Nucleon Resonance Electrocouplings from the CLAS Data on Exclusive Meson Electroproduction off Protons

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$\gamma_v NN^*$ transition helicity amplitudes (electrocouplings) of several prominent excited proton states are determined for the first time in independent analyses of $\pi^+ n$, $\pi^0 p$, and $\pi^+\pi^- p$ electroproduction off protons. Analysis of $\pi^+\pi^- p$ electroproduction has extended considerably information on electrocouplings of high lying N* states, which decay preferentially to the $N\pi\pi$ final states.

1 Introduction

The studies of nucleon resonance structure from the data on different exclusive meson electroproduction channels off nucleons represent an important direction in the N^* program with the CLAS detector with the primary objective of determining electrocouplings of all prominent excited proton states in a wide area of photon virtualities Q^2<5.0 GeV^2 [1]. In this paper we present the results on N^* electrocouplings obtained in independent analysis of $\pi^0 p$, $\pi^+ n$, and $\pi^+\pi^- p$ electroproduction off protons.

2 Evaluation of N^* electrocouplings from exclusive meson electroproduction data

The $\pi^+ n$, $\pi^0 p$, and $\pi^+\pi^- p$ exclusive channels are major contributors to meson electroproduction off protons in N^* excitation region. They are sensitive to N^* contributions and account for $\approx$ 90% of meson electroproduction cross section. Non-resonant contributions in these channels are different, while N^* electrocouplings remain the same, since resonance electroproduction and hadronic decay amplitudes are independent. Therefore, consistent values of N^* electrocouplings determined from different major meson electroproduction channels strongly support a reliable extraction of these fundamental quantities.

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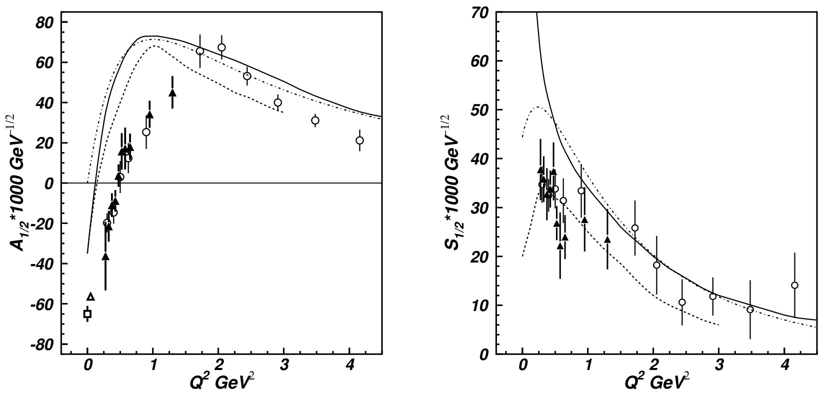

Figure 1: Electrocouplings of the $P_{11}(1440)$ resonance determined in independent analyses of the CLAS data on $N\pi$ (circles) and $\pi^+\pi^-p$ (triangles) electroproduction off protons. Square and triangle at Q^2=0 correspond to RPP [8] and the CLAS $N\pi$ [9] photoproduction results, respectively. The results of relativistic light-front quark models [10,11] are shown by solid and dashed lines, respectively. Results of the covariant valence quark-spectator diquark model [12] are shown by the dashed dotted line.

The CLAS data considerably extended information on π^+n, π^0p electroproduction off protons. A total of nearly 120000 data points on unpolarized differential cross sections, longitudinally polarized beam asymmetries, and longitudinal target and beam-target asymmetries were obtained with almost complete coverage of the accessible phase space [2]. The data were analyzed within the framework of two conceptually different approaches: a) the unitary isobar model (UIM) and b) a model, employing dispersion relations [3,4]. The two approaches provide good description of the $N\pi$ data in the entire range covered by the CLAS measurements: $W < 1.7$ GeV and $Q^2 < 5.0$ GeV^2, resulting in χ^2/d.p. < 2.0.

Nine independent one-fold-differential and fully-integrated $\pi^+\pi^-p$ electroproduction cross sections of protons are determined from the CLAS measurements [5,6] in 131 bins of W and Q^2 in a mass range $W < 2.0$ GeV, and with photon virtualities of $0.25 < Q^2 < 1.5$ GeV^2. Analysis of these data within framework of the meson-baryon JM reaction model [7,14] allowed us to establish all essential contributing mechanisms from their manifestation in the measured cross sections. Reasonable data description makes it possible to provide a reliable separation between resonant and non-resonant contributions needed for extraction of N^* electrocouplings from $\pi^+\pi^-p$ electroproduction data.

3 Results and discussion

Electrocouplings of the $P_{11}(1440)$, $D_{13}(1520)$ states have become available from independent analyses of the CLAS data on π^+n, π^0p ($Q^2 < 5.0$ GeV^2), and $\pi^+\pi^-p$ ($Q^2 < 1.5$ GeV^2)

electroproduction channels [2,14]. Their values obtained from these major meson electroproduction channels with different non-resonant mechanisms are in a good agreement. As an example, electrocouplings of the $P_{11}(1440)$ state are shown in Fig. 1. Consistent results on N^* electrocouplings demonstrate that the reaction models [4,7,10] mentioned in the Section 2 provide reliable evaluation of these fundamental quantities. It makes possible to determine electrocouplings of all resonances that decay preferentially to the either $N\pi$ or $N\pi\pi$ final states analyzing independently the $N\pi$ or $\pi^+\pi^-p$ electroproduction channels.

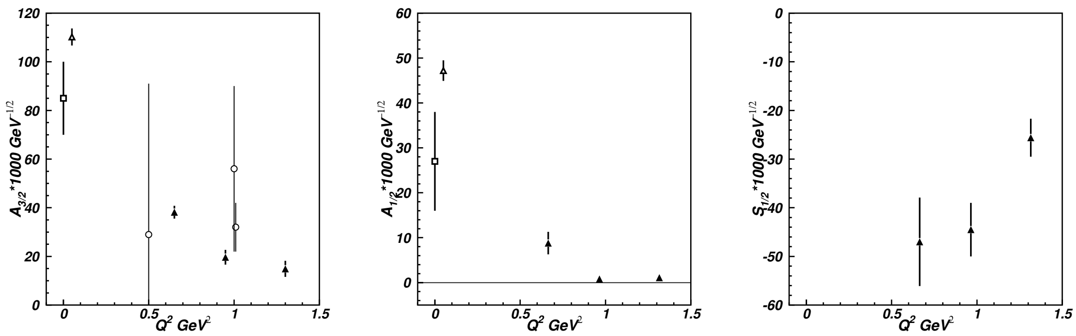

Figure 2: Electrocouplings of $D_{33}(1700)$ (left) and $S_{31}(1620)$ (middle and right) resonances from analyses of the CLAS data on $\pi^+\pi^-p$ [5,6] and world data [15] on $N\pi$ electroproduction off protons. Symbols are the same as in Fig. 1.

Preliminary results on electrocouplings of $S_{31}(1620)$, $S_{11}(1650)$, $F_{15}(1685)$, $D_{33}(1700)$ and $P_{13}(1720)$ states were obtained from the CLAS $\pi^+\pi^-p$ electroproduction data [5]. The CLAS results provide accurate data on the Q^2-evolution of the transverse electrocouplings and the first information on the longitudinal electrocouplings of all the above mentioned excited proton states. Several examples are shown in Fig. 2. A dominance of longitudinal $S_{1/2}$ electrocoupling is observed in electroexcitation of $S_{31}(1620)$ state at $Q^2 > 0.5$ GeV^2 (see Fig. 2).

The CLAS results on electrocouplings of prominent resonances stimulated the development of N^* structure models [16, 17]. The analysis of resonance electrocouplings within the framework of light front [10,11] and quark-spectator diquark [12] models, complemented by the coupled channel approach [13] demonstrate that the structure of N^* states in a mass range $W < 1.6$ GeV is determined by a combined contribution of an internal core of three dressed quarks and an external meson-baryon cloud. The recent studies in the light-front quark model [18] revealed an important role of dynamical mass and structure of dressed quarks in Q^2-evolution of of N^* electrocouplings. Furthermore, two conceptually different approaches of QCD-Dyson-Schwinger equations [19,20] and Lattice QCD [21–23]-are making progress toward the description of N^* electrocouplings from the first principles of QCD.

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