The Einstein-Podolsky-Rosen (EPR) paradox in single couples of images

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Statistical properties of fluctuations in quantum mechanics are described by ensemble averages, which are often estimated by time averages if the signal is stationary in time, but which can also be estimated by spatial averages if the signal is stationary in space on a sufficiently large area. Most of the experiments in quantum imaging record averages of temporal coincidences, i.e. characterize the spatial repartition of temporal averages, rather than spatial averages. As a partial exception, we have recently demonstrated a very high degree of EPR paradox by computing the spatial intercorrelation between twin images recorded on two EMCCD cameras [1]. However, it was necessary in this work to record a set of couples of images, at least 20 couples in the near field, in order to, first, retrieve the fluctuations by subtracting an average image and, second, compute the intercorrelation coefficient by adding the results of each couple of images.

In the present work we show that a single couple of images in each plane (near and far field) is sufficient to safely demonstrate an EPR paradox. On each couple of images, we have retrieved the fluctuations by subtracting the fitted deterministic gaussian or sinc shape and then have obtained an intercorrelation peak with a sufficient signal to noise ratio to distinguish this peak from random fluctuations, with 0 errors on 900 couples of images in the far-field and 5 errors over 900 in the near-field. We have determined a 95% confidence interval on the degree of paradox, which extends from 9 to 148 in the x direction, where walk-off occurs, and 17 to 271 in the y direction. Last, we have verified that the variance of the difference between twin images is below the quantum (poissonian) limit, in order to ensure the particle character of the demonstration.

This improvement of our previous results has been made possible by suppressing the fluorescence parasitic light coming from the elements of the experimental set-up, allowing an increase of the integral of the correlation coefficient from 0.1 to 0.25. This integral represents the ratio between the number of photon pairs and half the total number of photons, with a value of one in an ideal experiment where all photons are recorded with their twin. With this improved value, the number of coherence cells in a single image is sufficient to ensure a signal-to-noise ratio allowing a safe distinction between the true correlation peak and random fluctuations [2].

Patterns in an image are pure spatial information, without any time aspect, that is ultimately degraded by spatial fluctuations of quantum origin for very weak images. We demonstrate in this work that this information does obey quantum mechanics, which is different from previous works that showed that an image conveys a great number of quantum (temporal) channels in parallel.

[1] P.A Moreau et al. Phys. Rev. Letters **113,** 160401 (2014)
[2] E. Lantz et al. Phys. Rev. A **90**, 063811 (2014).