New ultra-bright source of entangled photons

G. Bitton, W.P. Grice, L. Zhang, J. Moreau, J. Barhen and V. Protopopescu
Center for Engineering Science Advanced Research
Computer Science and Mathematics Division
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830
bittong@ornl.gov

Abstract: An ultra-bright entangled photon source has been realized using two cascaded type-II crystals. Entanglement of photons originating from any point on the output cones is possible if a suitable optical delay line is used.

1. Introduction

Entangled photon states generated by spontaneous parametric down-conversion (SPDC) in non-linear crystals have been extensively used to test basic concepts in quantum mechanics as well as in an increasing number of applications. Substantial effort is currently invested in improving the quality of those sources, both in terms of the total number of entangled states produced by the source and the degree of the entanglement of those states. In this paper, we report on a new ultra-bright source of entangled photons realized using type-II SPDC in two crystals arranged in cascade. The optical axes of the crystals are at angles θ and $-\theta$ with respect to the pump beam direction (see Fig. 1). In such an architecture, the extraordinarily (ordinarily) polarized cone of the first crystal and the ordinarily (extraordinarily) polarized cone of the second crystal overlap. This overlapping removes the association between the photons' polarizations and their spatial location over the entire area of the output cones. Hence, one can use any part of the output cones as a source for entangled states, provided that suitable delay lines are installed.

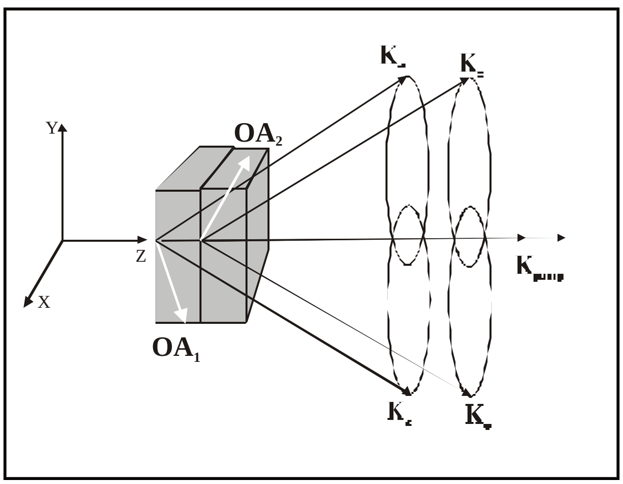

Fig. 1. The output cones from the two-cascaded crystals

A delay line is used to erase the information contained in the arrival times of the photons. Due to the birefringent nature of the crystals, photons with different polarizations travel at different speeds inside the crystals. Hence, the differences in the arrival times of the photons contain some information about their polarizations and about the crystal in which they were created. Failure to erase that information will result in a low degree of polarization entanglement. A rather simple delay-line may be used to increase the visibility over a large range of the output cones. Because the ordinary polarized photon from the first crystal (1o) travels along the same path as the extraordinarily polarized photon from the second crystal (2e), a simple birefringent delay is sufficient to equalize their average arrival times. A similar delay may be used in the path taken by the (1e) and the (2o) photons. As a result, the polarization of the photons cannot be distinguished by their arrival time.

2. Experiment and Results

The frequency doubled output of an ultra-fast Ti:Sapphire laser at 795 nm was used to pump two adjacent thin BBO crystals (1 mm each) with identically cut angles of $\theta=43.9^o$ suitable for type-II down-conversion. Two variable circular irises located 7.5 cm after the crystals are used to select two specific spatial directions. Quartz wedges with continuously variable thickness were used as delay lines. The detection package consisted of polarizing beam splitters preceded by half wave plates along with single photon detectors and interference filters (IF).

Polarization interference was measured with one of the polarizers at 45^o, while the angle of the other polarizer was varied. With no delay lines, poor visibility of 12% is observed, while an increase to 60% visibility is observed with the delay line in place. The bandwidth of the IF in this measurement was 20 nm. The visibility was found to increase when the bandwidth of the IF and the spectral-width of the pump beam were decreased. Further increases are expected following fine-tuning of the delay lines.

This source also exhibits space-time interference, as can be seen in Fig. 2. In this plot the coincidence counts are shown as a function of the thickness of the quartz wedge inserted into one of the optical paths, while the delay line in the other optical path was kept fixed. A fast oscillation of the coincidence counts as function of the thickness of the delaying material was observed along with a slower change in the visibility. The fringe spacing in Fig. 2. is related to a change of 88.2 μm of quartz in the delay line, which is consistent with the fringe spacing expected for 795 nm light.

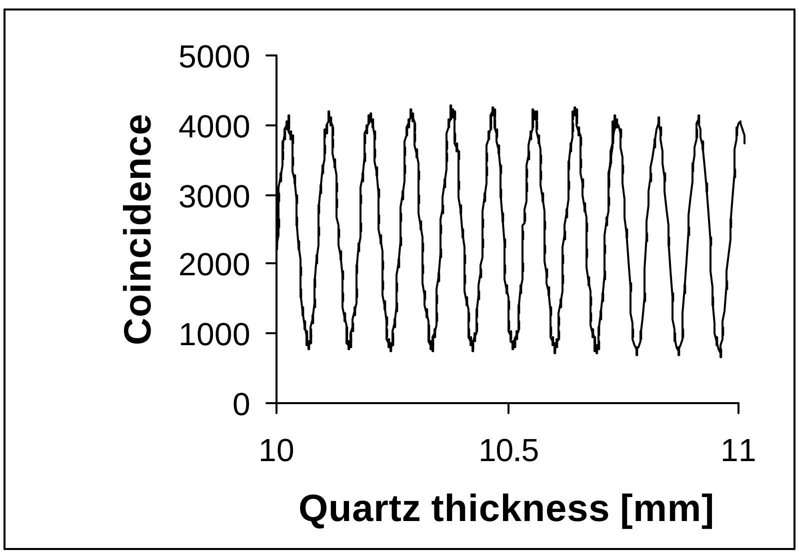

Fig. 2. Coincidence counts as function of the quartz thickness used in the delay line.

In summary, we have realized and characterized a new entangled photon source. Using two crystals in cascade with optical axes at specific directions, we were able to produce entangled photon states from any two conjugated points on the output cones. We have found that simple delay lines in the two output paths can be used to increase the visibility over a large range of the output cones.

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