# Measurement of cross sections of $p(e,e'\pi^+)n$ for near pion threshold and high-lying resonances at high $Q^2$

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**Abstract.** During the last decade, remarkable experimental data have been collacted in an extensive programs to study the excitation of nucleon resonance ($N^*$) at Jefferson Laboratory through pion-electroproduction using polarized electron beam and unpolarized proton target. The CEBAF Large Acceptance Spectrometer (CLAS) is well suited for the study of a broad range of kinematics in the invariant mass $W$ and photon virtuality $Q^2$ with nearly complete angular coverage for the hadronic decays. Electron scattering allows us to probe the effective degrees of freedom in excited nucleon states from meson-baryon to dressed quarks in terms of varying the distance scale. The study of nucleon structure allows us to understand these effective degrees of freedom. In this proceeding, I present preliminary cross sections for single pion production in mass range of high-lying resonances as well as near the pion threshold. Analysis of $N\pi^+$ cross sections together with $N\pi^0$ and $N\pi\pi$ exclusive electroproduction data, will allow us for the first time to determine electrocouplings of several high-lying excited proton states ($W \geq 1.6$ GeV) at photon virtualities that correspond to the transition toward the dominance of quark degrees of freedom. I also present preliminary result on the $E_{0+}$ multipole near pion threshold at 2.0 GeV$^2 \leq$ Q$^2 \leq$ 4.5 GeV$^2$ using exclusive $N\pi^+$ electroproduction data.

**Keywords:** cross section, exclusive pion electro-production, near pion threshold, high-lying resonances, high $Q^2$

## INTRODUCTION

Thanks to the remarkable CLAS experimental data collected during the past decade, new insights into nucleon structures have been obtained from studies of the $N^*$ states $P_{11}(1440)$, $D_{13}(1520)$, and $S_{11}(1535)$ [1]- [3]. However, the $SU(6)$x$O(3)$ scheme still predicts many well-known resonances with four star rating in the high mass region. There is also a big gap between the dressed quark regime and the perturbative QCD domain. In order to establish a better understanding of the connection between the two regimes at high $Q^2$, it is important to measure basic observables, such as cross section or asymmetry not only for the excited resonance but also for near pion threshold region. Recently, the light cone sum rule (LCSR) has been used to predict the axial form factor near pion threshold at high $Q^2$, to also interpret the $Q^2$ evolution of the $S_{11}(1535)$ resonance for both the transverse ($A_{1/2}$) and longitudinal ($S_{1/2}$) helicity amplitudes. This approach is an extension of the standard QCD sum rule [4]. At high $Q^2$, the LCSR approach allows us to understand the smooth transition between Low Energy Theorem (LET) and perturbative QCD (pQCD) near pion production threshold. Measurements of the generalized form factors near-threshold and of the resonance transition form factors at high $Q^2$ allow us to probe the internal structure of the excited state knowing the structure of the ground state. The various current resonance models predict not only different excitation spectra but also different $Q^2$ dependences of transition form factors. The mapping of the transition form factors for high-lying resonances and of the generalized form factor near-threshold will help us to better understand the underlying quark or hadronic structures [5]. With new data on $\pi^0$, $\pi^+$, $2\pi$, and $\eta$ electro-production, combined with the large coverage in $Q^2$, $W$, and center-of-mass angles, the study of nucleon resonances will become even more powerful tool in the exploration of nucleon structure in the domain of strong QCD and confinement.

In this proceeding, I present preliminary cross section for $p(e,e'\pi^+)n$ in two totally different kinematic domains, near-threshold (1.10 GeV $\leq$ W $\leq$ 1.15 GeV) and the high-mass regions ($W > 1.6$ GeV), for 2.0 GeV$^2 \leq$ Q$^2 \leq$ 4.5 GeV$^2$. These measurements have been performed by utilizing the CLAS in Hall-B. CLAS is a large acceptance instrument with sufficient resolution to measure the exclusive electro-production of mesons with nearly complete coverage in the center-of-mass angles, that allows for a detailed study of the excitation of nucleon resonances. The measurement of the cross sections in both kinematic regions provides useful information towards a better understanding of the transition between the validity of the constituent quarks and the pQCD regime where theoretical interpretations, within the LCSR are possible.

## RESULTS

The particle identification (PID) and kinematic corrections are applied for two entire kinematical region. The CLAS electron identification at the trigger level is done by requiring a minimum amount of energy in the electromagnetic calorimeter (EC) in coincidence with a signal in the Čerenkov counter (CC). Pions ($\pi^+$) are identified by a coincidence of drift chamber (DC) and time-of-flight counter (TOF). We made proper geometrical fiducial cuts, which were applied to both simulation and experimental data, these cuts are applied to select areas of uniform detector response that can be reproduced by simulation (GSIM) [6]. Under the one-photon-exchange approximation, the single pion electroproduction cross section factorizes,

$$\begin{aligned}\frac{k_\gamma^*}{p_\pi^*}\frac{d^2\sigma}{d\Omega} &= \sigma_T + \varepsilon\sigma_L + \varepsilon\sigma_{TT}\sin^2\theta_\pi^*\cos 2\phi_\pi^* + \frac{1}{\sqrt{2\varepsilon(1+\varepsilon)}}\sigma_{LT}\sin\theta_\pi^*\cos\phi_\pi^* \\ &+ h\frac{1}{\sqrt{2\varepsilon(1-\varepsilon)}}\sigma_{LT'}\sin\theta_\pi^*\sin\phi_\pi^* \,, \end{aligned} \quad (1)$$

where $p_\pi^*$, $\theta_\pi^*$ are the $\pi^+$ momentum and polar angle in the center-of-mass frame. $\phi_\pi^*$ is the azimuthal rotation of the $n\pi^+$ plane with respect to the electron scattering plane $(e,e')$, $h$ is the electron beam helicity, $k_\gamma^*$ is the equivalent photon energy, and $\varepsilon$ is the virtual photon polarization.

The Figure 1 (left) shows an example of preliminary cross sections as a function of $\phi_\pi^*$ at $W = 1.11$ GeV, $Q^2 = 2.05$ GeV$^2$, and cos $\theta_\pi^* = -0.1$. The cross section is compared with various models, such as Dubna-Mainz-Taipei (DMT), MAID2003 and Sato-Lee2004, which are black, blue dashed, and red dashed-dot lines, respectively. The

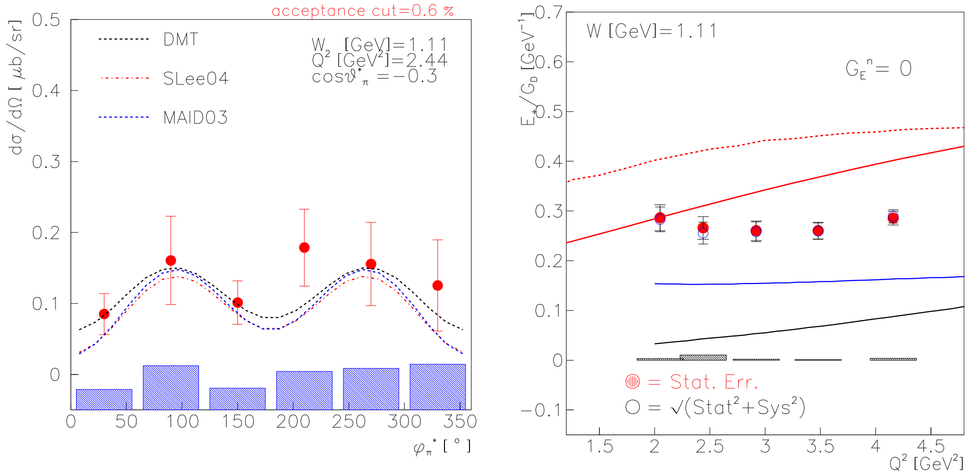


**FIGURE 1.** (Color online) An example of the preliminary $d\sigma/d\Omega$ [7] at $W = 1.11$ GeV, $Q^2 = 2.05$ GeV$^2$, cos $\theta^*_\pi = -0.1$ (left) and the extraction of the $E_{0+}$ multipole divided by dipole form factor ($G_D$) as function of $Q^2$ (right). The error bars of the data include only statistical errors and the shaded bars show the systematic uncertainties.

extraction of the $E_{0+}$ multipole divided by dipole form factor ($G_D$) as a function of $Q^2$ is shown in Fig. 1 (right) as well. Various models are presented, blue solid line: MAID2007 [8] for $E_{0+}/G_D$, black solid line: MAID2007 for $L_{0+}/G_D$, and red solid is the LCSR calculation using experimental electromagnetic form factors as input (red dash is pure LCSR).

Figure 2 shows examples of the preliminary differential cross sections at $W = 1.7$ GeV, $Q^2 = 2.6$ GeV$^2$. The fit of $\phi^*_\pi$-dependent cross sections allows us to obtain the structure functions. The fit function for $\frac{d\sigma}{d\Omega_\pi}$ has three parameters, $\frac{d\sigma}{d\Omega_\pi} = P_1 + P_2 \cos\phi^*_\pi + P_3 \cos 2\phi^*_\pi$, which corresponds to the structure functions $P_1 = \sigma_{T+L}$, $P_2 = \sigma_{LT}$ and $P_3 = \sigma_{TT}$, respectively. Figure 3 shows an example in comparison with published data [6] and existing physics models for high $W$. Left plot shows the $W$-dependent cross sections from both previous published data (red) and preliminary data (blue) at $Q^2 = 1.8$ GeV$^2$, $\phi^*_\pi = 112.5°$. The plot on the right side shows the $\phi^*_\pi$- dependent cross section comparison with models and previous data. Overall, the preliminary cross sections from thi new analysis for high $W > 1.6$ GeV are reasonably consistent with published data after taking $10\% - 20\%$ systematic uncertainty into account. However, most of existing physics models do not support any of the results high $W$.

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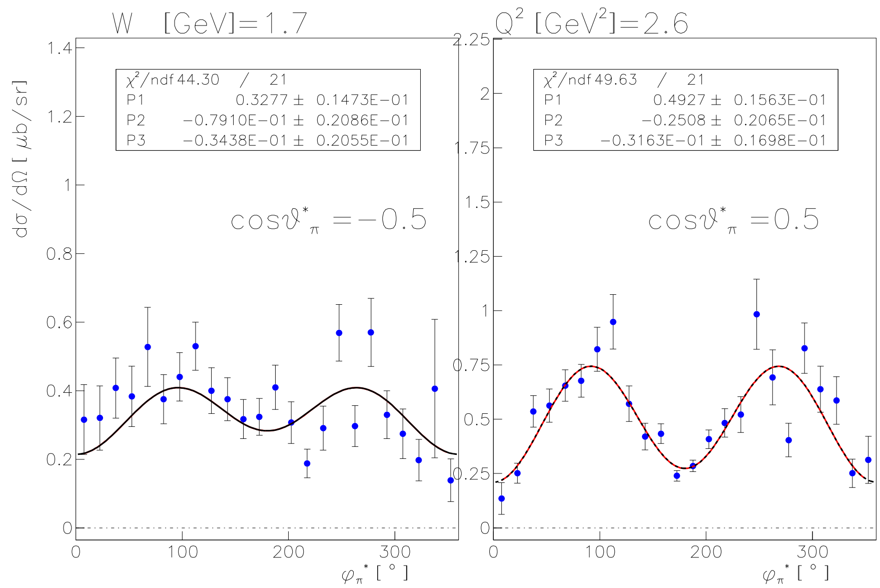


**FIGURE 2.** (Color online) An example of the preliminary $d\sigma/d\Omega$ at $W = 1.7$ GeV, $Q^2 = 2.6$ GeV$^2$, cos $\theta^*_\pi = -0.5$, and 0.5. The error bars of the data include only statistical errors.

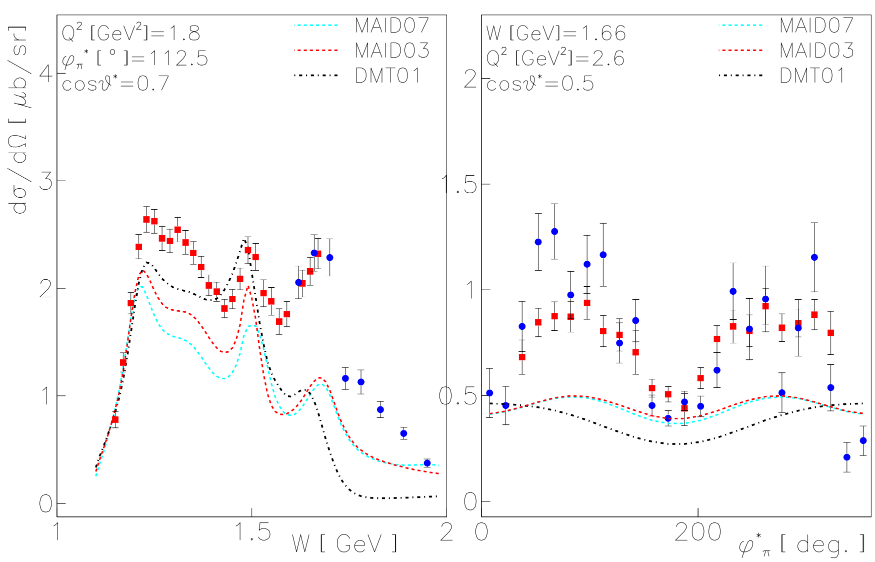


**FIGURE 3.** (Color online) Comparisons of the preliminary cross sections $d\sigma/d\Omega$ (blue bullets) with published CLAS data [6] (red bullets) and various present physics models. The error bars of the data include only statistical errors.


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