eA Pion Production at CLAS Aimed at Neutrinos

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Abstract. Preliminary results on semi-inclusive charged pion production in eA collisions at E_{beam}=5 GeV/c^2 are presented. The data were collected using the CLAS detector, which is a multipurpose, large acceptance, magnetic spectrometer located in Hall B at the Thomas Jefferson National Accelerator Facility. Distributions in W, Q^2, p_π, and θ_π are shown for data produced using deuterium and carbon targets. Preliminary comparisons with data simulated using the GENIE generator are made. The motivation for this work is to provide distributions useful for tuning the hadronic production models used in extracting results from current and next-generation neutrino oscillation experiments.

Keywords: electron, neutrino, scattering, cross sections, Jefferson Laboratory
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INTRODUCTION

The discovery of neutrino oscillations in the late 1990s launched a large international effort to further understand the nature of the oscillations and quantify the parameters of the neutrino mixing matrix that relates the neutrino mass and flavor eigenstates. Several of the experiments dedicated to this task are making measurements of 0.5 to a few GeV neutrinos interacting on nuclear targets.[1] In order to reach the desired measurement precision, these experiments must minimize systematic errors arising from nuclear models and the modeling of nuclear final state interactions of the produced hadrons. Electron scattering offers the opportunity to study nuclear effects in the hadron production in a system similar to what is seen with neutrinos and to tune the nuclear final-state interaction portions of the neutrino interaction simulation code.[2] The aim of this work is to provide differential cross section data for pion production in electron scattering on several nuclear targets of interest to the neutrino community for this purpose.

EXPERIMENTAL FACILITIES

The Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (JLAB) in Newport News, Virginia, USA, provides a continuous beam of electrons with energies up to 6 GeV and a current of up to 200

[1] Representing the CLAS Collaboration.

μA to one of three experimental halls.[3] Located in Hall B at JLAB is the CEBAF Large Acceptance Spectrometer (CLAS) which has been operating since 1997.[4] This large acceptance, multiparticle spectrometer is instrumented with wire chambers, gas Cherenkov counters, scintillation counters and electromagnetic calorimeters. CLAS has polar angle (θ) coverage from 8^o to 140^o and a momentum resolution for charged particles of around 1% down to momenta of 150 MeV/c. A toroidal magnetic field throughout the tracking volume is created by six superconducting coils distributed symmetrically around the beam direction and target. All these features make CLAS an ideal detector for studying the hadron production (and its A dependence) in eA scattering and it was used to record the data shown here.

This analysis uses data from the CLAS "eg2" running period in 2003 and 2004. The beam parameters and target for the eg2 period were chosen to facilitate studies of the process of hadronization and the onset of nuclear transparency[5]. During this time, an electron beam of 4-5 GeV was incident on two nuclear targets simulaneously. One of those targets was cryogenic deuterium while the other was a solid target fabricated from either carbon, aluminum, iron, tin, or lead. The simultaneous exposure of the two targets was an important feature of the experiment. The two targets in the beam were separated by 4 cm, which was far enough to allow for a clean identification of the event source while being close enough to provide a similar acceptance for the two targets. Consequently, time-dependent systematic effects, such as drifting gains and detector inefficiencies, cancel out in the ratio of observables between the two targets, increasing the precision of results reported as ratios. The eg2 target is well-described elsewhere[6].

EVENT SELECTION

Over 1.1 billion event triggers were taken with the deuterium and carbon targets in the beam. From this sample, events with an electron and one detected charged pion were extracted. A number of selection criteria were invoked to insure only high quality, well-reconstructed events with the topology of interest were kept for continued analysis. Fiducial cuts were enforced requiring that both the electron and the pion traversed regions of the detector with good tracking and calorimetric coverage. The dominant feature of these fiducial requirements was the removal of six, symmetric, azimuthally distributed regions where the superconducting coils for the magnet interfere with the detector acceptance. Restrictions were placed on the position of the track origin along the beam in order to ensure the events originated in either the deuterium target or the carbon target. For the electron ID, tracks were rejected if they had an even energy deposition as a function of depth in the electromagntic calorimeter, consistent with pions and muons at these energies. The electron momentum was required to be greater than 0.75 GeV (corresponding to a fractional energy transfer of less than 0.85) to avoid a trigger energy threshold in the calorimeter that could lead to a potential event selection bias that would be difficult to model. After all cuts approximately 10.9 million events with the electron interacting in the deuterium target were retained. The analogous sample on carbon was approximately 8.4 million events.

The large number of events in the data sample will allow for the study of differential cross sections which are, in principle, more powerful than integrated cross sections in

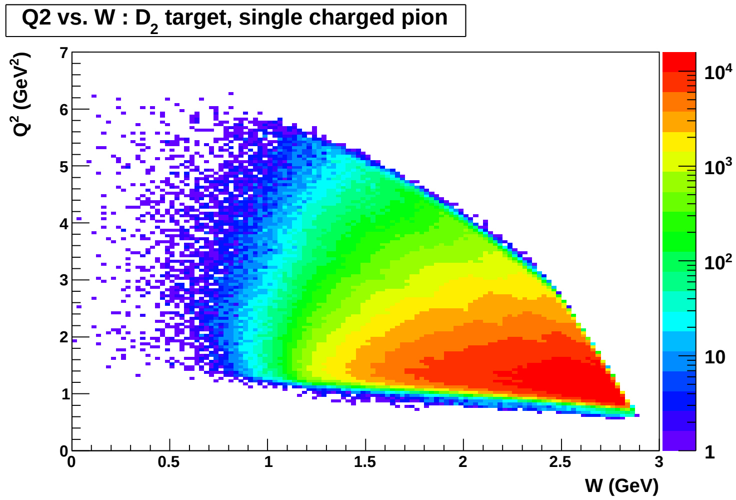

FIGURE 1. W versus Q^2 for events with a single detected charged pion which pass the selection cuts in this analysis.

constraining models of nuclear effects in these interactions. The coverage in W and Q^2 for the selected events is shown in Fig. 1. These events contain a single, detected, charged pion. A study of simulated data indicates approximately 60% of these events contain at least one undetected charged pion. The single pion event purity can be improved substantially by the use of a missing mass cut; but, this reduces the statistics, and the ability to make differential distributions, substantially. The results shown here do not have a missing mass cut enabled.

SIMULATED EVENTS

The use of simulated data in this work is essential for studies of acceptance, radiative corrections, and systematic errors. Simulated samples were created using the GENIE Monte Carlo generator package[7]. GENIE stands for Generates Events for Neutrino Interaction Experiments and the code represents a recent and ongoing effort at creating a flexible and powerful leptonic-nucleus(nucleon) event simulation package using modern software. The code is written in C++ and is designed in a modular fashion so that users can insert and compare different physics options for modeling various aspects of the event. Version 2.5.1 of GENIE, with the eA mode enabled, was used for this work. Relative to the default GENIE used for neutrino interactions, the eA mode of GENIE uses charged lepton cross sections from Rein-Sehgal[8] and Bodek-Yang[9] and includes small modifications to account for the probe charge in the hadronization model and resonance event generation[10].

Events generated by GENIE were passed through the CLAS detector simulation (GSIM) and then processed through the same analysis chain used for the data. A sufficiently large sample of simulated data was generated such that over 1.3 million and 1.1 million events with one detected, charged pion were retained for analysis after all cuts for the deuterium and carbon targets, respectively.

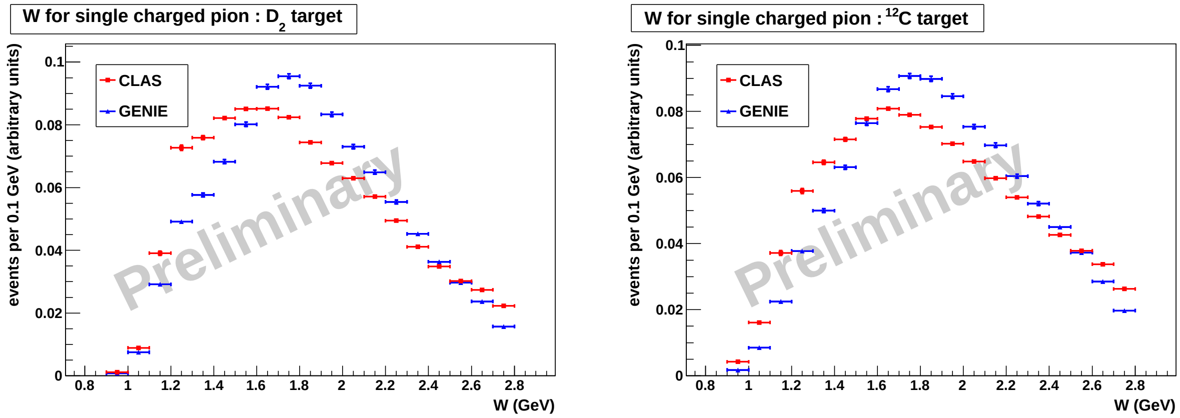

FIGURE 2. The acceptance-corrected distributions in W for deuterium (left) and carbon (right).

RESULTS

The results shown below are preliminary and include only statistical errors. The goal for the analysis is to achieve systematic errors of less than 10%. It is also important to note that no radiative corrections are included in the calculations. In addition, each of the distributions shown below are acceptance corrected. The acceptance correction factor was derived bin-by-bin as the ratio of simulated events reconstructed in a given bin to the simulated single-pion events generated in the same bin. This procedure depended on the facts that the simulation populated phase space broadly, had sufficient statistics to minimize problems due to fluctuations, and had post-reconstruction distributions that looked rather similar (in terms of shape and edges) to the data before acceptance correction. It is important to emphasize that the acceptances for these plots were corrected to the relevant single pion distributions.

Fig. 2 shows the acceptance-corrected W distributions for the selected events on deuterium (left) and carbon (right). The data is given by the red squares and the distribution for simulated data is represented by the blue triangles. In this differential distribution of W all the other variables are integrated over. Though W represents the invariant mass of the hadronic system in these events, is it calculated from leptonic information only.

Fig. 3 shows the acceptance-corrected distribution for another leptonic variable, Q^2. The Q^2 distribution is shown for selected events on deuterium (left) and carbon (right). The data is given by the red squares and the distribution for simulated data is represented by the blue triangles. In this differential distribution of Q^2 all the other variables are integrated over.

The pion momentum distribution for a mix of both charges is shown in Fig. 4. Again, the distribution is shown for selected events on deuterium (left) and carbon (right) and the data is given by the red squares and the distribution for simulated data is represented by the blue triangles. In this differential distribution of p_π the dependencies on the other variables are integrated out.

Fig. 5 gives a distribution for the acceptance-corrected angle, θ_π, for the pion relative to the beam direction in the laboratory frame. The distributions on the left (right)

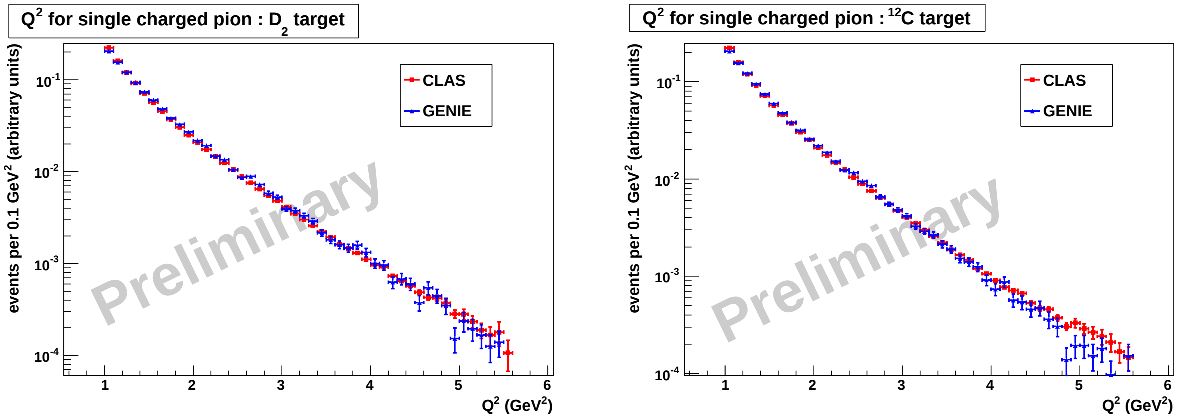

FIGURE 3. The acceptance-corrected distributions in Q^2 for deuterium (left) and carbon (right).

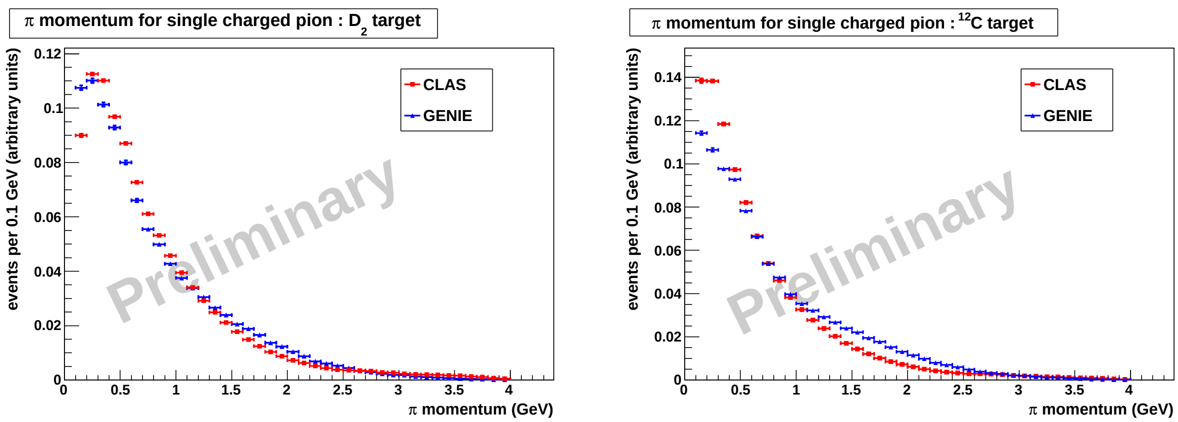

FIGURE 4. The acceptance-corrected distributions in p_π for deuterium (left) and carbon (right).

is derived from selected events on deuterium(carbon). The data are given by the red squares and the distribution for simulated data is represented by the blue triangles. In this differential distribution of p_π all the other variables are integrated over.

CONCLUSIONS

This is an encouraging, preliminary look at pion production in eA scattering with an eye toward providing information useful to the neutrino community. The results of this analysis to date illustrate the power of JLAB and the CLAS detector for providing high statistics, quality eA data in the energy range of interest to the neutrino community. The decent agreement between the data and GENIE is a positive thing for the ongoing neutrino experiments. However, radiative corrections need to be completed before that comparison is taken too seriously. Further, the systematic errors in this analysis need to be evaluated. It is expected that data taken on lead and iron targets will be included in

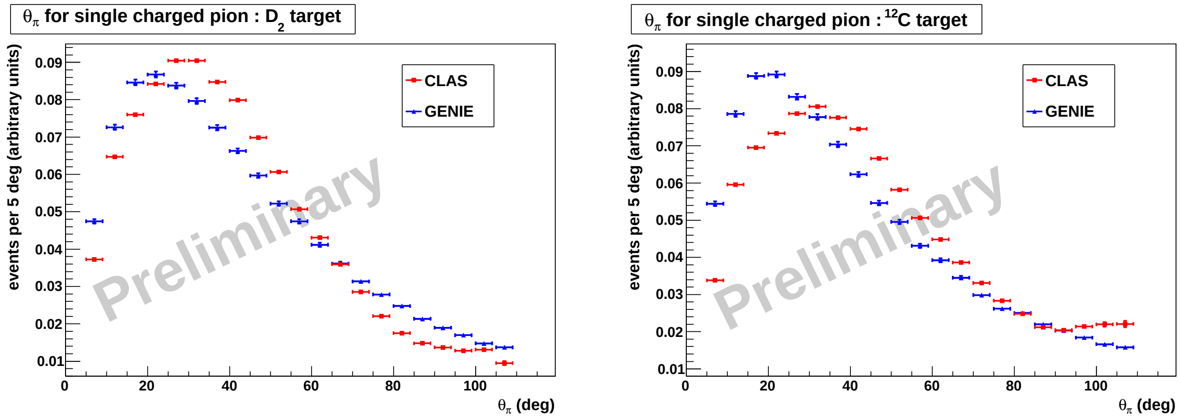

FIGURE 5. The acceptance-corrected distributions for θ_π for deuterium (left) and carbon (right).

the analysis soon. Future plans also include looking at the data more differentially and more inclusively than what is presented here.

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