Longitudinal Momentum vs Transverse Position of the Proton Constituents with an Electron Final State

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Abstract

This semester I worked on a project that will deal with being able to map and position the small particles that make up a nucleon. This will be accomplished by sending a high energy particle; in this case a photon into a proton(nucleon). After the photon is sent to hit the inside of a proton, it will collide with a quark causing it to rebound and sending two electrons that can be measured and analyzed. Using this information along with what we know about the nucleon structure we can better understand what happens inside the nucleon. Quarks are considered a meson particle and have an opposite in an antiquark. The symbol for this particle as used throughout this experiment is π . A 0 proton is defined as a nucleon along with a neutron and both of these particles fall under the classification of a Hardon.In a proton there are three consistent quarks. Quarks can have a positive or negative charge, an up quark has an eclectic charge of +⅔ and a down quark has an electric charge of -1/3

Introduction

Over the course of this past semester I was tasked with being able to learn basic linux skills that would allow me to be able to use the code that was provided by Professor Boer to analyze the different events that were taking place. In particular the physics that was being studied is considered hadronic physics, which is a subset of Nuclear physics. This is the physics that is studied in large colliders such as CERN in Europe or the Jefferson Lab here in Virginia. Understanding the properties of the fundamental particles such as hadrons can allow us to better understand the physics that takes place on the relatively small scales such as the nucleus of the atom. The processes that we focused on within the experiment centered around two processes which are Timelike Compton Scattering (TCS) or the Bethe Heitler (BH) process. The end result of the reaction leaves us in an electron final and we use these two methods to describe what is happening in the reaction. In particular we looked at the results in both low and high Qp2 situations which correspond to high and low energy electron levels.

A proton is made up of two up quarks and one down quark which is the explanation for a net +1 charge. Quarks and antiquarks are bound together through gluons which are a gauge boson and the particle responsible for what is known as the strong force. Gluons have a very small mass and carry no electric charge; however they interact with particles that have a color charge such as quarks and antiquarks. This theory of strong force is called quantum chromodynamics (QCD). Quarks bind together through the soft emissions of gluons which can cause other gluons, as well as pairs of quarks-antiquarks. Using electromagnetism quarks can be bound together using things such as soft photons yet, these only yield charged particles. The goal of this experiment is to break a quark out of what can be referred to as confinement and move it into a state of deconfinement with the energy of the system being the inverse to 1/distance. Ultimately the aim of the experiment is to use the information described above to be able to see inside a hardon. The nucleon is a complex particle and consists of a sea of quark/antiquark pairs. These quarks also have a dynamic property of spin. Using a form of elastic scattering we can get a transverse charge (quarks) in distributions from scattering form factors. Real photons will be sent into the nucleon with the end result being that of electrons scattering along with a decaying virtual photon that can also be labeled as an interaction particle. The energy range for this will be that of the magnitude of GeV. This will provide slice images of inside the nucleon that can be put together in order to “see” inside of the nucleon. Specifically in this experiment, the interest will be in measuring the angles of the end states of the electrons that are produced through the reaction.

Techniques Used

The experiment that was being conducted was done through Virginia Tech's science department server called Buick. On that server we used a program called DEEPGen which was developed by Professor Boer. This program generated large quantities of events on the order of magnitude of twenty million or higher. After the events were generated we used an analysis program that is called TCSana.cc which could be edited through manipulating the code through linux to the specific processes that we want which in this case were both TCS and BH. Once the events were generated we would then run the entirety of the events sample through TCSana which would deposit the results of the analysis into a separate directory in the server. This data could then be generated into histograms such as the one shown below that could be analyzed and compared with past results.

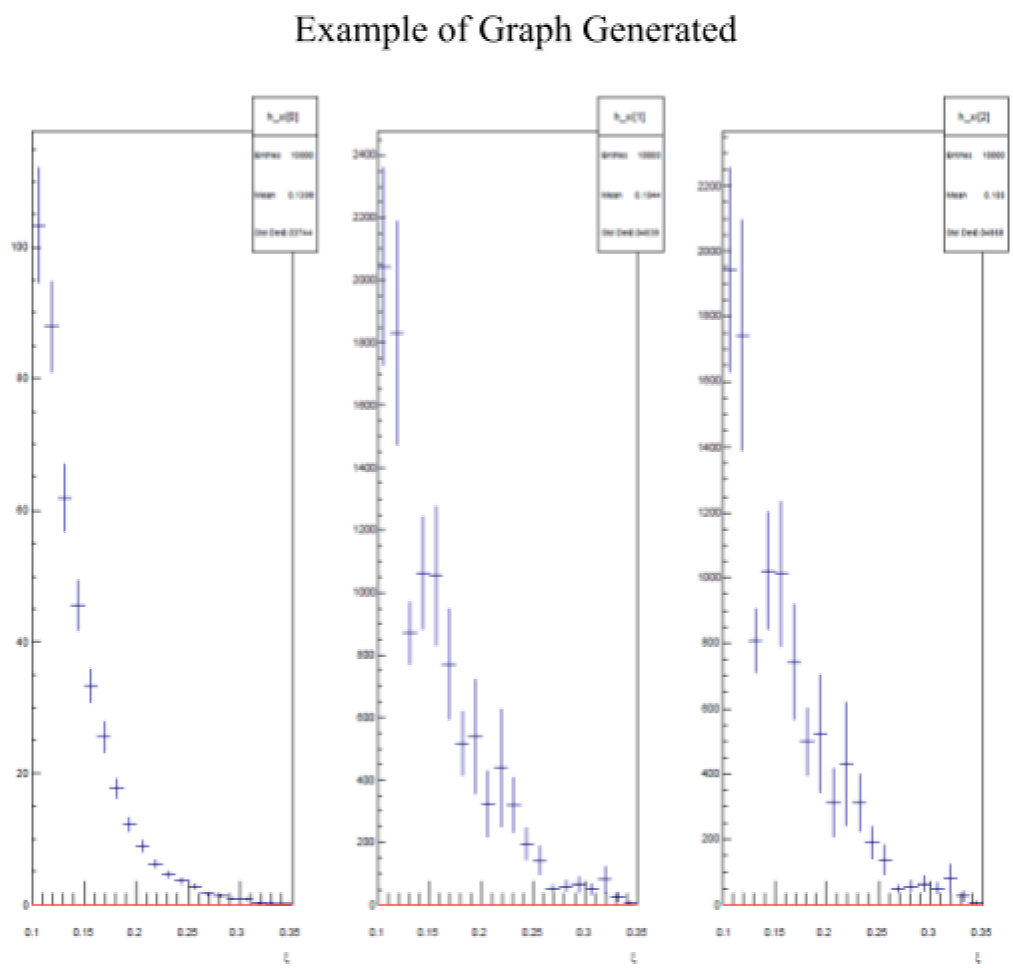


Figure 1: Graph of Xsi, the overall energy of the reaction.

Work Performed

As mentioned above, the work performed doing this research consisted mostly of analyzing the events that were generated using DEEPGen. This consisted of being able to understand how to manipulate the different code that was used by the different programs used in the experiment. The basic functions consisted of being able to navigate through the different directories and being able to edit the root code of TCSana using the “gedit” command to allow for easy access to insert in the root program code that would allow for TCSana to focus on the analysis of three variables. These variables are those of W_TCS, W_BH, and W_tot_unpol which represents the analysis of the TCS, BH, and total unpolarized processes respectively. The command evince will generate the three graphs and using our understanding of both the TCS and BH processes we can compare the results of the graphs with past results to see if what is found through the events generated is valid. TCS is sensitive to quark longitudinal momentum and this will cause there to be Generalized Parton Distributions (GPD). TCS focuses on the Time-like separated photon, in the initial part of the reaction we have a real photon and in the final part of the reaction we have a decaying virtual photon which is emitted from the nucleon. This part of the process is reflective of Quark distribution. The BH process has the same initial and final conditions as TCS. In this process the leptons interact with the nucleon and this causes it to be considered a lower resolution but this also carries information on the total charge distribution of the proton through “Form Factors”. Overall we analyzed both Large and Low Qp2 reactions with the number of events consisting of that on the order of ten thousand to fifty thousand events. The reaction can be seen visually in the image below.\

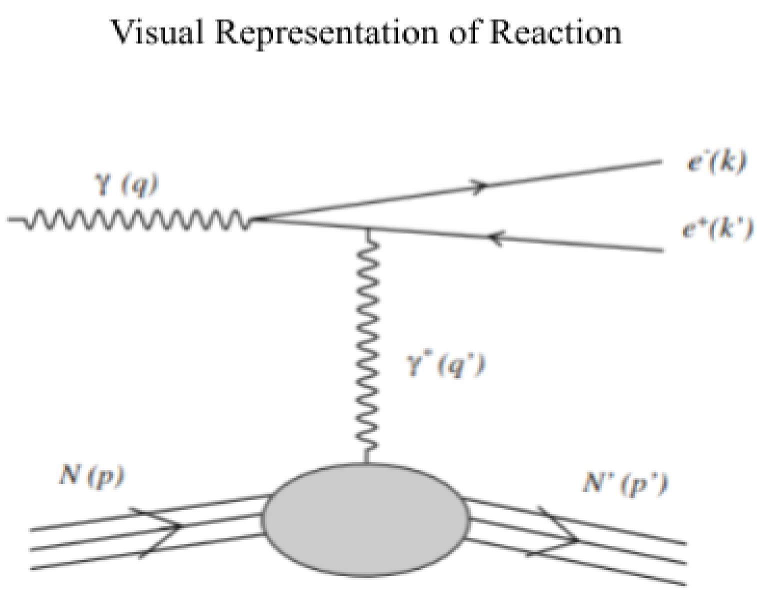


Figure 2: Picture of the reaction detailing the end state of the telectrons

Results and Interpretation

The results that were first obtained were with respect to the low Qp2 data set, the results can be interpreted through the explanation of the different angles. The theta **θ** angle in the reaction is the angle between the two end state electrons at the end of the reaction. The phi **ϕ** angle is the angle of the electrons with respect to the plane that they originally were traveling on leaving the hadron. We compare the results of the TCS and BH in both the low and high Qp2 reactions. The graphs below can show the graphs that were generated followed by explanation on the interpretation of the results.

Theta **θ**

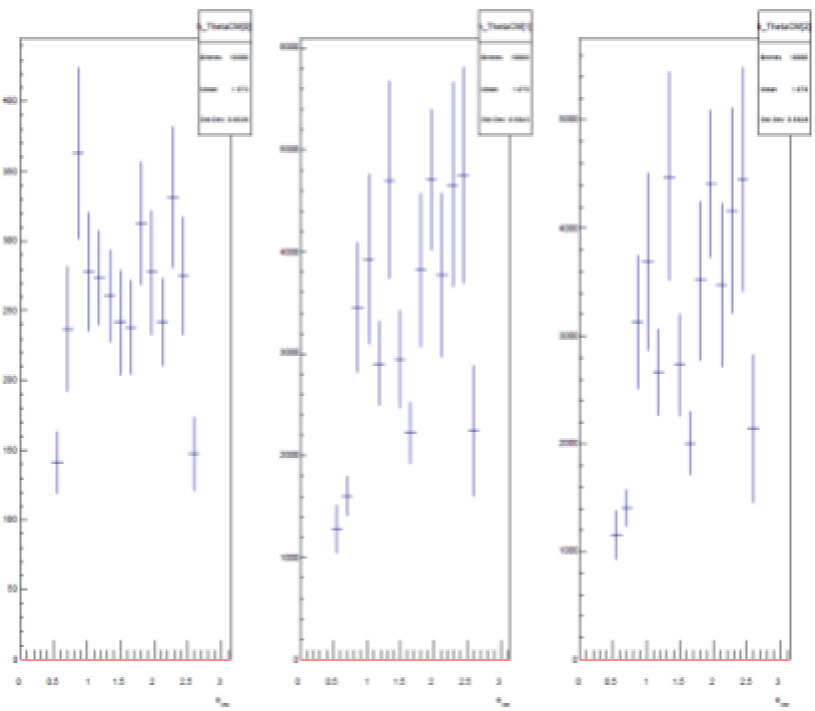


Figure 3: Histogram of Theta in Low Qp2

Phi **ϕ**

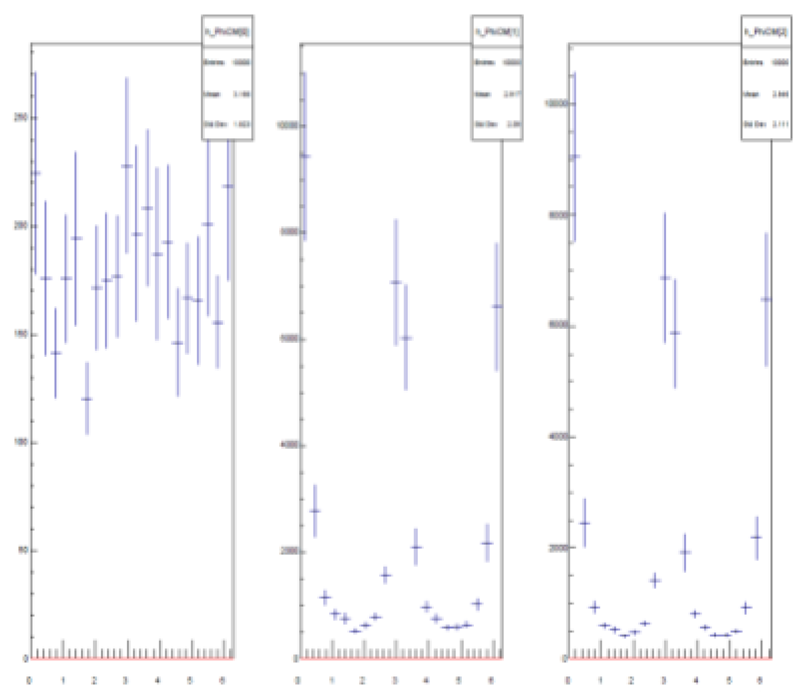
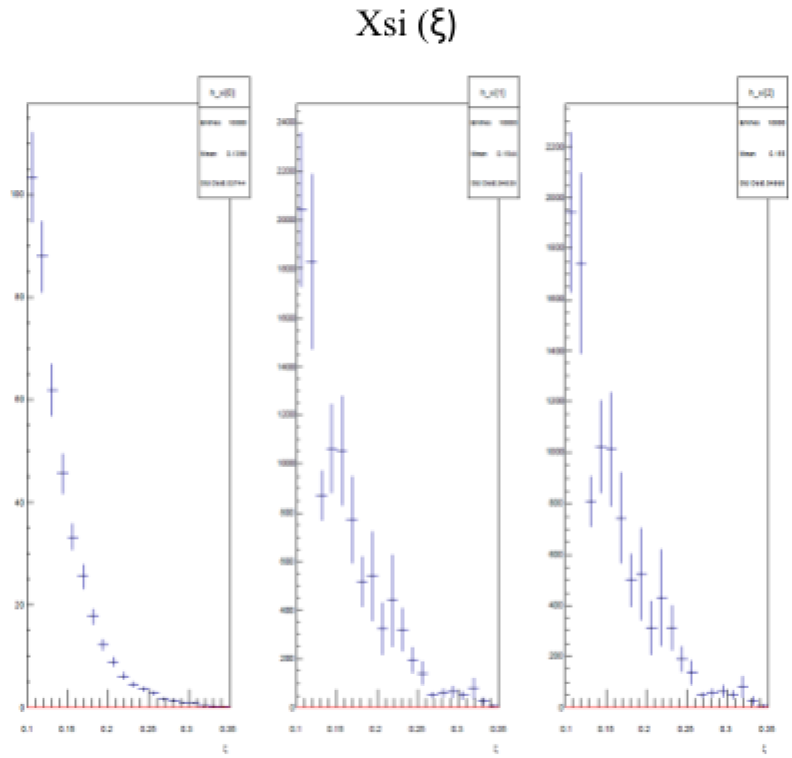


Figure 4: Histogram of Phi in Low Qp2

In all three figures including figure 3,4, and 5 we can see that the TCS graph is the first with the BH and lastly the Total Unpol graph being after respectively.

Figure 5: Graph of Xsi in low Qp2 Data Set



It can be noted that in the theta graph (Figure 3) the TCS graph peaks at about 90 degrees and has a slight bi-modial. There is an even momentum split. The BH has peaks at 0 and pi, it carries information about the proton through form factors. There is also a large momentum disparity and it cuts at a lower peak as well.
In the Phi graph (Figure 4) we can see that The TCS is evenly distributed however, it is random as there is some interference from the BH. The TCS carries information about the quark distribution. When compared to the the BH we can see that the BH is not random and it is the same as the total unpolarized graphs. The BH graph peaks at 0, pi, and 2pi which is basically 0 again. Again the BH carries information about Total Charge Distribution through form factors. In the Xsi graph (Figure 5) the energy of the reaction is shown as the reaction progresses. In the Large Qp2 files which can be seen in the graphs below.

Figure 6: Graph of Phi of large Qp2 in the graph you can see the same configuration of TCS on the left then BH in the middle with the total unpolarized on the far right.

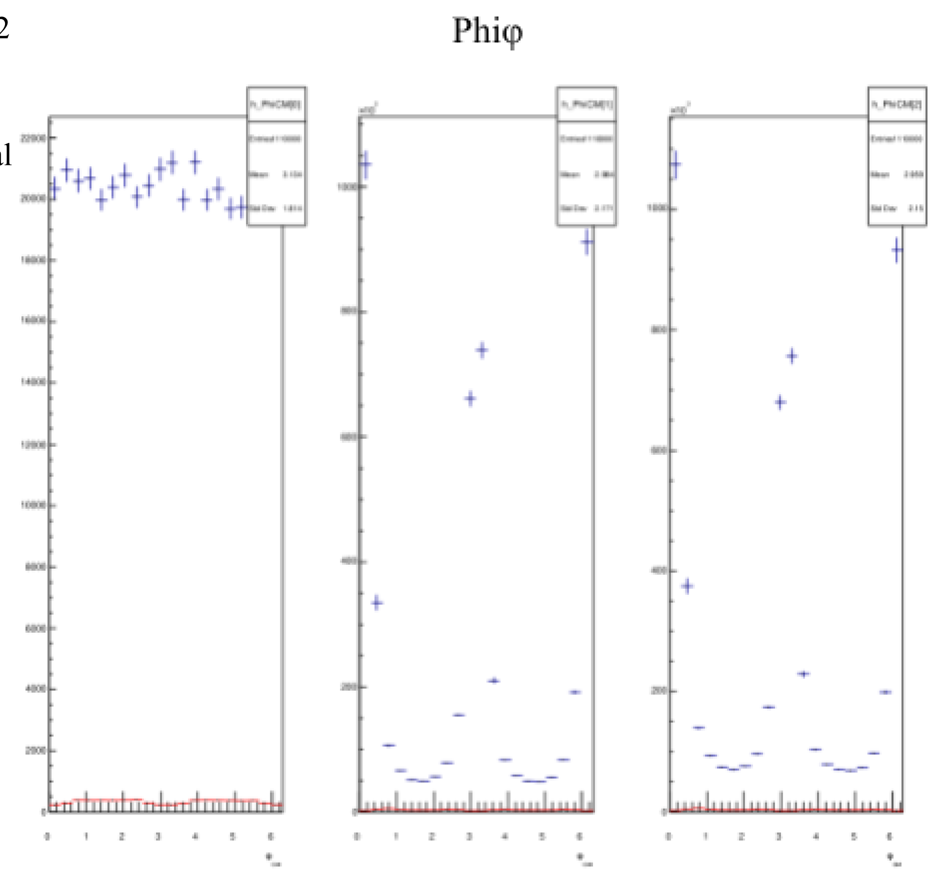
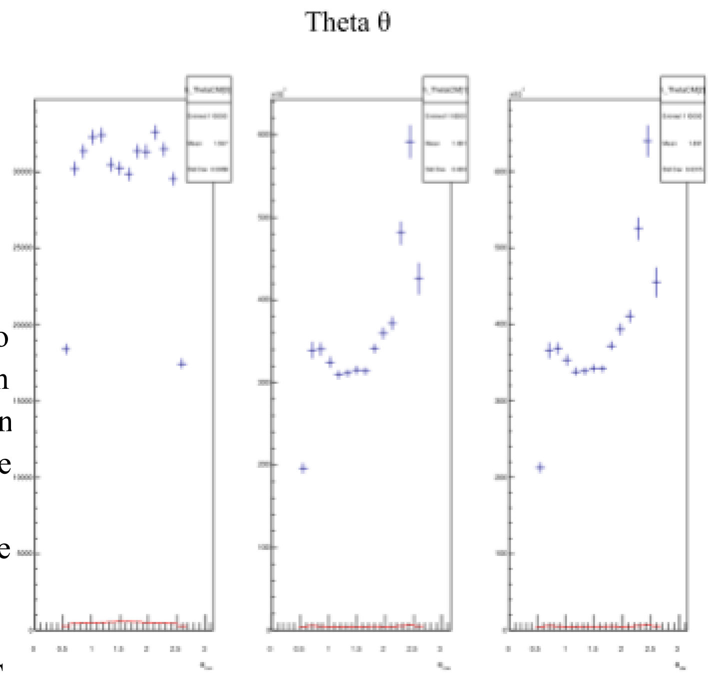


Figure 7: Graph of Theta of the large Qp2 sample.



After analyzing the graph of the large Qp2 as well we can see a similar data set to that of the low Qp2 one. In this analysis we included close to fifty million events and this allowed us to be able to get more accurate results. The peaks that are present in the BH samples are due to probability of having asymmetric events being high. BH also has two extremes as outcomes which are when the electron takes most of the energy and when the positron takes most of the energy. What we observe in the reaction takes place closer to the limits which depend on other variables like Xsi, t, and Qp2. We can also describe our analysis by saying that theta is an effective way to vary the ratio of TCS/BH because TCS is flat while BH depends heavily on theta. Phi can be thought of as the method of deconvolution. The distribution is made to fit in phi, and for each bin there is a different TCS/BH ratio as well as the evolution of the cross section. Theta also has the potential to be included however, it is less sensitive in the fits and it varies quickly. It would require integration of the distributions over phi and in the short time span of the reaction there would be data that would be lost. To counter this we integrate over theta which allows there to be more data at the end of the reaction and using a model we can calculate different scenarios of GDPs. It is also important to note that BH is not sensitive to GPDs, only TCS is, which can be an issue since what we are after is GPDs. We can manipulate how we analyze theta to be able to avoid cutting some data out yet this window is narrow since the TCS is small and there is still benefit to gain from the use of BH. It can be said that asymmetries are important due to ration and the subtraction will cause certain terms to cancel. Asymmetry can be defined as when all events with regards to the incoming photon spin towards one direction subtracted by the events that spin towards the opposite direction. This can be normalized and can be done for the other proton spin which can be along all three axes of x,y, and z. A factor that is important when it comes to asymmetries is that of the cross-term.

Conclusion

After analysis of the results of the data set we can see that there is a BH dominance throughout the reaction especially around the peaks of the BH. We can also begin to see that to isolate the TCS part of the reaction we will need to work more with theta by applying cuts around the peaks as well for the BH. It can also be said that the events generated are valid when compared to past events, in future research the aim should be to have a higher order analysis of TCS and be able to produce both TCS and BH cross terms as well. Double spin asymmetries are more difficult to attain because they are sensitive only to the real part of the reaction. In the event of a double asymmetry the imaginary part would cancel. These are dominated by the BH term however, still very interesting for the "second thing" about asymmetries. Double spin asymmetries are more sensitive to GPDs than BH, contrary to the total cross section. When the aim is to extract GPDs with fit, we will simultaneously fit cross section and asymmetries, since they all bring independent information. This unfortunately requires different experiments to have all the possibilities and currently, there are no measurements for this process.

Acknowledgements

Thank you to Professor Marie Boër for her creation and work with event generating code (DEEPGen) and analysis code (TCSana) as well as her constant support and guidance throughout our research.

Tristan Anderson for continuously helping us with the LINUX operating system and assisting us in generating our own data and navigating the base code