Exclusive electroproduction of the $\rho^+$ meson on the proton 
@ CLAS

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Abstract

We present preliminary results of the exclusive electroproduction of $\rho^+$ on the proton at CLAS. We discuss the interpretation of the cross sections in terms of $t$-channel Reggeon exchanges and in terms of Generalized Parton Distributions (GPDs) formalism.

Keywords: Nucleon structure; Exclusive vector meson electroproduction; Generalized Parton Distribution

1 Introduction

The exclusive electroproduction of mesons on the nucleon is an important tool to better understand the nucleon structure and, more generally, the transition between the low energy hadronic and high energy partonic domains of the Quantum Chromodynamics (QCD) theory. The CEBAF (“Continuous Electron Beam Accelerator Facility”) of the Jefferson Laboratory (JLab) at Newport News (USA) with its high intensity electron beam and its large acceptance spectrometer CLAS [1] (CEBAF Large Acceptance Spectrometer) offers a great opportunity to study the exclusive electroproduction of mesons, in particular those that have multi-particle decays.

This proceeding presents some first results for the exclusive electroproduction of the vector mesons $\rho^+$ on the proton at CLAS. These results come from the e1-dvcs experiment: the data were collected between March and May 2005 with a beam energy of 5.75 GeV and an integrated luminosity of $\sim 40$ fb$^{-1}$. It is the first ever measurement of cross section for the $\rho^+$ electroproduction channel. The presented results are still preliminary and more details can be found in ref. [2].

2 Data analysis

The final state that is analyzed is $e p \rightarrow en\pi^+\pi^0$. The final state particles $e$, $\pi^+$ and $\pi^0$ were detected in CLAS and the exclusive process was identified by selecting a neutron with the missing mass technique. Figure 1 shows the acceptance-corrected invariant mass $M_{\pi^+\pi^0}$ distributions for each $(Q^2, x_B)$ bin. One sees clearly the $\rho^+$ peaks around 775 MeV. They are, however, sitting on top of a non-negligeable two-pion background. We have used two contributions to fit these spectra: a skewed Breit-Wigner distribution to describe the resonant structure of the $\rho^+$ and a parametrization of the non-resonant two-pion continuum determined from simulations (mostly $e p \rightarrow en\pi^+\pi^0$ phase space). In order to extract the total cross section of the reaction $\gamma^* p \rightarrow n\rho^+$, we have calculated for each $(Q^2, x_B)$ bin the area of the Breit-Wigner (green curve in Fig. 1), the distributions being already normalized and corrected for the acceptance. A separation of the longitudinal cross sections from the transverse ones was performed by analysing the pion decay angles of the $\rho^+$ and relying on the SCHC (s-channel helicity conservation), which was checked experimentally.
Figure 1: $M_{\pi^+\pi^0}$ acceptance-corrected distributions, showing fits for the background subtraction. In black: experimental data; in green: Breit-Wigner of $\rho^+$; in purple: $M_{\pi^+\pi^0}$ projection of the non-resonant continuum $\gamma^* p \rightarrow n\pi^+\pi^0$ reaction; in red: total fit result. In this proceeding, units are arbitrary for the vertical scale.

3 Interpretation

We will compare in the following the extracted cross sections of the exclusive electroproduction of the $\rho^+$ with two theoretical approaches: on the one hand, the hadronic approach based on Regge theory and meson trajectory exchanges in the $t$-channel and on the other hand, the partonic approach based on the handbag diagram and GPDs. These two approaches are illustrated in Fig. 2. This comparison will be useful in order to better understand the domain of validity of these two approaches and constrain their inputs.

3.1 The Regge “hadronic” approach

The Regge approach is most appropriate at low $Q^2$ above the resonance region and at forward angles (where the cross section is largest). It consists of exchanges of meson “trajectories” in the $t$-channel. In the following, we will use the “JML” acronym to refer to the specific model developed by J.-M. Laget [3].

For the $\rho^+$ channel, the exchange trajectories are those of the $\pi^+$ and of the $\rho^+$. The free parameters in this model are the coupling constants at the hadronic vertices (most of them being well constrained) and the mass scales of the electromagnetic form factors.

Figure 3 shows the total cross section $\sigma(\gamma^* p \rightarrow n\rho^+)$ as a function of $W$ for fixed $Q^2$ compared with the JML calculation shown with the red curve. The JML model can successfully reproduce the cross sections for almost all of our $(Q^2, W)$ range. The decreasing cross section with $W$ can be explained in the Regge theory by an intercept ($\alpha(0) = 0.5$) of the $\rho^+$ trajectory which is dominant: $\sigma_{TOT} \propto s^{\alpha(0)-1}$. 

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Figure 2: Schematic representations of the Reggeon $t$-channel exchange (left) and of the handbag diagram (right) for exclusive vector meson electroproduction.

Figure 3: PRELIMINARY total cross section as a function of $W$ at fixed $Q^2$, for the reaction $\gamma^* p \rightarrow n \rho^+$. The red curves are the result of the JML model. Units are arbitrary on the y axis as the results are still preliminary.

3.2 The GPD “partonic” approach

The formalism of GPDs is valid in the so-called Bjorken regime, i.e. $Q^2, \nu \rightarrow \infty$ with $x_B = \frac{Q^2}{2 M \nu}$ finite. It was proven [4] that the dominant process for exclusive meson electroproduction, in the Bjorken limit, is given by the so-called handbag diagram represented in Fig. 2. The handbag diagram is based on the notion of factorization in leading-order/leading-twist pQCD between a hard scattering process, exactly calculable in pQCD, and a nonperturbative nucleon structure part that is parametrized by the GPDs.
For mesons, the factorization of the handbag diagram is only valid for the longitudinal part of the cross section. In the following we discuss the two particular GK [5] and VGG [6] GPD-based calculations that provide quantitative results for the longitudinal part of the exclusive meson cross sections.

Figure 4 shows longitudinal cross section of $\gamma^* p \to n \rho^+$ as a function of $W$ and for fixed $Q^2$. The results of the calculations of the GK and VGG model are shown, respectively, with the red and the blue curves. We see that both models fail to reproduce the data. This discrepancy can reach an order of magnitude at the lowest $W$ values. The trend of these particular GPD calculations is to decrease as $W$ decreases, whereas the data increase. The same behavior was observed, in the low $W$ region, for the exclusive electroproduction of the $\rho^0$ [7].

One can conclude that either the GPD formalism is not valid for our $Q^2$ coverage (due to important higher twist contributions for instance) or there is a fundamental contribution, which is missing in the way the GPDs are parametrized in the GK and VGG models.

3.3 Comparison of the $t$ slope for the $\rho^+$, $\rho^0$, $\omega$ and $\phi$ channels

The CLAS collaboration has measured the largest ever set of data for the exclusive electroproduction on the proton of the vector mesons $\rho^0$ [7], $\omega$ [8] and $\phi$ [9].

Figure 5 shows the slope of the differential cross section $d\sigma/dt$ for the $\rho^+$, $\rho^0$, $\omega$ and $\phi$ channels as a function of $W$ (in the top part) and as a function of $Q^2$ (in the bottom part). One can see the same
trends of this slope, $b$, for all mesons channels, which can be interpreted in simple and intuitive terms in the following way:

- $b$ increases with $W$: the size of the nucleon increases as one probes the high $W$ values (i.e. the sea quarks), which could mean that the sea quarks tend to extend to the periphery of the nucleon.
- $b$ decreases with $Q^2$: as we go to large $Q^2$, the resolution of the probe increases and we tend to see smaller and smaller objects.

Figure 5: The slope $b$ as a function of $W$ (on the top) and as a function of $Q^2$ (on the bottom) for the $\rho^0$, $\omega$, $\phi$ and $\rho^+$ channels.

4 Summary

We have presented (preliminary) first ever measurement of cross sections for the exclusive electroproduction of $\rho^+$ on the proton using the CLAS detector at JLab. These cross sections can be interpreted with two approaches:

- hadronic approach: the JML model describes well most of the features of the $\rho^+$ cross sections up to $Q^2 \sim 4.5$ GeV$^2$.
- partonic approach: GPD models fail to describe longitudinal $\rho^+$ cross sections especially for low $W$.

We also found the same trends of the variation of the $t$ slope as a function of $W$ and as a function of $Q^2$ for all $\rho^+$, $\rho^0$, $\omega$ and $\phi$ channels.
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