Simulation of Neutron Detection Efficiency in the CLAS12 detector

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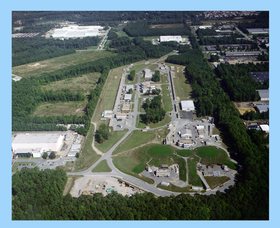
Jefferson Lab

Jefferson National Laboratory (JLAB) is a community of scientists using the 12-GeV Continuous Electron Beam Accelerator Facility (CEBAF) located in Newport News, VA to investigate the sub-atomic nature of matter, quarks and gluons, test the theory of Quantum Chromodynamics(QCD), and explore quark confinement. Quarks are sub-atomic particles confined inside of neutrons and protons. The 12-GeV electron beam is a continuous wave and high precision. The electrons travel a mile along an underground racetrack.

Experimental Halls A, B, C at JLAB



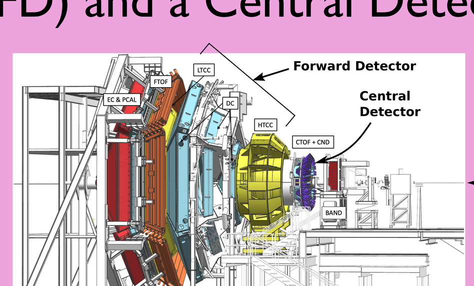
Above view of the electron racetrack at JLAB

Aim

We are focused on measuring the Magnetic Form Factor of the Neutron which is a fundamental quantity related to the distribution of magnetization or electric currents within the neutron. This form factor, along with others, will help us to experimentally test the accuracy of QCD and discover the charge and electric current distributions within the neutron. We extract the Magnetic Form Factor of the Neutron from the ratio of e-n/e-p scattering from deuterium. Neutrons are harder to detect than protons, so we need to measure the neutron detection efficiency (NDE) to determine the numerator accurately. We are focused on extracting the NDE from electron scattering events of the nuclear reaction (ep→e'n π^+). We determine the NDE by measuring the ratio of neutrons detected versus how many neutrons are expected.

CLAS12 Detector

The CEBAF Large Acceptance Spectrometer (CLAS12) detector uses drift chambers to measure the trajectory of charged particles, a toroidal magnetic field to bend the particles to measure momentum, cherenkov light to identify electrons, calorimeters to measure energy, and scintillators that measure time of flight. CLAS12 consists of a Forward Detector (FD) and a Central Detector (CD). We are focused on events in the FD.



CLAS12 Detector

Simulation

We use a sophisticated, physics-based simulation of CLAS12 (GEMC) to create pseudo-data to understand the CLAS12 response. We run batch jobs on the JLab farm using a shell script to manage and execute the commands to:

1. Generate events (initial 4-vector of tracks)
2. Filter those events to get the desired ones
3. Run GEMC
4. Convert file format from evio to hipo
5. Add background
6. Reconstruct the pseudo-data (i.e. extract the 4-vectors of each track)
7. Use groovy scripts to select events and determine the NDE.

Methods

- We use the nuclear reaction (ep → e'n π^+)-electron beam(e) on a proton target(p) producing a scattered electron(e'), neutron(n), and a pion(π^+) .
- We apply conservation of 3-momentum to get a missing 3-momentum vector.
- We get the missing mass from the missing 3-momentum and select the neutron peak.
- We assume there are no other missing particles besides the neutron and use the 3-momentum to predict the neutron trajectory and swim the track to see if the neutron will hit CLAS12.
- If the track hits, the expected neutron histogram is incremented.
- If the track misses CLAS12, the event is thrown out.
- For good events, we search for a neutron hit near the expected hit.
- We get the angle between the detected hit and the missing 3-momentum hit,, and place a cut on the angle.
- If the angle is less than 15 degrees, the NDE numerator at the neutron momentum value is incremented(detected neutron histogram).
- The ratio of the detected and expected histograms is the NDE.
- We used the production versions of the CLAS12 Common Tools to update our past work and to add a new feature, background merging to the simulation. These background events come from actual CLAS12 data and make GEMC more realistic. Different backgrounds are used for different beam energies and currents.

References

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2. G.P. Gilfoyle et al. Measurement of the Neutron Magnetic Form Factor at High Q 2 Using the Ratio Method on Deuterium. E12-07-104, Jefferson Lab, Newport News, VA, 2007. https://www.jlab.org/exp_prog/proposals/07/PR12-07-104.pdf.
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Results

We have simulated twenty million events using the JLab farm, reconstructed those events, and selected the ones of interest. Our criteria for selecting events and the preliminary results for the NDE are discussed here. Figure 1 is a 2-D histogram of missing mass (MM) vs momentum for the missing neutral particle. We can see a concentration of events at the neutron MM^2, so we know our data set will include neutrons. Figure 2 is the MM^2 for the missing neutral particle ^{1}H(e ,e' $\pi^+ X_n$) and again shows a peak at the neutron MM^2 . Figure 3 shows a 2-D histogram of the difference in x and y direction cosines between the path of the expected particle and the trajectory of a detected neutron. Events are concentrated at (0,0) and decrease as we move radially outwards,. A cut is placed around the center of the distribution to select neutrons. Figure 4 shows MM^2 for the missing particle after that selection cut is placed on the data. Figure 5 is a histogram of the momentum of expected neutrons and the detected neutrons. Their ratio constitutes NDE. Figure 6 shows the preliminary NDE results for simulation(blue) compared to measured NDE results from Spring, 2018 run (green). The simulation, within uncertainties, agrees with the data for the high momentum plateau. This region is important to reach high Q^2 with the e-n part of the neutron magnetic form factor measurement.[2]

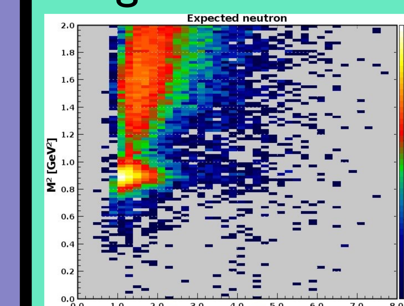


Figure 1: Histogram of MM^2 vs momentum for expected neutrons

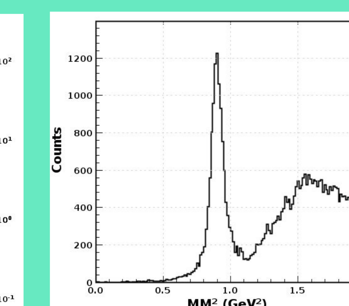


Figure 2: MM^2 for the missing particle ^{1}H(e ,e' π^+Xn)

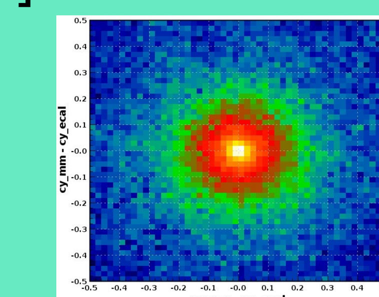


Figure 3: Selection cut for cx vx cy

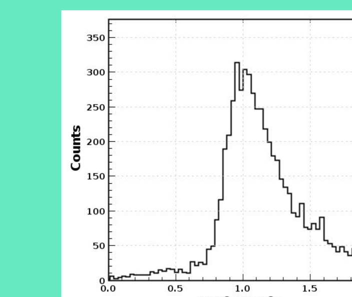


Figure 4: MM^2 for the missing particle ^{1}H(e ,e' π^+Xn) after cx vs cy selection cut

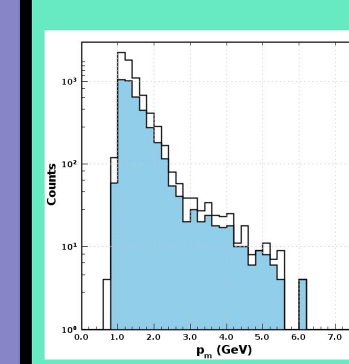
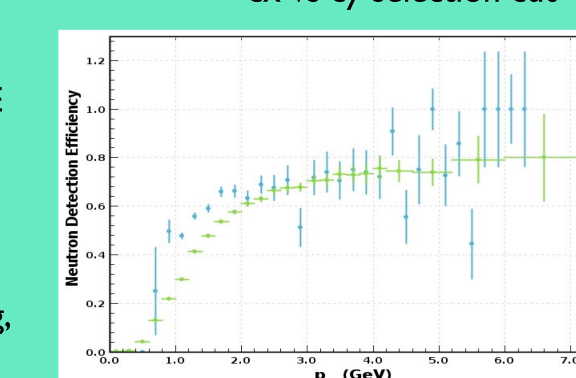


Figure 5: Histogram of momentum of expected neutrons(white) compared to detected neutrons (blue)

Figure 6: Preliminary NDE results for simulation(blue) compared to measured NDE results for Spring, 2018 run (green)



Conclusions

1. We have developed a full simulation from event generation to post-reconstruction analysis.
2. The event generator is Pythia.[7]
3. We have included background in our simulation to make it more realistic.
4. We are using the production version of GEMC which includes recent efforts at resolution matching of the CLAS12 components.
5. In our initial efforts to study the ^{1}H(e, e'pi $^+$n) reaction we extract the NDE and compare with a similar effort to extract the NDE from the data. This simulation is consistent with the data.[5]