A 19: Precision Measurements and Metrology: Interferometry II (with Q)

Time: Tuesday 14:30–16:45 Location: P 104

A 19.1 Tue 14:30 P 104

Theoretical study of Bose-Einstein condensates in optical lattices towards large momentum transfer atom interferometers — •Jan-Niclas Siemss[1], Ernst Maria Rasel[2], Klemens Hammerer[1], and Naceur Gaaloul[2] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Highly sensitive atom interferometers require the two interferometer arms to enclose a large area in spacetime.

In parallel to the implementation of large interrogation times in microgravity [1] and fountains [2], a larger spatial separation with large momentum transfer (LMT) enhances the sensitivity of atomic sensors. A promising method to realize these novel schemes is to combine Bragg pulses and Bloch oscillations in optical lattices to coherently split and recombine the atomic wave packets. However, the finite momentum width of the atomic ensemble or the damping of Bloch oscillations due to tunneling constrain the fidelity of the LMT.

We theoretically analyze the coherent acceleration of BECs in 1D optical lattices to understand and optimize pioneering experiments performed in the QUANTUS collaboration. To this end, a 1D-reduced Gross-Pitaevskii model [3] is adapted to interpret and propose realistic novel LMT schemes.

[1] H. Müntinga et al. Phys. Rev. Lett. 110, 093602 (2013)
[2] S. M. Dickerson et al. Phys. Rev. Lett. 111, 083001 (2013)
[3] L. Salasnich et al. Phys. Rev. A 66, 043613 (2002)

A 19.2 Tue 14:45 P 104

Fast BEC transport with atoms chips for inertial sensing — •Robin Corgier[1], Sirine Amri[2], Eric Charron[2], Ernst Maria Rasel[1], and Naceur Gaaloul[1] — [1]Leibniz University of Hanover, Germany — [2]Université Paris-Sud, France

Recent proposals in the field of fundamental tests of foundations of physics assume Bose-Einstein condensates (BEC) as sources of atom interferometry sensors. Atom chip devices have allowed to build transportable BEC machines with high repetition rates as demonstrated in the QUANTUS project. The proximity of the atoms to the chip surface is, however, limiting the optical access and the available interferometry time necessary for precision measurements. In this context, a fast and perturbation-free transport of the atoms is required. Shortcuts to adiabaticity protocols were proposed and allow in principle to implement such sequences with well defined boundary conditions. In this theoretical study, one can engineer suitable protocols to move atomic ensembles trapped at the vicinity of an atom chip by tuning the values of the realistic chip currents and external magnetic fields. Experimentally applicable trajectories of the atomic trap optimizing the transport time and reducing detrimental effects due to the offset of atoms positions from the trap center are found using a reverse engineering method. We generalize the method in order to optimize the size evolution and the center of a BEC wave packet in phase space. This allows an efficient delta-kick collimation to the pK level as observed in the Quantus 2 experiment. With such low expansion rates, atom interferometry experiments with seconds of drift time are possible.

A 19.3 Tue 15:00 P 104

Symmetric scalable large momentum transfer beam splitter — •Martina Gebbe[1], Sven Abend[2], Matthias Gersemann[2], Hauke Müntinga[1], Holger Ahlers[2], Wolfgang Ertmer[2], Claus Lämmerzahl[1], Ernst M. Rasel[2], and The QUANTUS Team[1,2,3,4,5,6] — [1]ZARM, Uni Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, HU Berlin — [4]Institut für Quantenoptik, Uni Ulm — [5]Institut für angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Due to their small spatial and momentum width ultracold Bose-Einstein condensates (BEC) or even delta-kick collimated (DKC) atomic ensembles are very well suited for high precision atom interferometry. We generate such an ensemble in a miniaturized atom-chip setup where BEC generation and delta-kick collimation can be performed in a fast and reliable way. We present a symmetric double Bragg diffraction technique offering interesting new features for atom interferometry. The coherent manipulation is directed along the horizontal axis and combined with Bloch oscillations in order to realize symmetric scalable large momentum beam splitters. We employ this new type of beam splitter to study the performance of scalable Mach-Zehnder interferometers whose sensitivity increases linearly with velocity separation. This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under grant numbers DLR 50WM1552-1557 (QUANTUS-IV-Fallturm).

A 19.4 Tue 15:15 P 104

A sensitive electrometer based on a Rydberg atom in a Schrödinger-cat state — •Eva-Katharina Dietsche, Arthur Larrouy, Adrien Facon, Serge Haroche, Jean-Michel Raimond, Michel Brune, and Sebastien Gleyzes — Laboratoire Kastler Brossel, College de France, ENS-PSL, UPMC-Sorbonne Universite, CNRS, Paris France

The Rydberg atoms are highly excited states where the electron is orbiting far from the nucleus. As a result, they have a huge electric dipole, making them ideal probes of the electric field. Rydberg states are highly degenerated. However, in the presence of a small electric field, this degeneracy is lifted and it is possible to drive transitions between the different Stark sublevels by applying radiofrequency fields. It is then possible to manipulate the state of the atom inside the manifold. We have recently shown that by using a radiofrequency field with a well-defined polarization it is possible to restrict the evolution of the atom to a subspace of the manifold where it behaves like a large angular momentum J. We have prepared non-classical states, similar to Schrödinger cat states, that allowed us to measure small variations of the electric field with a sensitivity beyond the standard quantum limit [1]. We are now investigating more complex manipulations of the atom to take advantage of the full richness of the Rydberg manifold. By using a combination of radiofrequency fields of different polarizations we can explore a larger part of the level structure. This opens the way to schemes that give access to higher moments of the electric field.

[1] A. Facon et al. Nature 535, 262-265 (2016)

A 19.5 Tue 15:30 P 104

Using Schrödinger cat states of Rydberg atoms to measure fast electric fields — •Eva-Katharina Dietsche, Arthur Larrouy, Adrien Facon, Serge Haroche, Jean-Michel Raimond, Michel Brune, and Sebastien Gleyzes — Laboratoire Kastler Brossel, College de France, ENS-PSL, UPMC-Sorbonne Universite, CNRS, Paris France

We present a quantum-enabled measurement of the electric field using Rydberg atoms. We prepare the atom in a quantum superposition of two circular states with principle quantum number n=50 and n=51. Using a radiofrequency field resonant with the Stark transition in the n=50 manifold we transfer the n=50 part of the wave function from its horizontal circular orbit to a tilted elliptical trajectory. This creates a Schrödinger cat superposition of two states with very different polarizabilities whose relative phase is highly sensitive to variations in the amplitude of the electric field. Detecting this phase change using Ramsey interferometry allows us to measure the electric field with a precision below the standard quantum limit (SQL) [1]. This allows using the Rydberg atom as a microscopic electrometer that can perform time-resolved field measurements with a very high bandwidth.

[1] A. Facon et al. Nature 535, 262-265 (2016)

A 19.6 Tue 15:45 P 104

Fock state metrology — •Fabian Wolf[1], Chunyan Shi[1], Jan Christoph Heip[1], Marius Schulte[3], Klemens Hammerer[3], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität, 30167 Hannover, Germany — [3]Institute for Theoretical Physics, Leibniz Universität, 30167 Hannover, Germany

The field of quantum metrology promises measurements with unprecedented accuracies and sensitivities using non-classical states. The idea behind quantum metrology is to prepare the investigated system or the measurement probe in a quantum states to reduce certain types of noise. In particular shot noise or quantum projection noise represents the major limitation for stability in state-of-the-art precision experiments ranging from gravitational wave detection to optical atomic clocks. The most prominent examples for states with non-classical features, previously investigated for this purpose are Schrödinger cat states and squeezed states and metrological gain compared to classical states has been demonstrated. Recently, investigations started to focus on the properties of states with negative Wigner function. However, so far the metrological gain of these states has not been verified experimentally. Here, we demonstrate that force measurements on an ion, trapped in a linear Paul trap can beat the classical limit, if the ion is initially prepared in a motional Fock state. Our scheme does not include any entanglement or squeezing and therefore illustrates the power of quantum interference due to negative Wigner functions for quantum metrology.

A 19.7 Tue 16:00 P 104

Phase magnification for robust atom interferometry beyond the SQL — •Fabian Anders — Institut für Quantenoptik, LUH Hannover, Deutschland

The two-axis counter-twisting interaction provides the possibility for detection noise robust atom interferometry beyond the standard quantum limit. Our scheme complements recent approaches based on one-axis twisting to magnify the interferometric phase.

In both concepts, the non-linear interaction is not only applied before the interferometer to generate entanglement, but also afterwards to amplify the signal. We compare both squeezing-echo approaches in their optimal performance as well as for experimentally feasible parameters. We find that varying the echo strength can further improve the robustness against detection noise. We obtain simple analytical results for the one-mode approximation of the scheme. Additionally, we investigate spin dynamics in a spinor condensate as suitable interaction to effectively implement this technique.

A 19.8 Tue 16:15 P 104

Random bosonic states for robust quantum metrology — Michał Oszmaniec[1], Remigiusz Augusiak[1,2], •Christian Gogolin[1,3], Janek Kołodyński[1], Antonio Acín[1,4], and Maciej Lewenstein[1,4] — [1]ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]Center for Theoretical Physics, Polish Academy of Sciences, Aleja Lotników 32/46, 02-668 Warsaw, Poland — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [4]ICREA-Institució Catalana de Recerca i Estudis Avançats, Lluis Companys 23, 08010 Barcelona, Spain

We study how useful random states are for quantum metrology, i.e., whether they surpass the classical limits imposed on precision in the canonical phase estimation scenario. We prove that random pure states drawn from the Hilbert space of distinguishable particles typically do not lead to super-classical scaling of precision. Conversely, we show that random states from the symmetric subspace typically achieve the optimal Heisenberg scaling. Surprisingly, the Heisenberg scaling is observed for states of arbitrarily low purity and preserved under the loss of fixed number of particles. Moreover, we prove that for such states a standard photon-counting interferometric measurement suffices to typically achieve the Heisenberg scaling of precision for all values of the phase at the same time. Finally, we demonstrate that metrologically useful states can be prepared with short random optical circuits.

A 19.9 Tue 16:30 P 104

The First Sounding Rocket Flight with an Atom Interferometer — •Stephan T. Seidel[1], Maike D. Lachmann[1], Dennis Becker[1], Wolfgang Ertmer[1], Ernst M. Rasel[1], and QUANTUS Collaboration[2] — [1]Institut für Quantenoptik, Universität Hannover — [2]LU Hannover, U Bremen, JGU Mainz, U Hamburg, HU Berlin, FBH, TU Darmstadt, U Ulm

The possibility of precise measurements of inertial forces using atom interferometry has led to a multitude of proposals for future satellite missions. These include missions aimed at geodetic measurements like a characterization of earth's gravitational field gradient and fundamental physics like a test of the universality of free fall.

Current ground based experiments are not suitable for the use on a satellite mission and a series of new technological and experimental techniques are required. This creates the necessity for pathfinder missions to test atom interferometer setups in relevant environments. To bridge this gap three sounding rocket missions are currently being prepared. The launch of the first mission is aimed at both the first creation of Bose-Einstein Condensates (BEC) and first demonstration of light atom interferometry in space.

Its payload can create BECs of 10^5 atoms from ^{87}Rb within two seconds. Therefore 70 experiments can be performed within the microgravity time including an observation of the phase transition and the characterization of the BECs after long free evolution times using atom interferometry. The system was qualified for the flight in a series of vibration tests and is currently in wait for favorable wind conditions.