Phenomenological studies of double charged pion electroproduction from the CLAS data.

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Abstract. Recent results from phenomenological studies of the CLAS data on $2\pi$ electroproduction off proton are presented. The analysis is focused on extracting the $N \rightarrow N^*$ electromagnetic transition amplitudes from the full data set on unpolarized 1-differential $2\pi$ cross-sections.

1. Introduction
The data from $\gamma p \rightarrow \pi^-\pi^+ p$ exclusive processes play an important role in studies of nucleon resonances with the CLAS detector \[1\]. Single and double pion channels combined account for major part of the total cross-section in the $N^*$ excitation region. These two channels offer complementary information on $N^*$'s. The single pion channel is mostly sensitive to resonances with masses less than 1.6 GeV, while many high lying states preferably decay with $2\pi$ emission. The studies of $2\pi$ electroproduction with CLAS for the first time provided the electrocouplings of high lying nucleon states \[2, 3\]. Moreover, $1\pi$ and $2\pi$ channels are strongly coupled by final state interactions (FSI). Therefore, data on $2\pi$ electroproduction are critical for $N^*$ studies in the combined analysis of major exclusive channels within the framework of coupled channel approaches. The most advanced coupled channel analysis, incorporating rigorous treatment of FSI in the 3-body $\pi\pi N$ final states was proposed recently \[4\].

For the first time a complete set of unpolarized single-differential cross sections was measured \[5, 6\]. Phenomenological analysis of these data open up the opportunity to establish the major contributing mechanisms and to determine the evolution of $N^*$ electrocouplings in a wide range of photon virtualities.

2. Two-pion electroproduction mechanisms from phenomenological analysis.
We have developed a phenomenological model, that incorporates particular meson-baryon mechanisms based on their manifestations in observables: as enhancements in invariant mass distributions, sharp forward/backward slopes in angular distributions. Analysis of earlier CLAS data \[5\] incorporated particular meson-baryon mechanisms needed to describe $\pi^+ p$, $\pi^+\pi^-$, $\pi^- p$ invariant masses and $\pi^-$ angular distribution. These cross sections were analyzed in the hadronic mass range from 1.41 to 1.89 GeV. The overall $Q^2$-coverage ranges from 0.5 to 1.5 $GeV^2$. In the 2005 version of this analysis approach (JM05) \[2\] double charged pion production was described by the superposition of quasi-two-body channels with the formation and subsequent decay of unstable particles in the intermediate states: $\pi^-\Delta^{++}$, $\pi^+\Delta^0$, $\rho^0 p$, $\pi^+D^{0*}_{13}(1520)$, $\pi^+F^{0*}_{15}(1520)$,
\[ \pi^- P_{33}^{++}(1640). \] Remaining direct \( 2\pi \) production mechanisms without formation of unstable intermediate particles were described by a set of exchange terms with the amplitudes as outlined in [8]. Implementation of exchange terms allowed much improved description of the \( \pi^- \) angular distributions [10].

The production amplitudes for the first three quasi-two-body intermediate states were treated as sums of \( N^* \) excitations in the \( s \)-channel and non-resonant mechanisms described in Refs [2, 7]. All well established 4 star resonances with observed decays to the two pion final states were included as well as the 3-star states \( D_{13}(1700), P_{11}(1710), P_{33}(1600), \) and \( P_{33}(1920). \)

The production amplitudes for the \( \pi^+ D_{13}^{0}(1520), \pi^+ F_{15}^{0}(1520), \pi^- P_{33}^{++}(1640) \) intermediate state were treated as non-resonant contributions only. Their parametrization is described in [2, 10].

In the JM05 approach we succeeded in describing all beforementioned observables in the CLAS data [5]. These results are presented in [10].

### 3. Global analysis of unpolarized cross-sections in \( 2\pi \) electroproduction

In the analysis of preliminary CLAS \( 2\pi \) data at \( W < 1.6 \) GeV and photon virtualities from 0.2 to 0.6 \( \text{GeV}^2 \) [6] for the first time we attempted to fit contributing mechanisms to the full set of unpolarized single-differential cross-sections. Nine single-differential cross-sections combined were fitted within the framework of JM05 approach in each \( W \) and \( Q^2 \) bin covered by measurements [6]. They consist of all single-differential cross-sections mentioned in previous section and also included \( \pi^+ \) and \( p \) angular distributions and three distributions over angles \( \alpha_{i,j} \) between two planes, composed by momenta of the two pairs of the final hadrons for three combinations amongst these pairs. To provide a better description of \( \pi^+ \) and \( p \) angular distributions, we modified the dynamics of direct \( 2\pi \) production mechanisms with respect to those used in JM05 version. The mechanisms of [8] were substituted by ladder-type double exchange processes, shown in Fig. 1

**Figure 1.** Direct \( 2\pi \) production mechanisms in JM06 model

The amplitude parametrization is presented in [6]. After these modifications we succeeded to describe CLAS data [6] in the entire kinematics covered by the measurements. As a typical example, description of an entire set of single-differential \( 2\pi \) cross-sections within the framework of the JM06 model version is shown in Fig. 2 together with the contributions from various mechanisms of JM06 approach.

The shapes of cross-sections for various contributing mechanisms are substantially different in the observables, but highly correlated by mechanism amplitudes. Therefore, a successful description of all unpolarized single-differential cross-sections allowed us to pin down all major
contributing processes. We found no need for remaining mechanisms of unknown dynamics. To check the reliability of the amplitudes for contributing processes, derived in phenomenological data analysis, we fixed all JM06 parameters, fitting them to six single-differential cross-sections: all invariant masses and three final state angular distributions. The remaining three distributions over $\alpha_{i,j}$’s angles were calculated, keeping JM06 parameters fixed. Reasonable description of $\alpha_{i,j}$’s angular distributions was achieved in the entire kinematics area covered by measurements. Therefore, we confirmed the reliability of $2\pi$ electroproduction mechanisms established in phenomenological data analysis within the framework of JM06 model.

In Fig. 3 we show electrocouplings of $P_{11}(1440)$, $D_{13}(1520)$ states, determined from the analysis of preliminary CLAS data on $2\pi$ electroproduction [6] within the framework of JM06 approach. For the first time we obtained information on $Q^2$-evolution of electrocouplings for these states from $\pi^-\pi^+p$ channel at $Q^2$ from 0.2 to 0.6 $GeV^2$. These photon virtualities are particularly sensitive to the contributions from $N^*$ meson-baryon dressing. Moreover, these data are not contaminated by the contribution from $P_{33}(1232)$ tail. The electrocouplings obtained from this analysis are in reasonable agreement with the results from $1\pi$ exclusive channel [9], as well as from the combined $1\pi/2\pi$ analysis [8].

4. Conclusions

A phenomenological model (JM06) has been developed for the description of $2\pi$ electroproduction in $N^*$ excitation region with the most complete accounting for contributing
Electromagnetic transition form factors for the $P_{11}(1440)$ (left) and $D_{13}(1520)$ (right) states, determined from analysis of CLAS single pion data (squares) and double pion data (open circles). The results from the combined $1\pi/2\pi$ data analysis at $Q^2=0.65\text{ GeV}^2$ are shown by filled circles. The photocouplings from the PDG are shown by black triangles.

Successful description of all unpolarized single-differential cross-sections was achieved at $W<1.6\text{ GeV}$ and at photon virtualities from 0.2 to 0.6 $\text{ GeV}^2$. Electrocouplings of $P_{11}(1440)$, $D_{13}(1520)$ states were derived from the combine fit of all unpolarized observables in $2\pi$ electroproduction.

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