Measurement of beam spin asymmetry for exclusive pion electroproduction reaction at Jefferson Lab Hall C

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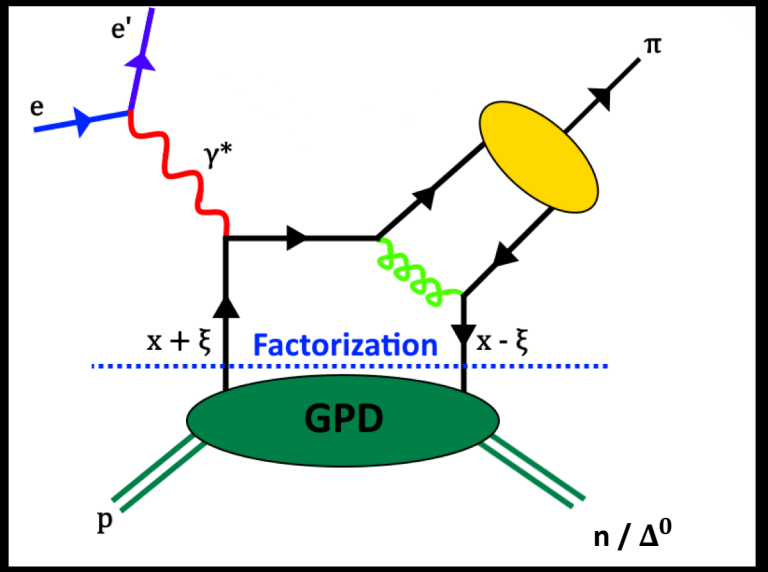
On behalf of Kaon-LT / Pion-LT collaboration

APS DNP Meeting (Boston 2024)

Introduction

- Generalized Parton Distributions (GPDs) are important tool to study 3D structure of hadrons.
  - Can be studied via DVCS or DEMP
- While significant work has been done for the study of ground state nucleon, little is known about the $N \rightarrow \Delta$ transition GPDs.
  - Only one measurement from CLAS12 with exclusive $\pi^- \Delta^{++}$ (Diehl et al. PRL 131 021901)



- Differential cross-section is dictated by virtual photon polarization ϵ.

$$2\pi \frac{d^2\sigma}{dtd\phi} = \epsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\epsilon(\epsilon+1)} \frac{d\sigma_{LT}}{dt} \cos\phi + \epsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi + p \cdot \sqrt{2\epsilon\,(1-\epsilon)}\, \frac{d\sigma_{LT'}}{dt} \sin\phi$$

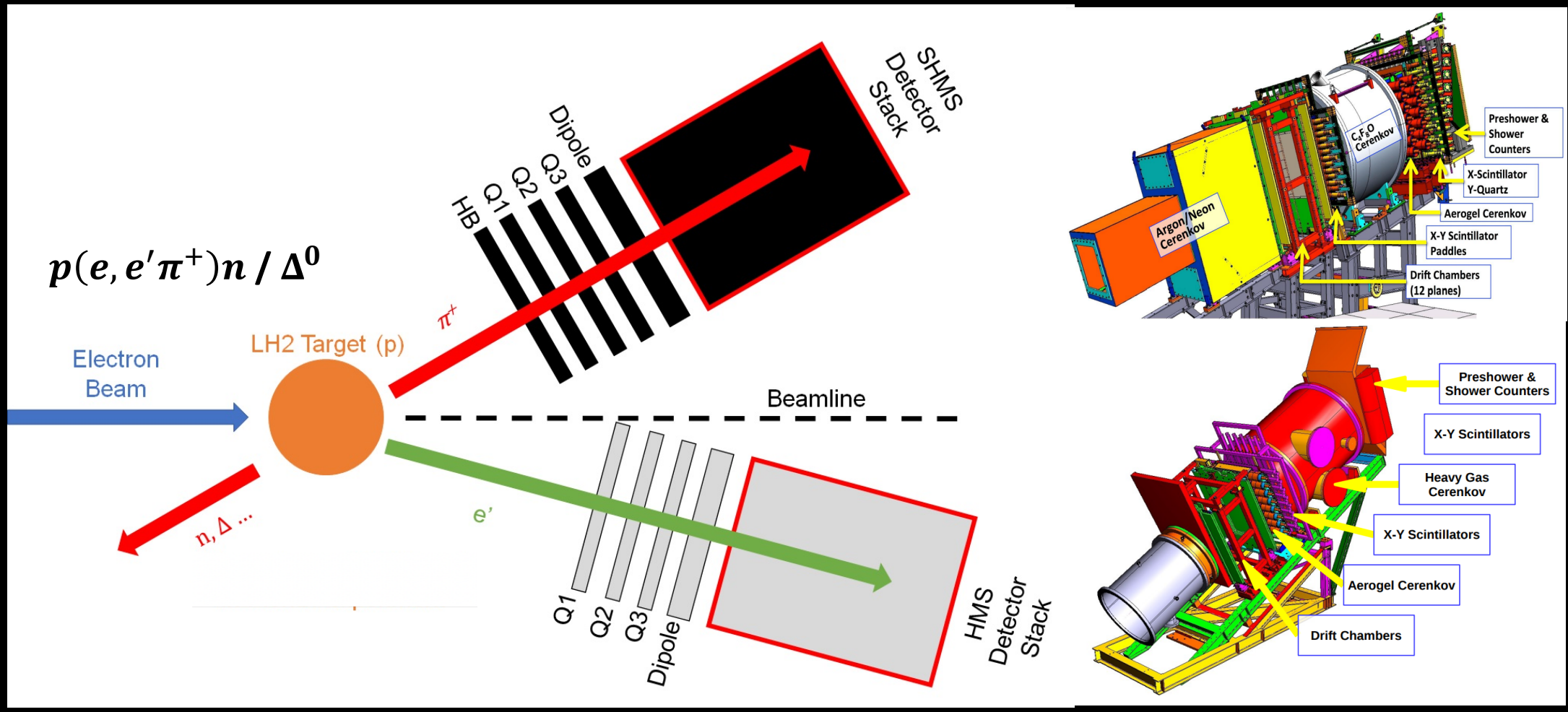
- $\sigma_{LT'}$ can be accessed through Beam Spin Asymmetry (A_{LU})

$$A_{LU} = \left[\frac{1}{P}\left(\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}\right)\right] = \left[\frac{1}{P}\left(\frac{Y^+ - Y^-}{Y^+ + Y^-}\right)\right] \propto \frac{\sigma^{LT'}}{\sigma^0}$$

P = $89^{+1}_{-3}\%$ (S. Wood and D. Gaskell)

Hall C @ Jeffferson Lab

Hall C 12 GeV upgrade was motivated by extreme forward angle requirements for L/T separation experiments.



Kaon-LT Experiment (E12-09-011)

- First dedicated experiment to study exclusive kaon electroproduction reaction.
  - Data collected 2018-2019 (~ 60 % complete)
- $p(e, e'K^+)\Lambda$ cross-section is ~ 1/10 times $p(e, e'\pi^+)n$ cross-section.
  - First paper on $p(e, e'\pi^+)n$ BSA under review (Postuma et al. PRL)
  - Ideal dataset to study $p(e, e'\pi^+)\Delta^0$ reaction.

E (GeV)	Q^2 (GeV^2)	W (GeV)	x_B	ε_{High} / ε_{Low}
10.6/8.2	5.5	3.02	0.40	0.53/0.18
10.6/8.2	4.4	2.74	0.40	0.72/0.48
10.6/8.2	3.0	2.32	0.40	0.88/0.57
10.6/6.2	3.0	3.14	0.25	0.67/0.39
10.6/6.2	2.115	2.95	0.25	0.79/0.25
4.9/3.8	0.5	2.40	0.09	0.70/0.45

ϕ Coverage

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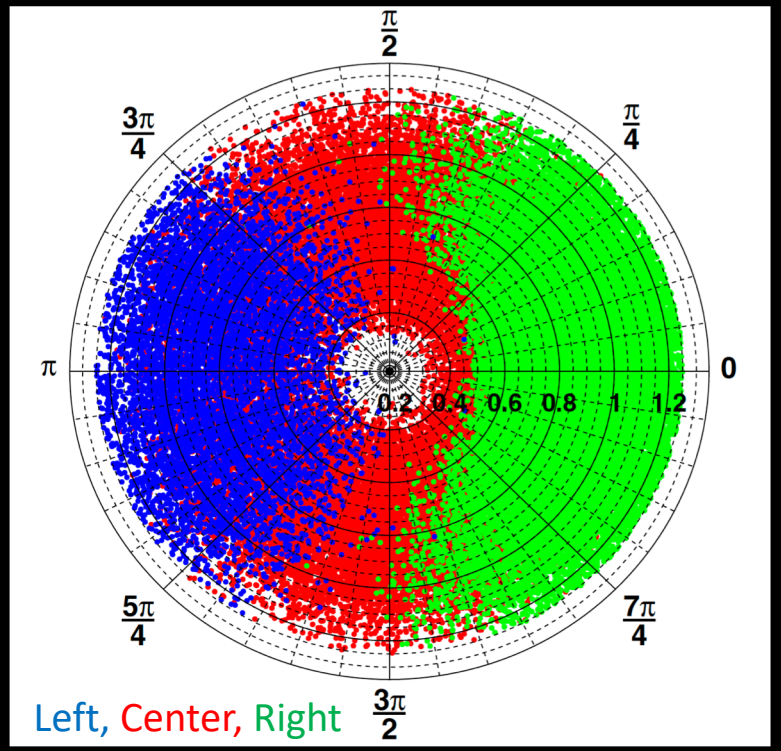
  - First paper on $p(e, e'\pi^+)n$ BSA under review (Postuma et al. PRL)
  - Ideal dataset to study $p(e, e'\pi^+)\Delta^0$ reaction.
- To get a full ϕ coverage, data is taken three degrees on the left and right of the *Q-vector* (in pion arm).

$Q^2 = 5.5\,, W = 3.02$

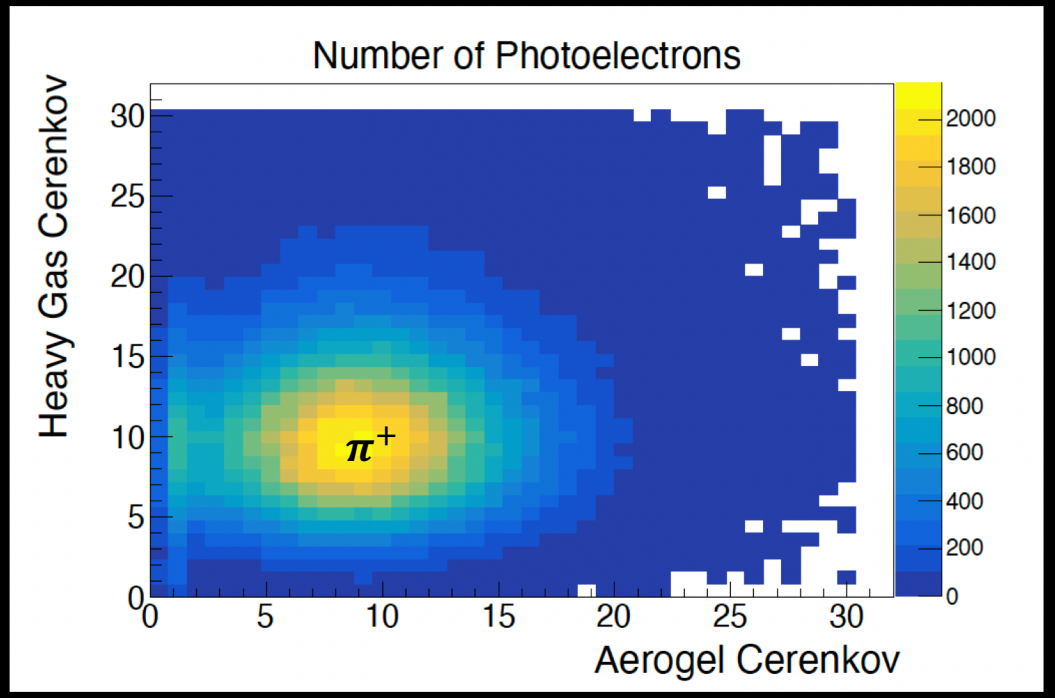


Radial axis – t

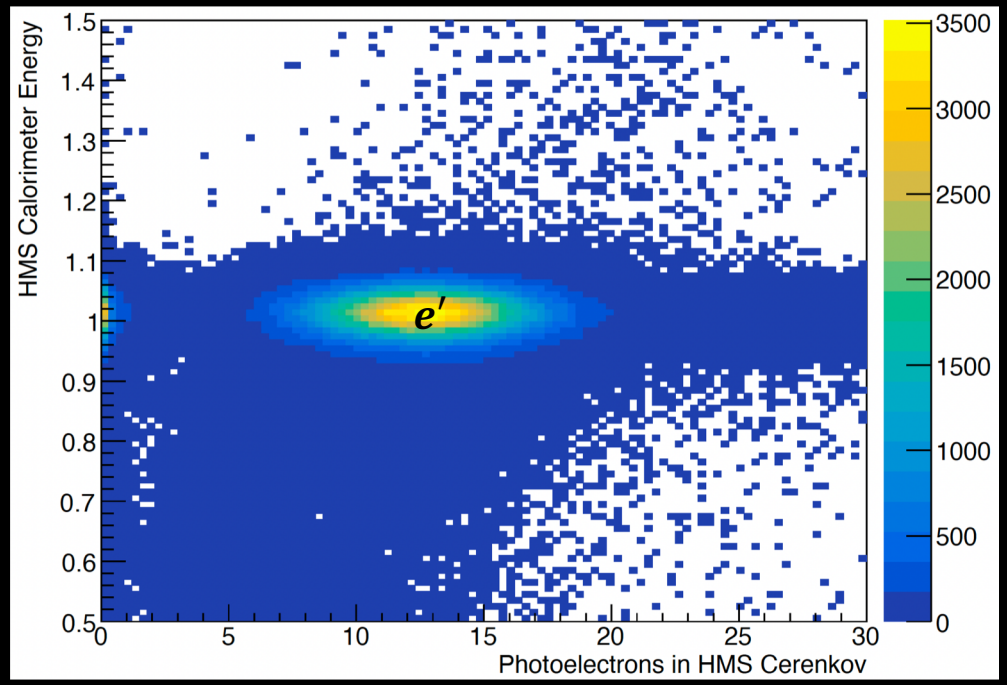
Azimuthal angle - ϕ

Particle ID

Pion Selection (SHMS)



Electron Selection (HMS)

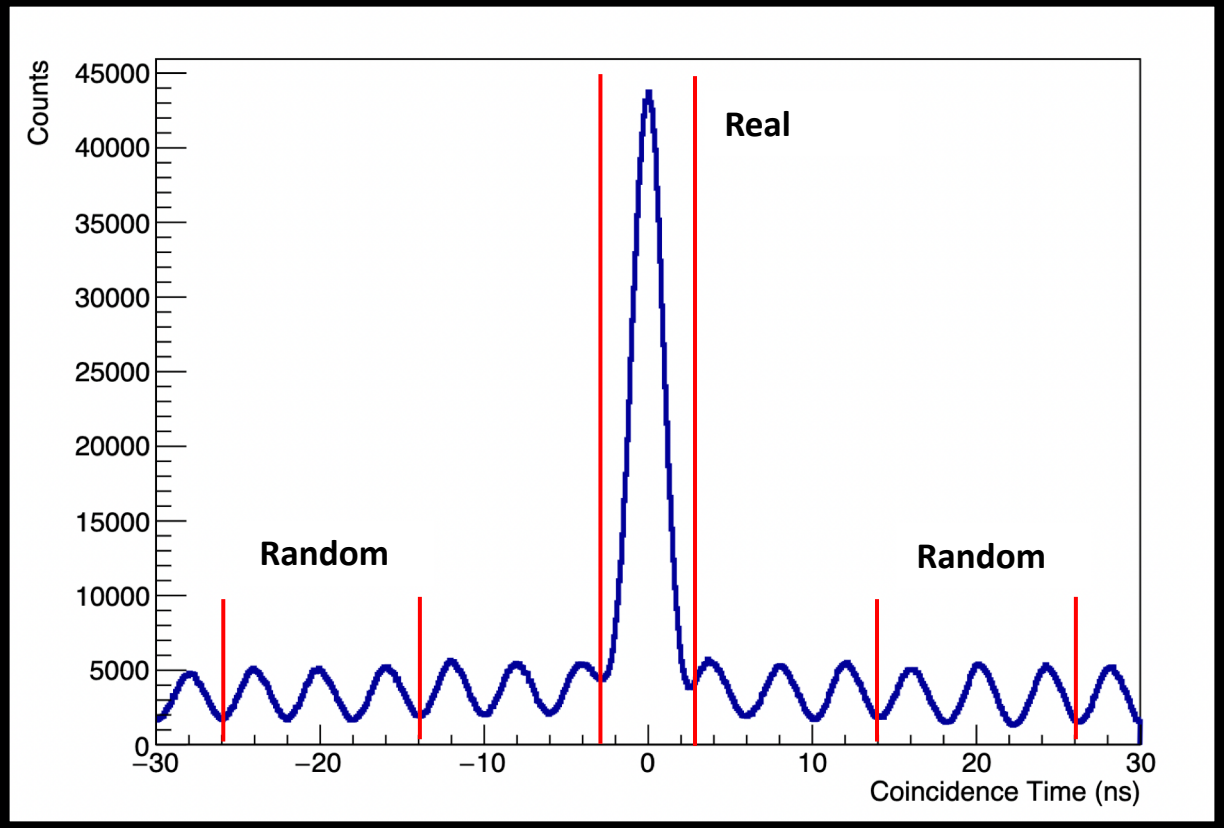


$Q^2 = 2.115\,, W = 2.95$

Event Selection

- $e' - \pi^+$ Coincidence

$$e' - \pi^+ \, Coin \, Time = HMS_{time} - SHMS_{time}$$

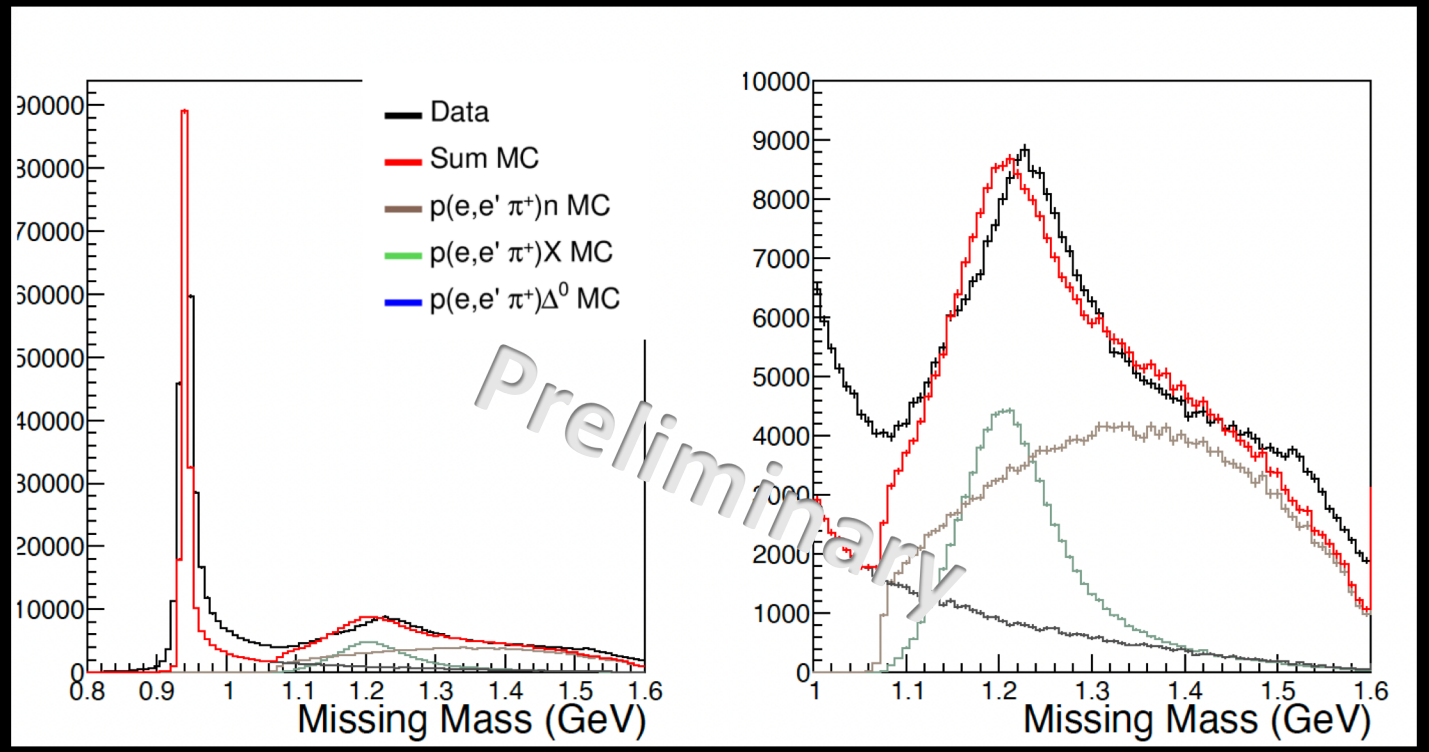


$$Q^2 = 2.115 \, , W = 2.95$$

Missing Mass

$$M_m = \sqrt{(E_e + m_p - E_{e'} - E_{\pi^+})^2 - (p_e - p_{e'} - p_{\pi^+})^2}$$

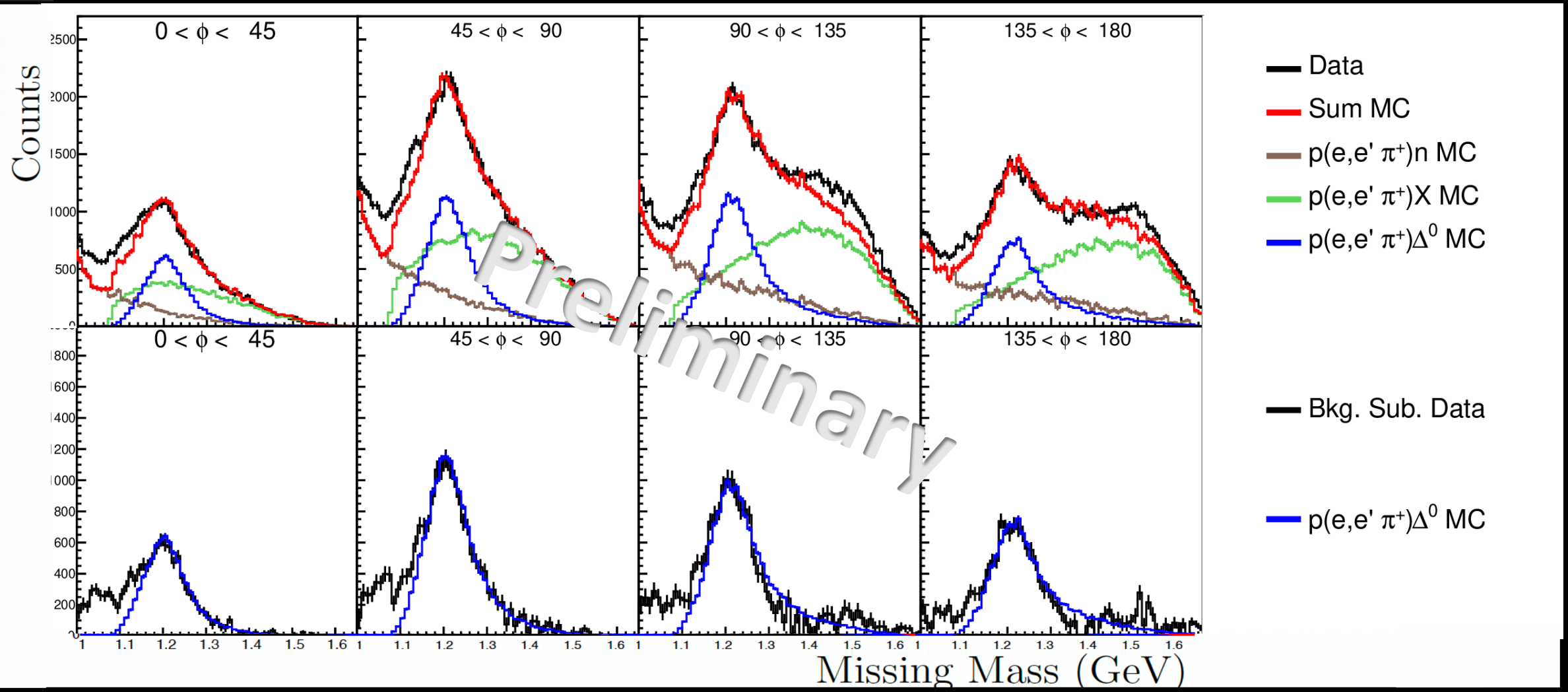
$p(e,e'\pi^+)n$ MC is subtracted by fitting it to the data in the neutron peak region.



$p(e,e'\pi^+)X$ MC is subtracted by fitting it to the data in the region (1.45-1.60 GeV).

$p(e,e'\pi^+)\Delta^0$ is fitted to the background subtracted data in the region (1.15-1.30 GeV).

Δ^0 Shape Study

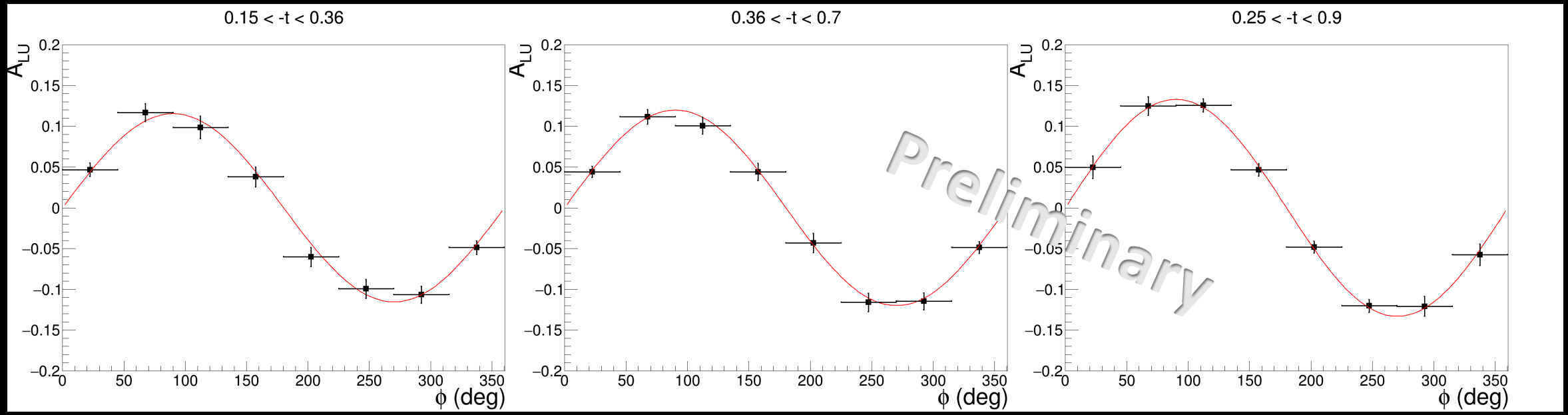


$Q^2 = 2.115\,, W = 2.95$

A_{LU} v/s ϕ

- BSA is calculated by integrating $p(e, e'\pi^+)\Delta^0$ missing mass (1.11 - 1.40 GeV).

$$A_{LU} = \left[\frac{1}{P}\left(\frac{Y^+ - Y^-}{Y^+ + Y^-}\right)\right] \qquad \delta_{stat} = \frac{2}{P}\sqrt{\frac{Y^+ . Y^-}{(Y^+ + Y^-)^3}}$$

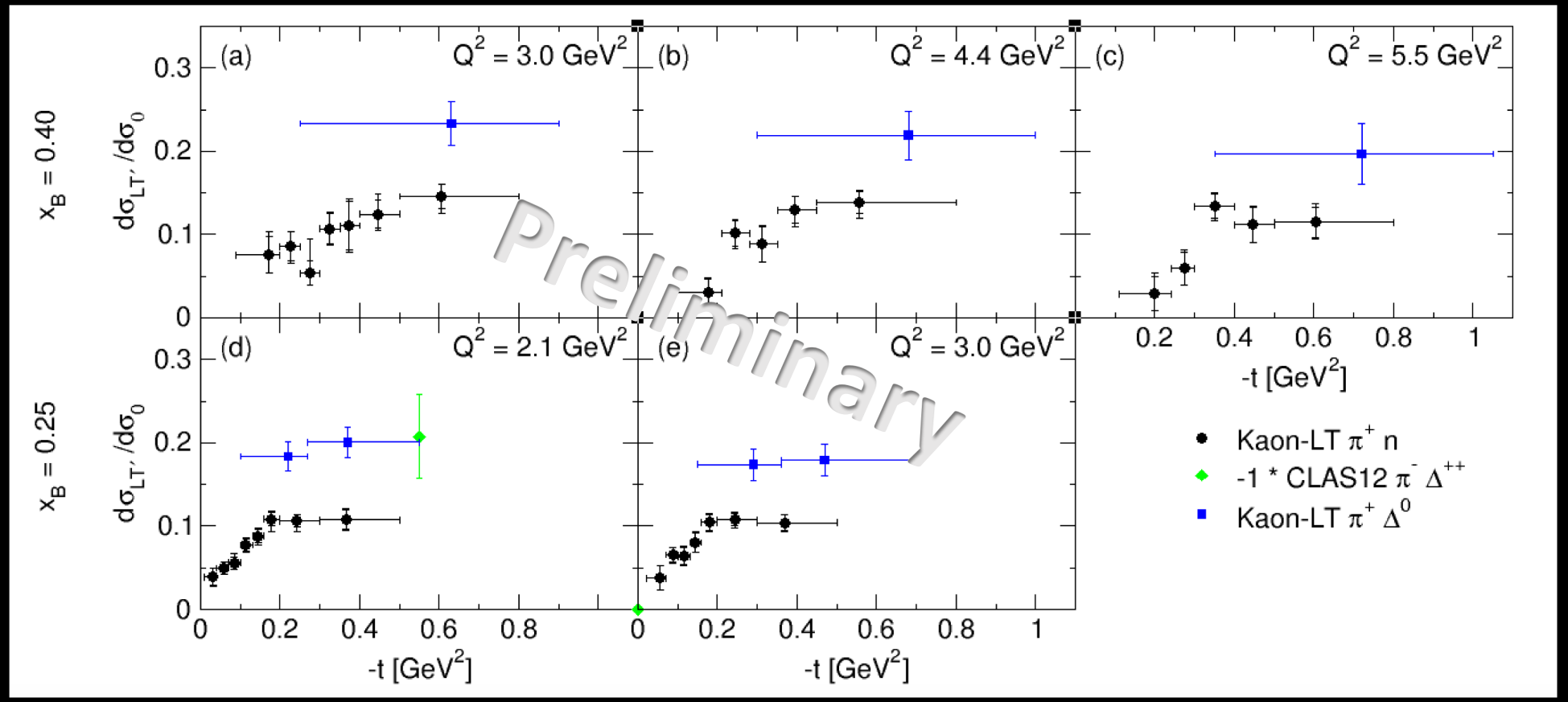


- Only statistical errors shown here.

$Q^2 = 3.0\ GeV^2$

$\sigma_{LT'}/\sigma_0$ v/s -t

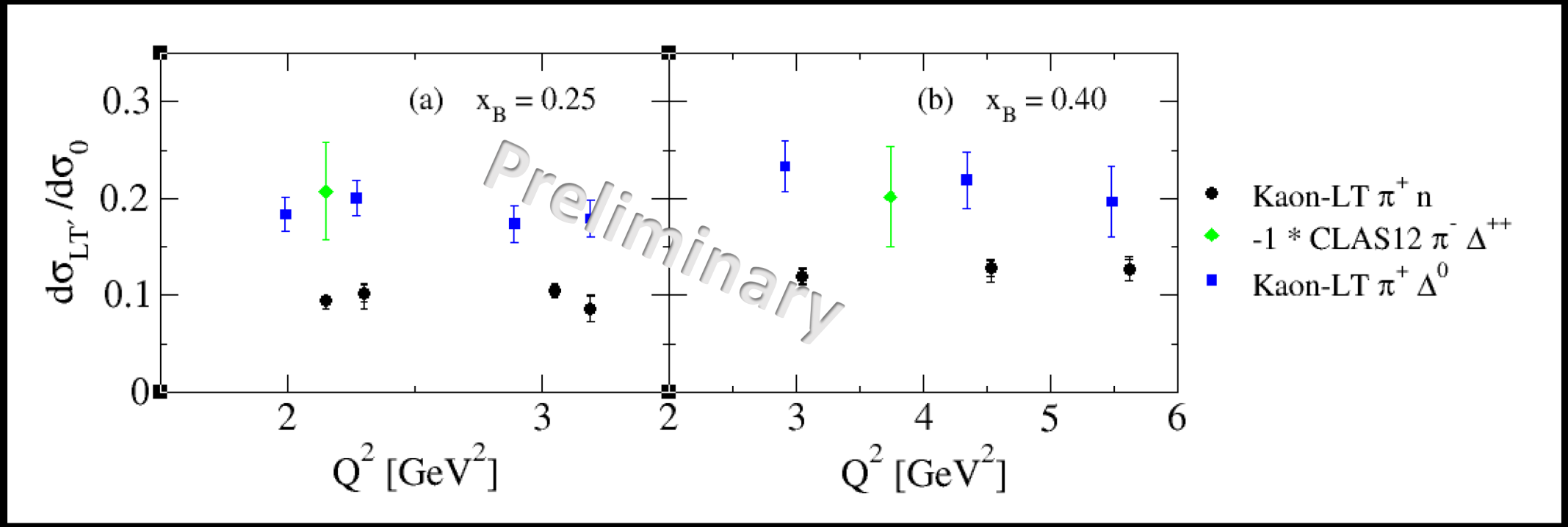
- Within limited –t coverage, $\sigma_{LT'}/\sigma_0$ show similar trend for both $\pi^+ n$ and $\pi^+ \Delta^0$
- The $\sigma_{LT'}/\sigma_0$ magnitude for $\pi^+ \Delta^0$ is approximately double than the $\pi^+ n$ across different settings.



- Only statistical errors shown here

$\sigma_{LT'}/\sigma_0$ v/s Q^2

- The $\sigma_{LT'}/\sigma_0$ magnitude for $\pi^+\Delta^0$ and $\pi^-\Delta^{++}$ is comparable across different settings.
  - The $\pi^-\Delta^{++}$ has opposite sign due to quark flavor change.



- Only statistical errors shown here

Summary

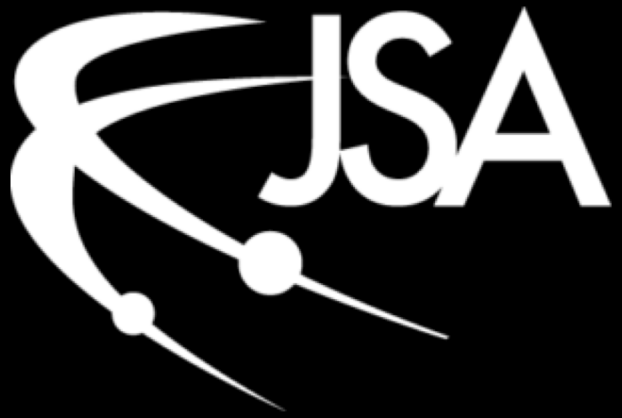
- Kaon-LT Experiment (E12-09-011) gives access to high statistic exclusive pion electroproduction data.

- Beam Spin Asymmetry analysis for $p(e, e'\pi^+)n$ is complete.
  - Paper under review (Postuma et al. PRL)

- **First measurement of Beam Spin Asymmetry for $p(e, e'\pi^+)\Delta^0$** is almost complete.
  - Currently evaluating systematic uncertainties.

- **Need theory support from both Regge and GPD framework to**
  - **Confirm hard-soft factorization**
  - **Extract transition GPDs**

Thank You !!!



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Kaon-LT and Pion-LT Collaboration

- Spokespeople

  Garth Huber, Dave Gaskell, Tanja Horn, Pete Markowitz

- Key Members

  Richard Trotta, Alicia Postuma, Portia Switzer, Stephen Kay, Vijay Kumar, Nathan Heinrich, Muhammad Junaid, Abdennacer Hamidi, Julie Roche

cua

University of Regina

Jefferson Lab

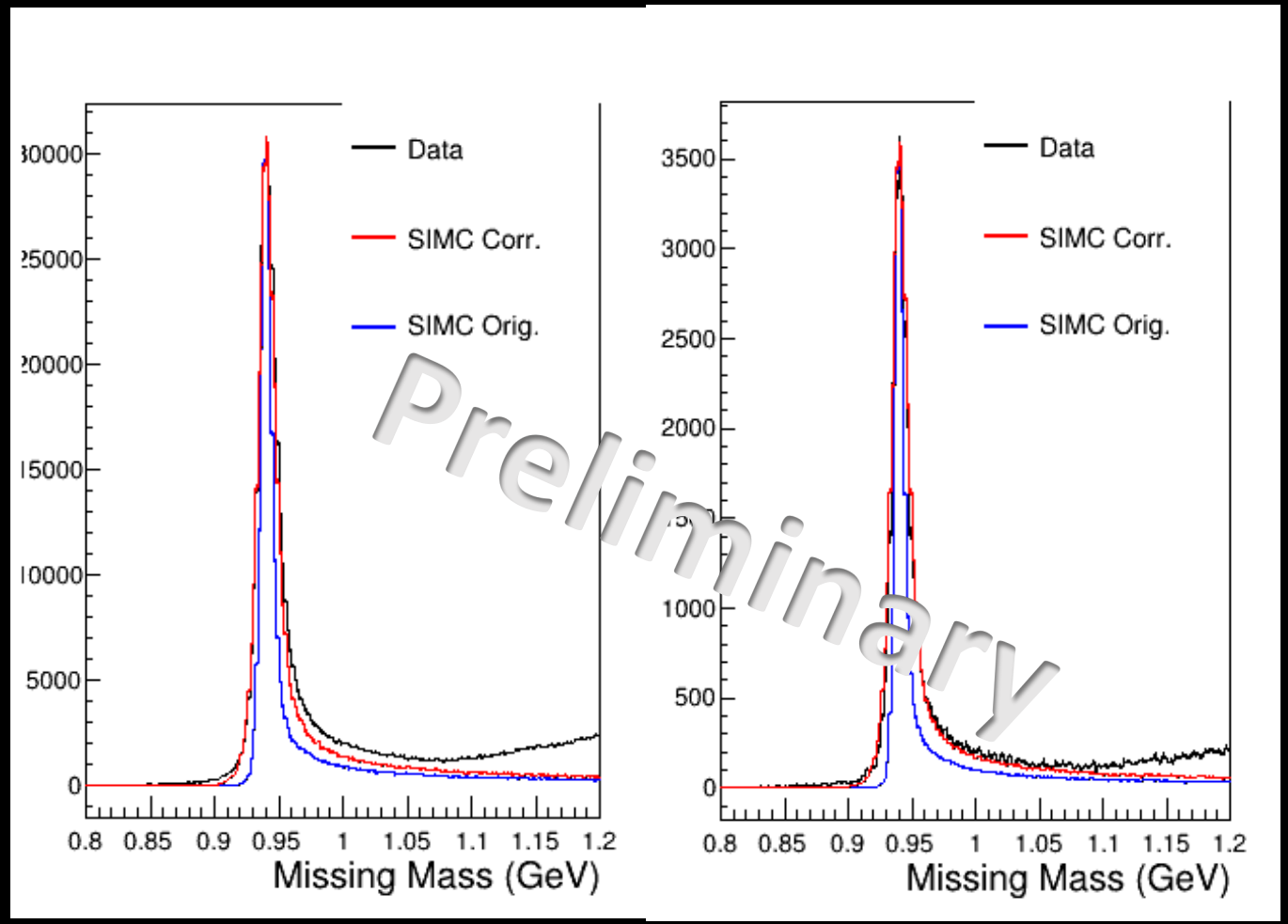
UNIVERSITY of York

OHIO UNIVERSITY

Backup

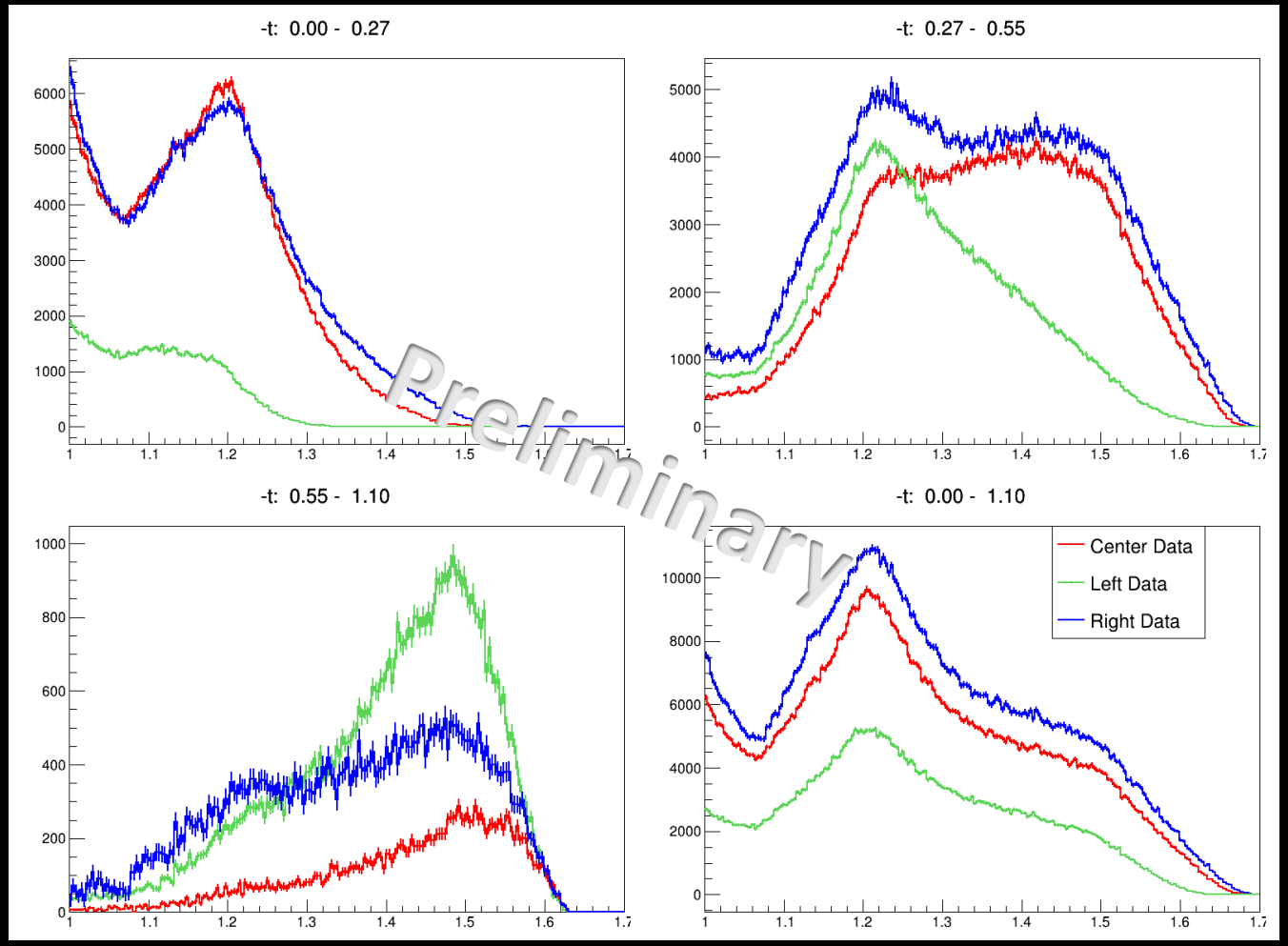
Monte Carlo Resolution Correction

- Hall C Monte Carlo (SIMC) drift chamber resolution has been optimized.
- Resolution difference b/w data and MC vary for different kinematics.
  - A global correction factor is used.
- A systematic uncertainty will be evaluated for remaining resolution difference.



$Q^2 = 2.115\,, W = 2.95$ $Q^2 = 4.4\,, W = 2.74$

Missing Mass (t-binning)



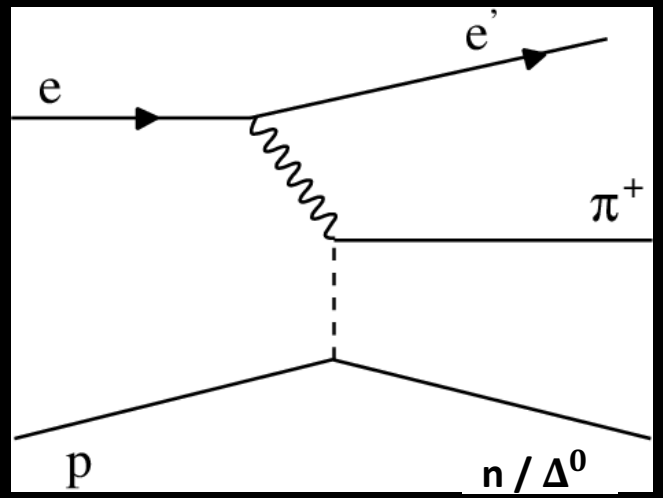
$Q^2 = 2.115\,, W = 2.95$

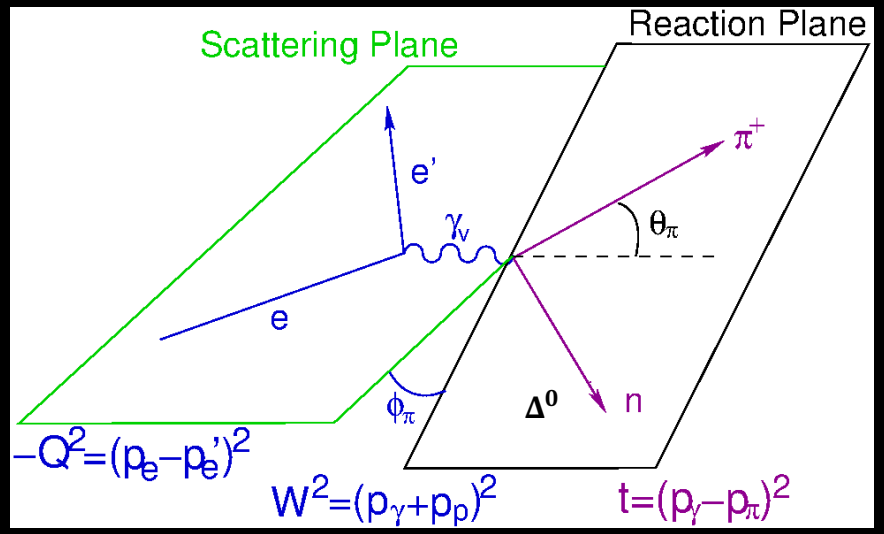
Exclusive Pion Electroproduction

- Pion is the lightest meson with two valence quarks.
- Pion electroproduction reaction is studied through ***"Exclusive Pion Electroproduction".***

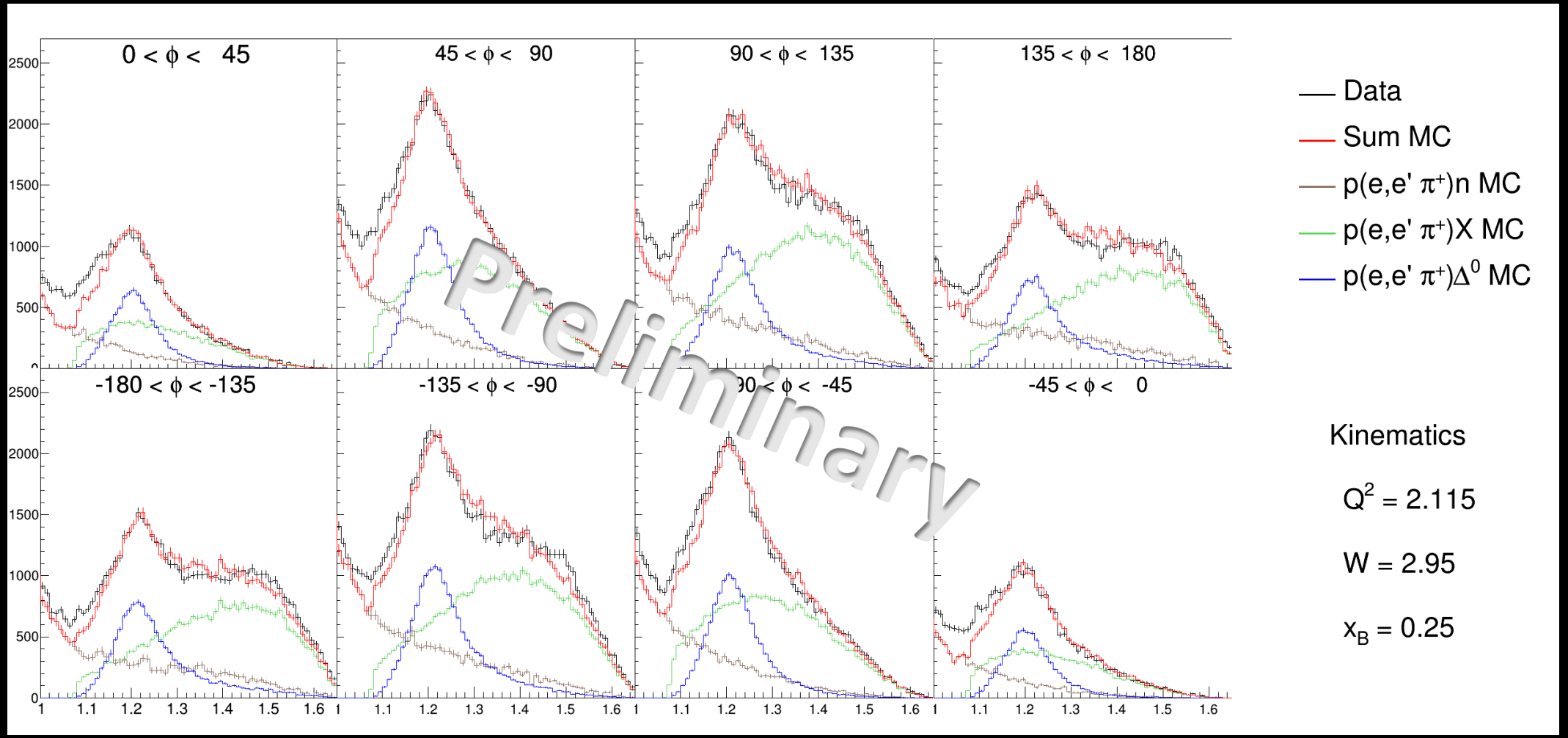
$$e + p \rightarrow e' + \pi^+ + n \; or \; \Delta^0$$

- **To study hadron structure, need a precise measurement of this rection.**
- **Important Kinematic Quantities**
  - $Q^2, W, -t \; and \; \phi$



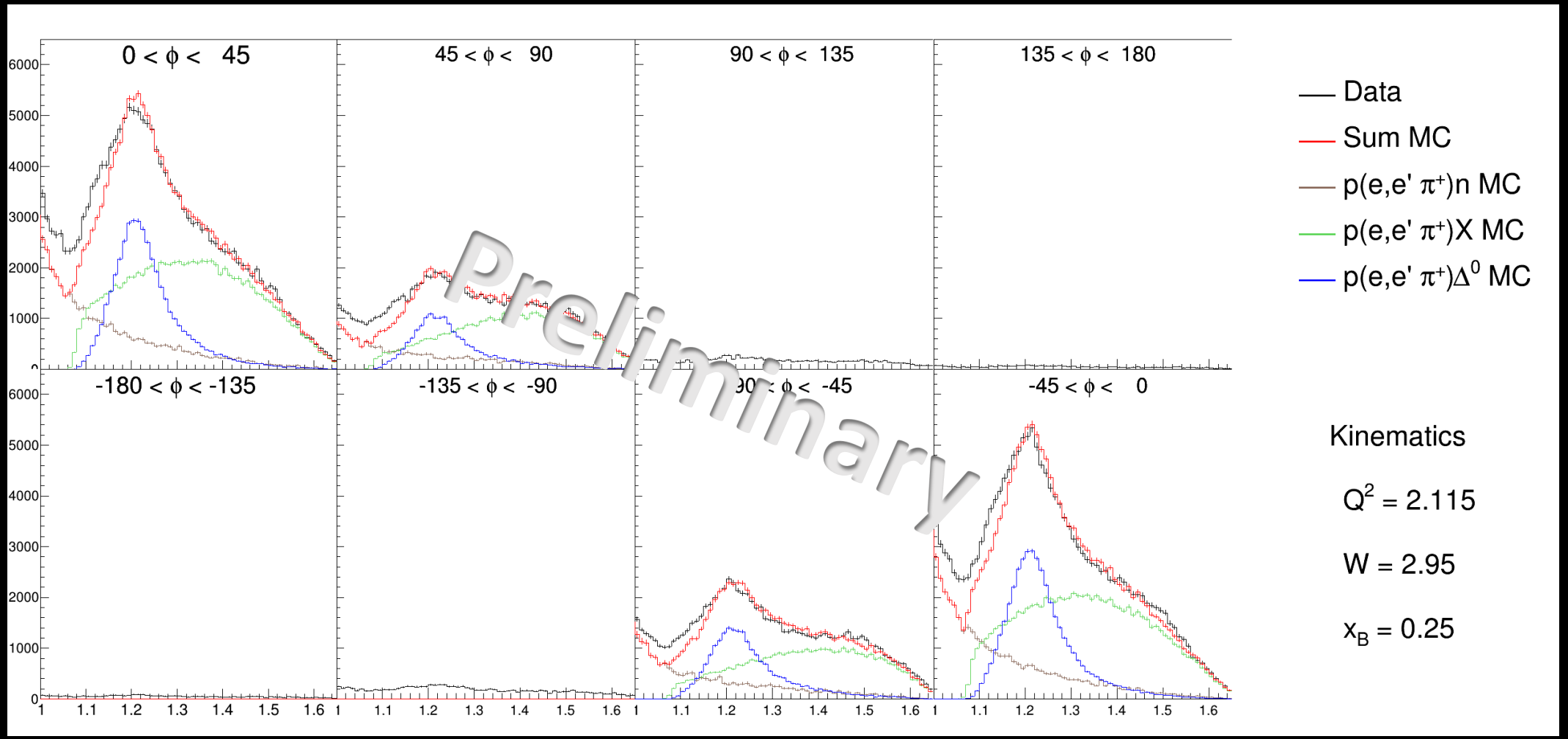


Δ^0 Shape study



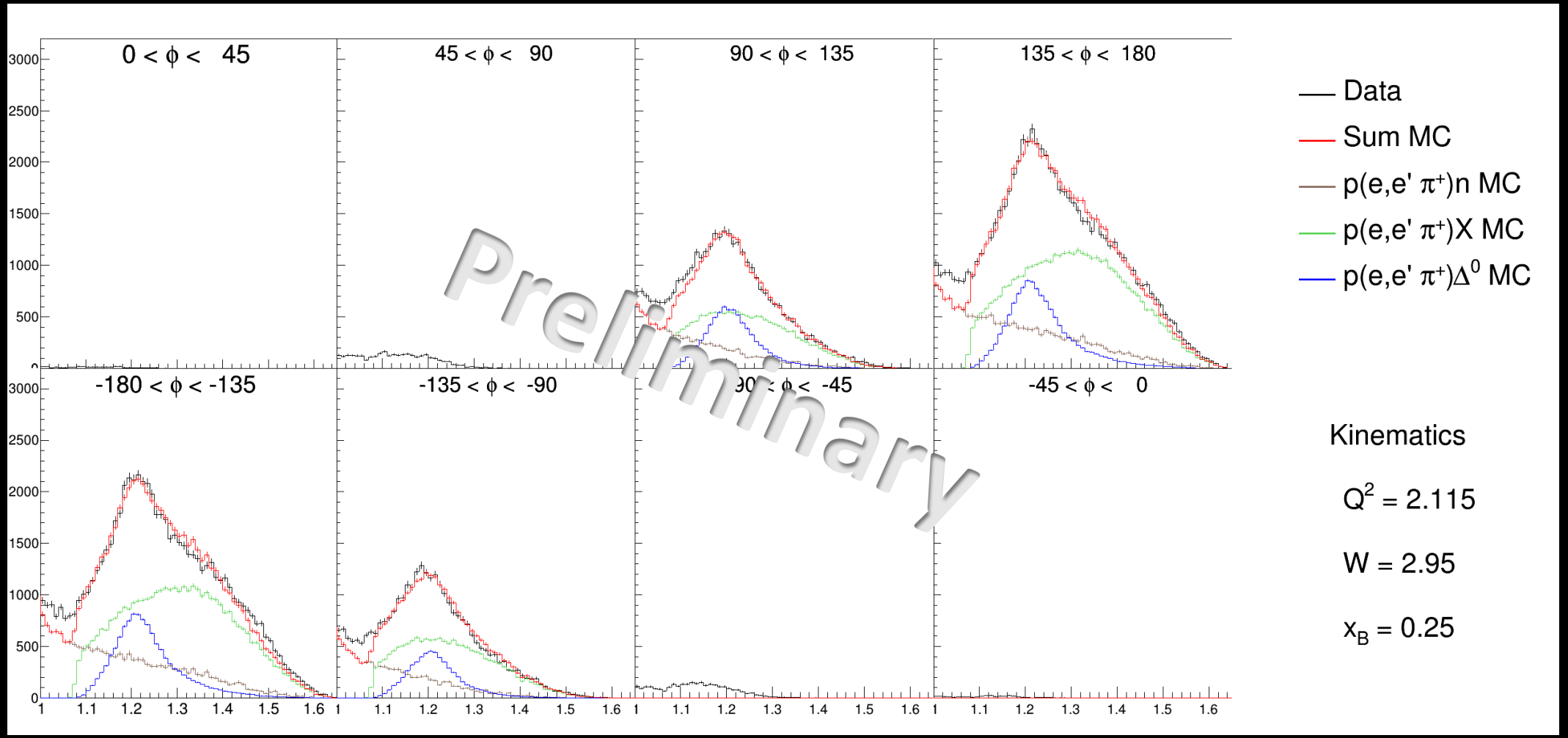
$Q^2 = 2.115\,, W = 2.95, Center$

Δ^0 Shape study



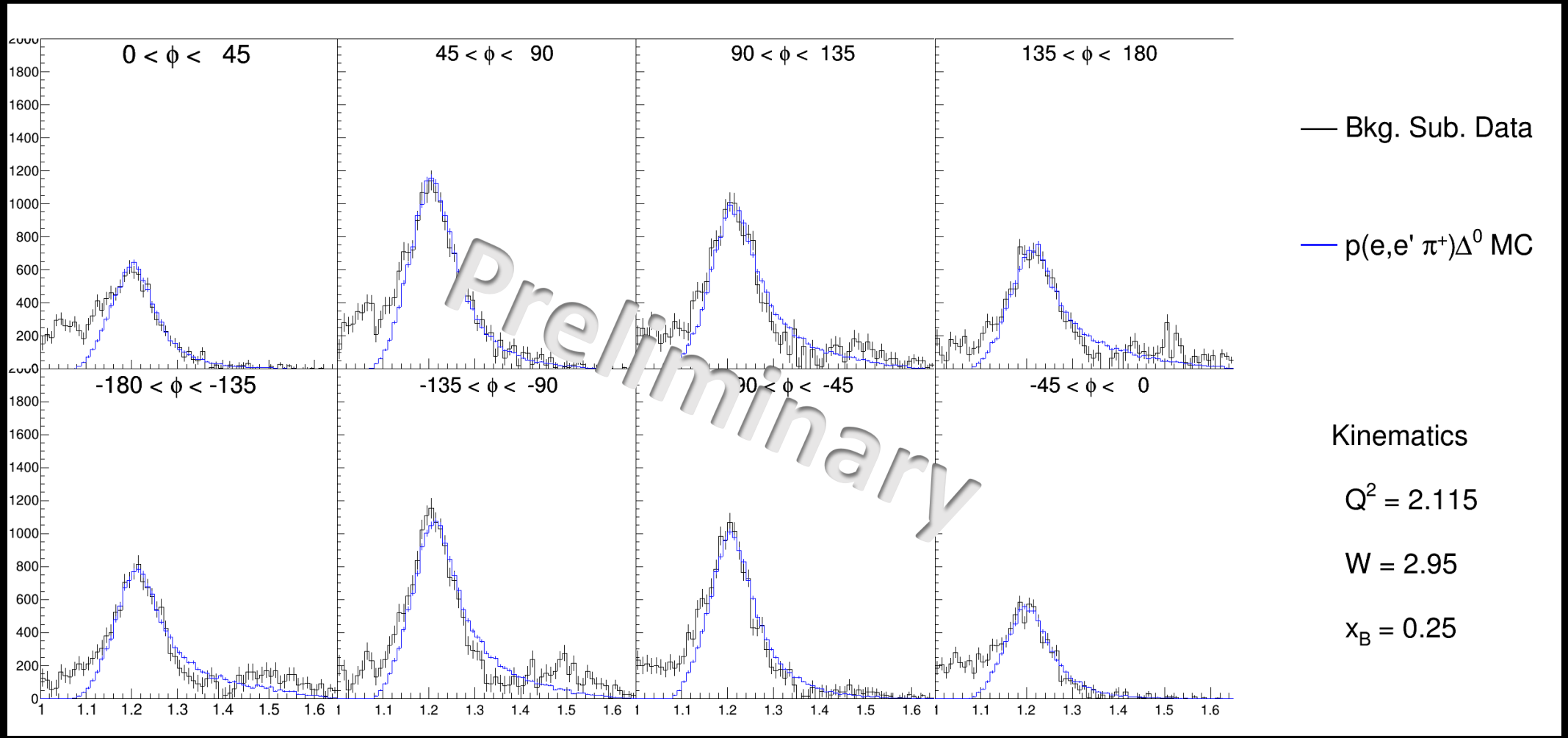
$Q^2 = 2.115, W = 2.95, Right$

Δ^0 Shape study



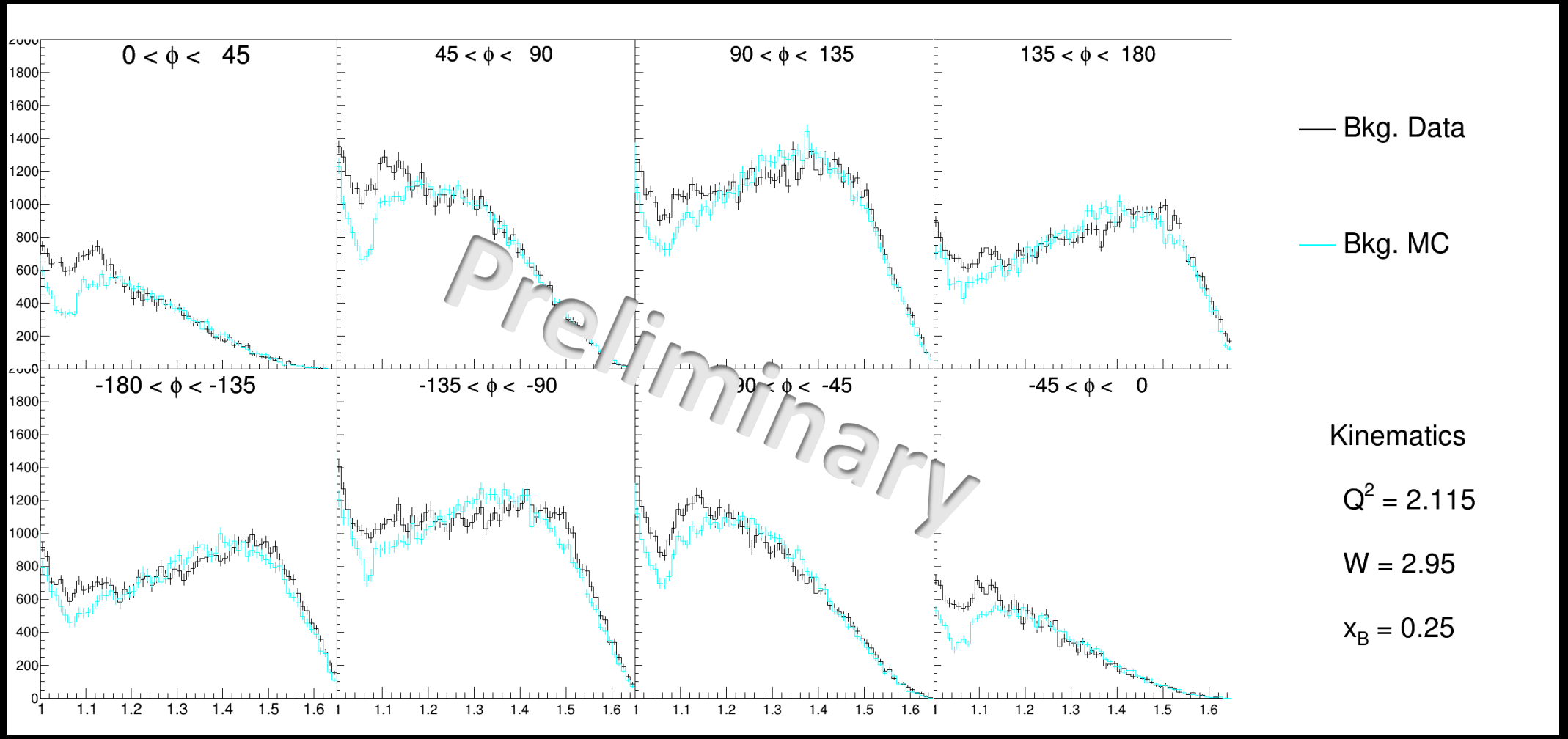
$Q^2 = 2.115 , W = 2.95, left$

Δ^0 Selection



$Q^2 = 2.115\,, W = 2.95$

Missing Mass - Background

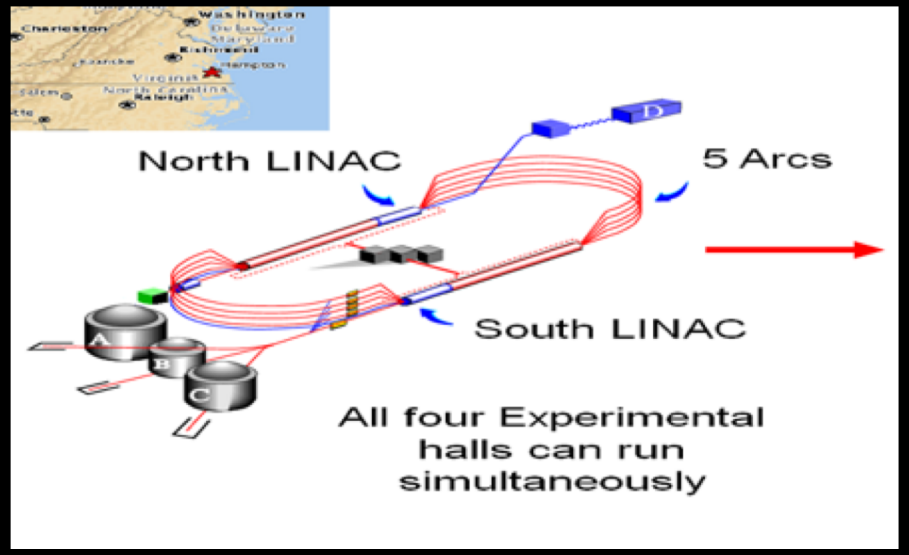


$Q^2 = 2.115 , W = 2.95$

ϕ Coverage

- Hall C 12 GeV upgrade was motivated by extreme forward angle requirements for L/T separation experiments.
- To get a full ϕ coverage, data is taken three degrees on the left and right of the *Q-vector* (in pion arm).
- *Measurements are only possible due to small angle capabilities of SHMS.*

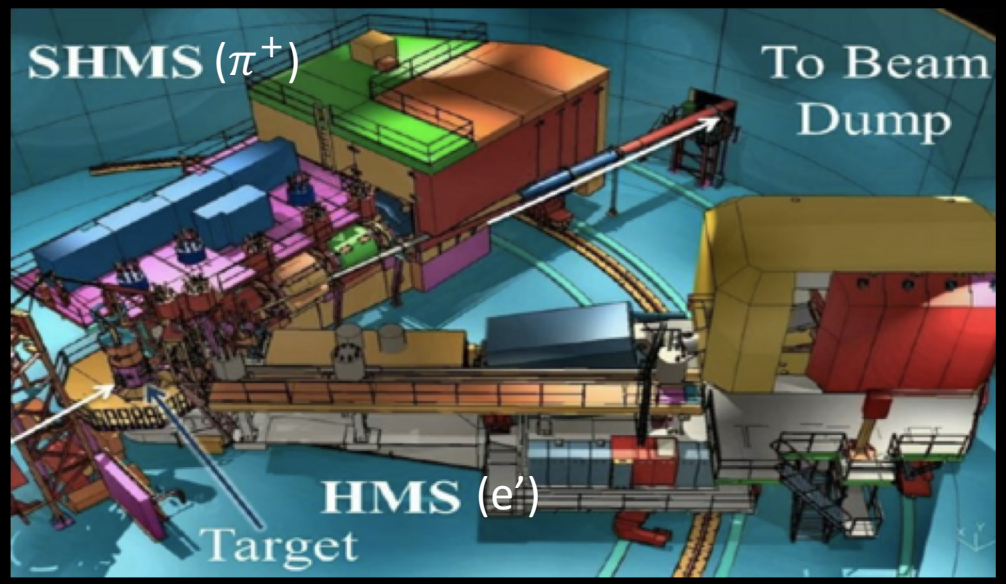
Thomas Jefferson National Accelerator Facility



- Consists of two superconducting electron LINACs.
- Capable of delivering high luminosity beam to four halls.
- Variable beam energies and high current (critical for L/T separation).

Hall C

- Specifically designed to measure precise cross-sections.
- Two advanced rotatable magnetic spectrometers (HMS and SHMS).
- Particles of specific momentum are studied by using a magnet system.



SHMS Detector System

DETECTOR	PURPOSE	NOTES
S1XY, S2XY Hodoscopes	Lowest-level Trigger. Time reference	
Aerogel Cerenkov	Particle ID, K+/p discrimination	n= 1.011,1.015, 1.03,1.05
Heavy-Gas Cerenkov	Particle ID, Trigger. $\pi^{\pm}/K^{\pm}$ discrimination	C_4F_{10} - Kept at roughly 1 atm pressure
Drift Chambers	Momentum Measurement. Tracking.	5mm max. drift 300 micron resolution
Preshower / Shower Counters	Particle ID, Trigger. Electron tag