Q 61: Quantum information: Atoms and ions V

Time: Friday 11:00–12:30 Location: E 214

Q 61.1 Fri 11:00 E 214

Heralded entanglement between solid-state qubits separated by 3 meters — •Hannes Bernien[1], Bas Hensen[1], Wolfgang Pfaff[1], Gerwin Koolstra[1], Machiel Blok[1], Lucio Robledo[1], Lilian Childress[2], Tim Taminiau[1], Matthew Markham[3], Daniel Twitchen[3], and Ronald Hanson[1] — [1]Kavli Institute of Nanoscience Delft, The Netherlands — [2]McGill University, Department of Physics, Montreal, Canada — [3]Element Six, Ltd., Ascot, United Kingdom

Here we present our most recent results towards the realization of scalable quantum networks with solid-state qubits. We have entangled two spin qubits in diamond, each associated with a nitrogen vacancy center in diamond [1]. The two diamonds reside in separate setups three meters apart from each other. With no direct interaction between the two spins to mediate the entanglement, we make use of a scheme based on quantum measurements: we perform a joint measurement on photons emitted by the NV centers that are entangled with the electron spins. The detection of the photons projects the spins into an entangled state. We verify the generated entanglement by single-shot readout of the spin qubits in different bases and correlating the results.

These results open the door to a range of exciting opportunities. For instance, the remote entanglement can be extended to nuclear spins near the NV center. Our recent experiments demonstrate robust methods for initializing, controlling and entangling nuclear spins by using the electron spin as an ancilla [2,3].

[1] H. Bernien et al., in preparation. [2] T. van der Sar et al., Nature 484, 82 (2012). [3] W. Pfaff et al., Nature Physics (2012).

Q 61.2 Fri 11:15 E 214

Dynamical quantum teleportation — •Christine Muschik[1], Eugene Polzik[2], and Ignacio Cirac[3] — [1]ICFO-Institut de Ciencies Fotoniques, Spain — [2]Niels Bohr Institute, Denmark — [3]Max-Planck-Institute, Germany

We introduce two protocols for inducing non-local dynamics between two separate parties. The first scheme allows for the engineering of an interaction between the two remote systems, while the second protocol induces a dynamics in one of the parties, which is controlled by the other one. Both schemes apply to continuous variable systems, run continuously in time and are based on instantaneous feedback.

Q 61.3 Fri 11:30 E 214

Quantum teleportation of a polarization state of a weak laser pulse to a single atom — •Daniel Burchardt[1], Norbert Ortegel[1], Kai Redeker[1], Julian Hofmann[1], Michael Krug[1], Markus Weber[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Quantum teleportation enables to transfer the quantum state of a particle to a remote location without sending the particle itself. Here, we report on teleportation of the polarization state of an attenuated laser pulse to a single ^{87}Rb atom stored in an optical dipole trap over a distance of 20 m. In a first step the atomic Zeeman state is entangled with the polarization state of a single photon[1]. The emitted photon interferes with the polarized photon of the laser pulse on a beam splitter enabling a Bell state measurement. This projects the atom to one of four well-defined states depending on the outcome of the Bell state measurement. To achieve a sufficient fidelity one has to ensure that the interfering photons are indistinguishable in all degrees of freedom except polarization. Additionally the Poissonian distribution of the laser source gives rise to a non-vanishing probability for multi-photon pulses. We determine the fidelity of the teleportation process by evaluating the density matrix of the new atomic state. This demonstrates e.g. the possibility of writing quantum states into a remote quantum memory.

[1] J. Volz et al., *Phys. Rev. Lett.*, 2006.

Q 61.4 Fri 11:45 E 214

Efficient teleportation between remote single-atom quantum memories — •Christian Nölleke, Andreas Neuzner, Andreas Reiserer, Carolin Hahn, Gerhard Rempe, and Stephan Ritter — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Teleportation is a prerequisite for the transfer of quantum information over large distances when the losses inherent in any quantum channel preclude a direct transfer. We demonstrate teleportation between two single-atom quantum memories in distant laboratories. By implementing a time-resolved photonic Bell-state measurement (BSM), which is based on two-photon quantum inference, we achieve a teleportation fidelity of 88%, largely determined by our entanglement fidelity. The problem of limited photon collection efficiency in free space is overcome by trapping each atom in an optical cavity. Compared to previous experiments with remote single material qubits, our approach boosts the overall efficiency by almost five orders of magnitude. This results in success probabilities not predominantly limited by the photon generation and collection efficiency but by the transmission and detection losses inherent in the photonic BSM.

Q 61.5 Fri 12:00 E 214

Entanglement quantification by neutron scattering — •Oliver Marty[1], Michael Epping[2], Hermann Kampermann[2], Dagmar Bruss[2], Martin Plenio[1], and Marcus Cramer[1] — [1]Institut f. Theoretische Physik, Universtität Ulm, Ulm, Germany — [2]Institute f. Theoretische Physik III, Heinrich-Heine Universität Düsseldorf, Düsseldorf, Germany

We present studies about the quantification of the entanglement contained in large samples of magnetic materials by structure factor measurements – a standard tool in analysing condensed matter systems. We discuss experimentally relevant models (such as Heisenberg [1], Majumdar-Ghosh and XY models) in different geometries and with different spin numbers. For those, lower bounds to entanglement measures can be read off directly from the cross section obtained in neutron-scattering experiments.

[1] N.B. Christensen *et al.*, Proc. Natl. Acad. Sci. USA, **104**, 15264 (2007)

Q 61.6 Fri 12:15 E 214

Fast and efficient detection of Zeeman states of ^{87}Rb via ionization — •Michael Krug[1], Daniel Burchardt[1], Norbert Ortegel[1], Kai Redecker[1], Julian Hofmann[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Current experiments in quantum information such as quantum repeaters and atomic quantum computers rely on the capability to read out qubits fast and efficiently. Here we present a novel readout scheme for a qubit encoded in (degenerate) Zeeman states of a single ^{87}Rb atom that fulfills these requirements.

In detail we use a two-photon transition with the first photon resonant to the D_1-line and the second at a wavelength of 445 nm to ionize the atom within 500 ns. For evaluating the scheme we generate entanglement between a spontaneously emitted photon and the Zeeman state of the atom. By measuring the polarisation of the photon we project the atom onto a selected superposition of Zeeman states. This superposition is directly ionized without lifting the degeneracy where the measurement basis is defined by the polarization of the D_1-light. We achieve a read out fidelity of the atom-photon state of 0.95 ± 0.03. Together with the implementation of channel electron multipliers[1] and the generation of entanglement between two separated atoms[2] this will be a key ingredient towards a loophole free test of Bell's inequality.

[1] F. Henkel et al., *Phys. Rev. Lett.* 105, 253001 (2010)
[2] J. Hofmann et al., *Science*, 337, 72 (2012)