Measuring the Deuterium Inclusive and Semi-Inclusive Pion Production Cross Sections in CLAS12

Caleb Fogler, Lawrence Weinstein, Florian Hauenstein
Old Dominion University, Norfolk, VA 23529

Abstract

Neutrino scattering experiments rely on neutrino event generators such as GENIE. Theoretical models used by GENIE have high uncertainties, so we will compare events from e-GENIE, an electron event mode of GENIE, with experimental electron scattering data. The goal of this project is to measure the deuterium inclusive and semi-inclusive pion production cross sections. We will compare these cross sections to e-GENIE productions which should constrain models in pion production events.

Pion Physics

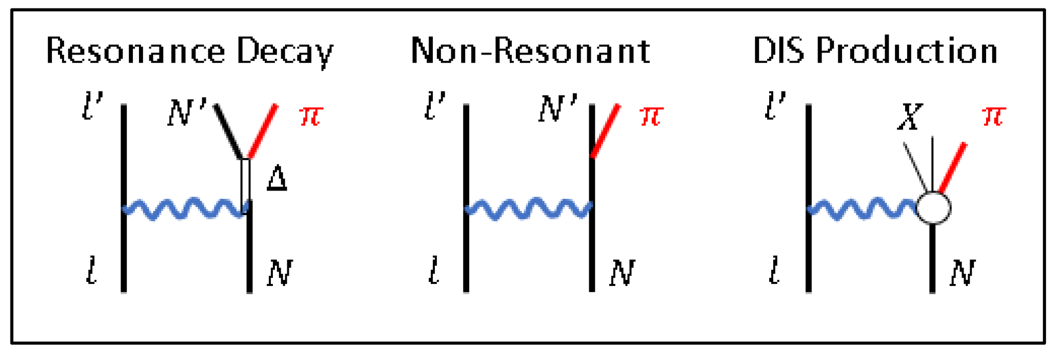

Figure 1: Types of pion production.

Pions are mesons consisting of combinations of up and down quarks and antiquarks. They are commonly produced in lepton scattering experiments. In Figure 1, one can see three types of pion production. In resonance decay, a lepton excites a nucleon to a resonant state, such as a delta particle, and the nucleon deexcites by producing a pion. In non-resonant production, the nucleon does not excite to a resonant state, but it still releases its energy via a pion. In Deep Inelastic Scattering (DIS) production, the lepton strikes a quark inside the nucleon and one of the resulting particles is a pion. It is classified as a type of non-resonant production in our experiment [1]. One can measure the pion production cross section as a function of the invariant mass squared. Figure 2 shows such a plot with data from a neutrino experiment and generated events from a neutrino event generator called GENIE.

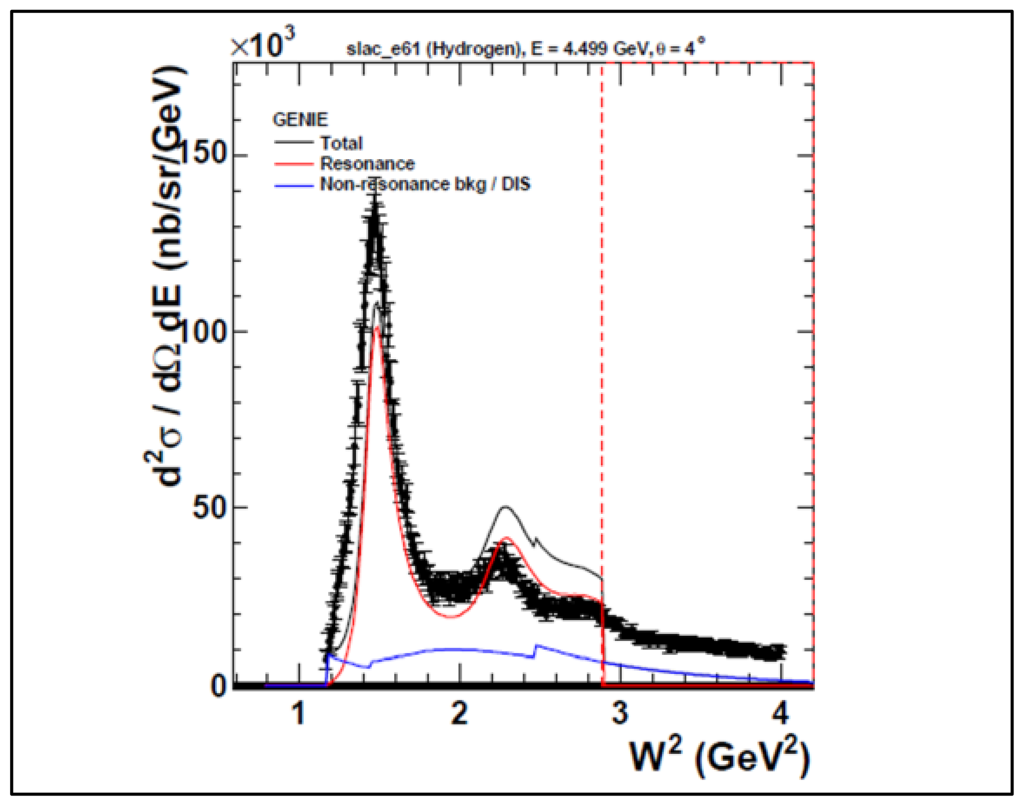

Figure 2: Pion production cross section from neutrino scattering [2].

Motivation

Neutrino scattering experiments are difficult and require the use of neutrino event generators such as GENIE. The difficulty comes from the neutrino beam's large energy spread and small cross section in nuclear scattering; consequently, the current data "is flux-averaged over a wide range of energies" [1]. GENIE simulates neutrino-nucleus scattering over many beam energies which allows the extraction of the neutrino flux from data.

Unfortunately, GENIE uses theoretical models that have high uncertainties. Reducing these uncertainties requires more experimental data, but these cannot come from neutrino experiments. Fortunately, electrons have similar scattering properties to neutrinos, and they have a larger nuclear scattering cross section and smaller energy spread. GENIE has an electron event generator mode called e-GENIE; the e4v collaboration revised it to compare its events with experimental electron scattering data to constrain the theoretical models.

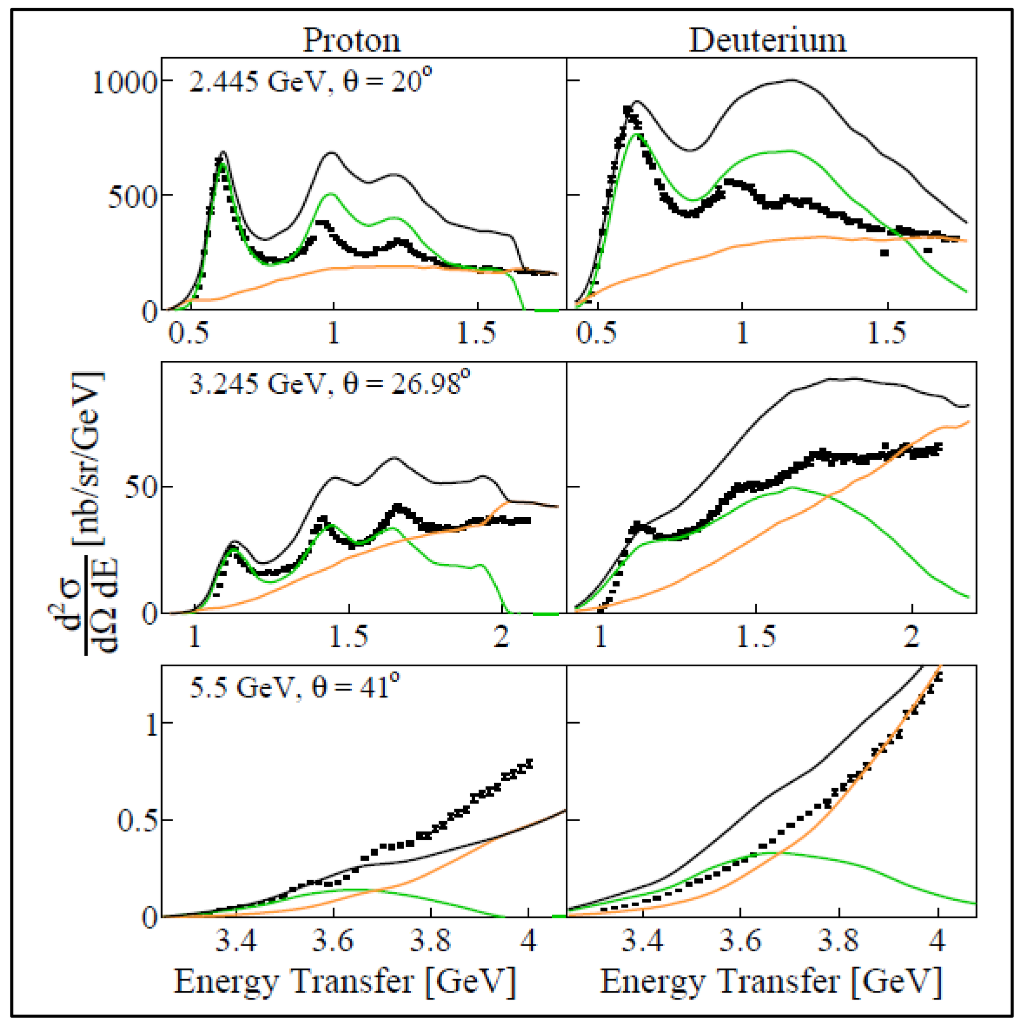

Figure 3: Inclusive cross sections from Hall C data [1]. The black points are data. The black lines are the total e-GENIE simulations, while the green lines are resonance production and the orange lines are non-resonant production.

The e4v collaboration performed an analysis of e-GENIE events with data from various experiments [1]. Figure 3 shows results from data taken in Hall C at the Thomas Jefferson National Accelerator Facility (JLab). The plots show proton (left) and deuterium (right) inclusive cross sections as a function of the energy transfer. Hall C took this data prior to JLab's 12GeV upgrade. However, we took data in Hall B with the upgraded beam and detectors. We wanted to use this data for the inclusive scattering analysis. In addition, no measured semi-inclusive pion production cross sections to compare with e-GENIE events. These reasons compelled us to conduct this experiment.

Experiment

We took data at JLab's Hall B with the CLAS12 spectrometer. The spectrometer consists of detectors around and downstream of the target (Figure 4). These include Cherenkov counters for particle discrimination (HTCC and LTCC), the Silicon Vertex Tracker (SVT) and the Drift Chambers (DC) to measure a particle's momentum, time-of-flight scintillators for particle identification (CTOF and FTOF), and calorimeters to measure a particle's energy (EC). Two superconducting magnets, a solenoid and a torus, allow us to separate positively charged particles from negative ones.

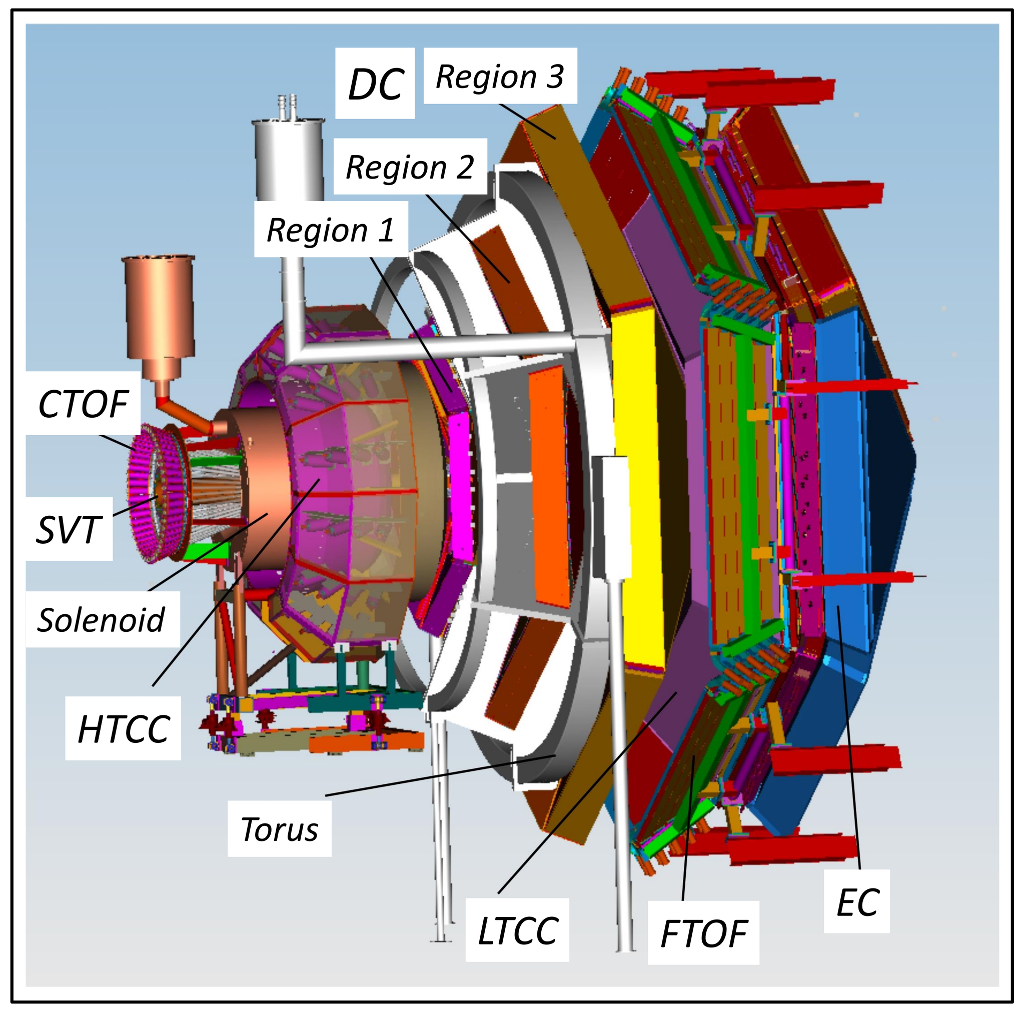

Figure 4: The CLAS12 setup. Adapted from [3].

We scattered 4.244 GeV electrons off a liquid deuterium target. Pion production events occurred as depicted in Figure 5. The electron scattered off the deuterium target in the center of the hall and passed through the detectors of the CLAS12 spectrometer. Pions produced by this scattering also passed through the spectrometer. We took data in the Fall of 2019 and have already begun analyzing it.

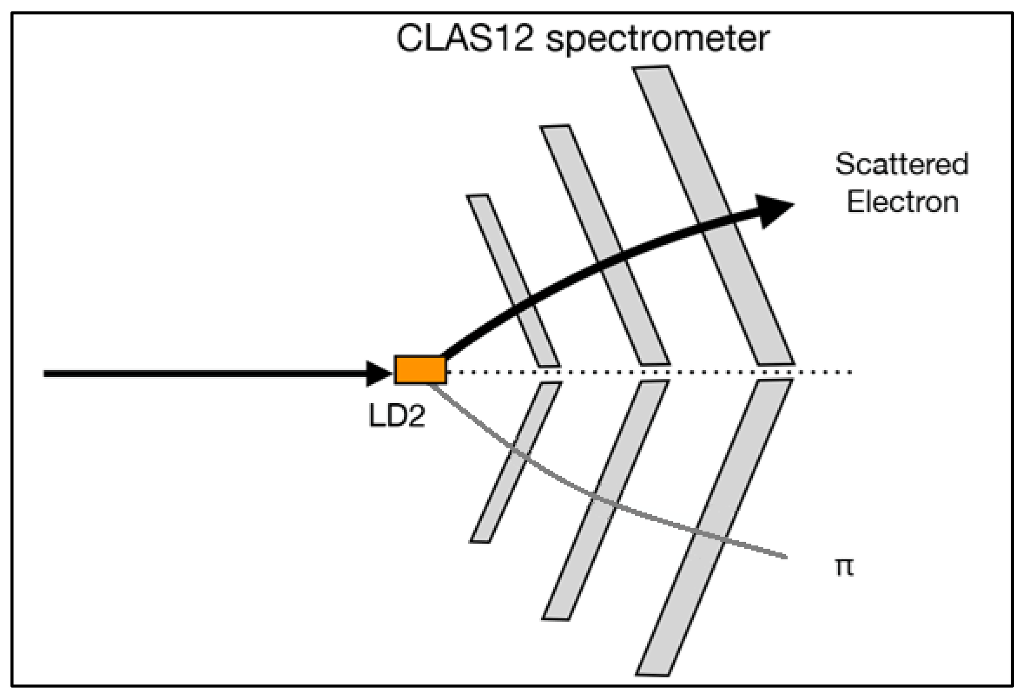

Figure 5: Semi-inclusive scattering in the CLAS12 setup.

Current and Future Analysis

Currently we are analyzing the data to identify pions and remove background events. Figure 6 shows a plot of particle velocity (β) as a function of momentum for one of the 4.244 GeV runs. One can see positive pions (π+) in the top curve near β = 1. The other curve consists of protons. We will develop cuts around the pion curve to exclude non-pion events.

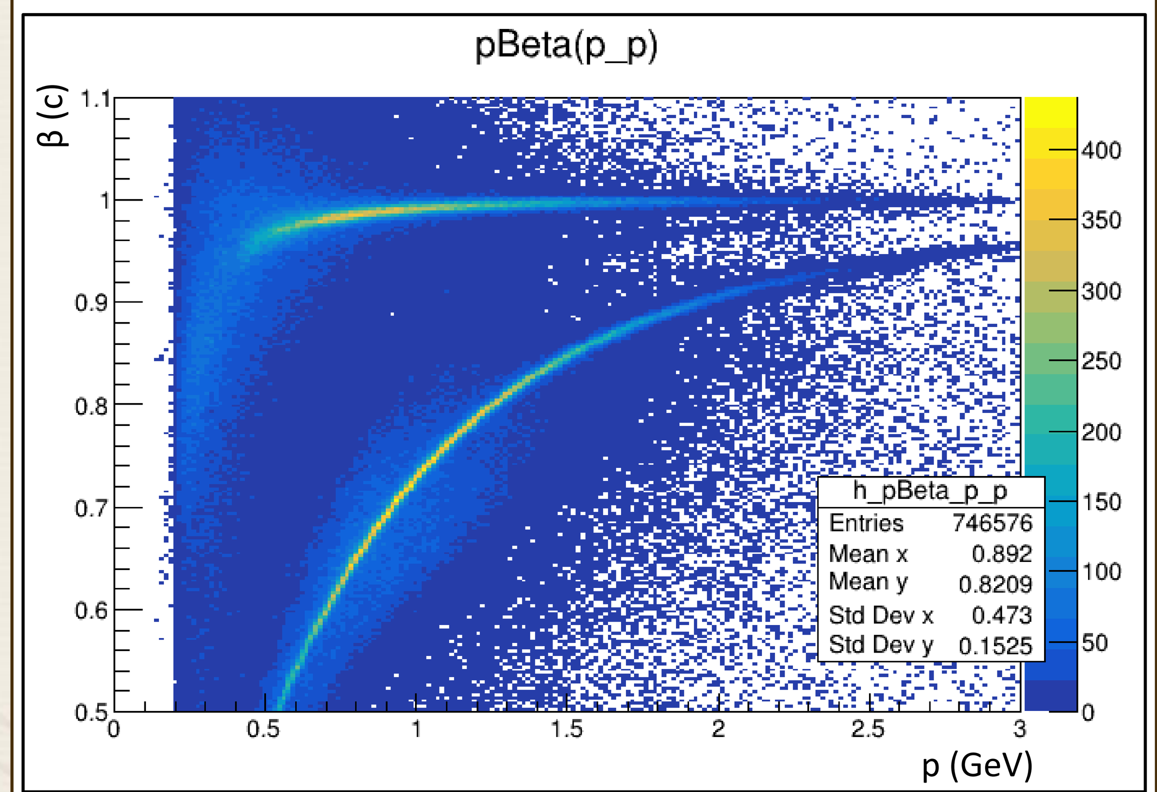

Figure 6: β vs momentum for run 11286.

Future work will involve simulation work for acceptance and radiative corrections, determining the yield and systematic uncertainty, inclusive and semi-inclusive event reconstruction, and measuring the cross sections. Once we measure the cross sections, we will compare them to e-GENIE events similar to what was done in [1]. This work will further refine the theoretical models used by GENIE and improve our ability to study neutrinos.

References

[1] A. Papadopoulou, A. Ashkenazi, S. Gardiner *et al*. "Inclusive Electron Scattering And The GENIE Neutrino Event Generator", arXiv:2009.07228v2 (2021).

[2] S. Dytman. *GENIE – past, present, and future*. FUNFACT at JLab. Newport News, VA. May 2015. PDF

[3] https://www.jlab.org/sites/default/files/images/physics/clas12-design.jpg

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