Q 62: Precision Measurements II (joint session Q/A)

Time: Friday 11:00–13:00 Location: HS 1221

Q 62.1 Fri 11:00 HS 1221

Noise Description in Bragg Atom Interferometer Using Squeezed States — •Julian Günther[1,2], Jan-Niclas Kirsten-Siemss[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Hannover, Germany — [2]Institut für Quantenoptik, Hannover, Germany

Using entanglement for N-particle states in matter wave interferometers allows one to outperform the standard quantum limit of $\frac{1}{\sqrt{N}}$ for the uncertainty in the phase measurement. We consider the use of one-axis twisted, spin squeezed atomic states in a Bragg Mach-Zehnder interferometer. We evaluate the phase uncertainty in the phase measurement taking into account the fundamental multi-port and multi-path nature of the Bragg processes, and determine optimally squeezed states for a given geometry.

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Q 62.2 Fri 11:15 HS 1221

Squeezing-enhanced Bragg guided BEC interferometry — •Matthew Glaysher[1], Robin Corgier[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität, Hannover — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, France

Atom interferometers test fundamental theories and have practical applications such as gravimeters, gradiometers and gyroscopes. Using uncorrelated or classically correlated atomic probes, state-of-the-art devices already operate at the standard quantum limit (SQL) set by their finite baseline and/or atom number resources.

To push the boundaries of compact devices, we study the realisation of a Bose-Einstein condensate (BEC) guided interferometer based on Bragg diffraction [R. Corgier et al., PRA, 103 (2021)]. Taking advantage of the BEC oscillations in the waveguide and the possibility to tune atom-atom interactions we investigate the generation of spin-squeezing dynamics between the two modes in well-defined and well-controlled momentum states. The entangled input state feeds a second interferometer sequence with quantum-enhanced sensitivity capabilities. Realistic aspects of the state-preparation parameters, including diffraction efficiencies and BEC collisions and deformations, are addressed in our scheme.

This project was funded within the QuantERA II Programme that has received funding form the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017733 with funding organisation DFG (project number 499225223).

Q 62.3 Fri 11:30 HS 1221

Analytical theory of double Bragg diffraction in light-pulse atom interferometers — •Rui Li[1], Klemens Hammerer[2], and Naceur Gaaloul[1] — [1]Leibniz University Hanover, Institute for quantum optics, Hannover, Germany — [2]Leibniz University Hanover, Institute for theoretical physics, Hannover, Germany

In this talk, we provide some new physical insights into a recently used tool in atom interferometry, namely the double Bragg diffraction (DBD). We derive an effective two-level-system (TLS) Hamiltonian via Magnus expansion for describing the so-called *quasi-Bragg regime* where most light-pulse atom interferometers are operating. With this effective TLS Hamiltonian, we systematically study the effects of polarization error and AC-Stark shift due to second-order process on the efficiency of double-Bragg beam-splitters. Furthermore, we show that effects of Doppler broadening can be easily included by extending our TLS description to a three-level-system description. With the help of our effective theory, we design an optimal beam-splitter via a time-dependent detuning and show its robustness against polarization error and asymmetric beam-splitting due to Doppler effect.

This work is supported through the Deutsche Forschungsgemeinschaft (DFG) under EXC 2123 QuantumFrontiers, Project-ID 390837967 and under the CRC1227 within Project No. A05 as well as by DLR funds from the BMWi (50WM2250A-QUANTUS+)

Q 62.4 Fri 11:45 HS 1221

Wave-packet evolution during laser pulses for single- and two-photon atomic diffraction — •Nadja Augst and Albert Roura — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm

Light-pulse atom interferometry is a valuable tool for high-precision inertial sensing and also offers promising prospects for dark-matter and gravitational-wave detection [1]. This work investigates the wave-packet evolution for an atom's center of mass during a laser pulse of arbitrary duration driving either a single-photon transition or Raman diffraction, and the results are also valid for Bragg diffraction in the deep Bragg regime. In particular, we consider the effects of finite pulse duration on the central trajectory of the atomic wave packets for beam-splitter and mirror pulses as well as pulses with arbitrary pulse areas. Our analysis encompasses a wide range of the cases including square and Gaussian pulse shapes as well as an arbitrary detuning of the central momentum.

While the resulting deviations of the central trajectories are typically quite small, they can have a significant impact on the interferometric phase shift in high-precision measurements and a detailed analysis is therefore important. Our approach relies on a description of the matter-wave propagation in terms of central trajectories and centered wave packets [2].

[1] K. Bongs et al., Nature Rev. Phys. 1, 731 (2019).
[2] A. Roura, Phys. Rev. X 10, 021014 (2020).

Q 62.5 Fri 12:00 HS 1221

Squeezing Enhanced Matterwave Interferometry with BECs — •Christophe Cassens, Bernd Meyer-Hoppe, and Carsten Klempt — Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, D-30167 Hannover, Germany

The gravitational acceleration can be measured with atom interferometers with unprecedented resolution. The ultimate resolution is fundamentally restricted by the standard quantum limit. This restriction can be lifted by operating the interferometer with entangled atoms, which carry quantum correlations among them. Here we present how a squeezed state in the magnetic field insensitive clock states of a Rb-87 BEC of 6000 atoms can be used to improve the sensitivity of an atom gravimeter sequence to -1.5dB below the SQL and -3.3dB below the sensitivity achieved in the same sequence with a coherent state. The here presented technique promises to be applicable in state-of-the-art BEC-based matterwave-interferometers and to increase their sensitivity especially in size, weight and power limited environments.

Q 62.6 Fri 12:15 HS 1221

Simulating matter-wave lensing of BECs in 2D and 3D — •Nico Schwersenz and Albert Roura — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm

The extended microgravity conditions granted by cold-atom experiments in space enable free-evolution times of many seconds, which can be exploited in high-precision measurements based on atom interferometry. However, in order to reach such long evolution times, it is necessary to employ ultracold atoms combined with matter-wave lensing techniques, and a detailed modeling is required.

We present full 3D numerical simulations performed on a GPU cluster of BECs freely expanding for tens of seconds and compare them to effectively 1D and 2D simulations for spherically- and axially-symmetric configurations. A particularly interesting case arises when the lensing potential is applied after the BEC has expanded sufficiently so that the diffraction effects associated with the finite size of the BEC dominate over the mean-field interaction. This enables the validation of our simulations in a regime where the time-dependent Thomas-Fermi approximation fails to provide an accurate description of the dynamics. Finally, as an application of our methods for axially-symmetric configurations, additional features that arise in the anisotropic case will be discussed as well.

Q 62.7 Fri 12:30 HS 1221

Simulation of atomic diffraction through a nanograting — •Matthieu Bruneau[1,2], Charles Garcion[1,2], Julien Lecoffre[2], Quentin Bouton[2], Eric Charron[3], Gabriel Dutier[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Laboratoire de physique des lasers, Université Sorbonne Paris Nord, Villetaneuse, France — [3]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France

Recent advances in the field of cold atoms have made atomic interferometry a versatile and precise tool with various applications, particularly in fundamental physics experiments.

This contribution focuses on the modeling of an experiment involving the diffraction of cold metastable Argon atoms through a transmission nanograting at the Laboratoire de Physique des Lasers. The observed diffraction pattern in this experiment is intrinsically related to the dispersion forces between the atoms and the material. A numerical model of the experiment has been developed, and the influence of these forces has been thoroughly investigated.

The simulation is based on an efficient numerical solution of the time-dependant Schrödinger equation that overcomes the limitations of the more standard semi-classical approach. This methodology provides an accurate description of the diffraction pattern, allowing a Casmir-Polder force measurement beyond the state of the art.

This work is supported by DLR funds from the BMWi (50WM2250A-QUANTUS+).

Q 62.8 Fri 12:45 HS 1221

Double Bragg atom interferometry with Bose-Einstein condensates in microgravity — •Julia Pahl[1], Anurag Bhadane[2], Dorthe Leopoldt[3], Sven Herrmann[4], André Wenzlawski[2], Sven Abend[3], Patrick Windpassinger[2], Ernst M. Rasel[3], Markus Krutzik[1,5], and The QUANTUS Team[1,2,3,4,6,7] — [1]HU Berlin — [2]JGU Mainz — [3]LU Hannover — [4]U Bremen — [5]FBH Berlin — [6]U Ulm — [7]TU Darmstadt

QUANTUS-2 is the 2nd generation mobile atom interferometer operating at the ZARM drop tower in Bremen. With its high-flux, atom chip-based atomic rubidium source, it serves as a pathfinder for future space missions. We are examining key technologies like the generation of Bose-Einstein condensates (BECs), implementation of magnetic lensing or application of various atom interferometry geometries with interferometry times over one second. In this talk, we present our latest results on double Bragg atom interferometry of magnetically lensed rubidium ensembles, using asymmetric Mach-Zehnder interferometers. By exploiting the emerging interferometer fringes we can visualize the anharmonicities of the magnetic lens and determine the interferometer contrast as well as the effective kinetic energy of the ensemble in a single shot. Interferometer times of $2T \approx 1.7\,s$ have been reached.

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