Study of Missing Mass Background in the CLAS12 Detector

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The Thomas Jefferson National Accelerator Laboratory (JLAB) is a community of scientists using the 12-GeV Continuous Electron Beam Accelerator Facility (CEBAF) and located in Newport News, VA as shown in figures 1 and 2. The JLAB mission is 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 neutrons and protons. The electrons travel a mile along an underground racetrack for up to five laps before hitting a nuclear target. [1]

Figure 1: Experimental Halls A, B, C at JLAB

Figure 2: Above view of the electron racetrack at JLAB

CLAS12 Detector

The CEBAF Large Acceptance Spectrometer (CLAS12) detector shown in figure 3 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 electron energy and detect neutrons, 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. Figure 4 shows an example of a CLAS12 event.[1]

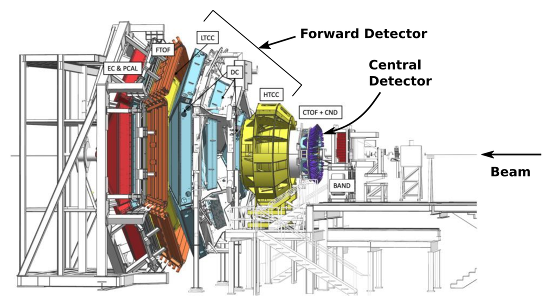

Figure 3: CLAS12 Detector

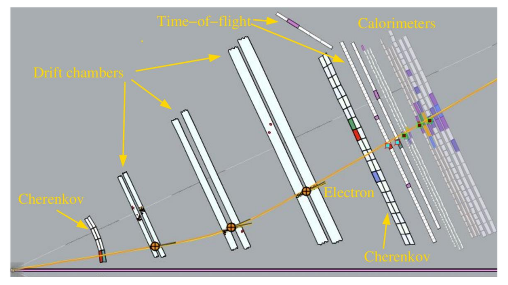

Figure 4: CLAS12 Event

Neutron Detection Efficiency

We are focused on measuring the Magnetic Form Factor of the Neutron (G_m^n) which is a fundamental quantity related to the distribution of magnetization or electric currents within the neutron. This form factor, along with others, will test the accuracy of QCD and the charge and electric current distributions within the neutron. We extract the G_m^n 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 extract 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. We assume the final state consists of $e'\pi^+n$ only and use the $e'\pi^+$ information to predict the neutron's position(expected) where it strikes the CLAS12 Calorimeter and then search for that neutron(detected) near the predicted hit. [2,3,4,5]

Motivation

To extract the NDE we need to determine the yield of expected and detected neutrons from the ep→e'n π^+ reaction. Figure 5 shows the missing mass distribution for one of the bins in missing momentum for detected neutrons. Note the significant background from higher mass events. The red curve is a fit to the central neutron peak with a low-mass tail. This low-mass tail can come from the neutron peak itself or the higher-mass contribution above 1.0 GeV/c^2. See Poster HA.00086 in this session for more details. Our motivation here is to develop a realistic simulation of the NDE reaction and then use the truth information from that simulation to study the source of the events in the low-mass tail. To that end, we assume the missing mass resolution of the simulation is smaller than the data, so we have to increase the resolution effect in the simulated data.

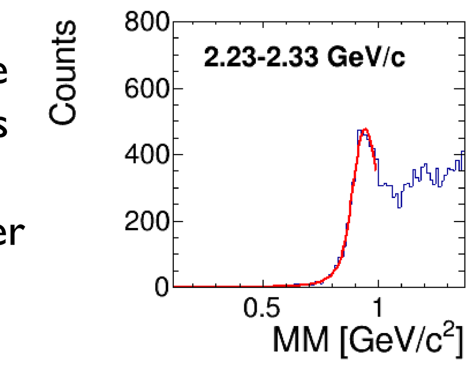

Figure 5: Missing mass distribution for one of the bins in missing momentum for detected neutrons

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:

- Generate events (initial 4-vector of tracks) using Pythia[6]
- Filter those events to get the desired ones
- Run GEMC to simulate the CLAS12 response
- Convert file format from evio to hipo
- Merge background hits
- Reconstruct the pseudo-data (i.e. extract the 4-vectors of each simulated track)
- Use groovy scripts to select events and determine the NDE

Methods

- We start with the reaction $'H(e,e'\pi^+)\chi_n$ and assume the missing particle χ_n is a neutron.
- We apply conservation of 3-momentum to get the missing 3-momentum vector
- We extract the missing mass and place cuts on it to select neutrons
- We use the missing 3-momentum to predict the neutron trajectory and swim the track to see if the neutron will hit the fiducial volume of the CLAS12 calorimeter
- If it hits, it is classified as an expected hit
- If the track misses CLAS12, we throw it out
- We then search for a neutron hit in the CLAS12 detector near the expected hit
- If it is found, we classify it as a detected neutron
- Even with the additional background, we hypothesized the resolution of the simulated data would be too small relative to the run data
- We increase the neutron peak resolution by using a smearing function that widens the pion and electron $\theta, \varphi,$ and momenta values which widens the missing-mass(MM) peak

Results

- We developed a series of Resolution Scale Factors (RSF) that smeared the neutron peak resolution in order to fit the slope of the low-MM^2 tail of the simulated data to the run data.
- We used an exponential to fit the slope of the low-MM^2 tail and extracted λ, the slope parameter shown in figure 6 for one RSF value.
- We expected to select an RSF by interpolating over a graph of λ vs RSF as shown in figure 7 and selecting the value that best matched the run data. We were unable to do so because the dependence of λ on RSF did not overlap the measured data.
- We decided to use the neutron peak in the simulated and measured distributions to investigate the resolution. We fit the central region of the neutron peak with a gaussian over the range from one sigma below the fitted peak value to one sigma above.
- We found the width/sigma of the simulated data with no smearing applied was actually larger than the data width. For the data we have a width of 0.034 GeV^2 while the simulation has a width of 0.050 GeV^2 as shown in figures 8 and 9.
- This explains the behavior seen in figure 7 with the slope of the distributions in the low-mass region.
- Figure 10 shows MM^2 distribution from the simulation. We used the truth information to separate $e'\pi^+n$ events (blue-green histogram) from background ones that had additional neutral particles, usually photons, in the final state (green histogram). There is a long, low-MM^2 tail from the neutron peak and one from the background events. In this calculation the high-MM^2 background in the region of the neutron peak is small.

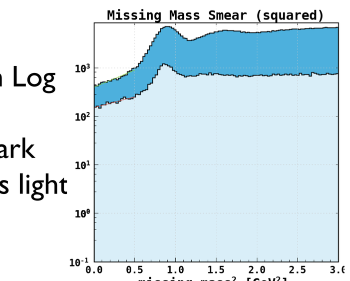

Figure 6: MM^2 on Log Scale for RSF=1.3, simulated data is dark blue and run data is light blue

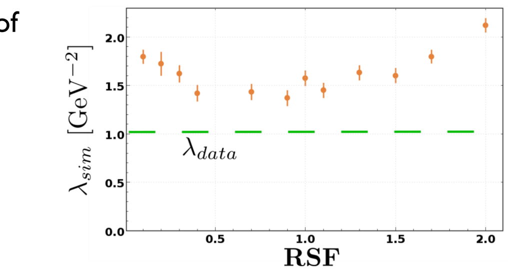

Figure 7: Graph of RSF vs Lambda (slope) with line representing run data value

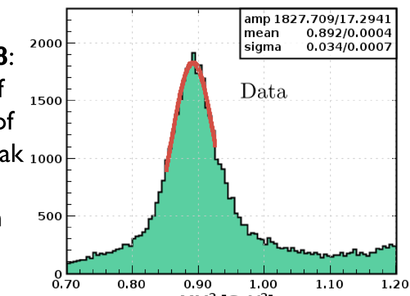

Figure 8: Graph of core fit of MM^2 peak with Gaussian on run data

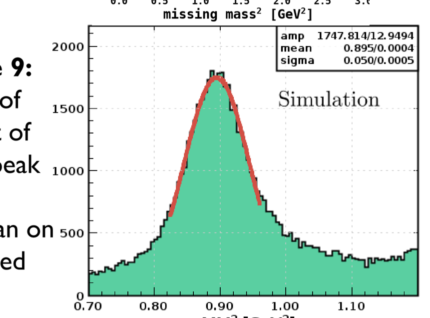

Figure 9: Graph of core fit of MM^2 peak with Gaussian on simulated data

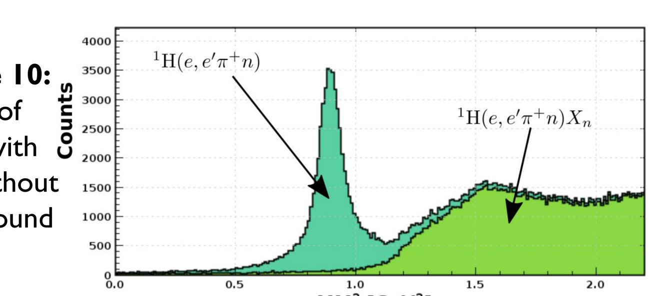

Figure 10: Graph of MM^2 with and without background

Conclusions

- We have developed a full end-to-end simulation of the NDE reaction including background.
- For this reaction, the simulated MM^2 width exceeds the data width making the simulation a good testing ground for our background study.
- Using the truth information from the simulation we separated $e'\pi^+n$ signal events $e'\pi^+n\ \chi_n$ background events. The undetected neutral particle is typically a photon. We found long, low-MM^2 tails from both sets of events and the background in the region of the neutron mass was small.

References

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