Q 36: Quantum Metrology and Interference

Time: Wednesday 14:30–16:30 Location: HS 3219

Q 36.1 Wed 14:30 HS 3219

Quantum parameter estimation with many-body fermionic systems and application to the quantum Hall effect — Olivier Giraud[1], Mark-Oliver Goerbig[2], and •Daniel Braun[3] — [1]Université Paris-Saclay, CNRS, LPTMS, 91405 Orsay, France — [2]Université Paris-Saclay, CNRS, Laboratoire de Physique des Solides, 91405 Orsay, France. — [3]Institut für theoretische Physik, Universität Tübingen, 72076 Tübingen, Germany

Quantum metrology with electronic sensors requires the description of the system with a fermionic quantum field theory. To this end, we calculate the quantum Fisher information for a generic many-body fermionic system in a pure state depending on a parameter. The parameter can be imprinted in the basis states, the state coefficients, or in both. We apply our findings to the quantum Hall effect and evaluate the quantum Fisher information associated with the optimal measurement of the magnetic field for a system in the ground state. Remarkably, the occupation of electron states with high momentum enforced by the Pauli principle leads to a super-Heisenberg scaling of the sensitivity with a power law that depends on the geometry of the sensor.

Q 36.2 Wed 14:45 HS 3219

Entanglement-induced collective many-body interference — •Tommaso Faleo[1], Eric Brunner[2], Jonathan W. Webb[3], Alexander Pickston[3], Joseph Ho[3], Gregor Weihs[1], Andreas Buchleitner[2,4], Christoph Dittel[2,4,5], Gabriel Dufour[2], Alessandro Fedrizzi[3], and Robert Keil[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [3]Institute of Photonics and Quantum Sciences, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, EH14 4AS, UK — [4]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [5]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg, Germany

Entanglement and interference are hallmark effects of quantum physics, introducing particularly rich dynamics within systems of multiple (at least partially) indistinguishable particles.

By combining entanglement and many-body interference, we propose a novel quantum effect to realize genuine N-particle interference. We experimentally demonstrate this effect in a four-photon interferometer, where a highly visible interference pattern emerges upon the joint detection of all photons, while interference at lower-order particle correlators is strictly suppressed. The observed interference is a function of the four-particle collective phase, a genuine four-body property.

Q 36.3 Wed 15:00 HS 3219

All-optical Bose-Einstein condensate generation for microgravity operation — •Janina Hamann[1], Jan Simon Haase[1], Alexander Fieguth[2], Jens Kruse[2], Carsten Klempt[1,2], and the INTENTAS Team[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]DLR Institut für Satellitengeodäsie und Inertialsensorik, Callinstraße 30b, 30167 Hannover

Atom interferometers are high-precision sensors for amongst others accelerations, rotations and magnetic fields. Space-borne atom interferometers promise a wide range of applications from geodesy to fundamental tests of physics. Their improved sensitivity due to prolonged interrogation times benefits from the macroscopic coherence length and slow expansion rates of Bose-Einstein condensates (BECs). A fundamental limit for the precision of AIs is the Standard Quantum Limit (SQL). The SQL can only be surpassed by using entangled ensembles of atoms in the interferometer. The INTENTAS project is designed as a source of entangled atoms that can be operated on a microgravity platform. To demonstrate sensitivity beyond the SQL rubidium atoms are cooled to a BEC, entangled with each other and detected with high precision. Evaporative cooling of the atoms is performed in a novel, robust crossed-beam optical dipole trap for all-optical BEC generation. In this talk the status of the project will be presented which includes characterization of the atom source on ground and first efforts towards the initial flight.

Q 36.4 Wed 15:15 HS 3219

Optimal Ramsey interferometry with echo protocols based on one-axis twisting — •Maja Scharnagl[1], Timm Kielinski[2], and Klemens Hammerer[2] — [1]Institute for Theoretical Physics, Leibniz University Hannover, Appelstrasse 2, 30167 Hannover, Germany — [2]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover, Appelstrasse 2, 30167 Hannover, Germany

We study a variational class of generalized Ramsey protocols that include two one-axis twisting (OAT) operations, one performed before the phase imprint and the other after. In this framework, we optimize the axes of the signal imprint, the OAT interactions, and the direction of the final projective measurement. We distinguish between protocols that exhibit symmetric or antisymmetric dependencies of the spin projection signal on the measured phase. Our results show that the quantum Fisher information, which sets the limits on the sensitivity achievable with a given uniaxially twisted input state, can be saturated within our class of variational protocols for almost all initial twisting strengths. By incorporating numerous protocols previously documented in the literature, our approach creates a unified framework for Ramsey echo protocols with OAT states and measurements.

Q 36.5 Wed 15:30 HS 3219

Exploring few-shot quantum metrology with photonic qubits — •Lukas Rückle[1,2], Jakob Budde[1,2], and Stefanie Barz[1,2] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), University of Stuttgart, 70569 Stuttgart, Germany

The use of quantum states for metrology tasks has been proven to surpass classical limits on the precision of estimating parameters. Recently, the framework of *probably approximate correct (PAC) metrology* has been introduced [1]. It not only enables the estimation of a parameter in an arbitrarily big parameter space without prior knowledge, but also gives bounds for few- and single-shot metrology settings. It thus bridges the rather theoretical case of performing infinitely many measurements and practical metrology tasks.

Here, we present experimental results in a photonic metrology setting. We show how to use different states and measurements and how for each case to optimize the prediction strategy of the parameter that shall be estimated. Our work shows how to implement the given new framework of PAC metrology and thus helps improving the precision of applications that only allow for a few measurements, e.g. when measuring fast varying systems.

[1] Meyer et. al, arXiv-preprint, arXiv:2307.06370 (2023)

Q 36.6 Wed 15:45 HS 3219

Microcombs for Digital Holography — •Stephan Amann[1], Edoardo Vicentini[2], Bingxin Xu[1], Yang He[3], Theodor W. Hänsch[1], Qiang Lin[3], Kerry Vahala[4], and Nathalie Picqué[1,5] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]CIC nanoGUNE BRTA, Donostia-San Sebastian, Spain — [3]Department of Electrical and Computer Engineering, University of Rochester, Rochester, New York, USA — [4]T.J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, California, USA — [5]Max-Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany

Digital holography is a versatile lensless three-dimensional imaging technique that allows access to the amplitude and phase information of microscopic samples with interferometric precision. We report on microcombs, broad optical spectra consisting of phase-coherent narrow lines which are generated in a high-Q optical microresonator, as novel sources for digital holography. We generate a microcomb of 100 GHz line spacing in a lithium niobate microresonator by pulsed-pumping, which facilitates the reliable control of the line spacing. The combined information of all lines allows to increase the unambiguous axial range of the object reconstruction from less than a micrometer to 1.5 millimeter. Due to their broad spectral bandwidth and large line spacing on the order of hundreds of GHz, microcombs enable the precise imaging of millimeter-sized objects at fast measurement times. Envisioned applications range from nanometer-precision surface profilometry to hyperspectral microparticle analysis.

Q 36.7 Wed 16:00 HS 3219

Reducing Schmidt mode cross-overlap inside SU(1,1) interferometers — •Dennis Scharwald and Polina Sharapova — Department of Physics, Paderborn University, Warburger Straße 100, D-33098 Paderborn, Germany

One of the central challenges in quantum metrology is improving the quality of interferometers, for example measured by their phase sensitivity. Classical interferometers operating with coherent light are bound in their sensitivity by the shot noise limit (SNL), while nonlinear SU(1,1) interferometers may surpass it and reach the Heisenberg scaling. [1]

In our recent work [2], we use the numerical approach of integro-differential equations for the description of the parametric down-conversion (PDC) process to show that using an appropriately shaped mirror makes it possible to easily surpass the SNL in an SU(1,1) interferometer ("compensated" setup). In this work, we aim to extend the discussion presented therein by analyzing the overlap of the Schmidt modes and show how cross-coupling between modes of the two PDC sections is eliminated in the compensated setup. As a consequence, this leads to an improvement of the quality of the interferometer visible from the supersensitivity at high parametric gain.

[1] M. Manceau *et al.*, New J. Phys. **19**, 013014 (2017)
[2] D. Scharwald *et al.*, Phys. Rev. Res. **5**, 043158 (2023)

Q 36.8 Wed 16:15 HS 3219

Lateral shear interferometry for shape accuracy measurements of 3D-printed micro-optics — •Yanqiu Zhao[1,2], Leander Siegle[1,2], and Harald Giessen[1,2] — [1]4th Physics Institute, University of Stuttgart, Stuttgart, Germany — [2]Stuttgart Research Center of Photonic Engineering, Stuttgart, Germany

We compare several methods of lateral shear interferometry to assess the shape accuracy of 3D-printed micro-optics. Different aberrations are added deliberately to the lens design of the 3D-printed micro-optics and accuracy of the interferometric methods is evaluated. Accuracies up to lambda/100 can be reached for micro-optics with 140 micrometer diameter and around 570 micrometer focal lengths. Using gray scale lithography, 3D-printing aspherical singlets with RMS wavefront aberrations of only 0.01 lambda is realizable.