Generation of Spatial Anti-bunching With Free Propagating Twin Beams

D. P. Caetano(*) and P.H. Souto Ribeiro

Instituto de Física, Universidade Federal do Rio de Janeiro, Caixa Postal 68528, Rio de Janeiro, RJ 22945-970, Brazil

(*)e-mail: dilson@if.ufrj.br

Abstract

We propose and implement a novel method to produce a spatial anti-bunched field with free propagating twin beams from spontaneous parametric down-conversion. The method consists in changing the spatial propagation by manipulating the transverse degrees of freedom through reflections of one of the twin beams. Our method use reflective elements eliminating losses from absorption in the objects inserted in the beams.

Introduction

Anti-bunching is a statistical property of a light field, where photons seems to repeal each other. This is a non-classical property of a light beam. Fields prepared in states presenting anti-bunching violate a classical inequality for the joint probability to detect two photons in same position and different times, or same time and different positions. As far as we know, the first experimental observation of photon anti-bunching is due to Kimble, Degenais and Mandel[1]. Their experimental investigation was performed in the time domain looking at the light emitted by atomic decay. They have measured joint probabilities for detection of photons with different time delays between each other. The spatial version of the anti-bunching was proposed and implemented by Nogueira, Walborn, Pádua, and Monken[2], with twin photons from the parametric down-conversion. In their experiment, the final state is prepared by propagation through special double-slits, leading to a beam in which photons seems to repeal each other in space.

In this work, we propose and implement an experimental scheme for obtaining spatial anti-bunching with free-propagating beams. It is based on the transfer of the angular spectrum from the pump to the twin beams of the down-conversion[3] and the manipulation of the transverse spatial coordinate of one of the beams. We obtain a highly anti-bunched beam. The preparation of the state is very efficient with respect to the incoming signal and idler beams.

State preparation

The experimental set-up is shown in Fig. 1. Before the pump laser reaches the non-linear crystal, it is passed through a thin wire and through an imaging lens, so that after pumping the crystal, the image of the wire is formed in a plane situated at a certain distance from it. This distance is the same as the distance between crystal and detectors. It has been demonstrated that the coincidence counting rate between signal and idler photons, has a transverse distribution that mimics the pumping beam intensity distribution[3]. Therefore, if the field distribution for the pump beam with our wire image is given by $W(\rho)$, the transverse coincidence counting rate between signal and idler photons in a detection plane at the same distance from the crystal is given by:

$$C(r) \propto \left| W[\beta(\rho_i + \rho_s)] \right|^2 \quad (1)$$

where ρ_i , ρ_s are the transverse coordinates for idler and signal detectors respectively and β is a constant depending on the distance between signal and idler detectors to the crystal.

It is easy to see that if the coincidence counting rate reproduces the intensity distribution of the pumping laser and it has two peaks with zero in between, this will lead to a conditional detection probability of finding two photons which is zero when the detectors are aligned and increases when they are displaced. This is indeed a condition for spatial anti-bunching, but this is not sufficient. Besides of violating the Cauchy-Shwarz inequality, the field is required to be stationary for the time anti-bunching or homogeneous for the spatial anti-bunching. The field prepared by pumping the non-linear crystal with the wire image angular spectrum, is clearly not homogenous, because the coincidence counting rate depends on the sum of the spatial coordinates of the detectors. Even they are homogeneous to the first order(that is to say, signal and idler beams have homogeneous

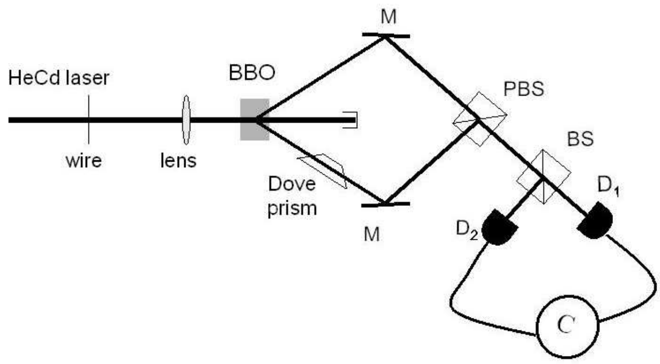

Fig. 1 - Experimental setup.

intensity distributions), in order to be homogeneous to second order, the coincidence counting rate should depend on the difference of the spatial coordinates of the detectors.

In order to overcome this difficulty, we have utilized the scheme displayed in Fig.1. Signal and idler beams from type II phase matching down-conversion are produced in a non-collinear configuration. The signal beam is passed though a Dove prism, so that its spatial coordinate y is changed to -y. As they have orthogonal polarizations, signal and idler beams can be fully recombined in a polarizing beam splitter. The recombined beam, is split in a non-polarizing beam splitter and the two output beams are sent to detectors. Now, the coincidence counting rate for scans in the y direction is given by:

$$C(y) \propto \left| W[\beta(y_i - y_s)] \right|^2 \quad (2)$$

This characterizes an homogeneous field and as it still keeps the pump image information, it will give rise to anti-bunched photons. The experimental demonstration is easier in one dimension, but the result can be easily extended to the two-dimensional case by insertion of a second Dove prism rotate by 90 degrees with respect to the propagation axis in anyone of the beams.

Experiment

The experiment have been performed with a cw horizontally polarized HeCd laser operating at 442nm pumping a 1cm long BBO crystal cut for type-II phase matching, as shown in Fig 1. The down-converted beams, signal and idler, at 884nm emerge from the crystal at an angle of 11^o with respect to the laser beam. Two mirrors and a polarizing beam splitter recombine the twin beams. In the signal path a Dove prism is inserted to produce the homogenous field distribution in second order. The combined beam propagates to a non-polarizing beam splitter and are sent to detectors D1 and D2 placed about 75cm from the crystal. Each detector assembly includes a slit of about 0.3mm width, a interference filter centered in 884nm with 10nm bandwidth, a 12.5mm focal length lens, and a single photon counter. The detectors are mounted on translation stages. Single and coincidences counts are recorded scanning the detector in the y direction.

Results and Discussions

Initially we put a 50mm diameter wire before the beam-splitter just to check the alignment of the detectors in the vertical direction. Fig. 2 show the single counts scanning D1 and D2 plotted in function of D2 position. A 25mm diameter wire and a 25cm focal length lens are placed in the laser beam before the crystal, such that the wire image is formed in the detection plane. In Fig. 3a is shown the coincidence profile scanning D2 and keeping D1 at the point of minimum of Fig. 2. As we can see, the image of the wire in the laser beam is transfered to the coincidence rate. We repeat this measurement with D1 displaced +0.4mm and -0.4mm with respect to the point of minimum of Fig. 2, and the results are shown in Figs 3b and 3c, respectively. The effect is shift the image at the same quantity, showing conditional behavior of the coincidence rate. Scanning D1 and D2 simultaneously in the same direction the coincidence rate is constant and equal to the minimum to the profile showed in Fig 3a, while scanning simultaneously and in the opposite direction, the coincidence rate depends on the sum of tranverse coordinates of the signal and idler. The coincidence profile for this two situations are shown in Fig 4.

In Fig. 4a we can see a background at level of minimum of Fig 3a, illustrating the homogeneous character of the field in the second order, while in the Fig 4b the image in coincidence appears about two times smaller than that of Fig. 3a.

We also have performed this measurements whitout the Dove prism. The transfered image to the coincidence rate is shown in Fig 5a, while the effect of displace D1 of +0.4mm and -0.4mm is shown in Fig. 5b and 5c, respectively. In contrast with the situation above described, the image in coincidence is shift in opposite direction of the displacement of D1. Scanning D1 and D2 simultaneously in the same direction the coincidence rate is anymore constant while scanning in opposite direction it is constant and equal to the minimum of Fig 5a. This results are shown in Fig6. Here, the coincidence rate depends on the sum of transverse coordinates of the signal and idler beams, so that the filed is no more homogeneous in second order, as illustrated in Fig. 6a, and the results can not be interpreted as a spatial anti-bunching.

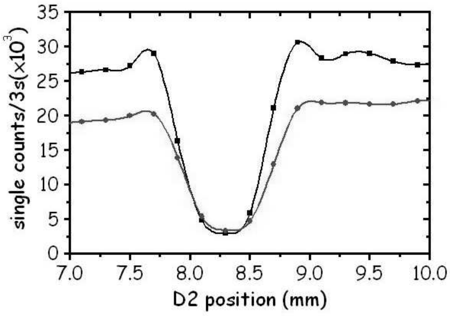

Fig. 2 – Intensity profile scanning D1(squares) and D2(circles) plotted in function of D2 positon.

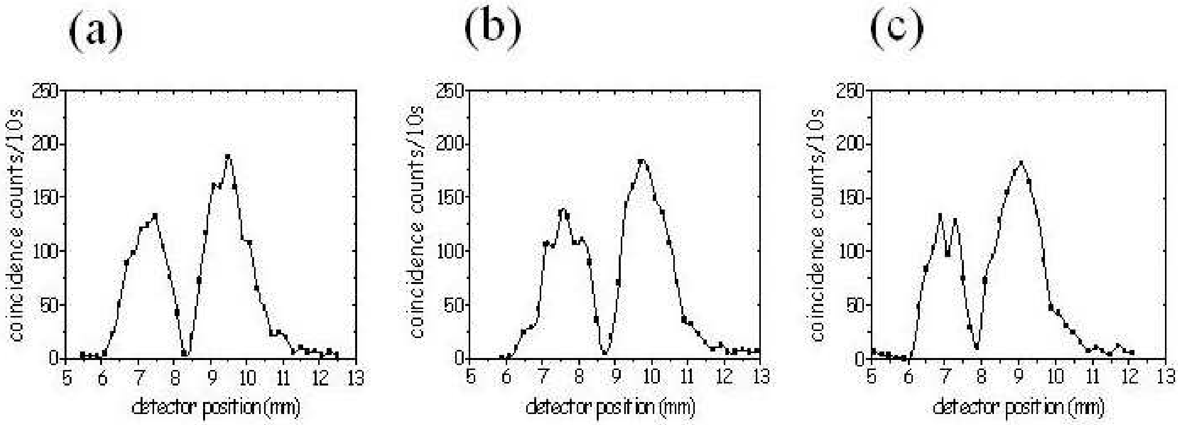

Fig. 3 – Coincidence profile scanning D2 with D1 fixed. (a) D1 at minimum of Fig. 2; (b) D1 displaced of +0.4mm; (c) D1 displaced of –0.4mm.

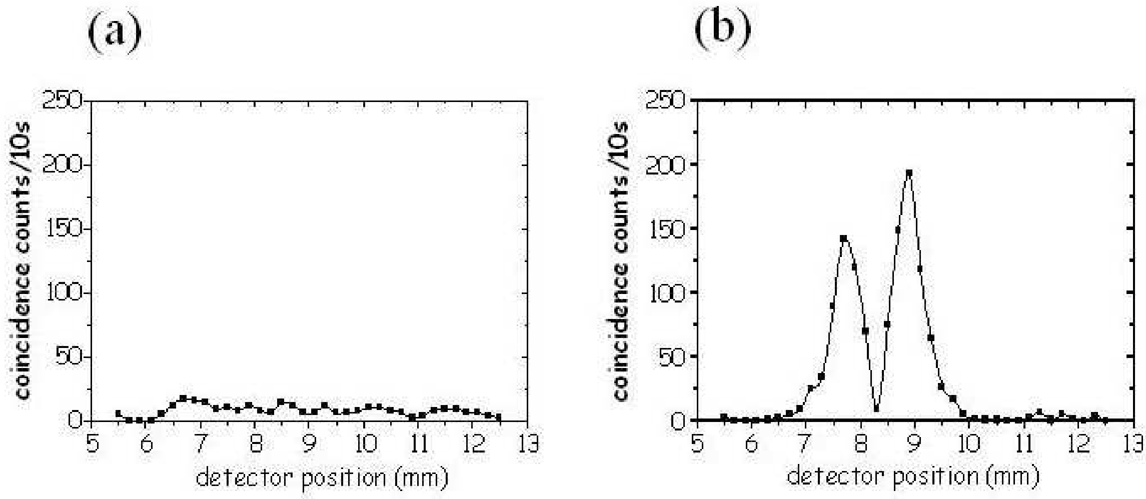

Fig. 4 – Coincidence profile scanning D2 and D1 simultaneously. (a)same direction; (b) opposite direction.

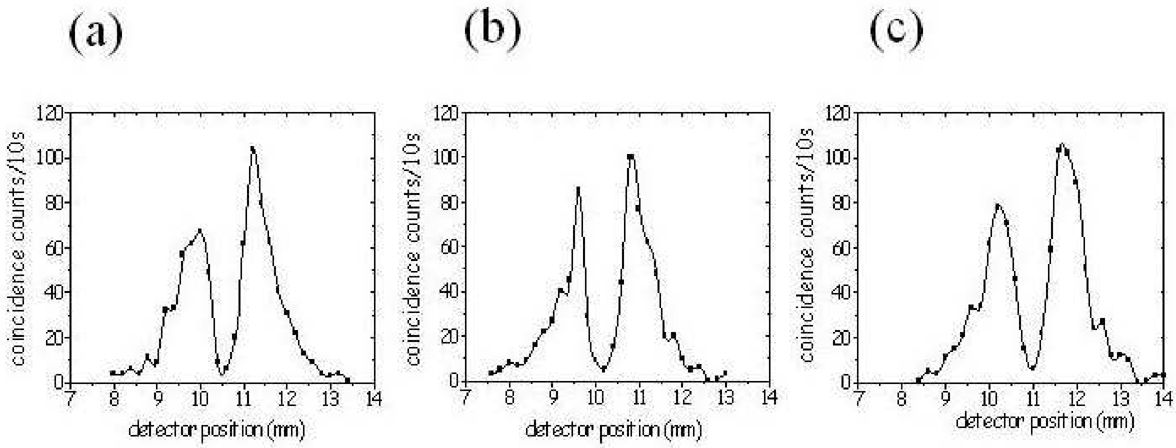

Fig. 5 – Coincidence profile scanning D2 with D1 fixed. (a) D1 at minimum of Fig. 2; (b) D1 displaced of +0.4mm; (c) D1 displaced of –0.4mm.

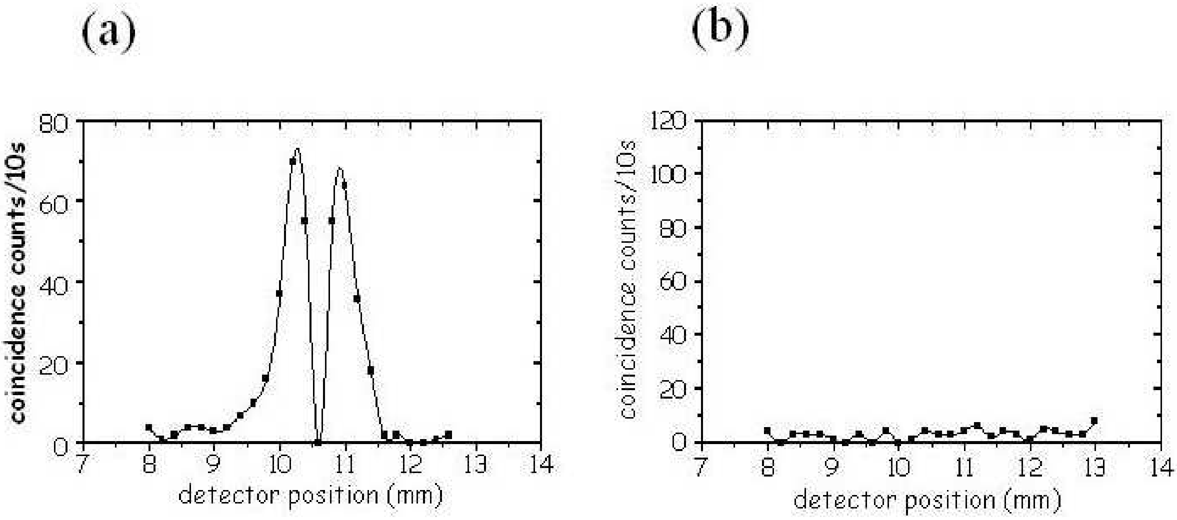

Fig. 6 – Coincidence profile scanning D2 and D1 simultaneously. (a)same direction; (b) opposite direction.

Conclusions

In conclusion, we have demonstrated experimentally the preparation and observation of a high visibility anti-bunched field with free propagating twin beams from the parametric down-conversion.

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