

Exclusive $\pi^0 p$ electroproduction in the resonance region with the CLAS12

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Analysis objectives

- Evaluation of exclusive $\pi^0 p$ electroproduction cross sections from the experimental data with CLAS12.
- Expected observables: $\frac{d\sigma}{d(-\cos\theta_\pi)d\phi_\pi}(W, Q^2, \theta, \phi)$,
BSA(W, Q^2, θ, ϕ), exclusive structure functions,
 $\sigma_U(W, Q^2, \cos\theta_\pi)$, $\sigma_{TT}(W, Q^2, \cos\theta_\pi)$, $\sigma_{TL}(W, Q^2, \cos\theta_\pi)$,
 $\sigma_{LT'}(W, Q^2, \cos\theta_\pi)$ for $\gamma_\nu p \rightarrow \pi^0 p$

CLAS12 N^* Program at intermediate Q^2

E12-09-003

Nucleon Resonance Studies with CLAS12
Gothe, Moiseev, Burkert, Cole, Joo, Stoler

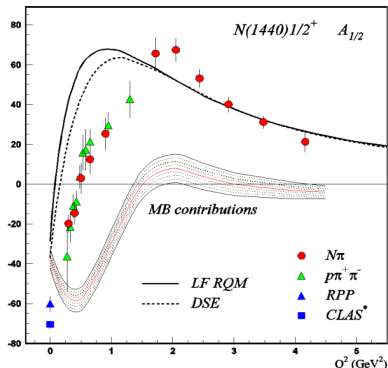
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KY Electroproduction with CLAS12
Carman, Gothe, Moiseev

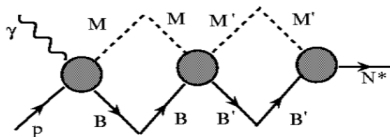
- Measure exclusive electroproduction cross section from an unpolarized proton target with polarized electron beam for $N\pi$, $N\eta$, $N\pi\pi$, KY:
 $E_{beam} = 6.5, 7.5$ GeV, $Q^2 = 0.5 \rightarrow 5$ GeV², $W \rightarrow 2$ GeV with nearly complete coverage of the final state phase space
- Key Motivation: emergence of the external deconfined meson baryon cloud from inner core of three confined quarks.

The experiments already started in February 2018!

Resolving Puzzle of the Roper Structure



The mechanisms of the meson-baryon dressing



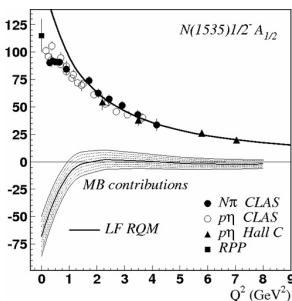
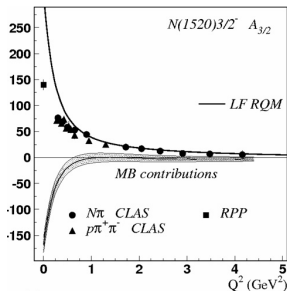
CLAS data in the range of $Q^2 < 5.0 \text{ GeV}^2$ reveal the structure of $N(1440)1/2^+$ as a complex interplay between inner core of three dressed quarks in the first radial excitation and external meson-baron (MB) cloud

LF RQM-Light Front Relativistic Quark Model:
V.D. Burkert, I.G. Aznauryan, Phys. Rev. C85, 055202 (2012); Phys. Rev. C95, 065207 (2017)

Quark core description within LF RQM and DSE is consistent

For more details on resolving Roper puzzle see:
V. D. Burkert and C.D. Roberts, Rev. Mod. Phys. 91, 011003 (2019)

$\gamma_\nu p N^*$ electrocouplings from $N\pi$, $N\eta$ and $\pi^+\pi^-p$ electroproduction



CLAS data points from:

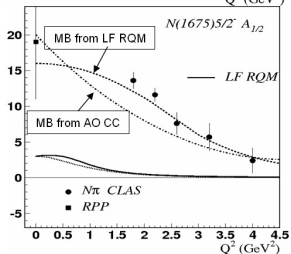
- I.G. Aznauryan et al., Phys. Rev. C80, 055203 (2009).
K. Park et al., Phys. Rev. C91, 045203 (2015).
V.I. Mokeev et al., Phys. Rev. C86, 035203 (2012).
V.I. Mokeev et al., Phys. Rev. C93, 025206 (2016).

LF RQM:

- I.G. Aznauryan and V.D. Burkert, Phys. Rev. C95, 065207 (2017).

AO CC:

- B. Julia-Diaz et al., Phys. Rev. C77, 045205 (2008).



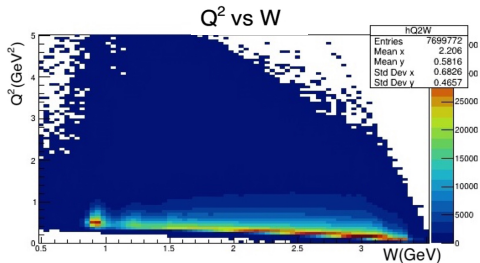
Consistent values of resonance electrocouplings from $N\pi$, $N\eta$, and $\pi^+\pi^-p$ electroproduction strongly support their reliable extraction

The structure of all resonances studied with CLAS represents a complex interplay between the inner quark core and external meson-baryon cloud.

N^* electroexcitation at intermediate Q^2 with CLAS12

Expected outcome: the $\gamma_V p N^*$ electrocouplings of most N^* states from the data in the range of $W < 2$ GeV and $Q^2 < 5$ GeV² for exclusive channels: πN , $\pi\pi N$, KY , K^*Y , KY^* .

kinematic coverage for RG-K data @ 6.535 GeV



The projected statistics suggests the opportunity to obtain $\pi^0 p$ electroproduction observables allowing us to determine electrocouplings of most resonances with substantial $N\pi$ decays. $\gamma_V p N^*$ electrocouplings will be obtained at $Q^2 < 5.0$ GeV² with fine binning over Q^2 $\Delta Q^2 \sim 0.3$ GeV² shedding light on the transition between meson-baryon cloud and quark core in the N^* structure.

Summary of results on $\gamma_{\nu}pN^*$ photo-/electrocouplings from CLAS

Exclusive meson electroproduction channels	Excited proton states	Q^2 -ranges for extracted $\gamma_{\nu}pN^*$ electrocouplings, GeV^2
$\pi^0 p, \pi^+ n$	$\Delta(1232)3/2^+$	0.16-6.0
	$N(1440)1/2^+, N(1520)3/2^-, N(1535)1/2^-$	0.30-4.16
$\pi^+ n$	$N(1675)5/2^-, N(1680)5/2^+, N(1710)1/2^+$	1.6-4.5
ηp	$N(1535)1/2^-$	0.2-2.9
$\pi^+ \pi^0 p$	$N(1440)1/2^+, N(1520)3/2^-$	0.25-1.50
	$\Delta(1620)1/2^-; N(1650)1/2^-; N(1680)5/2^+, \Delta(1700)3/2^-; N(1720)3/2^+, N'(1720)3/2^+$ $\Delta(1620)1/2^-; N(1650)1/2^-; N(1680)5/2^+, \Delta(1700)3/2^-; N(1720)3/2^+, N'(1720)3/2^+; \Delta(1905)5/2^+, \Delta(1950)7/2^+$	0.5-1.5 photoproduction

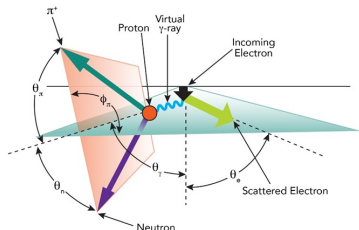
The website with numerical results and references: userweb.jlab.org/~mokeev/resonance_electrocouplings/

The interpolated/extrapolated CLAS results on $\gamma_{\nu}pN^*$ electrocouplings in the mass range $<1.8 \text{ GeV}$ and $Q^2 < 5.0 \text{ GeV}^2$:
userweb.jlab.org/~isupov/couplings/

Accessing Resonance Electrocouplings from the Differential Electroproduction Cross Sections off Protons

Ready-to-go approach for $\gamma_{\nu} p N^*$ electrocoupling extraction for $N\pi$ electroproduction:

Kinematics of exclusive π^*n electroproduction off protons (lab frame)

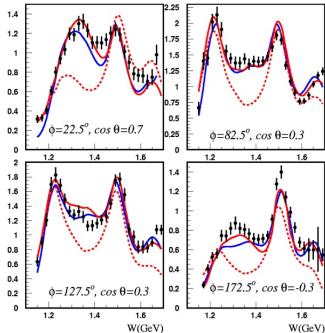


**π^*n and π^0p channels:
Unitary Isobar Model (UIM) and Fixed-t Dispersion Relations (DR)**

I.G. Aznauryan, Phys. Rev. C67, 015209 (2003)
I.G. Aznauryan et al. (CLAS), Phys. Rev. C80, 055203 (2009)
I.G. Aznauryan et al. (CLAS), Phys. Rev. C91, 045203 (2015)

$Q^2=2.05 \text{ GeV}^2$

- DR
- ⋯ DR w/o P11
- UIM



Selection of $\pi^0 p$ electroproduction events from CLAS12 data

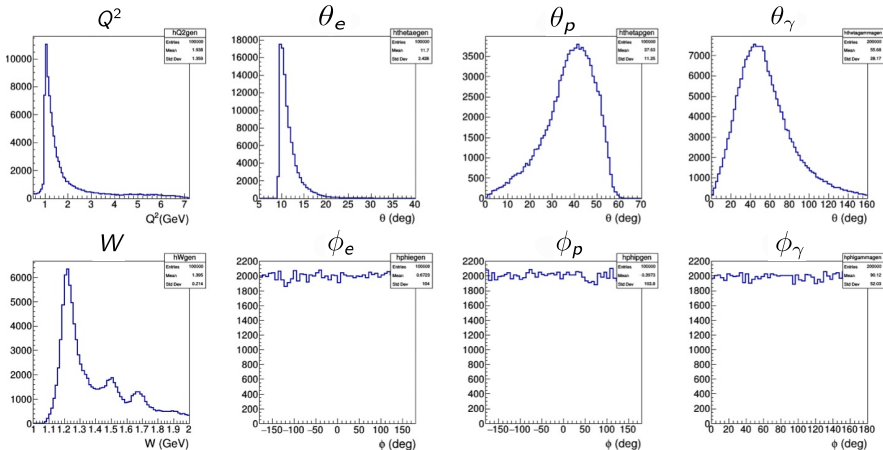
- RG-K data was analysed (10 % of expected statistics)
- For isolation of $\pi^0 p$ events event generator (EG) of $\pi^0 p$ electroproduction has been developed
- It allowed us
 - ▶ work out selection criteria from single pion channel
 - ▶ check quality and optimize cuts for the selection of $\pi^0 p$ events
- EG is based on the interpolation of the exclusive $\pi^0 p$ cross sections measured with the CLAS detector over W , Q^2 , $\cos\theta$, ϕ at the $W < 2$ GeV and $Q^2 < 5$ GeV²

Simulation of $\pi^0 p$ electroproduction

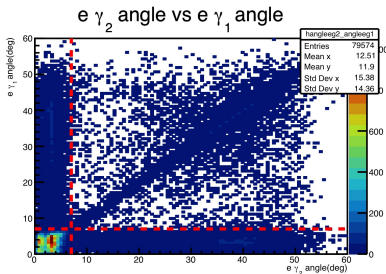
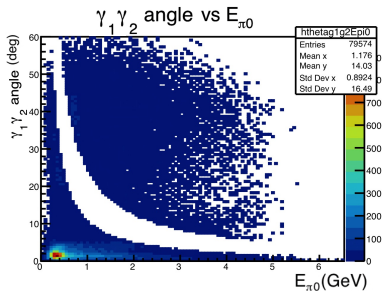
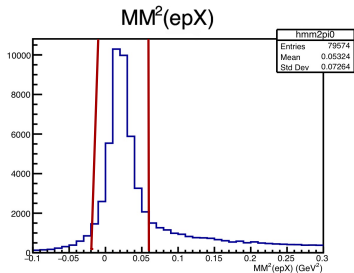
$E_{\text{beam}} = 6.535$ GeV

Data: Simulation (100000 events)

Reaction: $ep \rightarrow ep\pi_0 \rightarrow ep\gamma\gamma$



Selection criteria from simulation



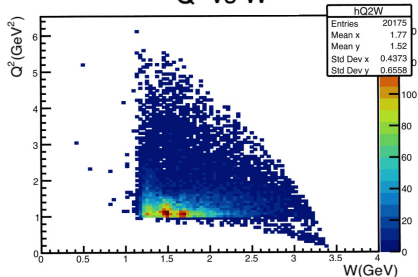
Events with missing mass inside pion peak was cutted out for background isolation.
 Events with angle between electron and either photons less 7 degrees should be cutted out.

Selection criteria from $p\pi^0$ events

- One electron, one proton and at least two gammas are detected.
- $E_e > 1$ GeV.
- $W > 1.07$ GeV
This cut actually isolate kinematic range above single pion threshold.
- We selected pair of photons with maximum energy.
Most of the background photons have small energies.
- $0.08 < M_{\gamma\gamma} < 0.35$ GeV. With this cut we isolate $\pi^0 pX$ events.
- $-0.2 < MM^2(epX) < 0.2$ GeV. With this cut we isolate $\pi^0 pX$ events.
- Angle between e and gammas $> 7^\circ$. This cut allowed us to cut out radiative photons from electron.
- $\theta_{\gamma_{1,2}} > 5^\circ$
- $\Delta v_z = |v_{zp} - z_{ze}| < 1 + \frac{4}{\rho_p}$ cm.
- $E_{\gamma_{1,2}} > 0.15$ GeV

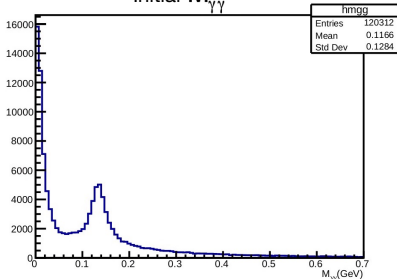
Checking the quality of isolation criteria

Q^2 vs W

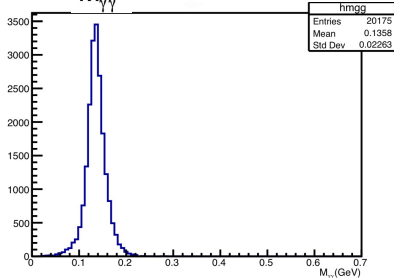


It is the result for applying obtained selections to reconstructed events for simulation. Significant reduction of background has been achieved.

Initial $M_{\gamma\gamma}$



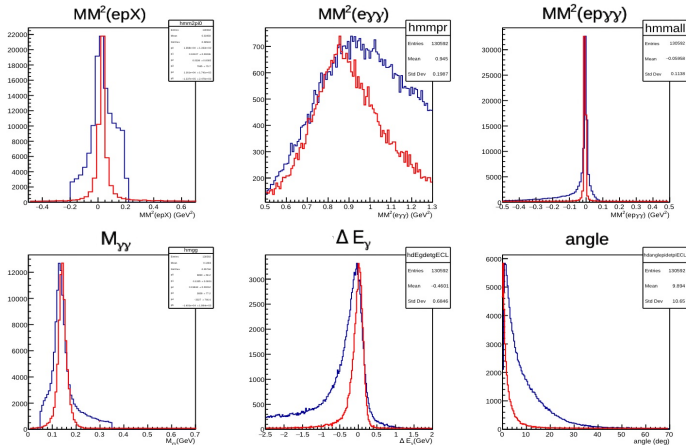
$M_{\gamma\gamma}$ after event selection



Comparison between experimental data and simulation for $\pi^0 p$ electroproduction

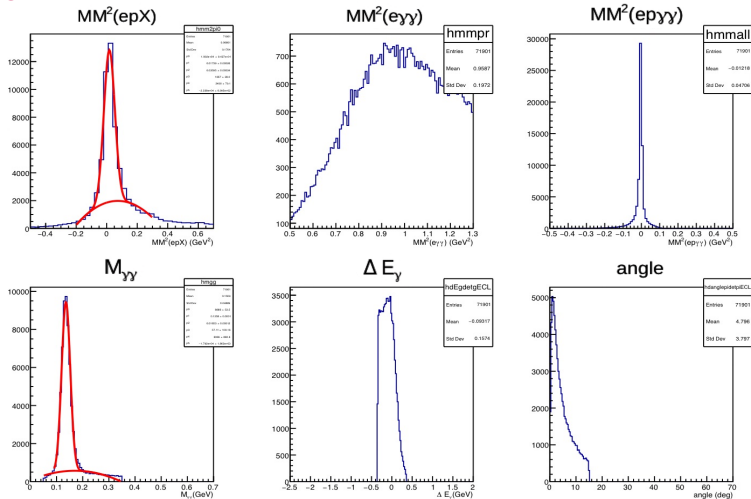
Red - simulation

Blue - experimental data



- $\vec{p}_{\pi_1^0} = \vec{p}_e + \vec{p}_p - \vec{p}_{e'} - \vec{p}_{p'}$
 - $\vec{p}_{\pi_2^0} = \vec{p}_{\gamma_1} + \vec{p}_{\gamma_2}$
- $\Delta E = (E_{\gamma_1} + E_{\gamma_2}) - (E_e + E_p - E_{e'} - E_{p'})$
 angle - angle between two vectors $\vec{p}_{\pi_1^0}$ and $\vec{p}_{\pi_2^0}$

Background reduction



- $\vec{p}_{\pi_1^0} = \vec{p}_e + \vec{p}_p - \vec{p}_{e'} - \vec{p}_{p'}$
 - $\vec{p}_{\pi_2^0} = \vec{p}_{\gamma_1} + \vec{p}_{\gamma_2}$
- $\Delta E = (E_{\gamma_1} + E_{\gamma_2}) - (E_e + E_p - E_{e'} - E_{p'})$
- angle - angle between two vectors $\vec{p}_{\pi_1^0}$ and $\vec{p}_{\pi_2^0}$

Conclusions and outlook

- The criteria for exclusive $\pi^0 p$ selection have been developed and used for selection $\pi^0 p$ events from CLAS12 data.
- Plan for the future:
 - ▶ Studies in the full statistics
 - ▶ Binning over W , Q^2 , θ_p , ϕ_p
 - ▶ Efficiency evaluation
 - ▶ Beam asymmetry evaluation
 - ▶ Cross-section evaluation
 - ▶ Structure function evaluation

Thanks for your attention!