Q 24: Quantum Effects: Entanglement and Decoherence III

Time: Tuesday 14:30–16:30 Location: B/gHS

Q 24.1 Tue 14:30 B/gHS

Loss-tolerant hybrid measurement test of Bell's inequality with weakly amplified N00N states — •Falk Töppel[1,2] and Magdalena Stobińska[3,4] — [1]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/Bldg. 24, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, Universität Erlangen-Nürnberg, Staudtstraße 7/B2, 91058 Erlangen, Germany — [3]Institute of Theoretical Physics and Astrophysics, University of Gdańsk, ul. Wita Stwosza 57, 80-952 Gdańsk, Poland — [4]Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland

Despite recent experimental and theoretical advances, thus far all Bell tests have suffered from loopholes. Most optical Bell tests rely on inefficient discrete-outcome measurements, often provided by photon counting detection. One possible way to close the detection loophole in optical Bell tests is to involve efficient continuous-variable measurements instead, such as homodyne detection. Here, we study a hybrid test of the Clauser-Horne-Shimony-Holt (CHSH) inequality that combines photon counting and homodyne detection applied to amplified two-photon N00N states. The scheme proposed is remarkably robust against experimental imperfections and suits the limits of current technology. It may therefore constitute an alternative platform for a loophole-free Bell test or other important quantum-technological applications. Furthermore, as experimentally accessible macroscopic quantum states of light are considered, our work also contributes to the exploration of entangled macroscopic quantum systems.

Q 24.2 Tue 14:45 B/gHS

Nonlocal photon correlations and violation of Bell inequalities for spatially separated classical light fields — •Daniel Bhatti[1], Raimund Schneider[1], Thomas Mehringer[1,2], Steffen Oppel[1], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany

Recently it was proposed that a violation of Bell's inequalities may not only be used to quantify correlations between quantum systems but also between coupled degrees of freedom of classical systems [1-3]. Such strong correlations among coupled degrees of freedom of classical systems, called classical entanglement, have been recently used to describe the coherence properties of classical light beams, either for discrete or continuous variables [1,3]. Here we demonstrate that Bell's inequalities can be equally violated with spatially separated particles produced by classical systems, i.e., photons emitted by classical light sources recorded in spatially separated modes. We thus show that non local multiparticle entanglement is not restricted to the quantum world but may be observed also with classical systems.

[1] B. N. Simon et al., Phys. Rev. Lett 104, 023901 (2010).

[2] K. H. Kagalwala, G. Di Giuseppe, A. F. Abouraddy, B. E. Saleh, Nat. Photonics 7, 72 (2013).

[3] P. Chowdhury, A. S. Majumdar, G. S. Agarwal, Phys. Rev. A 88, 013830 (2013).

Q 24.3 Tue 15:00 B/gHS

Interference in Photon Absorption and Emission by a single Atom — •Andreas Alexander Buchheit and Giovanna Morigi — Saarland University, Saarbrücken, Germany

The quest for systematically determining the fundamental constants requires new levels of precision in atomic spectroscopy. Frequency shifts of the order of a few hundred Hertz can be relevant for verifying the predictions of quantum electrodynamics such as the prediction for the proton radius. We discuss the derivation of a master equation for the spontaneous decay of a multilevel atom and set our focus on interference effects such as processes which can lead to the decay of a pairs of levels into a single state. These processes are typically neglected, but are present in the systematic derivation of the master equation of a multilevel atom. We analyse in detail their physical origin and determine the order of magnitude of their effect on the spectroscopic properties of the Hydrogen atom.

Q 24.4 Tue 15:15 B/gHS

Single-photon and macroscopical entanglement using nuclear ensembles — Wen-Te Liao[1,2,3], Christoph H. Keitel[1], and •Adriana Pálffy[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Center for Free Electron Laser Science, Hamburg, Germany

Recent developments of x-ray optics lay the foundation for controlling the quantum behavior of single x-ray photons, possibly by exploiting suitable resonant nuclear transitions. Here we propose a setup that actively manipulates the scattering channels of single x-ray quanta in nuclear forward scattering to create a nuclear polariton which propagates in two opposite directions in a ^{57}Fe sample [1]. The two counter-propagating polariton branches are entangled by a single x-ray photon and create a sub-Ångstrom wavelength standing wave excitation pattern that can be used as a flexible tool to dynamically probe matter on the atomic scale. As a second aspect we show that by combining an x-ray parametric down-conversion source and x-ray interferometry with nuclear resonant scattering techniques, two macroscopic crystals hosting Mössbauer nuclei located each on an interferometer arm can be entangled [2]. The coherence time of the entanglement state can be prolonged up to approx. 100 nanoseconds, opening new avenues for studies of the boundary between the quantum and classical worlds.

[1] W.-T. Liao, C. H. Keitel and A. Pálffy, Phys. Rev. Lett. 112, 057401 (2014).

[2] W.-T. Liao, C. H. Keitel and A. Pálffy, arXiv:1407.3292 (2014).

Q 24.5 Tue 15:30 B/gHS

The Singular Value Decomposition and the dimension of Bell test observables — •Michael Epping, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Deutschland

CHSH-type Bell inequalities can be written as linear combinations of expectation values in different settings. In the bipartite scenario the coefficients form a matrix. Bounds on the maximal value of Bell inequalities are called Tsirelson bounds. A simple Tsirelson bound is essentially given by the maximal singular value of this matrix of coefficients. The minimal dimension of observables that enable to reach the bound is a property of the coefficient matrix defining the Bell inequality. In this talk upper bounds on this minimal dimension are discussed. Roughly speaking low dimensional observables suffice, if the structure of the coefficient matrix is simple in a certain sense. The result will be illustrated with examples where the upper bound on the minimal dimension is two or even one.

Q 24.6 Tue 15:45 B/gHS

Entanglement of twisted photons in a $e^-e^+ \to 2\gamma$ annihilation — •Dmitry Karlovets[1,2] and Antonino Di Piazza[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [2]Tomsk Polytechnic University, Lenina 30, 634050 Tomsk, Russia

We show that in the electron-positron annihilation process $e^-e^+ \to 2\gamma$, when one of the initial particles carries some orbital angular momentum (vortex state) [1], the final photons become entangled in their quanta of orbital angular momentum [2]. This entanglement takes place only when the final photons are measured not as "pure" vortex states but as coherent superpositions with a non-vanishing quantum uncertainty of the orbital angular momentum, exactly as in quantum optics with twisted photons. Possibilities for experimental observation of such an entanglement and further generalizations to other quantum processes are discussed.

[1] D. V. Karlovets, Phys. Rev. A vol. 86, 062102 (2012). [2] D. V. Karlovets and A. Di Piazza, in preparation.

Q 24.7 Tue 16:00 B/gHS

Twisted photons' state evolution and bipartite entaglement decay in atmospheric turbulence — •Francesco Campaioli, Vyacheslav Shatokhin, and Andreas Buchleitner — Hermann-Herder-Straße 3 79104 Freiburg im Breisgau

When a photon with a well defined orbital angular momentum (OAM) traverses the atmosphere, its states spreads over the unbounded OAM basis. We study how the size of the effective finite-dimensional Hilbert space scales, as a function of the initial state and of the strength of the atmospheric turbulence. Our results are then used to infer the

dynamical evolution of bipartite OAM states and of the entanglement they carry, under the effect of weak turbulence.

Q 24.8 Tue 16:15 B/gHS

Distinguishing decoherence from alternative quantum theories by dynamical decoupling — •Christian Arenz[1], Robin Hillier[2], Martin Fraas[3], and Daniel Burgarth[1] — [1]Department of Mathematics, Aberystwyth University, Aberystwyth, UK — [2]Department of Mathematics and Statistics, Lancaster University, Lancaster, UK — [3]Theoretische Physik, ETH Zürich, Zürich, Switzerland

A longstanding challenge in the foundations of quantum mechanics is the verification of alternative collapse theories despite their mathematical similarity to decoherence. To this end, we suggest a novel method based on dynamical decoupling. Experimental observation of nonzero saturation of the decoupling error in the limit of fast decoupling operations can provide evidence for alternative quantum theories.