NSTAR2017 – The 11th International Workshop on the Physics of Excited Nucleons
23 August 2017

Investigation of Exclusive $\pi^+\pi^-$ Electroproduction off the Proton Bound in the Deuteron in the Resonance Region with CLAS

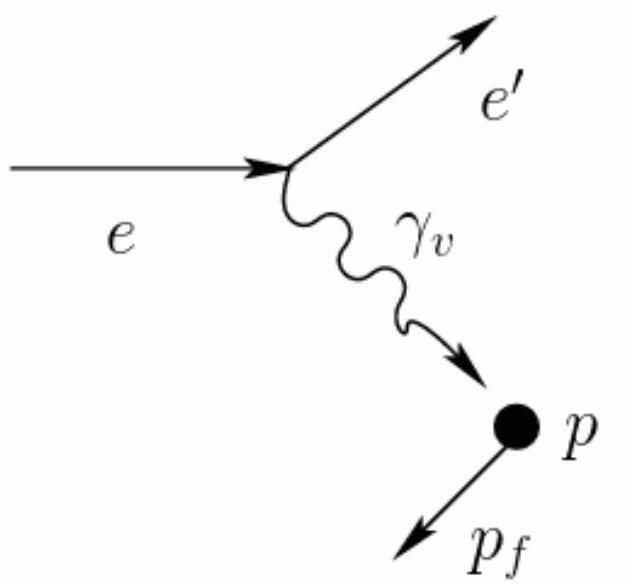
Speaker: Iuliia Skorodumina
(University of South Carolina)

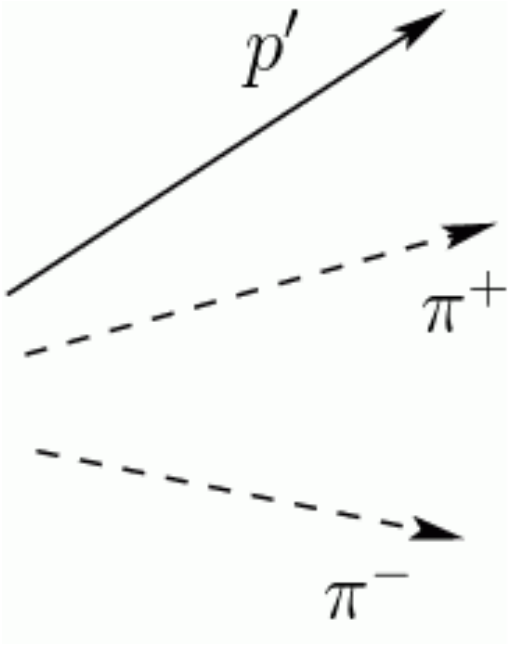
Partially supported by US National Science Foundation under grant PHY-120 5782

CLAS Deuteron Target Experiment

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

γ_v p(n) → p'(n')π^+ π^-





Final Goals

- To extract quasi-free integrated and single-differential cross sections of the reaction $\gamma_v\, p(n) \rightarrow p'(n')\pi^+\,\pi^-$ for W: [1.3, 1.825] GeV, Q^2: [0.45, 1] GeV^2

- To compare them with the cross sections of the analogous reaction on the free proton [1]

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

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

[1] G. Fedotov results. The paper is under preparation.

What is different from the free proton target experiment?

1) Considerably more complex effects of initial and final state interactions due to the presence of additional nucleon → lead to difficulties in exclusive event selection

2) Fermi motion of the target proton has the following consequences:

- Smearing of kinematical quantities (W, missing mass, etc.) if not all final particles are registered
- Different procedure of lab-to-cms transformation
- Moving proton experiment with fixed beam energy is equivalent to that on the proton at rest with varying beam energy

3) Off-shellness of the target proton

4) Possible modification of reaction amplitudes

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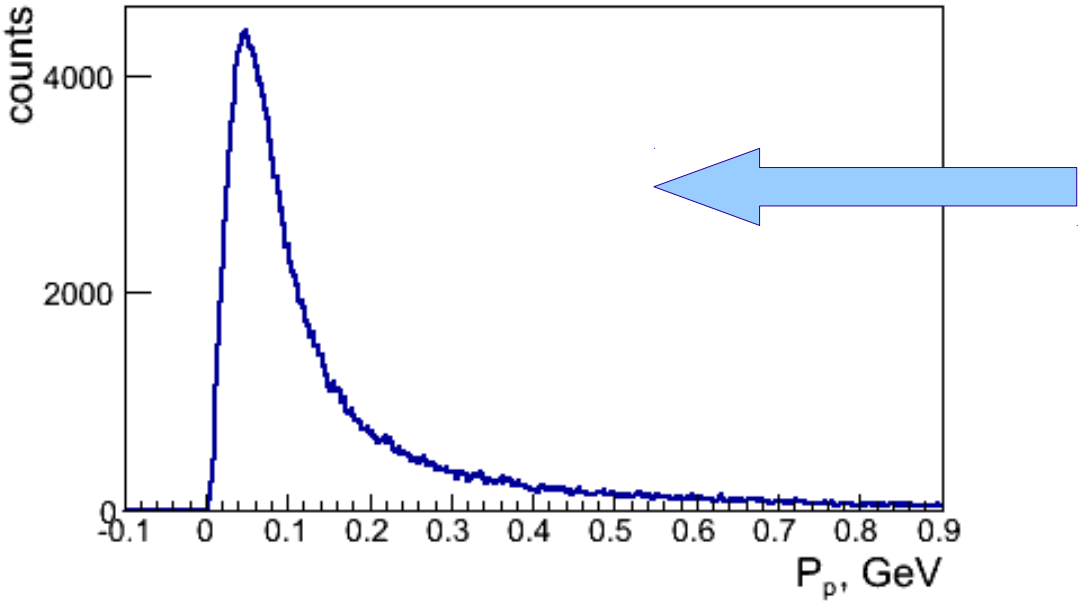
3) Off-shellness of the target proton

4) Possible modification of reaction amplitudes

Event Generation with TWOPEG

- TWOPEG [2] is new double-pion event generator developed in the framework of the preparation of Hybrid Baryon Search proposal (approved by PAC44)
- Fermi motion was implemented according to the Bonn potential [3]
- In this analysis TWOPEG is successfully used for the first time for the efficiency evaluation



Generated momentum of the target proton

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

where $\overrightarrow{P_i}$ are the three-momenta of the particle i.

[2] CLAS12-NOTE-2017-001 (arXiv:1703.08081)

[3] R.Machleidt, K. Holinde, and C. Elster, Phys. Rept., vol. 149, pp. 1-89, 1987

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

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EC-cut, CC-cut → Electron identification

β vs. p → Hadron identification

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

Corrections to the Cross Sections

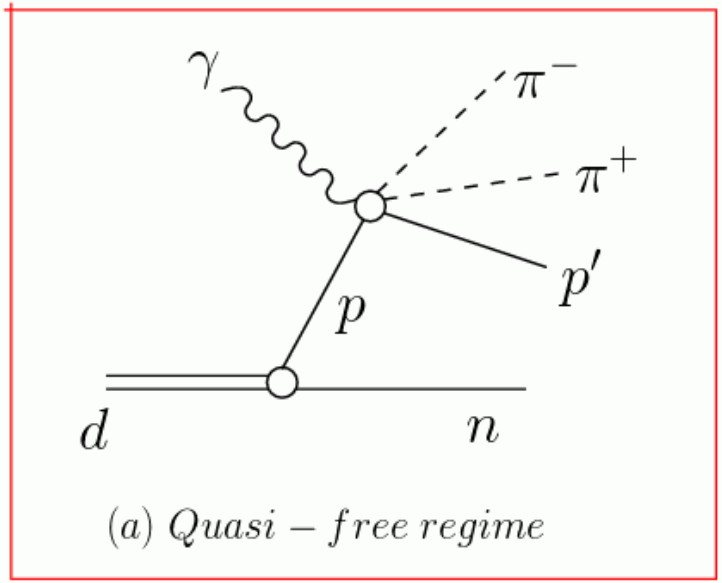
- *Correction due to FSI*
- Empty target subtraction
- Correction due to the filling cells with zero acceptance from the EG
- Radiative correction
- *Correction due to Fermi motion of the target proton*

Final State Interactions

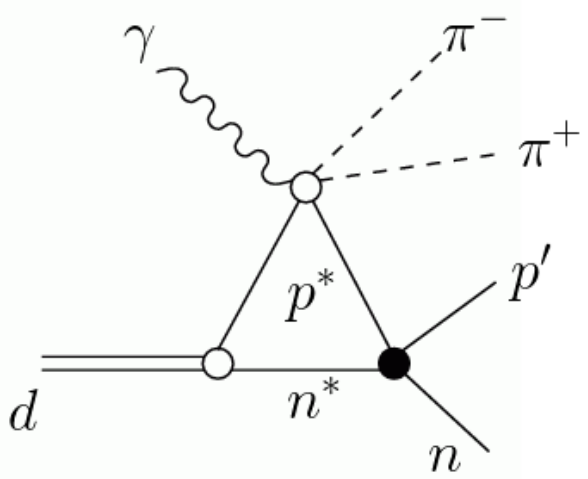
- Interaction of final hadrons with each other → rather small effect as it is known from 2pi production off the free proton

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

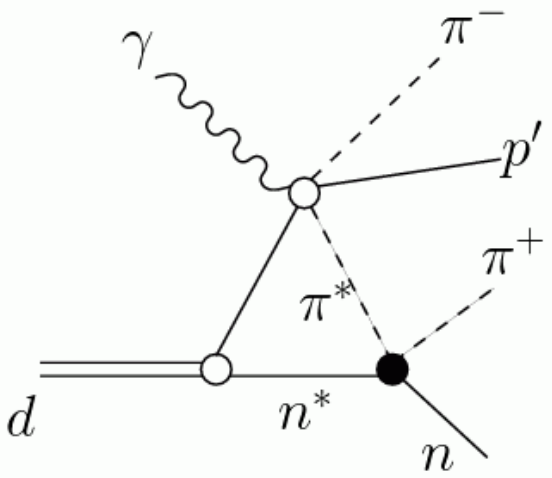
Quasi-Free Regime and FSI for p(n)π^+ π^- Final State



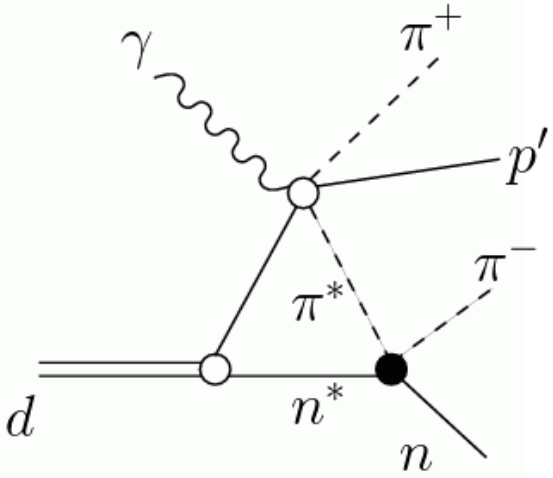
(a) $Quasi-free\ regime$



(b) $NN-FSI$



(c) $\pi N-FSI$



(d) $\pi N-FSI$

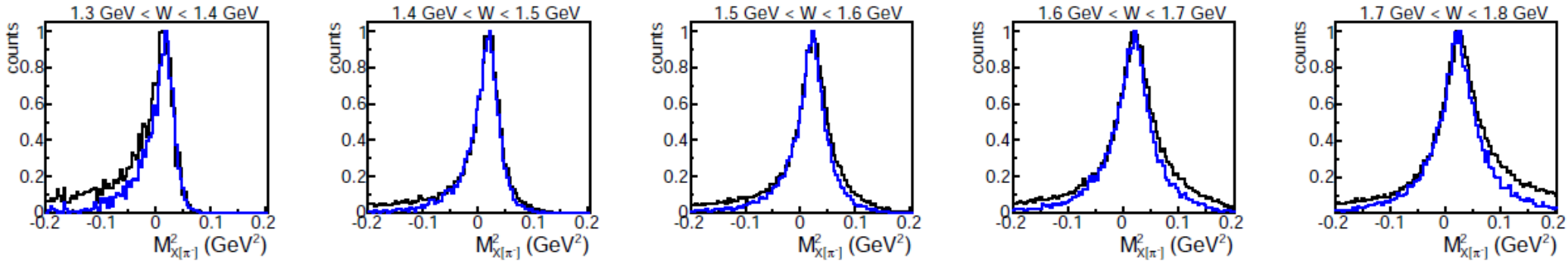
FSI for p(n)π^+ π^- Final State

FSI strongly depend on:

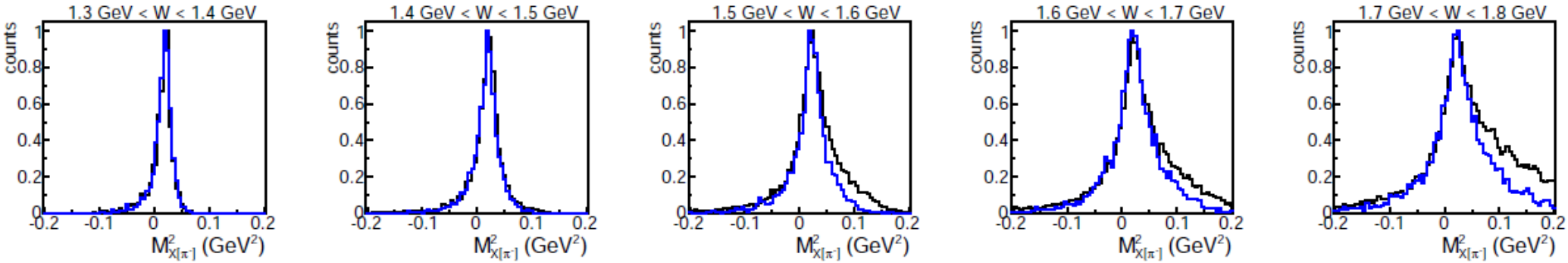
- Invariant mass of final hadron system (*W*)
- Scattering angles of final hadrons → FSI are topology dependent!

$$M^2_{X[\pi^-]} = [P^\mu_e + P^\mu_p - P^\mu_{e'} - P^\mu_{p'} - P^\mu_{\pi^+}]^2, \quad \text{where } P^\mu_i \text{ are the four-momenta of the particle } i.$$

Fully exclusive topology

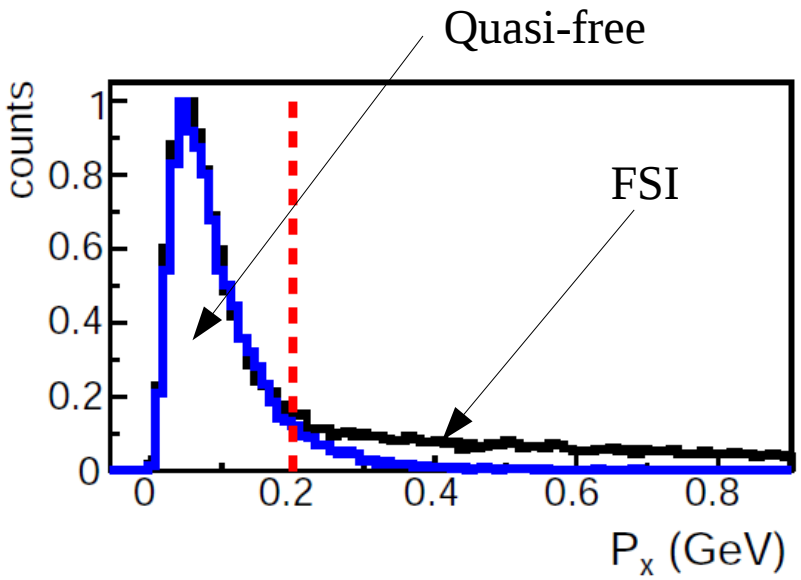


π^- missing topology



Black curve – data, **Blue curve** – simulation (FSI not included)

Selection of Quasi-Free Events in Fully Exclusive Topology

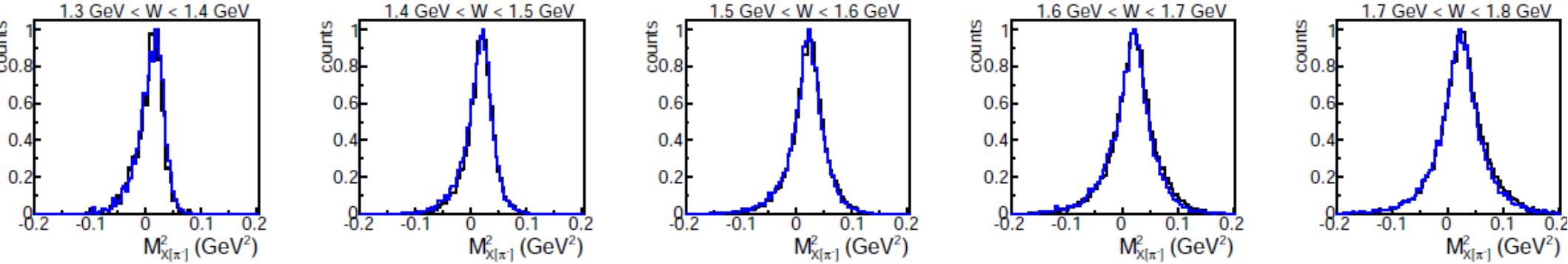


$$P_X = |\vec{P}_e - \vec{P}_{e'} - \vec{P}_{p'} - \vec{P}_{\pi^+} - \vec{P}_{\pi^-}|,$$

where $\vec{P}_i$ are the three-momenta of the particle i.

Cut P_x = 0.2 GeV selects quasi-free events.

After the cut.

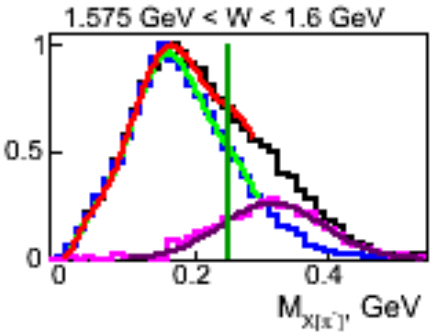


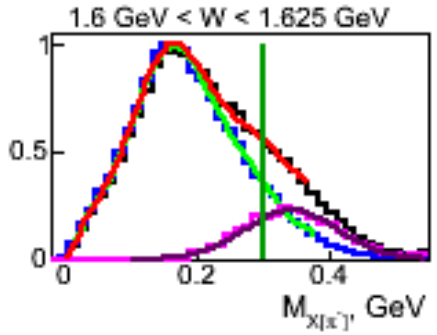
Black curve – data, **Blue curve** – simulation (FSI not included)

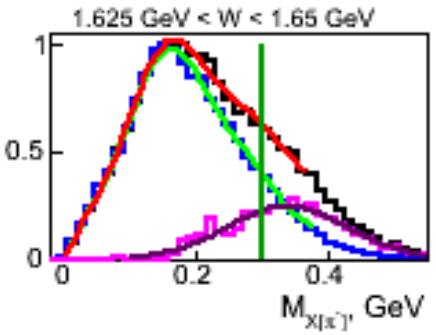
Effective FSI Correction for π^- Missing Topology

$$\frac{d^7\sigma_{corrected}}{dW\,dQ^2 d^5\tau} = \frac{d^7\sigma_{not\ corrected}}{dW\,dQ^2 d^5\tau} \times F_{fsi}(\Delta W)$$

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



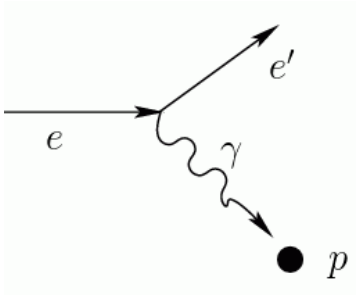




Black histogram – experimental data, **Blue histogram** – simulation, **Purple histogram** – their difference.
Red curve – fit to the data, **Green curve** – fit to the simulation, **Purple curve** – fit to the difference.

Invariant Mass of Final Hadronic System

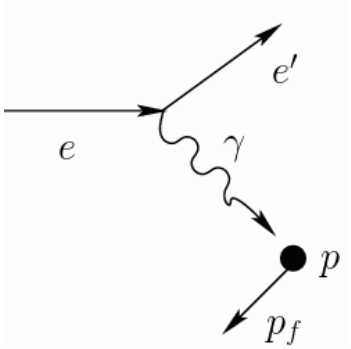
Proton at rest



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

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

Moving proton

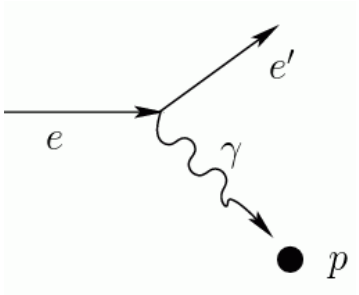


$$P_p^{\,moving} = (p_{fx}, p_{fy}, p_{fz}, \sqrt{m_p^2 + p_f^2})$$

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

Invariant Mass of Final Hadronic System

Proton at rest



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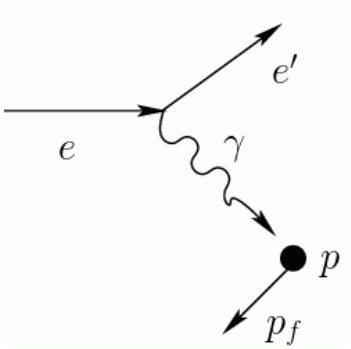


$$P_p^{\,moving} = (p_{fx}, p_{fy}, p_{fz}, \sqrt{m_p^2 + p_f^2})$$

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

P_f is unknown if π^- is missing

In target-at-rest assumption

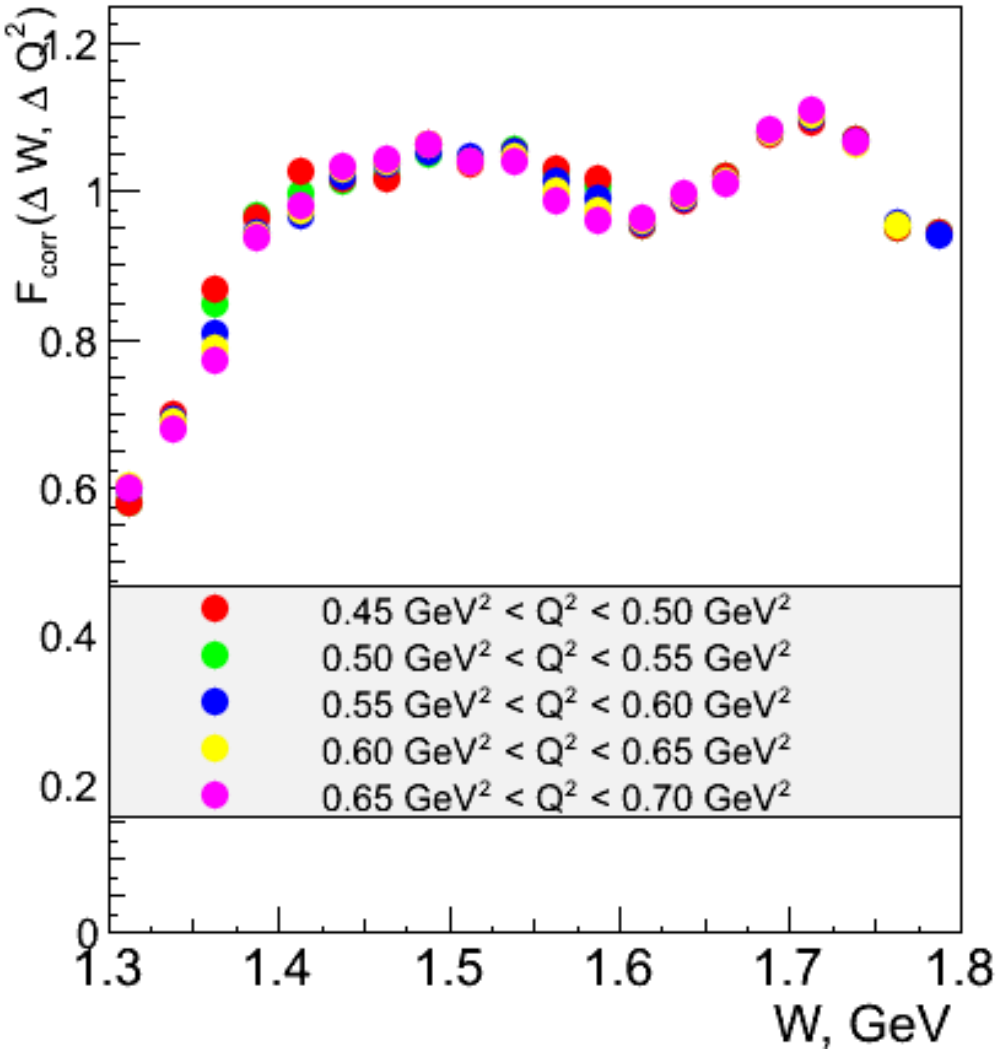
$$W_{fsm} = \sqrt{(P_p^{\,at\ rest} + P_{\gamma_v})^2}$$

Correcting the Effects of Fermi Motion on the Cross Sections

$$\frac{d^7\sigma_{corrected}}{dW_{true}dQ^2d^5\tau} = \frac{d^7\sigma_{not\ corrected}}{dW_{fsm}dQ^2d^5\tau} \times F_{corr}(\Delta W, \Delta Q^2, \Delta\tau)$$

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

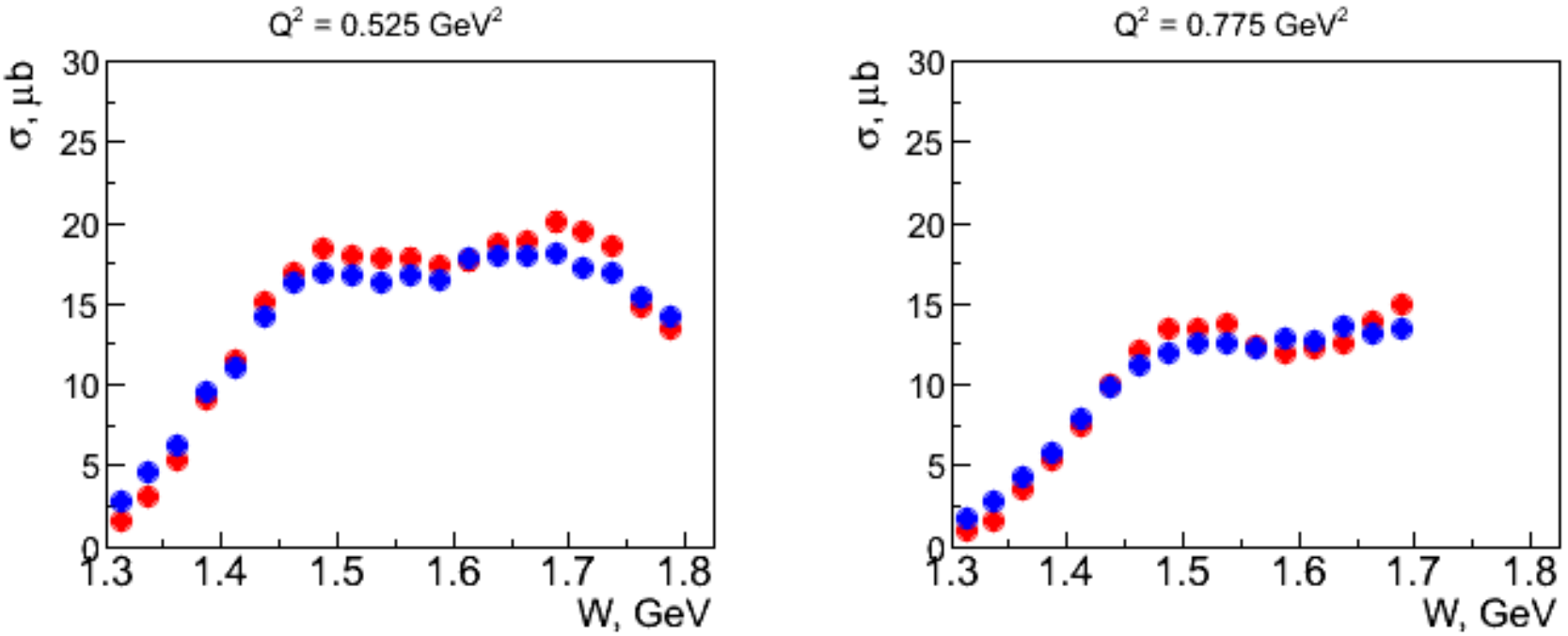
$$\frac{N_{nofermi}(\Delta W, \Delta Q^2, \Delta\tau)}{N_{fermi}(\Delta W, \Delta Q^2, \Delta\tau)}$$



$N_{nofermi}$ – from TWOPEG on free proton

N_{fermi} – from TWOPEG on moving proton

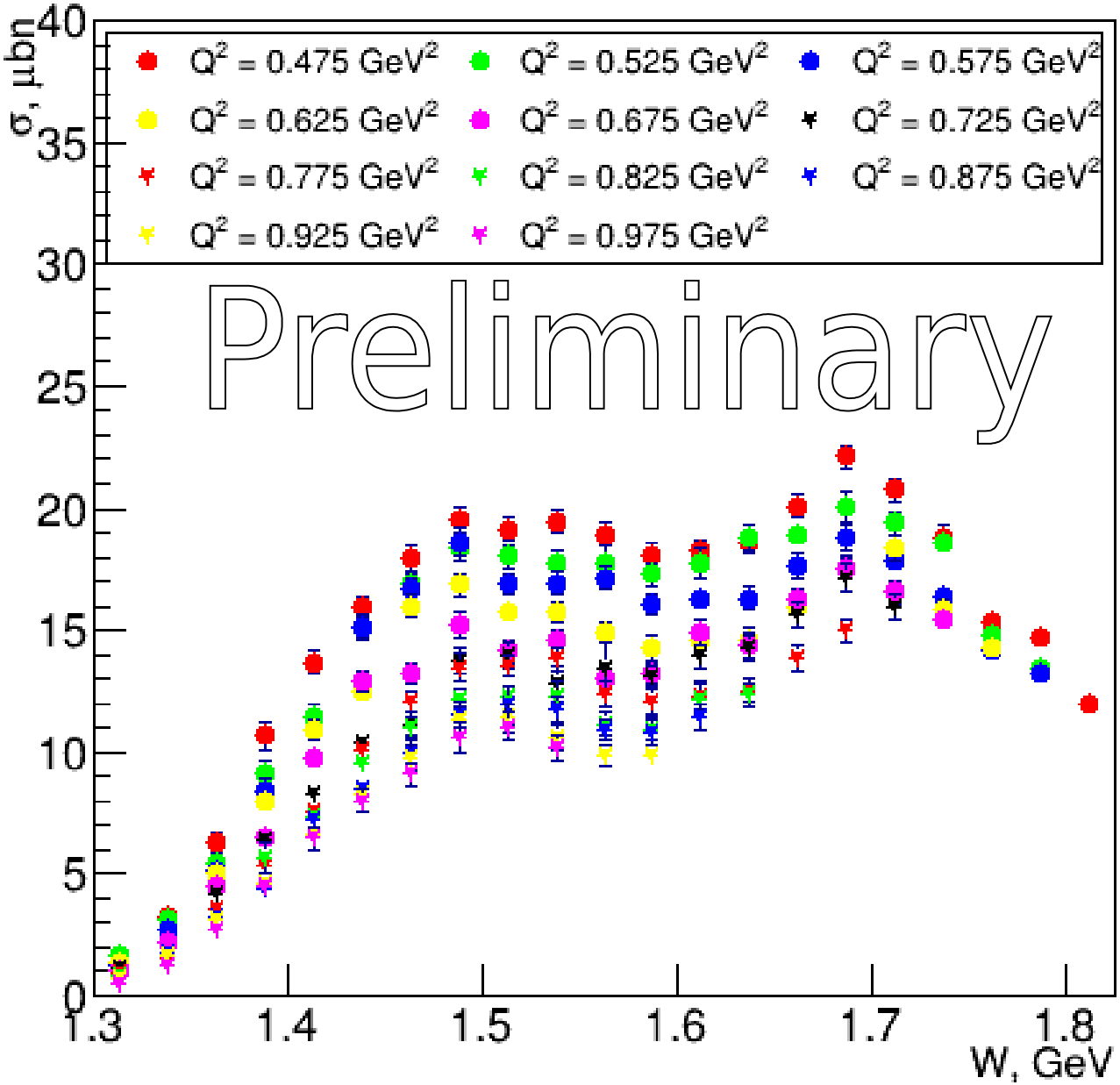
Comparison of the Integral Cross Section with and without Fermi Correction (preliminary)



Red symbols – experimental integral cross section *with* Fermi correction

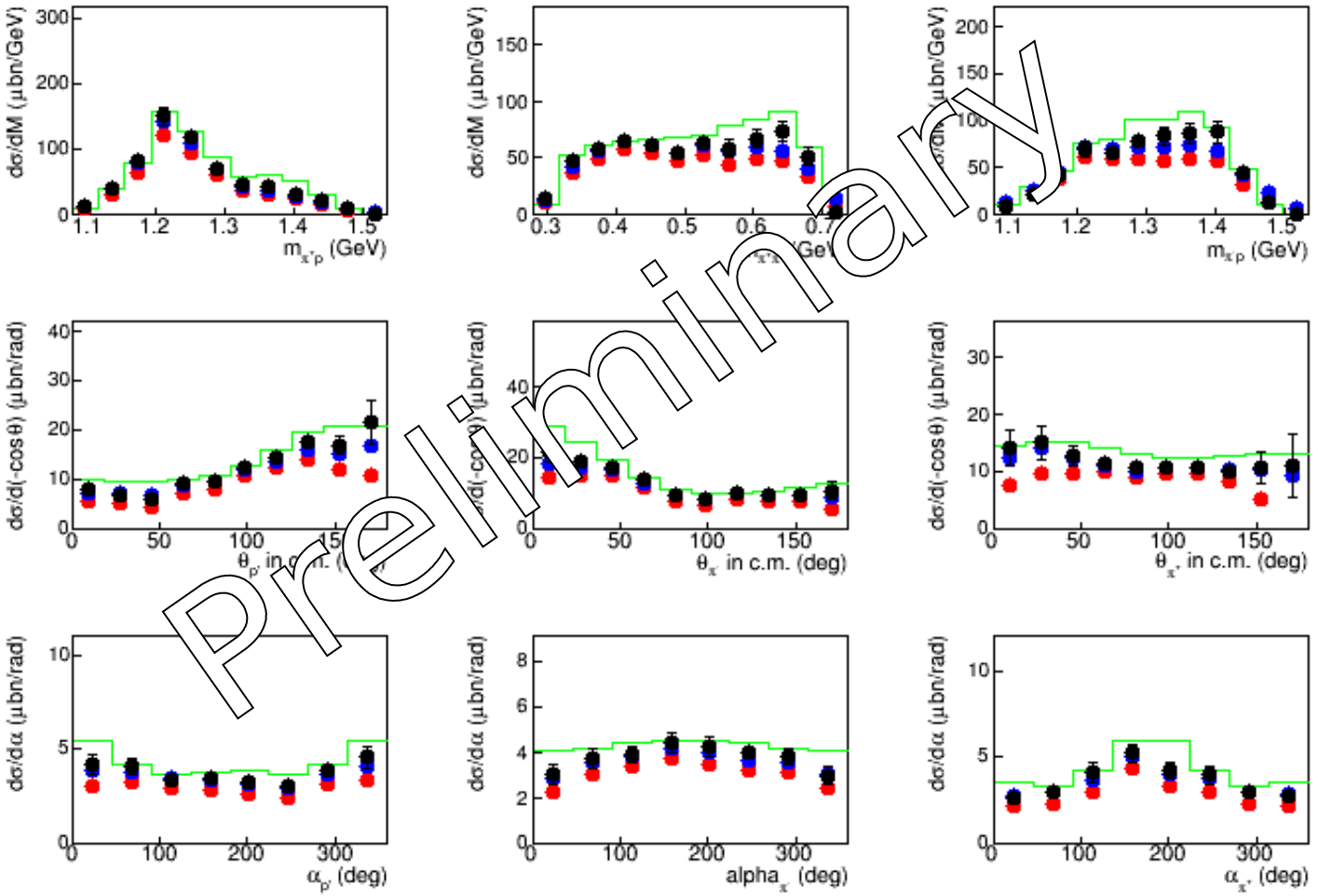
Blue symbols – experimental integral cross section *without* Fermi correction

Integrated Cross Sections (Preliminary)



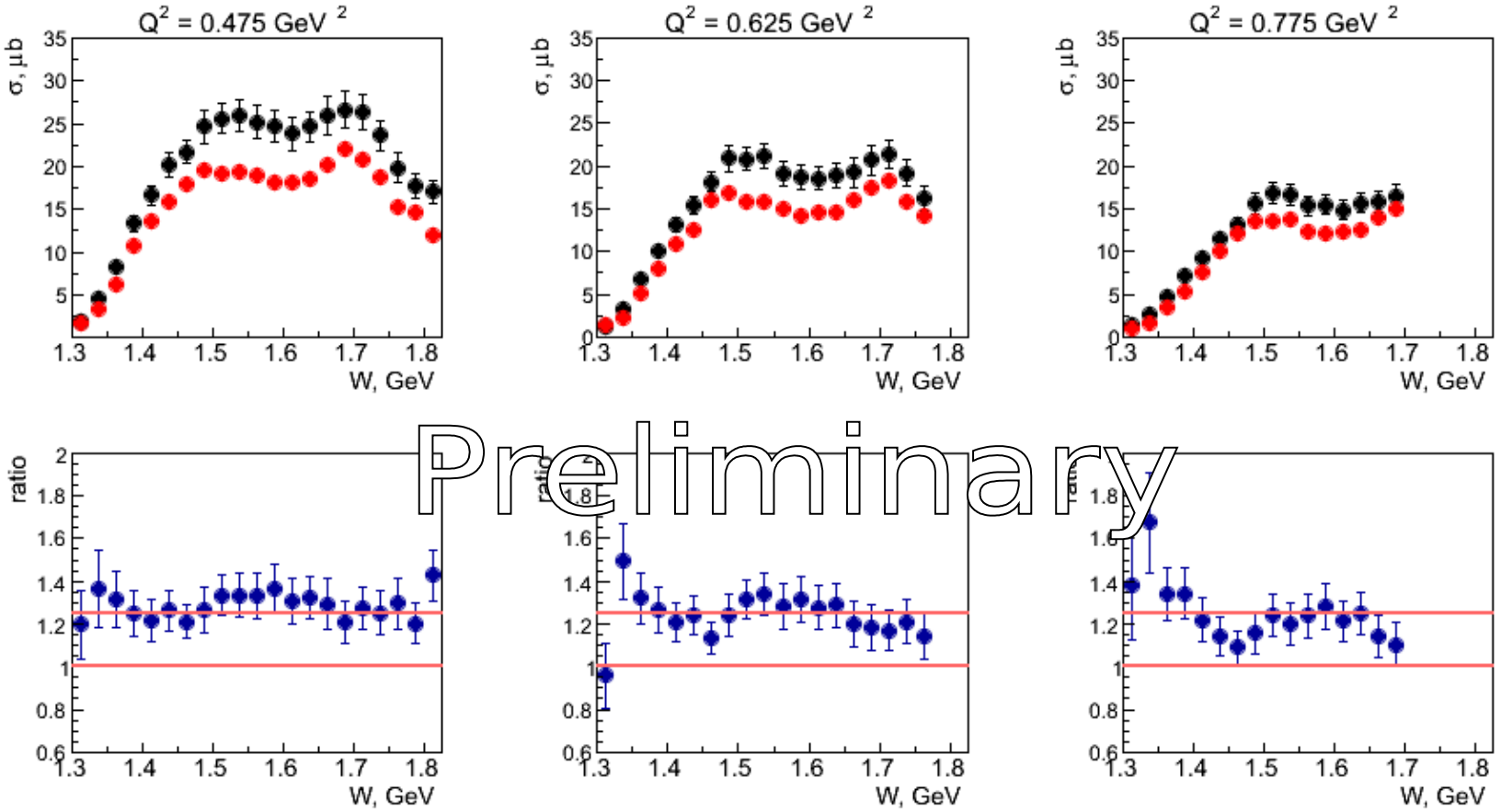
Differential Cross Sections (Preliminary)

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



Black symbols – *free* proton cross sections (e1e, E_{beam} = 2.039 GeV) [1],
error bars show both *statistical* and *systematical* uncertainties

Red symbols – *quasi-free* cross sections on proton in deuteron (e1e, E_{beam} = 2.039 GeV),
error bars show *statistical* uncertainty only

Blue symbols – their ratio

[1] G. Fedotov results. The paper is under preparation.

Conclusion

- Integral and single-differential cross sections of the reaction $\gamma_v\, p(n) \rightarrow p'(n')\pi^+\, \pi^-$ in quasi-free regime are extracted for the first time

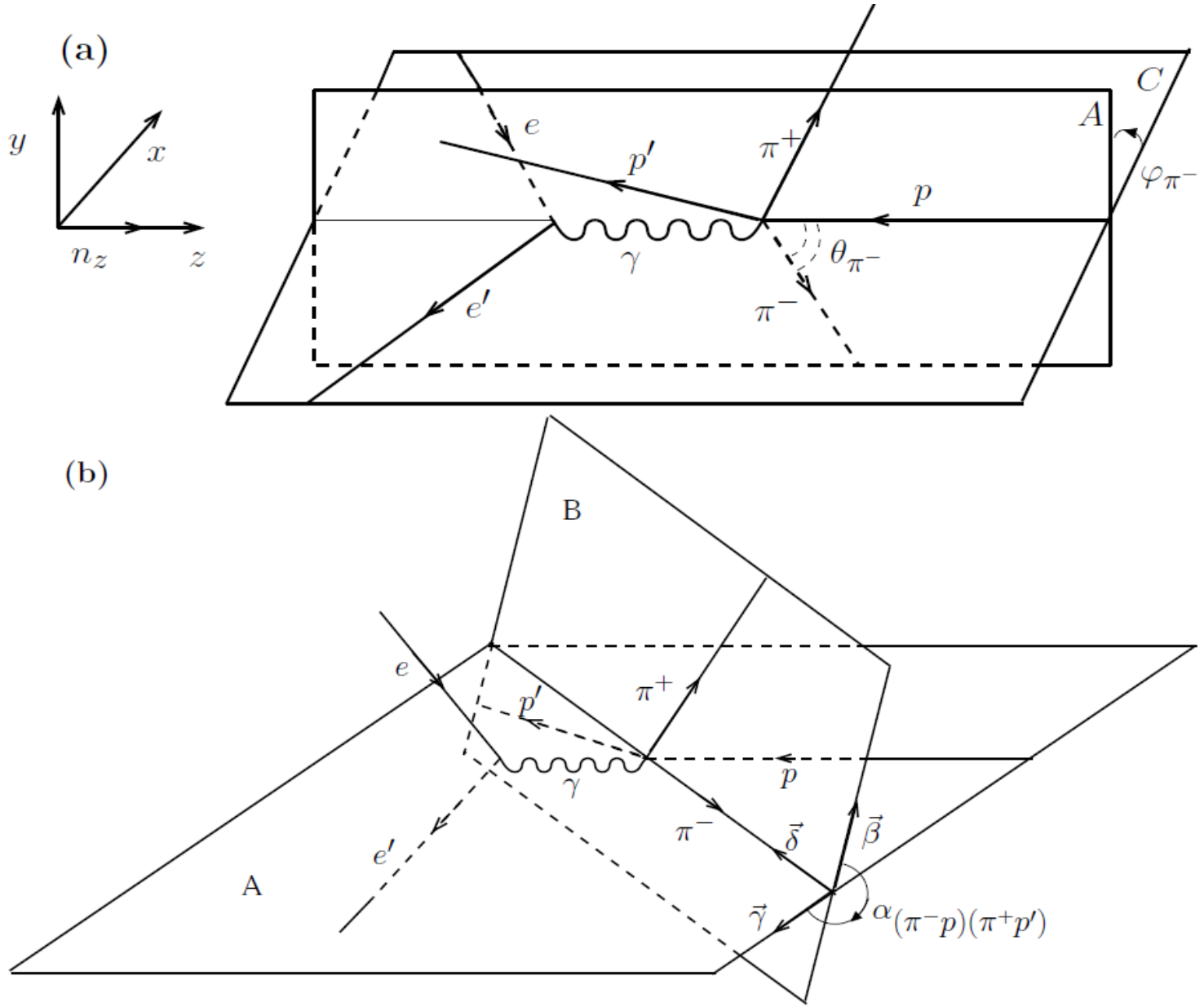
- The procedure of correcting the cross section distortion due to the Fermi motion is developed and applied

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

- TWOPEG was tested and for the first time used for the efficiency evaluation

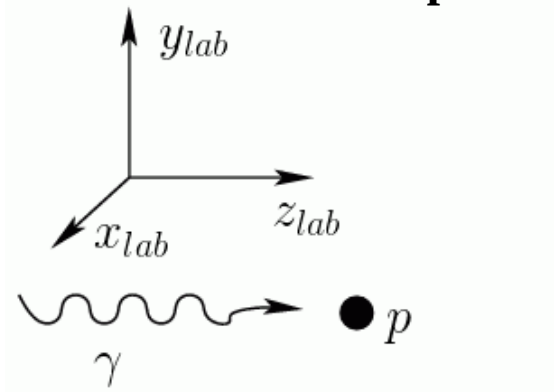
Thank you!

2π Kinematics



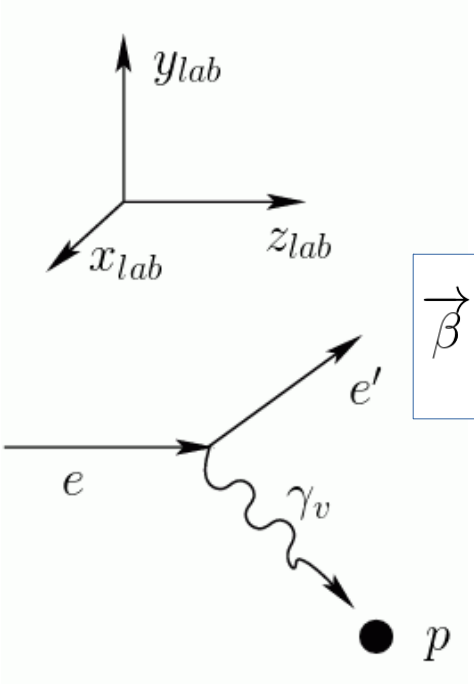
Lab-to-CMS Transformation

Photoproduction off the free proton

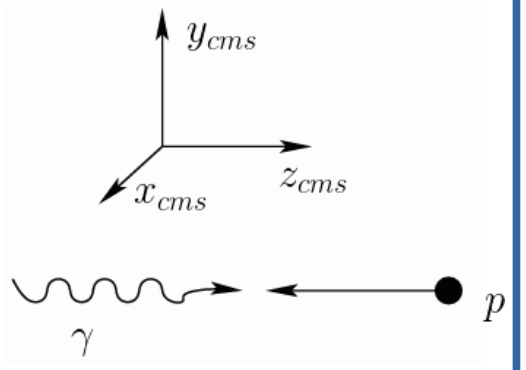


$$\vec{\beta} = \left(0, 0, \frac{|\vec{q_\gamma}|}{E_\gamma + m_p}\right)$$

Electroproduction off the free proton



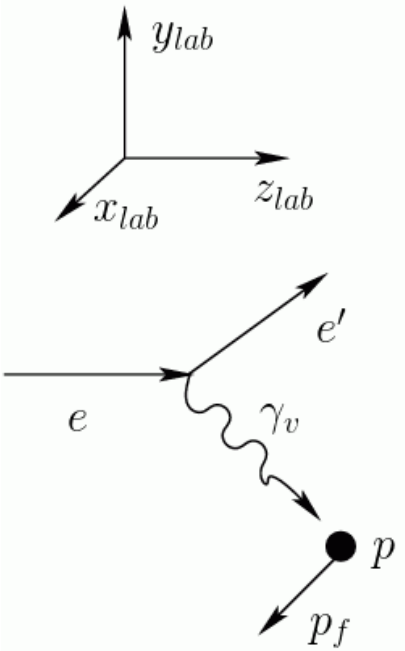
$$\vec{\beta} = \frac{\vec{q_\gamma}}{E_\gamma + m_p}$$



CMS

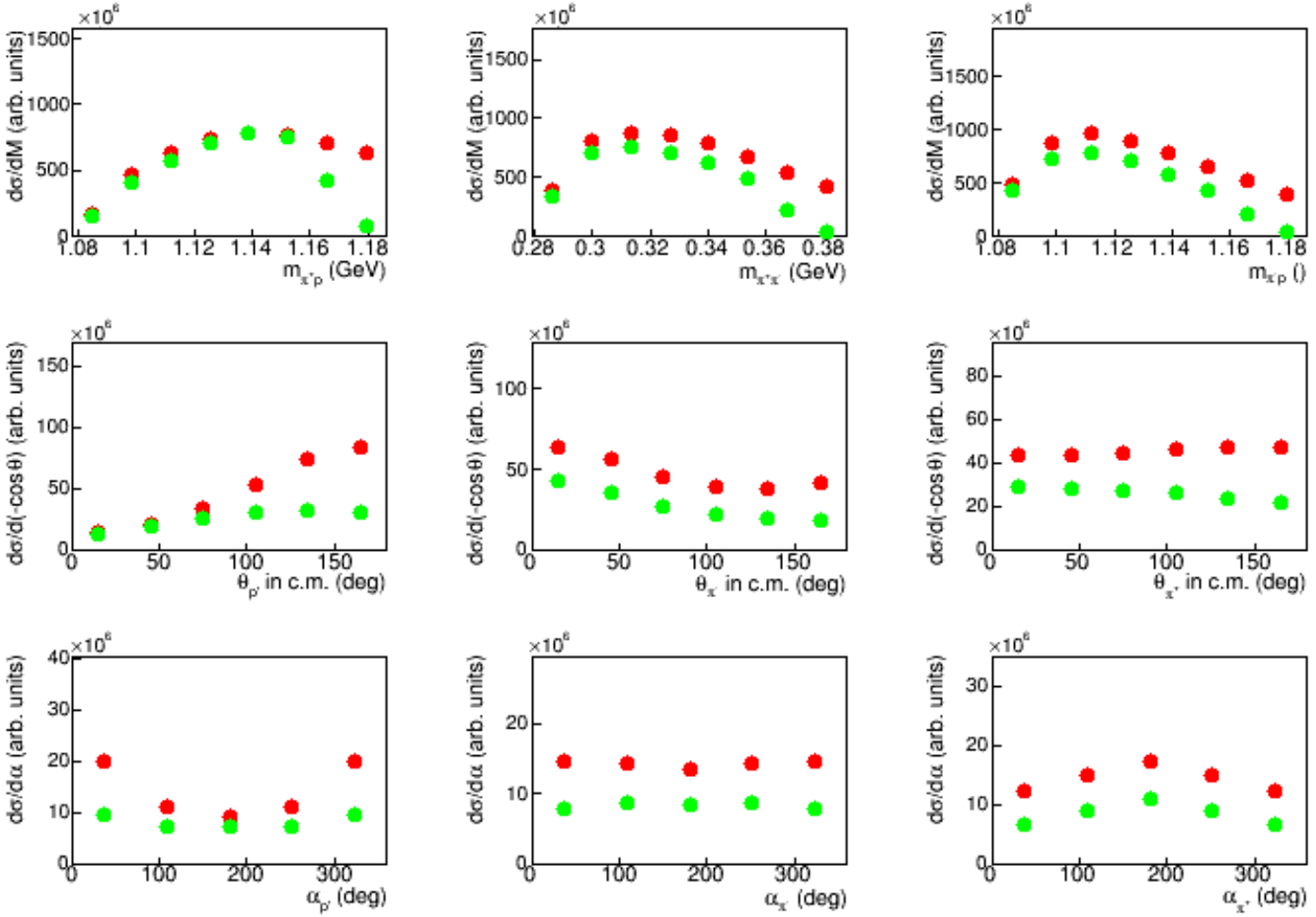
$$\vec{\beta} = \frac{\vec{q_\gamma} + \vec{p_f}}{E_\gamma + E_p}$$

Electroproduction off the moving proton



Fermi Correction

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

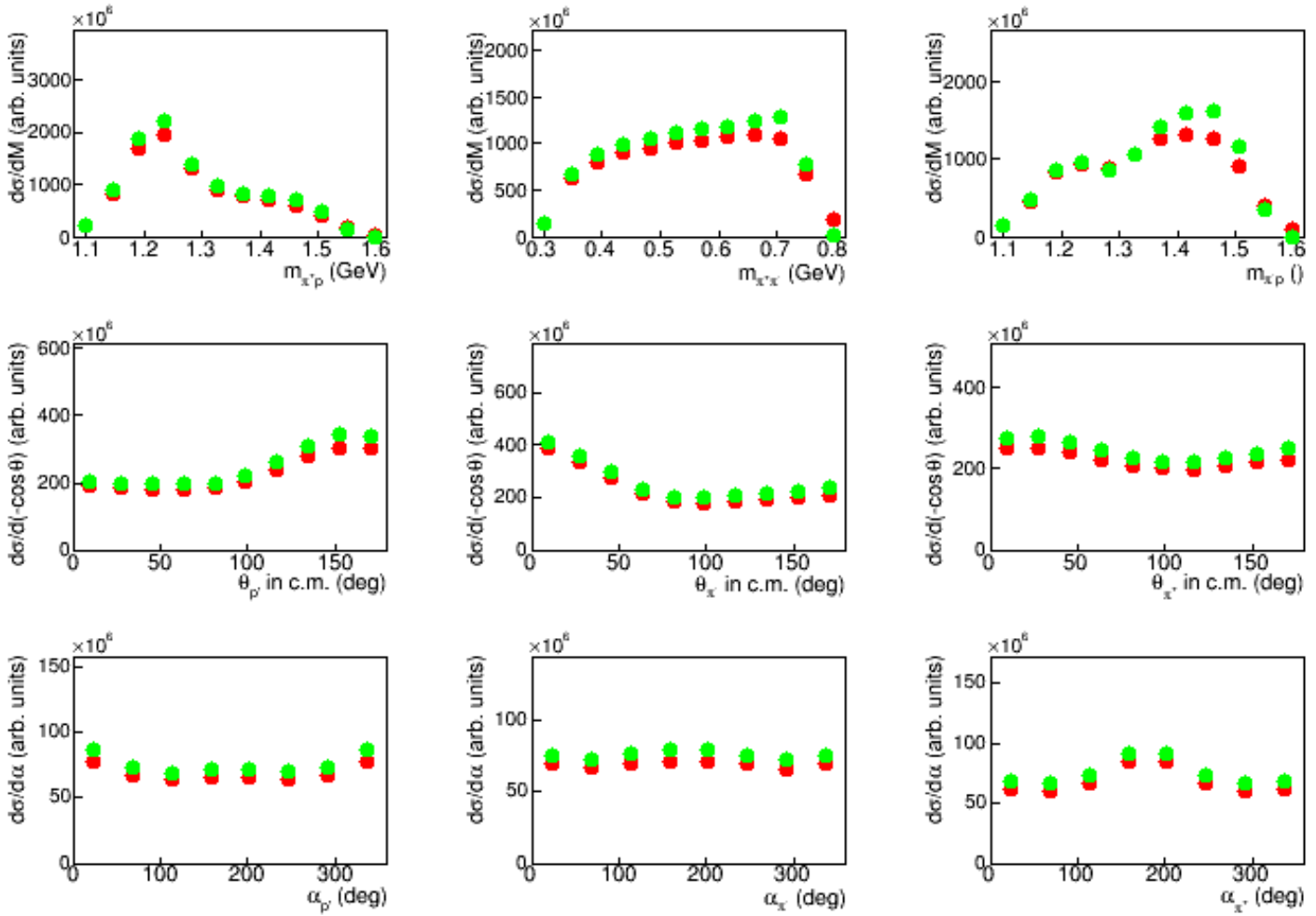


Red symbols – from EG for the moving proton

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