Simulation of the CLAS12 Dual Hydrogen-Deuterium Target

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The JLab Mission

The primary mission of Jefferson Lab (JLab) is to reveal the quark and gluon structure of nucleons and nuclei and to deepen our understanding of confinement. Jefferson Lab (JLab) is located in Newport News Virginia (figure 2) The central scientific instrument is the Continuous Electron Beam Accelerating Facility (CEBAF), a super-conducting, racetrack accelerator about a mile long with three unique detectors in Halls A,B and C. CEBAF runs at energies up to 6 GeV now and is being upgraded to 12 GeV. Figure 3 is an aerial view of the JLAB Facility, which includes CEBAF and experimental halls A, B and C.

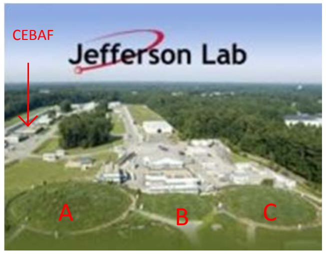

Figure 3: Aerial view of JLab showing CEBAF and Halls A,B,C

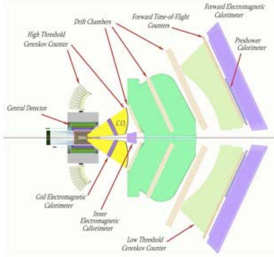

Figure 4: CLAS12

CLAS and CLAS12

The current detector in the Hall B CLAS will be replaced as part of the CLAS12 upgrade. CLAS12 (Figure 4) will be made up of drift chambers, Cherenkov counters, time of-flight- scintillators (TOF), and electromagnetic calorimeters. These components each contribute to the identification and measurement of particles produced in nuclear reactions. JLab is being upgraded to twice its current operating energy.

Simulating CLAS12

At JLab there is a need for high-performance computing for data analysis and simulations. The precision of many future experiments will be limited by systematic uncertainties and not statistical ones; making accurate simulations vital. Simulations are now being put in place for the CLAS12 upgrade. A physics-based simulation of a new detector (CLAS12) has been developed called gemc. This new program uses the package Geant4 to calculate the interactions of particles with matter in the components of CLAS12 (Figure 8).

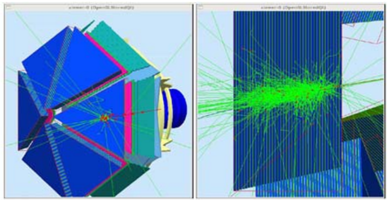

Figure 7: Simulated Particles propagating through the CLAS12 detector in gemc.

The Neutron Magnetic Form Factor

The Magnetic Form factor of the Neutron G^M_n is a fundamental quantity related to the distribution of charge and magnetization in the neutron. Measuring it is part of a broad effort to understand how nucleons are constructed from the quarks and gluons using quantum chromodynamics (QCD). QCD is a theory of the strong interaction (color force), a fundamental force describing the interactions of the quarks and gluons making up hadrons.

Measuring G_M^n

The quantity G_M^n is measured using the ratio method. We extract the ratio R of e-n to e-p scattering off liquid deuterium since there is no such thing as a "free neutron" target. Equation 1 describes R in terms of the quasielastic cross section for neutron and proton scattering. The cross sections are expressed in terms of the electric (E) and magnetic (M) form factors of the proton (p) and the neutron (n), 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 deuterium. The proton form factors are precisely known, G_E^n is small, and $a(Q^2)$ can be calculated. With a precise measurement of R G_M^n can be extracted. The angle θ in equation 1 is the electron scattering angle. To select quasielastic events we start with the 3-momentum of the scattered electron and assume elastic nucleon scattering. We then predict the position of the nucleon and select particles (p or n) that fall within a small angular cone around the predicted direction of the nucleon. The angle θ_{pq}, shown in Figure 1, is used to make this cut. It 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.

Equation 1:

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

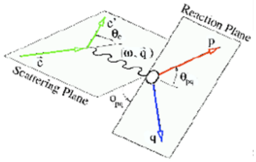

Figure 1: Kinematic quantities used to study e-p and e-n scattering from deuterium .

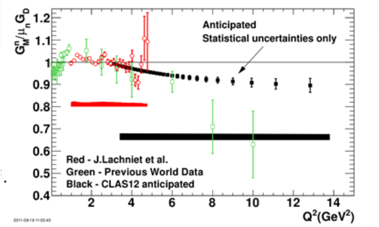

Figure 2: Existing and anticipated data for the neutron magnetic form factor.

Current Knowledge of G_M^n

Figure 2 shows our current knowledge of G_M^n. The red points show results from a CLAS6 experiment that used the same ratio method. The red bar graph shows the measured systematic uncertainty, the green points show previous world data, the black points are the anticipated results for the range in Q^2 of the CLAS12 measurement of G_M^n, and the black bar graph shows the anticipated systematic uncertainty.

Neutron Detection Efficiency

The ratio method is less sensitive to variation in experimental conditions (like beam current), but it does require the neutron detection efficiency to be precisely measured. To create a source of 'tagged' neutrons we use the p (e,e',π⁺n) reaction. The electron and π+ are detected and the position of the neutron is predicted in the electromagnetic calorimeter or the time-of-flight sensors. If the neutron falls within the CLAS12 acceptance it is classified as a 'found' neutron. We then search for a hit near the predicted position. If one is found, that neutron is classified as 'reconstructed'. We note here that we measured the neutrons in two, independent CLAS12 systems. The ratio of found to reconstructed neutrons is the detection efficiency. The performance of CLAS12 can vary with conditions. Calibration data doesn't necessarily stay constant over run periods. To account for this, we take an "in situ" calibration, or we take our measurements and calibrations at the same time. This is done by placing a liquid deuterium and liquid hydrogen target downstream from each other. [2]

The Dual Cell Target

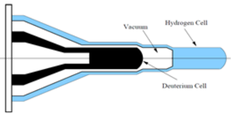

Figure 5: Schematic of the e5 target used for a CLAS 6 Experiment.

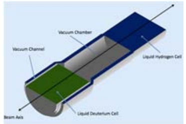

Figure 6:cut away diagram of the current design of the dual-cell target.

A schematic design of the targets is shown in Figure 5. An upstream (left) cell will hold liquid deuterium for production running and the downstream cell will hold liquid hydrogen for calibrations especially the measurement of the neutron and proton detection efficiencies. In the current design each cell is 1.5 cm long with a 2 cm gap in between the cells. The three-dimensional shape of the target can be obtained by rotating the target in Figure 5 about the beam axis (solid black line) so the supply lines are actually conical shells.

Figure 6 shows a cut-away diagram from our simulation of the target. The green portion is liquid deuterium, and blue portion is liquid . The targets parameters first produced by a perl script, stored in a mySQL database, and then read into the simulation at run time. Simulated particles start at a random point in the target volume and are propagated through the CLAS12 detector.

Results

We have incorporated a simulation of the target in *gemc* using Geant4 and have begun using it to study the properties of events scattered from the two cells. Some of the issues to investigate include the optimum distanc between the cells so we can separate events from the hydrogen and deuteriun targets. We ran SOCRAT, a software package for CLAS12 reconstruction and tracking, and produced the plot in Figure 7. The black histogram represents the generated z position of the a tracks v represents the SOCRAT reconstructed z position of a tracks vertex. We see two distinct peaks of reconstructed z events, which shows that we can distinguish between events created in each of the two target cells.

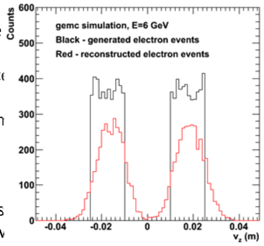

Figure 7:

References

[1]:J. Lachnet et al. Phys. Ref Left., 102, 19200 (2009)
[2]: W. Brooks