Q 54: Quantum Sensing II (joint session Q/QI)

Time: Thursday 11:00–12:45 Location: HS I PI

Invited Talk Q 54.1 Thu 11:00 HS I PI

New Opportunities for Sensing via Continuous Measurement — •Dayou Yang, Susana F. Huelga, and Martin B. Plenio — Institute of Theoretical Physics, University of Ulm, Ulm, Germany

The continuous monitoring of driven-dissipative quantum optical systems provides key strategies for the implementation of quantum metrology, with prominent examples ranging from the gravitational wave detectors to the emergent driven-dissipative many-body sensors. Fundamental questions about the ultimate performance of such a class of sensors remain open—for example, how to perform the optimal continuous measurement to unlock their ultimate precision; how to effectively enhance their precision scaling towards the Heisenberg limit? In this talk I will present our recent theoretical efforts towards answering these questions. In the first part I will present a universal backaction evasion strategy for retrieving the full quantum Fisher information from the nonclassical, temporally correlated fields emitted by generic open quantum sensors, thereby to achieve their fundamental precision limit. In the second part I will introduce dissipative criticality as a resource for nonclassical precision scaling for continuously monitored open quantum sensors, by establishing universal scaling laws of the quantum Fisher information in terms of critical exponents of generic dissipative critical points.

Q 54.2 Thu 11:30 HS I PI

Efficient simulations for long time dynamics of interacting quantum gases — •Annie Pichery and Naceur Gaaloul — Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Ultra-cold atomic ensembles are a prime choice for sources in quantum sensing experiments. In the case of atom interferometry, long interrogation times are highly desirable to obtain high precision results. This requires a great control of the input states in term of size and position dynamics, as well as an efficient description of the dynamics along the different steps of the evolution time.

Space provides an environment where atom clouds can float for extended times of several seconds, as well as miscibility conditions not possible on ground. However, simulating such dynamics of single species Bose-Einstein Condensates (BEC) or interacting dual species BEC mixtures presents computational challenges due to the long expansion times and centre of mass motion induced by a displacement of the atom clouds. In this contribution, we present scaling techniques to overcome these limits. We focus also on simulation methods to interpret experiments with non-harmonic potentials or including effects of wavefront aberrations during the pulse sequences of atom interferometry.

Q 54.3 Thu 11:45 HS I PI

Measuring Beam Displacements via Weak Value Amplification — •Carlotta Versmold[1,2,3], Jan Dziewior[1,2,3], Florian Huber[1,2,3], Lev Vaidman[4], and Harald Weinfurter[1,2,3] — [1]Ludwig-Maximilians-Universität, Germany — [2]Max-Planck-Institut für Quantenoptik, Germany — [3]Munich Center for Quantum Science and Technology, Germany — [4]Tel-Aviv University, Israel

Weak value amplification enables precise measurement of a laser beam's small angular and spatial displacements using interferometric setups. While traditionally limited to detecting displacements inside the interferometer, we present a system that detects external beam displacements through amplification in the dark port of the interferometer. Simultaneously, the beam can be spatially filtered since displacements are suppressed in the bright port. Using a Sagnac-type interferometer with a dove prism in one arm, external displacements are mirrored in this arm, which induces a relative deflection between the two interferometer arms, shifting the center of mass of the interference pattern. This shift is given by the initial displacements amplified by the weak value of the pre- and postselected interferometer states. With an amplification by a factor of up to 20, this experiment clearly demonstrates and also extends the applicability of the weak value measurement methods.

Q 54.4 Thu 12:00 HS I PI

Probing free-electron-photon entanglement with quantum eraser experiments — •Jan-Wilke Henke[1,2], Hao Jeng[1,2], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]University of Göttingen, 4th Physical Institute, Göttingen, Germany

Quantum entanglement is central to most emerging quantum technologies including quantum computation and sensing. While the interaction of free electrons with optical fields is expected to induce free electron-photon entanglement [1,2], its demonstration remains an outstanding challenge.

In this presentation, we propose a tangible experiment for generating and verifying quantum entanglement between free electrons and photons based on quantum erasure [3]. We introduce the basic concept, before describing possible implementations employing multiple electron beams in an electron microscope and demonstrating selected experimental key aspects. Finally, we discuss extending this scheme to entanglement tests and generating electron-electron entanglement. Such a demonstration of electron-photon entanglement will be a cornerstone of free electron quantum optics and could enable quantum-enhanced sensing in electron microscopy.

[1] O. Kfir, Phys. Rev. Lett. 123, 103602 (2019); [2] A. Konečná, F. Iyikanat, and F. J. García de Abajo, Sci. Adv. 8, eabo7853 (2022); [3] J.-W. Henke, H. Jeng & C. Ropers, arXiv:2404.11368 (2024)

Q 54.5 Thu 12:15 HS I PI

Theoretical treatment of a closed-loop excitation scheme for phase-sensitive RF E-field sensing using Rydberg atom-based sensors — •Matthias Schmidt[1,2], Stephanie Bohaichuk[1], Vijin Venu[1], Harald Kübler[1,2], and James P. Shaffer[1] — [1]Quantum Valley Ideas Laboratories, 485 Wes Graham Way, Waterloo, ON N2L 0A7, Canada — [2]5. Physikalisches Institut and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

In this talk, we present theoretical work aimed at understanding radio frequency phase measurement using all-optical, atom-based electric field sensors. Atom-based radio frequency field sensors have a number of applications in communications, radar and test and measurement. All of these applications benefit from being able to detect phase, but Rydberg atom-based sensors in the steady state are square law detectors. We investigate closed-loop excitations in cesium that preserve phase information in a probe laser signal transmission amplitude coupled to one transition of the loop. Insight into the mechanisms that enable phase determination is gained by analyzing the closed-loop processes. We developed an experimental protocol that allows to measure the amplitude and phase of the incident RF wave over a wide range of parameters. Furthermore, we apply the weak probe approximation to the Lindblad-master equation and find an analytic expression for the absorption coefficient. With this expression, we gain a deeper understanding of the multi-photon interference and how this applies to phase readout in the atom-based radio frequency sensors.

Q 54.6 Thu 12:30 HS I PI

A localized impurity in a mesoscopic system of SU(N) fermions — Juan Polo[1], Wayne Jordan Chetcuti[1], Anna Minguzzi[2], •Andreas Osterloh[1], and Luigi Amico[1] — [1]TII, QRC, Abu Dhabi, UAE — [2]Université Grenoble Alpes, CNRS, LPMMC, Grenoble, France

We investigate the effects of a static impurity, modeled by a localized barrier, in a one-dimensional mesoscopic system comprised of strongly correlated repulsive SU(N)-symmetric fermions. For a mesoscopic sized ring under the effect of an artificial gauge field, we analyze the particle density and the current flowing through the impurity at varying interaction strength, barrier height and number of components. We find a non-monotonic behaviour of the persistent current, due to the competition between the screening of the impurity, quantum fluctuations, and the phenomenon of fractionalization, a signature trait of SU(N) fermionic matter-waves in mesoscopic ring potentials. This is also highlighted in the particle density at the impurity site. We show that the impurity opens a gap in the energy spectrum selectively, constrained by the total effective spin and interaction. Our findings hold significance for the fundamental understanding of the localized impurity problem and its potential applications for sensing and interferometry in quantum technology.