REACTION OF TWO-PION PHOTOPRODUCTION OFF PROTONS AND THE STRUCTURE OF NUCLEON RESONANCES

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Physics Motivation

The N^* studies with CLAS (CEBAF Large Acceptance Spectrometer) at JLAB (Thomas Jefferson National Accelerator Facility) are focused on the exploration of the strong interaction in the non-perturbative regime of QCD through studies of transition form factors from the ground state to excited nucleon states. This helps us to determine the relevant degrees of freedom in describing excited nucleons. Another objective of the N^* program is the studies of the N^* spectrum with emphasis on the search for so-called "missing states".[1,2]

The processes $\gamma_{r,v}p \to \pi N$ and $\gamma_{r,v}p \to \pi\pi N$ are two major contributors to the meson photo- and electroproduction in the N^* excitation region, while the two-pion channel has better sensitivity to the high-lying resonances ($M > 1.6$ GeV), since most of them decay preferably into a final state with two pions. Moreover, these channels are strongly coupled by the final state interaction to channels with smaller cross sections and, therefore, may affect other channels, such as ηN, KY, and ωN. Thus, the information on the reactions of single and double pion photo- and electroproduction is important for global multichannel analyses within the framework of coupled channel approaches.[3] Analyses of both channels are needed for the reliable extraction of N^* parameters.

Constituent quark models (CQM) predict more baryon states than have been observed in experiments so far, and different models predict different numbers of states. Recent lattice QCD calculations[4,5] of the N^* spectrum suggest the existence of as many states as are expected in CQM models based on SU(6) spin-flavor symmetry. Therefore, CQM results on the existence of many new baryon states get substantial support from Lattice QCD. It motivates us to search for these new states in experimental data. The two-pion photo- or electroproduction off protons is one of the most suitable reaction channels for this purpose, because CQM calculations[6] predict that "missing" states are weakly coupled to the πN channel, while they should have substantial decays to the final states with two pions. For the first time the signal of a "missing state" candidate was observed[7] in the reaction $\gamma_v p \to \pi^+\pi^- p$ at Q^2 from 0.5 to 1.5 GeV^2. The structure at a CMS energy (W) ≈1.7 GeV could be explained assuming either substantially different $\pi\Delta$ and ρp hadronic decay widths of the conventional $P_{13}(1720)$ state with respect to the values[8] obtained in experiments with hadronic probes, or implementing a new candidate state $3/2^+(1725)$. In the latter case the parameters of $P_{13}(1720)$ remained at the values, which reasonably coincide with PDG data. Figure 1 shows the cross section of the $\pi^+\pi^- p$ electroproduction at eight Q^2 values. The bump at $W \approx 1.7$ GeV is clearly seen[7,9] at Q^2 from 0.5 to 5.0 GeV^2. The same reaction with real photons can provide a sensitive check for the existence of this candidate state in a combined analysis of two-pion photo- and electroproduction. The two-pion cross sections should be reproduced in both photo- and electroproduction with the same N^* hadronic decay widths. Furthermore, photoproduction data offer an opportunity to further constrain non-resonant mechanisms.

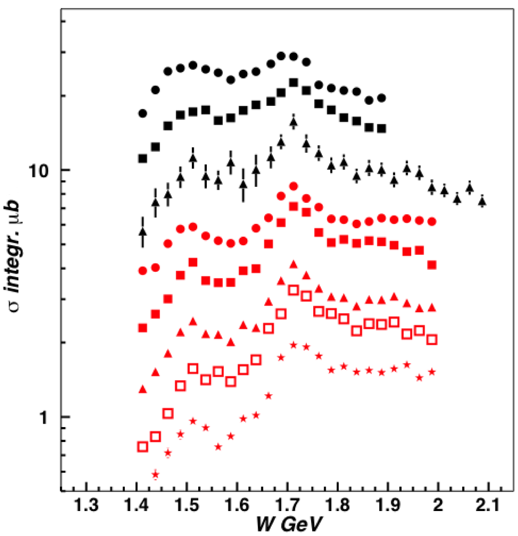

Figure 1: (color online) Integrated cross section for the reaction $\gamma_v p \rightarrow \pi^+\pi^- p$ as a function of W at different Q^2-values. Black symbols[7] correspond to $Q^2 = 0.65$, 0.95, and 1.3 GeV^2 and preliminary data at $Q^2 = 2.3$, 2.7, 3.3, 3.9, and 4.6 GeV^2 are shown in red.[9] Increasing Q^2 values correspond to decreasing cross section.

Cross section for $\gamma p \rightarrow \pi^+\pi^- p$ from CLAS data

We analyzed the data of the G11A run period obtained with the CLAS[10] detector in Hall-B at JLAB. CLAS is a superconducting spectrometer with almost 4π-acceptance. The JLAB accelerator delivers continuous electron beam with energies up to ≈6 GeV. The photon tagging system provides tagged photons with 0.5% energy resolution. The unique capability of CLAS to detect multi-particle final hadron states provides an ideal tool for the measurement of the $\gamma p \rightarrow \pi^+\pi^- p$ cross section.

In the G11A run 4 GeV electrons with a current of 60 nA hit the CLAS bremstrahlung target. Tagged photons with energies from 1.6 to 3.8 GeV were directed to a liquid hydrogen target. The CLAS trigger system was set to register events having at least two charged particles. During the run time of 50 days about 7×10^9 triggers were collected.

The large CLAS acceptance and the large number of events made it possible to obtain 1- and 2-fold differential cross sections in narrow W-bins of 25 MeV for the first time. We analysed the sample of events with at least 2 charged particles in the final state. Two-pion events were selected employing a kinematic fitting procedure.[11] Detector efficiency was evaluated in Monte–Carlo approach using the standard CLAS GSIM package. The

$\pi^+\pi^-p$ final state can be fully described with 5 variables. We choose a set of variables comprised of invariant masses of the final particle pairs $M(p\pi^+)$, $M(\pi^+\pi^-)$, CM solid emission angles of a proton ($\theta(p)$, $\phi(p)$) and the rotational angle ($\alpha(p)$) between the plane of the final $\pi^+\pi^-$ pair and the plane of initial and final proton. Our experiment provided nine 1-fold differential cross sections ($d\sigma/dM(i,j)$, $d\sigma/\theta(i)$, $d\sigma/\alpha(i)$, where i and j stand for p, π^+ or π^-) and 21 2-fold differential cross sections in each bin of W. Integration of 5-differential cross section is needed to afford reasonable statistical and systematical accuracy. All cross sections reported in this paper are preliminary.

The cross section integrated over the CLAS acceptance is shown in Fig. 2 as a function of W. The comparison with previously available data[12,13] demonstrates the effect of the limited detector acceptance that has not been taken into account in the JLAB data. CLAS has inactive areas at forward and backward angles.

A special procedure was developed to account for contributions to the cross section from dead zones. For each bin of any 1-fold differential cross section we compute the ratio R: the total amount of contributing 5-D cells over the number of active cells. The corrected cross section was obtained by multiplying the aforementioned cross section by R. We set the uncertainty related to this procedure to be equal to half of the increase in cross section value. Figure 3 shows final hadron CM angular distributions before and after this correction.

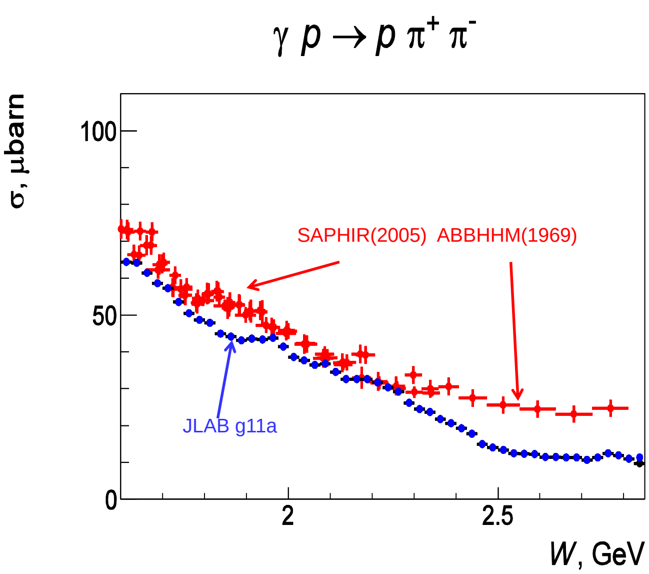

Figure 2: (color online) Integrated $\pi^+\pi^-p$ photoproduction cross section from the CLAS data in comparison with the SAPHIR[12] and ABBHHM[13] data. Only statistical errors are shown for the CLAS cross section.

Integrated cross sections before and after corrections are shown in Fig. 4. Corrected cross sections are systematically larger than world data at $W < 2.4$ GeV while at $W > 2.5$ GeV they become smaller. These discrepancies may be related to the still too naive assumption on the cross section behavior in inefficient areas. In the future we are planning to fit these data within a framework of JM model[14,15] in order to extrapolate the cross

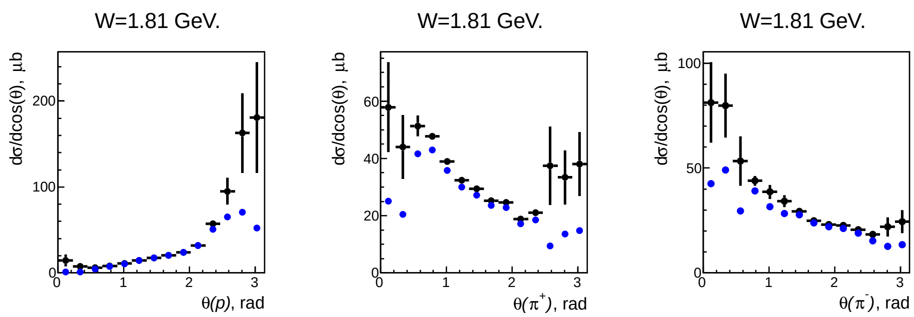

Figure 3: (color online) CM angular distributions of the final hadrons. Blue points correspond to the cross sections inside the CLAS acceptance. Corrected cross sections are shown in black. Uncertainties come mostly from the correction procedure.

section into dead area.

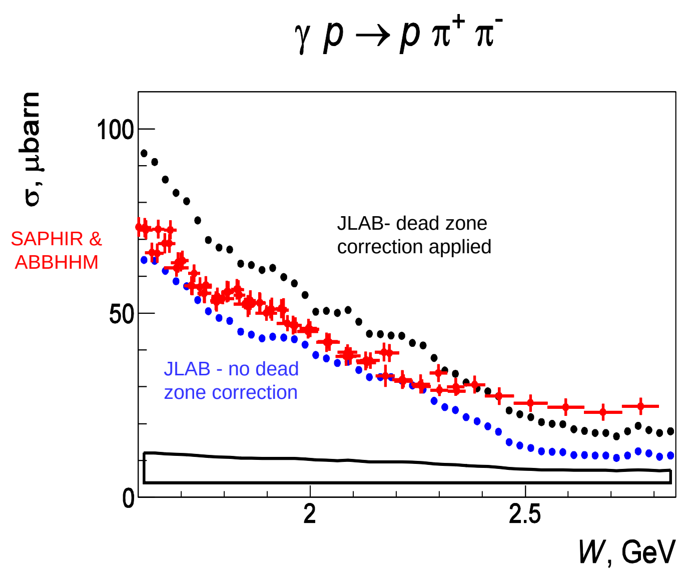

Figure 4: (color online) Integrated $\pi^+\pi^-p$ cross section from the CLAS data in comparison with the SAPHIR[12] and ABBHHM[13] data. Blue points correspond to the cross sections inside the CLAS acceptance. The corrected cross section is shown in black. The error band at the bottom of the plot shows systematical uncertainties related to the correction procedure.

Figure 5 demonstrates examples of the invariant mass distributions. Distributions over the rotational α angles are shown in Fig. 6. Examples of 2-fold differential cross section are presented in Fig. 7.

Summary

For the first time preliminary 1- and 2-fold differential cross sections for the reaction $\gamma p \to \pi^+\pi^-p$ have become available at CM energies from 1.6 to 2.8 GeV. A physics

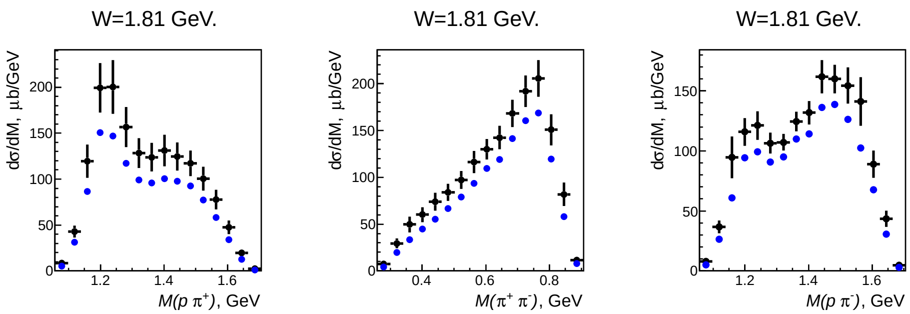

Figure 5: (color online) Invariant mass distributions of the final hadrons. See Fig. 3 for designations.

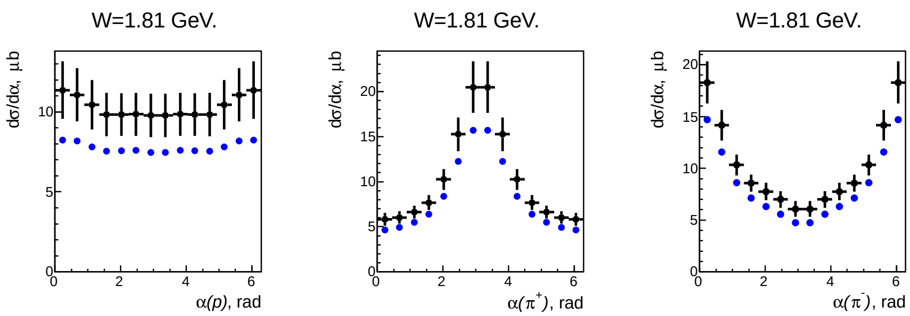

Figure 6: (color online) Rotational α angle distributions. See Fig. 3 for designations.

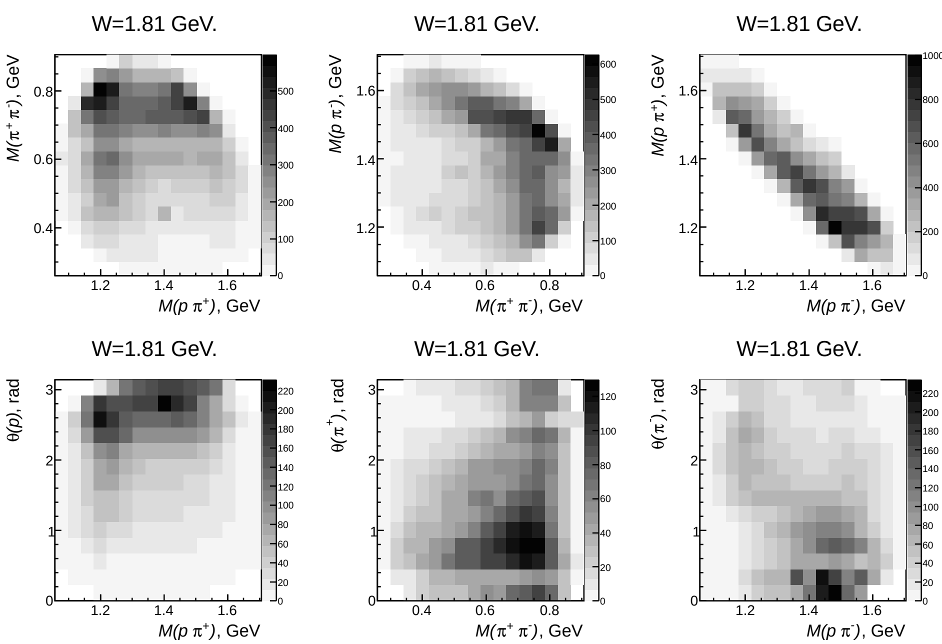

Figure 7: Examples of 2-fold differential cross sections.

analysis of this data within the framework of the reaction model[14,15] is in progress with the goal to obtain information on resonance photocouplings from this exclusive channel, which is particularly sensitive to high-lying N^*-states with masses above 1.6 GeV. A combined analysis of the $\pi^+\pi^-p$ photo- and electroproduction data off protons looks very promising in order to establish the nature of the structure at $W \approx 1.7$ GeV, which was observed in two-pion electroproduction.

Acknowledgements

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