Measurement of high lying nucleon resonances and search for missing state in double charged pion electroproduction off protons.

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1 Introduction

The studies of double charged pion production by virtual photons offer promising opportunities to investigate the structure of high lying nucleon excitations. The main part of excited nucleon states with masses above 1.6 GeV decay preferably on two and many pion final states. The virtual photon cross-sections (Fig1) exhibits resonance structures at hadron invariant masses W above 1.6 GeV, not seen in previous experiments with real photons [1]. Moreover, this exclusive channel could serve as a tool for missing baryon state search. According to quark model expectations, [2, 3, 4] missing baryon states should be decoupled with single pion final state, while probability for their two pion decays should be much larger and photocouplings of conventional and missing baryon states are expected to be comparable.

In this proceeding we discussed the results of CLAS data analysis on double charged pion production by virtual photons at W below 2.1 GeV and photon virtualities Q^2 below 1.5 GeV^2 [5]. The goals of analysis were: a) to extract information on high lying N^* ($M > 1.6$ GeV) photocouplings; b) search for possible signals from missing baryon states.

The analysis was performed in the frame of phenomenological approach [6, 7, 8], related N^* photocouplings with measured integrated and differential double charged pion production cross-sections and provided a tool for N^* photocoupling evaluation from data fit.

2 The approach for data analysis

The particular features of double charged pion production at excitation energy of high lying nucleon states are sizable overlap between different states and significant non-resonant mechanism contribution. These features create serious obstacles in

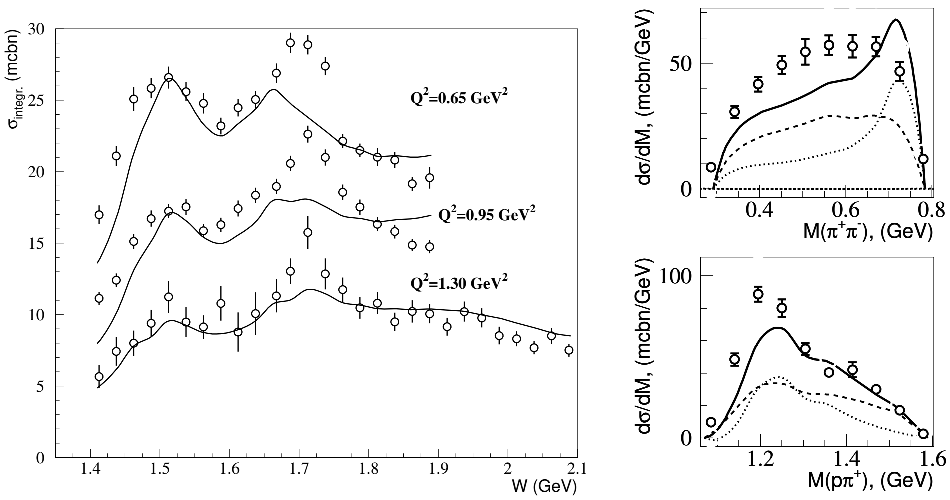

Figure 1: Left: total cross section for $\gamma_v p \to p\pi^+\pi^-$ as a function ow W. Data from CLAS for three Q^2 bins (0.5–0.8, 0.8–1.1 and 1.1–1.5 (GeV/c)^2) Error bars are statistical only. The curves represent our initial step calculation. Right: $\frac{d\sigma}{dM_{\pi^+\pi^-}}$ and $\frac{d\sigma}{dM_{p\pi^+}}$ from CLAS Q^2=0.8–1.1(GeV/c)^2) and W=1.7–1.725 GeV. The curve represent our initial step calculation. Dotted line includes all resonances, the dashed line includes only non-resonanant part, and the solid line is the full calculation.

attempts to extract N^* photocouplings in model independent way and require the development of reaction models, related N^* photocouplings with measured cross-sections.

In our approach [6, 7, 8] we parametrized the complexity of double charged pion production mechanisms at tree diagram level as superposition of quasi-two-body processes with formation of unstable particles in the final states and their's subsequent decay on stable final products. According to experimental data [1, 9] on Dalitz distributions for the final two pion-proton system, we included $\gamma p \to \pi^-\Delta^{++}$, $\gamma p \to \pi^+\Delta^0$, $\gamma p \to \rho p$ quasi-two-body processes, while rest of mechanisms were described in 3-body phase space approximation.

Each mentioned above quasi-two-body process was treated as superposition of N^* excitation in photon-proton s-channel and non-resonant mechanisms.

Nucleon resonance excitations were described in Breit-Wigner ansatz [6]. The strong decay amplitudes were related with LS partial decay widths on different hadronic final states and taken from hadronic data analysis [10, 11]. The electromagnetic excitation amplitudes were related with N^* transverse $A_{1/2}$, $A_{3/2}$ and longitudinal $C_{1/2}$ photocouplings. The photocoupling values were considered as free parameters to be extracted from data fit.

The non-resonant mechanisms in $\pi\Delta$ production were described by gauge invariant reggeizieted Born terms [6]. The electromagnetic and strong vertex functions were applied for description of pion in flight term, based on data on pion electromagnetic form factor [12] and NN scattering analysis [10], while vertices for all other terms were obtained providing gauge invariant total Born term amplitude.

We multiplied complete Born term amplitude by effective Reggeon coupling, which was free parameter extracted from data fit, assuming its independence from W and Q^2 kinematic variables. A special approach was developed to account the initial and final state interactions for this quasi-two-body mechanism as absorption of incoming and outgoing particles with absorptive coefficients estimated from data on πN amplitudes [6].

Non-resonant amplitudes for ρp production were described in diffractive ansatz, assuming helicity conservation [7].

We found our approach provides a reasonable description of world data on double charged pion production [1, 9] in kinematic region of our interest ($W < 3.5$ GeV Q^2,$-t$ are order of few GeV^2): a) W and Q^2 dependence of integrated cross-sections both for complete process and different quasi-two-body channel contributions; b) the invariant $(\pi^+\pi^-)$, (π^+p) invariant mass and angular distributions. Therefore, we believe our approach treat properly the main mechanisms of double charged pion production in N^* excitation region and could be used for CLAS data analysis.

3 The results of CLAS data analysis.

We analyzed CLAS data [5] on double charged pion production with the goals to extract Q^2-dependence of high lying state ($M > 1.6$ GeV) photocouplings and search for possible signals from missing states.

The measured integrated cross-sections are presented on Fig 1. The data base for analysis contains the set of $(\pi^+\pi^-)$ (π^+p) invariant mass and pi^- angular distributions, measured in each (W, Q^2) bin, shown on Fig 1.

As an initial step we try to describe the CLAS data [5] with N^* photocouplings taken from world data interpolation in the frame of SQTM approach [12]. N^* strong couplings were taken from hadron probe data analysis [10]. All good established states with below 2.0 GeV masses and non-negligible branching fractions for pi-Delta and rho-p decay were included. The quality of data description are shown on Fig 1. The calculations reproduce gross-features of (W, Q^2) dependence of integrated cross-sections, however failed to describe the structure around 1.7 GeV. We succeeded to describe the shape of $(\pi^+\pi^-)$ invariant mass distribution inside studied kinematic area apart from domain around 1.7 GeV structure.

The calculated $(\pi^+\pi^-)$ invariant mass distributions at W around 1.7 GeV exhibit sharp rho-peak in contradiction with smooth experimental data behavior (right panel on Fig 1). We found major resonant contribution in rho peak, arising from $P_{13}(1720)$ state with 70-85% decays to ρp final state.

Our next step was attempt to eliminate mentioned above discrepancies by means

N^* photocoupling modification, while N^* strong couplings were inside uncertainties obtained analysis experiments with hadron probes [10]. For that case the only way to reproduce smooth behavior in (pi+ pi-) mass distributions in W-bins inside 1.7 GeV structure is more than factor two reduction of $P_{13}(1720)$ photocouplings with respect to SQTM expectation [12]. We attributed excess of measured cross-sections at W <1.5 GeV with longitudinal $P_{11}(1440)$ excitation and implemented logitudinal strengths for Ropper to provide low W data fit. A quark-model prediction [12] for $D_{15}(1675)$, $D_{13}(1700)$ state were used, since both these state can not be excited in the frame of SQTM. We varied according to the normal distribution the N^* photocouplings around mentioned above nominal values with 20% r.m.s, based on evaluated uncertainties for SQTM predictions [12]. For each trial set of photocouplings we calculated set of mentioned above 1-differential cross-sections and estimated χ^2 from comparison between calculated and measured cross-sections values. The best solution was selected, minimizing χ^2, averaged over complete W range, separately for different Q^2-bins. The photocouplings, corresponded to the best solution were considered as extracted from data fit. The best solutions are shown on Fig 2. We reach reasonable data data description inside kinematic domain covered by measurements apart from structure around 1.7 GeV. The extracted photocouplings for $(70,1^-)$ supermultiplet states deviate from SQTM expectation not more than 30%, suggesting single quark transition between coherent 3-quark configurations in the ground and excited nucleon states as possibly main mechanism of N^* excitation at moderate Q^2 values below 1.5 GeV^2. The experimental data around 1.7 GeV manifest resonance like excess with respect to calculation in all measured Q^2 bins at the same position, indicating either presence of missing state or sizable departure of strong couplings of conventional states with respect to extracted in analysis [10, 11] and used in described above step of our fit or huge deviation of photocouplings of N^* around 1.7 GeV from SQTM [12] predictions.

We found $D_{13}(1700)$ and $P_{13}(1720)$ states are most likely candidates to fill gap around 1.7 GeV, since they have proper positions and high inelasticities, which would make difficult unambiguous strong coupling evaluation. There are also $D_{33}(1700)$, $F_{15}(1685)$ and $D_{15}(1675)$ states, which could contribute in 1.7 GeV structure, however $D_{33}(1700)$ has 300 MeV total widths, while positions of $F_{15}(1685)$ and $D_{15}(1675)$ definitely mismatch structure and any attempt of their's enhancement would spoil reasonable data description at W between 1.6 and 1.7 GeV. If we keep strong N^* couplings on values extracted in analysis [10, 11] the only way to to fill gap around 1.7 GeV structure enhancement of $D_{13}(1700)$ photocouplings, since the photocouplings of $P_{13}(1720)$ should be reduced even with respect to SQTM prediction to avoid rho-peak formation in $(\pi^+\pi^-)$ invariant mass distributions (Fig. 1). Varying photo and strong coupling as well as position for $D_{13}(1700)$ state, we reach reasonable reproduction of W-dependence of integrated cross-section, however failed in description of π^- angular distributions at forward angles (Fig 3). The same discrepancy takes place in all (W, Q^2) bins inside 1.7 GeV structure. Therefore, we drop-out hypothesis about $D_{13}(1700)$ photocoupling enhancement.

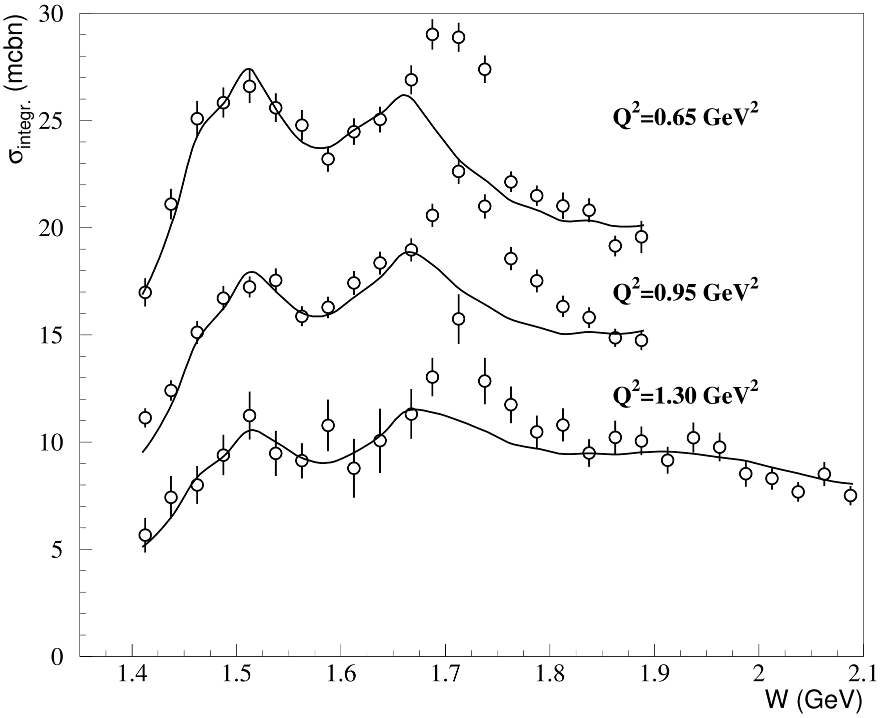

Figure 2: The comparison between CLAS data [5] and fit results, applying variation of N^* photocouplings, while N^* strong couplings are taken from data analysis of experiments with hadron probes [10]

Other opportunity we studied was the variation in large range significantly above uncertainties of analysis [10] of $\pi\Delta$, ρp strong couplings and position of $\mathrm{P}_{13}(1720)$, with simultaneous variation of position and the same channel strong couplings for another close and highly inelastic $\mathrm{D}_{13}(1700)$ state. The $\mathrm{P}_{13}(1720)$ state photocouplings were also varied, while other state photocouplings were kept on the best values extracted at the previous step of fit. We succeed to reproduce data reasonably in complete kinematic area covered by measurements (dashed lines on Fig. 3,4), however strong decay pattern of $\mathrm{P}_{13}(1720)$, emerged from our fit, turns out completely different with respect to available from analysis of data with hadron probes. The parameters of $\mathrm{P}_{13}(1720)$ state obtained in our analysis in comparison with PDG values are listed in the Table 1. At variance with PDG we got minor ρp and major $\pi\Delta$ decay branching fractions, allowing to reproduce the peak around 1.7 GeV by dominant contribution of $\gamma p \to \pi\Delta$ channel, without spoiling invariant $(\pi^+\pi^-)$ mass distributions due to small ρp coupling for $\mathrm{P}_{13}(1720)$ decay.

Considering this completely different strong decay pattern of $\mathrm{P}_{13}(1720)$ needs confirmation in future experiments, we studied also another way of data description, keeping N^* strong couplings inside uncertainties presented in analysis [10, 11].

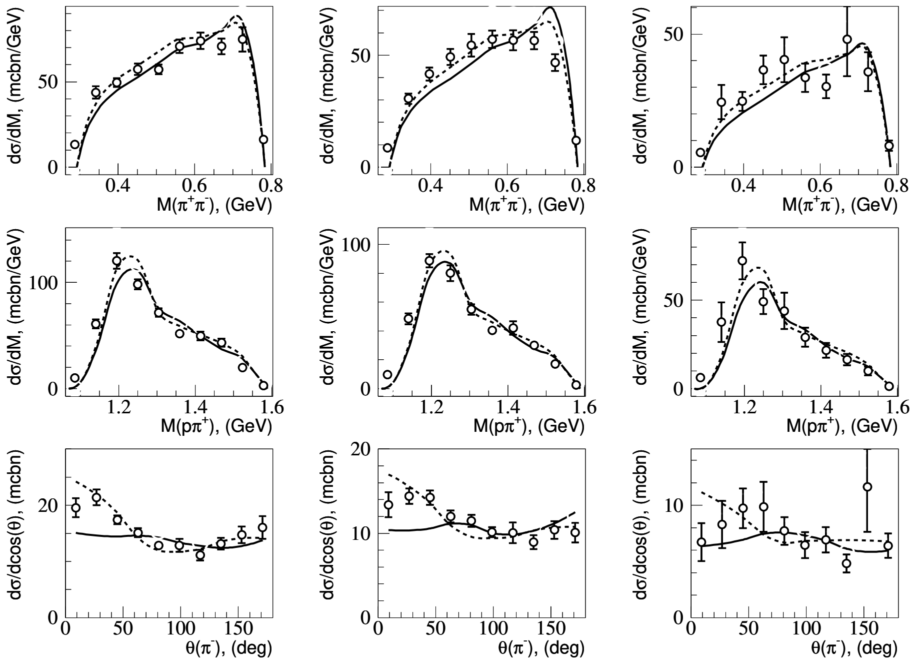

Figure 3: $\frac{d\sigma}{dM_{\pi^+\pi^-}}$ $\frac{d\sigma}{dM_{p\pi^+}}$ and $\frac{d\sigma}{d\cos\theta_{\pi^-}}$ from CLAS at W=1.7–1.725 GeV and at three mentioned Q^2 intervals (left to right). Solid curve corresponds to fit result with $D_{13}(1700)$ enhancement while the dashed curve corresponds to the fit result with new state inclusion.

We found that in this case reasonable data description could be reached implementing an additional missing baryon state, since, as argued above, there is no opportunity for enhancement of the conventional $D_{13}(1700)$ and $P_{13}(1720)$ states. We test the following quantum numbers for missing state: S_{I1}, P_{I1}, P_{I3}, D_{I3}, D_{I5}, F_{I5}, F_{I7} (where index I stands for isospin 1/2 or 3/2 necessarily ambiguous in single charge exclusive channel analysis), varying in large range rho-p and pi-delta strong couplings, position and photocouplings for missing state. We found the best data description for $P_{I3}(1720)$ quantum numbers, however S_{I1} choice can not be completely ruled-out. The quality data description are shown on Fig.4 by solid lines. The extracted parameters for missing baryon state are listed in the Table 1. The quality of data description for both hypothesis of missing baryon state $P_{I3}(1720)$ and conventional $P_{I3}(1720)$ with drastically modified strong decay pattern are indistinguishable, offering two alternative ways for description of structure around 1.7 GeV for the first time observed by CLAS Collaboration.

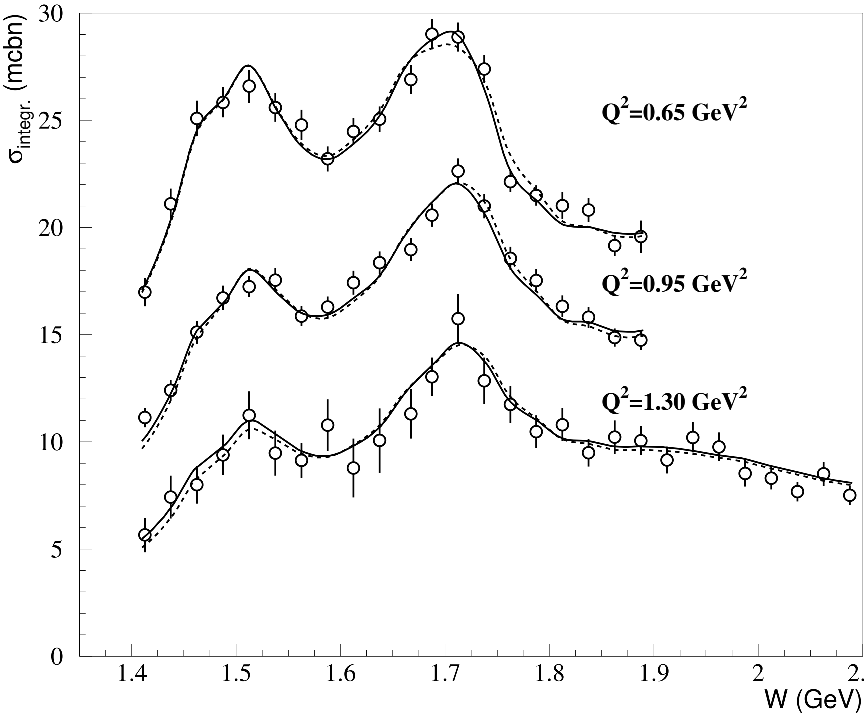

Figure 4: The comparison between CLAS data [5] and fit results for two alternative ways of data description: a) implementing $P_{I3}(1720)$ (I=1/2,3/2) missing state; b) with conventional $P_{13}(1720)$ but completely different strong decay pattern with respect to presented in analysis of data for hadron probes.

4 Conclusion

The Q^2 dependence of photocouplings for many states with masses above 1.6 GeV were extracted for the first time. The photocouplings for $(70,1^-)$ super-multiplet states follow SQTM predictions within 30%, suggesting single quark transition between coherent 3-quark configurations in the ground and excited nucleon states as possibly main mechanism for N^* excitation at $Q^2 < 1.5$ GeV^2

The resonant structure around 1.7 GeV, for the first time observed by CLAS Collaboration, could be manifestation of either $P_{I3}(1720)$ ($I = 1/2, 3/2$) missing baryon state,which should be implemented to provide data description, if N^* strong couplings are taken from analysis of data with hadron probes or completely another strong decay pattern of conventional $P_{I3}(1720)$ state. The future experiments with hadron probes on precise measurement of pi-delta and rho-p content of P_{13} partial wave as well as the studies of different exclusive channel in photo and electroproduction could allow to distinguish between these alternatives.

Q^2 (GeV/c^2)	$A_{1/2}$ ($10^{-3}/\sqrt{\mathrm{GeV}}$)	$A_{3/2}$ ($10^{-3}/\sqrt{\mathrm{GeV}}$)
0.65	15±25	-74±8
0.95	12±20	-53±6
1.30	3±14	-41±18

Table 1: Photocouplings of the new state (P_{13}(1720)).

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