauer et al., Nat. Phys. 4, 757-761 (2008)
[2] H. Schmitz et al., PRL 103, 090504 (2009) and
F. Zähringer et al., PRL 104, 100503 (2010)
[3] R. Schmied et al., PRL 102, 233002 (2009)

Q 32.7 Wed 16:00 HÜL 386

2D Arrays of RF-Addressable Ion Traps — •Muir Kumph[1], Michael Brownnutt[1], and Rainer Blatt[1,2] — [1]Insitut für Experimentalphysik, Innsbruck, Österreich — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Österreich

The design and testing of 2 dimensional arrays of ion traps is described and analyzed. Each ion trap is a point-like Paul trap which confines the ion in all 3 dimensions. However, the RF voltage on each segmented, RF electrode can be independently varied, allowing ions in neighboring traps to be brought close to one another, thereby tuning the interaction between them. Varying the RF drive of the traps in the 2D array allows for pairwise interactions in more than one dimension and provides a possible avenue for massive scalability of quantum computation and quantum simulation with trapped ions.