A Study of Spontaneous Parametric Down Conversion

Paroma Palchoudhuri and Carlos Escobar (mentor)
The College of Wooster, Wooster, Ohio and Fermi National Accelerator Laboratory, Batavia, Illinois

Abstract

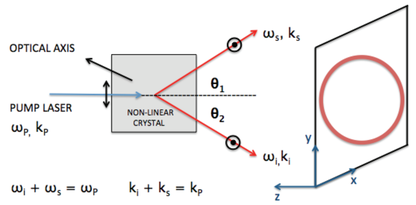
Type I spontaneous parametric down conversion is demonstrated using a non-linear, bi-refringent crystal (Beta Barium Borate), which is used to split vertically polarized photons of 405 nm into pairs of photons of 810 nm each . This conversion has to satisfy energy and momentum conservation. The optical axis of the crystal should lay on the plane formed by the beam direction and the laser polarization. A single photon detector (SPCM) is used to perform a 2D scan of the region defined by the down converted photon ring.

With a decrease in baseline the radius of the corresponding ring decreases. For baselines of 47 mm, 42 mm and 37 mm, the corresponding radii are 3.5 mm, 3 mm and 2.625 mm respectively. The angle that the down converted photons form with the pump beam is approximately 4.13 degrees. The width of the rings for each of the three baselines vary between 0.23 mm and 0.44 mm.

A 90 degree rotation of the polarization of the pump beam resulted in the absence of a ring since Type I spontaneous parametric down conversion cannot occur for a pump beam which is not an extraordinary ray.

Theory

• The phenomenon where a non-linear crystal is used to split incoming photons into pairs of photons obeying conservation of energy and momentum is called spontaneous parametric down conversion (SPDC). For type I SPDC the pump beam must have polarization parallel to the optical axis (OA) and the down converted photons orthogonal to it. In this process the crystal state remains unchanged.



Shorter wavelength
Higher frequency

Longer wavelength
Lower frequency

• **Conservation of Energy**

$$\omega_i + \omega_s = \omega_p$$

• **Conservation of Momentum**

Transverse:

$$|\vec{k_s}|\sin\theta_s = |\vec{k_i}|\sin\theta_i$$

Longitudinal:

$$|\vec{k_p}| = |\vec{k_s}|\cos\theta_s + |\vec{k_i}|\cos\theta_i$$

• When the polarization of a ray of light is in the plane that is formed by the optical axis and the direction of propagation of the pump beam, the ray is called an extraordinary ray.

• When the polarization of light is iperpendicular to the plane that is formed by the optical axis and the direction of propagation of the pump beam, the ray is called ordinary.

Type I Spontaneous Parametric Down Conversion

When an extraordinary ray splits into two ordinary rays.

$$e_p \rightarrow o_s + o_i$$

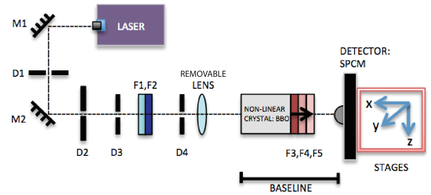
Type II Spontaneous Parametric Down Conversion

When an extraordinary ray splits into one ordinary ray and one extraordinary ray.

$$e_p \rightarrow o_s + e_i$$

Our experimental setup uses Type I spontaneous parametric down conversion.

Experimental Setup



• Vertically polarized light enters the crystal.

• Beta Barium Borate (BBO) is the non-linear crystal.

• BBO crystal is cut for SPDC at a split angle of 3 degrees.

• 405 nm (violet) pump beam comes from the laser.

• Two 810 nm (infrared) outgoing beams produced in the crystal.

• Detector is a single photon counting module having a dark count rate of approximately 120 Hz.

• M1 and M2 are mirrors that are used for beam alignment.

• D1, D2, D3 and D4 are the diaphragms that are used to control the intensity of the light beam entering the crystal and to remove the halo.

• F1 and F2 are glass filters to remove laser fluorescence.

• F3, F4 and F5 select the 810 nm wavelength and absorb the transmitted pump beam.

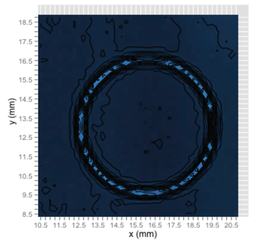
• The lens is used to focus the beam on the front face of the crystal.

• Baseline is the distance from the front face of the crystal to the sensitive area of the detector.

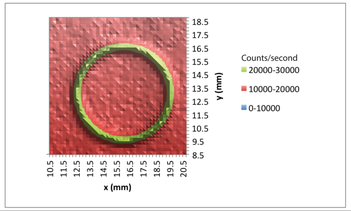
Results and Analysis

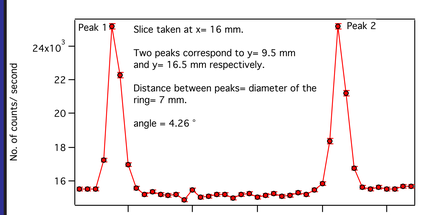
A two-dimensional scan of the region formed by the ring as a result of spontaneous parametric down conversion was taken. As the baseline decreases, the radii of the corresponding rings decrease. However, the angle formed between the down-converted rays and the direction of propagation of the pump beam remains constant at approximately 4.13 degrees.

Baseline = 47 mm



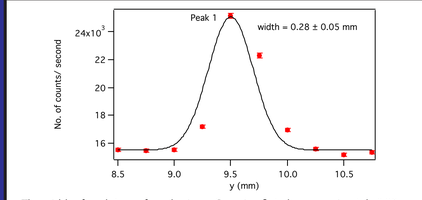
• z = 0 microns
• step size = 250 microns
• events/position = 10
• without lens
• Coordinates of the center of the ring = (15.68, 13.61) in mm.



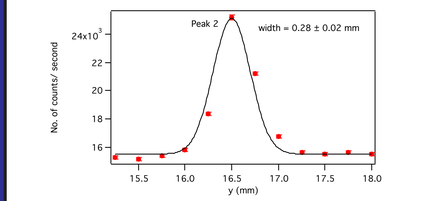


• Took a slice of the above ring (z = 0 microns) at x = 16 mm, and found the distance between the peaks to be 7 mm, i.e, radius of the ring = 3.5 mm.

• The half opening angle of spontaneous parametric down conversion is 4.26 degrees.

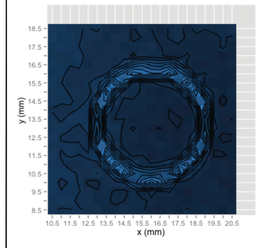


• The width of peak 1 was found using a Gaussian fit to be approximately 0.28 mm.

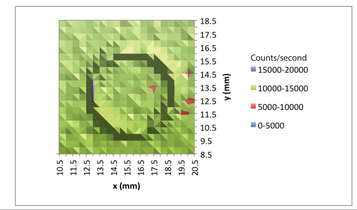


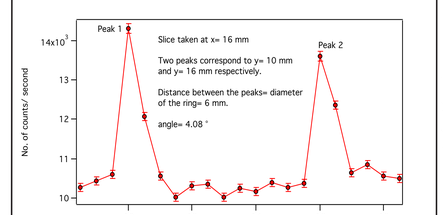
• The width of peak 2 was found using a Gaussian fit to be approximately 0.28 mm.

Baseline = 42 mm



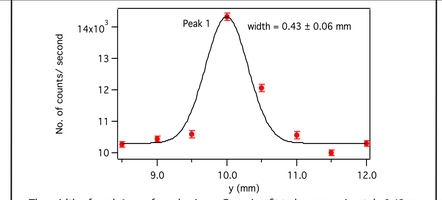
• z = 5000 microns
• step size = 500 microns
• events/position = 3
• without lens
• Coordinates of the center of the ring = (15.44, 13.51) in mm.



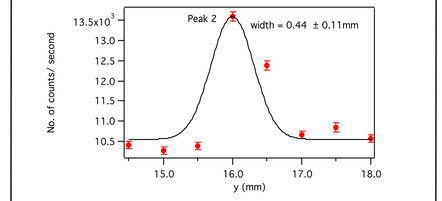


• Took a slice of the above ring (z = 5000 microns) at x = 16 mm, and found the distance between the peaks to be 6 mm, i.e, radius of the ring = 3 mm.

• The half opening angle of spontaneous parametric down conversion is 4.08 degrees.

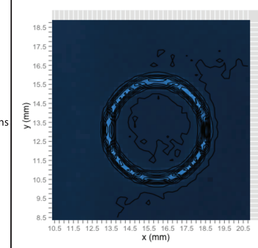


• The width of peak 1 was found using a Gaussian fit to be approximately 0.43 mm.

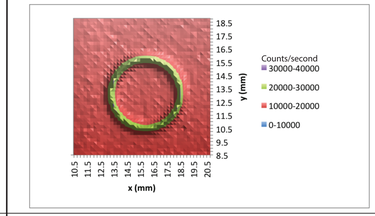


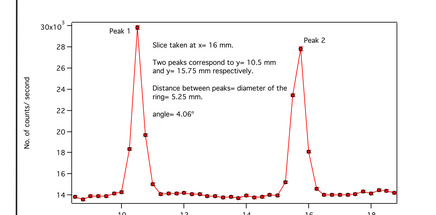
• The width of peak 2 was found using a Gaussian fit to be approximately 0.44 mm.

Baseline = 37 mm



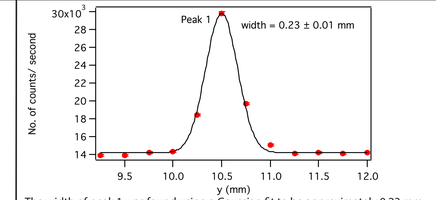
• z = 10000 microns
• step size = 250 microns
• events/position = 10
•without lens
• Coordinates of the center of the ring = (15.57, 13.62) in mm.



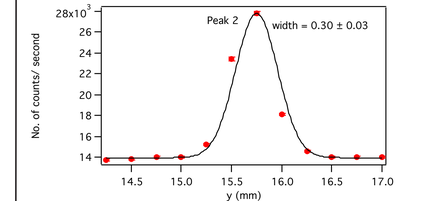


• Took a slice of the above ring (z = 10000 microns) at x = 16 mm, and found the distance between the peaks to be 5.25 mm, i.e, radius of the ring = 2.625 mm.

• The half opening angle of spontaneous parametric down conversion is 4.06 degrees.

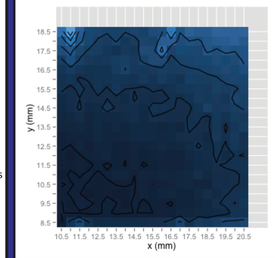


• The width of peak 1 was found using a Gaussian fit to be approximately 0.23 mm.



• The width of peak 2 was found using a Gaussian fit to be approximately 0.30 mm.

Rotation of the Optical Axis of the Crystal



• Baseline = 47 mm
z = 0 microns
Step size = 500 microns
events/position = 3

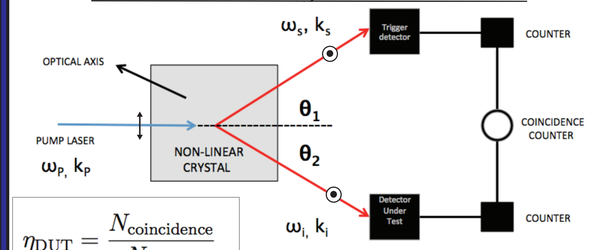
• Optical axis of the BBO crystal was rotated by 90 degrees. The pump beam is now an ordinary ray.

• As expected, no ring is formed, indicating the absence of SPDC.

• Background light is seen.

• The ring was recovered using a half-wave plate to rotate the polarization of the laser pump to horizontal (results not shown).

Calibration of a Single Photon Detector



$$\eta_{DUT} = \frac{N_{coincidence}}{N_{trigger}}$$

$N_{coincidence}$ = No. of coincidence events in a particular time window.

$N_{trigger}$ = No. of trigger events in the same time window.

• Coincidence of the two single photon detectors, the trigger and the detector under test (DUT), is used to determine the quantum efficiency of the DUT.

Future Work

• Improve the method of analysis and experimentation in order to provide a better defined fit to determine the radius and width of the ring that is formed by spontaneous parametric down conversion.

• Extend the experimental setup to encorporate a second single photon detector in order to use coincidence of the two detectors to calibrate and determine the efficiency of the DUT.

Conclusion

• We reconstructed the full ring formed as a result of spontaneous parametric down conversion using a single photon detector. Previous images of such rings were obtained by taking pictures using CCD cameras or infrared films, involving a long exposure time. This is the first time an image of the ring is obtained by a scan.

• All the properties of the parametrically down converted light were confirmed, such as polarization properties and opening angles.

• The radius of the ring shrinks with a decrease in baseline and the angle that the spontaneously down-converted rays form with the direction of propagation of the photon beam remains constant at approximately 4.13 degrees. The width of the rings corresponding to each of the three baselines fall within a range of 0.23 mm to 0.44 mm.

Acknowledgements

• We thank Paul Rubinov for his assistance with the data acquisition system and control of the experiment. Paul and Adam Para are also thanked for stimulating discussions regarding the experiment.

• We also thank Dagmawi Ayalew of The College of Wooster, Ohio, for his consistent help and advice in designing a script to analyze the collected data.

• Finally, we thank the Department of Energy / Office of Science and Fermi National Accelerator Laboratory for funding this research project.

This work was supported by the U.S. Department of Energy, Office of Science and Fermi Naional Accelerator Laboratory under the Internship for Physics Majors (IPM) program.