Double Charged Pion Production Model for Studies of N* Structure and Strong Interaction Dynamic in Non-Perturbative Domain.

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Abstract

A phenomenological approach to describe double charged pion production by real and virtual photons at $W < 3.0$ GeV and in Q^2, t range $\sim$ few GeV^2 is presented. The approach is aimed to extract an information about N^* excitations by photons and mechanisms of vector meson production from the analysis of measured cross sections. A comparison between model calculation and world data on double charged pion production is performed along with a first analysis of preliminary data from TJNAF experiments E-93-006 and E-93-031.

1 Introduction

Studies of charged double pion production by real and virtual photons represent an important direction in the investigation of N^* structure and strong interaction dynamic in non–perturbative domain in exclusive photo- and electroproduction channels, now in progress in Hall B at Jefferson Lab [1]. This exclusive channel could provide complementary information with respect to single pion production, like about $P_{11}(1440)$ excitation and form factors of high lying N^*s ($M(N^*) > 1.6$ GeV), which decay mainly into multipion final states. This channel also offers a promising opportunity for "missing" baryon states search, as according to quark model expectations, "missing" N^* also would preferably decay into multipion final states, their electromagnetic couplings being of similar magnitude as for well established N^*s.

Studies of ρ-meson production at $2.6 < W < 2.9$ GeV excitation region would allow to investigate soft and hard mechanism competition in the transition domain, where both meson-baryon degrees of freedom and non-perturbative dressed quark-gluon interactions could contribute.

A particular feature of the charged double pion production channel is the interference of many non-resonant mechanisms giving rise to a sizeable background. This poses serious restrictions on the application of model-independent approaches such as partial-wave analysis to extract an information on N^* form factors. Instead, the information on N^* excitation in this exclusive channel could be extracted in the framework of a model approach relating N^* electromagnetic form factors with measured observables: differential cross sections, asymmetries, etc. In this contribution we present a phenomenological approach to describe charged double pion production by real and virtual photons, currently covering the W region up to $W = 4.0$ GeV and applicable in the Q^2 and t range, where meson-baryon degrees of freedom are still relevant (few GeV^2). Our approach relates N^* electromagnetic helicity amplitudes with measured cross sections as well as parameters of phenomenological mechanisms as Regge trajectory -quark couplings and therefore allows to extract an information on the N^* excitation and different non-resonant mechanism competition from experimental data.

The developed approch also was used to extract from measured double charge pion production cross-section the information about different quosi-two-body channels cross-section (both integrated and t-dependence) as $\gamma p \to \rho p$, $\gamma p \to \pi^- \Delta^{++}$, $\gamma p \to f_2(1270)p$.

2 Model description

The main charged double pion production mechanisms were parametrized at the level of meson-baryon tree diagrams. The reaction amplitude was assumed to be a superposition of $\gamma p \to \pi^- \Delta^{++}$, $\gamma p \to \pi^+ \Delta^0$ and $\gamma p \to \rho p$ quasi-two-body processes with subsequent decay of intermediate Δ and ρ. Above N^* excitation region we also implemented $f_2(1270)$ meson and effective heavy Δ^{++} particle production mechanisms to describe the structures clearly seen in $\pi^+\pi^-$ and $\pi^+ p$ innvariant mass distributions of E-93-031 JLAB experiment. The rest of mechanisms were parametrized as an amplitude $C(W, Q^2)$ representing a function of W and Q^2 to be determined from the data fit in each W–Q^2 bin. The quasi-two-body amplitudes were estimated in Breit-Wigner ansatz as product of unstable particle $(\Delta^{++}, \Delta^0, \rho, f_2(1270))$ production amplitude and their's decay [2,3]. The decay amplitudes for Δ and ρ were calculated from the effective Lagrangians [3] with mass-dependent form factors taken from ref. [4]. The model for evaluation of unstable particle (Δ, ρ) production amplitudes is described in details in ref. [5,6]. Here we present only the main ingredients.

The quasi-two-body amplitudes were treated as a superposition of N^* excitations and non-resonant mechanisms. N^* excitation was estimated in Breit-Wigner ansatz, where N^* decay amplitudes to $\pi\Delta$ and ρp final state in resonant point were taken from the analysis of [7]. To first make realistic predictions of the resonant content, we took PDG values [8] for real photons and a Single Quark Transition Model (SQTM) fit [9] for virtual photons as a starting point to describe N^*'s electromagnetic excitation. From the other hand these values could be considered as free parameters to be extracted from data fit. Non-resonant processes for $\gamma p \to \rho p$ sub-channel were described in the frame of diffractive vector dominance model ref [10]. For $W > 2.0$ GeV we described non-resonant ρ-production as superposition of Pomeron and f2 Regge trajectory exchange in the t-channel and nucleon Regge trajectory exchange in the u-channel, following the approach presented in [12]. Quark-reggeon couplings were considered as free parameters to be extracted from the data fit. Non-resonant contributions for $\gamma p \to \pi^- \Delta^{++}$, channel were described by a superposition of Born terms initially proposed in [11]. To treat photon and pion off-shell behavior we implemented in the pion-exchange amplitude an electromagnetic pion form factor taken from ref. [13] and a $\pi N \Delta$ vertex function obtained in NN scattering analysis [14]. We substituted the pion propagator in the pion-in-flight term by a pion Regge trajectory as proposed in ref. [15].

We developed a specific approach to describe the interaction with open inelastic channel in the initial and final states [5] for the $\pi\Delta$ channel: ISI and FSI effects were treated as a partial absorption of incoming γp and outgoing $\pi^- \Delta^{++}$ particles; the penetration (absorption) coefficients were related with elastic ρp and $\pi\Delta$ scattering amplitudes, estimated in the frame of an isobar model [16] based on world data on πN scattering.

The model provides good description of the world data available on double charge pion production at kinematical range of our interest. The reasonable reproduction of invariant mass angular distributions as well as W and Q^2 dependences both for complete double charge pion production cross-sections and cross-sections for the quasi-two-body channels mentioned above is achieved. As an example in Fig. 1 we present a comparison of our model description and the data [17] on W-dependence of $\gamma p \to \pi^+\pi^- p$ integrated cross-sections for real photons.

3 Preliminary TJNAF data analysis

We used our model for analysis of E-93-006 JLAB experiment data on double charge pion production by real photons at W between 2.6-2.9 GeV and at $-t < 5.0$ GeV^2, presented on Adelaide-2000 Conference by Dr. M.Battaglieri. The developed approach was explored for the extraction of $\gamma p \to \rho p$ quasi-two-body channel cross-section t-dependence from the data on $(\pi^+\pi^-)$, $(\pi^+ p)$ invariant mass distributions collected in different t-bins. Reggeon quark couplings were free parameters to be determined from a simultaneous fit of $\pi^+\pi^-$ and $\pi^+ p$ invariant mass distributions in the set of different t-bins. We also applied a multiplicative factor for the overall N^* resonant amplitude and the data on the invariant mass distributions were reproduced pretty good with a value of this factor between 0.8-1.1. The t-dependence of $\gamma p \to \rho p$ cross-section extracted in the framework of our approach is presented in Fig. 2 by points with error bars. For the first time the data on this exclusive cross-section were obtained for $-t > 0.5$ GeV^2 and $W < 3.0$ GeV.

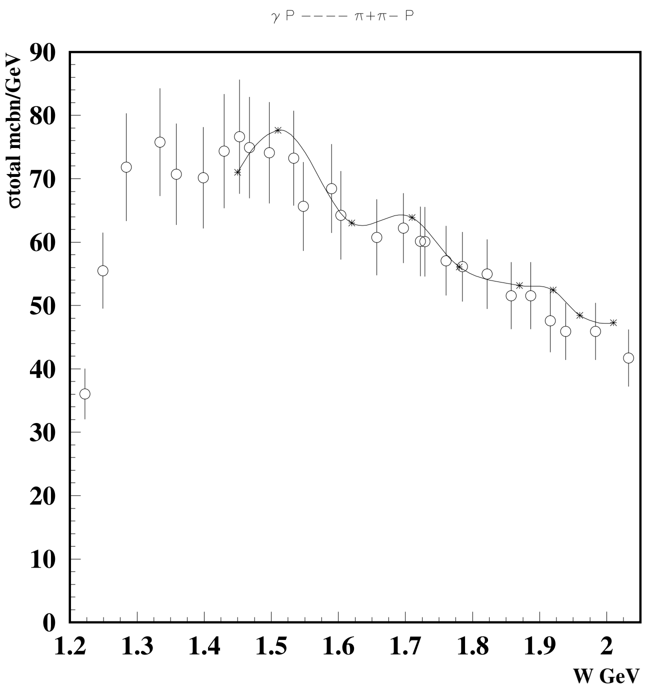

Figure 1: Calculation results for total $\gamma p \to \pi^+\pi^- p$ reaction cross section in comparison with the data [17].

Dashed and dotted lines in Fig. 2 represent the non-resonant mechanism contribution in $\gamma p \to \rho p$ cross-section evaluated in our model with mean values of Pomeron f2 couplings, determined from the data fit at $-t < 1.0$ GeV^2, and mean value of nucleon Regge trajectory coupling determined from the data fit at $-t > 4.0$ GeV^2. The complete model calculations are shown in Fig. 2 by the dash-dotted line. They includes the non-resonant processes and N^* contribution with multiplicative factor 0.9 for the resonant amplitude. In the model [19] t-dependence of $\gamma p \to \rho p$ cross-section was evaluated in the frame of quark-gluon interaction mechanisms as a superposition of two gluon exchanges with quark correlation effects. To describe the data at the highest t, the nucleon and Δ u-channel Regge trajectories were implemented in the model [19]. The predictions of model [19] are shown in Fig. 2 by solid line.

At $0.3 < -t < 1.0$ GeV^2 both descriptions [19] and ours are in good agreement and also coincide with the data. Therefore Pomeron exchange or two gluon exchange in this kinematical domain in fact accounts for main mechanisms of ρ photoproduction. Moreover, good coincidence between our phenomenological evaluation and the model [19] demonstrates that for $-t < 1.0$ GeV^2 Pomeron exchange represents an effective description of two gluon exchange, confirming previous treatment of Pomeron as a gluonic object.

For $-t$ above 2.0 GeV^2 and below 4.0 GeV^2 the N^* contribution to ρ photoproduction expires by a few orders of magnitude the Reggeon exchange cross-section. In the model [19] the predicted cross-section appears to be by a factor of 3-4 lower with respect to those measured at $2.5 < -t < 3.5$ GeV^2, keeping sizeable space for N^* contribution.

The dominant N^* contribution in ρ photoproduction at $-t$ above 2.0 GeV^2 and W between 2.6-2.9 GeV represents new unexpected feature, which would offer a promising way to study the N^* behaviour far off-shell.

Moreover at $-t > 2.0 GeV^2$ we have a dominant contribution of N^* excitation tail, while integrated over t N^* excitation cross-section does not expire a few percent of the total ρ photoproduction cross-section. Therefore this exclusive channel offers a promising opportunity to study the high lying N^* structure and in particular to search for "missing" baryon states.

Our approach was used to extract an information on N^* excitation from the measured $\gamma p \to \pi^+\pi^- p$ cross section at $Q^2 = 0.65$ GeV^2. We analyzed the preliminary data on invariant mass distributions in the W range between 1.41 and 1.88 GeV obtained in E-93-006 experiment and presented at NSTAR2000

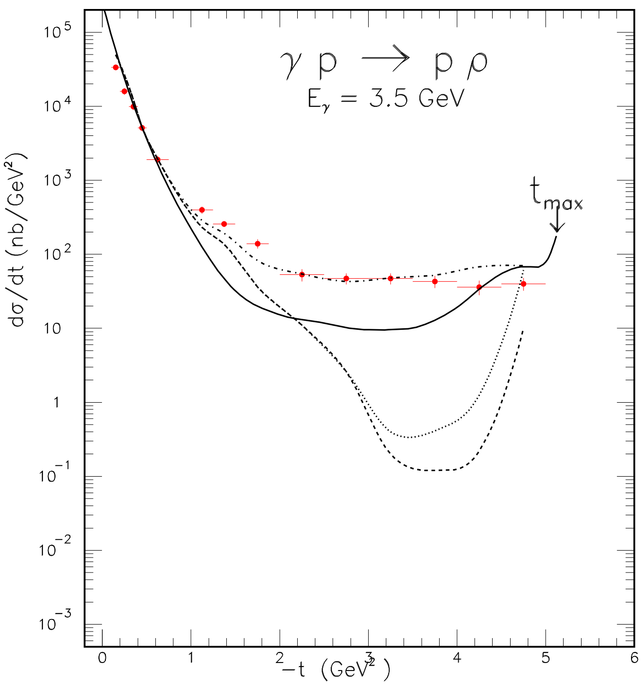

Figure 2: t-dependence of $\gamma p \to \rho p$ cross-section. Cireles: data from CLAS: dashed and dotted lines: our evaluation of non-resonant contributions (Pomeron, f2, nucleon Regge trajectory exchange), dashed-dotted line: our complete evaluation (non-resonant processes and N^* contribution) solid line: model [19] evaluation.

Workshop in Jefferson lab by Dr. M.Ripani. First, we calculated resonant and non-resonant amplitudes of the two pion electroproduction reaction using STQM fit [9] for the N^* electromagnetic amplitude and the results of analysis [7] for N^*'s decays to $\pi\Delta$ and ρp final states. We implemented as free parameters two multiplicative constants for the overall N^* excitation amplitudes in both subchannels. Then we extracted these two parameters and 3-body phase space $C(W,Q^2)$ values from simultaneous fit of $\pi^+\pi^-$ and π^+p invariant mass distributions separately in each W bin. The non-resonant part of the cross section was then calculated from the sum of all non-resonant amplitudes. The resonant part was estimated as a difference between complete cross section and its non-resonant part. In Fig. 3 the cross section evaluated from the invariant mass distribution fit is compared with the preliminary data of E-93-006 JLAB experiment.

Decomposition of the cross section to the resonant and non-resonant parts is also shown in Fig 3. There are two pronounced structures in the resonant part of the cross section situated at W between 1.4 and 1.55 GeV and approximately at 1.7 GeV.

We found that in the W range 1.5–1.55 GeV the experimental data on invariant $\pi^+\pi^-$ and π^+p distributions [1] are reasonably reproduced with the parameters of the $D_{13}(1520)$ and $P_{11}(1440)$ states taken from ref. [7,9], while the data description at $W < 1.46$ GeV requires an increase in the N^* strengths with respect to those parameters; this feature could indicate a contribution from both $D_{13}(1520)$ and $P_{11}(1440)$ to the structure at lower W, with a possible excess of $P_{11}(1440)$ strength compared with available predictions [7,9]. This apparent signal from $P_{11}(1440)$ state is intriguing, as this state is masked in single pion production by the $\Delta(1232)$ tail.

The structure at 1.7 GeV is expected to be composed by $D_{13}(1700)$, $P_{13}(1720)$ and $D_{33}(1700)$ states; current data on both electromagnetic and strong parameters of these states are poor and the information on these high lying N^* excitations is particularly relevant for understanding of the N^* structure in the non-perturbative domain.

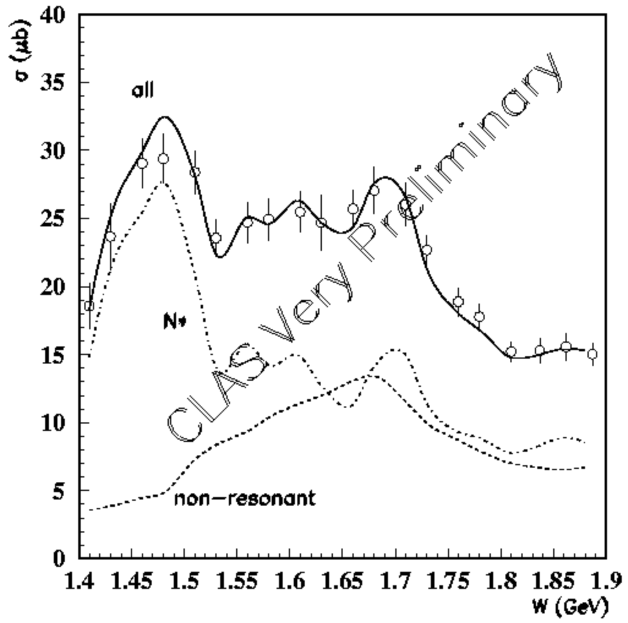

Figure 3: Total virtual photon cross section as a function of the CMS energy W for $ep \to ep\pi^+$ (missing π^-) at Q^2 between 0.5 and 0.8 GeV^2. Circles: data from CLAS [1]; dashed line: our evaluation of non-resonant contributions (isobar model + phase space); dot-dashed line: our evaluation of N^* contributions in the overall double pion production; solid line: our analysis including N^*s and background.

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