Q 54: Quantum Information (Quantum Repeater)

Time: Thursday 14:00–15:45 Location: Q-H12

Q 54.1 Thu 14:00 Q-H12

Atom-Atom Entanglement over 33 km Telecom Fiber — •Pooja Malik[1,2], Tim van Leent[1,2], Matthias Bock[3], Florian Fertig[1,2], Robert Garthoff[1,2], Sebastian Eppelt[1,2], Yiru Zhou[1,2], Tobias Bauer[3], Wei Zhang[1,2], Christoph Becher[3], and Harald Weinfurter[1,2,4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Fachrichtung Physik, Universität des Saarlandes, Saarbrücken, Germany — [4]Max-Planck Institut für Quantenoptik, Garching, Germany

Scalable quantum networks will allow for secure quantum communication and distributed quantum computing. Heralded entanglement between distant quantum memories is one of the building blocks for such networks. To this end, we present our results of heralded entanglement between two independent quantum memories generated over fiber links with a length of up to 33 km. The two quantum memories consist of a single Rubidium (^{87}Rb) atom each and are located 400 m apart [1]. In order to entangle the two (^{87}Rb) atoms, we start with entangling the spin state of an atom with the polarization state of a photon in each node. The emitted photons (780 nm) are then converted to the low loss telecom S band (1517 nm) to overcome high attenuation loss in optical fiber over longer distances [2]. Finally, these photons are guided to a middle station where a Bell-state measurement swaps the entanglement to the atoms.

[1] T.van Leent et al., arXiv:2111.15526 (2021)
[2] T.van Leent et al., Phys. Rev. Lett. 124, 010510 (2020)

Q 54.2 Thu 14:15 Q-H12

Coupling Erbium Dopants to Nanophotonic Silicon Structures — •Andreas Gritsch, Lorenz Weiss, Stephan Rinner, Johannes Früh, Florian Burger, and Andreas Reiserer — Quantum Networks Group, Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, D-85748 Garching, Germany – Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität München, Fakultät für Physik, Schellingstraße 4, D-80799 München, Germany

Erbium dopants are promising candidates for the implementation of large-scale quantum networks since they can combine second-long ground state coherence [1] with coherent optical transitions at telecommunication wavelength [2].

Recent results show that erbium ions implanted into silicon nanostructures are integrated at well-defined lattice sites with narrow inhomogeneous (~1 GHz) and homogeneous (<20 kHz) linewidths and long lifetimes of the optical excited states (~0.25 ms) [3]

We proceed towards the control of individual erbium dopants by fabricating photonic crystal cavities which may reduce the lifetime by more than three orders of magnitude. This will allow us to resolve and control individual dopants, making our system a promising candidate for the implementation of distributed quantum information processing over large distances.

[1] M. Rancic, et. al., Nat. Physics, 14, 50-54 (2018), [2] B. Merkel, et. al., Phys. Rev. X 10, 041025 (2020), [3] A. Gritsch, et. al., Arxiv, 2108.05120 (2021).

Q 54.3 Thu 14:30 Q-H12

A one-node quantum repeater — Stefan Langenfeld, Philip Thomas, •Olivier Morin, and Gerhard Rempe — Max-Planck-Institute für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

For long distance quantum communication, losses in optical fibers constitute a real hurdle. Indeed, because the transmission efficiency scales exponentially with distance, any qubit exchange is basically impossible beyond typically 500km. The quantum repeater solves this problem via an improved rate-versus-distance scaling by dividing a long link into multiple short ones.

Using a cavity QED platform, ^{87}Rb atoms in a high-finesse optical cavity, we have developed all the necessary features required to implement a quantum repeater: long coherence time qubit memories [1], accurate control of the photon shape [2], low-cross-talk random access memories [3]. With these capabilities in hand, we have implemented an elementary quantum repeater. At the central node, two atoms send photons (entangled with the atomic states) repeatedly until it is received by each end of the link. Eventually, a Bell measurement is realized on the two atoms which entangles the two ends of the link. With this experimental realization, we observed an improvement by a factor 2 in the rate-versus-distance scaling, the central feature of a quantum repeater [4].

[1] M. Körber *et al.*, Nat. Photonics **12**, 18 (2018).
[2] O. Morin *et al.*, Phys. Rev. Lett. **123**, 133602 (2019).
[3] S. Langenfeld *et al.*, npj Quantum Inf **6**, 86 (2020).
[4] S. Langenfeld *et al.*, Phys. Rev. Lett. **126**, 230506 (2021).

Q 54.4 Thu 14:45 Q-H12

Larmor precession-free atom-photon entanglement using Raman scattering from a single ^{40}Ca^{+} ion — •Matthias Kreis, Jelena Ritter, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Atom-photon entanglement is an essential resource for a sender-based quantum repeater scheme. One implementation is a flying qubit, encoded in the polarization of an emitted photon, which is entangled with a stationary qubit, encoded in the internal state of a single ion. If Zeeman leves are used for the ionic qubit, the phase of the generated atom-photon state depends on the emission time of the photon, due to the magnetic energy splitting [1,2].

In order to make the phase time-independent, one can use an ion trapped inside a cavity [3]. In this scheme, a bi-chromatic laser with the same frequency difference as the involved Zeeman-shifted transitions in the ion is used.

Here, we report on a alternative scheme using a single ^{40}Ca^{+}-ion together with an external cavity that acts as a quantum eraser. The cavity filter removes unwanted spectral components, which results in detection-time independent atom-photon entanglement. We present the generation of phase-stable atom-photon entanglement at 393 nm and at 854 nm wavelength with fidelity 0.95.

[1] C. Kurz et al., Phys. Rev. A **93**, 062348 (2016).
[2] M. Bock et al., Nat. Commun. **9**, 1998 (2018).
[3] A. Stute et al., Nature **485**, 482-485 (2012).

Q 54.5 Thu 15:00 Q-H12

Coherent manipulation of RF-dressed qubit states in a single ^{40}Ca^{+} ion — •Pascal Baumgart, Hubert Lam, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, D-66123 Saarbrücken

Fluctuating environmental magnetic fields are detrimental for quantum coherence of Zeeman levels of single trapped ions, which may be utilised as stationary quantum bits in quantum communication protocols. By properly dressing the Zeeman levels, one may create magnetic field-independent qubits (clock transitions) [1]. We study the dressed manifolds of the $S_{1/2}$ and $D_{5/2}$ levels in a single ^{40}Ca^{+} ion by Ramsey spectroscopy, combining RF and laser excitation (similar to [2]), with the perspective of storing quantum information in magnetic field-insensitive qubits with long coherence time.

[1] N. Aharon et al., New J. Phys. **21**, 083040 (2019)
[2] K. N. Dietze, MSc Thesis, TU Braunschweig, (2019)

Q 54.6 Thu 15:15 Q-H12

Quantum teleportation based on a full 4-state atom-photon Bell measurement — •Jan Arenskötter, Omar Elshehy, Christian Haen, Floriane Brunel, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, D-66123 Saarbrücken

The projection on Bell states is a key procedure for quantum-state teleportation and for entanglement swapping schemes as required for a quantum repeater [1,2]. We present a scheme that distinguishes between all four hybrid atom-photon Bell-states. It is based on heralded absorption [3] of the photonic qubit by a ^{40}Ca^{+} ion whereby the non-absorbed photons pass the ion in a second passage by a time delayed back-reflection. The scheme is demonstrated via atom-to-photon quantum teleportation of a qubit encoded in the $D_{5/2}$ Zeeman sub-levels of the ion onto the polarization qubit of a single 854 nm photon. We use a cavity-enhanced spontaneous parametric down-conversion source in interferometric configuration as resource of polarization entanglement which is tailored to match the $D_{5/2}$ - $P_{3/2}$ transition at 854 nm. Quantum process tomography between the atomic input states and the photonic output states validates the successful projection onto the

Bell-states.

[1] M. Zukowski et al., Phys. Rev. Lett. **71**, 4287 (1993)
[2] H.-J. Briegel et al., Phys. Rev. Lett. **81**, 5932 (1998)
[3] C. Kurz et al., Nat. Commun. **5**, 5527 (2014)

Q 54.7 Thu 15:30 Q-H12

Simultaneous single-photon extraction from two ^{40}Ca^{+} ions in a single trap — •Max Bergerhoff, Omar Elshehy, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Atom-photon interfaces [1,2] are a basic requirement for any ion-based quantum network [3]. We are pursuing the implementation of a 'quantum repeater cell' according to [4] on the basis of photon emission and absorption; some steps of the required functionality have been realized, such as high-fidelity entanglement between a single ion and a telecom photon [2].

Here, we report an experiment for creating atom-photon entanglement with two ^{40}Ca^{+} ions in the same trap, separately coupled to single-mode fibers. We present the optical setup to separate the 854 nm photons from the two ions and characterize it with arrival time measurements of the photons.

The width of the wave packets of the separately collected photons gives us lower bounds for the quantum repeater functionality. We further discuss the g$^{(2)}$-function obtained by correlating arrival times of the two wave packets. We detect 0.56 photon pairs per second.

[1] C. Kurz et al., Nat. Commun. 5, 5527 (2014)
[2] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[3] H. Kimble, Nature 453, 1023-1030 (2008)
[4] D. Luong et al., Appl. Phys. B 122, 96 (2016)