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Exclusive π^- Electroproduction off the Neutron in Deuterium in the Resonance Region

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Abstract. The goal of our research is to provide the exclusive $\gamma^*(n) \rightarrow p^+\pi^-$ reaction cross section from deuterium data using the correction factor that account for the final state re-scattering that can be determined from the data set itself. The "e1e" Jefferson Lab CLAS data set that we analyze includes both a hydrogen and deuterium target run period, which allows a combined analysis of pion electroproduction off the free proton, the bound proton, and the bound neutron under the same experimental conditions. Hence it will provide the experimentally best possible information about the off-shell and final state interaction effects in deuterium, which must be considered in order to extract the neutron information. This data set will provide results with a kinematic coverage for the hadronic invariant mass W up to 1.7 GeV and in the momentum transfer Q^2 range of $0.4 - 1.0$ GeV/c^2. The cross section analysis of this data set is currently underway, which will considerably improve our knowledge of the Q^2 evolution of $\pi^- p$ electroproduction cross sections off bound neutron needed for the extraction of excited neutron state electrocouplings for the first time.

1 Introduction

The nucleon resonance (N^*) studies are crucial to our understanding of the structure and interaction of hadrons, and are poised to push the development of quark models and QCD-based calculations forward. QCD is very successful at large Q^2 within the perturbative regime with current quarks and gauge gluons as the fundamental degree of freedom, however when Q^2 drops down to the non-perturbative regime, there is a transition to completely different degrees of freedom, the dressed quarks and gluons as well as the mesons and nucleons, which requires the development of the based on QCD non-perturbitive approaches [1] for description of the phenomena corresponding to this scale such as the nucleon structure and its excitations. Therefore we need to accumulate sufficient and precise data on meson electroproduction reactions to pin down the distance dependent baryon structure and eventually to shed light on dynamics of non-perturbitive strong interaction from these experimental data. On the experimental side, although the low-lying excited states of the proton have been studied in greater detail, there is still very few data available on neutron excitations [2]. Because of the inherent difficulty in obtaining a free neutron target, a deuterium target is the best alternative.

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2 Preliminary results

2.1 Accounting for the re-scattering in the final state

In order to get to the exclusive $\gamma^* n \rightarrow p\pi^-$ reaction cross section from the deuterium, the final-state-interaction (FSI) correction and the off-shell effect need to be studied well. The correction factor (R) related to the final state re-scattering can be extracted directly from data by using

$$R_{FSI} = \frac{\left(\frac{d\sigma^{quasi-free}}{d\Omega^*_{\pi^-}}\right)}{\left(\frac{d\sigma^{full}}{d\Omega^*_{\pi^-}}\right)}, \tag{1}$$

where the exclusive quasi-free process can be isolated by applying cuts on missing mass square of the spectator proton (m_s^2) and its missing momentum ($|\vec{P_s}|$), and the exclusive full process was obtained from cutting on the missing mass square of the spectator proton only. Figure 1 shows the spectator momentum distribution (black line) from data with the detector-smeared generated proton momentum distribution from the Bonn potential (blue line). For $|\vec{P_s}| < 200\, MeV$, the comparison between the two curves reveals that the quasi-free process is absolutely dominant in this region. When $|\vec{P_s}| > 200\, MeV$, the final state interaction becomes the dominant process. This shows that we can successfully separate the quasi-free process by cutting on $|\vec{P_s}|$ at $200\, MeV$. Preliminary results of R_{FSI} as a function of the polar angle of pion in the Center of Mass (CM) frame (θ^*_π) are shown in Fig. 2.

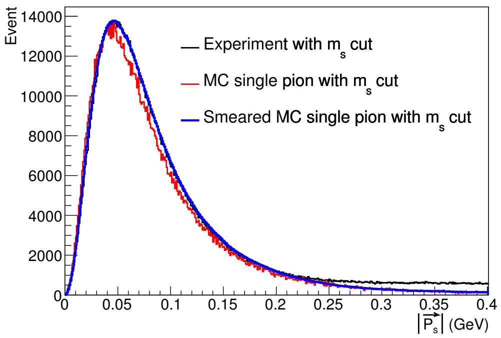

Figure 1. (Color online) The black line represents the missing momentum distribution of the unmeasured proton from data. Based on Bonn potential, the Monte Carlo simulated proton momentum distribution leads to the red line and the detector-smeared simulated distribution to the blue line.

2.2 Cross section

After particles identification, fiducial cuts, and the exclusive quasi-free event selection, the cross section for the quasi-free exclusive $\gamma^*(n) \rightarrow p^+\pi^-$ reaction with unpolarized electron beam and unpolarized deuteron target is given by

$$\frac{d^4\sigma}{dWdQ^2d\Omega_{\pi^*_-}} = \Gamma_\upsilon \frac{d\sigma}{d\Omega^*_{\pi^-}}, \tag{2}$$

where Γ_υ is the virtual photon flux defined by Eq. (3), in which ϵ is the transverse polarization of the virtual photon, $\nu = E_{beam} - E_{scattered\ electron}$, and θ_e is the scattering angle of electron in the lab frame.

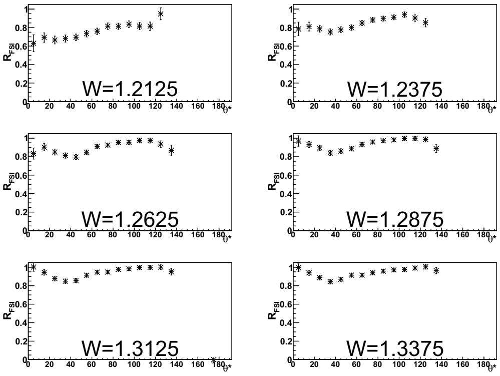

Figure 2. The FSI correction factor R_{FSI} as a function of (θ_π^*) is represented by the stars for different W bins at $Q^2 = 0.7\,GeV$.

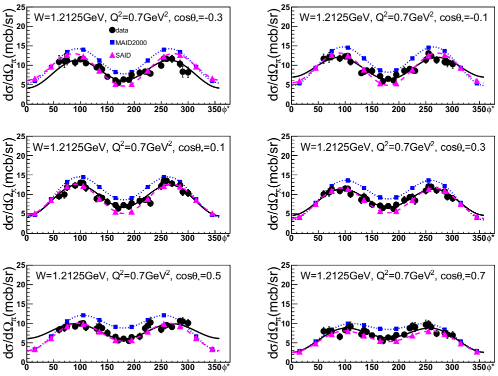

Figure 3. (Color online) A typical example of the CM frame $\phi_{\pi^-}^*$ dependent cross section for different $cos\theta_\pi^*$ values at $Q^2 = 0.7\,GeV$ and $W = 1.212\,GeV$ in comparison to MAID2000 (blue dotted line) and SAID (purple dashed line) predictions. Black solid line is the fit to extract structure functions.

$$\Gamma_\upsilon = \frac{\alpha}{4\pi}\frac{1}{E_{beam}^2 M_n^2}\frac{W(W^2 - M_n^2)}{(1-\epsilon)Q^2},\ \epsilon = (1 + 2(1 + \frac{\nu^2}{Q^2})tan^2\frac{\theta_e}{2})^{-1} \tag{3}$$

Finally, quasi-free differential pion electroproduction cross section, after the final state rescattering was taken off, is given by

$$\frac{d\sigma}{d\Omega_{\pi^-}^*} = \frac{1}{\Gamma_\upsilon}\frac{1}{R_{FSI}}\frac{d^4\sigma}{dWdQ^2d\Omega_{\pi^*_-}}. \tag{4}$$

Figure 3 shows the CM frame $\phi_{\pi^-}^*$ dependent differential cross section in the Δ resonance region as a typical subset of the available data. We also compare the cross section with two physics models SAID [4] and MAID2000 [3].

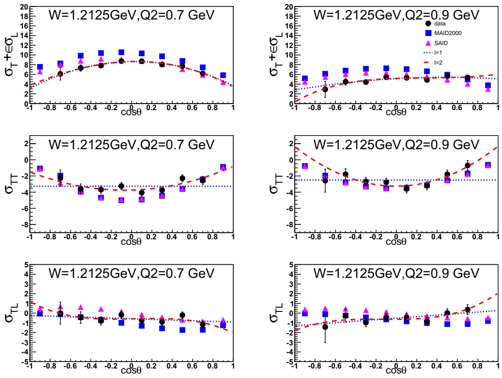

Figure 4. (Color online) $\sigma_T + \epsilon\sigma_L$, σ_{TT}, and σ_{TL} in the Δ resonance region for different Q^2 bins corresponding to top, middle, and bottom row (black points), which are compared to MAID2000 (blue squares) and SAID (purple triangles) predictions. The blue dotted and red dashed lines are Legendre polynomial fits to the black points for $l = 1$ and $l = 2$, respectively.

2.3 Structure function

The hadronic cross section $\frac{d\sigma}{d\Omega^*_{\pi^-}}$ is fit in terms of $cos\phi^*$ (Eq. (5)) to extract the structure function. The fitting function has three fit parameters a,b, and c, which corresponds to structure functions $\sigma_T + \epsilon\sigma_L$, σ_{TT}, and σ_{TL}, respectively.

$$\frac{d\sigma}{d\Omega^*_{\pi^-}} = a + b\cos 2\phi^* + c\cos\phi^*,\ a = \sigma_T + \epsilon\sigma_L,\ b = \epsilon\sigma_{TT},\ c = \sqrt{2\epsilon(1+\epsilon)}\sigma_{TL} \tag{5}$$

An example of typical structure functions as a function of $cos\theta^*_\pi$ for $Q^2 = 0.7\,GeV$ and $0.9\,GeV$ at $W = 1.212GeV$ are shown in Fig. 4 in comparison to SAID [3] and MAID2000 [2] models . In order to gain some insight on the dominant partial wave contribution in this particular resonance region, we also perform a Legendre polynomial expansion of the structure functions up to $l = 2$, see Fig. 4.

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