Demonstration of spatial entanglement

K. Wagner, J. Janousek, H. Zou, V. Delaubert, S. Pereira, C. C. Harb,
N. Treps, P. K. Lam and H.-A. Bachor
ACQAO, Department of Physics, Australian National University, Australia

We have demonstrated the entanglement of the spatial properties (position and direction) of two laser beams. This is the first time optical multimode entanglement has been created and it a very clear demonstration of the original ideas of Einstein, Podolsky and Rosen, applied to the position and momentum of continuous laser beams. We have achieved this result by combining a TEM00 reference beam with a squeezed TEM10 squeezed beam, and then entangling this beam with another TEM10 squeezed beam [1]. Measurement of the real part of the two TEM10 components of the entangled beams then shows the position of the beams, and the imaginary parts show the transverse beam momentum.

A direct comparison of the correlations between the two beams allows us to calculate the degree of inseparability. The two beams are entangled if these correlations are stronger than can be attained by classical means. EPR entanglement is measured by making predictions on what will be measured on one beam, based on a measurement of the other beam. We measure the differential position and momentum and demonstrate that our beams have fluctuations in these two properties below the quantum noise limit (QNL), as shown in the central part of Figure 1. We have measured a degree of inseparability of 0.51, and a degree of EPR paradox [2] of 0.62.

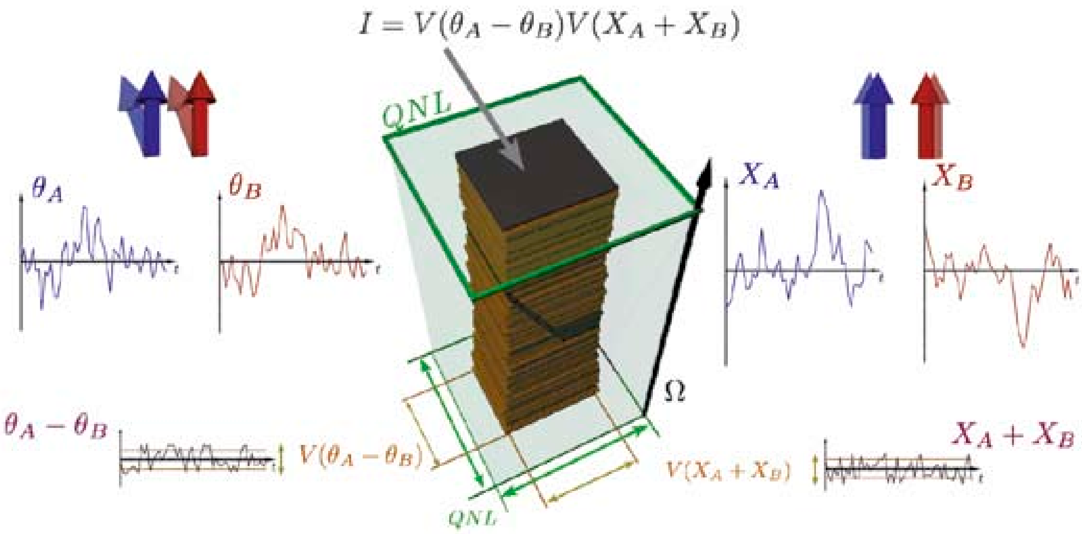

Figure 1: Each entangled beams position (left) and direction (right) is above the QNL. But when we measure the differential position and direction, we can see that these two properties are below the QNL, as seen by the variances $V(X_A + X_B)(\Omega)$ and $V(\theta_A - \theta_B)(\Omega)$. The product $V(X_A + X_B)(\Omega)V(\theta_A - \theta_B)(\Omega)$ gives the degree of inseparability, shown as the area the square in each slice of the central tower.

References

[1] M. Lassen, V. Delaubert, J. Janousek, K. Wagner, H.-A. Bachor, P.K. Lam, N. Treps, P. Buchhave, C. Fabre, and C.C. Harb, Phys. Rev. Lett. **98**, 083602 (2007).
[2] M.D. Reid, Phys. Rev. A **40**, 913 (1989).