New Results on $\gamma_v p \rightarrow \pi^+ \pi^- p$ Cross Sections in the Second and Third Resonance Regions

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Physics Motivation

- Extension of the Q^2-evolution results of electrocouplings to excited nucleons into the second and third resonance regions with new $\pi^+\pi^-p$ electroproduction data off protons in Q^2 bins of six times smaller size than previously achieved.

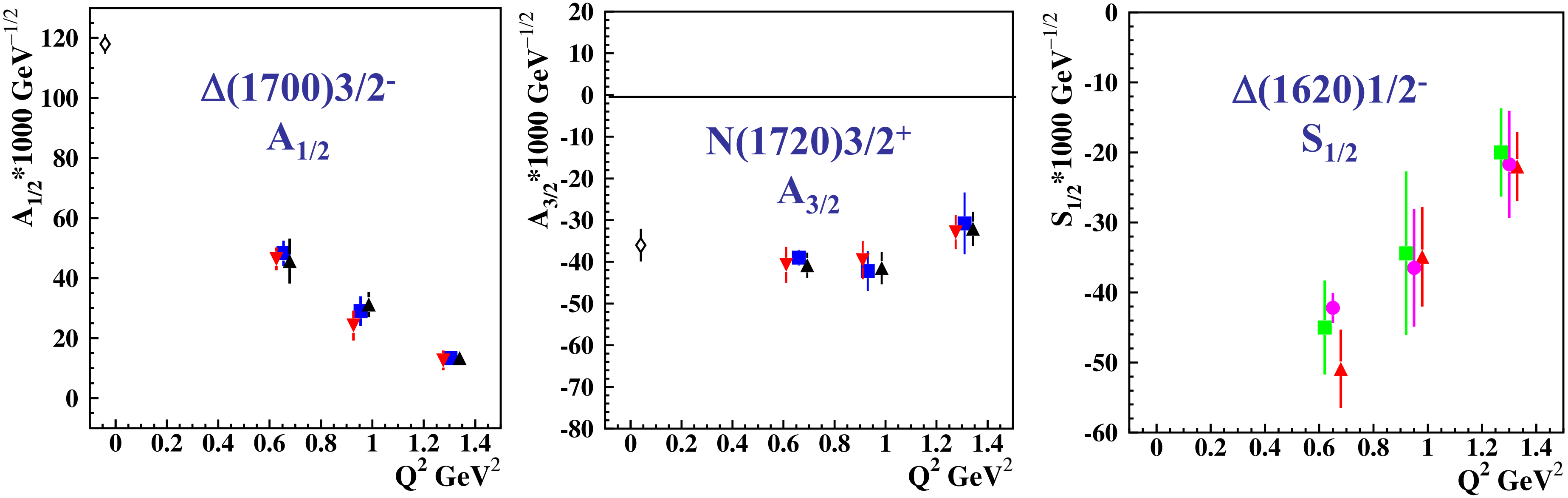
- Almost model independent check of the reliability of the extracted electro-couplings through the comparison of $N\pi$ and $\pi^+\pi^-p$ electroproduction results.

- Major source of information on electrocouplings of the nucleon resonances that decay preferentially to the $N\pi\pi$ final states.

- First detailed information on the structure of a new baryon state N'(1720)$3/2^+$ uncovered in the combined analysis of the CLAS $\pi^+\pi^-p$ photo- and electro-production data.

- New opportunities to explore dynamic di-quark correlations and meson-baryon cloud effects in the structure of baryons with an orbital excitation of L=1.

Higher-Lying Resonance Electrocouplings



Independent fits in different W-intervals
green: 1.46<W<1.56 GeV
magenta: 1.56<W<1.66 GeV
red: 1.61<W<1.71 GeV
blue: 1.66<W<1.76 GeV
black: 1.71<W<1.81 GeV
result in self-consistent electrocouplings and hence offer sound evidence for their reliable extraction.

V. Mokeev *et al.*, Phys. Rev. C **93**, 025206 and EPJ Web Conf. 113 (2016) 01013

- The electrocouplings of the Δ(1620)1/2⁻, N(1650)1/2⁻, N(1680)5/2⁺, Δ(1700)3/2⁻ , and N(1720)3/2⁺ resonances were obtained at 0.5 GeV^2<Q^2<1.5 GeV^2, but just in three wide Q^2 bins.
- Improved information on their Q^2 evolution expected from the new e1e data collected in six times smaller Q^2 bins will provide further insight into the structure of orbital nucleon excitations with L=1.

Branching Fractions in the 2nd and 3rd Resonance Regions

PDG values

State	$\eta_{N\pi}$	$\eta_{N\eta}$	$\eta_{N\pi\pi}$
$P_{11}(1440)$	0.55-0.75		0.3-0.4
$D_{13}(1520)$	0.55-0.65	0.0023	0.2-0.3
$S_{11}(1535)$	0.35-0.55	0.42	0.1-1.0
$S_{31}(1620)$	0.2-0.3		0.7-0.8
$S_{11}(1650)$	0.5-0.9	0.05-0.15	0.1-0.2
$F_{15}(1680)$	0.65-0.7		0.3-0.4
$D_{13}(1700)$	0.12		0.85-0.95
$D_{33}(1700)$	0.1-0.2		0.8-0.9
$P_{11}(1710)$	0.05-0.2	0.1-0.3	0.4-0.9
$P_{13}(1720)$	0.11	0.04	>0.7

The analysis of the e1e data measured with CLAS in Hall-B at JLab will be presented in this talk.

New N’(1720)3/2^{+} State and its Properties

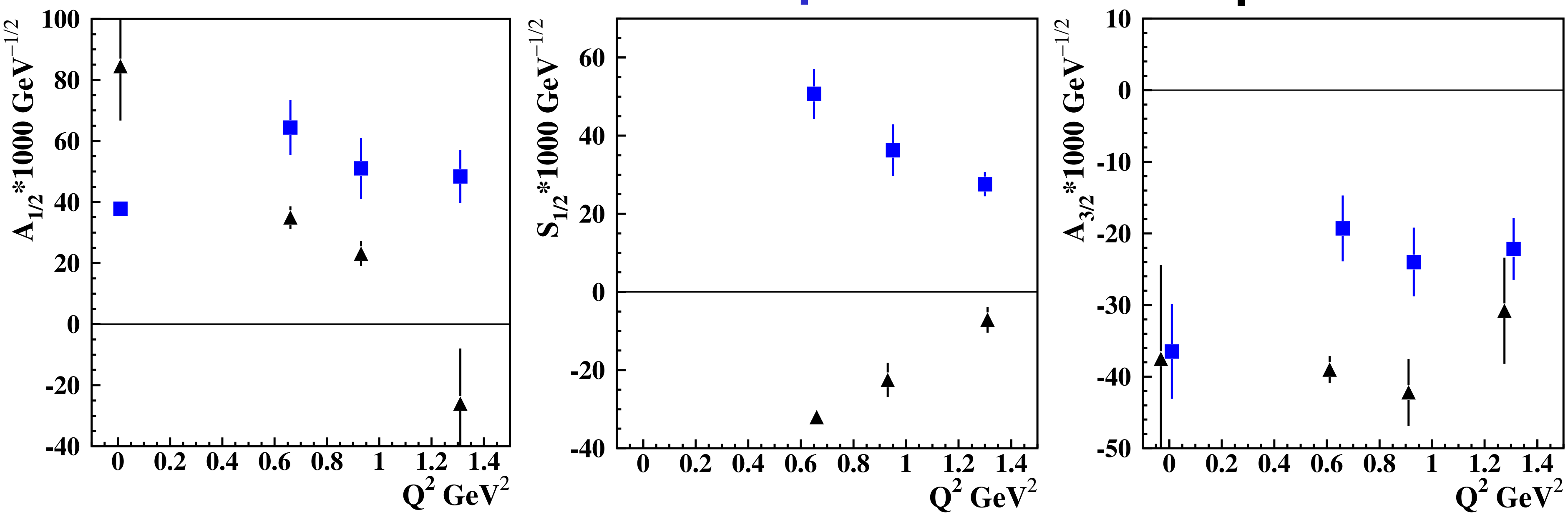
N* hadronic decays from JM15 that incorporates N’(1720)3/2^{+}

Resonance	BF(πΔ), %	BF(ρp), %
N’(1720)3/2^{+}		
electroproduction	**47-64**	**3-10**
photoproduction	**46-62**	**4-13**
N(1720)3/2^{+}		
electroproduction	**39-55**	**23-49**
photoproduction	**38-53**	**31-46**
Δ(1700)3/2^{-}		
electroproduction	**77-95**	**3-5**
photoproduction	**78-93**	**3-6**

A successful description of $\pi^+\pi^-p$ photo- and electro-production cross sections at Q^2=0, 0.65, 0.95, and 1.30 GeV^2 has been achieved by implementing a new N’(1720)3/2^{+} state with Q^2-independent hadronic decay widths of all resonances that contribute at W~1.7 GeV, that allows us to claim the existence of a new N’(1720)3/2^{+} state.

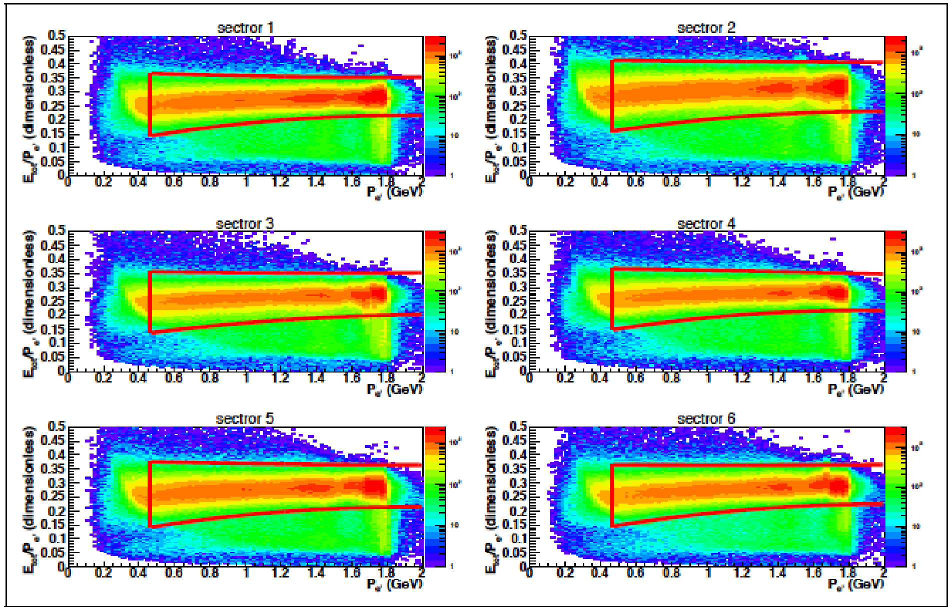
Mass: 1.715-1.735 GeV
Width: 120 6 MeV
N’(1720)3/2^{+}

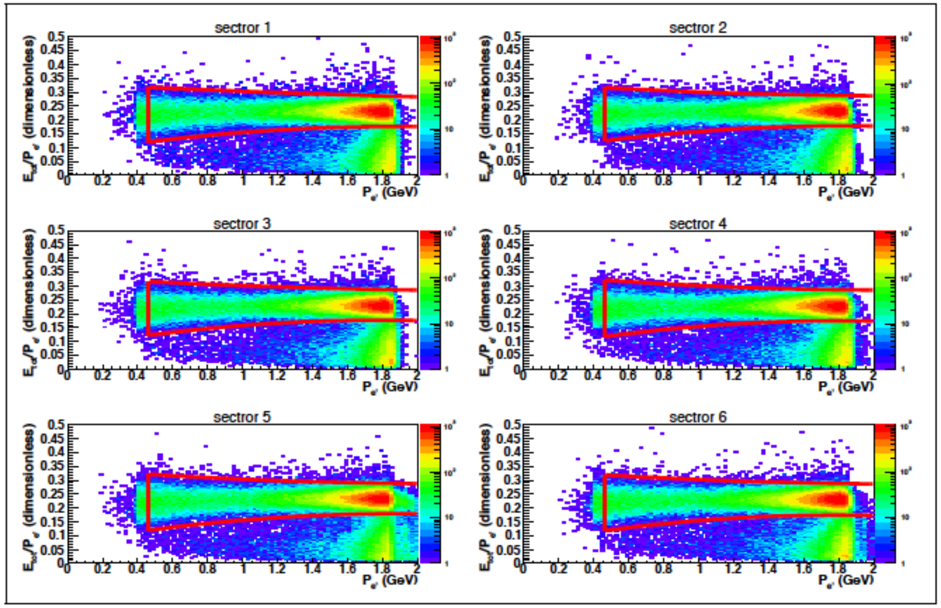
Mass: 1.743-1.753 GeV
Width: 112 8 MeV
N(1720)3/2^{+}



Electron Identification

Electrons are identified by their coincident signals produced in the SC, DC, EC and CC detector elements as the first in time particles.



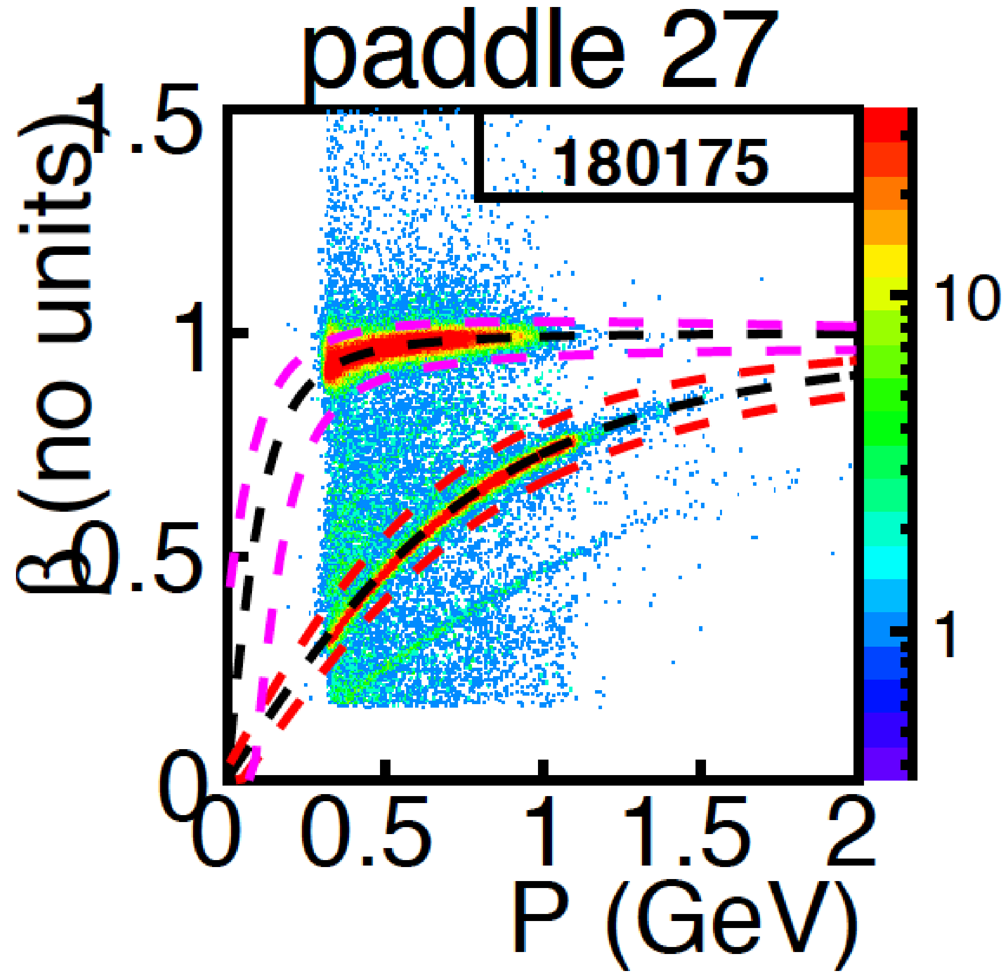


- ➢ Total energy deposited in the electron calorimeter (EC) divided by electron momentum versus electron momentum.
- ➢ Left 6 plots represents real data distributions for the 6 CLAS sectors, while the 6 plots on the right side represent the corresponding Monte-Carlo distributions.
- ➢ We identify events enclosed by the red curves as electrons.

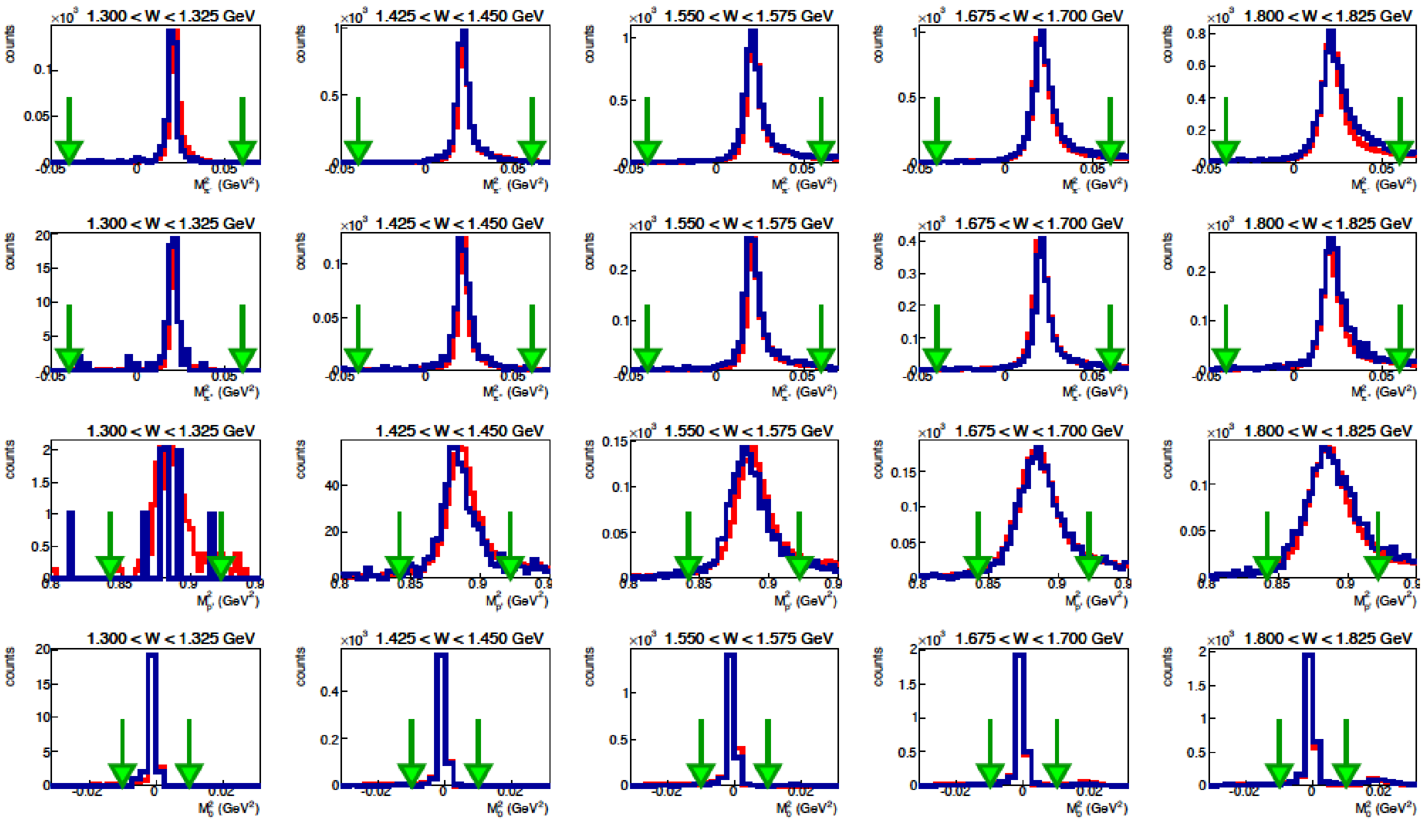
Hadron Identification

To identify hadrons information from the drift chambers (DC) and time-of-flight detector paddles (SC) are used.

β versus momentum distribution snapshot for positively charged particles seen by ToF scintillator paddle 27 of CLAS sector one. Black dashed curves are theoretical calculations with exact hadron mass assumptions. Events between the two purple and two red dashed curves are selected as π^+ and proton candidates, respectively.



Topologies and Exclusivity Cuts



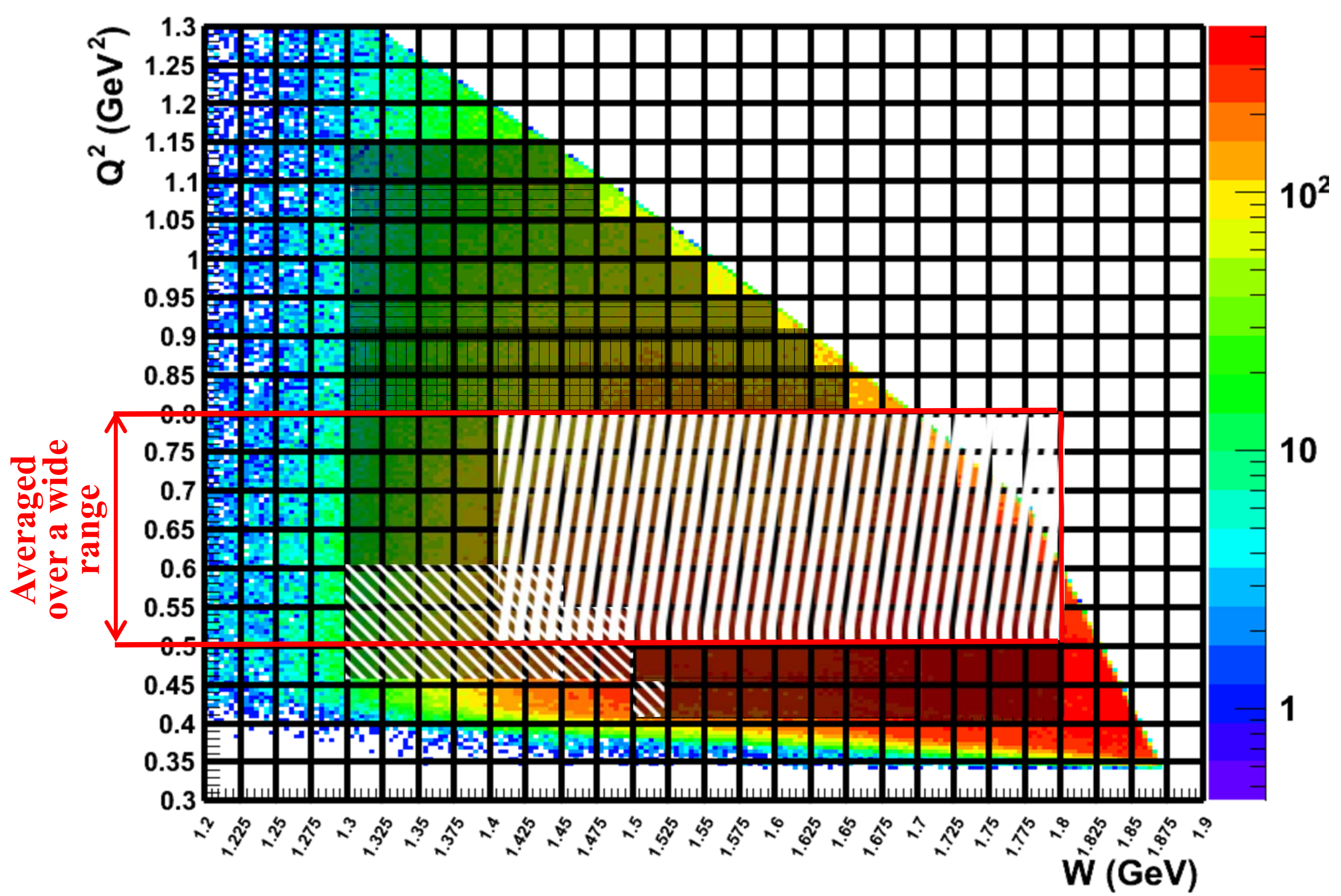
Topology	Statistics (%)
π^- missing	≈70
π^+ missing	≈10
proton missing	≈10
exclusive	≈10

Summary of Cuts and Corrections

Cuts	Data	Simulation
Fiducial	yes	yes
EC-cut	yes	yes
CC-cut	yes	no/yes
β vs. p	yes	yes
θ vs. p	yes	yes
Electron momentum correction	yes	no
Proton energy loss correction	yes	yes
Exclusivity cut	yes	yes

Radiative corrections were applied on a level of cross sections and the overall normalization was checked by comparison of the elastic cross section with the Bosted parameterization.

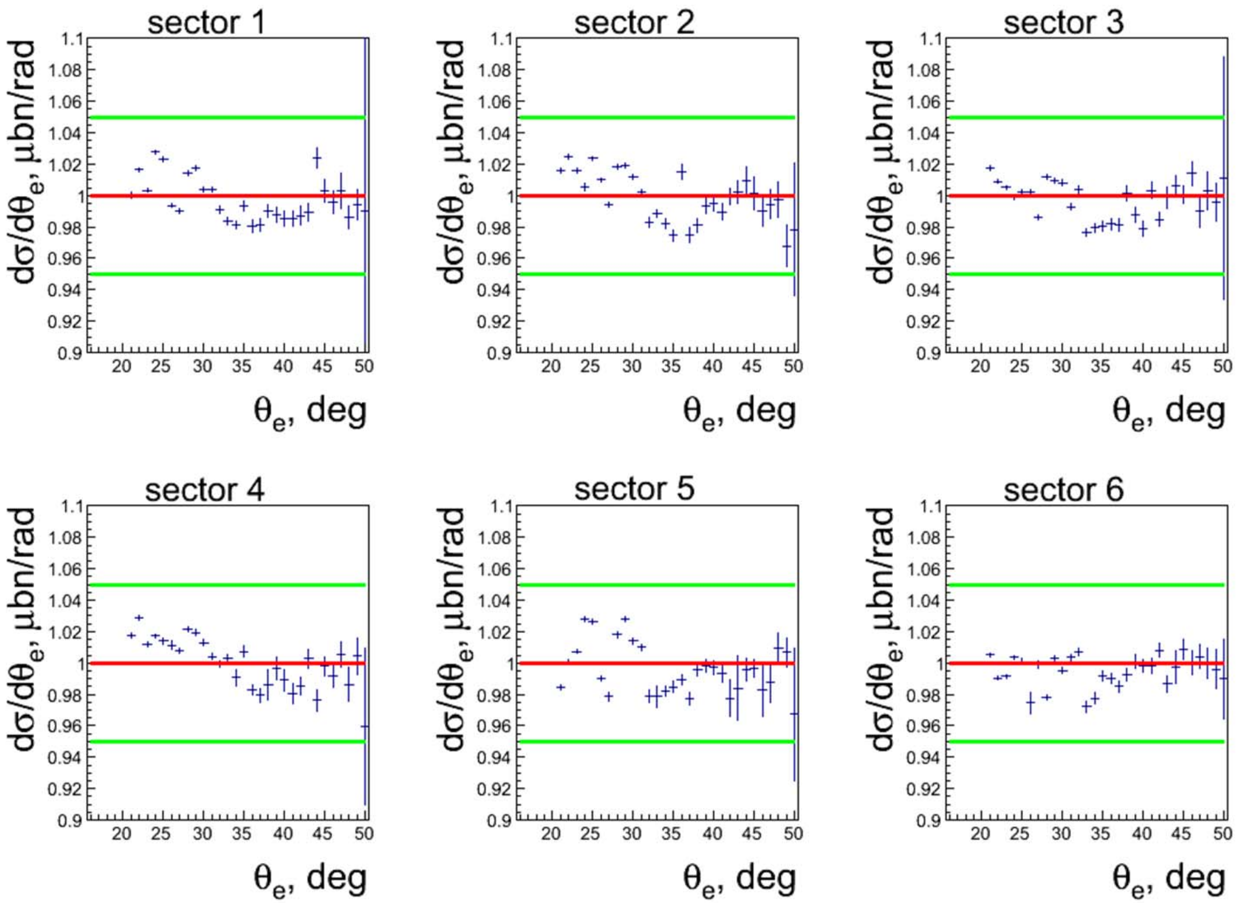
$N\pi^+\pi^-$ Electroproduction Kinematic Coverage



$p\pi^+\pi^-$ event yields over W and Q^2. Gray shaded area new e1e data set, hatched area at low Q^2 already published e1c data by G. Fedotov *et al.* and hatched area at higher Q^2 published data in one large Q^2 bin by M. Ripani *et al.*

Cross Section Normalization Check

Ratio of the elastic cross section to the P. Bosted parameterization plotted versus θ_e. The parameterized cross sections are "radiated" and compared to the e1e elastic cross sections that are correspondingly not corrected for radiative effects.



Good agreement in all 6 sectors

Kinematic Variables

$ep \to e'p'\pi^+\pi^-$ **in single photon exchange approximation** $\gamma_v p \to p'\pi^+\pi^-$

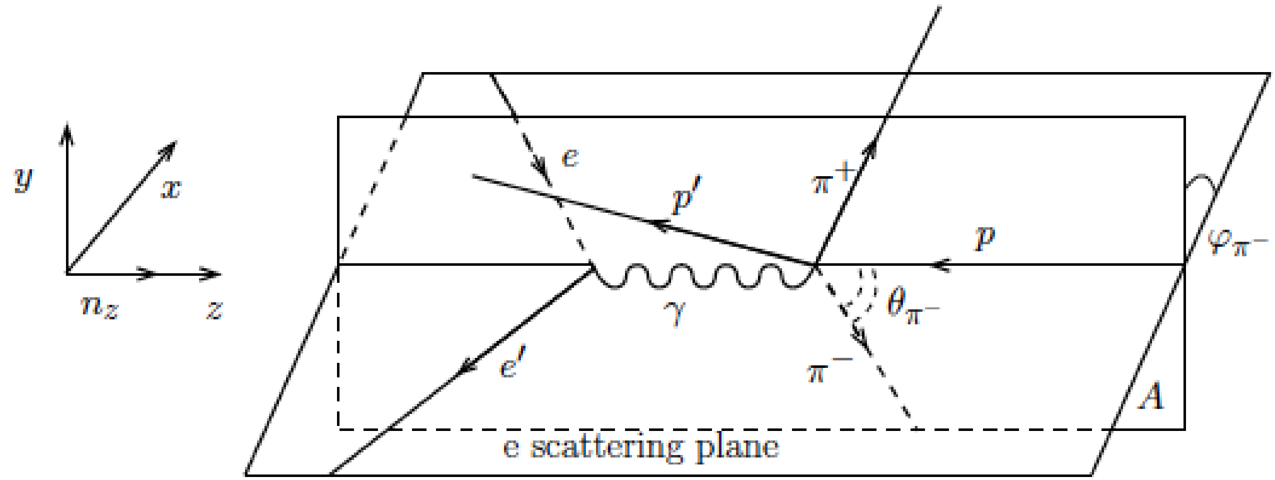
From experiment → $$\frac{d^7\sigma_e}{dW\,dQ^2 d^5\tau} = \Gamma_v \frac{d^5\sigma_v}{d^5\tau}$$ ← **From JM model (fit to the data)**

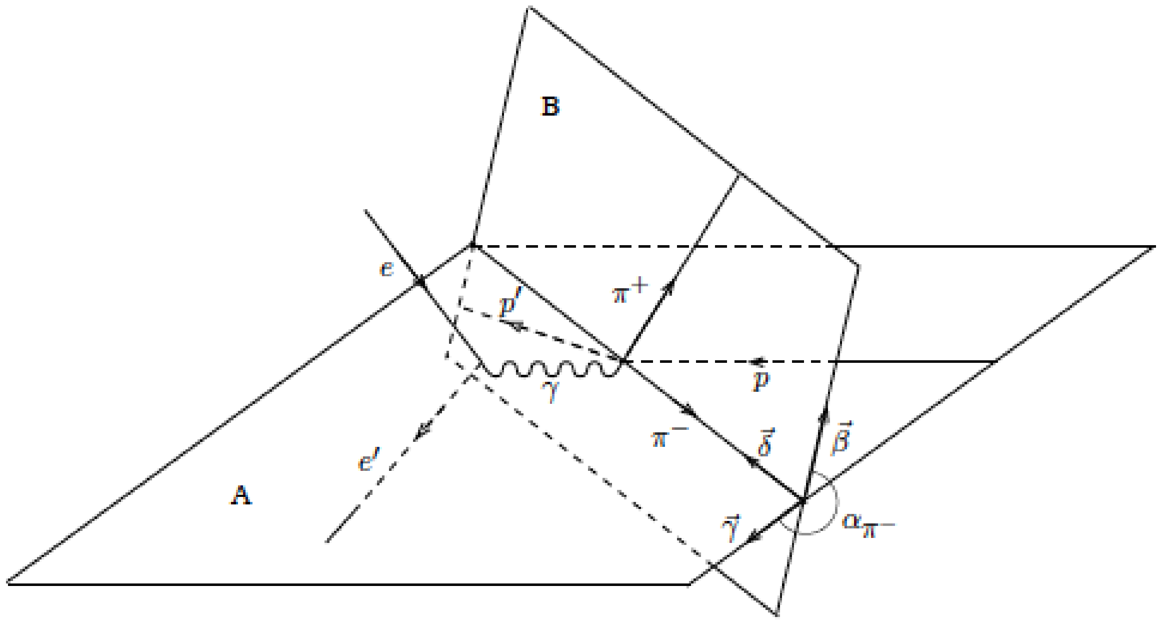
Final hadrons are described by 5 independent variables

$$M_{\pi^+\pi^-}, M_{\pi^+p}, \theta_p, \varphi_p, \alpha_p$$
$$M_{\pi^+\pi^-}, M_{\pi^-p}, \theta_{\pi^+}, \varphi_{\pi^+}, \alpha_{\pi^+}$$
$$M_{\pi^+\pi^-}, M_{\pi^+p}, \theta_{\pi^-}, \varphi_{\pi^-}, \alpha_{\pi^-}$$

All three sets of hadronic variables are used to extract cross sections. The difference between total cross sections obtained by the integration over various sets of hadronic variables is interpreted as systematic uncertainty.

Definition of Final Hadron Angles





Cross Section Determination

$$\frac{d\sigma}{dW\,dQ^2 dM_{p\pi^+} dM_{\pi^+\pi^-} d\Omega d\alpha_{\pi^-}} = \frac{1}{F\cdot R}\frac{\left(\frac{\Delta N_{full}}{Q_{full}} - \frac{\Delta N_{empty}}{Q_{empty}}\right)}{\Delta W \Delta Q^2 \Delta\tau \left(\frac{l\rho N_A}{q_e M_H}\right)}$$

$$\Delta\tau = \Delta M_{p\pi^+} \Delta M_{\pi^+\pi^-} \Delta(-cos(\theta_{\pi^-}))\Delta\varphi_{\pi^-}\Delta\alpha_{\pi^-}$$

ΔN_{full} and ΔN_{empty} are the numbers of events inside a seven-dimensional bin for runs with hydrogen - and empty target, respectively. F is the efficiency determined by the Monte Carlo simulation. R is the radiative correction factor. Q_{full} and Q_{empty} are the integrated Faraday cup charges for runs with hydrogen - and empty target, respectively, and q_e is the elementary charge. ρ is the density of liquid hydrogen at T = 20 K. l is the length of the target (l = 2 cm). M_H is the molar density of the natural mixture of hydrogen and N_A is Avogadro's number. ΔW and ΔQ^2 are kinematical bins determined by the electron scattering kinematics. $\Delta\tau$ is the hadronic five-dimensional kinematic phase-space element.
Due to statistical limitations only single-fold differential cross sections were analyzed:

$$\frac{d\sigma}{dM_{\pi^+\pi^-}} = \int \frac{d^5\sigma}{d^5\tau} d\tau^4_{M_{\pi^+\pi^-}}; \qquad d\tau^4_{M_{\pi^+\pi^-}} = dM_{\pi^+p} d\Omega_{\pi^-} d\alpha_{\pi^-}$$

$$\frac{d\sigma}{dM_{\pi^+p}} = \int \frac{d^5\sigma}{d^5\tau} d\tau^4_{M_{\pi^+p}}; \qquad d\tau^4_{M_{\pi^+p}} = dM_{\pi^+\pi^-} d\Omega_{\pi^-} d\alpha_{\pi^-}$$

$$\frac{d\sigma}{d(-cos\theta_{\pi^-})} = \int \frac{d^5\sigma}{d^5\tau} d\tau^4_{\theta_{\pi^-}}; \qquad d\tau^4_{\theta_{\pi^-}} = dM_{\pi^+\pi^-} dM_{\pi^+p} d\varphi_{\pi^-} d\alpha_{\pi^-}$$

$$\frac{d\sigma}{dM_{\alpha_{\pi^-}}} = \int \frac{d^5\sigma}{d^5\tau} d\tau^4_{\alpha_{\pi^-}}; \qquad d\tau^4_{\alpha_{\pi^-}} = dM_{\pi^+\pi^-} dM_{\pi^+p} d\Omega_{\pi^-}$$

$$d^5\tau = dM_{\pi^+\pi^-} dM_{\pi^+p} d\Omega_{\pi^-} d\alpha_{\pi^-}$$

New 2π Event Generator

- Based on JM15 and the newest data.
- Written on C++.
- Takes into account the cross section dependence on the beam energy.
- Allows to obtain cross section values directly from the event generator (EG).
- EG generates phase space distributions and applies the cross section as weight to each event.

List of data included:

Electroproduction

1) CLAS data at E_{beam} = 2.445, E_{beam} = 4 GeV
M. Ripani et al. [CLAS Collaboration], Phys. Rev. Lett. 91, 022002 (2003)
V. I. Mokeev et al. [CLAS Collaboration], Phys. Rev. C 86, 035203 (2012)

2) CLAS data at E_{beam} = 1.515 GeV
G. V. Fedotov et al. [CLAS Collaboration], Phys. Rev. C 79, 015204 (2009)

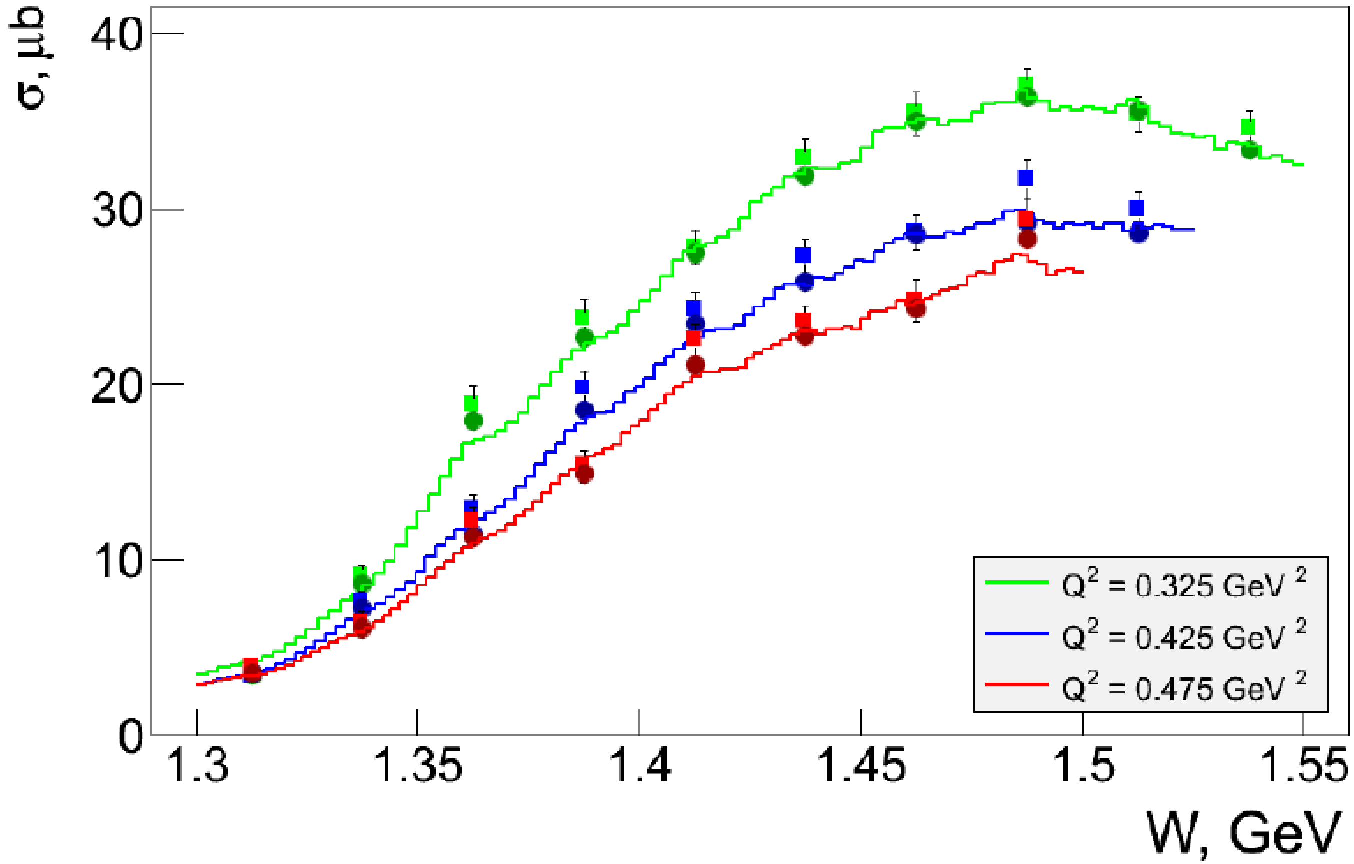
Photoproduction

3) CLAS g11a experiment
E. Golovach et.al. CLAS ANALYSIS NOTE (under review)

4) SAPHIR Eur. Phys. J. A 23, 317 (2005).
ABBHM Collab., Phys. Rev. 175, 1669 (1968)

More information on new EG avaliable on Iu. Skorodumina's wiki page:
https://clasweb.jlab.org/wiki/index.php/NEW_2PI_EVENT_GENERATOR

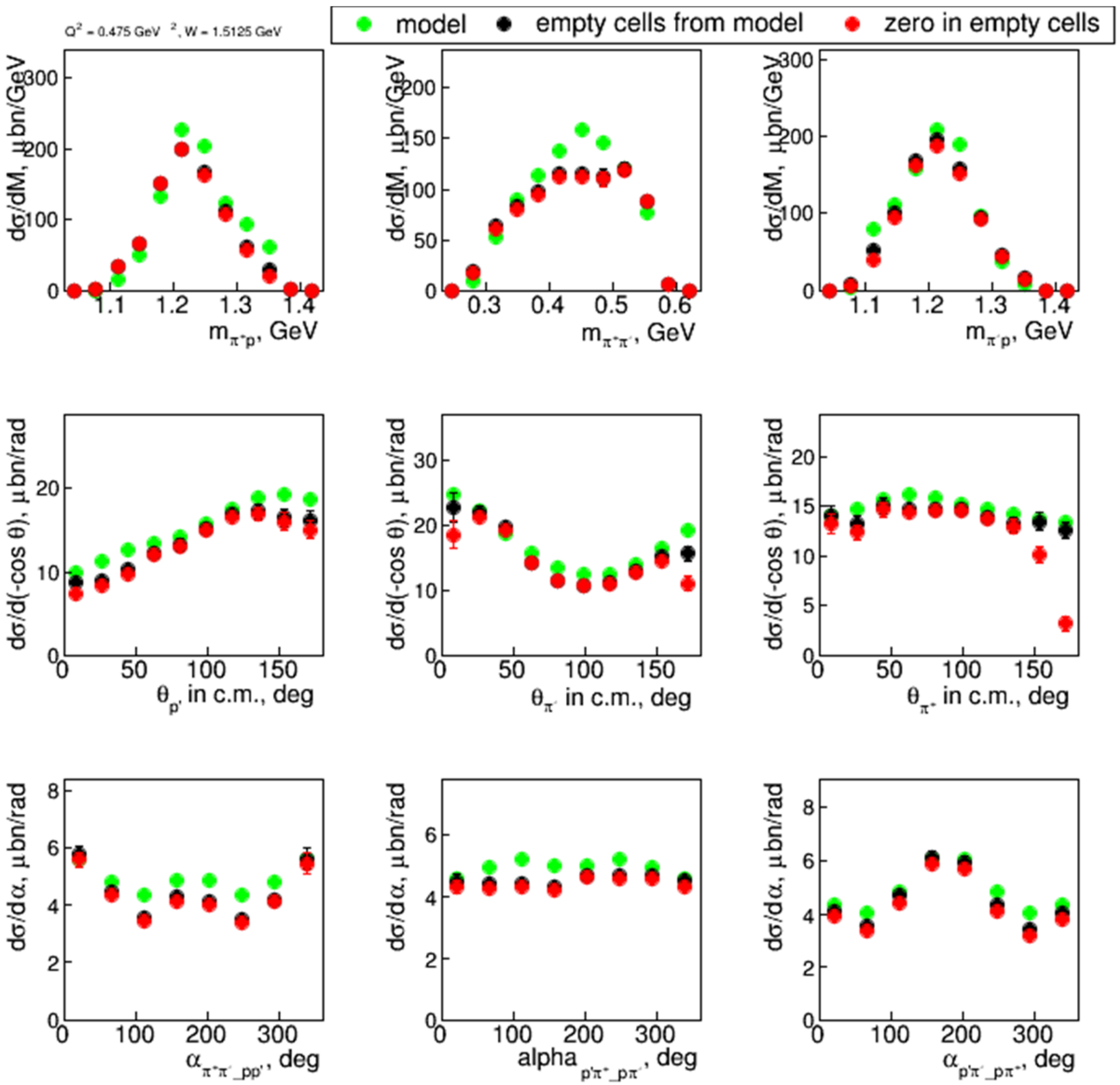
New EG in Comparison with Experimental Data



- Squares – data (G. V. Fedotov *et al*., Phys. Rev. C 79, 015204 (2009))
- Circles – model
- Curves – event generator

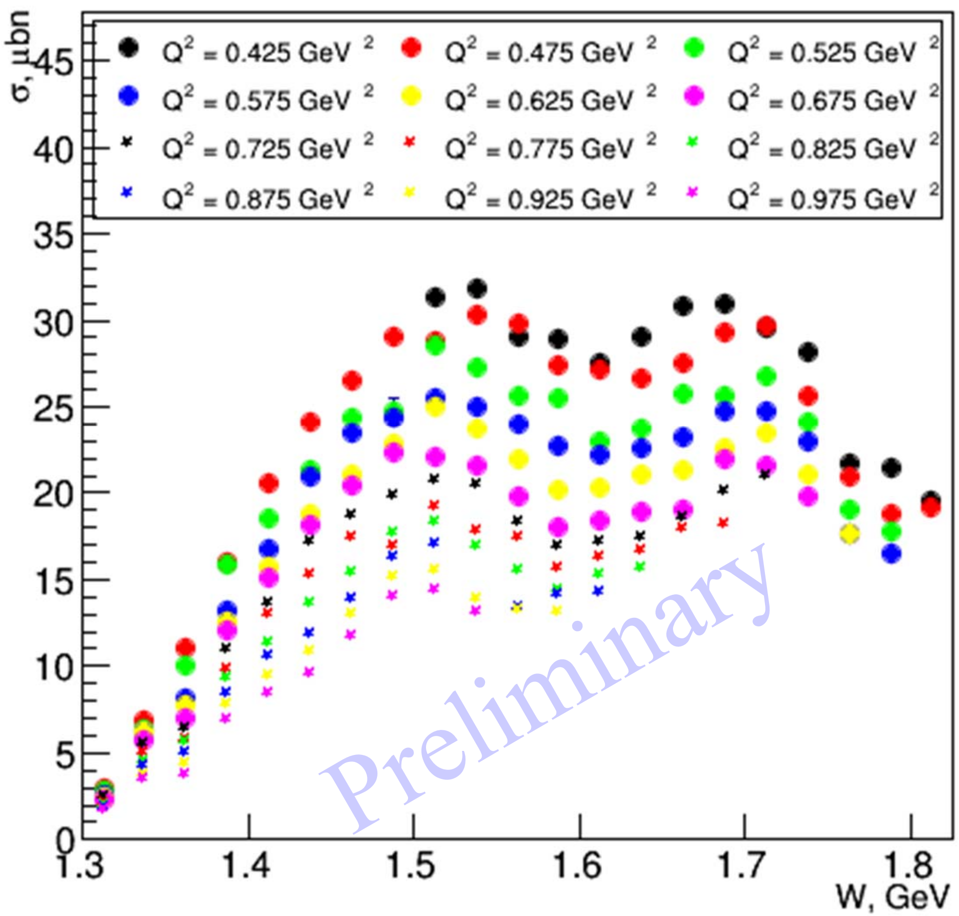
One-Fold Differential Cross Sections from e1e

$Q^2 = 0.475\ GeV^2$, $W = 1.5125\ GeV$



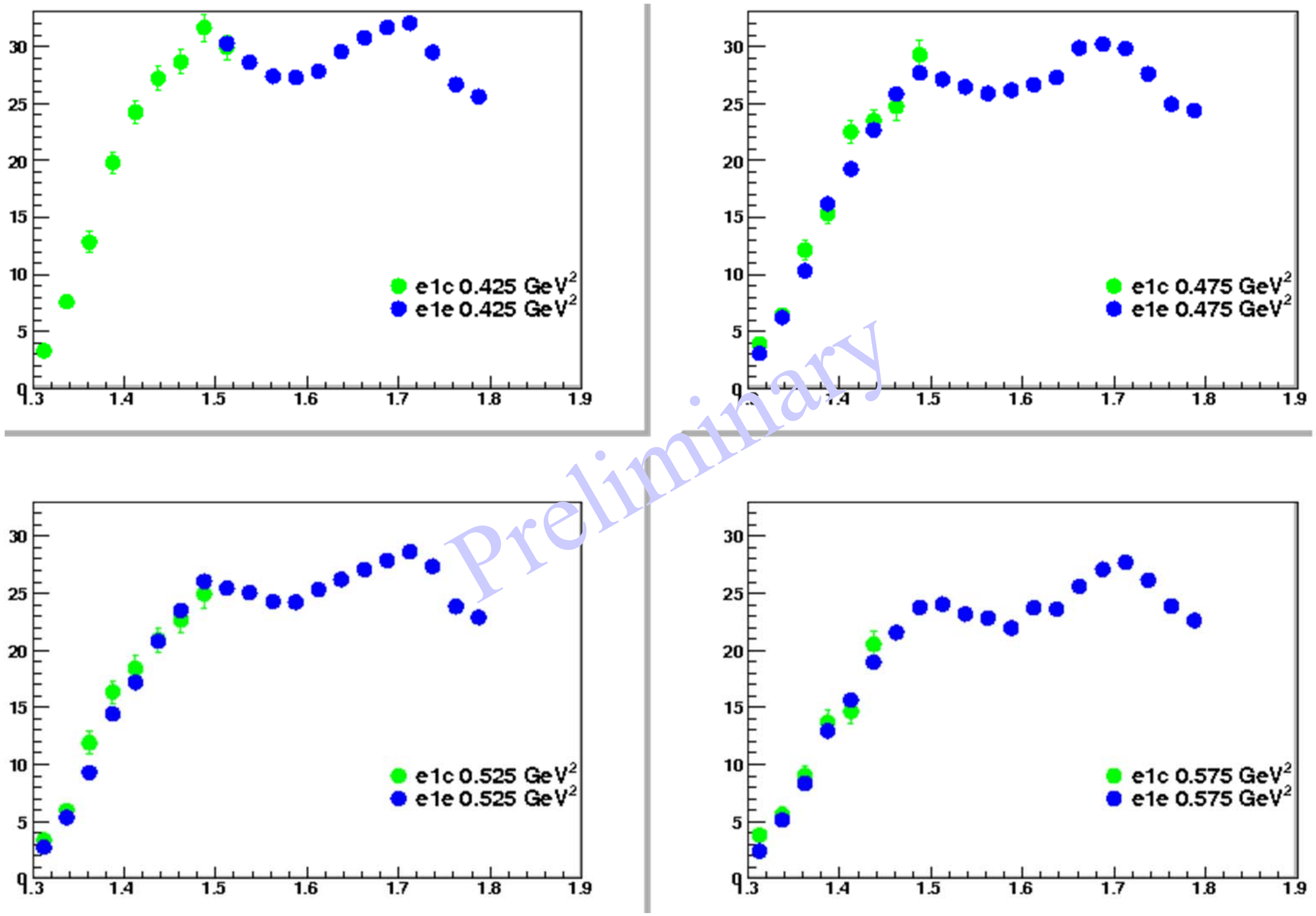
- Combination of all available topologies allows to minimize contributions from zones with zero acceptance.
- New advanced method to fill zones with zero acceptance based on the new 2π event generator .

W-Dependences of Integrated Cross Section



Twelve bins in Q^2 are available.

Comparison of Integrated Cross Sections with Existing Data



Green dots represent published data (Fedotov *et al.*, PRC79, 015204 (2009)), while the blue dots represent the new e1e data. Good agreement in overlapped areas.

Conclusions

- Preliminary data on $\gamma_v p \rightarrow \pi^+\pi^- p$ cross sections were obtained for W from 1.3 GeV to 1.825 GeV and Q^2 from 0.4 GeV^2 to 1 GeV^2.
- Kinematic coverage and statistics exceed the previously available CLAS data and allow for a six times finer binning in Q^2.
- The phenomenological analysis of this data will considerably extend the available information on the Q^2 evolution of the high lying N* electrocouplings.
- Analysis of this data together with $\pi^+\pi^- p$ photoproduction data will provide first detailed access to the structure of the new baryon state N'(1720)$3/2^+$.