FM 24: Quantum Sensing: Entanglement and Beyond Shot Noise

Time: Monday 16:30–18:30 Location: 3044

FM 24.1 Mon 16:30 3044

Entanglement Enhanced Quantum Microscopy — •Raphael Nold, Joel Schmidt, Tobias Linkewitz, Florian Kaiser, and Jörg Wrachtrup — 3. Physikalisches Institut Universität Stuttgart, Stuttgart, Germany

In metrology, interferometers are widely used for precision measurements. The sensitivity of interferometers with classical light is limited by the shot noise. To overcome this classical standard quantum limit one can make use quantum correlated particles. However, the associated detection schemes are generally very complex and slow. To overcome those issues, we present a nonlinear two-photon interferometer were photons pairs are produced by a PPKTP down converting crystal. By passing through this crystal two times we entangle two paths, which leads to interference in the signal-photon intensity (instead of the ordinary photon pair interference). We exploit the associated measurement speed advantage to investigate the possibility of an entanglement enhanced quantum microscope for cell analysis. Our goal is to enhance hereby the signal to noise ratio beyond the classical limitation.

FM 24.2 Mon 16:45 3044

Squeezing and entanglement in spinor Bose-Einstein condensates — Karsten Lange[1], Jan Peise[1], Ilka Kruse[1], Giuseppe Vitagliano[2,3], Iagoba Apellaniz[3], Matthias Kleinmann[3], Géza Tóth[3], and •Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria — [3]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain

Spin-changing collisions can be employed for the generation of entanglement in spinor Bose-Einstein condensates, in close analogy to optical parametric down-conversion. I will present the creation of two types of entangled states, Twin-Fock states and two-mode squeezed states. Both states can be applied for interferometry beyond the Standard Quantum Limit.

We have demonstrated that such entangled states can be separated in the spatial domain to transfer the entanglement from internal to external degrees of freedom [1]. I will discuss methods to employ spin-entangled Bose-Einstein condensates for inertially sensitive atom interferometers.

[1] K. Lange, J. Peise, B. Lücke, I. Kruse, G. Vitagliano, I. Apellaniz, M. Kleinmann, G. Toth, C. Klempt, Entanglement between two spatially separated atomic modes, Science 360, 416 (2018).

FM 24.3 Mon 17:00 3044

Probing Quantum Vacuum Fluctuations Using Electro-Optical Sampling — •Frieder Lindel[1], Robert Bennett[1,2], and Stefan Yoshi Buhmann[1,2] — [1]Albert-Ludwigs-Universität Freiburg, 79104 Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, 79104 Freiburg, Germany

Quantum vacuum fluctuations of the electromagnetic field present an intrinsic limit to the sensitivity of optic based detectors, such as for example the one used recently to detect gravitational waves. Furthermore they govern important observable processes in nature like spontaneous emission, the Lamb shift or dispersion forces. More recently, a new way to access these fluctuating vacuum fields has been established using electro-optical sampling [1].

Using macroscopic quantum electrodynamics we derive a general theoretical framework for the propagation of a laser field through a nonlinear crystal in the presence of vacuum fluctuations. This formalism includes absorption and dispersion as well as possible effects stemming from scattering events. We apply the framework to explore how electro-optical sampling can be used to probe different properties of the vacuum field in an experiment such as e.g. how it changes in the present of cavities or how one can access their spectral distribution and spatial correlations. Our theory can also be used for the description of spontaneous parametric down-conversion and hence for the generation of entangled photons.

[1] C. Riek et al., Science 350, 420 (2015)

FM 24.4 Mon 17:15 3044

Quantum Fourier Transform algorithm for sensing applications — •Vadim Vorobev, Sebastian Zaiser, Nikolas Abt, Durga Dasari, and Jörg Wrachtrup — 3rd Physical Institute, University of Stuttgart, Stuttgart, Germany

In recent decade several milestones were reached along the way to perform nanolocalised nuclear magnetic resonance sensing with chemical resolution [1,2, 3]. Among the others a significant step towards increasing the resolution of the sensor is the usage of the quantum memory associated with the nuclear spin [4] which gives the possibility to perform correlation spectroscopy measurements with record resolution. The drawback of such approach is a long time overdraft due to the waiting time between the two correlation steps. This time could be efficiently used for storing processing the information sensed by the electron spin within multi qubit register formed by nearby nuclear spins. Here we present an experimental demonstration of the quantum phase estimation algorithm for sensing external classical and quantum signals.

References:
[1] N. Aslam et. al. Science 2017
[2] M. Pfender et. al. Nano Let. 2019
[3] P. Neumann et. al. Science 2010
[4] M. Pfender et. al. Nat. Com. 2017

FM 24.5 Mon 17:30 3044

Maximal quantum Fisher information for mixed states — •Lukas J. Fiderer[1], Julien M.E. Fraïsse[2], and Daniel Braun[1] — [1]Eberhard-Karls-University Tuebingen — [2]Seoul National University

The optimal initial state for estimating a parameter encoded to the state through unitary dynamics has been known since long: an equal superposition of eigenstates corresponding to the largest and smallest eigenvalue of the generator of the unitary dynamics. In principle, such an optimal initial state can be prepared by applying an appropriate unitary transformation to an available pure state.

However, access to pure states is not always granted in realistic measurement setups, for instance, due to noise or interactions with an environment. In the present work, we answer the following question: Given a mixed state, what is the optimal initial state that can be prepared with the help of a unitary transformation?

We give the quantum Fisher information for this optimal initial state and extend results from Pang et al. for optimal quantum metrology with pure states and Hamiltonian control to the regime of mixed states. In particular, we prove that even from thermal states of arbitrary finite temperature we can prepare initial states that allow for Heisenberg scaling.

FM 24.6 Mon 17:45 3044

Approximate quantum non-demolition measurements — Sami Boulebnane, Mischa P. Woods, and •Joseph M. Renes — Institute of Theoretical Physics, ETH Zürich

With the advent of gravitational wave detectors employing squeezed light, quantum waveform estimation—estimating a time-dependent signal by means of a quantum-mechanical probe—is of increasing importance. As is well known, backaction of quantum measurement limits the precision with which the waveform can be estimated, though these limits can in principle be overcome by “quantum nondemolition” (QND) measurement setups found in the literature. Strictly speaking, however, their implementation would require infinite energy, as their mathematical description involves Hamiltonians unbounded from below. This raises the question of how well one may approx- imate nondemolition setups with finite energy or finite-dimensional realizations. Here we consider a finite-dimensional waveform estimation setup based on the “quasi-ideal clock” and show that the estimation errors due to approximating the QND condition decrease slowly, as a power law, with increasing dimension. As a result, we find that good QND approximations require large energy or dimensionality. We argue that this result can be expected to also hold for setups based on truncated oscillators or spin systems.

FM 24.7 Mon 18:00 3044

Fundamental limits of the coherence in a two-component BEC — •Yifan Li[1], Tilman Zibold[1], Boris Décamps[1], Mat-

teo Fadel[1], Paolo Colciaghi[1], Krzysztof Pawlowsky[2], and Philipp Treutlein[1] — [1]Department of Physics, University of Basel — [2]Center for Theoretical Physics, Polish Academy of Sciences, Poland

We report experiments on the fundamental limits of coherence in two-component Bose-Einstein condensates (BECs) of 87Rb on an atom chip. We measure the increase of phase noise with time by performing Ramsey interferometry and find that the coherence of two-component BECs is mainly limited by interaction induced phase noise. This so-called clock-shift effect results in a dominant source of phase noise which depends on the fluctuations of total numbers of atoms and can be only partially canceled in data analysis due to the random nature of atom loss. To further understand the decoherence, we prepare nearly pure BECs in superpositions of hyperfine states and measure the rates of the dominant collisional loss processes. The decoherence process can be mitigated by relaxing the trapping potential and further suppressed by tuning the interactions with a state-dependent potential. Our experimental findings are relevant for compact atomic clocks realized in similar cold or ultracold atomic systems where atomic interactions are a limiting factor.

FM 24.8 Mon 18:15 3044

Investigation of noise sources down to the shot-noise limit in Ytterbium-doped fiber amplifiers — •Alexandra Popp[1,2,3], Victor Distler[4], Kevin Jaksch[1,2,3], Florian Sedlmeir[1,2], Christian R. Müller[1,2], Nicoletta Haarlammert[4], Thomas Schreiber[4], Christoph Marquardt[1,2], Andreas Tünnermann[4], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany. — [2]Department of Physics, University of Erlangen-Nuremberg (FAU), Erlangen, Germany. — [3]SAOT, Graduate School in Advanced Optical Technologies, Erlangen, Germany. — [4]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Jena, Germany.

Ytterbium-doped fiber laser amplifiers are known for their high single-pass gain and average powers up to the kilowatt range in single mode operation. Recently, amplitude noise in these systems has attracted attention due to its suspected capabilities as a potential source of phase disturbance leading to transverse mode instabilities [1]. We use balanced self-homodyne detection to measure the amount of noise in a Ytterbium-doped fiber pre-amplifier typically used in kW experiments, quantifying the impact of different noise sources at various frequencies with respect to the fundamental shot-noise limit.

[1] C. Stihler *et al.* Opt. Express 26, 19489-19497 (2018)