Q 28: Quantum Gases (Bosons) III

Time: Wednesday 10:30–12:30 Location: S HS 037 Informatik

Invited Talk Q 28.1 Wed 10:30 S HS 037 Informatik
Spatial entanglement patterns and Einstein-Podolsky-Rosen steering in a Bose-Einstein condensate — •Tilman Zibold, Matteo Fadel, Boris Decamps, Yifan Li, and Philipp Treutlein — Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland

We investigate the entanglement between spatially separated parts of a spin squeezed Bose-Einstein condensate of rubidium atoms. By resolving the spin distribution we are able to detect correlations between spins in different parts of the cloud. The observed spin correlations go beyond classical correlations and reveal spatial non-separability. By inferring measurement outcomes of non-commuting observables in one region based on measurements in a separate region we are able to seemingly beat the Heisenberg uncertainty relation, realizing the EPR paradox with an atomic many particle system. Our findings could be relevant for future quantum enhanced measurements of spatially varying observables such as electromagnetic fields.

Q 28.2 Wed 11:00 S HS 037 Informatik
Revealing entanglement in a spinor BEC by simultaneous and spatially resolved readout of two non-commuting spin observables — •Philipp Kunkel, Maximilian Prüfer, Stefan Lannig, Rodrigo F. Rosa-Medina, Alexis Bonnin, Martin Gärttner, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, Heidelberg

The information that can be extracted from a single projective measurement on a given quantum system is fundamentally limited. Extending the dimension of the original Hilbert space by coupling to auxiliary empty modes and performing unitary transformations in this enlarged space augments the accessible information. We experimentally apply such a scheme to a spinor Bose-Einstein condensate of ^{87}Rb in the $F = 1$ hyperfine manifold in a crossed dipole trap. In this system, we generate a many-particle entangled state via spin mixing resonant with specific spatial modes which are selectively addressed. We transfer population to the empty $F = 2$ manifold (auxiliary modes) by microwave coupling and perform independent spin rotations in both subsystems. In this way we get access to two non-commuting spin observables measured in a single shot of the experiment. Exploiting the spatial resolution of our imaging system and the symmetry of the spatial modes we directly extract their respective dynamics. Our measurement technique allows us to reveal the dynamically generated entanglement in the individual modes.

Q 28.3 Wed 11:15 S HS 037 Informatik
Multipartite Entanglement From Quench Dymamics in Spinor Bose Gases using Bogoliubov Theory — •Beatrice Latz[1,2], Ricardo Costa de Almeida[1,2], and Philipp Hauke[1,2] — [1]Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg, Germany

Multipartite entanglement is a resource for quantum-enhanced metrology. We study this enhancement in the context of quench dynamics and phase transitions in quantum many-body systems using Quantum Fisher Information (QFI). The QFI is a witness for genuine multipartite entanglement that can be quantified by experimental observables. Here, we consider Spinor Bose-Einstein condensates (BEC) which provide a well-controlled systems to study quantum phenomena. In line with experiments, a quench is followed by spin changing collisions which are associated with the creation of entanglement. In particular, we are interested in these spin mixing dynamics at long times after weakly quenching a thermal Spinor-1 BEC. We examine these dynamics at the theoretical level and compute observables relevant to the QFI in the framework of Bogoliubov theory. There, we show that the QFI in different phases of the Spinor-1 BEC at finite temperatures can be extracted from the occupation of Bogoliubov modes after a controlled quench. Our approach allows us to identify highly entangled states and is used to develop new measurement protocols for studying quantum-enhancement in such systems.

Q 28.4 Wed 11:30 S HS 037 Informatik
Many-particle interference in the dynamics of bosonic mixtures — •Gabriel Dufour[1,2], Tobias Brünner[1], Alberto Rodríguez[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg

We present a general framework to study the effect of many-particle interference on the dynamics of partially distinguishable bosons [1]. We start by showing how observables can be classified according to the order of the interference processes to which they are sensitive. In non-interacting systems, expectation values of single-particle observables are insensitive to the mutual indistinguishability of the particles, whereas those of two-particle observables show a clear signature of two-body interference processes. In interacting systems, however, the distinguishability of the initial Fock state also affects the expectation value of single-particle observables because of interaction-induced interference [2].

[1] T. Brünner, Signatures of partial distinguishability in the dynamics of interacting bosons, PhD thesis, Albert-Ludwigs-Universität Freiburg (2018)
[2] T.Brünner, G. Dufour, A. Rodríguez, A. Buchleitner, Phys. Rev. Lett. 120, 210401 (2018)

Q 28.5 Wed 11:45 S HS 037 Informatik
Running coupling inferred from higher order correlations in a spinor BEC — •Maximilian Prüfer[1], Torsten V. Zache[2], Philipp Kunkel[1], Stefan Lannig[1], Alexis Bonnin[1], Helmut Strobel[1], Jürgen Berges[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg — [2]Institut für theoretische Physik, Universität Heidelberg

Strongly correlated systems far from equilibrium can exhibit dynamically generated weak couplings of the relevant degrees of freedom [1]. Here, we study this phenomenon experimentally using quantum simulations in a spinor Bose gas of ^{87}Rb with ferromagnetic interactions. Recently it has been shown that this system features universal dynamics in the transversal spin after a quench [2]. Employing a novel detection scheme, we can now simultaneously extract length as well as orientation of the transversal spin spatially resolved. This allows for a systematic analysis of the experimental data building on higher order correlations and with that the access of the couplings of an effective field theory describing the system near a non-thermal fixed point. The observed strong momentum dependence of the coupling suggests the expected dynamically generated weak couplings for low momenta.

[1] Berges, J. et al., PRL **101**, 041603 (2008)
[2] Prüfer, M. et al., Nature **563**, 217-220 (2018)

Q 28.6 Wed 12:00 S HS 037 Informatik
Coupled superfluidity in binary Bose mixtures in two dimensions — •Volker Karle — Ruprecht-Karls-Universität Heidelberg

We consider a two-component Bose gas in two dimensions at low temperature with short-range repulsive interaction. In the coexistence phase where both components are superfluid, inter-species interactions induce a nondissipative drag between the two superfluid flows (Andreev-Bashkin effect). We show that this behavior leads to a modification of the usual Berezinskii-Kosterlitz-Thouless(BKT) transition in two dimensions. We extend the renormalization of the superfluid densities at finite temperature using the renormalization group approach and find that the vortices of one component have a large influence on the superfluid properties of the other, mediated by the nondissipative drag. The renormalization group flow implies that the topological vortex unbinding transition in one component can lead to the collapse of superfluidity also in the other component, and thereby couple their critical temperatures to a unique value.

Q 28.7 Wed 12:15 S HS 037 Informatik
Spin thermometry of individual neutral impurities coupled to a Bose-Einstein condensate — •Jens Nettersheim[1], Felix Schmidt[1], Daniel Mayer[1], Daniel Adam[1], Jennifer Koch[1], Quentin Bouton[1], Tobias Lausch[1], and Artur Widera[1,2] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

The measurement of (local) thermodynamic properties of a quantum system is the key for a detailed understanding of thermalization and dynamic in nonequilibrium quantum systems. Temperature, i.e. the distribution of kinetic energy, was measured so far by investigating motional dynamics of the total system or impurities immersed.

Here, we present a novel way of local in-situ thermometry based on the spin dynamic of individual neutral Caesium (Cs) atoms with total spin F=3 in a Bose-Einstein condensate (BEC) with total spin F=1. Elastic collisions thermalize the impurity, reflecting temperature in the kinetic energy distribution of the impurities. By contrast, for spin-exchange processes, the competition between endo- and exoergic spin exchange, coupling the kinetic energy to the internal degree of motion, unambiguously maps the temperature onto the quasi-spin population of the impurity. The sensitivity of the thermometer can be adjusted via the external magnetic field changing the Zeeman energy splitting. Our work thus provides a novel way of performing in-situ thermometry by measuring internal state populations rather than atomic motion.