Q 2: Quantum Communication I

Time: Monday 14:30–16:45 Location: P 3

Group Report Q 2.1 Mon 14:30 P 3

Event-ready Bell test using entangled atoms simultaneously closing detection and locality loopholes — •Wenjamin Rosenfeld[1,2], Daniel Burchardt[1], Kai Redeker[1], Robert Garthoff[1], Norbert Ortegel[1], Markus Rau[1], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Bell's inequality allows testing experimentally whether nature can be described in a local-realistic way. In order for such a test to be meaningful, at least two major requirements need to be fulfilled: the detection efficiency of the particles has to be high enough and the measurements on the two sides have to be space-like separated in order to avoid loopholes. It is due to these demanding requirements, that it took more than 40 years of experimental development until such tests became possible.

Here we present our results for a Bell test using heralded entanglement of two neutral Rb-atoms over a distance of 400 m [1]. The obtained violation of $2.22 \pm 0.033 > 2$ provides a strong evidence against local realism. Beyond their fundamental importance such tests also form the basis for novel communication methods like device-independent quantum key distribution. Moreover, entanglement of remote quantum memories is a central building block of future quantum repeaters.

[1] arXiv:1611.04604 [quant-ph]

Q 2.2 Mon 15:00 P 3

Large-Alphabet Quantum Key Distribution Using Spatially Encoded Light — •Tristan Tentrup, Willemijn Luiten, Peter Hooijschuur, Reinier van der Meer, and Pepijn Pinkse — University of Twente, Enschede, The Netherlands

In order to transmit a secret message between a sender (Alice) and a receiver (Bob), both parties need a shared secret for encryption and decryption. Quantum Key Distribution (QKD) provides a secure way of generating such shared keys. The original BB84 protocol uses a two-dimensional polarization basis, limiting the information content of a single photon to 1 bit. Using the position of single photons as one basis and the Fourier space as second basis, one can construct a pair of mutually unbiased higher-dimensional bases. This improves not only the security of the protocol, but also the key generation rate. We present our experimental results with an encoding scheme using a Spatial Light Modulator (SLM) allowing two nearly orthogonal alphabets with in the order of 10^3 symbols and an information content per single photon of about 10 bit.

Q 2.3 Mon 15:15 P 3

Time-Frequency Quantum Key Distribution Over Free Space — •Fabian Beutel[1,2], Jasper Rödiger[1,2], Nicolas Perlot[1], Ronald Freund[1], and Oliver Benson[2] — [1]Fraunhofer Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany — [2]Humboldt-Universität zu Berlin, AG Nanooptik, Newtonstraße 15, 12489 Berlin, Germany

Quantum key distribution (QKD) enables the creation of a common secret key between two remote parties that are connected by a quantum channel. In the time-frequency (TF)-QKD scheme, Alice encodes her bits either in the arrival time (Pulse Position Modulation) or in the center frequency (Frequency Shift Keying) of weak laser pulses. Due to the time-frequency uncertainty relation, an eavesdropper can only extract limited information from intercepting these pulses. As with the traditional BB84 QKD scheme, post processing allows for the distillation of a secret key.

We have successfully implemented the TF-QKD scheme by using mostly off-the-shelf telecom components and avalanche photodiodes operating at 1550 nm. With our setup we achieve secret-key rates of more than 400 kbit/s back-to-back and 80 kbit/s over a 25 km fiber spool. Furthermore, we have tested our scheme over an outdoor free-space test range of 390 m in the Berlin city center and are currently in the process of extending it to longer outdoor test ranges.

Q 2.4 Mon 15:30 P 3

A Compact Quantum Key Distribution Sender Module for Handheld Operation — Gwenaelle Mélen[1], Tobias Vogl[2], Peter Freiwang[2], •Jannik Luhn[2], Clemens Sonnleitner[2], Wenjamin Rosenfeld[2], and Harald Weinfurter[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Ludwig-Maximilians-Universität, Munich, Germany

Quantum Key Distribution (QKD) over free space channels offers a multitude of different application scenarios – provided it can be combined with conventional communication systems. Employing micro-optics and waveguide circuits enables a new level of integration. Here we present a novel miniaturized sender module ready for handheld operation in combination with a tracking receiver.

Our system implements a BB84-like protocol. A visible beacon laser allows aiming and is modulated for synchronization purposes. A classical communication channel between sender and receiver is established by means of a smartphone via Wi-Fi. We will report on results demonstrating secure key rates on the order of a few 100 kBit/s in mounted and a few 10 kBit/s in handheld operation at quantum bit error ratios (QBERs) of less than 2%.

Our concept should enable QKD sender optics no larger than a single match. With this size and robustness it is well suited for a huge variety of communication schemes. It can be integrated in mobile phones or optical wireless systems, but also be combined with classical communication links, e.g., free-space optical systems in urban areas or even micro-satellites thereby enabling global key exchange.

Q 2.5 Mon 15:45 P 3

Photon-photon to atom-photon entanglement transfer — •Stephan Kucera, Jan Arenskötter, Pascal Eich, Matthias Kreis, Philipp Müller, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Implementation of a quantum network with single atoms as quantum nodes and single photons as channels between the nodes requires their interfacing in receiver mode, whereby the photonic qubit is mapped onto the internal degrees of freedom of the atom [1]. Combining such a receiver interface with a source of entangled photon pairs enables the distribution of entanglement between network nodes.

We implemented the heralded state-mapping protocol of [2] to operate a single trapped $^{40}Ca^+$ ion in receiver mode. Using a high-brightness narrowband source of resonant entangled photon pairs, we transferred the photon-photon polarization entanglement to atom-photon entanglement by heralded absorption of one photon of the pair. Quantum state tomography on the polarization qubit of the other photon of the pair and the atomic spin qubit after absorption demonstrates the preservation of the entanglement.

[1] Kurz et al., Phys. Rev. A **93**, 062348 (2016).
[2] Kurz et al., Nat. Commun. **5**, 5527 (2014).

Q 2.6 Mon 16:00 P 3

Spectral properties of single photons from a single Ca^+ ion — •Philipp Müller, Tristan Tentrup, Marc Bienert, Jürgen Eschner, and Giovanna Morigi — Universität des Saarlandes, Experimentalphysik, Campus E 2.6, Saarbrücken

Pure photonic quantum states, such as Fourier-limited single photons, are optimal qubit carriers to attain high bandwidth in quantum communication. They are generated, for example, from a single trapped ion in a Raman-scattering process [1, 2]. The same process allows heralded single-photon absorption [3].

We developed a method, based on resolvent theory and the residue theorem, to calculate the spectro-temporal properties of the Raman-emitted photon for incident light of arbitrary spectrum and for excitation by coherent light or by single photons. We particularly include the branching ratio of the three-level system.

Application to the experimental situation of a trapped single Ca^+ ion allows us to control the atom–photon interaction, optimise the photon-generation efficiency, and generate single photons with tailored properties.

[1] Almendros et al., Phys. Rev. Lett. **103**, 213601 (2009).
[2] Kurz et al., New J. Phys. **15**, 055005 (2013).
[3] Kurz et al., Phys. Rev. A **93**, 62348 (2016).

Q 2.7 Mon 16:15 P 3

Polarization-entangled photon pairs from a cavity-enhanced down-conversion source in Sagnac configuration — •Jan Arenskötter, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

An efficient resource of entanglement in atom–photon-based quantum networks are polarization-entangled photon pairs generated by type-II spontaneous parametric down-conversion.

Up to date, the best entanglement values are achieved by single-pass conversion in Sagnac configuration [1]. On the other hand, the highest pair rates are reported in cavity-enhanced sources [2]. We combine the two approaches and generate frequency-degenerate photon pairs at 854 nm wavelength in a signal- and idler-resonant bow-tie resonator with 10 MHz linewidth, tuned to resonance with the $D_{5/2} \leftrightarrow P_{3/2}$ transition in the $^{40}Ca^{+}$ ion. We achieve a brightness of $5.4 \cdot 10^3\,(\mathrm{s\,MHz\,mW})^{-1}$ fiber-coupled pairs with up to 97 % fidelity (at 20 mW pump power) to a maximally entangled state, whose phase is fully adjustable between Ψ^+ and Ψ^-. This source will be employed in quantum communication experiments [3].

[1] Kuzucu et al., Phys. Rev. A **77**, 032314 (2008).
[2] Luo et al., New J. Phys. **17** 073039 (2015).
[3] Kurz et al., Phys. Rev. A **93**, 62348 (2016).

Q 2.8 Mon 16:30 P 3

Conversion of single photons from a trapped $^{40}Ca^{+}$-ion to the telecom range — •Pascal Eich, Matthias Bock, Matthias Kreis, Stephan Kucera, Jan Arenskötter, Christoph Becher, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

A key ingredient for quantum networks is the controlled generation and distribution of photons as carriers of quantum information, in order to establish the communication between atomic network nodes. For long-range communication, the need for quantum frequency conversion of such photons from atomic wavelengths into the low-fiber-loss telecom range arises.

We generate triggered, polarization-controlled single photons at 854 nm on the $P_{3/2} \leftrightarrow D_{5/2}$ transition of a single trapped $^{40}Ca^{+}$-ion, and investigate their conversion to the telecom O-band at 1312 nm via difference-frequency generation in a nonlinear waveguide. We study the single-photon character as well as the polarization of the photons before and after the conversion process.