Time-like Compton Scattering off of a Neutron

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Abstract

The purpose of this research is to examine Time-like Compton Scattering of off a neutron. My research will use simulations written by Marie Boer. This will be done by using the Generalized Parton Distributions. The simulations will be used to determine the feasibility of an experiment using a photon to probe the quark and gluon contributions within a neutron. As well determine good positions to place detectors.

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1. Introduction

Research in particle physics has led to the interest in describing the quark and gluon compositions within nucleons.

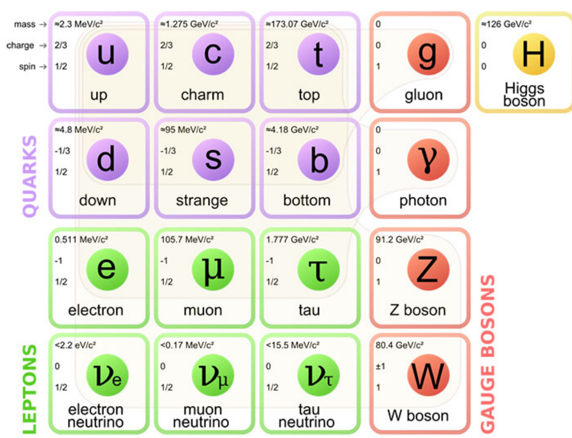

Figure 1: Standard Model of Particle Physics [1]

There are two categories of quarks present within a nucleon, the first being the valance quarks. Valance quarks of interest are the up and down quark along with the gluon, the force carrier. Protons are made up of two up quarks and one down quark. Neutrons consist of one up quark and two down quarks. The second category of quarks within a nucleon are the sea quarks. Sea quarks consist of a quark - antiquark pair which are connected via gluons. The contributions of the quark- antiquark pair to the nucleon are of interest and will continue to be studied. This research intends to look at the feasibility of an experiment that would examine their contributions to the nucleon.

A way to access the quarks and gluons within the nucleon is Time-like Compton Scattering (TCS). TCS is a process that involves an incoming photon which then interacts with the quark or gluon in the nucleon. As a result of this interaction, a virtual photon is created which then decays into an electron-positron pair. A diagram of this can be found in Figure 2 below.

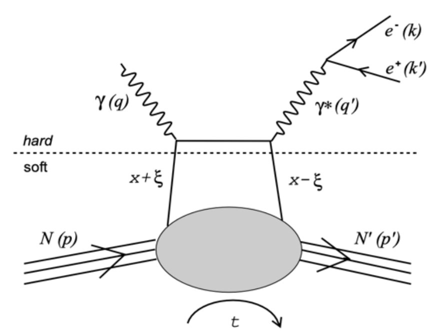

Figure 2: Handbag diagram of TCS [2]

Another process that would be present in the actual implementation of this experiment is the Bethe-Heitler (BH) process. This process is similar, but it doesn't provide access to the same information that TCS will. This is because TCS can view the nucleon as individual quarks and gluons and not a charged sphere. This brings up one of the goals of this research, which is to determine a place to put the detectors so that TCS can be studied and not BH.

TCS is important because it allows us to use the information from the reaction to help determine the Generalized Parton Distributions (GPD) within the nucleon. GPDs are a way of describing the quarks and the gluons in the nucleons. GPDs are comprised of four parts: H, E, $\widetilde{H}$, $\widetilde{E}$. The BH process, as well as TCS, allow us access to GPD H. TCS off of a longitudinally polarized neutron allows us to examine parts of GPD E.

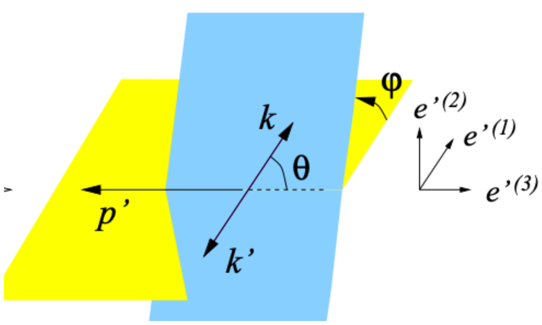

Figure 3: Angles within the reaction [3]

The reaction provides insight into important physical quantities which can be measured. From Figure 2, we can see the importance of determining theta (Θ) and phi (Φ). These variables will help determine where to set up the detectors, as well as provide insight into the counts and ratios of TCS/BH that are available at different values. The counts and the ration of TCS/BH are important for this experiment. To make this experiment possible, a large number of events need to be able to be measured. Not only this, but the physics of interest is at places where the TCS/BH ration is favored for TCS. More quantities of interest can be seen above in Figure 2. Xi (ξ) will provide information related to calculating the GDP. Another quantity of interest is Qp^2. Qp^2 is the energy related to the measured electron.

2. Simulations

The simulations were run using Professor Marie Boer's existing code. Her generator (DEEPgen) would construct data of events. These events were then plotted by Professor Boer's plotting program, Ana. Weighted data was generated and given to me, which was what was then used for this research. The data was of simulations run on a longitudinally polarized neutron and circularly polarized photon. From the data, 29,212,780 different events were analyzed.

3. Results

From the data, sets of graphs were made. In each set, the graph on the left represents the total counts vs. the respective quantity. The graph on the right represents the ration of TCS to BH vs. the respective quantity. In each graph, the red represents the raw data and the blue represents the data after cuts have been made. Following these graphs, a graph showing the combined Φ and Θ in a 2-D heat map is shown to help visualize the data.

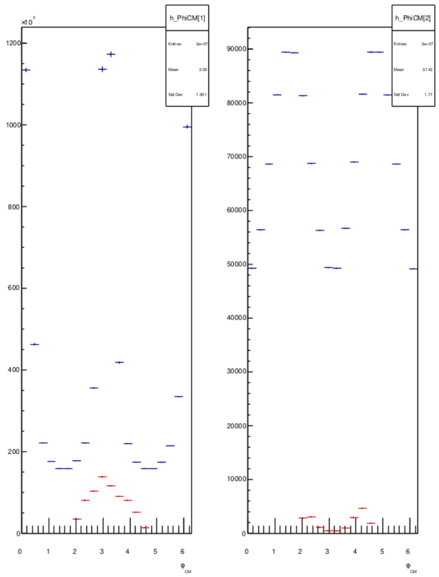

Figure 4: Graphs showing counts and TCS/BH vs. Phi

Figure 4 shows the difference in total counts and the counts of interest, the TCS. From this, at a Φ of approximately pi (π), the total counts spike. For the right graph, which is demonstrating ratios of TCS to BH, the spikes are located around $\frac{\pi}{2}$ and $\frac{3\pi}{2}$.

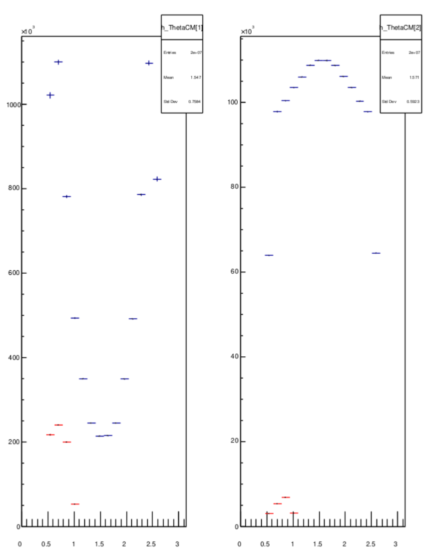

Figure 5: Graphs showing counts and TCS/BH vs. Theta

Figure 5 shows the difference in total counts and the counts TCS/BH vs. the angle Θ. The left graph shows the highest counts at $\frac{\pi}{4}$ and $\frac{3\pi}{4}$. The graph on the right shows high TCS/BH at $\frac{\pi}{2}$.

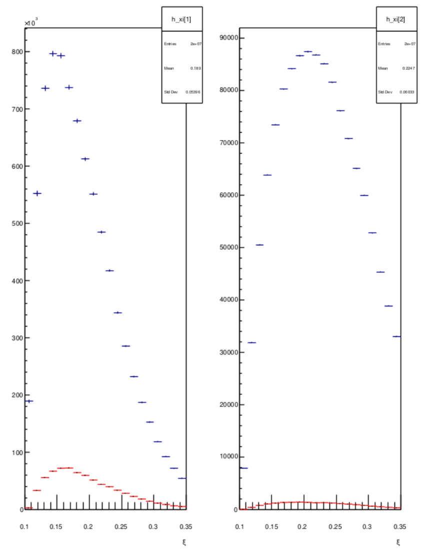

Figure 6: Graphs showing counts and TCS/BH vs. Xi

Figure 6 shows the difference in total counts and counts of TCS/BH and the related quantity ξ.

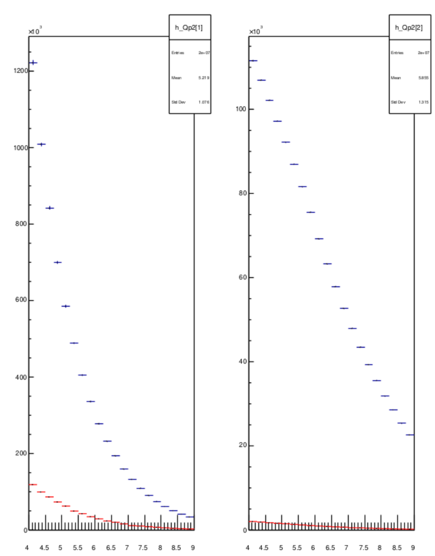

Figure 7: Graphs showing counts and TCS/BH vs Qp^2

Figure 7 shows the values of Qp^2 and the counts that it is measured in.

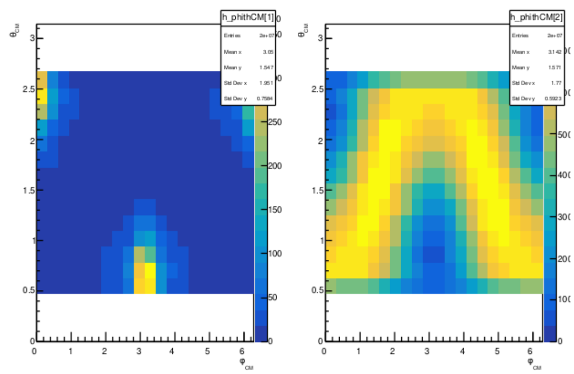

Figure 8: Phi and Theta on a 2-D heat map

The left graph of figure 8 shows the overall total counts of Φ and Θ. It can be seen that the most counts occur in the yellow areas. The graph on the right shows Φ and Θ vs. the ratio of TCS/BH.

4. Interpretation of Results

From Figure 4, it is shown that around π in the total counts a spike appears. This is different from the ratio of TCS/BH, which has a spike around $\frac{\pi}{2}$ and $\frac{3\pi}{2}$. This brings up a common theme from this research. The places where the most counts are occurring are not the places that are dominated by TCS. Instead, these places have high counts of BH interactions. This is also shown in Figure 5, the theta graphs, where the total counts peak around $\frac{\pi}{4}$ and $\frac{3\pi}{4}$ and the TCS/BH peaks around $\frac{\pi}{2}$. Again, these graphs show that the maximums of the places with the most counts are the minimums of the places with large TCS/BH ratios. The graph of ξ demonstrates shows the expected ξ values, which are used to create the GDPs for the quarks. The graph of Qp^2 shows the energy of the measured electron. The graph shows that a Qp^2 between 4 approximately 4-6 GeV^2 will provide high counts with high TCS/BH ratio. Figure 8 shows the 2-D heat map of Φ and Θ. The graph on the left shows the angles where the most counts would be measured. The graph on the right shows angles where the TCS component is more prevalent. This shows the issue where the places with the most counts are not the places with the interesting physics. A medium point will have to be selected where counts are relatively high and TCS ratios are also relatively high. Comparing all the graphs, I propose that acceptable angles for Φ and Θ would be Φ from $\frac{\pi}{2}$ to π or π to $\frac{3\pi}{2}$ and Θ from $\frac{\pi}{4}$ to $\frac{\pi}{2}$ or $\frac{\pi}{2}$ and $\frac{3\pi}{4}$ with the center point of the detector being in the middle of these ranges. Below, in Figure 9 is the 2-D heat map but with a box around this range for better visualization.

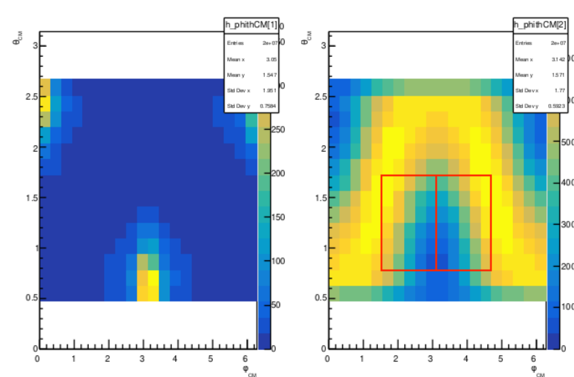

Figure 9: 2-D Heat map of Φ and Θ with boxes depicting region of good Φ and Θ

Figure 9 depicts a region that possess semi high total counts, as well as a region that possess semi high TCS/BH. It would be necessary to use the middle of this region where there is a high overlap and to stay away from the edges.

5. Conclusion

From the data gathered and graphed, it can be seen that for Φ and Θ a region exists that would be possible to run this experiment. The success of this experiment will provide access to information which will allow for GPD H to be examined. Furthermore, pairing the results of this successful experiment with the results from a transversely polarized proton will allow physicists to determine GPD E. Some further issues need to be discussed and analyzed to confirm this. First, this research was done without consideration to the number of counts per unit time, i.e., events per day, week, month. This poses a problem as factoring in time will defiantly change the accepted region. Another possibility of factoring in time would be the conclusion that the experiment is not viable as not enough events would occur to get usable data. A different conclusion drawn from this research is that having a Qp^2 between approximately 4-6 GeV^2 will provide enough energy to sufficiently measure a good TCS/BH ratio.

Citations

1. Hobbs, Bernie. “How Does the 'Bible' of Quantum Physics Work?” *ABC News*, ABC News, 14 July 2017, https://www.abc.net.au/news/science/2017-07-15/the-standard-model-of-particle-physics-explained/7670338.
2. Boër, Marie, et al. “Timelike Compton Scattering off the Neutron.” ArXiv.org, 10 Oct. 2015, https://arxiv.org/abs/1510.02880.
3. Berger, E. R., et al. “Timelike Compton Scattering: Exclusive Photoproduction of Lepton Pairs.” *ArXiv.org*, 4 Oct. 2001, https://arxiv.org/abs/hep-ph/0110062.