

High efficiency pulsed spectral-mode entanglement generation

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Abstract

We introduce a new scheme for generating pulsed spectral-mode entanglement in engineered parametric downconversion (PDC) processes. We experimentally benchmark this technique via two-photon interference and dispersive fibre spectroscopy. As a proxy for more complex multi-photon protocols we implement a pulsed spectral-mode entanglement swapping scheme with near unity success probability.

Photonic quantum technologies rely on the generation of high-quality single-photons. A key open challenge is to encode as much information as possible into a single photon to enhance the efficiency of quantum protocols. For this reason, the last few years have seen increasing interest in going beyond polarisation encoding exploiting different degrees of freedom (DoF) of light, such as orbital angular momentum, time and frequency.

Here we present a new scheme for generating spectral-mode entanglement in PDC photon pairs, enabled by our nonlinearity engineering technique [1, 2]. By tailoring the ferroelectric domains' structure of a poled crystal we can indeed reshape its phase-matching function (PMF) to generate PDC photons spectrally-entangled in an arbitrarily high-dimensional Hilbert space, complementing the temporal-mode framework developed in [3]. We experimentally benchmark our technique in group-velocity-matched KTP crystals at telecom wavelengths. The crystal's PMF is designed to generate maximally entangled singlet states in the pulsed spectral-mode space: $|\psi^-\rangle = \frac{1}{\sqrt{2}}(|\wedge\rangle|\vee\rangle - |\vee\rangle|\wedge\rangle)$. This can be verified with two-photon interference and joint-spectrum (JSI) reconstruction via dispersive fibre time-of-flight spectroscopy. We measure a nearly-unity visibility of the antibunching interference that, combined with the characteristic shape of the interference pattern and the joint-spectrum, represents an unequivocal signature of the biphoton wavefunction's antisymmetry (see fig. 1). We finally demonstrate the scalability of our technique to multiphoton scenarios by implementing a pulsed spectral-mode entanglement swapping scheme between two photon-pairs produced in two different crystals.

Our technique can be easily implemented as it consists in a standard single-pass PDC setup, achieves high biphoton rates ($> 4\text{KHz}$ detected-pairs/mW, 60% symmetric heralding), is compatible with other DoF encodings and can be adapted with small overhead to waveguide sources for integrated quantum photonics applications.

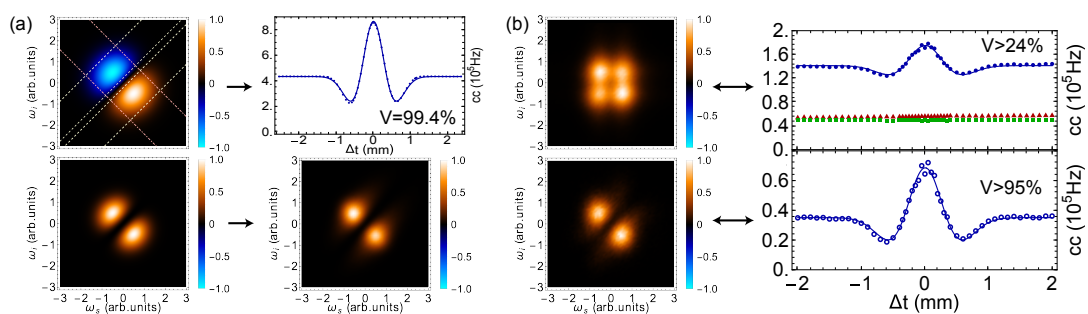


Figure 1: **(a)** Theoretical joint spectral amplitude and JSI (left) with corresponding experimental interference pattern and JSI (right). **(b)** Experimental JSIs and corresponding interference patterns non-postselected (top) and postselected (bottom) on fourfold coincidences: we measure a protocol success rate higher than 95%

- [1] F. Graffitti et al. *Pure down-conversion photons through sub-coherence-length domain engineering*, *Quantum Sci. Technol.* **2**, 035001 (2017).
- [2] F. Graffitti et al. *Independent high-purity photons created in domain-engineered crystals*, *Optica* **5**, 514-517 (2018).
- [3] B. Brecht et al. *Photon temporal modes: A complete framework for quantum information science*, *Phys. Rev. X* **5**, 041017 (2015).