Generation of entangled particle beams

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One of the most fundamental properties of quantum mechanics is non-locality, meaning the measurement of a quantum state in one location can have an instantaneous effect on another state that is arbitrarily distant. This property has been tested with light via EPR entanglement, but tests using particles with mass have not yet been carried out. Our contribution towards this goal has been to develop and analyse a system which provides the resources to carry out such a test.

As part of previous work in ACQAO, we have examined a system where an atom laser was generated from a metastable helium (He*) Bose-Einstein condensate (BEC). We showed that when the coupling between the atom laser and the BEC was sufficiently large, the transverse profile of the atom laser developed well-defined “peaks”. These peaks arise from two conical beams of particles being emitted along the long axis of the BEC (see Figure 1).

These cones are generated via a novel four-wave mixing process that relies on the s-wave scattering rates for the two atomic species in the BEC being different. In our system this leads to dynamic instabilities in the BEC, which are exponentially amplified at specific momenta [2]. A 1D truncated Wigner simulation of a He* BEC is displayed in Figure 2, showing how specific momenta along the long axis of the BEC become heavily populated over time.

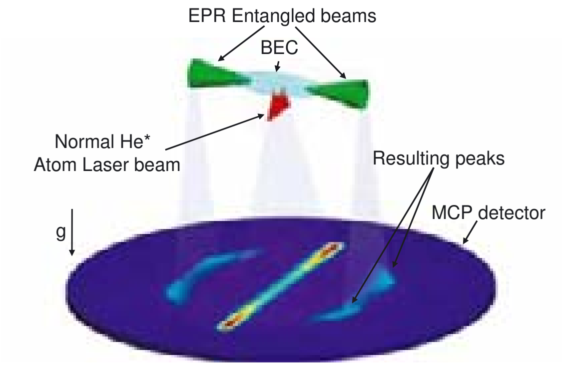

Fig. 1: Transverse atom laser profile

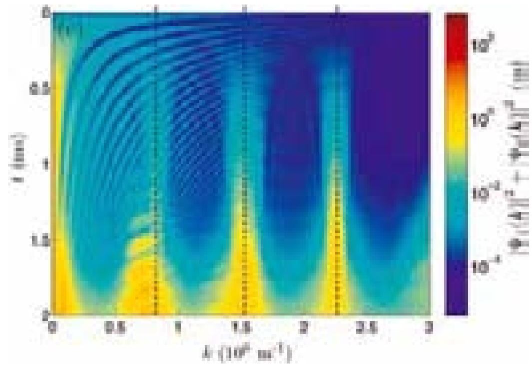

Fig. 2: Amplification at specific momenta (simulation)

The evolution of the fluctuation operators describing these momenta are given by [2]

$$\begin{aligned}\hat{\Lambda}(\mathbf{k},t) &= e^{i\omega(\mathbf{k})t}\left(\sinh(\gamma(\mathbf{k})t)\hat{\Lambda}'^{\dagger}(-\mathbf{k},0)+\cosh(\gamma(\mathbf{k})t)\hat{\Lambda}(\mathbf{k},0)\right),\\ \hat{\Lambda}'(\mathbf{k},t) &= e^{-i\omega(\mathbf{k})t}\left(\sinh(\gamma(\mathbf{k})t)\hat{\Lambda}^{\dagger}(-\mathbf{k},0)+\cosh(\gamma(\mathbf{k})t)\hat{\Lambda}'(\mathbf{k},0)\right),\end{aligned}$$

which are identical to those governing degenerate parametric down conversion (PDC) in optics. Consequently, just as PDC is a source of EPR-entangled photon pairs, the cones in our system consist of EPR-entangled atom pairs.

References

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[2] G. R. Dennis and M. T. Johnsson, J. Phys. A **82**, 033615 (2010).