# Role of Pump-beam Orbital Angular Momentum in Type-II Parametric Down-conversion

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**Abstract:** We experimentally show that nonzero pump-beam angular momentum plays a different role in type-II parametric down-converstion than in type-I. We explore the reason(s) why pump-beam profile does not appear in coincidence imaging of type-II down-converstion.

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In the nonlinear process of spontaneous parametric down-conversion (SPDC), photon pairs generated can be sinultaneously entangled in energy, momentum, and polarization (in type-II process). Recently, it has been shown that the photon pairs in SPDC can also be entangled in angular momentum, another physical variable which has received much attention recently [1]-[3]. However, most experiments performed so far involving angular momentum in SPDC are for type-I process.

It has been demonstrated that the coincidence image carries information about the pump-beam profile in type-I SPDC [3]. Intuitively, one might expect similar results if a type-II SPDC experiment is performed. Nevertheless, as already pointed out in [1], the case of type-II SPDC could be different from that of type-I SPDC in that the former may lack the necessary symmetry for conservation of angular momentum in transfer from the pump photons to down-converted pairs. If there is nonzero angular momentum exchange between the nonlinear material and the interacting optical fields, the pump-beam-profile information may be lost and not appear in the coincidence image.

A 2-mm long beta-barium-borate (BBO) crystal cut for type-II phase matching ($\theta = 49^o, \phi = 30^o$) is used to study the angular-momentum transfer in SPDC. The experimental setup is similar to that of [3] [see Fig. 1(a)]. A polarizor in front of the fixed detector is used to select either horizontally or vertically polarized photons.

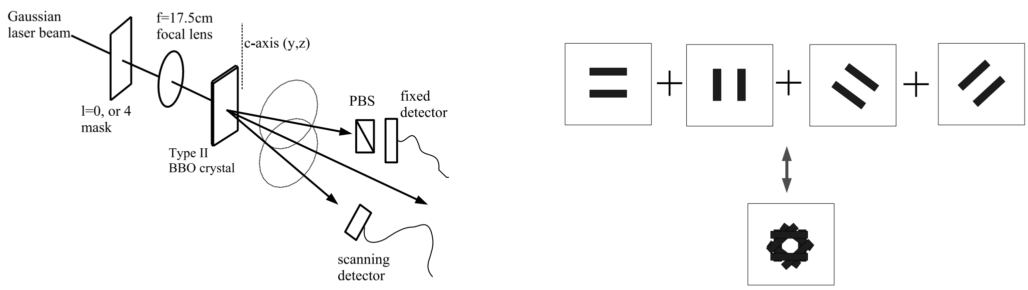


Fig. 1. LEFT: A schematic of the experimental setup. A laser beam with central wavelength of 351.1nm is holographically prepared in the $l = 4$ state of orbital angular momentum and focused on a $\chi^{(2)}$ nonlinear crystal (BBO) cut for type-II phase matching (in practice, BBO was tilted slightly to avoid collinear interaction). One photon of the down-converted pairs at the ring crossings is detected by a fixed detector while the other photon is collected by a scanning detector. Attached to both detectors are interference filters at 702nm with 10nm bandwidth. PBS: polarizing beam splitter. RIGHT: Four at different orientations mapped onto one mask.

As the experimental data show [see Fig. 2], when a Laguerre-Gaussian beam with $l = 4$ orbital angular momentum is used to pump the crystal, the coincidence images do not possess donut-like patterns and, therefore, do not carry the pump-beam-profile information. In addition, the coincidence images for the twin photons with orthogonal polarizations are quite different from each other. One may resort to [4] for the explanation that the observed coincidence images are only the sliced parts of the whole donut profile.

However, when the pump-beam has zero orbital angular momentum, surprisingly, its profile information shows up in the coincidence image [see Fig. 3], which carries information of the whole pump-beam profile, instead of a sliced piece of it. This eliminates the possibility that the pump focusing affected the coincidence images to such an extent that only a small portion of the pump-beam profile remains visible in the coincidence images. This comparison of the case of $l = 4$ pump with that of $l = 0$ pump leads us to believe that the nozero orbital angular momentum is the cause.

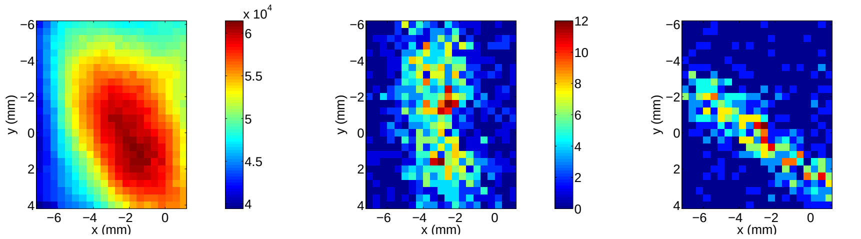


Fig. 2. Experimental data with $l = 4$ pump. The laser power was 0.6W and the data-taking period. LEFT: Single counts. MIDDLE and RIGHT: Coincidence counts with horizontally (210 seconds data-taking period) and vertically (110 seconds data-taking period) polarized photons entering the fixed detector, respectively.

When carrying out the quantum imaging experiment with a pump-beam possessing zero orbital angular momentum, we replaced the $l = 4$ holographic mask with a double-slit mask. The experiment was done with four different orientations for the double-slit mask: $0^o, 45^o, 90^o$, and $135^o$. The pump power was 0.6W and the data-taking period was 20 seconds for each orientation. The coincidence image shown in Fig. 3 is the sum of all the coincidence-detection data, which corresponds to a pump beam that is produced with the four double-slits at different orientations mapped together on one mask [see Fig. 1 RIGHT].

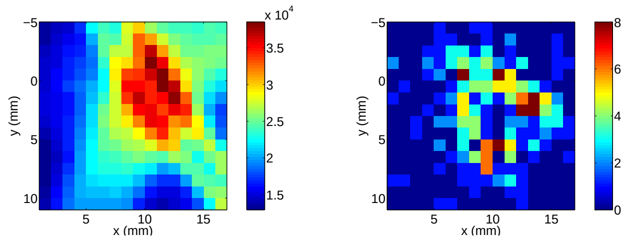


Fig. 3. Experimental data with $l = 0$ pump. LEFT: Single counts. RIGHT: Sum of all coincidence counts with double-slits at four different orientations.

We conclude that the nonzero orbital angular momentum of the pump beam plays yet unknown role in type-II SPDC. The loss of the pump-beam-profile information in the coincidence image is probably related to the nonzero orbital angular momentum of the pump beam. Regarding further study, first of all, we will do orbital-angular-momentum conservation measurement, as in [2], to see if the orbital-angular-momentum transfer is violated. Secondly, we will generate a donut-like pump beam with zero orbital angular momentum, and measure what will happen to the coincidence image. Finally, based on the experimental results, we will carry out theoretical analysis to anwser the question: Is there any inherent connection between the distorted coincidence image and the nonzero orbital angular momentum of the pump beam in type-II SPDC? This work was supported in part by the Quantum Imaging MURI funded through the U.S. Army Research Office.

## References


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