

# Spatially distributed genuine multipartite entanglement enables Einstein-Podolsky-Rosen steering of atomic clouds

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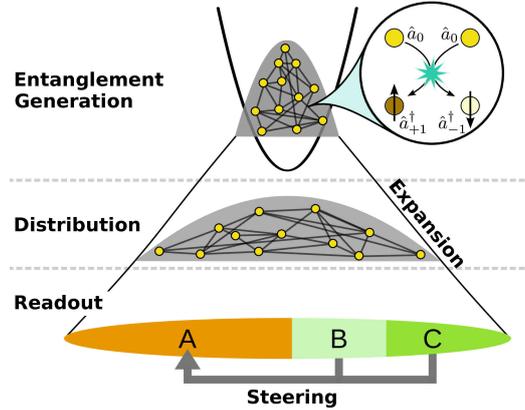


Figure 1: Experimental scheme to distribute entanglement in space [1].

Heisenberg's uncertainty relation poses a fundamental limit on the simultaneous knowledge of two noncommuting observables. Yet, quantum mechanics allows for nonlocal correlations between two systems such that a measurement in one system enables predicting the outcome in the other one with a precision beating the local uncertainty limit which is known as Einstein-Podolsky-Rosen (EPR) steering [2]. These nonlocal correlations are one of the key resources for quantum technologies. Here, we experimentally show that entanglement, which is produced in a Bose-Einstein condensate (BEC) by local contact interactions in a single spatial mode, can be spatially distributed to yield nonlocal correlations which we verify by demonstrating EPR steering ([1], see Fig. 1). Our experiment illustrates that entanglement of indistinguishable particles can be mapped to individually addressable subsystems, which has been proposed recently [3][4]. This kind of entanglement is therefore as useful, in the sense of the LOCC (local operation and classical communication) paradigm, as entanglement between distinguishable particles.

We start our experiment with a  $^{87}\text{Rb}$  BEC held in a crossed optical dipole trap. The atoms are prepared in the magnetic substate  $m_F=0$  of the  $F=1$  hyperfine manifold. We use spin mixing to coherently populate the states  $m_F=+1$  and  $m_F=-1$  with atom pairs which is equivalent to spin nematic squeezing [5]. Since the atoms of the BEC are in principle indistinguishable, the correlations are shared among all atoms in the atomic cloud. By switching off the longitudinal confinement, the BEC expands in the remaining wave-guide potential and the entanglement is distributed in space. After expansion, we read out the relevant spin observable by applying a resonant rf-pulse followed by state selective absorption imaging. The high optical resolution of our imaging system enables the definition of distinct systems by partitioning the absorption signal. We measure two noncommuting spin observables and find in each partition that the fluctuations well exceed the local uncertainty constraint. Yet, we show that the measurement outcome in one subsystem of the atomic cloud can be used to infer the result in the remaining part better than allowed by the fundamental local Heisenberg uncertainty, which verifies that these parts are EPR entangled. Moreover, by partitioning the absorption signal into three parts of equal length, we demonstrate that each part is steered by the remaining ones. This confirms threeway steering.

To further elucidate the multipartite character of the generated entanglement, we construct a witness which connects the inference value of bipartite EPR steering to genuine multipartite entanglement. With this witness we reveal up to genuine five-partite entanglement.

## References

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