Q 14: Precision Measurements and Metrology III

Time: Tuesday 10:30–12:15 Location: Q-H11

Q 14.1 Tue 10:30 Q-H11

Atom interferometry in the presence of quadratic potentials — •Matthias Zimmermann — Institute of Quantum Technologies, German Aerospace Center (DLR), 89081 Ulm, Germany

Matter-wave interferometers employing trapped atoms are promising candidates to enhance the achievable interferometer time. These compact devices could, for instance, be employed for precision measurements of accelerations and rotations.

This talk will address several fundamental issues that arise for atom interferometry in the presence of quadratic potentials. In particular, we distinguish classical and quantum closing conditions which have a crucial influence on the contrast and thus the signal of the interferometer. Moreover, we present modifications [1] of existing devices that allow their operation within compact geometries. As a particular example, we demonstrate a modified version of the T^3 interferometer [2,3] in the presence of quadratic potentials. We analyze advantages and potential drawbacks of this device, and suggest measures to overcome the latter.

[1] M. Zimmermann, *Interference of Matter Waves - Branch-dependent dynamics, the Kennard phase, and T^3 Stern-Gerlach interferometry*, Ph.D. thesis, Ulm University (2021).
[2] M. Zimmermann et al., *T^3 interferometer for atoms*, Appl. Phys. B **123**, 102 (2017).
[3] O. Amit et al., *T^3 Stern-Gerlach Matter-Wave Interferometer*, Phys. Rev. Lett. **123**, 083601 (2019).

Q 14.2 Tue 10:45 Q-H11

3D Simulations of Guided BEC Interferometers — •Rui Li[1], Simon Kanthak[2], and Naceur Gaaloul[1] — [1]Leibniz Universität Hannover, Institute of Quantum Optics, Hannover, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, Berlin, Germany

Atom interferometry has grown into an extremely successful tool for precision measurements since the pioneering works of Mark Kasevich and Steve Chu [1, 2]. Experiments with record-breaking precision have been performed in the fields of inertial sensing and tests of the foundations of physics. These high precision measurements are achieved either by large momentum transfer (LMT) or long interrogation times (LIT). Bose-Einstein Condensates (BECs) can be used to further enhance precision atom interferometry due to its high coherence and narrow momentum width. In this talk, we use numerical methods to study BEC interferometers in an optical guide by time-evolving 3D Gross-Pitaevskii equation (GPE). We specifically investigate the double-Bragg diffraction (DBD) of BEC pulsed by two retroretlecting laser beams and its momentum distribution after time of flight (ToF) in the guide, which is provided by the dipole trap of the red-detuned Gaussian laser beam.

[1] Kasevich M. and Chu S., Phys. Rev. Lett., 67 (1991) 181.
[2] Kasevich M. and Chu S., Appl. Phys. B, 54 (1992) 321.

Q 14.3 Tue 11:00 Q-H11

Simulations of Integrated Laser-Guided Atom Interferometers — •Matthew Glaysher, Hannah Paltzer, Ernst Maria Rasel, and Naceur Gaaloul — Leibniz Universität Hannover, Institute of Quantum Optics, Germany

Atom interferometry provides a highly accurate measurement tool, its applications ranging from inertial sensing and navigation to tests of fundamental physics. High precision interferometry is achieved either by Large Momentum Transfer or long interrogation times. Whereas the more common light pulse interferometer schemes can produce the necessary momentum transfer, guided interferometers can achieve long interrogation times. For guided ensembles it is essential to understand the internal interactions, as well as the continuous interactions with a light field, to realize a phase-sensitive interferometer. For this purpose we combine the computation of the dynamics of Bose-Einstein Condensates (BECs) by numerically solving the Gross-Pitaevskii-Equation (GPE) and classical n-particle simulation. We specifically investigate beam-splitting mechanisms and the phase evolution of BECs in a guided system, in which the guide is realized by dynamically shaped cavity modes or painted potentials.

Q 14.4 Tue 11:15 Q-H11

Analytic theory for Bloch-oscillation-based LMT atom interferometry — •Florian Fitzek[1,2], Jan-Niclas Siemss[1,2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Light-pulse atom interferometers are quantum sensors that enable a wide range of high-precision measurements such as the determination of inertial and electromagnetic forces or the fine-structure constant. Increased sensitivities can be achieved by implementing large momentum transfer (LMT) techniques. A well-known method to increase the momentum separation between the two arms of the interferometer are Bloch oscillations. Despite operating in the adiabatic regime, finite lattice ramping times will eventually lead to non-adiabatic corrections.

We develop an analytic model that describes non-adiabatic corrections to excited Bloch bands and verify our model by comparing to an exact numerical integration of the Schrödinger equation [Fitzek et al., Sci Rep 10, 22120 (2020)]. Furthermore, we characterize losses to excited Bloch bands as well as losses to the continuum to discuss their role for the realization of LMT atom interferometry.

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Q 14.5 Tue 11:30 Q-H11

QUANTUS - Theory in the Ulm group — •Richard Lopp[1], Alexander Friedrich[1], Enno Giese[3], Wolfgang P. Schleich[1,2], and the QUANTUS Team[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm — [2]Institute of Quantum Technologies, German Aerospace Center (DLR) — [3]Institut für Angewandte Physik, Technische Universität Darmstadt

Atom interferometry provides a unique opportunity not only for probing the foundations of physics at the interplay of relativity and quantum theory, but also for devising diverse, compact applications like sensors. In this spirit, the long-standing and fruitful QUANTUS collaboration investigates the dynamics of Bose-Einstein condensates under microgravity conditions and its application to atom interferometry. In particular, the QUANTUS theory group in Ulm focuses on a fundamental modelling of the light-matter dynamics, its impact on interferometric experiments, as well as potential setups to improve sensitivitity in the test of relativistic physics and fundamental principles. In this contribution, we will present an overview of the current, diverse work of the QUANTUS theory group in Ulm, and provide a perspective on upcoming projects of the newly starting QUANTUS+ collaboration.

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Q 14.6 Tue 11:45 Q-H11

Probing Physics beyond the Standard Model with ultracold Mercury — Thorsten Groh, •Felix Affeld, Quentin Lavigne, and Simon Stellmer — Physikalische Institut, Universität Bonn, Germany

The standard model of physics is a well-established theory, yet it fails to capture a number of experimental observations. Related topics include the search for cold dark matter candidates, the origin of the cosmological baryon asymmetry, and finite neutrino masses.

In our experiment, we aim to investigate physics beyond the standard model using ultracold gases of mercury. Mercury's high mass, its low sensitivity to blackbody radiation, and the availability of seven stable isotopes make it a unique candidate for such studies.

We report on the measurement of the isotope shifts of various transitions in mercury. Emerging nonlinearities in this measurement could hint towards a fifth force mediated by a new boson Φ that would couple neutrons and electrons.

Q 14.7 Tue 12:00 Q-H11

Analyse von thermischen Einzelionenwellenpaketen durch Flugzeitmessungen — •Felix Stopp, Henri Lehec, Luis Ortiz-

Gutiérrez und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Wir kontrollieren die Eigenschaften von Einzelionen-Wellenpaketen außerhalb einer Paulfalle: Dafür wird ein $^{40}Ca^{+}$-Ion im harmonischen Fallenpotential eingeschlossen und durch Laserkühlung präpariert. Nach anschließender Extraktion propagiert das Ion zu einem 0.27m entfernten Detektor. Die Auswertung der Ankunftszeitverteilung erlaubt direkte Rückschlüsse auf die Breite des vorher in der Falle präparierten thermischen, bzw kohärent-angeregten Wellenpaketes [1]. Weiterhin wird der erste deterministische Ionenspringbrunnen präsentiert, bei dem einzelne Ionen aus der Falle in den freien Raum extrahiert und nach dem Flug reflektiert werden, um sie mit einer Einfangrate von >95.1 % im Fallenpotential wieder zu fangen [2]. Als Anwendungen dieser Methoden sehen wir neuartige Ionen-Interferometer bzw. die Verbindung von Ionenfallen Quantenprozessor-Knoten.

[1] F. Stopp et al., New J. Phys. **23** 063002 (2021)
[2] F. Stopp et al., arXiv:2108.06948 (2021)