Study of Inelastic Background for Quasielastic Scattering from Deuterium at 11 GeV

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G_m^n: The Magnetic Form Factor of the Neutron

G_m^n is a fundamental quantity of the neutron that reveals information about the distribution of charge and electron currents within the neutron. It is important for our understanding of how the neutron is constructed out of its constituent quarks. Quantum Chromodynamics (QCD) is the foremost theory of quark-gluon interactions, and G_m^n is an essential experimental benchmark. The goal of this research was to understand background events in an experiment E12-07-104 [1] approved for future running at Jefferson Lab.

JLab, CEBAF, CLAS and CLAS12

Jefferson Lab (JLab) is located in Newport News Virginia focusing on understanding the nature of the quark-gluon interaction. The central scientific instrument at JLab is the Continuous Electron Beam Accelerating Facility (CEBAF). CEBAF creates an incredibly precise, continuous, beam of electrons that allows exclusive measurements to be made. CEBAF runs at energies up to 6 GeV and is in a race track shape 7/8ths of a mile long (Figure 1). Our work is done in Hall B with the CEBAF Large Acceptance Spectrometer (CLAS) see Figure 2. The detector almost completely surrounds the target, and is composed of many layers such as drift chambers, Cerenkov counters, time of flight scintillators, and electromagnetic calorimeters. These components each contribute to the identification and measurement of particles which CLAS detects. JLab will be upgraded to twice its current operating energy, and will have a new detector in Hall B called CLAS12. The new detector is based on what we learned from CLAS and modified for higher luminosity and other enhancements. We are part of a collaboration that will build, commission, and operate the new detector (Figure 3).

Figure 1: Jefferson Lab

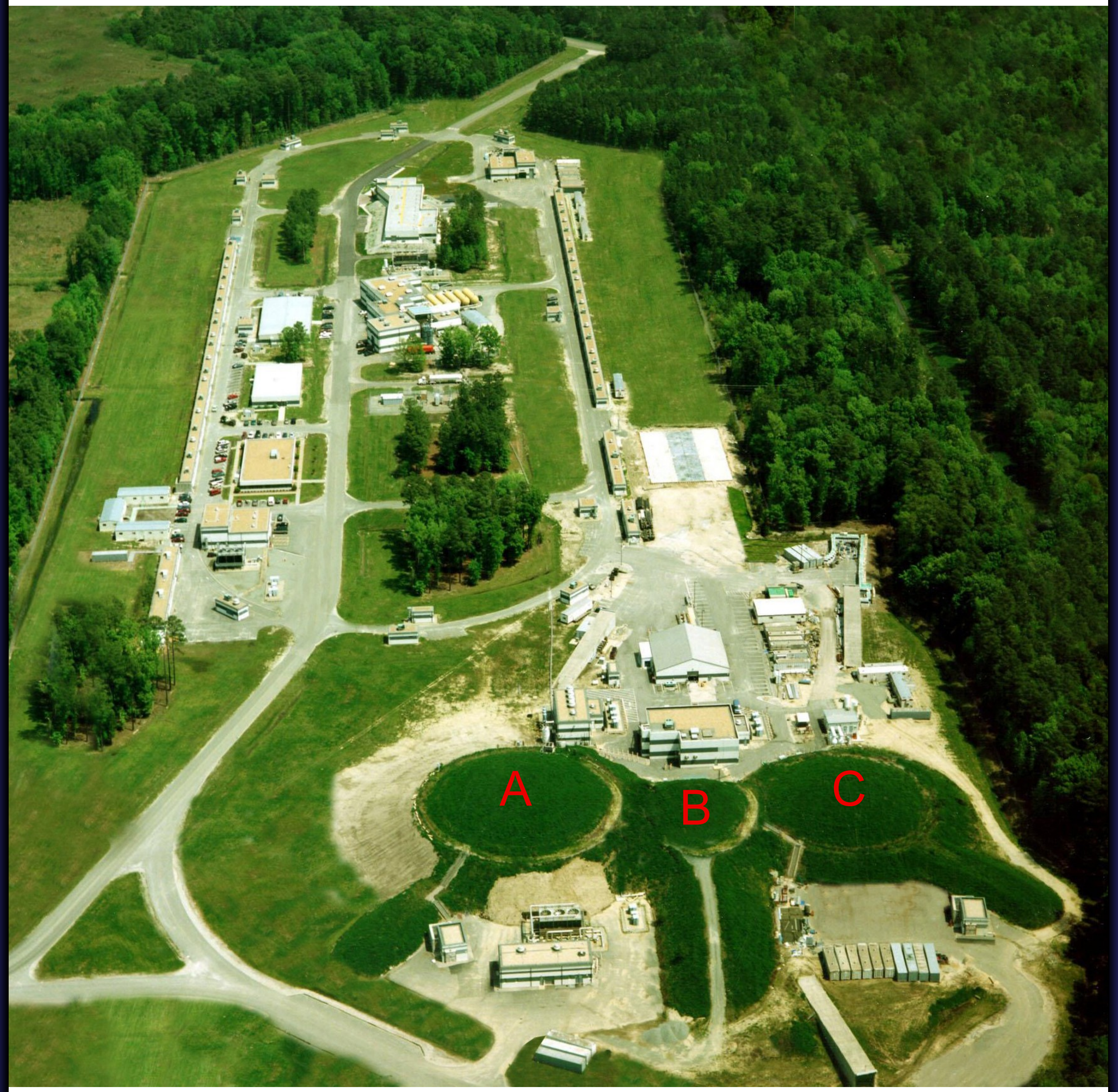


Figure 2: CLAS Detector

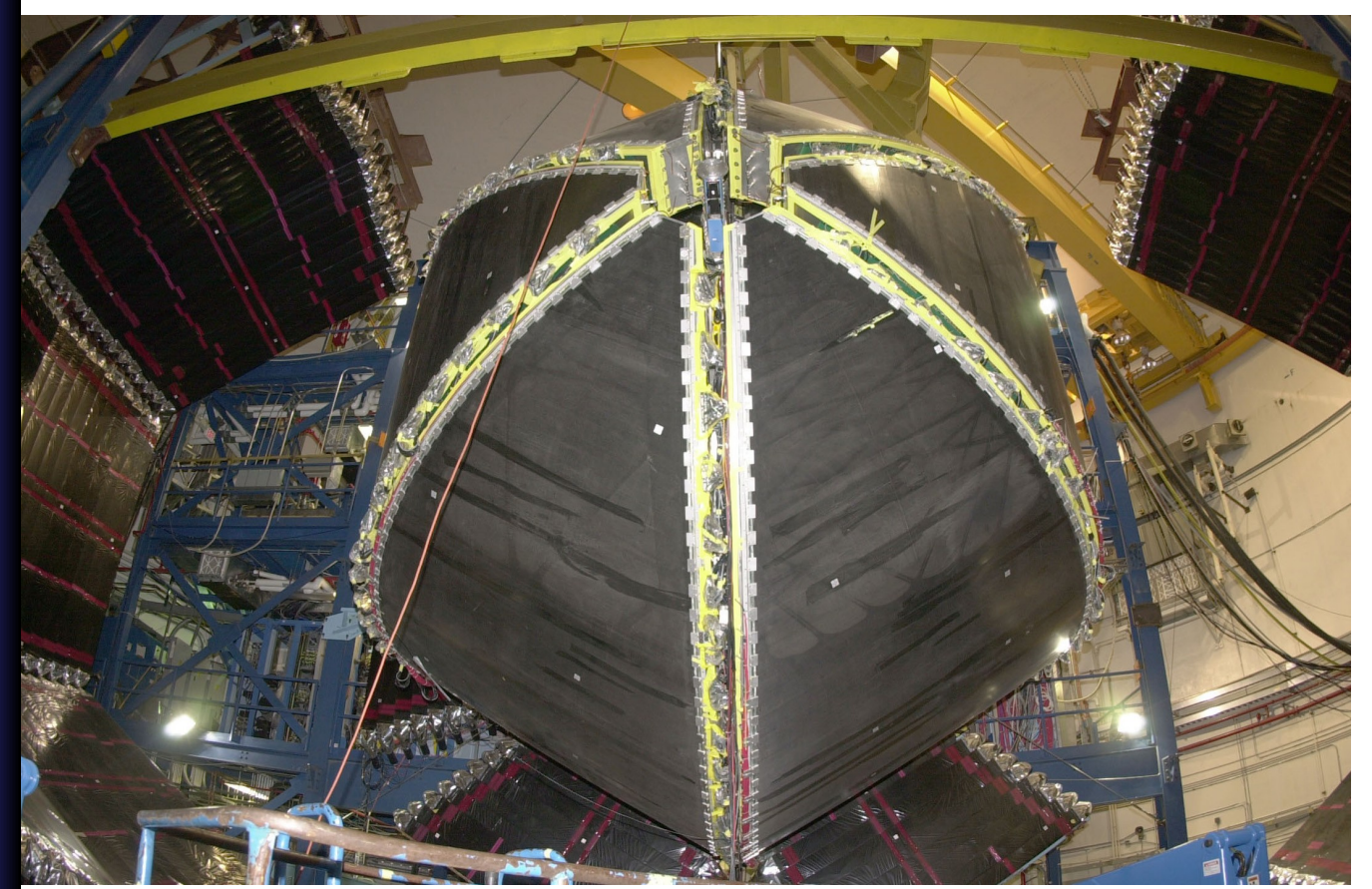
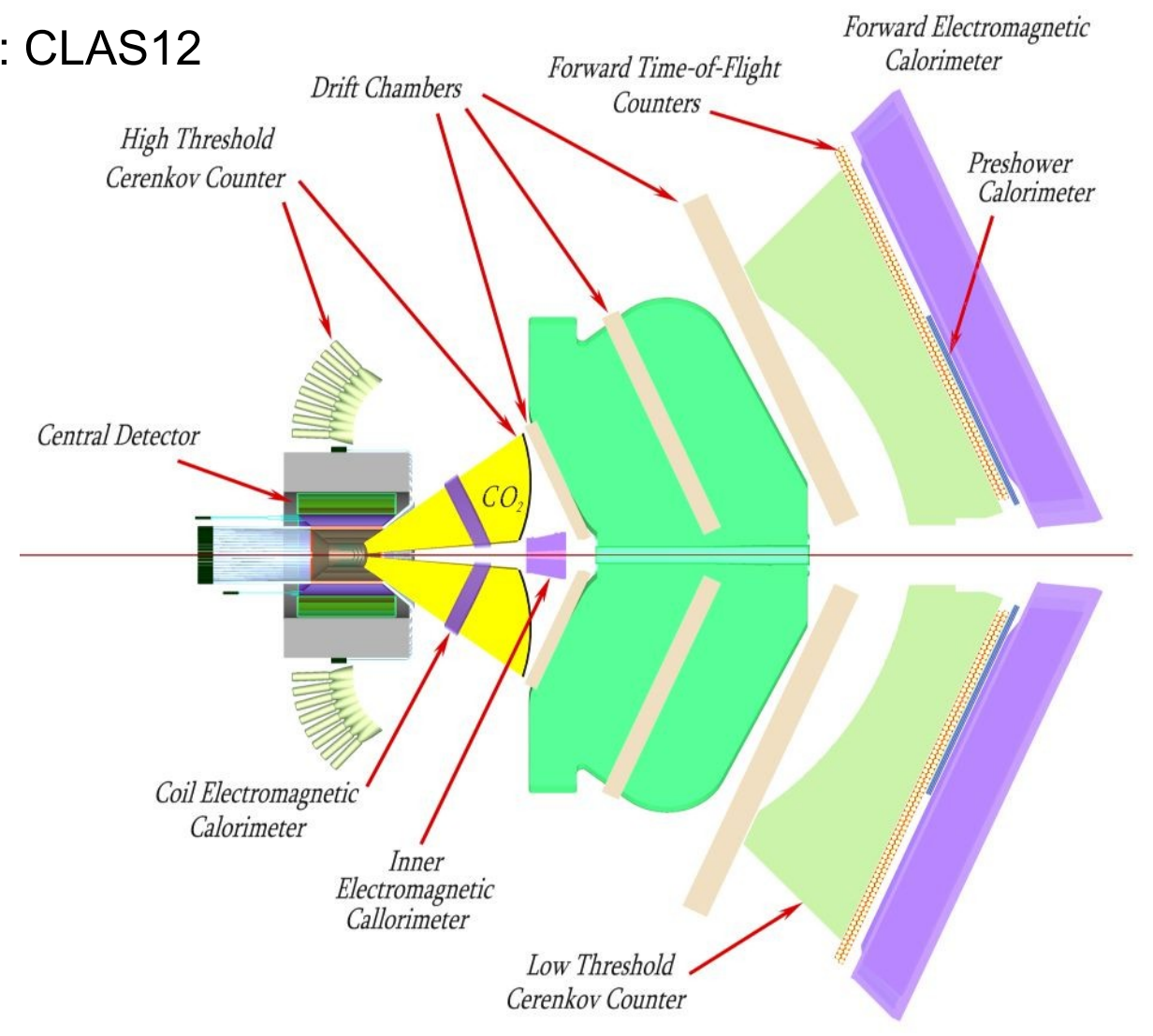


Figure 3: CLAS12



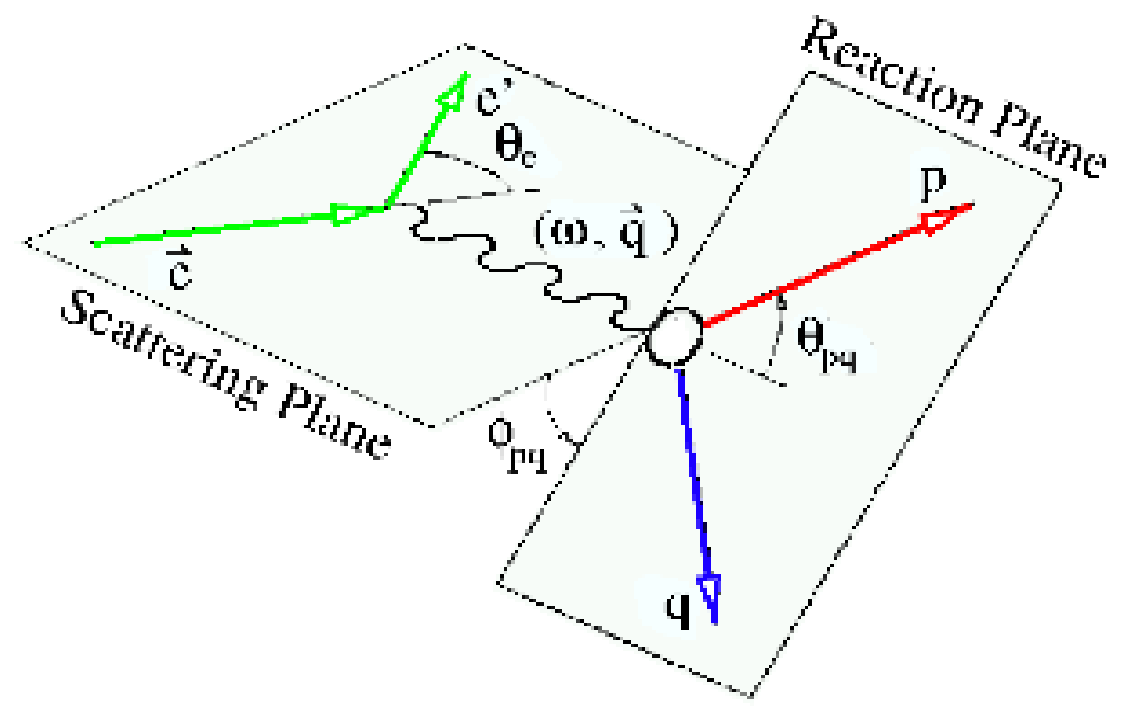
How G_m^n is Measured

By shooting a continuous beam of electrons at a deuteron target and observing the scattered electrons and hadrons we can determine the distribution of charge and current within the neutron. The quantity G_m^n is measured using the ratio method. We measure the ratio R of e-n to e-p scattering (see Eqution 1), and we write the quasielastic cross sections for neutron and proton scattering in terms of the form factors G_E^p, G_M^p, G_E^n and G_m^n, and a correction factor $a(Q^2)$ for the effects of bonding in the deuterium. Since the proton form factors are more precisely known, G_E^n is small, and $a(Q^2)$ can be calculated, with a precise measurement of R, we can extract G_m^n. These events tend to come out along the direction of the 3-momentum "kick", and therefore have a small θ_{pq}. Inelastic events are emitted at larger θ_{pq}. The kinematic variable θ_{pq} is defined as the angle between the 3-momentum transfer and the scattered nucleon direction. We select quasielastic events by requiring θ_{pq} to be small. Fiqure 4 shows how θ_{pq} is defined.

Equation 1: Ratio Method

$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\frac{d\sigma}{d\Omega}(D(e,e'p))} = a(Q^2)\frac{\frac{{G_E^n}^2+\tau {G_M^n}^2}{1+\tau} + 2\tau {G_M^n}^2\tan^2(\frac{\theta}{2})}{\frac{{G_E^p}^2+\tau {G_M^p}^2}{1+\tau} + 2\tau {G_M^p}^2\tan^2(\frac{\theta}{2})} \qquad \tau = \frac{Q^2}{4M^2}$$

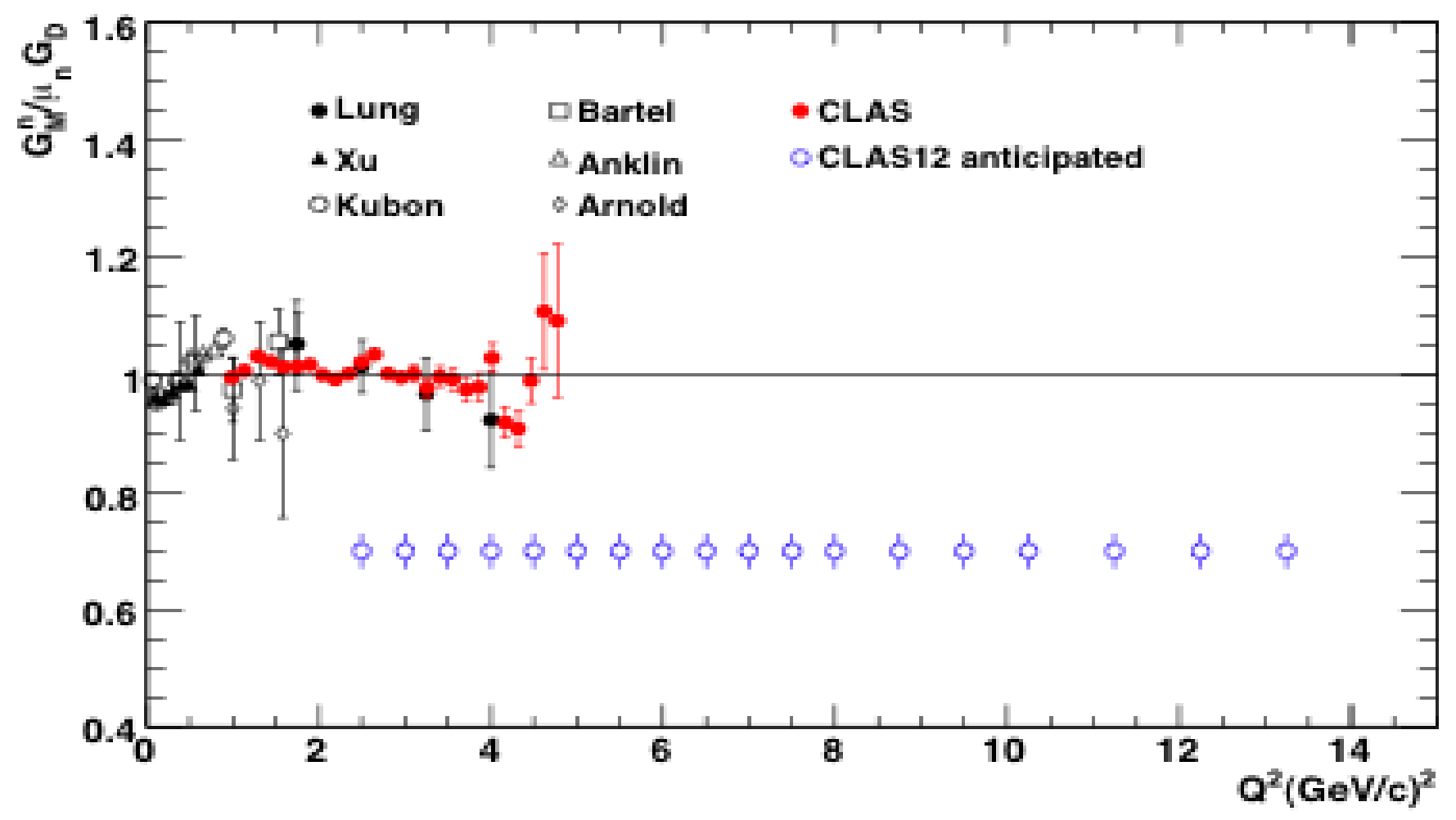
Figure 4: θ_{pq}



Current Knowledge of G_m^n

Figure 5 shows our current knowledge of G_m^n. The red points show results from a CLAS experiment which used the same ratio method we described here. The plot also shows anticipated results for the range and systematic uncertainty we expect for the proposed experiment (E12-07-104).

Figure 5: Current Knowledge of ***G_m^n***



Background at Higher Energy

Determining G_m^n depends on our ability to accurately measure the ratio of quasielastic neutron to proton events, but as Q^2 increases, the number of quasielastic events is much less than the number of inelastic events generated. Being able to separate quasielastic events from inelastic events is therefore essential to the success of this experiment at higher energy. Our ability to seperate quasielastic and inelastic events for $Q^2 < 13$ GeV² is excellent. However, at the highest Q^2 bin, the cross section is falling and the challenge to extract the quasielastic products is greater. This is the focus in this project.

Simulating the Experiment

Many programs were used to simulate the experiment at higher energy levels. We used separate codes to first generate the inelastic (GENEV)[2] and quasielastic (QUEEG)[3] events. Then we used fastMC to simulate CLAS12. Finally we used ROOT to select events and analyze the data from the simulation. ROOT was used to create histograms of the data. By creating cuts on the data within ROOT we were able to better understand the background (inelastic) scattering at higher Q^2.

Analysis

The figures below compare the number of total events (black), inelastic events (green) to the number of quasielastic events (red). Without any cuts, inelastic background events clearly dominate (Figure 6), but as more cuts are added, the quasielastic events become more prominent. In Figure 7 we require the detection of a neutron in the final state and no additional particles (hermiticity cut). The proportion of quasielastic events is larger, but still much less than the inelastic counts. In Figure 8 we require $\theta_{pq} < 1$ which dramatically reduces the proportion of inelastic events. By requiring a $W^2 < 1.2$ GeV² (vertical line in Figure 8), we reduce the proportion of inelastic events even further. Figure 9 shows the results of a mathematical model created using a high statistics simulation for the quasielastic production and the inelastic background. A linear combination of the simulated distribution of quasielastic and inelastic background events were fitted to the total events. The fit is the blue curve. This model allows us to extract the quasielastic events from the total. The uncertainty on G_m^n from the fit is 10% for neutrons (shown here) and 6% for protons. We are exploring other methods to improve the precision of this analysis.

Figure 6: Inclusive Electron Scatterig

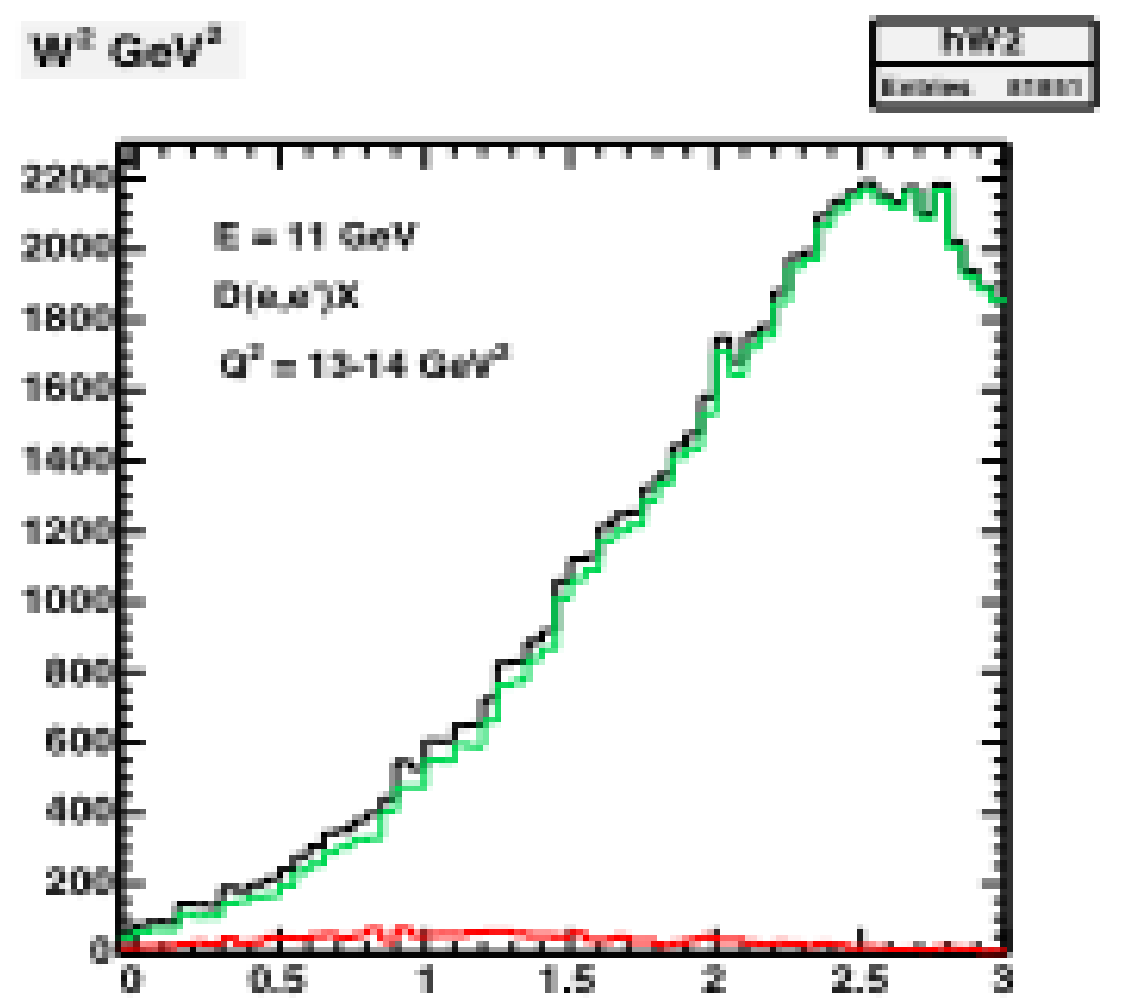


Figure 7: Electron-Neutron coincidence with hermiticity cut

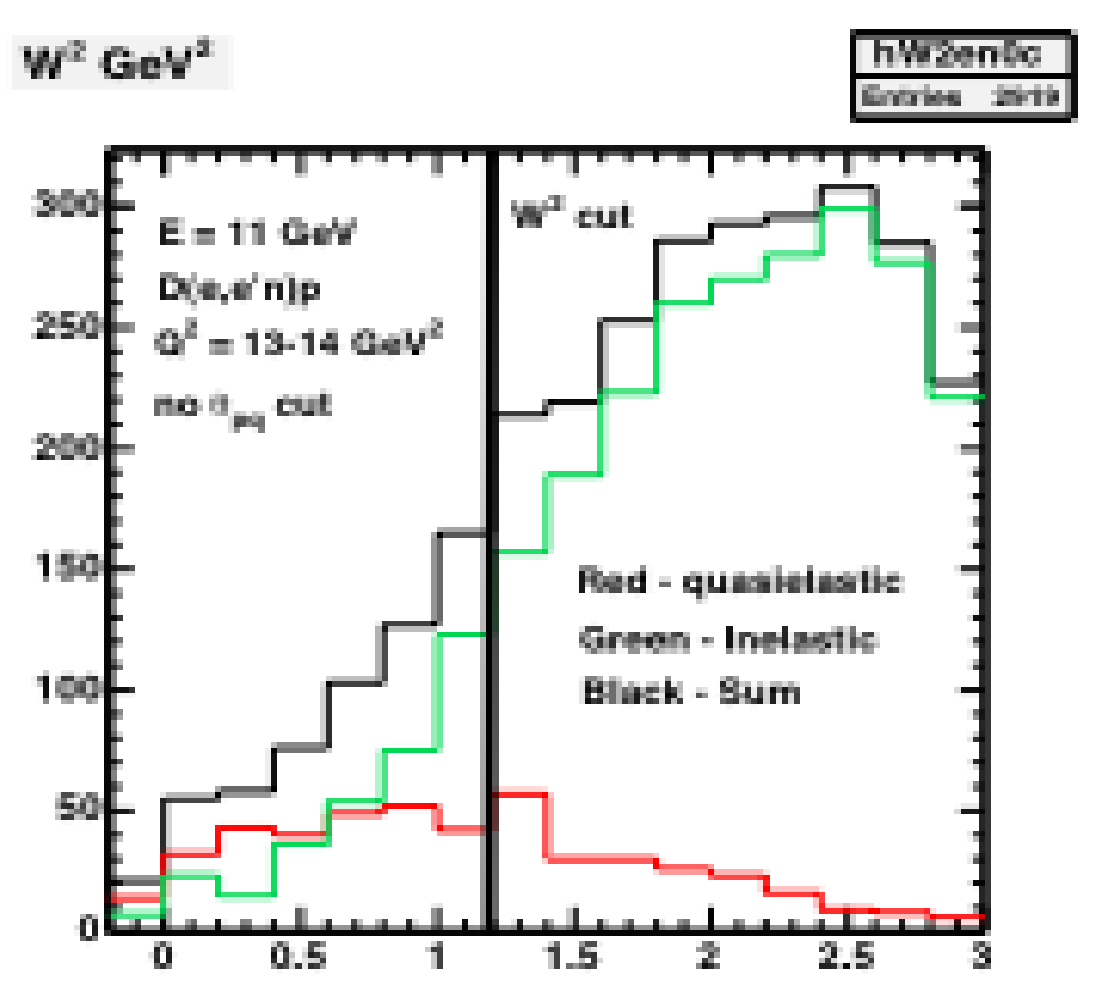


Figure 8: Same as Figure 7 with additional θ_{pq} cut

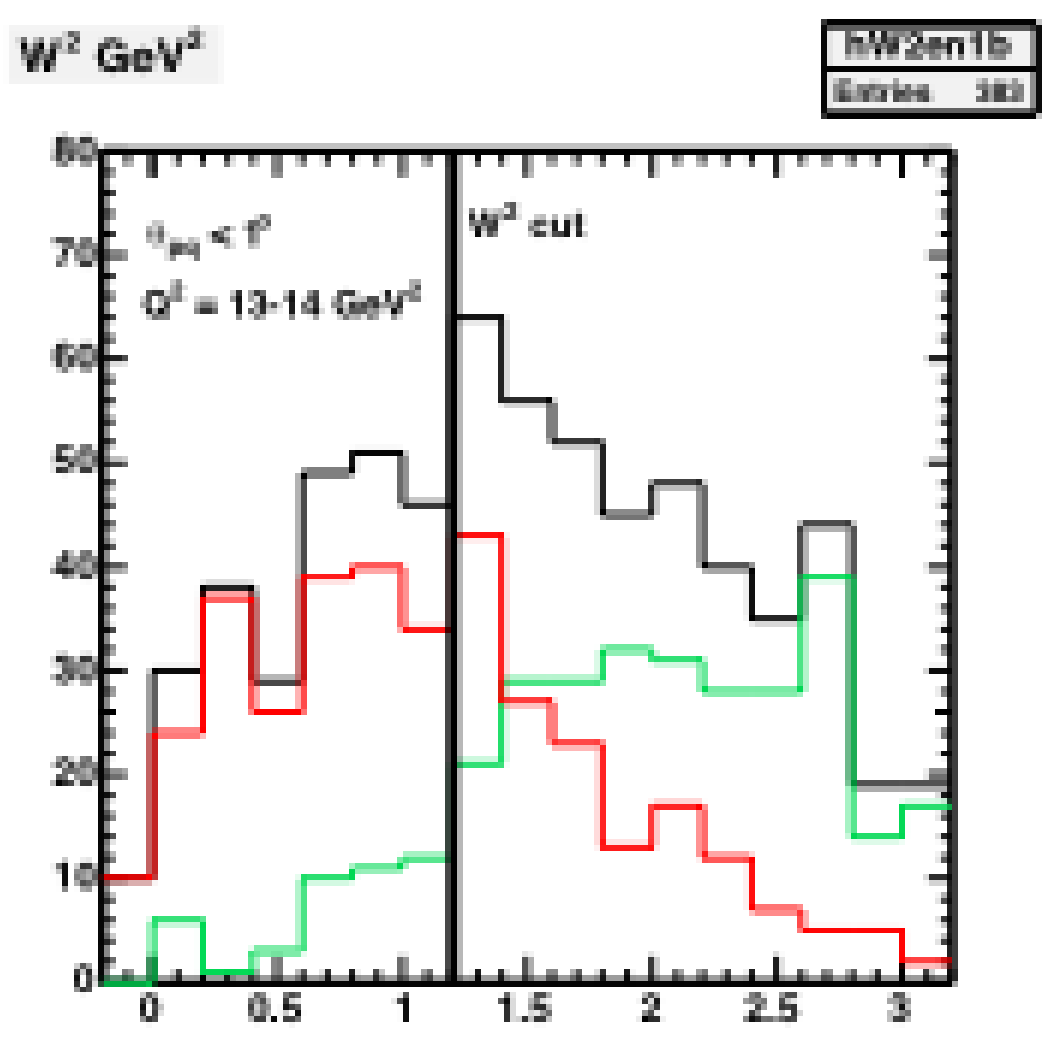
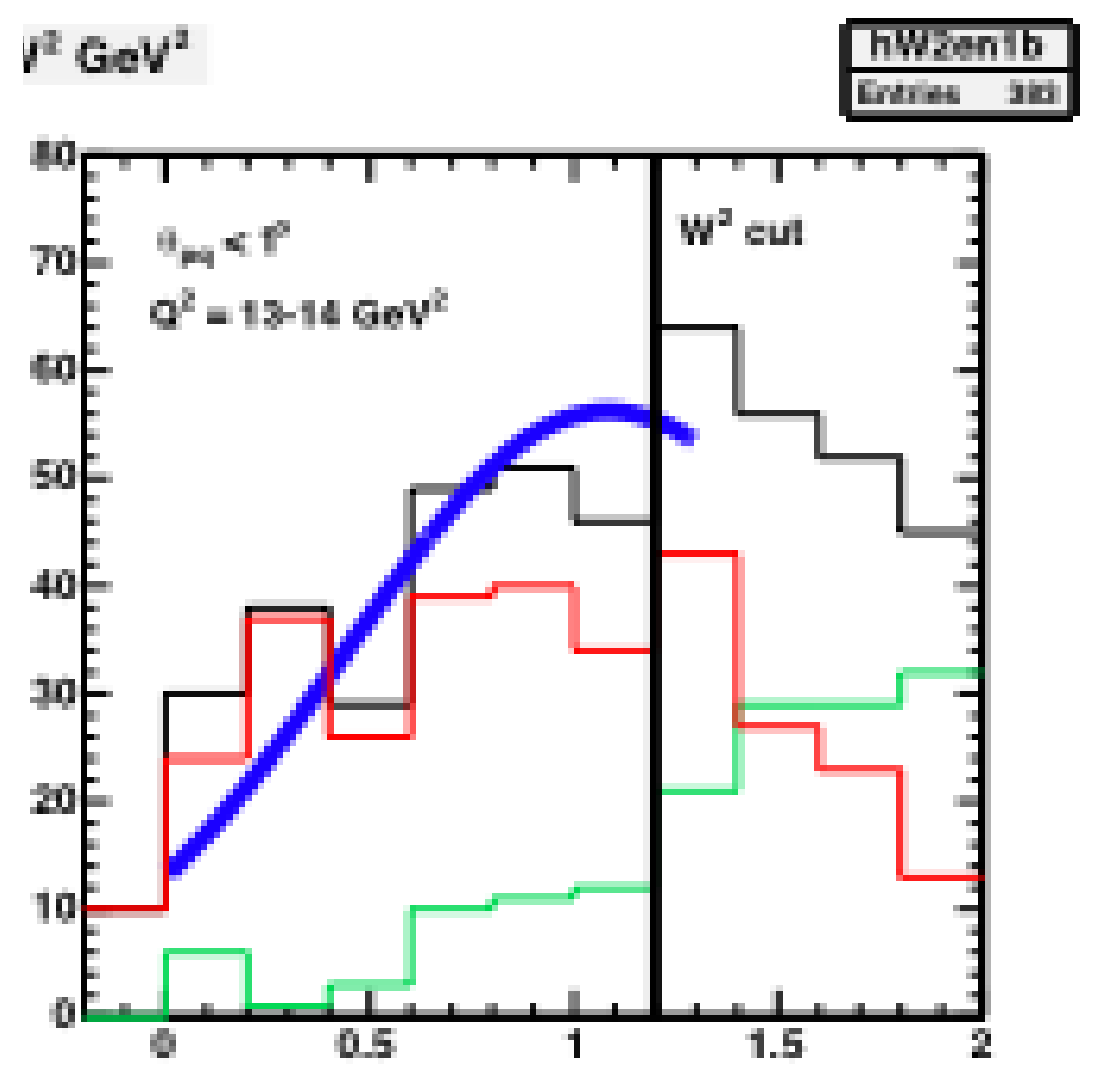


Figure 9: same as Figure 8 with fit from shapes generated in simulation



Conclusion

Without any cuts, the background events outnumber the quasielastic events in the range $Q^2 = 13 – 14$ GeV2 at a ratio of hundreds to one. However, after applying various cuts, the quasielastic events make up approximately 50% of the final set detected events. This increase in number, along with the use of mathematical models will allow us to better remove background events at high Q^2. We found the anticipated statistical uncertainty on G_m^n in the highest Q^2 bin is about 10% for neutrons and 6% for protons.

References

1. G.P. Gilfoyle, J.D. Lachniet, W.K. Brooks, B. Quinn, and M.F. Vineyard. 'Measurement of the Neutron Magnetic Form Factor at High Q2 Using the Ratio Method on Deuterium', CLAS Experiment E12-07-104, Jefferson Lab, 2007.

2. J. D. Lachniet, Ph.D. thesis, Carnegie-Mellon University, Pittsburgh, PA, USA (2005).

3. P. Corvisiero et al., Nucl. Instr. and Meth. A346, 433 (1994).