Q 51: Quantum Optical Correlations

Time: Thursday 14:30–16:30 Location: HS 1199

Invited Talk Q 51.1 Thu 14:30 HS 1199

From the origin of antibunching to novel quantum light sources based on two-photon interference — •Martin Cordier, Luke Masters, Gabriele Maron, Xin-Xin Hu, Lucas Pache, Philipp Schneeweiss, Max Schemmer, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Generating useful quantum states of light is key to many applications in quantum science and technology. Here, I will report on a new approach to controlling and tailoring the photon statistics of light fields. It is based on an effect, which we put into evidence in a recent experiment and which challenges the conventional notion that a single two-level emitter can only scatter one photon at a time [1]. There, we show that photon antibunching in resonance fluorescence arises from the destructive interference between two types of two-photon scattering processes, referred to as coherent and incoherent scattering. Building on this insight, we also study the collective enhancement of this incoherently scattered two-photon component when laser light propagates through an atomic ensemble. By adjusting the number of atoms and the laser detuning, we have full control over the two-photon interference, which allows us to tune the photon statistics of the transmitted light from strong photon bunching to antibunching [2,3].

[1] Masters et al., Nature Photonics 17, 972 (2023). [2] Prasad et al., Nature Photonics 1 (2020). [3] Cordier et al., Phys. Rev. Lett. 131, 183601 (2023).

Q 51.2 Thu 15:00 HS 1199

Boson bunching is not maximized by indistinguishable particles — •Benoît Seron[1], Leonardo Novo[1,2], and Nicolas J. Cerf[1] — [1]Centre for Quantum Information and Communication, Brussels, Belgium — [2]International Iberian Nanotechnology Laboratory (INL), Braga, Portugal

Boson bunching is amongst the most remarkable features of quantum physics. A celebrated example in optics is the Hong-Ou-Mandel effect, where the bunching of two photons arises from a destructive quantum interference between the trajectories where they both either cross a beam splitter or are reflected. This effect takes its roots in the indistinguishability of identical photons. Hence, it is generally admitted – and experimentally verified – that bunching vanishes as soon as photons can be distinguished, e.g., when they occupy distinct time bins or have different polarizations. Here we disproof this alleged straightforward link between indistinguishability and bunching by exploiting a recent finding in the theory of matrix permanents. We exhibit a family of optical circuits where the bunching of photons into two modes can be significantly boosted by making them partially distinguishable via an appropriate polarization pattern. This boosting effect is already visible in a 7-photon interferometric process, making the observation of this phenomenon within reach of current photonic technology. This unexpected behavior questions our understanding of multiparticle interference in the grey zone between indistinguishable bosons and classical particles.

Q 51.3 Thu 15:15 HS 1199

Superradiant bursts of light from cascaded quantum emitters: Experiment on photon-photon correlations — Constanze Bach, Christian Liedl, Arno Rauschenbeutel, •Philipp Schneeweiss, and Felix Tebbenjohanns — Department of Physics, Humboldt-Universität zu Berlin, Germany

Recently, superradiant bursts of light have been, for the first time, experimentally observed for a cascaded quantum system. This was realized using an ensemble of waveguide-coupled two-level atoms that exhibit chiral, i.e., propagation direction-dependent coupling to the waveguide mode. Here, we experimentally study this collective radiative decay of a fully inverted atomic ensemble and measure the second order quantum correlation function, $g^{(2)}(t_1, t_2)$, of the light emitted by the atoms into the waveguide. We observe $g^{(2)} \approx 2$ in the beginning of the decay ($t_1 = 0, t_2 = 0$), followed by a decrease to $g^{(2)}(t_1, t_2 = t_1) \approx 1$ within the characteristic time scale of the burst dynamics. This can be interpreted by assuming that, following an initially independent emission, the atoms synchronize during their decay, leading to an emission that more and more resembles the photon statistics of a coherent state. In addition to these observations, we find an anti-correlation of photon detection events, i.e., $g^{(2)}(t_1, t_2) < 1$, in certain parameter regions in which $t_1 \neq t_2$. Our measurement outcomes can be well described with a model based on the truncated Wigner approximation. Our findings contribute to understanding the fundamentals of light–matter interaction and help engineering protocols for the generation of non-classical light. [1] C. Liedl et al., arXiv:2211.08940

Q 51.4 Thu 15:30 HS 1199

Multiple Quantum Coherence signals by multilevel atoms with internal degeneracy — •Vyacheslav Shatokhin[1,2] and Andreas Buchleitner[1,2] — [1]Physikalisches Institut der Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing der Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Manifestations of dipole-dipole interactions in dilute thermal atomic vapors are difficult to sense, because of strong inhomogeneous broadening. Recent experiments with alkali-metal atoms revealed signatures of such interactions in fluorescence detection-based measurements of multiple quantum coherence (MQC) signals. We develop an open quantum systems theory of MQC signals in dilute thermal gases, which allows us to obtain good qualitative agreement with the experimental observations.

In the present talk, we outline the characteristic features of our theory which incorporates the vector character of the atomic dipoles, as well as driving laser pulses of arbitrary strength and polarization, includes the far-field coupling between the dipoles, which prevails in dilute ensembles, and effectively accounts for the atomic motion via a disorder average. We then discuss the impact of the multilevel internal structure of alkali-metal atoms on the fundamental properties of MQC signals.

Q 51.5 Thu 15:45 HS 1199

Large Deviation Statistics of Adiabatic Open Quantum Dynamics — •Paulo Paulino[1], Igor Lesanovsky[1,2], and Federico Carollo[1] — [1]Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

The state of an open quantum system undergoing an adiabatic process evolves by following the instantaneous stationary state of its time-dependent dynamical generator. This observation allows one to completely characterize, for generic adiabatic evolutions, the (average) master equation dynamics of the system. However, it does not provide information about the behavior of the system in single dynamical realizations, or single experimental runs. As a consequence, our understanding of full counting statistics of interesting quantities, such as the number of photons emitted by a slowly-driven optical system or the time-integrated stochastic entropy production in an adiabatic machine, remains rather limited. Here, we make progress in this direction and derive the full counting statistics of emission-related observables in generic adiabatic open quantum dynamics. We further compute the probability associated with any possible trajectory of the observable and devise a dynamics which can realize it as its typical behavior. Our findings provide a way to characterize and engineer adiabatic open quantum dynamics as well as to fully control their fluctuating behavior.

Q 51.6 Thu 16:00 HS 1199

Multi-particle Hong-Ou-Mandel interference with Ultracold Atoms — •Martin Quensen, Mareike Hetzel, and Carsten Klempt — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany

Two photons, coupled by a 50:50 beamsplitter, always exit at the same output port. This effect was first observed in 1987 by Hong, Ou and Mandel and lies at the heart of quantum optics, as it describes the interference of single, indistinguishable bosons.

Here, we demonstrate this effect with massive particles instead of photons, and extend it to the interference of up to eight atoms at once. To achieve this, we employ spin-changing collisions in a Bose-Einstein condensate of Rb-87 and generate coherent superpositions of multiple twin-atom pairs. A dynamic, low-noise microwave source realizes the 50:50 beamsplitter-like coupling via Rabi oscillations. We use an optical-molasses-based detection setup to count the number of atoms in the output ports with single-atom accuracy.

The observation of the Hong-Ou-Mandel effect in our setup paves the way for the generation and analysis of entangled quantum states of massive particles with increasing fidelity and atom number. The concepts can be employed for realizing Heisenberg-limited atom interferometry with mesoscopic states of matter.

Q 51.7 Thu 16:15 HS 1199

Simulations of Hong-Ou-Mandel interference for parametric down-conversion in lossy waveguides — •Denis Kopylov[1,2], Polina Sharapova[1], Silia Babel[3], Laura Padberg[3], Michael Stefszky[3], Christine Silberhorn[3], and Torsten Meier[1,2] — [1]Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [2]Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [3]Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Nowadays, parametric down-conversion (PDC) provides a flexible framework for the experimental realization of various types of non-classical light. Waveguide-based PDC sources are especially relevant for integrated quantum optical circuits, however imperfections of long nonlinear waveguides may lead to losses of the PDC field and consequently the desired quantum state cannot be realized exactly.

In this work we study numerically the Hong-Ou-Mandel (HOM) interference for PDC, generated in lossy nonlinear waveguides and show how the HOM interference pattern reveals the presence of losses. In our approach we solve the Heisenberg-Langevin equation for broadband multimode type-II PDC. Hong-Ou-Mandel interference is calculated in the framework of Gaussian states detected with click-detectors which allow us to study the non-perturbative PDC regime. The difference between internal waveguide losses and coupling losses of PDC on the HOM interference is demonstrated and analyzed.