Validation of ÉChelle-based Quantum-classical Discriminator of Light

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The SUPERTWIN research project explores how de Broglie wavelength of a multi-partite quantum state of photons can be used to build super-resolution instruments, e.g., optical microscopes. Essential was to validate that de Broglie wavelength is not destroyed by the imperfections of optical systems.

In the framework of the European FET-OPEN SUPERTWIN project, 3 industrial, 3 academic and 3 Research Technology Organizations (RTOs) joined forces to achieve nanometer resolution in optical microscopy, a potential breakthrough enabled by quantum properties of entangled photons.

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 was 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 (QCD).

The source of bi-photons at 810 nm is the spontaneous parametric down-conversion (SPDC) in a periodically poled potassium titanyl phosphate (PPKTP) crystal (Figure 1), pumped by diode laser operating at 405 nm.

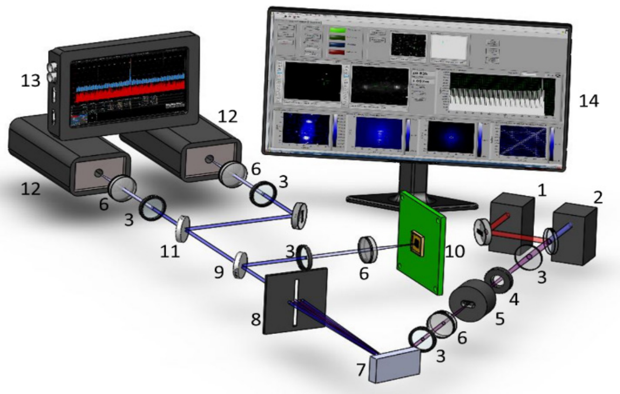

Figure 1: Breadboard: (1) Laser 795 nm; (2) Laser 405 nm; (3) Lenses; (4) Half-wave plate; (5) PPKTP crystal; (6) Filters; (7) Echelle grating; (8) Adjustable slit; (9) Flip-flop mirror; (10) 32x32 SPAD-array; (11) Beamsplitter; (12) Single SPAD detectors; (13) Oscilloscope; (14) PC.

A vertical cavity surface emitting laser (VCSEL) at 795 nm with beam propagating in the same direction as the SPDC, is added as a reference source of classical photons with wavelength close to 810 nm. 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 intensity signal detection $G^{(1)}$ and the evaluation of the Glauber correlation pattern $G^{(2)}$ 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 810 nm coincide with all diffraction orders of the classical pump beam at 405 nm, while the orders of the classical 810 nm photons (also VCSEL wavelength 795 nm, Figure 2a) coincide only with the even orders of classical photons at 405 nm. Placing a slit at an odd 405 nm order and a combination of filters transmitting 795/810 nm and blocking 405 nm we may select predominantly bi-photon states at 810 nm as this diffraction angle is prohibited for classical photons at 810 nm (Figure 2c). Bottom row in Figure 2 illustrates this effect on $G^{(2)}$. Panel (d) presents the spatial correlation pattern of classical 795 nm VCSEL beam. Panel (e) presents the features in (d) with added anti-diagonal (bi-photon) pattern from SPDC bi-photons. The diagonal feature is caused by crosstalk and accidental coincidences produce horizontal and vertical lines. For panel (f), additionally to the configuration in panel (e), 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.

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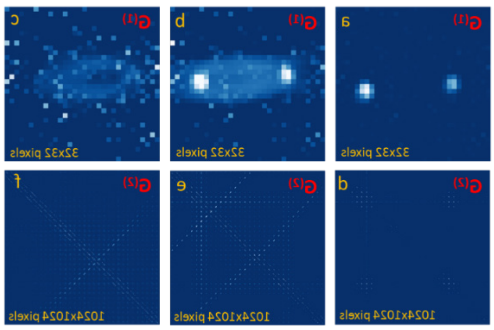

Figure 2: Intensity $G^{(1)}$ (top row) and correlations $G^{(2)}$ (bottom row): pure coherent 795 nm laser [a & d], mixed 795 laser and 810 nm bi-photon states at QCD input [b & e] and output [c & f] with filtered 810 nm bi-photon state.

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