Q 34: Quantum Effects: Entanglement and Decoherence

Time: Wednesday 14:30–16:45 Location: P 4

Group Report Q 34.1 Wed 14:30 P 4

Tunable entanglement resource in elastic electron-exchange collisions out of chaotic spin systems — •Bernd Lohmann[1], Karl Blum[1], and Burkhard Langer[2] — [1]Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Strasse 9, 48149 Münster, Germany — [2]Physikalische Chemie, Freie Universität Berlin, Taku-Strasse 3, 14195 Berlin, Germany

Elastic collisions between initially unpolarized electrons and hydrogen-like atoms are discussed aiming to analyze the entanglement properties of the correlated final spin system. Explicit spin-dependent interactions are neglected and electron exchange only is taken into account. It is shown that the final spin system is completely characterized by a single spin correlation parameter depending on scattering angle and energy. Its numerical value identifies the final spins of the collision partners to be either in the separable, entangled, or Bell correlated regions.

The symmetry of the scattering process allows for the construction of explicit examples applying methods of classical communication and local operations for illustrating the concepts of nonlocality versus separability.

It is shown that strong correlations can be produced violating Bell's inequalities significantly. Furthermore, the degree of entanglement can be continuously varied simply by changing either the scattering angle and/or energy. This allows for the generation of tunable spin pairs with any desired degree of entanglement. We suggest to use such nonlocally entangled spin pairs as a resource for further experiments, for example in quantum information processes.

Q 34.2 Wed 15:00 P 4

Observation of genuine three-photon interference — •Thomas Kauten[1], Sascha Agne[2], Jeongwan Jin[2], Evan Meyer-Scott[2,3], Jeff Salvail[2], Deny Hamel[4], Kevin Resch[2], Gregor Weihs[1], and Thomas Jennewein[2] — [1]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [2]Institute for Quantum Computing, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada — [3]Department of Physics, University of Paderborn, 33098 Paderborn, Germany — [4]Département de Physique et d'Astronomie, Université de Moncton, Moncton, New Brunswick E1A 3E9, Canada

Multiparticle quantum interference is important for our understanding and exploitation of quantum information and for fundamental tests of quantum mechanics [1]. An example for multi-partite correlations is the Greenberger-Horne-Zeilinger (GHZ) state [2]. In a GHZ-state, three particles are correlated while no pairwise correlation is found. Those strong correlations have been studied theoretically since 1990 but no three-photon GHZ interferometer has been realized experimentally. Here we demonstrate three-photon interference that does not originate from two-photon or single photon interference. We observe phase-dependent variation of three-photon coincidences with $(90.5 \pm 5.0)\%$ visibility [3] in a generalized Franson interferometer [4] using energy-time entangled photon triplets [5].

[1] Pan et al., Rev. Mod. Phys. 84, 777 (2012). [2] Greenberger et al., Am. J. Phys. 58, 1131 (1990). [3] Agne et al., arXiv:1609.07508 (2016). [4] Franson Phys. Rev. Lett. 62, 2205 (1989). [5] Hübel et al., Nature 466, 601-603 (2010).

Q 34.3 Wed 15:15 P 4

Autonomous quantum error correction with application to quantum metrology — •Florentin Reiter[1,2,4], Anders S. Sørensen[3], Peter Zoller[1,2], and Christine A. Muschik[1,2] — [1]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria — [2]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [3]Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen, Denmark — [4]Current address: Harvard University, Department of Physics, 17 Oxford Street, Cambridge, MA 02138, USA

We present a quantum error correction scheme that stabilizes a qubit by coupling it to an engineered environment which protects it against spin- or phase flips. Our scheme uses always-on couplings that run continuously in time and operates in a fully autonomous fashion without the need to perform measurements or feedback operations on the system. The correction of errors takes place entirely at the microscopic level through a build-in feedback mechanism. Our dissipative error correction scheme can be implemented in a system of trapped ions and can be used for improving high precision sensing. We show that the enhanced coherence time that results from the coupling to the engineered environment translates into a significantly enhanced precision for measuring weak fields. In a broader context, this work constitutes a stepping stone towards the paradigm of self-correcting quantum information processing.

Q 34.4 Wed 15:30 P 4

Subradiant Emission from Statistically Independent Classical Light Sources — •Daniel Bhatti[1,2], Raimund Schneider[1,2], 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

Super- and subradiance, i.e., the cooperative emission of spontaneous radiation by an ensemble of identical two-level atoms, is one of the intriguing problems in quantum optics. While superradiance is usually observed from symmetric Dicke-states, subradiance is typically attributed to nonsymmetric Dicke-states [1]. Recent theoretical and experimental investigations of higher-order intensity correlations have shown that even thermal light sources (TLS) are able to emit superradiant light in particular directions [2,3]. Here, we investigate the Nth-order intensity correlation functions of N TLS for different detector configurations leading to the production of directional subradiance. By relating the phenomenon to subradiance of antisymmetric quantum states, we find that the classical directional subradiance reflects a quantum feature. We present the first measurements of directional subradiant emission from TLS confirming the theoretical predictions.

[1] R. H. Dicke, Phys. Rev. 93, 99 (1954).
[2] S. Oppel, et al., Phys. Rev. Lett. 113, 263606 (2014).
[3] D. Bhatti, et al., Phys. Rev. A 94, 013810 (2016).

Q 34.5 Wed 15:45 P 4

Stability of quantum statistical ensembles with respect to local measurements — •Walter Hahn[1,2] and Boris V. Fine[1,2] — [1]Skolkovo Institute of Science and Technology, Moscow (Russia) — [2]Institute for Theoretical Physics, University of Heidelberg (Germany)

We introduce a stability criterion for quantum statistical ensembles describing macroscopic systems. An ensemble is called *stable* when a small number of local measurements cannot significantly modify the probability distribution of the total energy of the system. In this talk, we apply this criterion to lattices of spins-1/2 and particularly focus on recent results obtained in numerical simulations of interacting spin systems. Thereby we show that the canonical ensemble is nearly stable, whereas statistical ensembles with much broader energy distributions are not stable. In the context of the foundations of quantum statistical physics, this result justifies the use of statistical ensembles with narrow energy distributions such as canonical or microcanonical ensembles.

Q 34.6 Wed 16:00 P 4

Two Oscillators and Spectral Entanglement — •Andreas Kurcz and Carsten Henkel — Institute of Physics and Astronomy, University of Potsdam, Karl-Liebknecht-Str. 24/25, 14476 Potsdam, Germany

We consider two coupled oscillators within independent heat baths as a toy-model to study heat transport [1] and non-equilibrium steady states [2] in open quantum systems. We analyse correlation functions of the oscillator coordinates that provide a spectral representation of the covariance matrix familiar from continuous variables [3]. The Fluctuation Dissipation Theorem [4] is applied in order to generalize criteria for entanglement into the frequency domain. One key concept is the linear response matrix whose peaks allow to identfy the normal modes of the coupled system. We explore a wavelet analysis of quadratures to provide a link between entanglement witnesses and experimental protocolls. The model is very genereal and may cover different regimes dependent on the spectral densities of the heat baths, temperatures, and coupling strength.

[1] G. Barton, J. Phys.: Condens. Matter 27, 214005 (2015). [2] I. Dorofeyev, Can. J. Phys. 91, 537 (2013). [3] C. Weedbrook et. al.,

Rev. Mod. Phys. 84, 621 (2012). [4] G. W. Ford, J. T. Lewis, and R. F. O' Connel, Phys. Rev. A 37, 4419 (1988).

Q 34.7 Wed 16:15 P 4

Experimental observation of non-Markovianity in a trapped-ion quantum system — •Matthias Wittemer, Govinda Clos, Ulrich Warring, Heinz-Peter Breuer, and Tobias Schaetz — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Any realistic quantum system interacts with its environment. Thereby, the open system builds up entanglement and correlations with the environment and exchanges information. Trapped ions offer a high level of control of internal and external degrees of freedom and are well-suited to engineer closed and open quantum systems. This enables systematic studies of entanglement, decoherence, and thermalization in quantum systems of variable complexity [1]. With our trapped-ion system we experimentally study the flow of information in a closed quantum system between a subsystem and its environment and characterize associated memory effects [2]. We prepare different environmental states and realize different interactions between system and environment to measure the non-Markovianity as a function of these parameters.

[1] G. Clos *et al.*, Phys. Rev. Lett. **117**, 170401 (2016)
[2] H.-P. Breuer *et al.*, Phys. Rev. Lett. **103**, 210401 (2009)

Q 34.8 Wed 16:30 P 4

Extensions of a quantum transport model of the FMO photosynthetic complex — •Hlér Kristjánsson[1,2], Jonathan Brugger[1], Gabriel Dufour[1], Christian Scheppach[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Alberts-Ludwigs-Universität, Freiburg i. Br., Germany — [2]Blackett Laboratory, Imperial College, London, United Kingdom

The potential role of non-trivial quantum coherence effects in the Fenna-Matthews-Olson (FMO) photosynthetic complex has been the subject of various experiments as well as theoretical quantum transport models since the discovery of remarkably long-lived coherences in the complex ten years ago. The FMO complex connects the photon-capturing antenna to the reaction centre in green sulphur bacteria by acting as a wire for energy transport. It can be modelled as a disordered system with a few sites, each described by a two-level system.

In this talk we consider the model for quantum transport in disordered systems proposed by Walschaers *et al.* [1], based on centrosymmetry of the Hamiltonian and a dominant doublet coupling between the input and output sites. We then discuss three extensions to this model to create a more realistic description of energy transport in the FMO complex: (i) variable energy levels for different sites, (ii) coupling to vibrational modes of the system, and (iii) including the coupling of the wire to both the antenna and the reaction centre.

[1] M. Walschaers, R. Mulet, T. Wellens, and A. Buchleitner, *Phys. Rev. E* **91**, 042137 (2015)