Q 34: Quantum Information (Quantum Communication) I

Time: Wednesday 14:00–15:45 Location: S HS 002 Chemie

Q 34.1 Wed 14:00 S HS 002 Chemie

High-resolution spectroscopy of deterministically generated single photons from a single ^{40}Ca^{+} ion — •Matthias Kreis, Konstantin Klein, Jurek Frey, Chrisitan Haen, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Single photons with well-controlled spectral and temporal properties are an essential resource for optical quantum communication protocols. Complementing existing work on the temporal shape of such photons, here we report on the measurement of their spectra, theoretically treated in [1].

We investigate single photons generated from a single ^{40}Ca^{+}-ion by a controlled Raman scattering process in the Λ-shaped 3-level configuration consisting of the $D_{5/2}(m = -5/2)$, $P_{3/2}(m = -3/2)$, and $S_{1/2}(m = -1/2)$ Zeeman states.

The spectra are measured with a temperature-stable, 396-mm long Fabry-Perot cavity with 620 kHz linewidth, a finesse of 611 and 6 % on-resonance transmission, actively stabilized to a 393-nm laser resonant to the ion. Photons are generated with up to 150 kHz repetition rate and detected behind the cavity with up to 30 Hz count rate.

[1] P. Müller et al., Phys. Rev. A **96**, 023861 (2017).

Q 34.2 Wed 14:15 S HS 002 Chemie

Quantum randomness based on single photon anti-bunching — •Xing Chen[1], Jörg Wrachtrup[1,2], and Ilja Gerhardt[1,2] — [1]3. Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology, IQST, Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstraße 1, D-70569 Stuttgart, Germany

The generation of quantum randomness has often be taken for granted, when, for example, laser photons impinge on a beam-splitter. Unfortunately, a large number of assumptions are applied to label this process as a quantum process. While true "loop-hole free" experiments [1] are hard to implement, an intermediate version might deliver the proof if a measurement is based on a quantum process. Here we present our approach to bind the amount of true randomness on a measure of the non-classicality of a single photon stream. Our experimental implementation is based on a single NV-center and the generated single photons impinge on a beam splitter – the outcome of clicks on two single photon detectors is interpreted as ones and zeros. The non-classicality of the stream is testified by an anti-bunching measurement [2], and gives an entropy bound on the quantumness of the generated random numbers.

References: [1] S. Pironio, A. Acin, S. Massar, A. B. de la Giroday, D. N. Matsukevich, P. Maunz, S. Olmschenk, D. Hayes, L. Luo, T. A. Manning, et al., Nature 464, 1021 (2010), ISSN 0028-0836, URL http://dx.doi.org/10. 1038/nature09008. [2] H. Paul, Rev. Mod. Phys. 54, 1061 (1982), URL https://link.aps.org/doi/10.1103/RevModPhys.54.1061.

Q 34.3 Wed 14:30 S HS 002 Chemie

Cavity based production of entangled atom-light Schrödinger-cat states — •Severin Daiss[1], Bastian Hacker[1], Stephan Welte[1], Lukas Hartung[1], Armin Shaukat[1], Stephan Ritter[1,2], Lin Li[1,3], and Gerhard Rempe[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching — [2]Present address: TOPTICA Photonics AG, Lochhamer Schlag 19, 82166 Gräfelfing — [3]Present address: Huazhong University of Science and Technology, Wuhan 430074, China

Quantum mechanics allows for the entanglement of microscopic and macroscopic states, as illustrated by Schrödinger's famous gedanken experiment [1]. An experimentally accessible model system uses the superposition of optical coherent states with different phases as a macroscopic system. It is decribed by continuous variables and its size can be tuned with the average number of photons. To produce a Schrödinger cat state, we reflect a coherent pulse from an atom-cavity system, entangling the atomic spin with the phase of the incoming pulse [2]. Manipulating and measuring the atom allows to produce a plethora of different optical cat states with possible applications in continuous-variable quantum communication.

[1] E. Schrödinger, *Naturwissenschaften* **23**, 807 (1935)
[2] B. Wang and L.-M. Duan, *Phys. Rev. A* **72**, 022320 (2005)

Q 34.4 Wed 14:45 S HS 002 Chemie

Single atoms in crossed fiber cavities — •Dominik Niemietz, Manuel Brekenfeld, Joseph D. Christesen, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Garching, Deutschland

Cavity quantum electrodynamics provides a rich toolbox for the investigation of fundamental phenomena in quantum physics through increased light-matter coupling which enables many intriguing applications in quantum information processing [1]. A new manufacturing process of cavity mirrors [2, 3] paves the way for fiber cavities which have small mode volumes and therefore larger coupling rates. Due to their smaller dimensions, fiber cavities also allow for new cavity geometries, including coupling a single emitter to two independent and perpendicular cavity modes. We have set up a new experiment consisting of two crossed fiber cavities which realizes this unique cavity geometry. We will present measurements on trapped atoms coupling to both cavities including first results of a new quantum memory scheme.

[1] Reiserer et al., Rev. Mod. Phys. 87, 1379 (2015)
[2] Hunger et al., New J. Phys. 12, 065038 (2010)
[3] Uphoff et al., New J. Phys. 17, 013053 (2015)

Q 34.5 Wed 15:00 S HS 002 Chemie

High-dimensional multiport for structured photons — •Robert Fickler[1,2], Florian Brandt[1], Frederic Bouchard[3], and Marcus Huber[1] — [1]Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Vienna, Austria — [2]Laboratory of Photonics, Tampere University of Technology, Tampere, Finland — [3]Department of Physics, University of Ottawa, Ottawa, Canada

Light with a complex transverse amplitude structure invokes interesting fundamental properties and enables novel applications in classical and quantum optical experiments. One particularly interesting application is the use of structured photons as high-dimensional quantum states that are known to be beneficial in various quantum information tasks. However, to use their full potential the ability to perform any unitary operations is indispensable. So far, only cyclic operations on a specific subset of spatial modes, i.e. azimuthally structured photons, have been realized. Here, we present a scheme to perform any unitary operation on all transverse spatial modes using multiple phase modulations, which are designed by wavefront matching techniques. We implement this so-called multiport for spatial modes by multiple reflections of a phase-only spatial light modulator and perform a broad range of single photon operations, including X and Z-gates for all types of spatial modes and controlled quantum gates for high-dimensional quantum states. Our result will pave the way to perform quantum computation tasks using only one beam path without the need for interferometric setups.

Q 34.6 Wed 15:15 S HS 002 Chemie

Entanglement protection of high-dimensional states by adaptive optics — •Giacomo Sorelli[1], Nina Leonhard[2], Vyacheslav N. Shatokhin[1], Claudia Reinlein[2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg i. Br. — [2]Fraunhofer-Institut für Angewandte Optik und Feinmechanik IOF, Jena

High-dimensional, discrete quantum systems (qudits) present several advantages over simple two-level systems (qubits). In particular, qudits increase the information encoded in a single carrier. Besides, high-dimensional bases result in stronger violations of Bell inequalities, which can enhance the security of entanglement-based quantum key distribution. Spanning a discrete, infinite-dimensional Hilbert space, photonic orbital angular momentum (OAM) states are suitable candidates for the realisation of such high-dimensional states. On the downside, the defining feature of OAM-carrying light beams, namely their helical wave front, is fragile with respect to turbulence induced phase distortions.

We consider the potential of adaptive optics (AO) to protect entanglement of high-dimensional OAM states against detrimental atmospheric effects. We show how AO is able to reduce crosstalk among the OAM modes, and consequently the entanglement decay as well as photon losses. Finally, a test of the AO-stabilised output state against high-dimensional Bell inequalities shows that the transmitted entanglement allows for secure communication, even under strong turbulence.

Q 34.7 Wed 15:30 S HS 002 Chemie

Entanglement dynamics of orbital angular momentum qubit states upon diffraction on 'cake-slice' apertures — •Sabrina Unmüssig, Giacomo Sorelli, Vyacheslav N. Shatokhin, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Light beams carrying orbital angular momentum (OAM) have attracted much interest because of their capacity to encode high-dimensional quantum states in their phase fronts. When such beams are diffracted on obstacles [1], their phase fronts get distorted. This leads to the spreading of the initial, well-defined OAM state over the OAM basis and, as a consequence, to the loss of information.
In the case of diffraction on 'cake-slice' apertures, the product of the width $\Delta\ell$ of the output distribution of OAM states and of the angular uncertainty $\Delta\phi$, defined by the opening angle of the aperture, is bounded from below by the uncertainty principle for angular position and momentum [2]. We study the output entanglement of a pair of counterpropagating photons, prepared initially in a maximally entangled OAM qubit state, upon diffraction on two identical 'cake-slice' apertures. We vary the apertures' opening angle and analyze the resulting entanglement loss in terms of the above uncertainty relation [2].

[1] G. Sorelli et al. *Phys. Rev. A* **97**, 013849 (2018).
[2] S. Franke-Arnold et al. *New J. Phys.* **6**, 103 (2004)