CLAS Collaboration Meeting, Hadron Spectroscopy

Investigation of Exclusive π+π- Electroproduction off the Proton Bound in the Deuteron in the Resonance Region with CLAS

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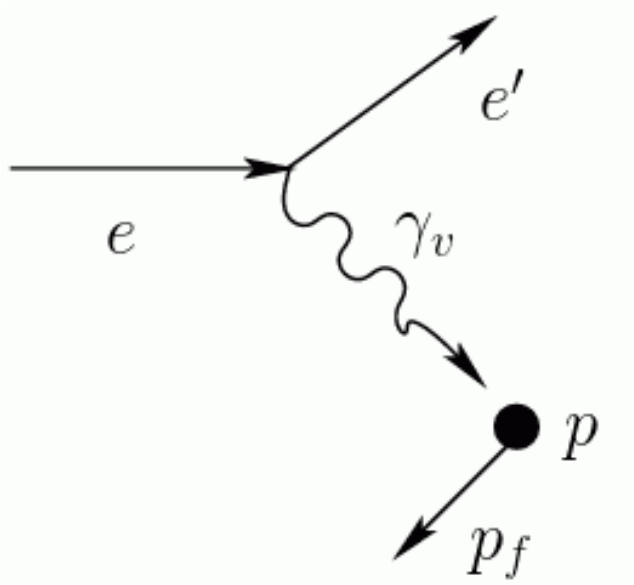
(University of South Carolina)

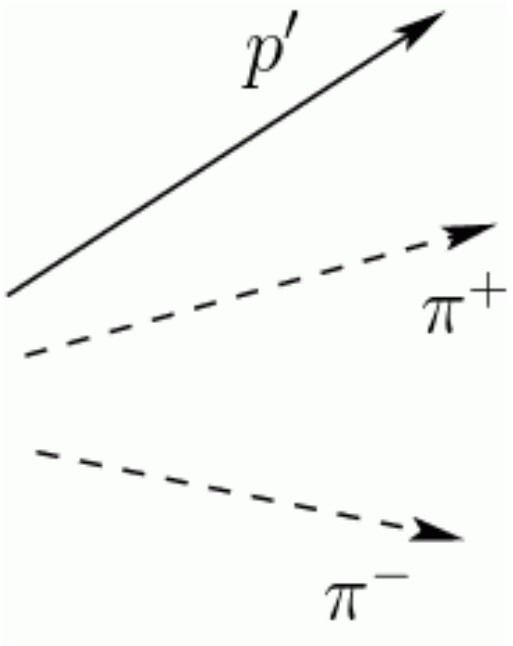
Thursday, 3 November 2016

Deuteron Target Experiment

(e1e run, E_{beam} = 2.039 GeV)

$\gamma_v\, p(n)$ → $p'(n')\pi^+\,\pi^-$





What is different from the free proton target experiment?

1) Fermi motion of the target proton which leads to:

- *W*-smearing if not all final particles are registered
- Different procedure of lab-to-cms transformation

2) Considerably more complex effects of initial and final state interactions due to the presence of spectator neutron

3) Off-shellness of the target proton

4) Possible modification of reaction amplitudes

Final Goals

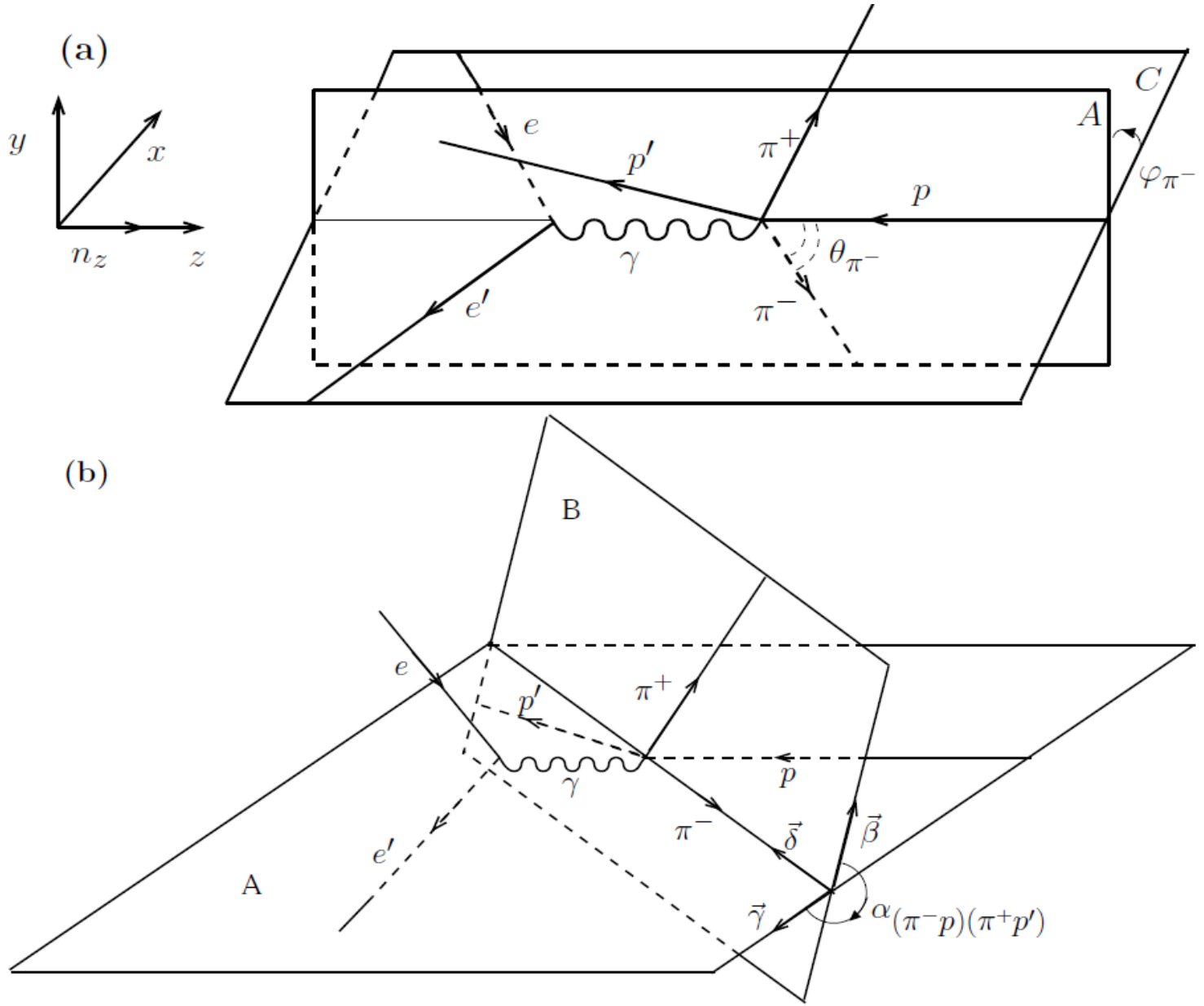
- To extract fully integrated and single differential cross sections of the reaction $\gamma_v\, p(n) \rightarrow p'(n')\pi^+\,\pi^-$ in the resonance region 1.3 GeV < W< 1.825 GeV, 0.45 GeV^2 < Q^2 < 1 GeV^2

- To compare them with the cross sections of the analogous reaction off the free proton

$$\frac{d^7\sigma_e}{dW\,dQ^2 d^5\tau} = \Gamma_v \frac{d^5\sigma_v}{d^5\tau}$$

$$d^5\tau \;=\; dM_{\pi^+ p}\, dM_{\pi^+\pi^-}\, d\Omega_{\pi^-}\, d\alpha_{[\pi^- p][\pi^+ p']}$$

2π Kinematics



2π Event Selection

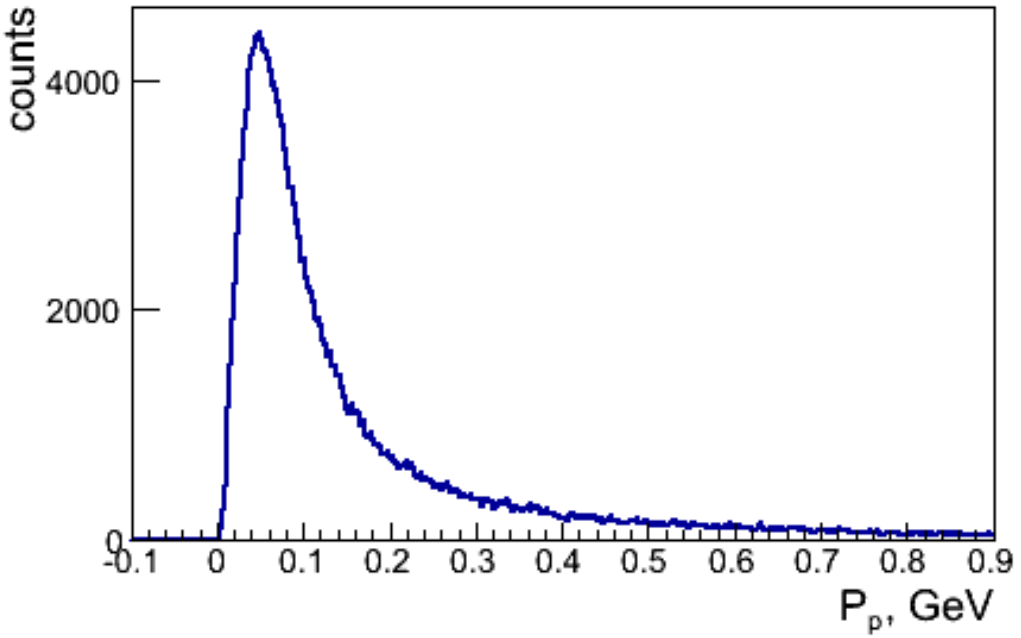
Cuts	Data	Simulation
Fiducial	yes	yes
EC-cut	yes	yes
CC-cut	yes	no/yes
β vs. p	yes	yes
θ vs. p	yes	yes
Electron momentum correction	yes	no
Proton energy loss correction	yes	yes
Exclusivity cut	yes	yes

Corrections to the Cross Sections

- *FSI correction*
- Empty target subtraction
- Correction due to the filling cells with zero acceptance from the EG
- Radiative correction
- *Correction due to Fermi motion of initial proton*

Event Generation

- To generate 2pi events new 2pi event generator developed in the framework of the preparation of Hybrid Baryon Search proposal (approved by PAC44) was used
- This EG is based on the newest data on 2pi production off the free proton
- In this analysis new 2pi EG is successfully used for the first time for the efficiency evaluation



In order to generate 2pi events off the moving proton Fermi motion was implemented into the EG according to the Bonn potential

$$P_p = \left| \overrightarrow{P_e} - \overrightarrow{P_{e'}} - \overrightarrow{P_{p'}} - \overrightarrow{P_{\pi^+}} - \overrightarrow{P_{\pi^-}} \right|$$

Topologies of γ_v p(n) → p'(n')π^+ π^-

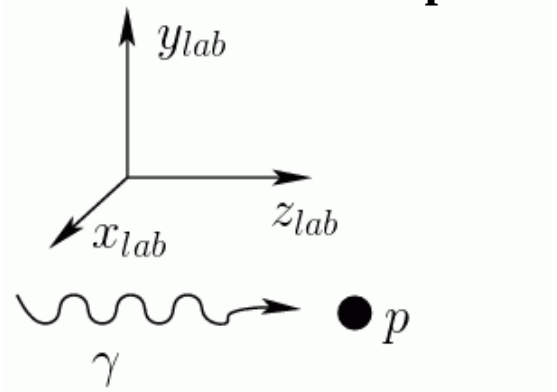
- All final particles are registered (10%) – fully exclusive topology
- π^- is missing (70%)

- π^+ is missing (10%) → misidentification with γ_v n(p) → p'(n')π^- and γ_v n(p) → p'(n')$\pi^-\pi^0$ channels

- p is missing (10%) → misidentification with γ_v n(p) → n'(p')π^+ π^- channel

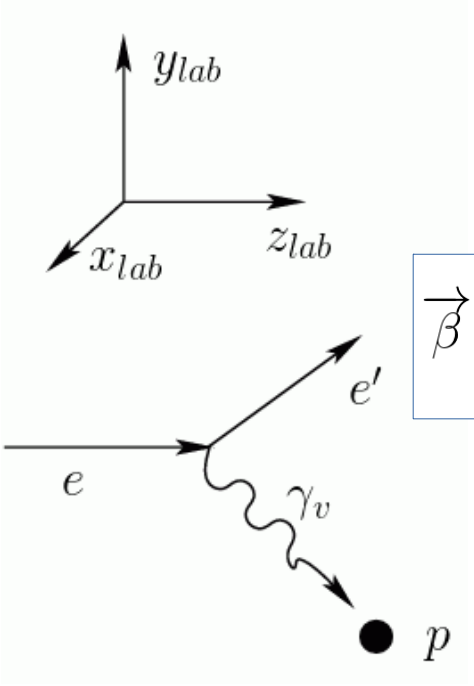
Lab-to-CMS Transformation

Photoproduction off the free proton

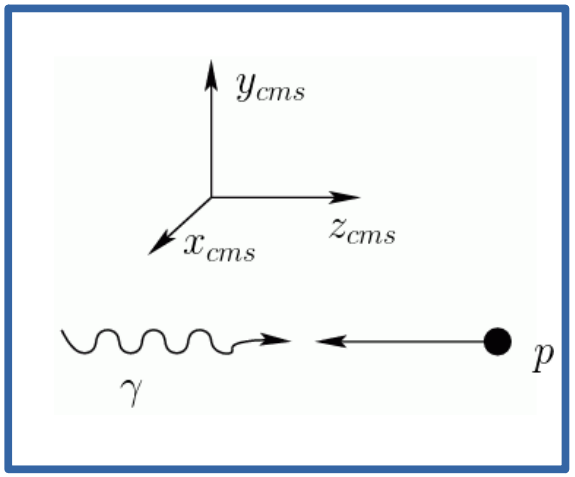


$$\vec{\beta} = \left(0, 0, \frac{|\vec{q_\gamma}|}{E_\gamma + m_p}\right)$$

Electroproduction off the free proton



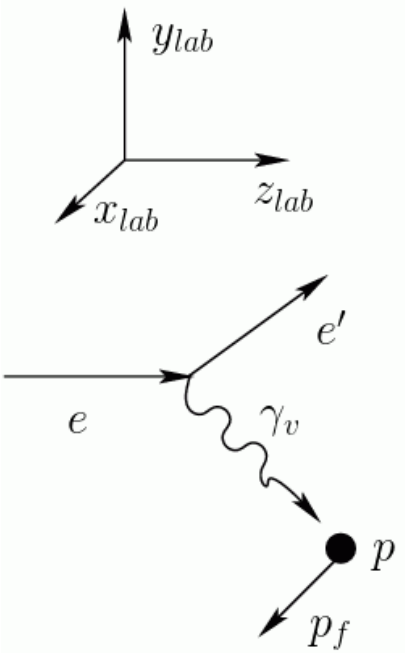
$$\vec{\beta} = \frac{\vec{q_\gamma}}{E_\gamma + m_p}$$



CMS

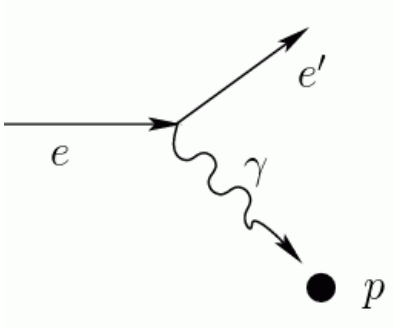
$$\vec{\beta} = \frac{\vec{q_\gamma} + \vec{p_f}}{E_\gamma + E_p}$$

Electroproduction off the moving proton



Invariant Mass of Final Hadronic System

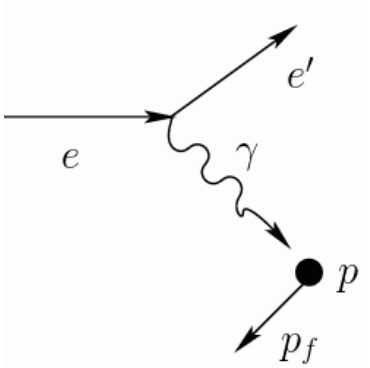
Free proton



$$P_p^{\,at\ rest} = (0, 0, 0, m_p)$$

$$W_{true} = \sqrt{(P_p^{\,at\ rest} + P_{\gamma_v})^2}$$

Moving proton



$$P_p^{\,moving} = (p_{fx}, p_{fy}, p_{fz}, \sqrt{m_p^2 + p_f^2})$$

$$W_{true} = \sqrt{(P_p^{\,moving} + P_{\gamma_v})^2}$$

P_f is unknown if π^- is missing

In target-at-rest assumption

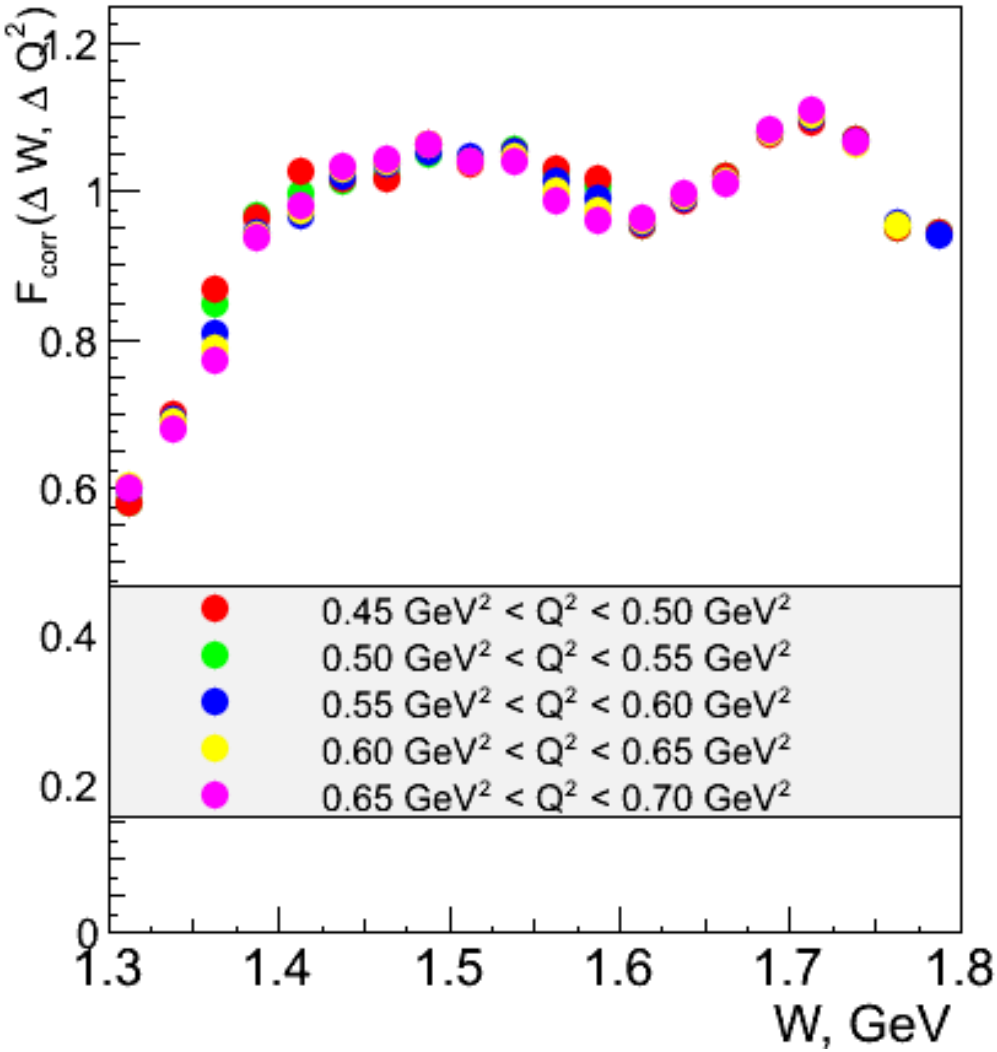
$$W_{fsm} = \sqrt{(P_p^{\,at\ rest} + P_{\gamma_v})^2}$$

Correcting the Effects of Fermi Motion on the Cross Sections

$$\frac{d\sigma}{dW_{true}dQ^2d\tau} = \frac{d\sigma}{dW_{fsm}dQ^2d\tau} F_{corr}(\Delta W, \Delta Q^2, \Delta\tau)$$

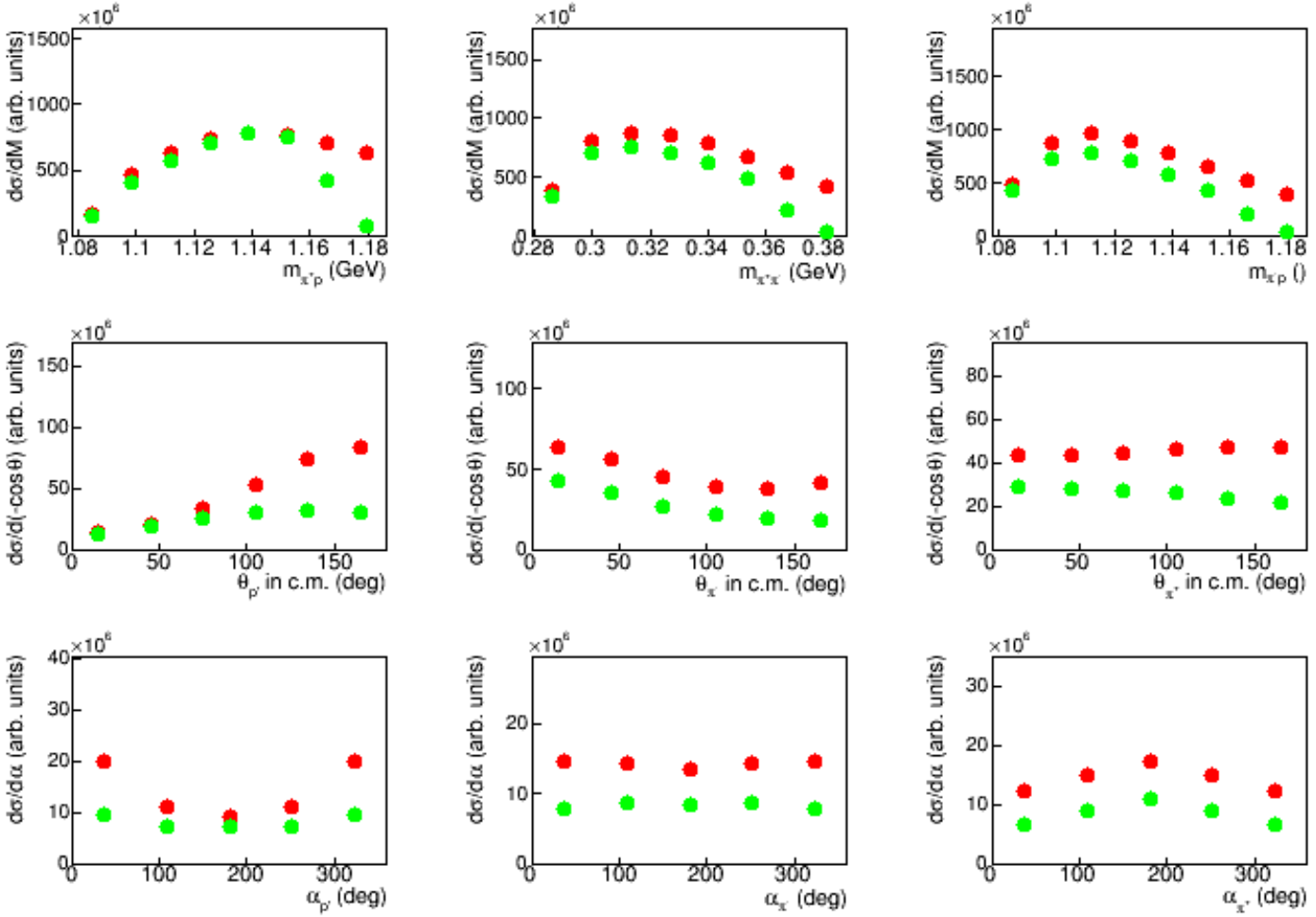
$$F_{corr}(\Delta W, \Delta Q^2, \Delta\tau) =$$

$$\frac{N_{nofermi}(\Delta W, \Delta Q^2, \Delta\tau)}{N_{fermi}(\Delta W, \Delta Q^2, \Delta\tau)}$$



Fermi Correction

W = 1.3125 GeV, Q^2 = 0.475 GeV^2

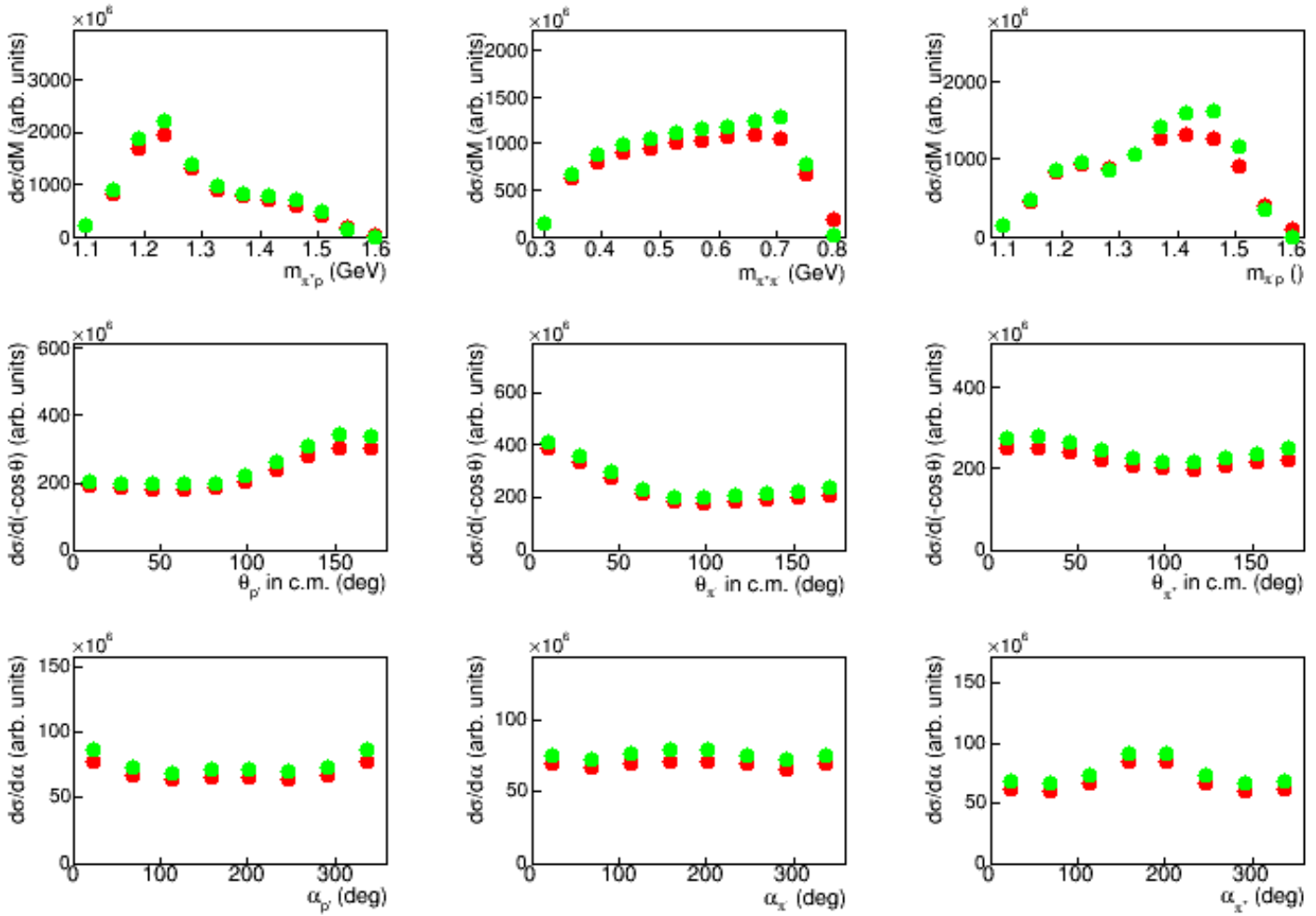


Red symbols – from EG for the moving proton

Green symbols – from EG for the free proton

Fermi Correction

W = 1.7125 GeV, Q^2 = 0.475 GeV^2



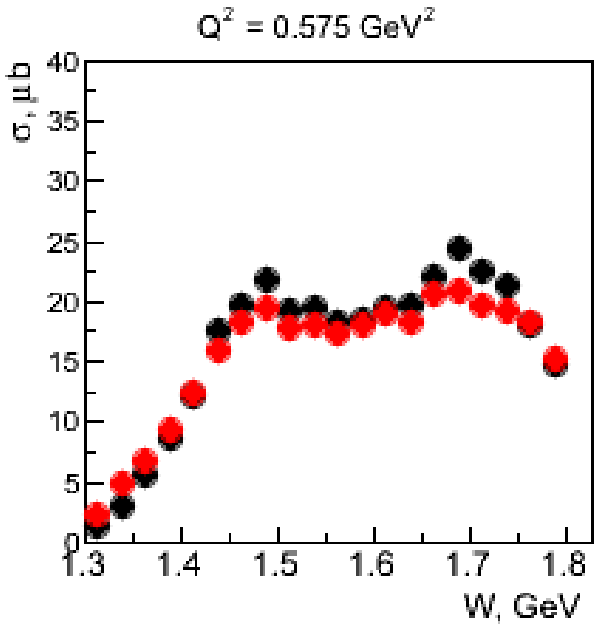
Red symbols – from EG for the moving proton

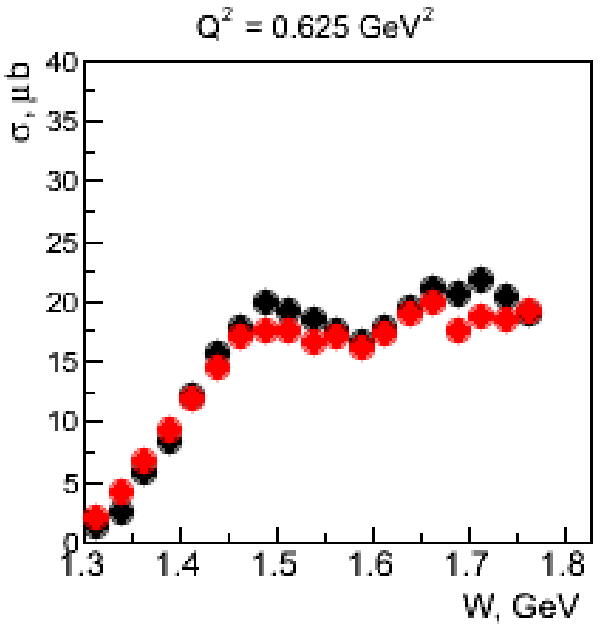
Green symbols – from EG for the free proton

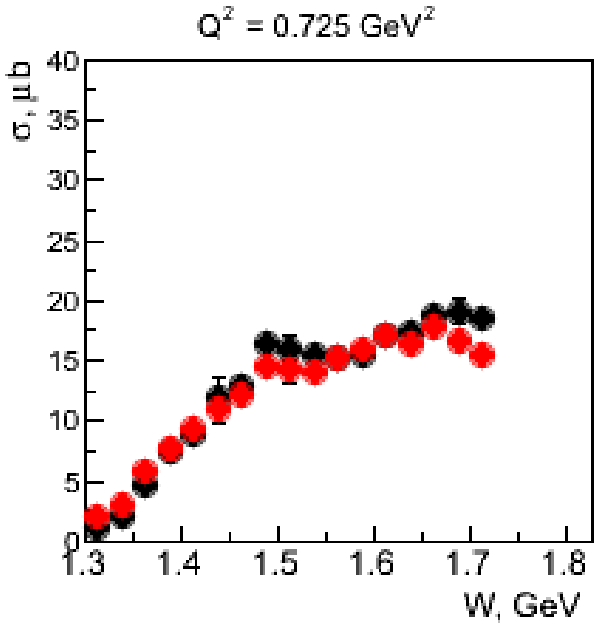
Comparison of the Integral Cross Section with and without Fermi Correction (preliminary)

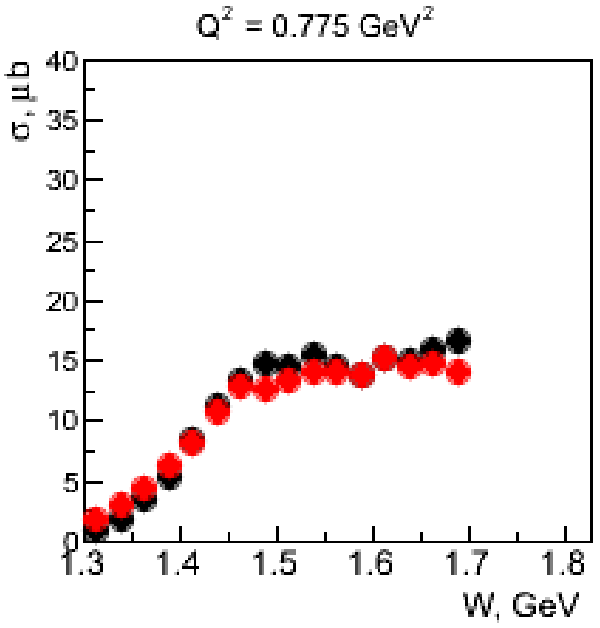
Black symbols – cross section with Fermi correction

Red symbols – cross section without Fermi correction









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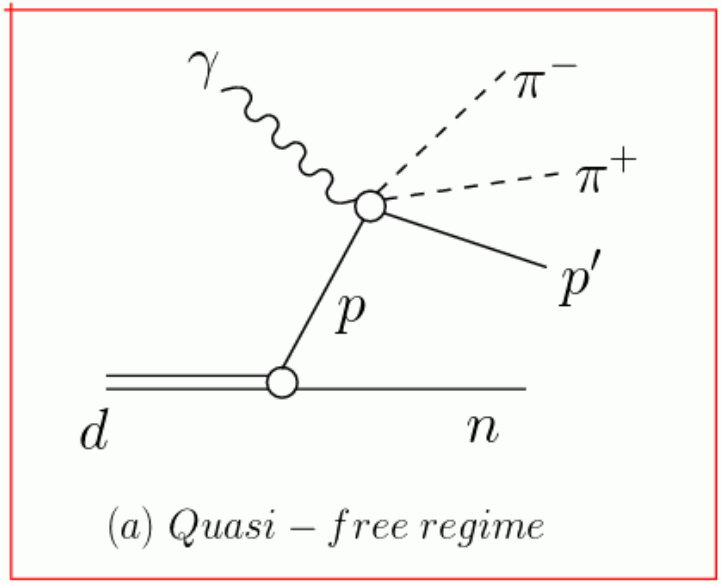
Final State Interactions

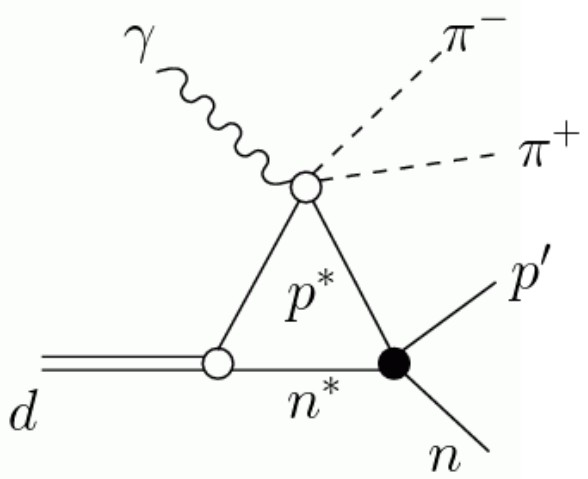
- Interaction of final hadrons with each other → rather small effect as it is known from 2pi production off the free proton

- Interaction of final hadrons with the spectator neutron = rescattering under the influence of the strong interaction via resonant and/or non-resonant mechanisms → noticeable effect

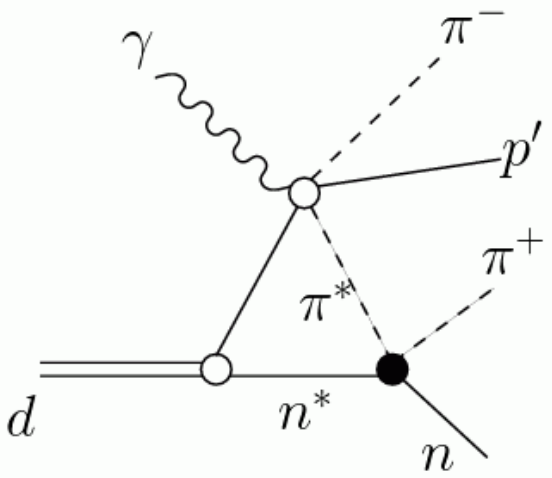
Quasi-Free Regime and FSI for p(n)π^+ π^- Final State



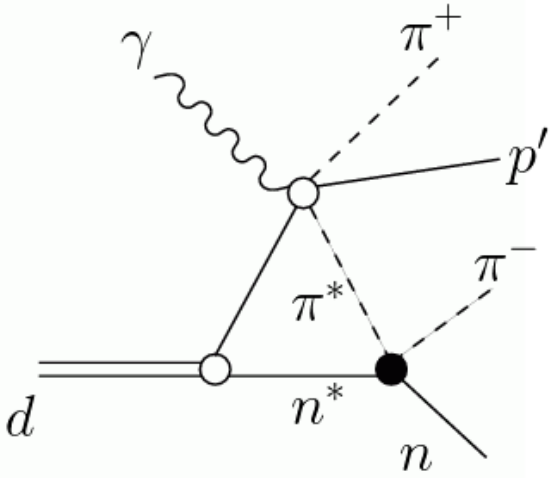
(a) $Quasi-free\ regime$



(b) $NN-FSI$



(c) $\pi N-FSI$



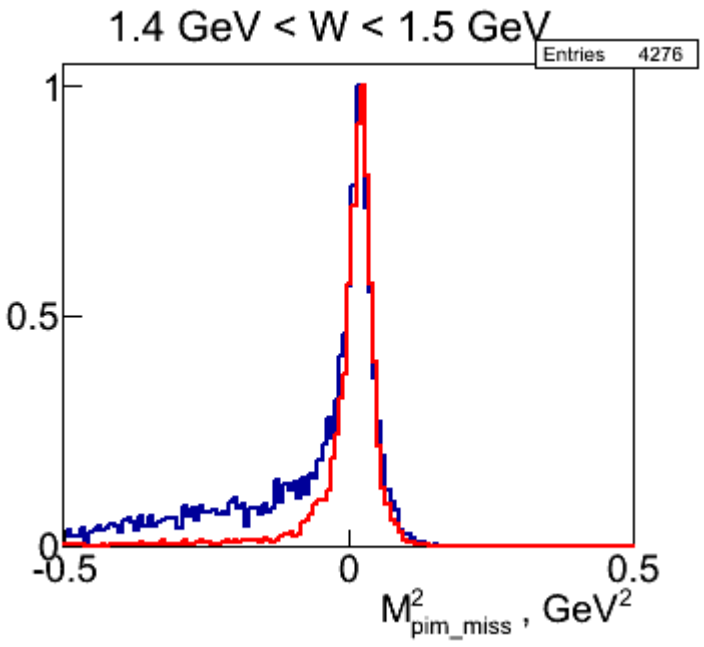
(d) $\pi N-FSI$

FSI for p(n)π^+ π^- Final State

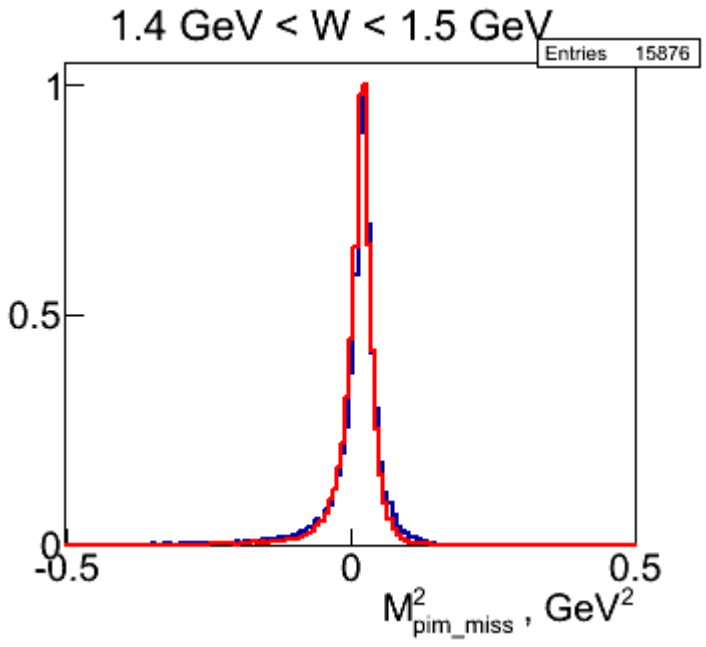
FSI strongly depend on:

- Invariant mass of final hadron system (*W*)
- Scattering angles of final hadrons → FSI are topology dependent!

$$M_x^2 = (P_e^\mu + P_p^\mu - P_{e'}^\mu - P_{p'}^\mu - P_{\pi^+}^\mu)^2$$



Fully exclusive topology



π^- missing topology

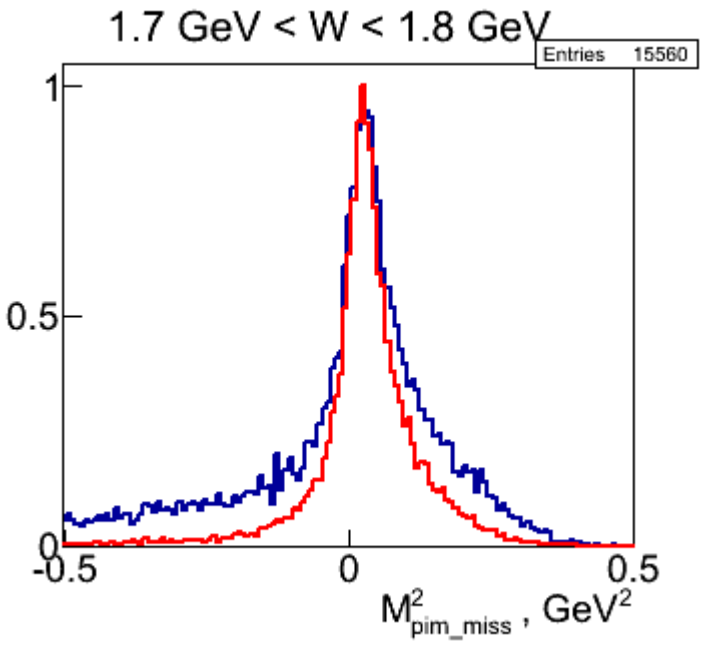
Blue curve – data, **Red curve** – simulation

FSI for p(n)π^+ π^- Final State

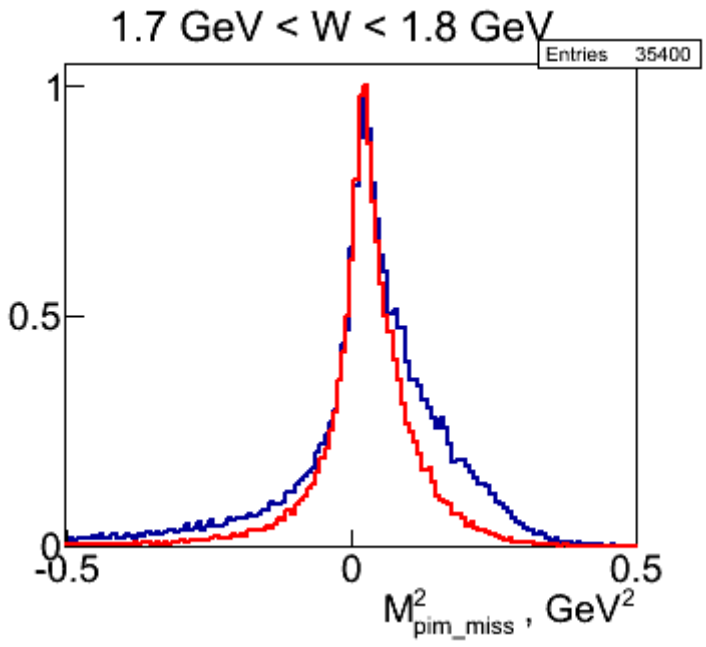
FSI strongly depend on:

- Invariant mass of final hadron system (*W*)
- Scattering angles of final hadrons → FSI are topology dependent!

$$M_x^2 = (P_e^\mu + P_p^\mu - P_{e'}^\mu - P_{p'}^\mu - P_{\pi^+}^\mu)^2$$



Fully exclusive topology



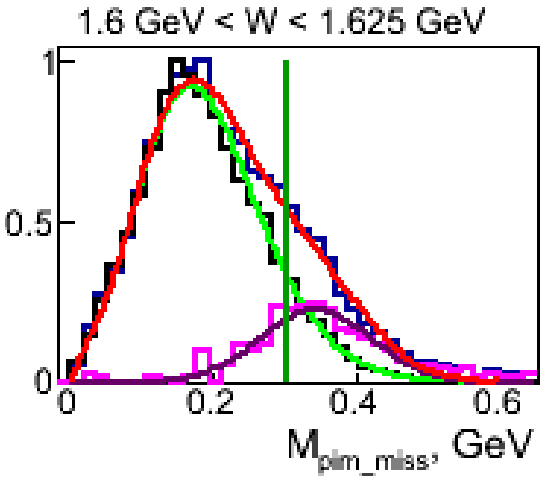
π^- missing topology

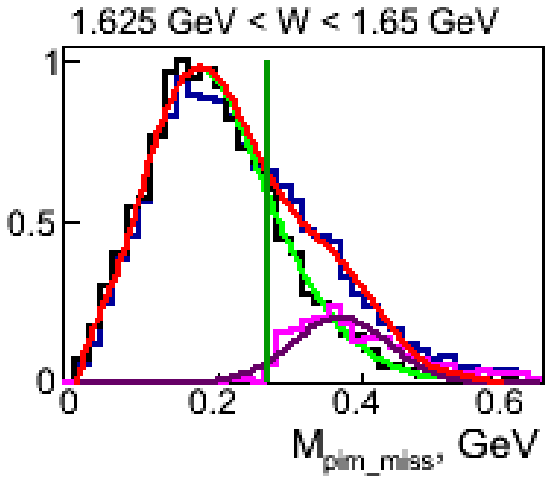
Blue curve – data, **Red curve** – simulation

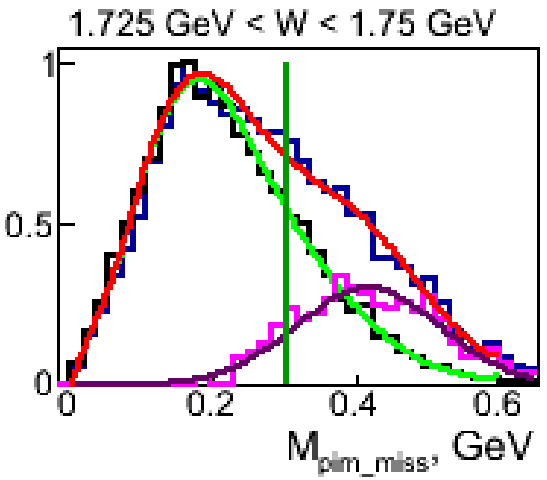
Effective FSI Correction

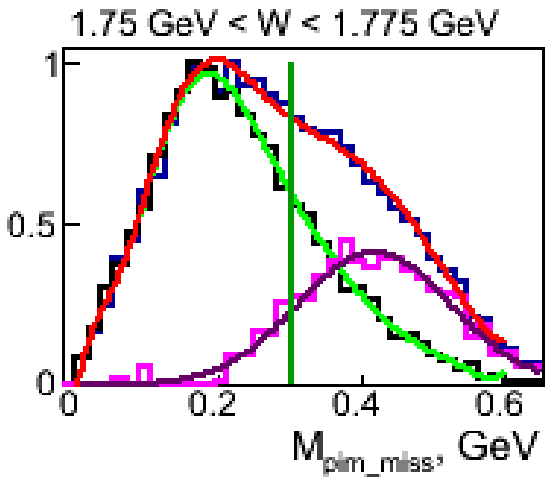
$$\frac{d\sigma_{corrected}}{dW\,dQ^2 d\tau} = \frac{d\sigma_{not\ corrected}}{dW\,dQ^2 d\tau} F_{fsi}(\Delta W, \Delta Q^2)$$

$$F_{fsi}(\Delta W, \Delta Q^2) = \frac{Area\ under\ green}{Area\ under\ red}$$

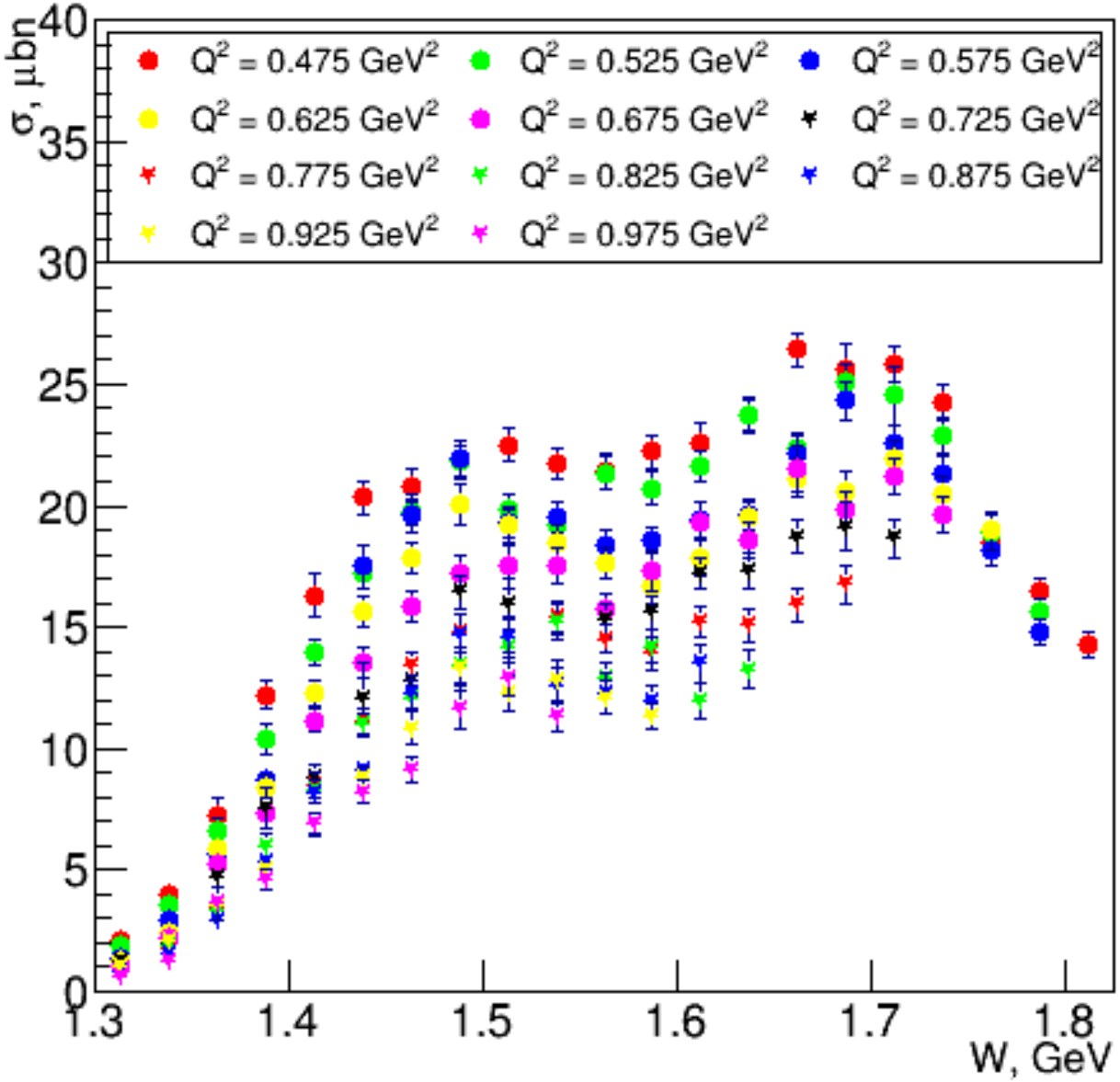








Integrated Cross Sections (Preliminary)



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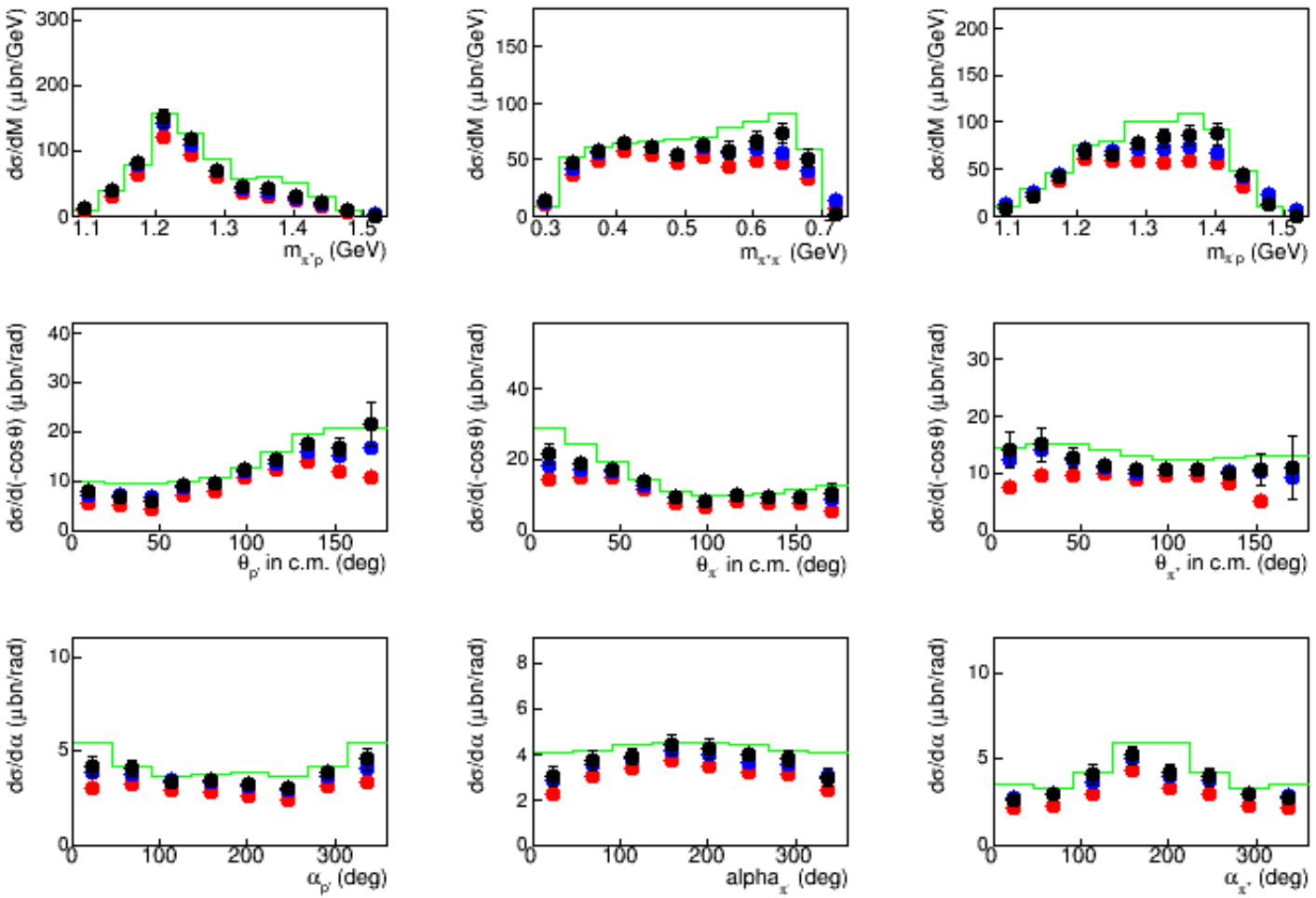
Differential Cross Sections (Preliminary)

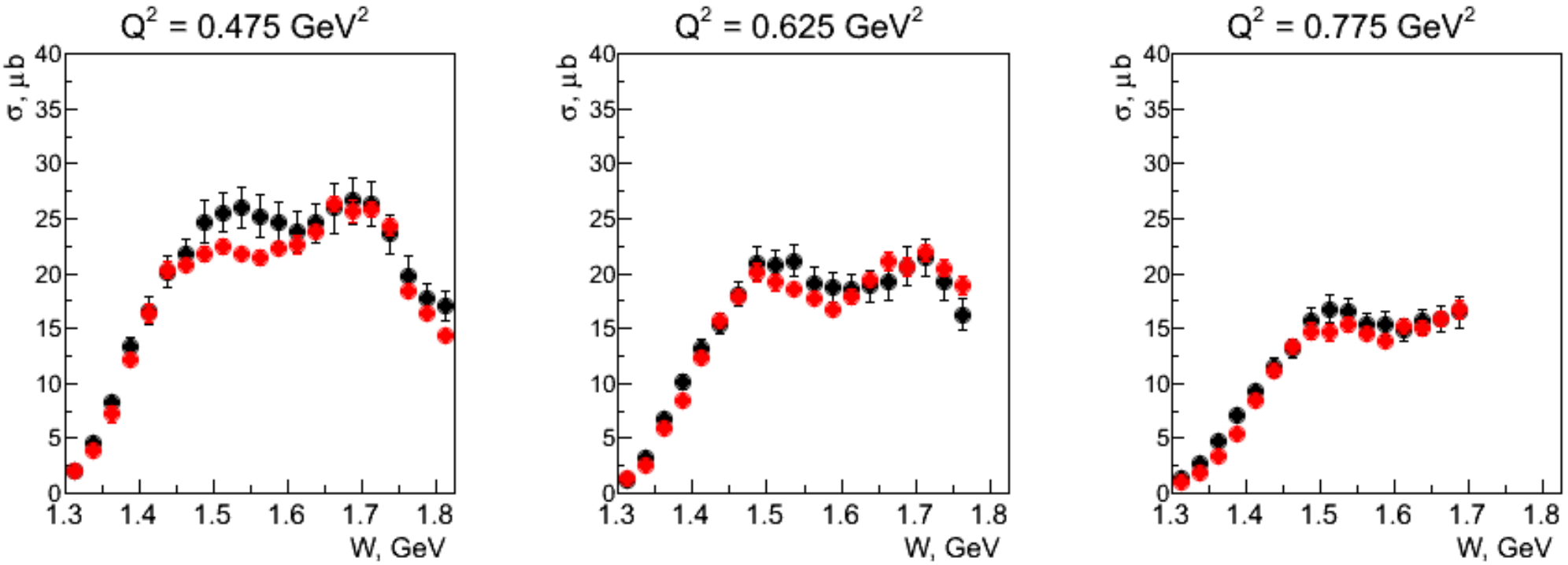
$W = 1.6375$ GeV, $Q^2 = 0.475$ GeV^2



Red symbols – empty cells are NOT filled **Blue symbols** – empty cells are filled

Black symbols – Fermi correction is applied **Green curve** – from EG off the free proton

Comparison with Free Proton Cross Sections
(Preliminary)



Black symbols – free proton cross sections (e1e, E_{beam} = 2.039 GeV)
error bars show both statistical and systematical uncertainties
G. Fedotov analysis note under review

Red symbols – bound proton cross sections (e1e, E_{beam} = 2.039 GeV)
error bars show statistical uncertainty only

Conclusion

- Fully integrated and single differential cross sections of the reaction $\gamma_v\, p(n) \rightarrow p'(n')\pi^+\, \pi^-$ in the resonance region are extracted for the first time

- The method of implementation the Fermi motion of the target proton into the 2pi event generation is developed and successfully applied

- The procedure of correcting the cross section distortion due to the Fermi motion is developed and applied in multidimensional sense

- The procedure of selecting events in quasi-free kinematics is developed

- New 2pi event generator was tested and for the first time used for the efficiency evaluation