# Beam-Helicity Asymmetry

## $\gamma P \rightarrow P' K^{+}K^{-}$ system

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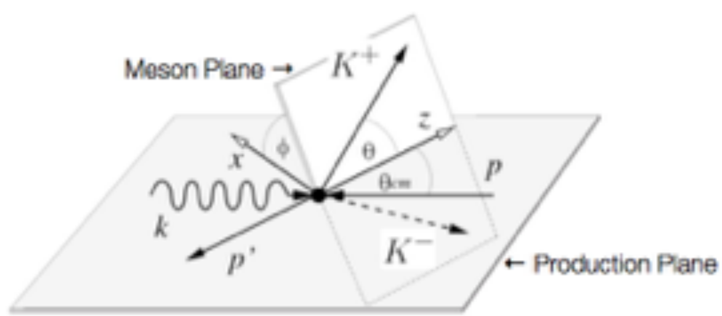
The project's focus is on an experiment performed at Jefferson Lab with the CEBAF large Acceptance Spectrometer using circularly polarized photons incident on a hydrogen target. For this project, the system of interest is the $\gamma P \rightarrow P' K^{+}K^{-}$. Through analyzing this system in it's center of momentum, two planes are created. For this experiment, the angle between the production plane and meson plane, the phi angle, is what is analyzed. The final results consist of a plot of the phi angle and beam helicity asymmetry. The results show some asymmetry and can be attributed to several theories explaining why the system shows this asymmetry.

## Introduction:

This project explores the beam helicity asymmetry of the $\gamma P \rightarrow P' K^+K^-$ system. In this system a circularly polarized photon ($\gamma$) is incident on a hydrogen target producing a recoil proton (P') and $K^+K^-$ mesons. Due to the circularly polarized photon, its helicity is either up or down (+1 or -1) [4]. By analyzing the system in its center of momentum, two planes are created. The production plane and meson plane create an angle, called phi, labeled in the picture following this section. The purpose of this project is to plot the helicity of the photon as it changes with that angle. It is important to study the helicity asymmetry because it can explain an element of the spin density matrix. In a two level spin state, such as a circularly polarized photon, there is a probability matrix, Ψ, that includes $|c1|\ e^{i\gamma}$ and $|c2|\ e^{i\gamma}$. This leaves four unknown variables to solve for. Several of the variables can be measured, but it still leaves variables unknown. The spin density matrix takes the inner product between Ψ to form a matrix of variables that states everything needed to know about the states of the system. Through this experiment, the input system is known and the output of the system is found. Using this information, the spin density matrix can be verified. The spin states of the particles want to be conserved, but in some events within this system, this is not possible which produces asymmetry. Because of this, the results are expected to show asymmetry [1].



# Theory:

The photon’s helicity is measured, tracked using Jefferson Lab’s photon tagger system, and then recorded using ROOT programming [3]. When displaying the helicity of the photon, the program shows two peaks. Half of the events measure the photon to have a helicity of -1 (down) and the other half show the photon’s helicity to be +1 (up). This shows that the overall helicity of the photon is 50% up and 50% down. This is expected, but this project is interested in the helicity of certain phi angles. The first formula needed for this experiment is the beam helicity asymmetry formula [6].

$$I^{\odot} = \frac{1}{P_\gamma}\frac{\sigma^{\uparrow}-\sigma^{\downarrow}}{\sigma^{\uparrow}+\sigma^{\downarrow}}$$

Experimentally the formula will be taken to be:

$$I^{\odot}_{\text{exp}} = \frac{1}{P_\gamma}\frac{N^{\uparrow}-N^{\downarrow}}{N^{\uparrow}+N^{\downarrow}}$$

The N’s up and down arrows correspond to the beam’s helicity being an up or down state. P gamma is the polarization of the beam and is found using the following equation [1]:

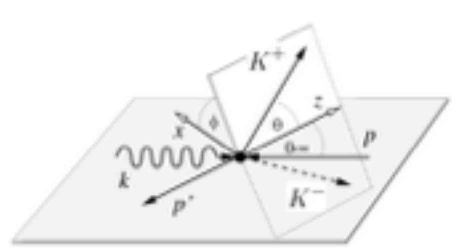
$$P_\gamma = \frac{E_\gamma(E_e + \frac{E_e - E_\gamma}{3})}{E_e^2 + E_\gamma^2 - \frac{2}{3}E_e E_\gamma}P_e$$

In this equation, Eɣ is energy of the photon. Ee is energy of the electron beam and, Pe is the polarization of the electron beam. The beam helicity asymmetry will them be calculated for several angles of phi [4].

## Methods:

The first step of the project was to analyze the data received from Jefferson Lab in a ROOT file. A code was written to take the data and make cuts to restrict the data to show accurate exclusive $K^+K^-$ measurements. Every 2 nanoseconds a photon would be fired at the target, the data was showing overlap in results so a cut was placed on the timing measurements to fix the data. Next, cuts were created where to restrict the detected particles to within the target. Three more cuts were made to fix the resolution of the scintallator. For this experiment Jefferson Labs were only interested in energy above 3.6 GeV which was another cut that needed to be made [1]. Lastly, several cuts were made on missing mass to insure that the only data that was left would be exclusively $PK^+K^-$. In creating these cuts, the invariant mass of the $K^+K^-$ graph showed a sharp peak at 1020 MeV. The peak is at 1020 MeV because the $K^+K^-$ mesons decayed from a ϕ meson which has invariant mass of 1020 MeV. By seeing the data peak at that point, it shows that a significant amount of events that resemble ϕ mesons being produced through the experiment. Because this project is interested in only those events, it is important to create a noticeable peak at that 1020 MeV mark. Before these cuts, the graph showed very little resemblance of a peak at 1020 MeV, by making the cuts, it got rid of the data that was adding noise to the graph and allowed the peak to be enhanced.

The next step was to create a separate code that took the fixed data and added variables and new 'leaves' to the file. ROOT files are composed up of leaves that display different measurements or data. By creating new leaves, it enables future code to take the measurements just by importing the leave's information. This code created 4-vector components for all of the particles in the reaction (beam, target, $K^+$, $K^-$, P'). They were set using the data in the original ROOT file which measured each of the particles position and energy. Then, using the 4-vectors and a ROOT method, the entire system was changed into its center of momentum. The reaction, in its center of momentum, can be visualized using the following picture:



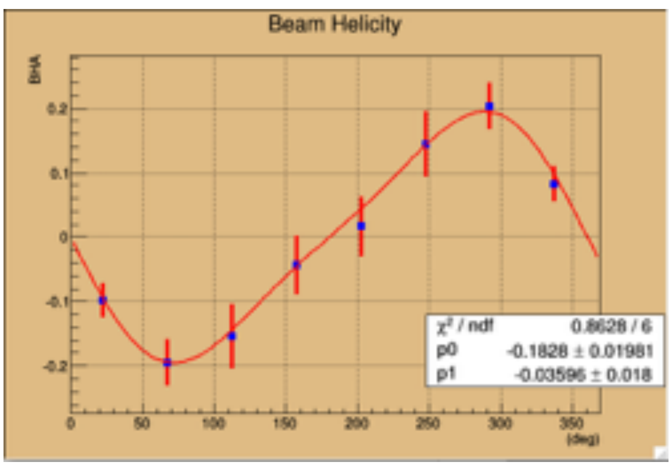
Lastly, this code was then able to use a ROOT method to create a new leaf that displayed the values of phi (shown in the picture above).

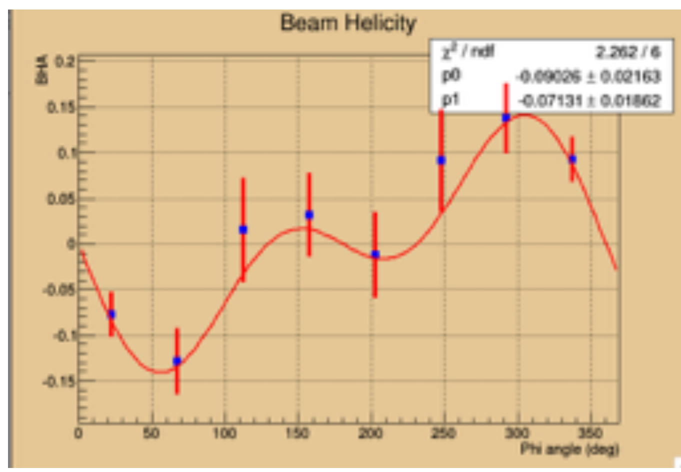
After that a third code was written to create the final piece of the project. This code is what produces the results in graph form. A loop was created to calculate the beam helicity asymmetry, using the formulas explained earlier. This was looped over several phi angles. From there, the code graphed the beam helicity asymmetry versus the phi angles.

A fourth code was written to further exclude unnecessary data in the graph. The ROOT's plot of the invariant mass showed a peak at 1020 MeV created in the first code. This project is only interested in the events that peaked at that point, so this code's goal is to create an accurate cut on the peak to exclude background data. If the correct fit cannot be applied to the peak, then a rough cut surrounding the peak can also be used.

## **Data:**

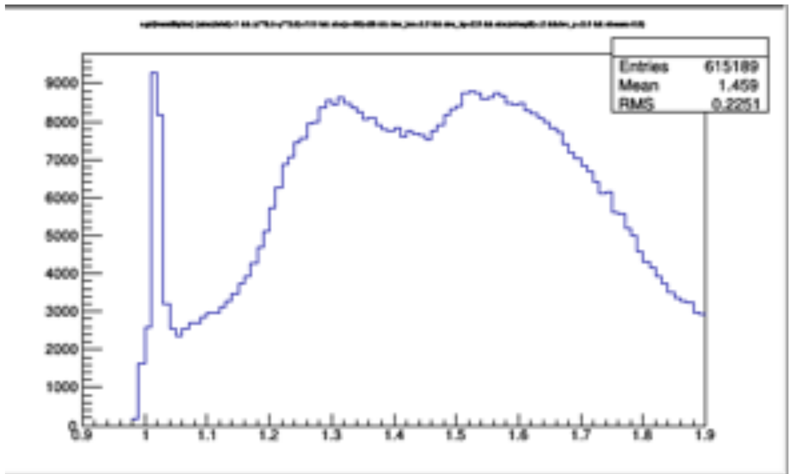
The final results of the experiment are as follows.




The graph on the left is the beam helicity asymmetry versus phi with a rough cut spreading 60 MeV wide centered at 1020 MeV [1]. This cut is wider which includes more events. The graph on the right is the beam helicity asymmetry versus phi with a rough cut spreading 10 MeV wide centered at 1020 MeV. This cut is more narrow and allows less event to be included in the experiment.

The following is the plot of the invariant mass of the $K^+K^-$ after the first code cleaned up the data.



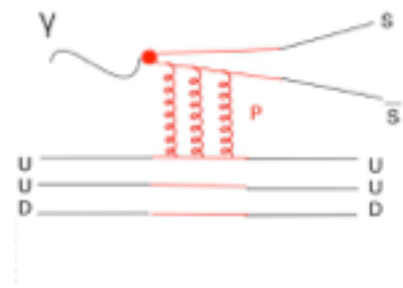

This graph is important to the accuracy and precision of the results. The important part of this graph is the peak at 1020 MeV. Because this project is only interested in the exclusive $K^+K^-$ system, the only data that is needed is the events that peak at 1020 MeV. This is where the rough cut is created. The fourth code, that was used to create a fit to exclude background data, was not completed which forced a rough cut to be used instead. A rough cut surrounding 1020 MeV will be directly related to how accurate the final graphs are. In the graph on the left up top, the cut is wide so it includes more events which may contribute to more background noise being included in the data. The graph on the right is likely to be more accurate than that on the left. Although the most accurate would be to code a fit that cuts the peak along a curve.

# Discussions and Conclusions:

Both graphs show results that support asymmetry being present in the $\gamma P \rightarrow P' K^+K^-$ system. This is known because if there was no asymmetry in the system then there would be a flat line at 0 [7]. The waves, shown in both graphs, prove that there is asymmetry. Further analysis of the graphs lead to some theories as to why there is an asymmetry.

A)


B)




The two Feynman diagrams above represent a couple explanations as to why there is asymmetry in the $\gamma P \rightarrow P' K^+K^-$ system. Diagram A shows the helicity states of the photon, phi meson, and the exchange particle. If the exchange particle's spin is 0, then the phi meson's spin will be whatever the incoming photon's spin is. If the exchange particle's spin is -1 and the photon's spin is 1 then the phi meson's spin will be 0. The system wants to achieve conservation of spin. The problem arises when both the exchange and photon's spin is 1 or -1. In order to achieve conservation of spin, the phi meson would have to be 2 or -2, but a Phi meson cannot have -2 or 2 as a spin state. This is what causes asymmetry [7].

Diagram B shows a display of the quarks each of the particles have (photon, phi meson, proton, recoil proton) [1]. Again, the system has to conserve the quark number. Typically there is no way for a photon to produce a strange and anti strange quark. This is why the pomeron exchange exists. The diagram B shows the pomeron exchange. There are two views of this exchange. Some believe that a pomeron exchange would produce no asymmetry in a system. Then there are others that believe it would produce slight asymmetry [7]. My results can be applied to the pomeron exchange in two ways. It can be viewed to prove that the system does involve the pomeron exchange which would prove that it has asymmetry attached to it. Or, it could prove that because the results showed asymmetry, the system had nothing to do with the pomeron exchange. In order to figure out which of the above it true, it would have to be analyzed by theorists and further experiments would have to be performed.

There are a few places where discrepancies can occur in this project. One main discrepancy is if enough cuts were made in the first code to exclude or include the right amount of data. Many scientist have their own opinions on more or less cuts to make, although the graph of the invariant mass, produced from the first code, enhanced the 1020 peak, meaning that the cuts made did discard many events that were background noise. Another discrepancy is how to handle the system when the phi angle is at 180 degrees. It is impossible to decipher, in the code, whether the plane is 180 facing one direction or 180 facing the other direction. This can be solved by analyzing the resulting graphs. The graphs at 0, 180 and 360 are all the same so it is unnecessary to worry about how to figure out what placement the plane is in. They are all the same regardless.

To further this project and make it more accurate, a fit needs to be created on the invariant mass peak. The fit would demonstrate background data versus useful data. By creating this fit, it would provide the most accurate way to cut the invariant mass ensuring the most amount of events without contaminating the data with background noise. Also, further analysis of the results need to be made. The beam helicity asymmetry leads to evidence of a component of the spin density matrix. Through analysis of the graphs, that component can be better understood.

## Bibliography:

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