CAP-ProQuP Workshop: Abstracts

June 2-4, 2014

Invited talks

What can we learn from $G^{(2)}$ about the entanglement?

Jan Chwedenczuk (Warsaw)

It is often difficult to detect the entanglement among the particles in a many-body system. To accomplish this task, some metrological criteria such as the spin-squeezing or the Fisher information, are often used. Here we discuss some simple experimental scenarios which, basing on the knowledge of the second order correlation function, allow for the detection of the particle entanglement. We demonstrate that the violation of the Cauchy-Schwarz inequality is a proof of particle entanglement. We also show that the violation of the CHSH inequality proofs not only the non-local correlation between two distant modes but also among the constituent particles.

Fundamental - extracting the Fisher information without tomography & Application - upscaling of squeezing to large numbers

Markus Oberthaler (Heidelberg)

We report on the recent achievements in the Heidelberg labs which touch on fundamental but also important aspects for applications of entangled many atomic states. The fundamental aspects are the successful implementation of a novel method for extracting a lower bound for the Fisherinformation from experimental observations. For that purpose we generate a non-gaussian many particle state by long time dynamics starting at an unstable fixed point. We find in the regime where all variances are larger than given by classically limiting coherent state still useful entanglement is present. With that resource at hand we demonstrate interferometry beyond classical limits employing a maximum likelihood analysis of the data - independently confirming that entanglement is present. From the more applied perspective we will report on a method which allows upscaling of coherent spin squeezing to large numbers. The experiment reveals that more than 13000 atoms can be squeezed by 5dB. A straightforward extrapolation from our 1D experiment to 3D we find that the same squeezing can be expected for 10 million particles. Employing this resource of large squeezed states combined with swapping of squeezing to magnetic sensitive but only weakly interacting magnetic substates we implement a magnetometer as well as a gradiometer performing beyond the classical limit. The measured sensitivities are competitive with other state of the art detectors with comparable detection volume.

Density correlation function of expanding Bose gas

Mirek Brewczyk (Warsaw)

We study, within a framework of the classical field approximation, the density correlation function of expanding Bose gas for the whole range of temperatures across the Bose-Einstein condensation threshold. We are particularly interested in the case of elongated system where there is a huge discrepancy between the existing theory and experimental results [1]. We find, in agreement with the experiment, that the density correlation function is not reduced for temperatures below the critical one as it is predicted by the ideal Bose gas theory. This behaviour is attributed not just to the presence of interactions in the system. It is strictly related to the existence of dark solitons in the elongated gas at thermal equilibrium.

[1] A. Perrin et al., Nature Phys. 8, 195 (2012)

Detecting multiparticle entanglement of Dicke states

Carsten Klempt (Hannover)

Spin dynamics in Bose-Einstein condensates allows for the generation of many-particle entangled states. We show that the created state is similar to a Dicke state with up to 8000 atoms. We present a novel criterion for estimating the amount of entanglement based on a measurement of the global spin. Our criterion proves that our state contains at least genuine 28-particle entanglement. Additionally, we infer a generalized squeezing parameter of 11.4(5) dB.

Non-Equilibrium Dynamics of One-Dimensional Bose Gases

Tim Langen (Atominstitut Wien)

I will give an overview of our recent results on the dynamics and thermalization of isolated quantum systems. In our experiment a one-dimensional Bose gas is split coherently into two parts. The time evolution following this quench leads to the establishment of a quasi-steady prethermalized state, which differs strongly from thermal equilibrium. Time-resolved measurements reveal that the thermal correlations of this prethermalized state first emerge locally and then spread through the system in a light-cone-like evolution. Moreover, the results show that the relaxed states of this nearly integrable quantum system can be described through a generalized Gibbs ensemble. Finally, I will discuss the dynamics in situations where the two parts of the system differ in atom number, and report on the current progress in the study of thermalization beyond the transient prethermalized state.

Puce team, Palaiseau

Correlations in momentum space of a one-dimensional Bose gas

Aisling Johnson

We report the measurement of two point correlations in momentum space of a one-dimensional Bose gas (1D BG) with repulsive interactions. In a 1D BG a smooth crossover from an ideal (non-interacting) gas to a condensate-like regime occurs because of the repulsive interactions that suppress bosonic bunching. Density fluctuations are thus reduced just like in a true condensate. This has been observed on our experiment using an atom chip to confine the atoms in a 1D geometry [1]. However if one measures the momentum distribution n_k of a quasi-condensate and an ideal Bose gas, lorentzian-like distributions, with similar scaling with respect to density and temperature, are observed in both phases. Moreover, bosonic bunching is present in both regimes in momentum space contrary to real space. The two-point correlations $\langle \delta n_k \delta n_{k'} \rangle$ on the other hand show differences between the two phases: negative regions appear in the quasi-condensate phase. We compare the experimental results with quantum Monte Carlo calculations and analytical results in the quasi-condensate limit.

[1] T.Jacqmin et al.,Physical Review Letters 106, 230405 (2011)

Quench-induced breathing mode of one-dimensional Bose gases

Bess FANG

We measure the position- and momentum- space breathing dynamics of trapped one-dimensional Bose gases. The profile in real space reveals sinusoidal width oscillations whose frequency varies continuously through the quasicondensate to ideal Bose gas crossover. A comparison with theoretical models taking into account the effect of finite temperature is provided. In momentum space, we report the first observation of a frequency doubling in the quasicondensate regime, corresponding to a self-reflection mechanism. The disappearance of this mechanism through the quasicondensation crossover is mapped out. [1]

[1] B. Fang et al., arXiv:1312.3169

*He** team, Palaiseau

Hong-Ou-Mandel experiment with cold atoms

Raphael Lopes

During this talk I'll present the recent developments on the creation and manipulation of atomic pairs produced from a Bose-Einstein condensate in a moving 1D optical lattice. Namely, I'll present our attempt to realize a Hong-Ou-Mandel experiment in momentum space.

The 2nd Order Coherence of Superradiance from Bose-Einstein Condensate (BEC)

Almazbek Imanaliev

The 2nd order correlation function of superradiantly emitting atoms from Metastable Helium BEC is measured and compared with the corresponding correlation function of atoms undergoing stimulated emission. We conclude that superradiant emission shows a correlation function of thermal sample, as ordinary spontaneous emission does, despite its strong gain mechanism.

Rb2 team, Vienna

Interferometry with non-classical motional states of a Bose-Einstein condensate

Sandrine Van Frank

We implement an interferometric scheme with non-classical motional states of an elongated ^{87}Rb Bose-Einstein condensate in a trap. We isolate a two-level system of transverse motional states and use Optimal Control Theory methods to excite different coherent superpositions. In a previous series of experiments, we created a full population inversion to the first excited state and observed the decay of this state into twin-atom beams. In this investigation, we push the Optimal Control procedure a step further and implement series of pulses similar to $\pi/2$ rotations on the Bloch sphere. We illustrate this concept by realizing a Ramsey-type interferometric sequence. With this work, we show that manipulating a complex, interacting many-body system in a reproducible and coherent way is possible. This will be relevant for a large class of schemes in the context of quantum computation and metrology. Moreover, its ability to precisely prepare complex, highly excited states makes this approach a valuable tool for the study of many-body dynamics.

Generation of squeezed atomic states of a Bose-Einstein condensate in a double-well potential

Tarik Berrada

We have developed a Mach-Zehnder interferometer for interacting Bose-Einstein condensates (BECs) on our atom chip setup [1]. We are using it to study the generation of atomic squeezing in condensates trapped in an elongated double-well potential created by means of radio-frequency dressing.

By coherently splitting a single BEC, we could produce a strongly number-squeezed state with fluctuations of the population imbalance between the two wells reduced by 60% compared to a coherent state. We used it to demonstrate the link between number squeezing and interaction-induced phase diffusion. Moreover, the reduced number fluctuations, associated to a very high coherence, imply 8 dB of spin squeezing, indicating the entanglement of more than 150 atoms in the BEC.

I will discuss these results and give estimates of the amount of squeezing achievable with our current splitting protocols. I will then present two new splitting procedures that we are about to implement on our experiment. Eventually, I will discuss effects beyond the two-mode approximation that we already observe in our pairs of elongated quasi-condensates.

[1] T. Berrada et al., Nature Communications 4, 2077 (2013).

Second-order correlations in amplified twin-atom beams

Robert Bücker (Max Planck Institute for the Structure and Dynamics of Matter, Hamburg)

We present experimental results on second-order correlations in a one-dimensional twin-atom beam system, prepared by amplified emission from a highly excited quasicondensate [1]. During the emission, only a very small number of mode pairs become macroscopically occupied, the interference of which gives rise to local and non-local second-order correlation features, indicative of the onset of stimulated emission and buildup of entanglement [2]. Techniques to extract such correlation functions from fluorescence images of expanding one-dimensional atom clouds are introduced, that allow for the detection of stronger-than-classical correlation features. By applying those, strong violation of the Cauchy-Schwarz inequality by distant correlations is shown for a broad range of matter-wave populations. As an outlook, prospects of tailoring the momentum correlations in amplified twin-beam emission, and directly demonstrating strong entanglement between twin atoms will be discussed.

[1] R. Bücker et al., Nature Physics 7, 608 (2011)
[2] T. Wasak et al., New Journal of Physics 16, 013041 (2014)