# Finding Phase Matching Angles for Entangled Photons

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## Introduction

The current setup that we have in the optics lab is a setup to created correlated photon pairs. it is a Type-I down conversion setup setup that uses a 405nm laser passing though a Beta Barium Borate (BBO) crystal at an angle of 29.2deg to produce our entangled photon pairs. to the change the direction of the entangled pairs then we just have to change the angle of the BBO crystal by 0.4deg.

## SPDC Background

since we had a Type-I down conversion setup the entangled photons will have a total frequency of $\omega_p$ with $\omega_1$ and $\omega_2$ being the individual frequencies of the photons such that $\omega_p = \omega_1 + \omega_2$. This is assuming the momentum of the light is being conserved. inside the crystal. There are 2 equations that need to be satisfied.

$$n_p\omega_p = n_1\omega_1 cos(\theta)_1 + n_2\omega_2 cos(\theta)_2$$

$$0 = n_1\omega_1 sin(\theta)_1 + n_2\omega_2 sin(\theta)_2$$

- $n_p$, $n_1$ and $n_2$ are the indices of refraction for all light frequencies: $\omega_p$, $\omega_1$, and $\omega_2$ inside the crystal
- The angles $\theta_1$ and $\theta_2$ are the angles formed by the momentum of the entangled photon pairs
- If $\omega_1 \neq \omega_2$ then the photons that leave the crystal will form a cone with half of $\theta_1$ and the other will be half of $\theta_2$. below is the expected behavior of the entangled photon pairs.

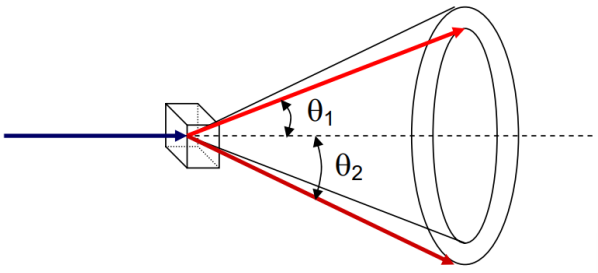



Figure 1: Projected diagram of the angles of the photon pairs

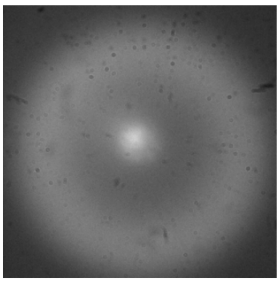


Figure 2: This figure shows what the down converted photon pairs should look like using a CCD camera

# Goal

The goal that we are trying to achieve is to find what angles give us the best picture of the entangled photon pairs. we want to know where are the 'dead' spots in our image.

# Methodology

The first step was to find all of $npfp$, $nifi$ and $nsfs$. This was done by first selecting half of the 740 wavelength. Then we use the formulas that were given in the galvez paper on page 9:

$$n_o(\lambda) = [\ 2.7359 + 0.01878/(\lambda^2 - 0.01822) - 0.01354\ \lambda^2\ ]^{1/2}$$

$$n_e(\lambda) = [\ 2.3753 + 0.01224/(\lambda^2 - 0.01667) - 0.01516\ \lambda^2\ ]^{1/2}$$

Figure 3: formula for determining the signal and idler wavelengths

once these wavelengths are calculated we can find solve for nsfs, and nifi these would in turn give us the solutions for the kz components: $n_s f_s cos(\theta_s)$ and $n_i f_i cos(\theta_i)$ the same can be done for the ky components: $n_s f_s sin(\theta_i)$ and $n_i f_i sin(\theta_i)$. we then need to choose the best value for theta that would give us the lowest percent error for our chosen wavelength. This was found by solving for $\theta_i$ then solving for $\theta_s$ the formulas used were:

$$n_p f_p = n_s f_s cos[1 + \frac{(\frac{-n_s f_s}{n_s w_s})^2}{2}] + (1 + \frac{\theta^2}{2})$$

to solve for:

$$\theta_i = \frac{-n_2 w_s}{n_i w_i}\theta_s$$

using the angles from these equations gave us a good starting point for an approximation for the angles for the entangled pairs.

Once the data was recorded we needed to create a graph of entangled photons similar to the one produced in the galvez paper. in order to create multiple circles based of the data gathered i simply looked up how to make a circle in python and there were multiple guides. Translating the data into code was simple once i realized that the formulas for the kz and ky components were themselves quadratic formulas.

# Results

Once all of the data was calculated and codded into spyder our resulting graph looks this:

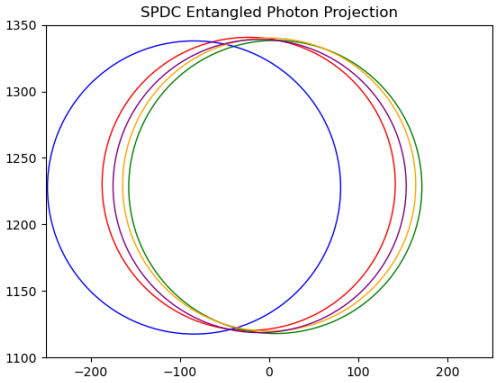



Figure 4: This is a multi-color image of the entangled photon pairs

## Future Steps

In the future it might be wise to actual test these projects as well as to have more precise angles for $\theta$. It might alos be useful to write some code to actually find the thetas for us given a value in python.