Imaging Quantum Correlations through a Scattering Medium

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We report photon-counting imaging of entangled photon-pairs of high Schmidt number transmitted through a scattering medium lying either in the near-field or in the far-field of the entangled photons source. We demonstrate that spatial momentum or position quantum correlations, measured between twin images recorded onto two separate detectors, exhibit in both cases speckle patterns. Moreover, the total correlation is only slightly lowered by the scattering.

Introduction

Among all the experiments dealing with quantum correlation properties of Spontaneous Parametric Down Conversion (SPDC) [1–4], some studies adress the propagation of entangled two-photon states through random medium [5–7]. While in [6] two single-point detectors are scanned in the image planes, we propose in this paper to directly image, onto two separate electron-multiplying charge coupled device (EMCCD) cameras operating in photon-counting regime [8], the two-photon states transmitted through a scattering medium. Here, far-field and near-field quantum correlations are evidenced depending on the two reported imaging configurations. Finally, we performed stochastic simulations [9] to confirm the experimental results.

Experimental protocol and results

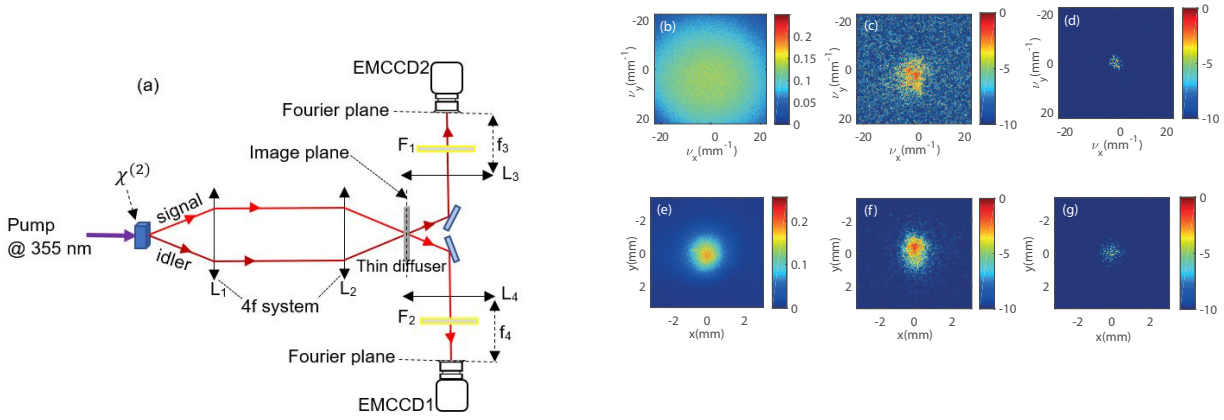

FIG. 1: (a) Experimental setup for far-field measurement: (b) average photon number in single far-field images (signal or idler) of SPDC, (c) measured correlation function in dB between 40 000 twin images and (d) correlation function issued from 10 000 stochastic simulations. For the near-field correlations: (e) average photon number in single near-field images (signal or idler) of SPDC, (f) measured correlation function in dB between 70 000 twin images and (g) correlation function issued from 10 000 stochastic simulations

The experimental set-up for the far-field correlations is illustrated in Fig. 1a. Entangled photon pairs are generated by type-II SPDC in a $0.8\,mm$ long β-barium borate (BBO) crystal pumped by a collimated pulsed laser at $355\,nm$. The output face of the crystal is imaged onto the diffuser using a $4-f$ imaging system. The photon pairs transmitted by the diffuser are separated thanks to walk-off. Far-field detection is performed by two EMCCD cameras lying in the focal plane of lenses L_3 (f_3=150 mm) and L_4 (f_4=150 mm). Before detection, SPDC beams are spectrally filtered around degeneracy with narrow-band interferential filters F_1 and F_2 (@$710\,nm, \Delta\lambda = 4\,nm$). For the near-field correlations, we only replace the $4-f$ imaging system by a $2-f$ imaging system ($f = 150\,mm$). In this case, the position of the diffuser lies in the far-field of the crystal and the EMCCD cameras image the near-field. Fig. 1b and

Fig. 1e show respectively the far-field and near-field images of the SPDC simply conditioned by the phase matching condition and the pump beam shape, respectively. As shown in [6], the absence of a speckle pattern in the single-beam images of the SPDC results from the incoherent character of the light formed by a single beam of the entangled light. In contrast, and in agreement with [6], the cross correlation of the images exhibits speckle patterns in the far-field (Fig. 1c) as well in the near-field (Fig. 1f). This experimental cross correlation image corresponds to the spatial distribution of signal-idler quantum correlations after traversal of the scattering medium.

Conclusion

We have experimentally studied at the quantum level spatial correlations of bi-photon states by using two EMCCD cameras. As expected, studies have shown the absence of single-photon speckle patterns when bi-photon states are transmitted through a random medium whereas the near-field and far-field two-photon imaging exhibit speckle patterns. Unlike [6] where only a small part of the photon is used, far-field and near-field correlations have been evidenced on the whole set of photons. Our experiment could be adapted to news technologies using spatial light modulator (SLM) to control quantum state of the light in random medium [10].

[1] B. M. Jost, A. V. Sergienko, A. F. Abouraddy, B. E. A. Saleh, and M. C. Teich, Optics Express.3, 81 (1998).
[2] E. Brambilla, A. Gatti, M. Bache, and L. A. Lugiato, Phys. Rev. A 69, 023802 (2004).
[3] O. Jedrkiewicz, E. Brambilla, M. Bache, A. Gatti, L. A. Lugiato, and P. Di Trapani, J. Mod. Opt. 53, 575 (2006).
[4] J.-L. Blanchet, F. Devaux, L. Fufaro, and E. Lantz, Phys. Rev. Lett 101, 233604 (2008).
[5] S. Smolka, A. Huck, U. L. Andersen, A. Lagendijk, and P. Lodahl, Phys. Rev. Lett. 102, 193901 (2009).
[6] W. H. Peeters, J. J. D. Moerman, and M. P. van Exter, Phys. Rev. Lett. 104, 173601 (2010).
[7] H. Defienne and S. Gigan, Phys. Rev. A 99, 053831 (2019).
[8] E. Lantz, J. L. Blanchet, L. Fufaro, and F. Devaux, Mont. Not. R. Astron. Soc. 386, 2262 (2008).
[9] E. Lantz, N. Treps, C. Fabre, and E. Brambilla, Euro. Phys. J. D 29, 437 (2004).
[10] H. Defienne, M. Reichert, and J. W. Fleischer, Phys. Rev. Lett. 121, 233601 (2018).