Q 32: Quantum information: Atoms and ions III

Time: Tuesday 14:00–16:00 Location: A 310

Group Report Q 32.1 Tue 14:00 A 310

Strong coupling between single atoms and non-transversal photons — •Jürgen Volz, Christian Junge, Danny O'Shea, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien, Atominstitut, Stadionallee 2, A-1020 Wien, Austria

The interaction between single atoms and single photons lies at the heart of quantum optics and has been investigated in a number of groundbreaking experiments with high-finesse cavities confining the photons. In this context, whispering-gallery-mode (WGM) microresonators have recently demonstrated their high potential as quantum technological devices because they achieve ultra high quality factors and, at the same time, enable in- and out-coupling of light with near-unit efficiency using tapered fiber couplers.

Remarkably, photons in such resonators are in general not transversally polarized and the electric field amplitude can have a strong component in the direction of propagation. Here, we experimentally demonstrate that the presence of this longitudinal field component significantly alters the physics of light–matter interaction. As a model system, we strongly couple single ^{85}Rb atoms to an ultra high-Q bottle-microresonator — a novel type of WGM microresonator. Our spectroscopic data agrees well with the predictions of a generalized theoretical model which includes a full vectorial description of the resonator modes. As an application, we describe our progress towards the realization of a four-port device capable of coherently routing photons between two optical fibers coupled to the resonator mode.

Q 32.2 Tue 14:30 A 310

High fidelity state-selective detection by scattering laser light — •Sabine Wölk and Christof Wunderlich — Experimentelle Quantenoptik, Universität Siegen, Siegen, Germany

An important ingredient for experiments in quantum information science is efficient quantum state-selective detection. With trapped ions high fidelity, single-shot detection of qubit states by scattering and detecting near-resonant laser light is state-of-the-art. The fidelity of detection could be limited, because during the measurement process it is possible that the ion changes its state. This could happen, for example, through spontaneous emission or off-resonant excitations.

For ions, where only one of the qubit states can decay to the other state and then stays there, detection schemes exist that take this effect into account [1, 2]. However, for ions like $^{171}Yb^+$ both qubit states can be populated during detection. Therefore, we have to take into account that not only one but several state-changes are possible during one measurement. In this talk we present generalizations of existing measurement schemes to this type of ions, discuss new approaches, and present detailed simulations.

[1] A. H. Myerson et. al., Phys. Rev. Lett. **100**, 200502 (2008)
[2] B. Hemmerling et. al., New J. of Phys. **14**, 023043 (2012)

Q 32.3 Tue 14:45 A 310

Laser Quantum Control of ^{9}Be$^+$ Using an Optical Frequency Comb — •Anna-Greta Paschke[1], Malte Niemann[1], Timko Dubielzig[1], Martina Carsjens[1,2], Matthias Kohnen[2,1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]PTB Braunschweig

A CPT symmetry test experiment based on a g-factor comparison between single trapped (anti-)protons is currently being designed in our group. We aim to overcome the main experimental challenge, single-shot state readout for single (anti-)protons, by transferring their spin states to a co-trapped "logic" ^{9}Be$^+$ ion for readout using quantum logic operations [Heinzen and Wineland, PRA **42**, 2977 (1990)].

At low magnetic fields, the required quantum logic operations on ^{9}Be$^+$ are typically carried out using stimulated Raman two-photon transitions driven by pairs of phase-coherent CW laser fields. Their detuning is near-resonant with the qubit splitting of typically only a few GHz. Our experiment requires a rather high magnetic field (>1 T). The resulting qubit splitting easily exceeds 28 GHz and renders the CW approach unattractive. We explore optical frequency combs [Hayes *et al.*, PRL **104**, 140501 (2010)] for driving stimulated Raman transitions in ^{9}Be$^+$. Here, a considerable experimental challenge arises from the small excited state fine structure splitting of ≈ 200 GHz, which requires a careful design of the comb's spectral properties. We discuss stimulated Rabi rates, spontaneous scattering rates, spectral compression and spectral pulse shaping in order to obtain an optimized spectrum.

Q 32.4 Tue 15:00 A 310

Controlled emission and absorption of single photons by two distant single ions — •Michael Schug[1], Jan Huwer[1,2], Christoph Kurz[1], Philipp Müller[1], and Jürgen Eschner[1] — [1]Universität des Saarlandes, Experimentalphysik, Campus E2 6, 66123 Saarbrücken, Germany — [2]ICFO - Institut de Ciences Fotoniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain

A prerequisite for the realization of a quantum network is controlled emission and absorption of single photons by a single atom. Here we present controlled quantum interaction between two remotely trapped calcium ions by single photons. We release a single photon with controlled temporal shape from the sender ion and transmit it over one meter distance to the receiver ion. There we detect photon absorption with a quantum jump scheme. In continuous photon generation mode, the absorption reduces significantly the lifetime of the long lived $D_{5/2}$ state at the receiver ion. For triggered photon generation, we observe coincidences between the quantum jump event and the emission trigger of a photon.

Q 32.5 Tue 15:15 A 310

Photon blockade meets electromagnetically induced transparency — •Haytham Chibani[1], Eden Figueroa[1], James Alves De Souza[2], Celso Jorge Villas Boas[2], and Gerhard Rempe[1] — [1]Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Universidade Federal de São Carlos, Departamento de Física, 13565-905 - Sao Carlos, SP - Brasil

One of the outstanding goals of quantum optics is the realization of controllable nonlinearities at the level of single quanta of matter and light. Here, we theoretically study the optical control of the quantum dynamics of a system which merges single-atom, cavity quantum electrodynamics with electromagnetically induced transparency, namely a three-level atom strongly coupled to a high-finesse cavity. We explore the photon statistics of the light emitted from the cavity by calculating the equal-time second-order intensity correlation function $g^{(2)}(0)$. We find a rich structure in the behavior of $g^2(0)$ which ranges from strong anti-bunching ($g^{(2)}(0) \approx 0$) to strong bunching ($g^{(2)}(0) \approx 100$), and which can be optically tuned via the control field intensity. We also show that when the system is strongly driven, $g^2(0)$ shows two anti-bunching dips at different control field intensities resulting from a single photon and a two-photon blockade respectively. The observed quantum control paves the way towards the implementation of a novel quantum device which allows the switching and/or the attenuation of the amplitude noise of a laser beam.

Q 32.6 Tue 15:30 A 310

An optical resonator as a model for single-photon-single-atom absorption experiments — •Marianne Bader[1,2], Simon Heugel[1,2], Alexander Chekhov[1,3], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Erlangen, Germany — [3]Department of Physics, M.V. Lomonosov Moscow State University, Russia

An optical resonator can be used as a model system for the dynamics of the interaction of a single photon and a two-level system. Following this comparison, the energy stored inside the resonator is an analogue to the probability for absorption of the photon by the two-level system. Both systems respond in a similar way to the temporal profile of the incident light field [1]. For both, resonators and two-level systems, an optimized process is achieved by using an exponential rising pulse with a time constant matching the lifetime of the system. Using such an optimal pulse shape, the above mentioned processes reach an unit efficiency under idealized conditions.

In this contribution, we present experiments on coupling to a resonator and discuss the influence of various pulse shapes to the energy storage efficiency.

[1] Heugel et al., Laser Physics 19 (2009)

Q 32.7 Tue 15:45 A 310

A reversible optical memory for twisted photons — •Dominik Maxein[1], Lucile Veissier[1], Adrien Nicolas[1], Lambert Giner[1], Alexandra S. Sheremet[2], Elisabeth Giacobino[1], and Julien Laurat[1] — [1]Laboratoire Kastler Brossel: Université Pierre et Marie Curie, École Normale Supérieure, and CNRS, 4 place Jussieu, 75252 Paris Cedex 05, France — [2]Department of Theoretical Physics, State Polytechnic University, 195251, St.-Petersburg, Russia

"Twisted" single-photons carrying an orbital angular momentum (OAM) are promising information carriers in various quantum information protocols. They indeed offer the possibility of encoding and processing of information in high-dimensional Hilbert spaces, thus potentially allowing for higher efficiencies and enhanced information capacity. To use these states in quantum networks, light-matter interfaces play a crucial role, e.g. the reversible mapping of OAM into and out of atomic memories. Seminal experiments in this direction with "bright" OAM-carrying beams have already been performed [Pugatch et al, PRL **98**, 203601 ('07) and Moretti et al, PRA **79**, 023825 ('09)]

Here, we report on a multimode optical memory for the storage and retreival of the OAM of light, for the first time at the single-photon level. The light is mapped into and out of a cold atomic ensemble, using the dynamic electromagnetically-induced transparency protocol. We use very faint light pulses in Laguerre-Gaussian modes as signal and show that the handedness of their helical phase structure is preserved. This opens the possibility to the storage of qubits encoded as superpositions of orbital angular momentum states.