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 on deuterium, carbon, iron and lead 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 final state interaction models used in extracting results from current and next-generation neutrino oscillation experiments.

1. Introduction

Having established θ_{13} to be relatively large, the neutrino physics community is pushing to probe CP violation in the neutrino sector. Toward this end, long-baseline neutrino experiments need to reduce their systematic errors in order to maximize CP sensitivity. An important component of long-baseline experimental design is the use of two detectors, one near the beam source and one far away. The flux and backgrounds are measured in the near detector and propagated to far detector where the oscillation measurement is made relative to the propagated expectation with the hope that the uncertainties largely cancel out. However, the cancelation is imperfect since the flux, detector and possibly the target nuclei differ between the far and near detectors, and it is necessary to use a neutrino interaction model to bridge the gap between the detectors.

Comparisons of recent data from MiniBooNe [1] to theoretical models have shown significant disagreements in the pion kinetic energy distribution for single pion production on carbon that imply our understanding of final state interactions in nuclei, and in the neutrino interaction models used by oscillation experiments, may need to be refined [2]. 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[3]. 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.

2. 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 μA to one of three experimental halls[4]. Located in Hall B at JLAB is the CEBAF Large Acceptance Spectrometer (CLAS) which has been operating since 1997[5]. 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[6]. During this time, an electron beam of 4-5 GeV was incident on two nuclear targets simultaneously, allowing for systematic error cancelations in ratio measurements. One of those targets was cryogenic deuterium while the other was a solid target fabricated from either carbon, aluminum, iron, tin, or lead[7].

3. Event selection

Around 5 billion event triggers were taken in eg2. From this sample, events with an electron and at least 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. For the electron ID, tracks were rejected if they had an even energy deposition as a function of depth in the electromagnetic calorimeter, consistent with pions and muons at these energies. The electron momentum was required to be greater than 0.64 GeV (corresponding to a fractional energy transfer of less than 0.872) 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, the data sample consisted of approximately 28 million events on deuterium and roughly 5/8/2.5 million events on the C/Fe/Pb targets, respectively.

The large number of events in the data sample allows for the study of multi-differential cross sections which are, in principle, more powerful than integrated cross sections in constraining models of nuclear effects in these interactions. In addition to the reconstruction-driven fiducial cuts mentioned above, further fiducial cuts are enforced in order to insure that the final cross sections are defined in an azimuthally symmetric way that is easy for others to implement in models for comparison. For the electron these cuts are: $\theta_e < 54°$, W$>$ $(-2.25)Q^2 + 4.9$, 1$<$ Q^2 $<$4, 1$<$ $W < 2.8$. The electron distribution is shown in the W-Q^2 plane, along with these cuts, in Fig. 1. Similar cuts are made for positive and negative pions in the θ_π-p_π plane (not shown here). For events in which more than one charged pion was reconstructed, the leading pion was used to define the pion variables in this analysis. The use of missing mass to isolate single pion events was considered, but the loss of statistics was sufficient to compromise the differential aspect of the analysis.

4. 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 version 2.5.1 of the GENIE Monte Carlo generator package[8] with the eA mode enabled. Relative to the default GENIE used for neutrino interactions, the eA mode of GENIE uses charged lepton cross sections from Rein-Sehgal and Bodek-Yang and includes small modifications to account for the probe charge in the hadronization model and resonance event generation[9]. Ongoing work includes updating the

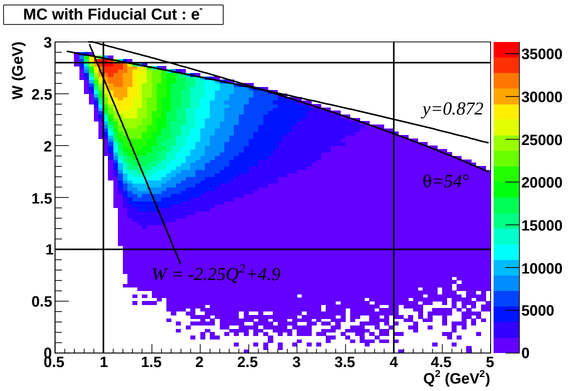

Figure 1. W and Q^2 distribution for events surviving the basic event selection.

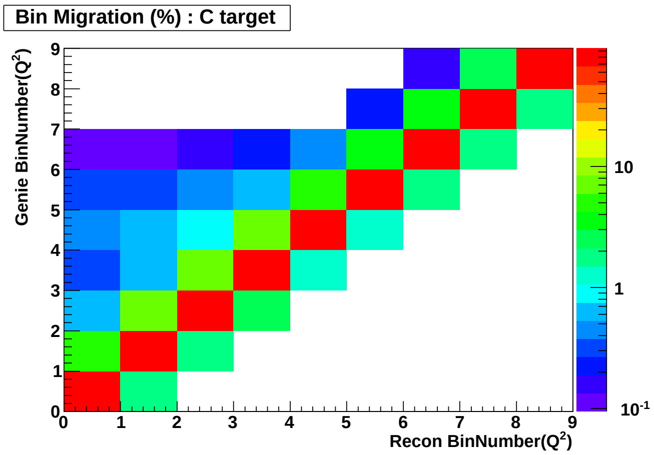

Figure 2. Bin migration matrix for Q^2 for the carbon target.

simulated samples using version 2.6.8 of GENIE, which includes improvements in the model of FSI relative to version 2.5.1.

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 0.5-0.8 million events were retained after all cuts for analysis for each target.

5. Results

The efficiency and acceptance were determined bin-by-bin using the simulated data. Generally the bin migration was less than 10%. The bin migration matrix for Q^2, with the other variable integrated over for the carbon target, is shown in Fig. 2 as an example.

Radiative corrections were done using the Externals All routine used in the eg1-DVCS experiment[10]. This routine was used for leptonic side radiative corrections with the elastic peak contribution removed (since this analysis requires a pion). Radiative corrections to the hadronic side were not considered, in part because hadronic side radiative corrections are ignored typically in neutrino physics.

The results shown below in Figs. 3 through 5 are preliminary and include only statistical errors. Though the analysis produces fully five dimensional differential cross sections in W, Q^2, p_π, and θ_π, only selected plots are shown here. Except for the charge and the variable shown, all other variables are integrated over in these plots.

Remaining work on this analysis include the transition to a new version of GENIE and the evaluation of systematics. The aim is to publish the final results in early 2014.

[1] A.A. Aguilar-Arevalo *et al.*, MiniBooNE Collaboration, **Phys. Rev. D**83, 052007, 2011.
[2] See, for example, Lalakulich and Mosel, (2013), arXiv:1304.2409 [nucl-th].
[3] C. Andreopoulos, *Electron scattering data and its use in constraining neutrino models*, presented at the Sixth International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region, Sitges, Spain, May 2009.
[4] See http://www.jlab.org.
[5] B.A. Mecking *et al.*, **NIM A** 503 (2003) 513.
[6] The eg2 running period took data for JLAB experiments E02-104 (Quark propagation through cold QCD matter) and E02-110 (Q^2 dependence of nuclear transparency for incoherent rho electroproduction).
[7] H. Hakobyan *et al.*, **NIM A** 592 (2008) 218.
[8] See http://www.genie-mc.org.
[9] C. Andreopoulos, Private communication, March 2011.
[10] P. Bosted, EG1-DVCS technical note 5, 2010.

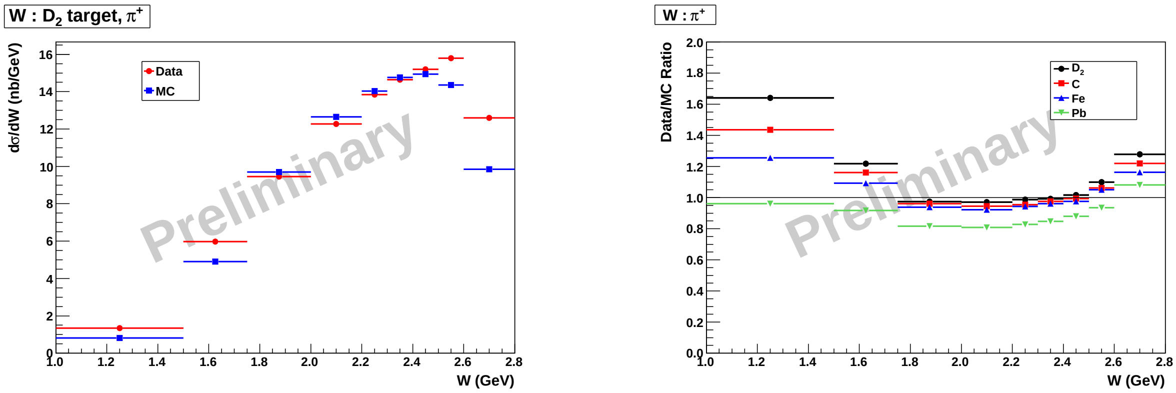

Figure 3. Left: $d\sigma/dW$ for data and simulated events with positive pions on the deuterium target. Right: The ratio of $d\sigma/dW$ for data to that for simulated events for events with positive pions for each target.

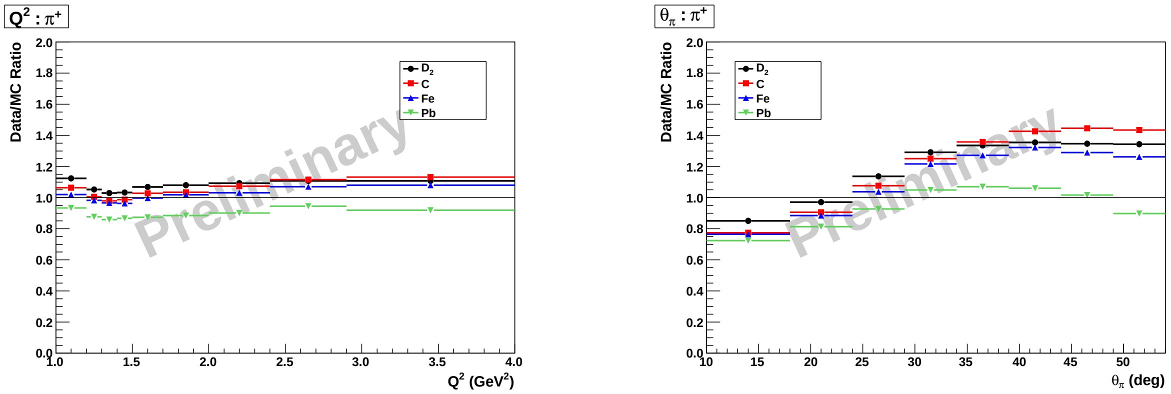

Figure 4. Left: The ratio of $d\sigma/dQ^2$ for data to that for simulated events for events with positive pions for each target. Right: The ratio of $d\sigma/d\theta_\pi$ for data to that for simulated events for events with positive pions for each target.

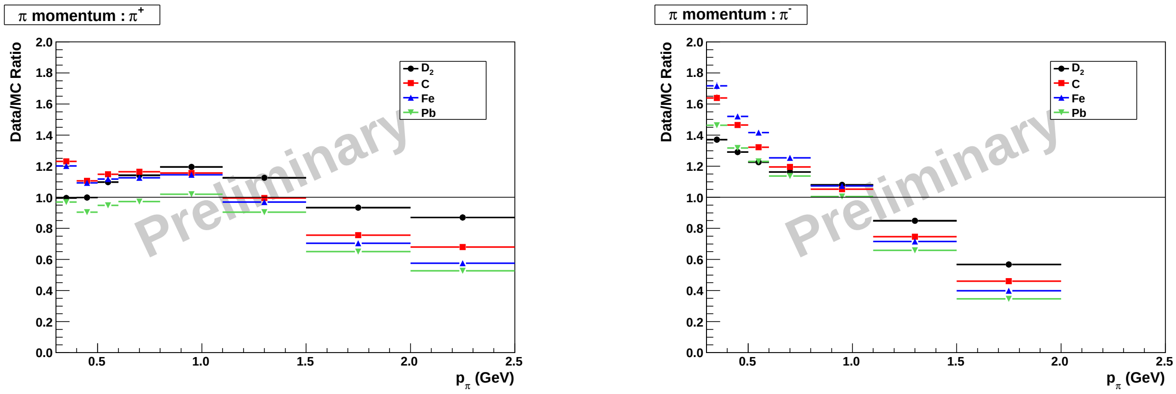

Figure 5. Left: The ratio of $d\sigma/dp_\pi$ for data to that for simulated events for events with positive pions for each target. Right: The ratio of $d\sigma/dp_\pi$ for data to that for simulated events for events with negative pions for each target.