Q 49: Quantum gases (Miscellaneous)

Time: Thursday 14:00–16:00 Location: e214

Invited Talk Q 49.1 Thu 14:00 e214

New physical concepts: Fermionic Exchange Force and Bose-Einstein Force — •Christian Schilling — Arnold Sommerfeld Center for Theoretical Physics, LMU München

The particle-exchange symmetry has a strong influence on the behavior and the properties of systems of N identical particles. While fermionic occupation numbers are restricted according to Pauli's exclusion principle, $0 \leq n_k \leq 1$, bosonic occupation numbers can take arbitrary values $0 \leq n_k \leq N$. It is also a matter of fact, however, that occupation numbers in realistic systems of interacting fermions and bosons can never attain the maximal possible value, i.e., 1 and N, respectively. By resorting to one-particle reduced density matrix functional theory we provide an explanation for this: The gradient of the exact functional diverges repulsively whenever an occupation number n_k tends to attain the maximal value. In that sense we provide in particular a fundamental and quantitative explanation for the absence of complete Bose-Einstein condensation (as characterized by $n_k = N$) in nature. These new concepts are universal in the sense that the fermionic exchange force and the Bose-Einstein force are present in all systems regardless of the particle number N, the spatial dimensionality and the interaction potentials.

Q 49.2 Thu 14:30 e214

Measurement of identical particle entanglement and the influence of antisymmetrisation — •Jan Hendrik Becher[1], Enrico Sindici[2], Ralf Klemt[1], Philipp M. Preiss[1], Andrew J. Daley[2], and Selim Jochim[1] — [1]Physics Institute, Heidelberg University, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Department of Physics and SUPA, University of Strathclyde, Glasgow G4 0NG, UK

We explore the relationship between symmetrisation and entanglement through measurements on few particle systems in a multi-well potential. In particular, considering two or three trapped atoms, we measure and distinguish entanglement characterised in terms of spatial modes from genuine multipartite entanglement arising from two different physical origins: antisymmetrisation of the fermionic wavefunction and interaction between particles. We quantify this through the entanglement negativity of states, and the introduction of an antisymmetric negativity, which allows us to understand the role that symmetrisation plays in the measured entanglement properties.

Q 49.3 Thu 14:45 e214

Dynamics of a 3D Bose gas in an optical lattice driven by local particle loss — •Christopher Mink, Axel Pelster, and Michael Fleischhauer — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

We study both the steady states and the dynamics of a weakly interacting Bose gas, which is confined by an optical lattice in one spatial dimension as well as an isotropic harmonic trap in the two transveral directions and with local particle loss. To this end we start from first principles and use coherent-state phase space methods in order to derive a Fokker-Planck description of the emerging Bose-Einstein condensates. Neglecting quantum fluctuations we determine the condensate wave functions at each lattice site approximately by using a suitable variational ansatz. We discuss the strengths of this approach and demonstrate the limits of its applicability. Finally, we take quantum fluctuations into account by reducing the dimension of the Fokker-Planck equation and study their impact on the time evolution of the system numerically. With this we aim at reproducing the experimental results of Ref. [1] concerning the refilling dynamics of an empty site without any free parameters.

[1] R. Labouvie, B. Santra, S. Heun, and H. Ott, Phys. Rev. Lett. **116**, 235302 (2016)

Q 49.4 Thu 15:00 e214

Observation of a non-equilibrium phase transition in the second order coherence of a Bose-Einstein condensate of photons — •Fahri Emre Ozturk[1], Tim Lappe[2], Göran Hellmann[1], Frank Vewinger[1], Julian schmitt[3], Jan Klaers[4], Hans Kroha[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn — [2]Physikalisches Institut and Bethe Center for Theoretical Physics, Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [3]Present address:Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom — [4]Present address: Complex Photonic Systems (COPS), MESA+ Institute for Nanotechnology, University of Twente, 7522 NB Enschede, The Netherlands

Bose-Einstein condensates have been realized with cold atomic gases, exciton-polaritons and more recently with photons in dye-filled optical microcavities. In the latter system, grand canonical Bose-Einstein condensation has been demonstrated with enhanced statistical number fluctuations in the condensed state. Here we report on the observation of a transition between an oscillatory and a bi-exponential phase of the second order coherence of the condensate. The experiments are performed in a dye-filled optical microcavity at conditions very close to thermal equilibrium, with pumping and loss resulting in time-reversal symmetry breaking. The results show that photon Bose-Einstein condensates in a part of the phase diagram are separated by a phase transition from the non-equilibrium phenomenon of lasing.

Q 49.5 Thu 15:15 e214

Quantum simulation of a U(1) lattice gauge theory — Bing Yang[1], •Robert Ott[2], Hui Sun[1], Han-Yi Wang[1], Torsten V. Zache[2], Jad C. Halimeh[3,4], Zhen-Sheng Yuan[1], Philipp Hauke[3,4], and Jian-Wei Pan[1] — [1]Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Philosophenweg 16, 69120 Heidelberg — [3]Im Neuenheimer Feld 227, 69120 Heidelberg — [4]Via Sommarive 14, 38123 Povo (TN), Italy

The modern description of elementary particles is built on gauge theories. Such theories implement fundamental laws of physics by local constraints, such as Gauss's law in the interplay of charged matter and electromagnetic fields. Here, we demonstrate the quantum simulation of an extended U(1) lattice gauge theory, and experimentally quantify the faithfulness to Gauss's law. We use single-species bosonic atoms in alternating wells of a 71-site optical superlattice to realize charged matter and gauge fields, and experimentally benchmark the dynamics of their interaction by sweeping across a quantum phase transition. Enabled by new measurement techniques, we certify Gauss's law by extracting probabilities of locally gauge-invariant states from correlated boson occupations across three adjacent wells. Our results demonstrate that Gauss's law can be faithfully engineered in large-scale quantum simulators of gauge theories.

Q 49.6 Thu 15:30 e214

Non-Linear Multi-Component Excitations in a Spinor Bose-Einstein Condensate — •Stefan Lannig[1], Christian-Marcel Schmied[1], Maximilian Prüfer[1], Philipp Kunkel[1], Marc Robin Strohmaier[1], Helmut Strobel[1], Thomas Gasenzer[1], Panayotis G. Kevrekidis[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institute for Physics, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Department of Mathematics and Statistics, University of Massachusetts, Amherst, MA 01003-9305, USA

Far from equilibrium the presence or absence of non-linear excitations in a quasi-one-dimensional spinor Bose-Einstein condensate (BEC) leads to different universal scenarios in the effective long-wavelength properties of the system [1, 2]. To investigate this effect, we consider the basic scenario of only a few controlled excitations.

Here, we experimentally study such excitations in a quasi-one-dimensional spin-1 BEC of ^{87}Rb. Using an acousto-optical deflector we generate pairs of multi-component excitations in a controlled manner by local spin rotations and study their properties in the spatial degree of freedom and spin [3]. As these non-linear multi-component excitations exhibit long lifetimes we are able to observe their time evolution, and, in particular, collisions between them. We find that such interactions crucially depend on the internal spin structure of the excitations.

[1] Prüfer, M. et al., Nature **563**, 217 (2018)
[2] Schmied, C.-M. et al., Phys. Rev. A **99**, 033611 (2019)
[3] Kunkel, P. et al., Phys. Rev. Lett. **123**, 063603 (2019)

Q 49.7 Thu 15:45 e214

Realization of Bose-Einstein condensation in higher Bloch bands of the optical honeycomb lattice — •Tobias Klafka, Alexander Ilin, Julius Seeger, Phillip Gross, Klaus Seng-

stock, and Juliette Simonet — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

Bose-Einstein condensates in higher Bloch bands of optical lattices immensely extend the possibilities for quantum simulation of solid-state models. Unconventional superfluids and new topological states of matter are expected to emerge by the interplay of spin and orbital degrees of freedom as well as the lattice symmetry. We report on Bose-Einstein condensation in the second and forth band of a bipartite honeycomb lattice. Tuning the energy offset between the two sublattices allows a controlled transfer to higher bands. We have investigated the emergence of coherence for these metastable states as well as the interplay of band relaxation dynamics and condensation by tracing the dynamics in the Brillouin zones. Understanding these non-equilibrium processes constitutes an essential requirement for the stabilization of unconventional spinor condensates in higher bands.