Analysis of Quasi-Elastic *e-n* & *e-p* Scattering from Deuterium

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Introduction

Jefferson Lab's (JLab) goal is to unravel the quark-gluon structure of nuclei and understand quantum chromodynamics (QCD) [1]. JLab has completed an upgrade that doubled the beam energy to 12 GeV (Fig. 1) and built new detectors modeling one in Hall B called CLAS12. We are preparing for an experiment with CLAS12 to extract elastic electromagnetic form factors [2]. These are fundamental observables; they show us distribution of charge and magnetization in nucleons and nuclei.

Figure 1. JLab site.

We are preparing for an approved experiment with CLAS12 to measure the neutron magnetic form factor (G_m^n). We have developed an end-to-end analysis from simulation to extraction of the ratio, *R*, of electron-neutron (*e-n*) to electron-proton (*e-p*) scattering to probe G_m^n in Quasi-Elastic (QE) kinematics. In QE scattering, the electron scatters off a nucleon under near elastic conditions inside a nucleus. *R* is closely related to G_m^n. We have simulated *R* as a function of the square of the four-momentum transfer from beam to target, Q^2.

The CLAS12 Detector

- CLAS12 (Fig. 2) is a large-acceptance spectrometer over a large solid angle [1].
- The Superconducting Torus is used to generate a toroidal magnetic field in the forward detection to bend charged particles and extract their momenta.
- The Superconducting Solenoid is used for large angle scattering.
- The Forward and Central Detectors measure the 4-momenta of reaction products. The Forward Detector will be used to extract G_m^n.
- The Pre-Shower and Electromagnetic Calorimeter (PCAL/EC) are used to measure the energies of electrons, protons, and other charged particles and to detect neutrons [3,5].
- Drift chambers measure the particle trajectories.
- The Forward Time-of-Flight (FTOF) system consists of plastic scintillator paddles to measure TOF of charged particles.
- The Forward Micromegas detector is a gaseous detector on a parallel plate electrode structure used to measure additional track points.
- The High and Low Threshold Cerenkov Counters (HTCC & LTCC) are used for particle identification.

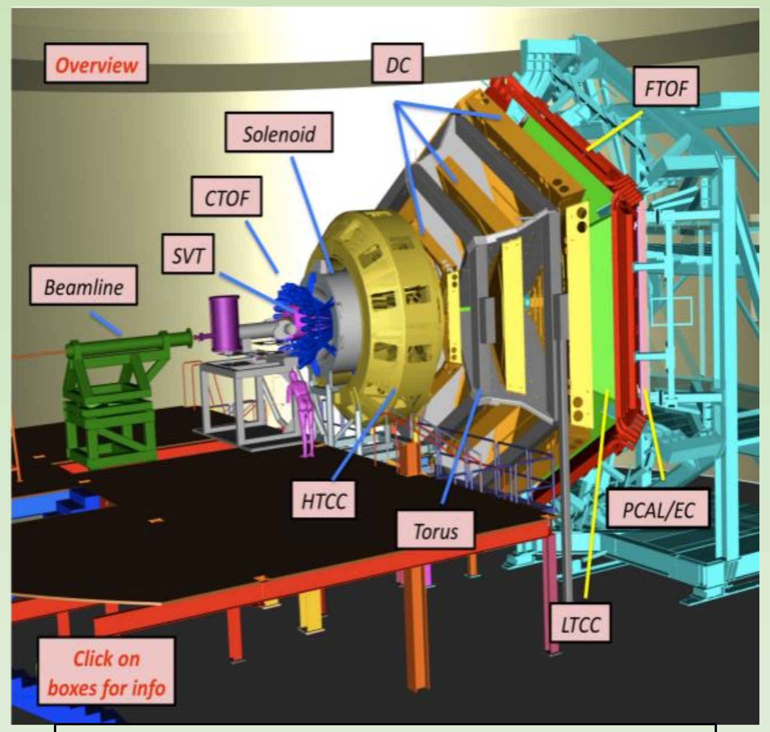

Figure 2. Computer designed image of CLAS12

Neutron Detection

Neutron detection is more difficult then proton detection. The PCAL/EC used for neutron detection consists of alternating layers of scintillator and lead. The scintillator layer is made of paddles that form the triangular shape of each sector (Fig. 3) [3,5]. The strips are rotated 120° within each set of three layers. The neutrons produce light in the scintillators that is collected by a photo multiplier tube and triangulated to find it's position (Fig. 4).

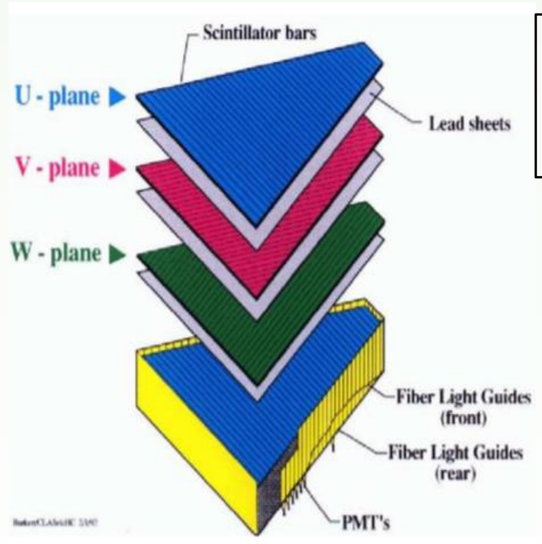

Figure 3. Expanded views of the EC showing lead and scintillator layers.

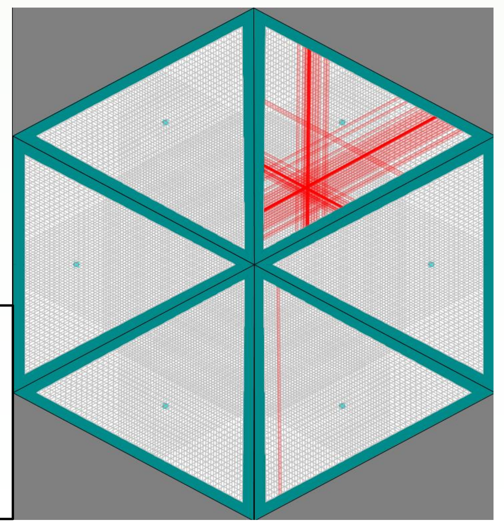

Figure 4. Cross sectional view of PCAL showing triangulation of scintillator bars to locate particle.

Simulation of Events

We have developed algorithms to study *e-n* and *e-p* QE events in CLAS12 [2]. Using the quasi-elastic event generator (QUEEG) with the CLAS12, physics-based simulation *gemc*, we simulate *e-n* and *e-p* events. The CLAS12 Java-based common software tools are used to reconstruct the events. This work will prepare us for actual data collected from CLAS12 in the future. The procedure is as follows:

1. Generate quasi-elastic *e-n* and *e-p* 4-momentum vectors from QUEEG.
2. Use the Monte Carlo code *gemc* to simulate the CLAS12 response for the generated events.
3. Convert to a high performance agnostic file format (HIPO) to reduce file size and run time.
4. Reconstruct the QE events using CLAS12 Common Tools in the Forward Detector.
5. Use the electron information to predict neutron and proton 3-momentum trajectories.
6. Swim both particles though the magnetic field and require both to strike the sensitive volumes of CLAS12. This ensures the acceptance is the same for both nucleons. Fig. 5 and 6 show typical nucleon events in the Forward Detector.
7. Look for a neutron or proton near the value predicted from the electron information.
8. Place an angular cut between predicted 3-momentum of the nucleon and the measured value, θ_{pq}, separating QE and inelastic events.
9. If the event passes the θ_{pq} cut, then count that nucleon as a found particle.

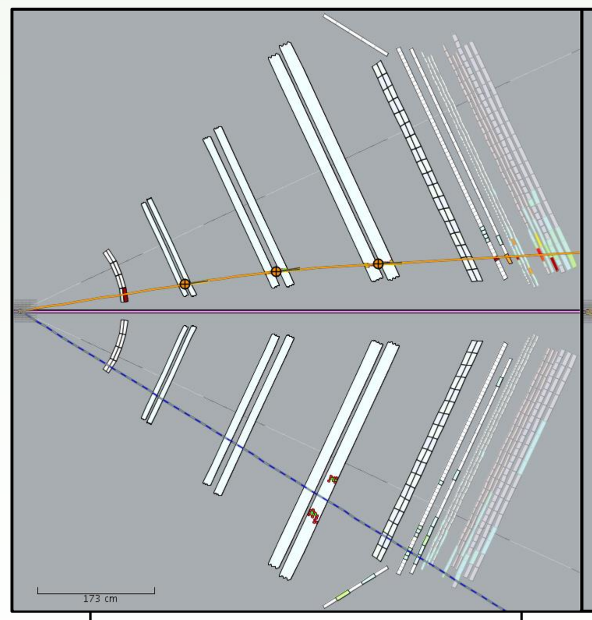

Figure 5. Simulation of found neutron hitting PCAL/EC

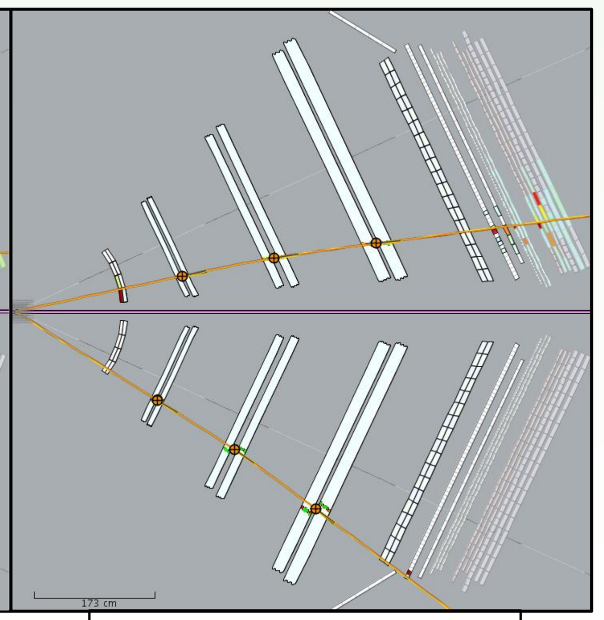

Figure 6. Simulation of found proton through FTOF

Results

We have written an analysis code to extract *R* from the simulation and are now testing. The analysis is ongoing and not all corrections are in place. Fig. 7 shows the electron scattering angle versus its momentum for *e-n* events. The red curve represents the elastic theory

$$E' = \frac{E}{1 + 2\frac{E}{M_n}\sin^2\frac{\theta}{2}}$$

where E is the beam energy and M_n is the mass of the neutron. Our simulated electron information matches the theory. The variations above and below the elastic curve are due to QE effects from the intrinsic fermi-motion between the nucleons within the deuterium nucleus.

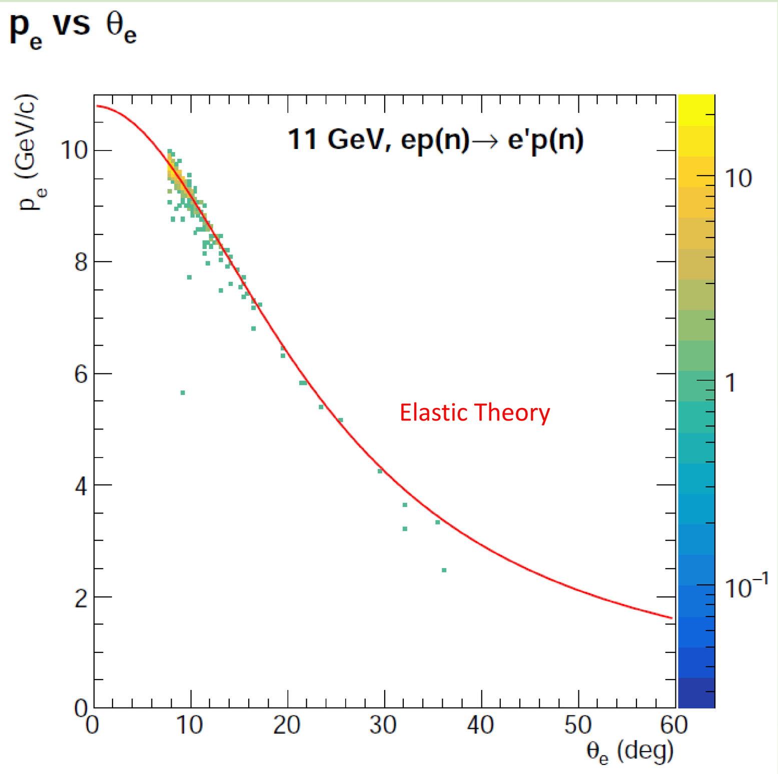

Figure 7. Electron Scattering Angle Vs Momentum

Future Work

We are working to apply corrections to *R* by accounting for Neutron and Proton Detection Efficiencies (NDE and PDE), radiative corrections, and corrections for Fermi motion. We also need to study the impact of background events that contaminate the QE peak.

References

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