Universität Basel

Research Project

Bell correlations in Bose-Einstein condensates

Third-party funded project

Project title Bell correlations in Bose-Einstein condensates
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Organisation / Research unit
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In 1964, J. Bell discovered that the parts of a composite quantum system can show correlations that are stronger than any local realist theory allows. The existence of these Bell correlations has profound implications for the foundations of physics and at the same time underpins a variety of quantum information technologies that are currently being developed. While Bell correlations have been observed in systems of at most a few (usually two) particles, their role in many-body systems is largely unexplored. There are many open questions on how to create, detect and quantify Bell correlations in many-body systems, on their use in quantum technology, and on the connection between Bell correlations and many-particle entanglement. In this project, we will use atomic Bose-Einstein condensates on an atom chip - an exceptionally well-controlled quantum many-body system - for experiments on Bell correlations and many-particle entanglement and their application in quantum technology. In a recent breakthrough, the applicant's group reported the first observation of Bell correlations in a many-body system. Based on this result, we will study in depth the character of these correlations between atoms in a Bose-Einstein condensate. We will develop and test improved Bell correlation witnesses, including those that detect genuine many-particle Bell correlations, and aim at closing the statistics loophole. We will explore the possibility of performing a device-independent Bell test with hundreds of atoms. Moreover, we will investigate the use of Bell correlations in many-body systems for quantum information tasks. In previous experiments, entanglement and Bell correlations were detected between atoms in the same cloud, by performing global manipulations and measurements on the entire atomic ensemble. In this project we will go further and perform experiments with two spatially separated, individually addressable Bose-Einstein condensates. Based on a recent proposal, we will explore the generation of Einstein-Podolsky-Rosen (EPR) entanglement between the two condensates through collisions in a state-dependent potential. Such EPR entanglement is relevant for quantum metrology, because it allows to predict the outcome of spin measurements in one cloud conditioned on a corresponding measurement in the other cloud with higher precision than what is allowed by a naive application of the Heisenberg uncertainty relation. In the next step, we will explore Bell correlations between the two separate Bose-Einstein condensates, where the nonlocal character of these correlations can be directly revealed. We will explore the possibility of directly violating a Bell inequality with the two condensates in a device-independent way. The main applicant, Prof. Dr. Philipp Treutlein, is a young associate professor in the Department of Physics at the University of Basel. During the past five years, he and his team set up an experiment that offers exceptional control over the quantum state of mesoscopic Bose-Einstein condensates. The atoms are trapped and manipulated using a microfabricated atom chip, a powerful technique that no other experiment in Switzerland is currently using. A series of experimental results on spin-squeezing, entanglement, quantum metrology, and Bell correlations have been obtained with this setup. Experimental studies of Bell correlations in many-body systems are just beginning, and many open questions remain to be investigated. Building on the promising initial results obtained recently by the applicant's group, the goal of the present proposal is to explore this uncharted territory further. In 1964, J. Bell discovered that the parts of a composite quantum system can show correlations that are stronger than any local realist theory allows. The existence of these Bell correlations has profound implications for the foundations of physics and at the same time underpins a variety of quantum information technologies that are currently being developed. While Bell correlations have been observed in systems of at most a few (usually two) particles, their role in many-body systems is largely unexplored. There are many open questions on how to create, detect and quantify Bell correlations in many-body systems, on their use in quantum technology, and on the connection between Bell correlations and many-particle entanglement. In this project, we will use atomic Bose-Einstein condensates on an atom chip - an exceptionally well-controlled quantum many-body system - for experiments on Bell correlations and many-particle entanglement and their application in quantum technology.

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