Q 9: Quantum Information: Quantum Computation I

Time: Monday 14:30–16:15 Location: B/gHS

Group Report Q 9.1 Mon 14:30 B/gHS

Experimental realization of Quantum Fourier Transform based on multiple coupling — •Theeraphot Sriarunothai[1], Christian Piltz[1], Svetoslav Ivanov[2], Andrés Varón[1], Gouri Giri[1], and Christof Wunderlich[1] — [1]Department Physik, Universität Siegen, 57068 Siegen, Germany — [2]Department of Theoretical Physics, Sofia University St Kliment Ohridski, Sofia 1164, Bulgaria

Here we present tools to realize a quantum computer. Using a MAgnetic field Gradient Induced Coupling (MAGIC) scheme, we have demonstrated addressability of individual ions, single qubit gates and conditional quantum dynamics. Now we show that either joint or selective coupling between qubits can be chosen.

Consisting of the mentioned tools, a novel route to implement Quantum Fourier Transform (QFT) is presented, using microwave driven trapped $^{171}Yb^+$ ion qubits in a static magnetic gradient, which features adjustable long-range coupling between (non-)neighbouring ions. This enables to interact between all pairs of qubits simultaneously. Implementation of QFT using this method is significantly faster compared to the conventional sequential approach.

An experimental study of sub-sequences of the optimized QFT sequence is presented. During the whole sequence, the system dynamics are protected by dynamical decoupling pulses which are interleaved with the QFT sequence. We characterize the performance of the realization by comparing the results of basis states with the theoretical calculation. Furthermore, the QFT gate is also applied to some particular quantum states to calculate their periods.

Q 9.2 Mon 15:00 B/gHS

Engineering and observation of interacting quasiparticles in a quantum many-body system — Petar Jurcevic[1,2], Philipp Hauke[1,3], •Christine Maier[1,2], Cornelius Hempel[1,2], Ben P. Lanyon[1,2], Peter Zoller[1,3], Rainer Blatt[1,2], and Christian F. Roos[1,2] — [1]Institut für Quantenoptik und Quanteninformation, ÖAW, Technikerstr. 21a, 6020 Innsbruck — [2]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck — [3]Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck

The key to explaining and controlling a range of quantum phenomena is to study how information propagates around many-body systems. This quantum dynamics can be described by particle-like carriers of information that emerge in the collective behaviour of the underlying system, so called quasiparticles. We engineer such quasiparticles in a quantum many-body system of trapped atomic ions, whose interactions are determined by a transverse-field Ising Hamiltonian [1]. In my talk, I will present how we approximately construct the Eigenstates of the system, perform spectroscopy on low lying energy levels and observe signatures of quasiparticle interactions in our system [2].

[1] P. Jurcevic et al., Nature, **511**, 202-205 (2014).
[2] P. Jurcevic et al., *in preparation.*

Q 9.3 Mon 15:15 B/gHS

Improvement of hybrid solid state spin systems for quantum information processing — •Nabeel Aslam, Matthias Pfender, Sebastian Zaiser, Philipp Neumann, and Jörg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart, Deutschland

Individual electron and nuclear spins in solids (e.g. phosphorus in silicon [1] or nitrogen-vacancy (NV) centers in diamond) are considered as candidates for the implementation of quantum information processing. For fault-tolerance, error correction is required. For example, the electron spin of the NV center and coupled nuclear spins form a logical qubit, for which phase flip error correction was implemented [2]. For more sophisticated quantum error correction codes the number of applicable nuclear spins as well as their coherence properties need to be enhanced. Both parameters are improved with the application of high magnetic fields. Correspondingly, methods for manipulation and readout of the whole spin register up to E-band frequencies (60-90 GHz) are introduced. First experimental results including T1 lifetimes of single nuclear spins exceeding several minutes are shown. The electron spin T1 lifetime limits the coherence time (T2) of nuclear spins. Methods to overcome this limit are discussed and first implementations are demonstrated.

[1] Muhonen, Juha T., et al., Nature Nanotechnology (2014). [2] Waldherr, G., et al., Nature 506, 204 (2014).

Q 9.4 Mon 15:30 B/gHS

Scaleable two and four qubit parity measurement with a threshold photon counter — •Luke C.G. Govia[1], Emily J. Pritchett[1,2], Robert McDermott[3], and Frank K. Wilhelm[1] — [1]Theoretical Physics, Universität des Saarlandes, Saarbrücken, Germany — [2]HRL Laboratories, LLC, Malibu, CA 90265, USA — [3]Department of Physics, University of Wisconsin, Madison, WI 53706, US

Multi-qubit parity readout is a central ingredient to quantum information processing, with applications ranging from quantum error correction to entanglement generation. As the physical implementation of QIP technologies grows in size, so too does the need for scalable readout protocols. Here we present a scalable, high-fidelity, quantum nondemolition readout protocol for the parity of two or four qubits using a single dispersively coupled cavity and a photon counter. By selectively populating the cavity dependent on the qubit parity, it is possible to non-destructively readout the qubit parity using a phase insensitive photon counter, without gaining any further qubit-state resolving information. We describe our protocol in the context of superconducting integrated circuits, where the cavity is a microwave resonator, and as an example photon counter we choose the Josephson photomultiplier (PRL 107, 217401 (2011)).

Q 9.5 Mon 15:45 B/gHS

Controlling motional degrees of freedom in a triangular array of individual rf-surface traps. — •Henning Kalis, Manuel Mielenz, Frederick Hakelberg, Matthias Wittemer, Ulrich Warring, and Tobias Schaetz — Albert-Ludwigs-Universität Freiburg, Physikalisches Institut

Geometrical frustration has turned out to be a mechanism for inducing exotic quantum disordered phases [1], whose dynamics have proven to be complicated to tackle on classical computers. Overcoming this difficulty, we try to follow Feynman's approach of quantum simualtions [2]. We chose a bottom up approach for such a quantum simulation [3] based on trapped $^{25}Mg^+$ ions. We implement the most basic geometry that exhibits frustration, using as an equilateral trianglular ion trap array [4]. In our setup ions are located in three distinct potential wells seperated by either 40 or 80 μm.
Moreover high-fidelity quantum control is obligatory and has been demonstrated in linear Paul-Traps [5,6]. Extending simulations into 2D, it is detrimental to implement deterministic control of the individual degrees of freedom e.g. spin-sates, eigenfrequencies and eigenmodes.
We report on recent results, showing manipulation of all degrees of freedom. In addition we outline the next steps towards ion-ion interaction of all constituent ions.

[1]Phys. Rev. B 63, 224401 (2001). [2]Int. J. Theor. Phys., VoL 21, Nos. 6/7, (1982). [3]New J. Phys. 15, 085009 (2013). [4]Phys. Rev. Lett. 102, 233002 (2009). [5]Nature Physics 4, 757 - 761 (2008). [6]Science 340, 583*587 (2013).

Q 9.6 Mon 16:00 B/gHS

Cellular-automaton decoders for topological quantum memories — •Michael Herold[1], Earl T. Campbell[1,2], Jens Eisert[1], and Michael J. Kastoryano[1,3] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK — [3]Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark

We present a new framework for constructing topological quantum memories, by recasting error recovery as a dynamical process on a field generating cellular automaton. We envisage quantum systems controlled by a classical hardware composed of small local memories, communicating with neighbors, and repeatedly performing identical simple update rules. This approach does not require any global operations or complex decoding algorithms. Our cellular automata draw inspiration from classical field theories, with a Coulomb-like potential naturally emerging from the local dynamics. For a 3D automaton coupled to a 2D toric code, we present evidence of an error correction threshold above 6.1 % for uncorrelated noise. A 2D automaton equipped with a more complex update rule yields a threshold above 8.2 %. Our framework provides decisive new tools in the quest for realizing a passive dissipative quantum memory.