

Validation of échelle-based quantum-classical discriminator with novelty SPAD array sensor

Valentin Mitev¹, Laurent Balet¹, Nicolas Torcheboeuf¹, Leonardo Gasparini², Matteo Perenzoni², Bänz Bessire³, André Stefanov³, Alexander Mikhalychev⁴, Dmitri Mogilevtsev⁴, Dmitri Boiko¹

1. CSEM, rue de l'Observatoire 58, Neuchâtel 2000, Switzerland;

2. Fondazione Bruno Kessler, Via S. Croce, 77, 38122 Trento, Italy;

3. University of Bern, Hochschulstrasse 6, 3012 Bern, Switzerland;

4. Institute of Physics, National Academy of Sciences of Belarus (IPNASB), Nezavisimosti Ave 68, Minsk 220072, Belarus

Imaging with non-classical photons allows one to bypass the Rayleigh resolution limit and classical shot-noise level [1, 2]. Such schemes will operate with large photon number, produced by sources, where the entangled and classical states have the same wavelength. In this case, the discrimination of the classical and quantum states by wavelength selection with optical filters is not possible. It has been already demonstrated, that the diffraction of bi-photons at reflection or transmission gratings manifests a pattern equivalent to that of classical photons with half of their wavelength [3, 4]. These demonstrations point to the use of quantum diffraction in discriminating quantum and classical states, having the same (or close) wavelength. The motivation in this work is to validate the approach of quantum-classical photons discrimination.

The source of bi-photons at 810nm is the SPDC in a PPKTP crystal, pumped by diode laser operating at 405nm. A VCSEL at 795nm with beam propagating in the same direction as the SPDC and the residual of the pump beams, is added as a reference source of classical photons with wavelength close to 810nm. The combined beam, i.e., the SPDC and VCSEL, and residual pump, is directed to and diffracted by an échelle grating at high orders (31.6 gr/mm). The signal detection, the evaluation of the Glauber correlation function $G^{(2)}$ and the visualization of the $G^{(2)}$ patterns are carried on a novelty SPAD array, developed purposely for imaging with entangled photons [5].

In this setup, all diffraction orders of bi-photons at 810nm coincide with all diffraction orders of the classical pump beam at 405nm, while the orders of the classical 810nm photons (also VCSEL wavelength 795nm) coincide only with the even orders of classical photons at 405nm. Placing a slit at an odd 405nm order and a combination of filters transmitting 810nm and blocking 405nm, we may select a flux of predominantly bi-photons at 810nm as this diffraction angle is prohibited for classical photons at 810nm. Figure 1 illustrates this effect. Panel (a) presents the spatial correlation pattern of classical 795nm VCSEL beam. The diagonal feature is caused by cross-talk and accidental coincidences produce horizontal and vertical lines [5]. Panel (b) presents the features in (a) with added anti-diagonal (bi-photon) pattern from SPDC bi-photons. For panel (c), additionally to the configuration in panel (b), a slit is placed after the grating to select only one order of SPDC. Note the clear bi-photon correlation pattern as anti-diagonal and the complete blocking of classical light at the same wavelength.

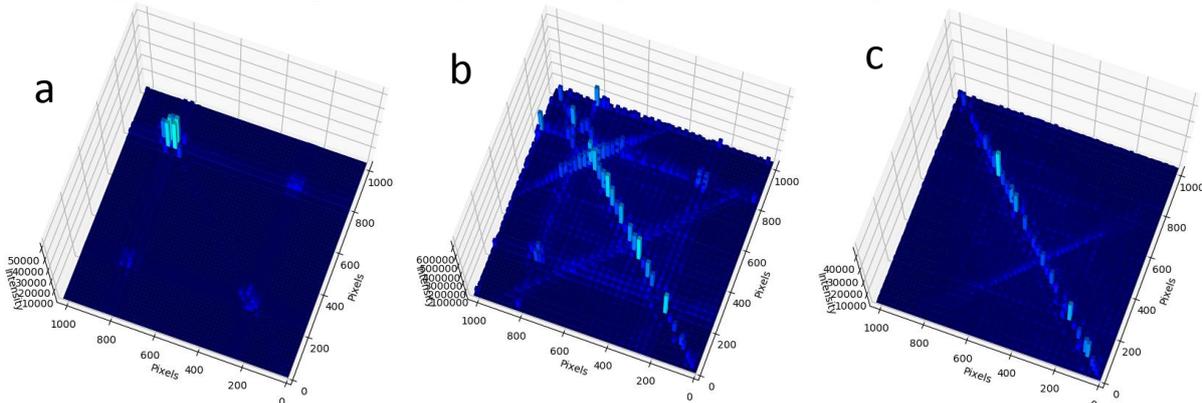


Fig. 1 Glauber correlations function $G_2(\text{Pixel}_{x1y1}, \text{Pixel}_{x2y2})$; (a) Laser 795nm only; (b) SPDC and laser 795nm; (c) SPDC only. On each panel both X- and Y- axis present the pixel number of the SPAD array; the color scale show the number of coincidence event with accidental background and pixel crosstalk removed.

References

- [1] Y. Kawabe, H. Fujiwara, R. Okamoto, K. Sasaki and S. Takeuchi, "Quantum interference fringes beating the diffraction limit, *Opt. Express*, **15**, 14244-14250 (2007).
- [2] T. Ono, R. Okamoto, and S. Takeuchi, "An entanglement-enhanced microscope", *Nat. Comm.*, **4**, 2426 (2013).
- [3] M. Ostermeyer, D. Puhlmann and D. Korn, "Quantum diffraction of biphotons at a blazed grating", *J. Opt. Soc. Am. B*, **26**, 23472356, (2009).
- [4] R. Shimizu, K. Edamatsu and T. Itoh, "Quantum diffraction and interference of spatially correlated photon pairs generated by spontaneous parametric down-conversion", *Phys. Review*, **A67**, 041805-1/4, (2003).
- [5] L. Gasparini, B. Bessire, M. Unternährer, A. Stefanov, D. Boiko, M. Perenzoni and D. Stoppa, "Novel CMOS sensor for improved quantum imaging", 11 April 2017, SPIE Newsroom. DOI: 10.1117/2.1201701.006847, (2017).