Hello everyone and welcome to my presentation for PHYS 437 A – Measuring the Quantum Beat

Before we continue, just wanted to give a short summary of contents

* I begin with the premise and motivation behind the project speaking about particle distinguishability and a plan of attack to help determine this
* Next, I will collect the building blocks necessary to help me determine particle distinguishability, by defining the object being tested, how it will be tested, and the methodology used to analyze the results of assessment
* I will then assemble these blocks in such a way to detect the quantum beat, and find the likelihood of measuring a coincidence count
* I will conclude with a summary of these results and future considerations

Without further ado: Particle Indistinguishability

Looking at this picture, can we determine the outcome of this collision? We would probably say that the blue one will deflect up while the red will deflect down. Now suppose I strip it of colour? Can we still talk about the trajectory of the particles? I suppose I could then speak about the left and right particles. But what if they were quantum particles? According to Heisenberg’s uncertainty principle, position has very little meaning outside the time of measurement. This inability to differentiate between particles is quantum phenomenon called Indistinguishability. This seems like a simple thought experiment; however this can have large effects on experimental data as well.

Due to the nature of optical quantum computing; it often requires the generation of entangled photon pairs that are indistinguishable. But how do we know that this is the case? In this experiment I aim to demonstrate that the Hong-Ou Mandel experiment can be used to determine the distinguishability of photons.

Motivated by “Time- Resolved Two-Photon Interference” by Legero, Wilk, Kuhn, and Rempe I seek to do the following:

* + Demonstrate Quantum Beat
  + Compare Probability Distribution found with Idealized HOM Probability Distribution

I do this by following the process outlined in “Signatures of Hong-Ou-Mandel Interference at Microwave Frequencies

* + Perform Hung-0u-Mandel Experiment on Incident Photons
  + Determine the associated second order Correlation Function
  + Integrate Second-order correlation function over all possible detection times

In order to carry out this plan successfully, I need the following 3 Mathematical descriptions, which I seek to outline in my next slides

Photon generation and destruction falls naturally under the framework of the quantum harmonic oscillator, especially when considering that the electromagnetic field quantization recovers a form that looks like the harmonic oscillator. However, the quantization of electromagnetic field uses solutions of the electromagnetic field that are polarization dependent. How do we involve frequency?

Through the combined efforts of Glauber and Titulaer, a relationship between the inverse of photon lifetime and spectrum of frequency that a photon contains. Given this, a spatio-temporal definition for a photon was made possible. In this project we will be using the function defined by Legero, Wilk, Kuhn, and Rempe. With the following variable definitions

* is the temporal separation between photons
* is the central frequency between photon a and b
* is the separation between photons a and b

We have now established the mathematical shape of the photon, let us find a framework for the Hong-Ou-Mandel experiment

First demonstrated by Chung Ki Hong, Zheyu Ou, and Leonard Mandel in 1987. This experiment is a landmark experiment in quantum optics; however, its implementation is rather simple. Two photons are incident on a beam splitter, this emits output photons which are incident on two photodetectors. The researchers then measured the detection delay between the photodetectors. The results of which were unexpected.

Hong, Ou, and Mandel found that when there was no temporal separation between the photons and the photons were indistinguishable, there was no coincident counts. That is to say that there were no simultaneous photon detections in both photodetectors.

This can be demonstrated mathematically as follows:

* The state of the system is vacuum state, upon which two photon creation are acting
* The beamsplitter transformation that takes input photons a and b and generates outputs c and d

We can combine these to get the final result of the HOM experiment – No Coincidence Counts!

We have now arrived at our final building block, the second order correlation function. This was motivated by the experimental results of R. Hanbury-Brown and R. Twiss, who wanted to prove that a beam splitter was sufficient to determine star size. They found that the average fluctuations in the input intensity were proportional to the average fluctuations in the output photocurrents.

These outputs can be modelled via the second order correlation function. In quantum optics, photon counts, rather than intensity are used, and we end up with the following form.

Now that we’ve established our building blocks, let’s see what we can make with them. In our previous slide, we established a second-order correlation function, however these are with respect to input photons. We make a small change so that they represent output photons c and d.

However, this comes with a catch that we don’t know what the output photons look like, however if we recall the beam splitter transformation, we can recast what we have in terms of the input photons which we do know everything about.

The resulting equation is rather cumbersome, but it can be simplified with the following considerations:

* We are only considering single photon emissions, so we can ignore terms that are operator squared like a^2 or adag^2
* The time dependence is only in the temporal mode function, not in the operators themselves
* Use of the vacuum state as established in the HOM Experiment section
* And the expectation number of the number operator on the first excited state is 1

We are left with the following simple form for the second order correlation function

Into which we input the mode function given by LWKR, which gives us the following equation.

We can graph this over different frequency differences, and what we note is that as the difference in frequency increases so too does the number of fringes within the envelop – The Quantum Beat

However, we can pursue this a little further. We want to know how the likelihood of measuring a coincidence count has changed. We can do this by considering the probability distribution over all detection times. We do this mathematically by integrating the second order correlation function over all detection times t and all detection delays tau. We are left with the following equation, which we can graph to contrast against the idealized HOM dip.

We have the correlation plotted on the blue axis, frequency difference on the green, and temporal delay on the red. What we can see is that as the frequency difference changes, the HOM dip steadily rises from its idealized position. This acts as a second confirmation for photon distinguishability.

In summary, we have confirmed that the HOM experiment can be used as a verification for photon indistinguishability. We can calculate the second order correlation function associated to the HOM experiment and detect the presence of the quantum beat by graphing it. We can also integrate this function over all possible detection times and detection delays and contrast it against the idealized HOM dip as further confirmation for photon distinguishability.

So where does this take us going forward? Industry standards for quantum optics are spontaneous parametric down conversion for photon generation. However, this process is probabilistic rather than deterministic. One of the ways we can move away from this is in the use of the quantum dot. I seek to test the Reimer group’s quantum dot and measure the distinguishability of the photons that it emits.