Exclusive π^0p electroproduction in the resonance region with the CLAS12

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Analysis objectives

- Evaluation of exclusive π^0p 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$(W, Q^2, \theta, \phi)$, 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 $\gamma_v p \to \pi^0 p$

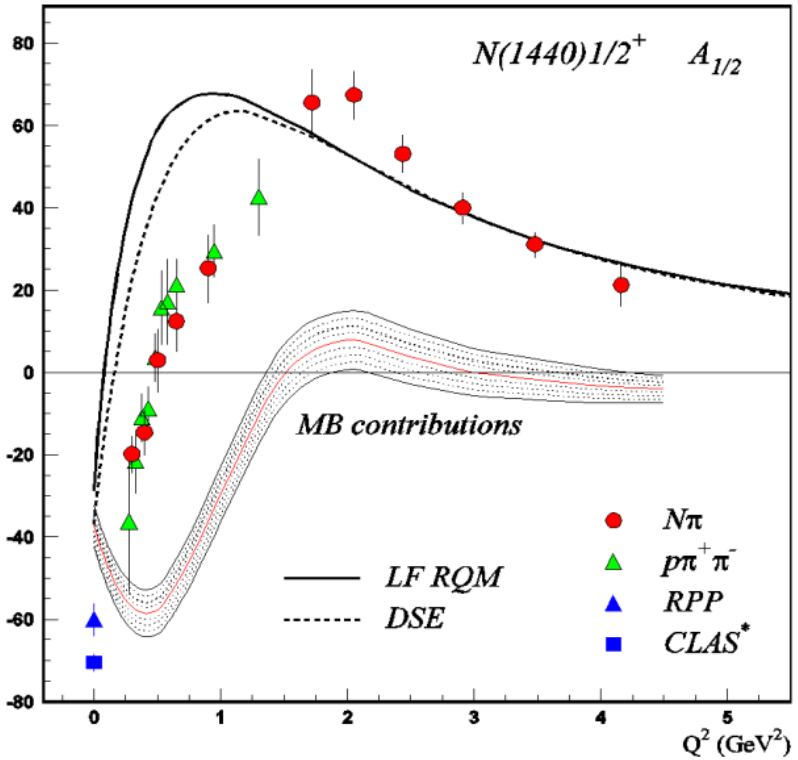
CLAS12 N^* Program at intermediate Q^2

E12-09-003	E12-06-108A
Nucleon Resonance Studies with CLAS12	KY Electroproduction with CLAS12
Gothe, Mokeev, Burkert, Cole, Joo, Stoler	*Carman, Gothe, Mokeev*

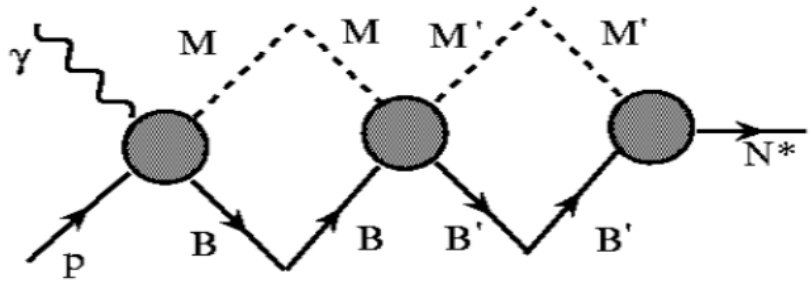
- Measure exclusive electroproduction cross section from an unpolarizes proton target with polarized electron beam for $N\pi$, $N\eta$, $N\pi\pi$, KY:
  $E_{beam} = 6.5$, 7.5 GeV, $Q^2 = 0.5 \rightarrow 5$ GeV^2, $W \rightarrow 2$ GeV with nearly complete coverage of the final state phase space
- Key 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



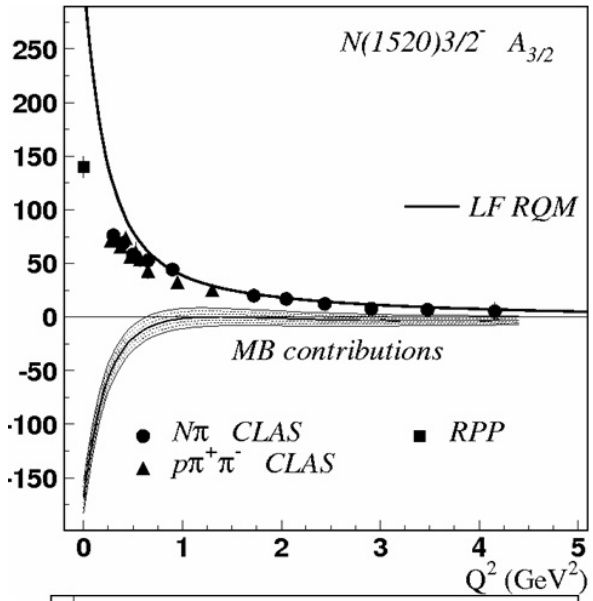
CLAS data in the range of Q^2<5.0 GeV^2 reveal the structure of N(1440)1/2+ as a complex interplay between inner core of three dressed quarks in the first radial excitation and external meson-baron (MB) cloud

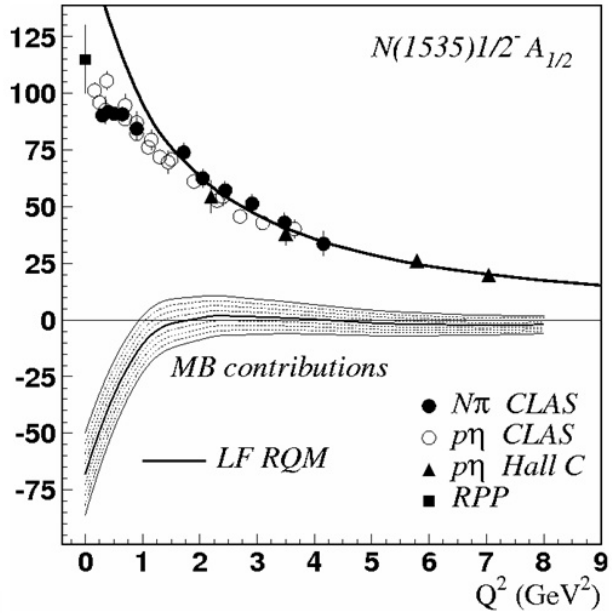
LF RQM-Light Front Relativistic Quark Model: V.D. Burkert, I.G. Aznauryan, Phys . Rev. C85, 055202 (2012); Phys. Rev. C95, 065207 (2017)

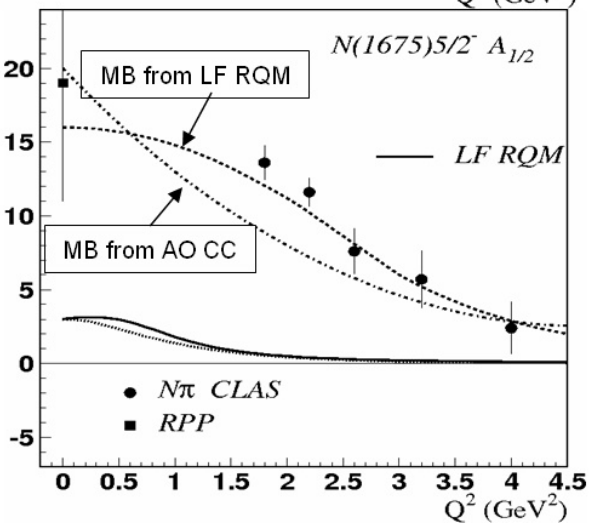
Quark core description within LF RQM and DSE is consistent

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

$\gamma_v pN^*$ 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).

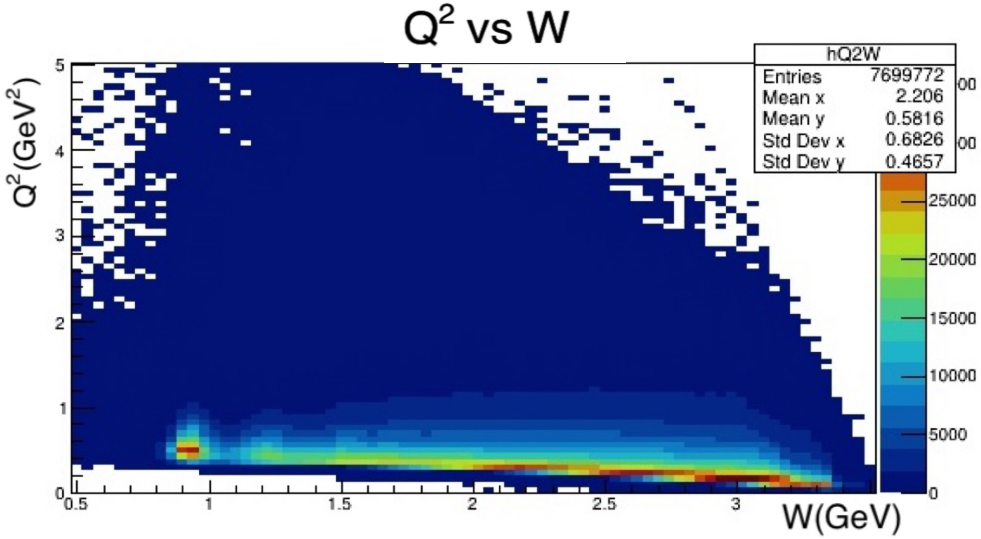
Consistent values of resonance electrocouplings from $N\pi$, $N\eta$, and $\pi^+\pi^-p$ electroproduction strongly support their reliable extraction

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 $\gamma_v pN^*$ electrocouplings of most N^* states from the data in the range of $W < 2$ GeV and $Q^2 < 5$ GeV^2 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 electrocoiuplings of most resonances with substantial $N\pi$ decays. $\gamma_v pN^*$ electrocouplings will be obtained at $Q^2 < 5.0$ GeV^2 with fine binning over Q^2 $\Delta Q^2 \sim 0.3$ GeV^2 shedding light on the transition between meson-baryon cloud and quark core in the N^* structure.

Summary of results on $\gamma_v pN^*$ photo-/electrocouplings from CLAS

Exclusive meson electroproduction channels	Excited proton states	Q^2-ranges for extracted $\gamma_v pN^*$ 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
$\pi^+\pi^- p$	$N(1440)1/2^+$, $N(1520)3/2^-$	0.25-1.50
	$\Delta(1620)1/2^-$, $N(1650)1/2^-$, $N(1680)5/2^+$, $\Delta(1700)3/2^-$, $N(1720)3/2^+$, $N'(1720)3/2^+$	0.5-1.5
	$\Delta(1620)1/2^-$, $N(1650)1/2^-$, $N(1680)5/2^+$, $\Delta(1700)3/2^-$, $N(1720)3/2^+$, $N'(1720)3/2^+$, $\Delta(1905)5/2^+$, $\Delta(1950)7/2+$	photoproduction

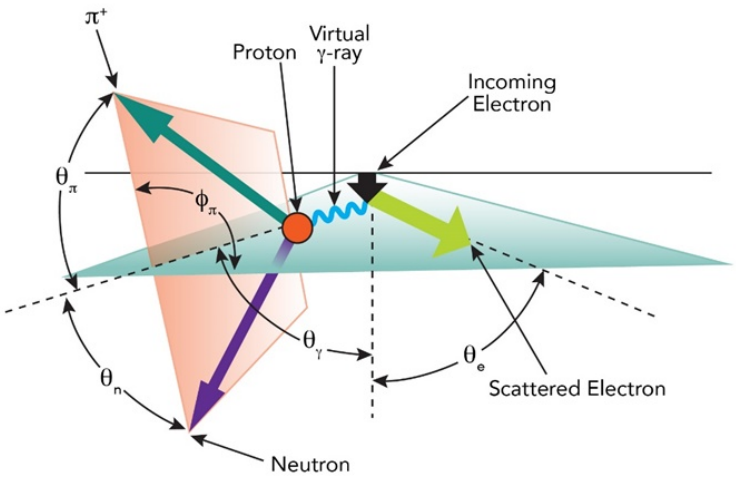
The website with numerical results and references: userweb.jlab.org/ ~mokeev/resonance_ electrocouplings/

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

Accessing Resonance Electrocouplings from the Differential Electroproduction Cross Sections off Protons

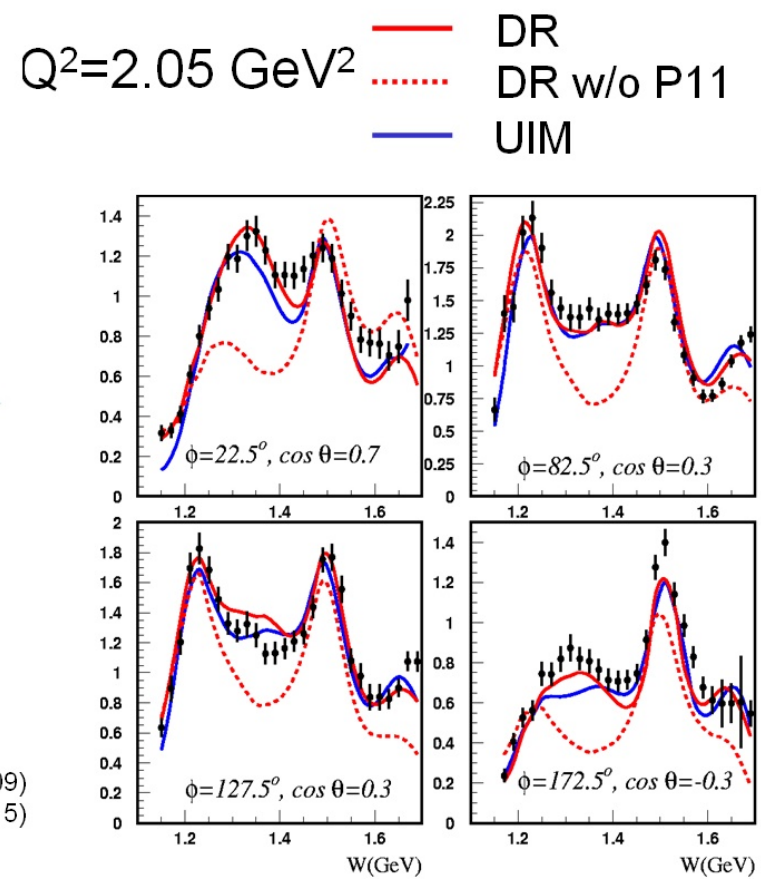
Ready-to-go approach for $\gamma_v pN^*$ electrocoupling extraction for $N\pi$ electroproduction:

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)



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 mesuared with the CLAS detector over W, Q^2, $\cos\theta$, ϕ at the $W < 2$ GeV and $Q^2 < 5$ GeV^2

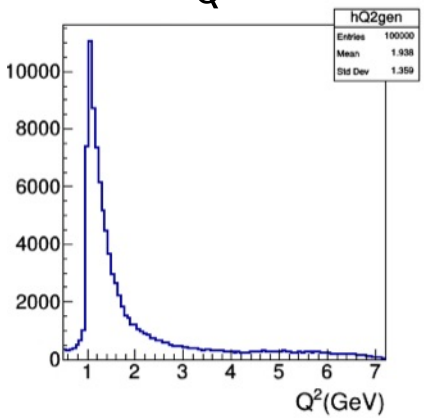
Simulation of $\pi^0 p$ electroproduction

E_{beam}=6.535 GeV

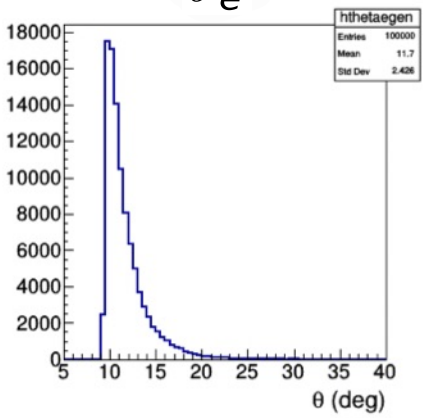
Data: Simulation (100000 events)

Reaction: ep->epπ_0->ep$\gamma\gamma$

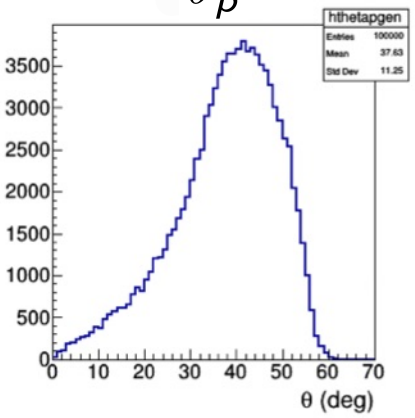
Q^2



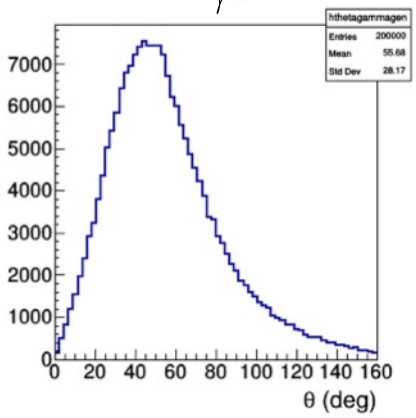
θ_e



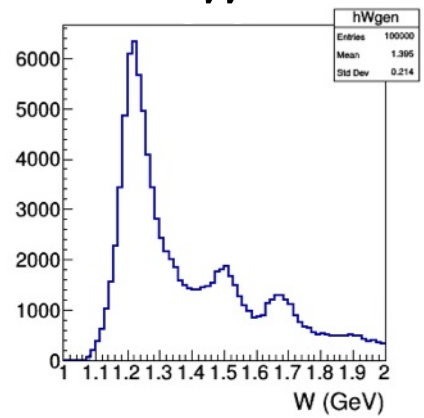
θ_p



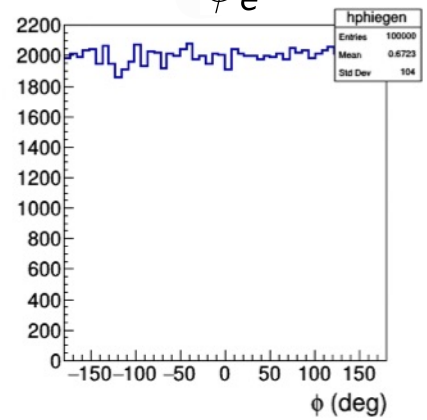
θ_γ



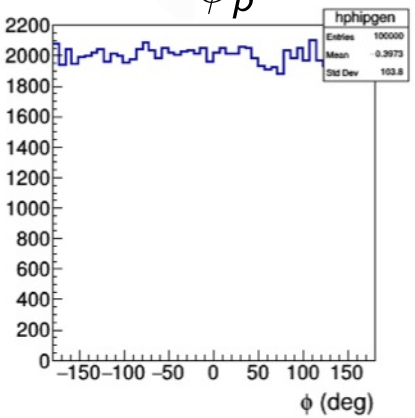
W



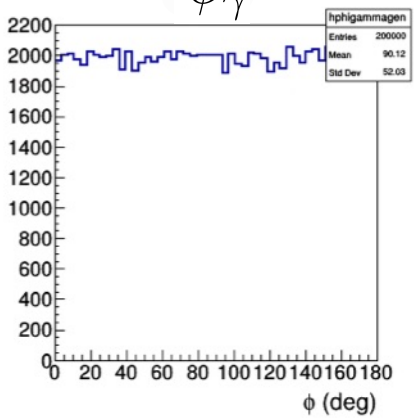
ϕ_e



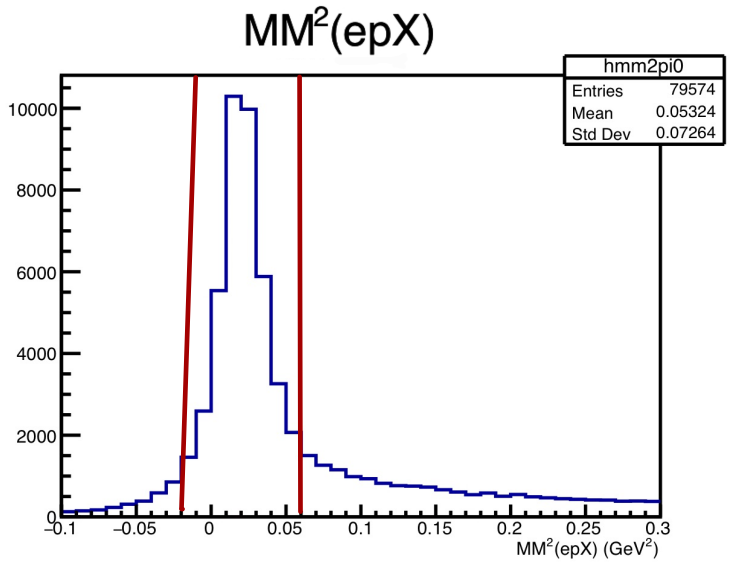
ϕ_p

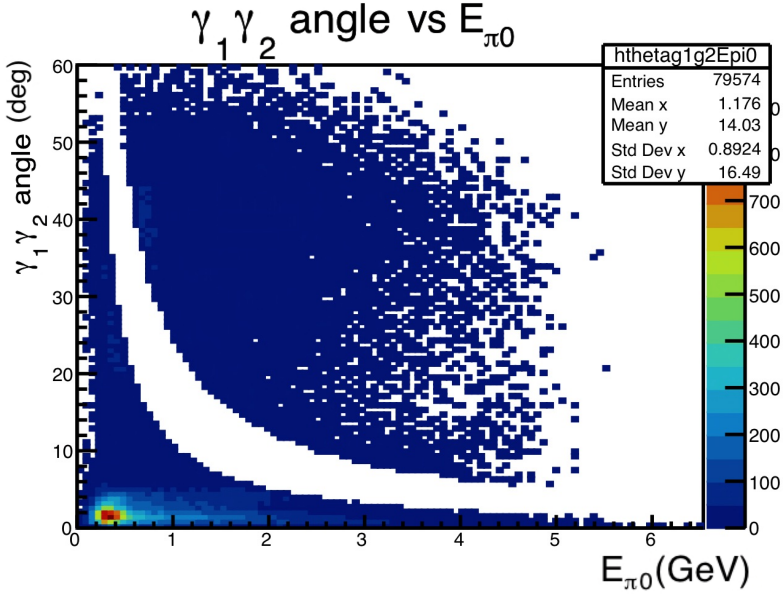


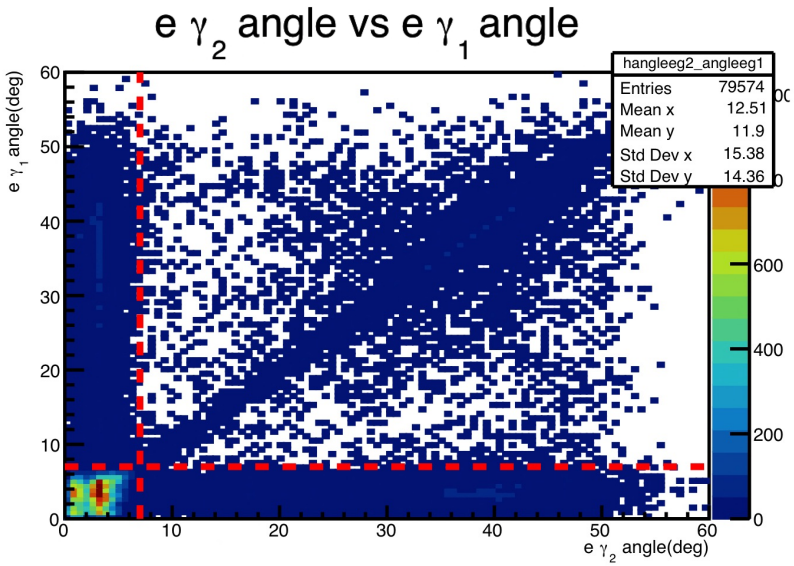
ϕ_γ



Selection criteria from simulation







Events with missing mass of pion located between two vertical lines were cutted out for background isolation.
Events with angle between electron and either photons should be cutted out.

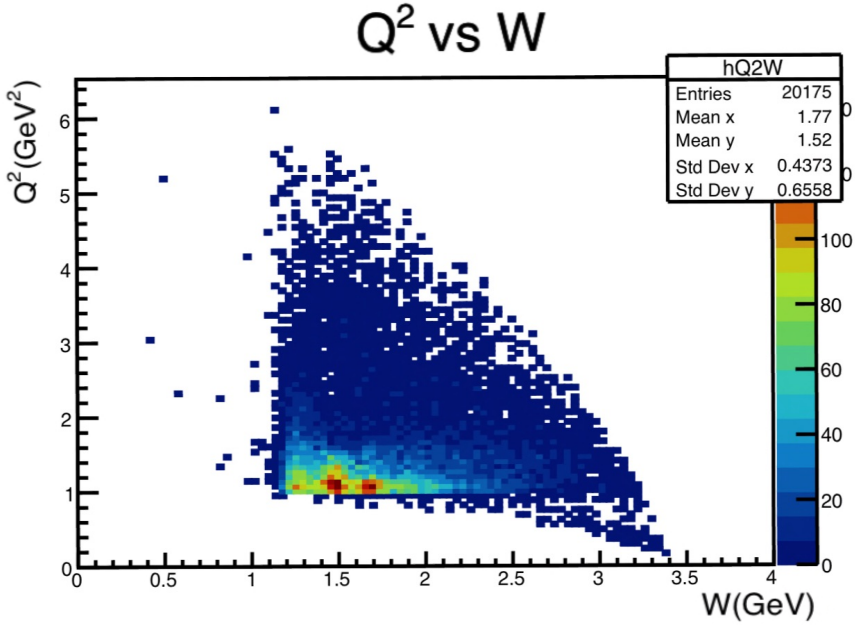
Selection criteria from $p\pi^0$ events

- One electron, one proton and at least two gammas are detected.
- $E_e > 1$ GeV.
- $W > 1.07$ GeV

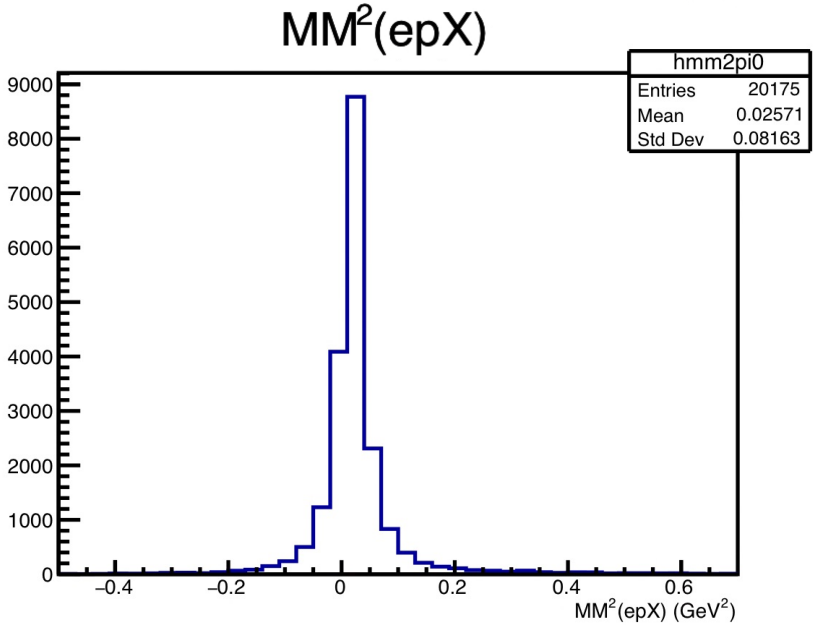
  This cut actually isolate kinematic range above single pion threshold.
- We selected pair of photons with maximum energy.

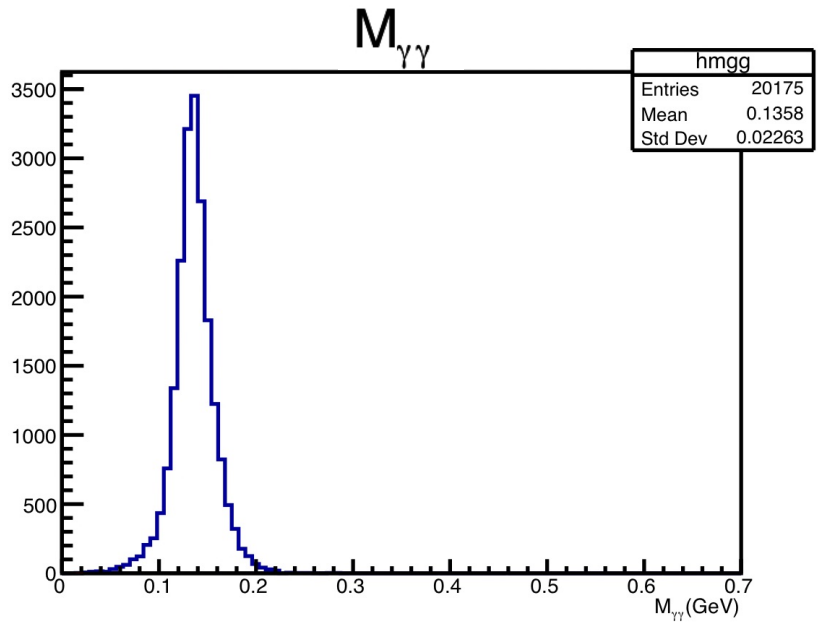
  Most of the background photons have small energies.
- $0.08 < M_{\gamma\gamma} < 0.35$ GeV. With this cut we isolate $\pi^0 pX$ events.
- $-0.2 < MM^2(epX) < 0.2$ GeV. With this cut we isolate $\pi^0 pX$ events.
- Angle between e and gammas $> 7^\circ$. This cut allowed us to cut out radiative photons from electron.
- $\theta_{\gamma_{1,2}} > 5^\circ$
- $\Delta v_z = |v_{zp} - z_{ze}| < 1 + \frac{4}{p_p}$ cm.
- $E_{\gamma 1,2} > 0.15$ GeV

Checking the quality of isolation criteria



It is the result for applying of obtained selections for generated events. We can see significant reduction of background.

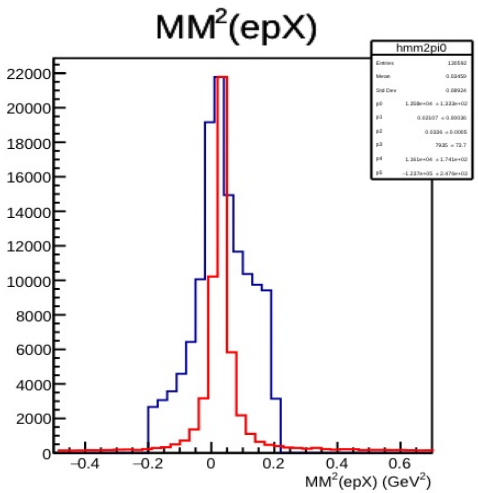


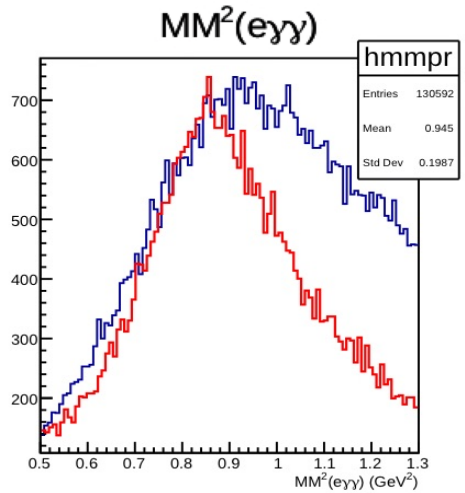


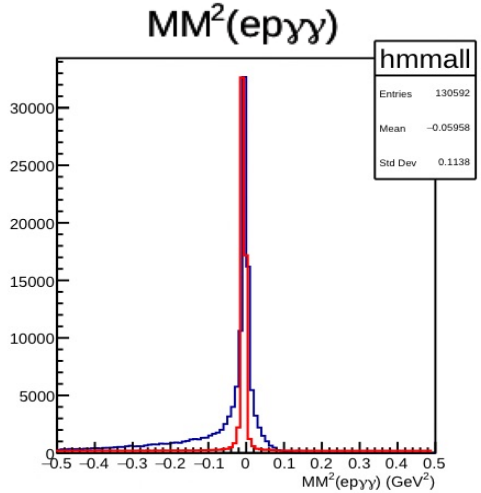
Result without optimization

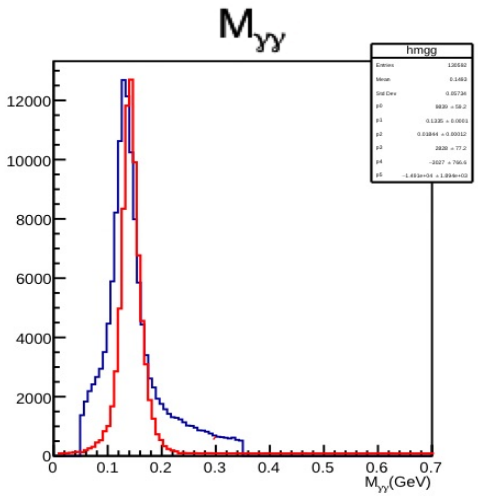
Red - simulation

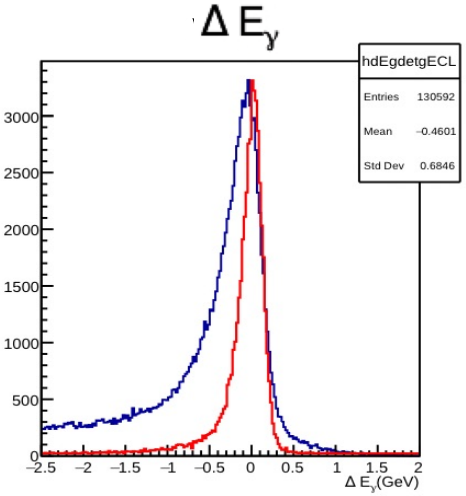
Blue - experimental data

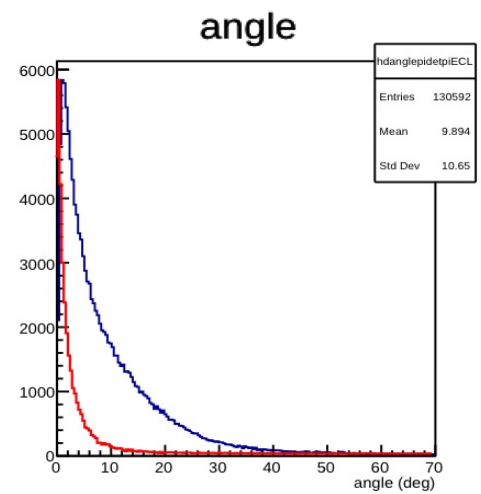










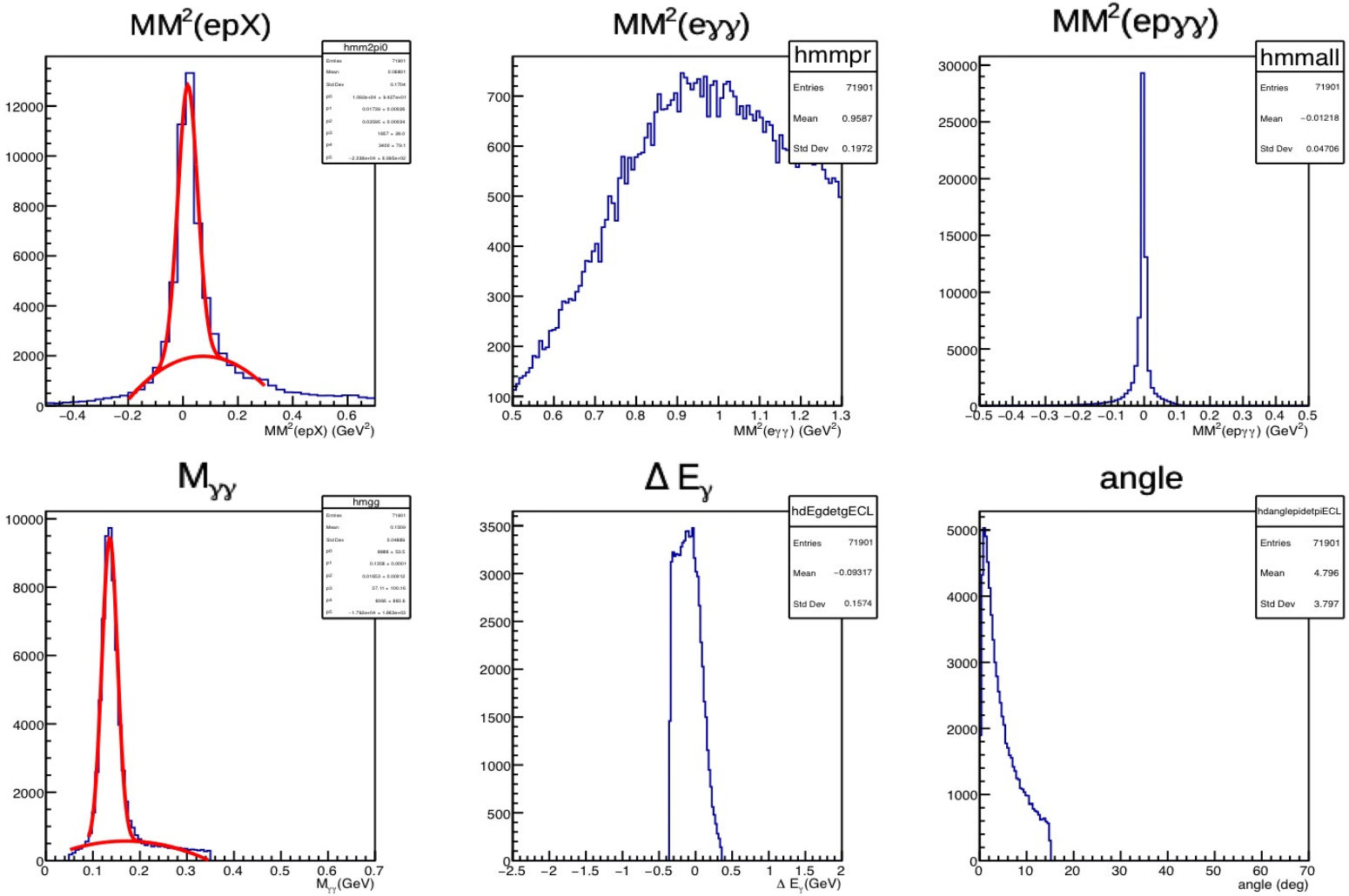


1. $\overrightarrow{p}_{\pi_1^0} = \overrightarrow{p}_e + \overrightarrow{p}_p - \overrightarrow{p}_{e'} - \overrightarrow{p}_{p'}$, 2. $\overrightarrow{p}_{\pi_2^0} = \overrightarrow{p}_{\gamma_1} + \overrightarrow{p}_{\gamma_2}$

$\Delta E = (E_{\gamma_1} + E_{\gamma_2}) - (E_e + E_p - E_{e'} - E_{p'})$

angle - angle between two vectors $p_{\pi_1^0}$ and $p_{\pi_2^0}$

Result with optimization



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angle - angle between two vectors $p_{\pi_1^0}$ and $p_{\pi_2^0}$

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