A Deuteron Quasielastic Event Simulation for CLAS12

Omair Alam and Gerard Gilfoyle
Department of Physics, University of Richmond

Introduction

One of the fundamental goals of nuclear physics is to understand the structure and behavior of strongly interacting nuclei in terms of its basic constituents, quarks and gluons. An important step towards this goal is the characterization of the internal structure of the nucleon; the elastic electric and magnetic form factors of the proton and neutron are key ingredients of this characterization. The elastic electromagnetic form factors are directly related to the charge and current distributions inside the nucleon and are among the most basic observables of the nucleon.

JLAB, CEBAF

Jefferson Lab (JLab), located in Newport News Virginia, focuses on understanding the nature of the quark-gluon interaction that binds protons, neutrons, and nuclei together. The central scientific instrument at JLab is the Continuous Electron Beam Accelerator Facility (CEBAF). CEBAF creates a precise, continuous, beam of electrons that allows exclusive measurements (detect multiple particles from each event) to be made. CEBAF now runs at energies up to 12 GeV. Hall B currently houses the CEBAF Large Acceptance Spectrometer (CLAS12). CLAS12 consists of eight detector subsystems for the base equipment with more than 60,000 channels. There are two major parts, the forward detector and the central detector. It will detect and measure the properties of charged and neutral particles produced in collision with the electron beam.

Figure 1: CEBAF site and end station

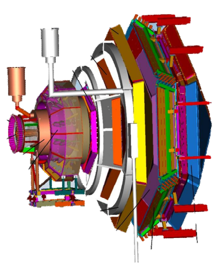

Figure 2: Design Drawing of CLAS12

Measuring the Neutron Magnetic Form Factor

An experiment to measure the neutron magnetic form factor(G^n_m) is planned for the new CLAS12 (JLab Experiment E12-07-104). This form factor is extracted from the ratio of quasielastic electron-neutron to electron-proton scattering off a liquid deuterium target. In order to realistically simulate this experiment, we have developed the QUasiElastic Event Generator (QUEEG) which models the internal motion of the nucleons in deuterium. It extends a previous version used in Hall B to measure the form factor at lower energy[1].

Quasielastic Event Generator

To simulate the quasielastic production we treat the deuteron as composed of two, on-shell nucleons, one of which will act as a spectator in the interaction. The quasielastic interaction is then elastic scattering with the target nucleon.

Options were added to the original QUEEG code to improve the simulation of the experiment to measure G^n_m

1) Included a dependence on the azimuthal angle between the scattering plane (defined by the incoming and scattered electrons) and the reaction plane (defined by the detected nucleon momentum and the 3-momentum transfer).
2) Simulated a realistic event vertex distribution for a cylindrical target.
   a) We randomly distributed the event vertex along the beamline in the target region. So, when the center of the target was at -15 and the target was 20 mm long, the plot we obtained was a uniform distribution spanning from -25mm to -5 mm. See Figure 3.
   b) We also used von Neumann rejection to select random points in the plane traverse to the beamline within a fixed radius from the beam. By discarding all the points in the x-y plane whose length from the target radius was greater than the target radius itself, we obtained uniformly distributed x and y components in a circle of radius R_t. So, when the target centre was (0,0) and R_t was 6.5 mm, we obtained a circle of radius 6.5 mm which represented the cross section of the target. See Figure 4.
3) Added a threshold on the missing momentum, p_m, i.e. the momentum of the spectator nucleon. This option enables us to obtain better Monte Carlo statistics at larger p_m where the cross section is small.
4) Exported the simulated results in LUND format for use with Geant4 Monte Carlo Simulation(GEMC)
5) Incorporated minimum and maximum limits on the electron scattering angle. This option enables us to simulate the kinematic region more efficiently.
6) The original code was part of a suite of programs that used locally-developed libraries. We streamlined the libraries needed for QUEEG and modified the directory structure and build systems to make the program more robust and accessible.

Testing the Program

QUEEG generates events that are used as input to the CLAS12, physics-based simulation Monte Carlo (GEMC). This program simulates the particle's interaction with each component of CLAS12 and is a tool to study the response of the detector. Root, a data analysis framework provided by CERN, was used for histogramming and graphing to view and analyze the distribution of the x, y and z vertices of the electrons and neutrons.

Results

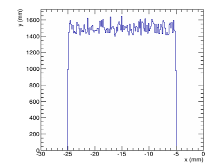

Figure 3: Z axis of LD_2 target

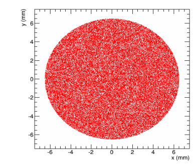

Figure 4: Cross section of LD_2 target

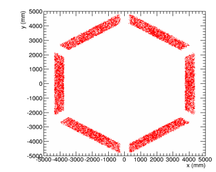

Figure 5: Outer Panel of Forward Time of Flights

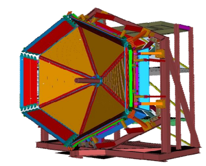

Figure 6: Forward Time of Flight Design CLAS12

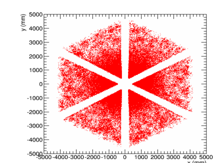

Figure 7: Electromagnetic Calorimeter Plot

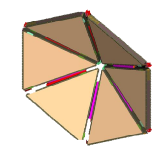

Figure 8: Electromagnetic Calorimeter Design CLAS12

Figure 5 and 7 are obtained with GEMC and show hits in the Forward time-of-flight (FTOF) subsystem and the Electromagnetic Calorimeter (EC). The adjacent figures (Figure 6 and 8) show design drawings of each subsystem. The EC is located just behind the FTOF in the forward detector. (See Figure 2). The hit distributions are consistent with the detectors' geometry and validate the new LUND output option in QUEEG.

Summary and Conclusion

We modified source code for queeg to produce output in the LUND format, set the position of the center of the LD_2 target, and simulate a realistic deuterium target. An initial study of the impact of the target structure and material revealed only limited effects from the target simulated[2].

References

[1] J.D. Lachniet et al., 'A High Precision Measurement of the Neutron Magnetic Form Factor using the CLAS Detector', CLAS Analysis Note, 2008-103 (2008).
[2] G.P. Gilfoyle and O. Alam et. al. CLAS-NOTE 2014-007, Jefferson Lab., 2014