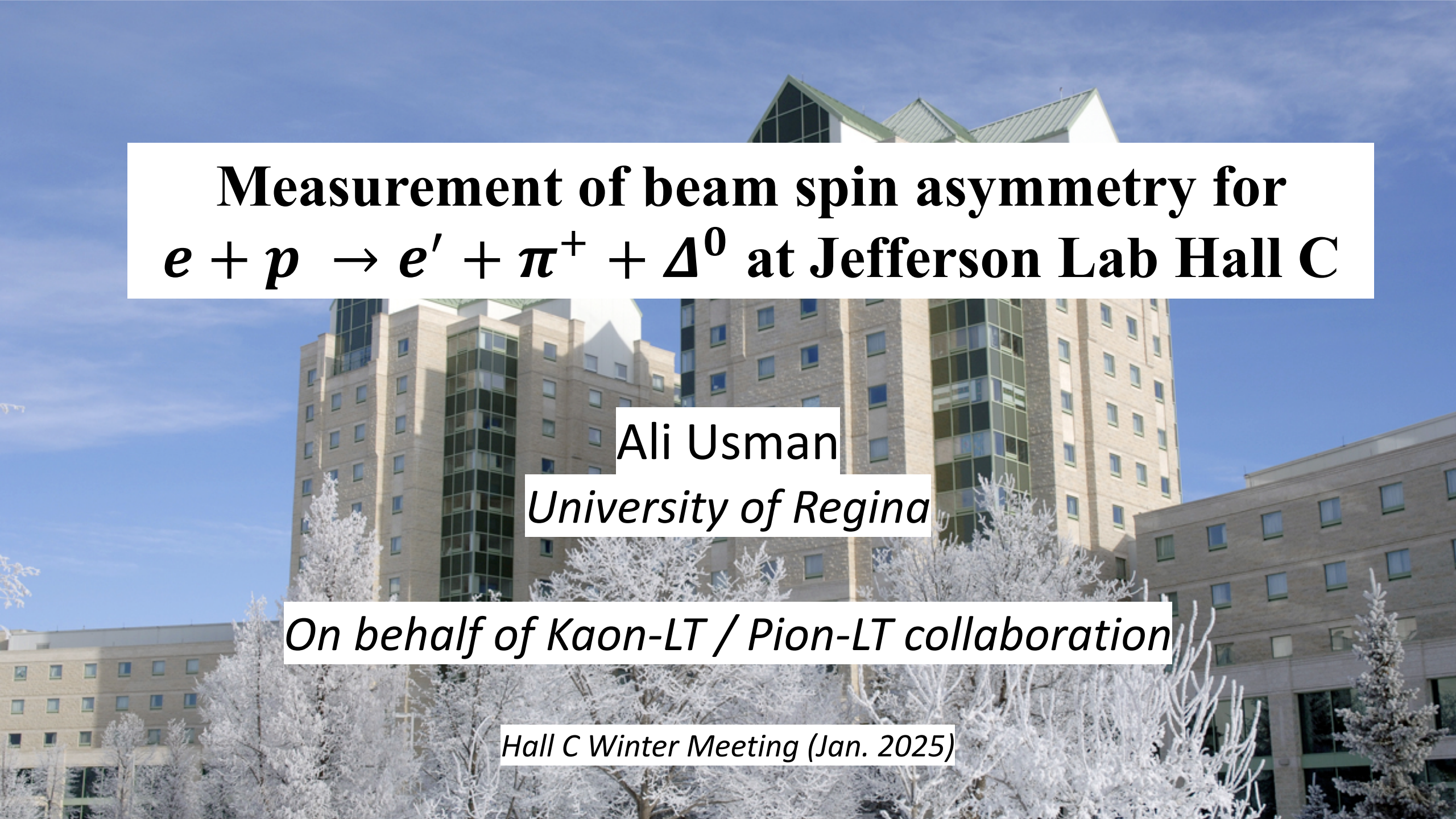


Measurement of beam spin asymmetry for $e + p \rightarrow e' + \pi^+ + \Delta^0$ at Jefferson Lab Hall C

Ali Usman

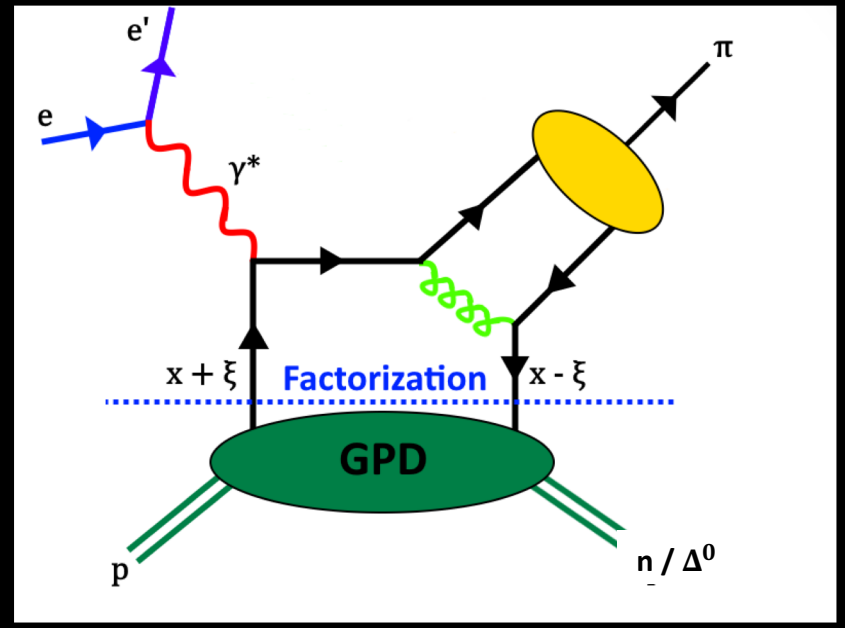
University of Regina

On behalf of Kaon-LT / Pion-LT collaboration

Hall C Winter Meeting (Jan. 2025)

Generalized Parton Distributions

- Generalized Parton Distributions (GPDs) are important tool to study 3D structure of hadrons.
  - Deep Virtual Compton Scattering (DVCS)
  - Deep Exclusive Meson Production (DEMP)
- Measurements of GPDs require
  - Confirmation of applicability of hard-soft QCD factorization mechanism at intermediate Q^2.
- 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)
  - Pioneering theory work on Transition GPDs for exclusive $\pi\Delta$ electroproduction (Kroll, Passek-Kumericki PRD 107, 054009)



Exclusive Meson Electroproduction

- Exclusive pion electroproduction reaction

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

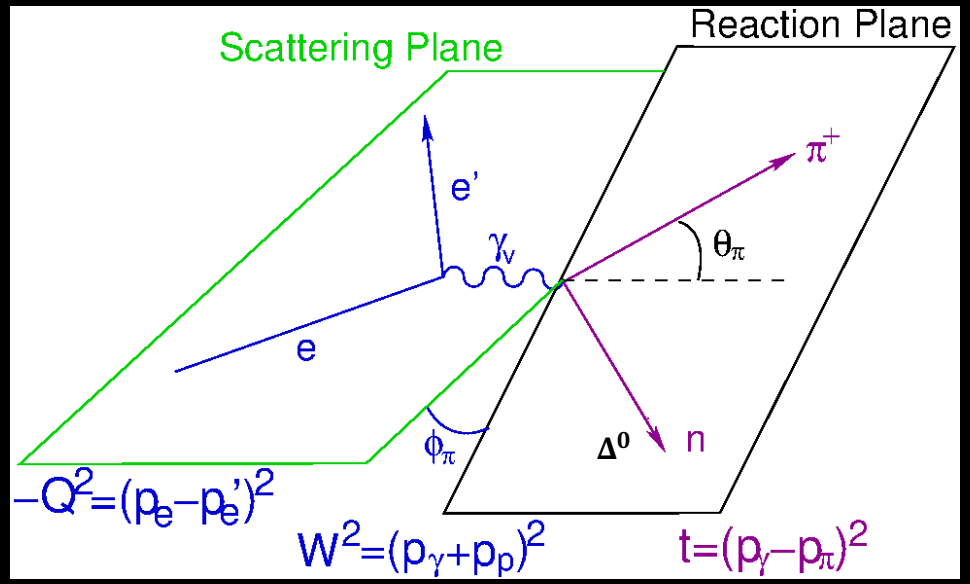
- Differential cross-section is dictated by virtual photon polarization ϵ.

$$2\pi \frac{d^2\sigma}{dtd\phi} = \epsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\epsilon(\epsilon+1)} \frac{d\sigma_{LT}}{dt} cos\phi + \epsilon \frac{d\sigma_{TT}}{dt} cos2\phi + p \cdot \sqrt{2\epsilon\,(1-\epsilon)} \frac{d\sigma_{LT'}}{dt} \sin\phi$$

- "ϵ" is polarization of virtual photon

$$\epsilon = \left[1 + 2\frac{(E_e - E_{e'})^2 + Q^2}{Q^2} \cdot tan^2 \frac{\theta_{e'}}{2}\right]^{-1}$$

- Cross-section, $\sigma_{LT'}$, is extracted using a longitudinally polarized electron beam.



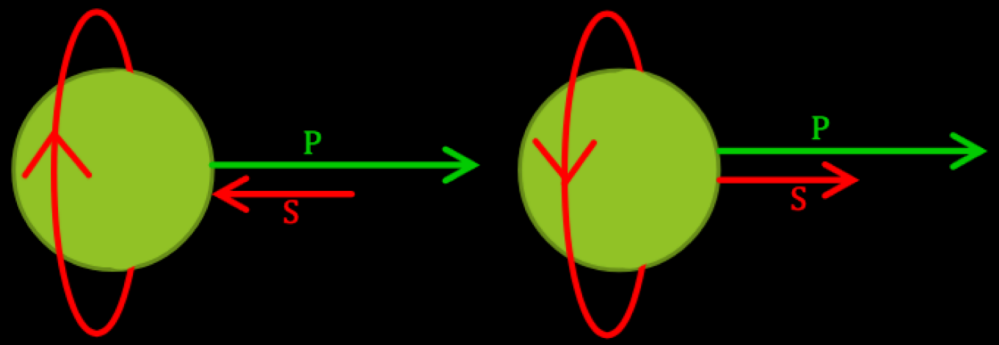
Beam Spin Asymmetry

- BSA is difference in cross-section based on helicity (+1, -1) of incident electron.
- $\sigma_{LT'}$ interference between transversely and longitudinally polarized virtual photons
  - Can be accessed through Beam Spin Asymmetry (A_{LU})

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

→ **Unpolarized cross-section**

- Acceptance and efficiencies cancel in the ratio.
- Beam polarization "*P*" is measured at source ($P = 89^{+1}_{-3}\ \%$ Gaskell and Wood)



Kaon-LT Experiment (E12-09-011)

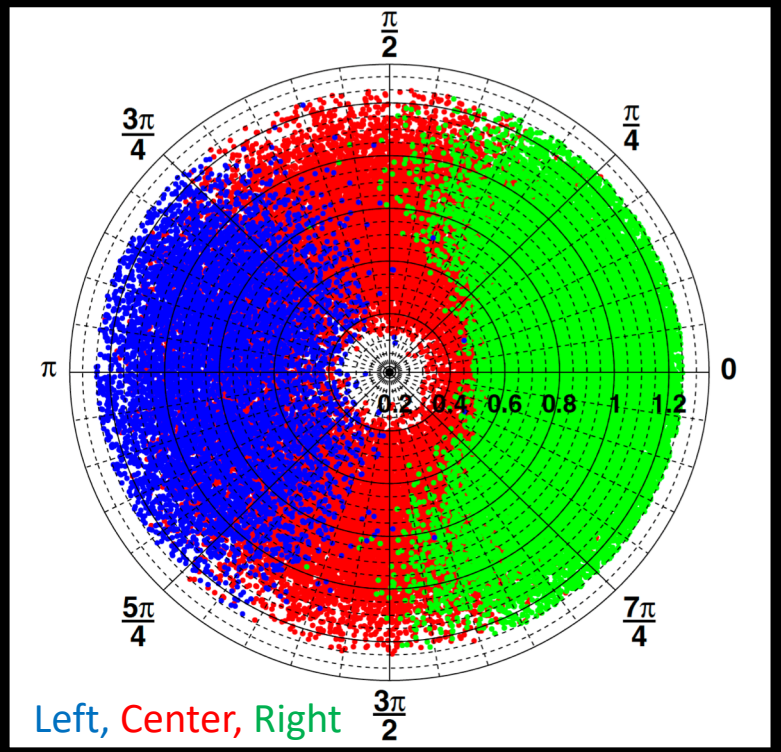
- First dedicated experiment to study exclusive kaon electroproduction reaction.
  - Data collected 2018-2019 (~ 60 % complete)
- $p(e, e'K^+)\Lambda$ cross-section is ~ 1/10 times $p(e, e'\pi^+)n$ cross-section.
  - First paper on $p(e, e'\pi^+)n$ BSA under review (Postuma et al.)
- Ideal dataset to study $p(e, e'\pi^+)\Delta^0$ reaction.
  - Experiment kinematics are designed to have the Λ missing mass region in center of phase space.
- For BSA, only 10.6 GeV data is used.

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

- Kaon-LT Experiment used standard HMS (electron arm)-SHMS (pion arm) configuration in Hall C.
- 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.*
- *For beam spin asymmetry, ϕ dependence is measured by binning the data in 8 equal size bins (for each SHMS setting).*

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

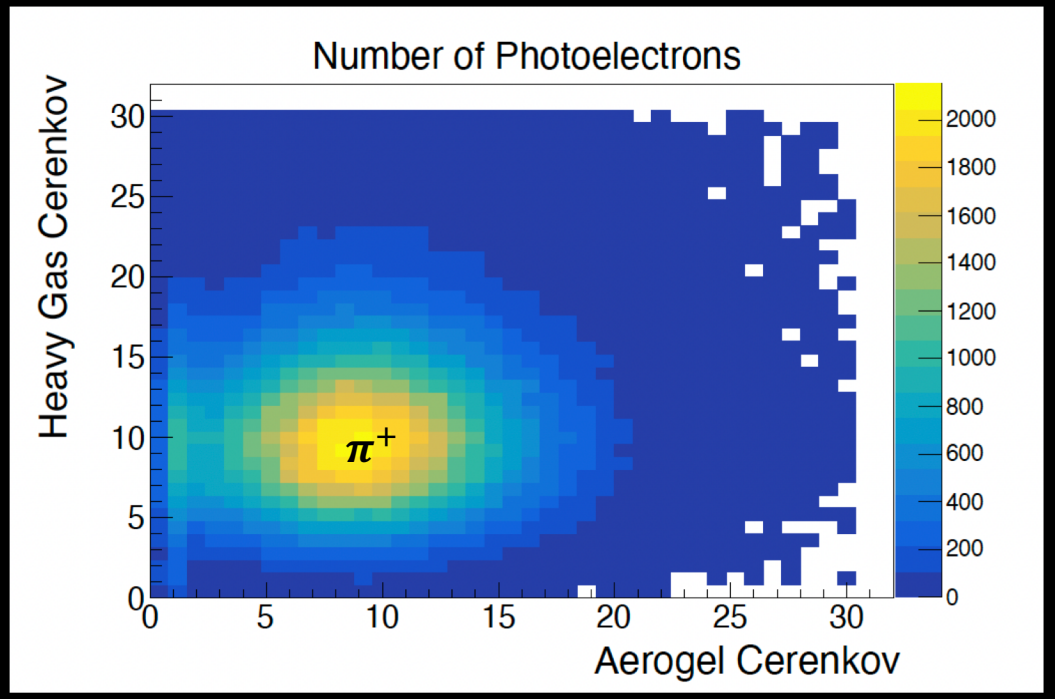


Radial axis – t

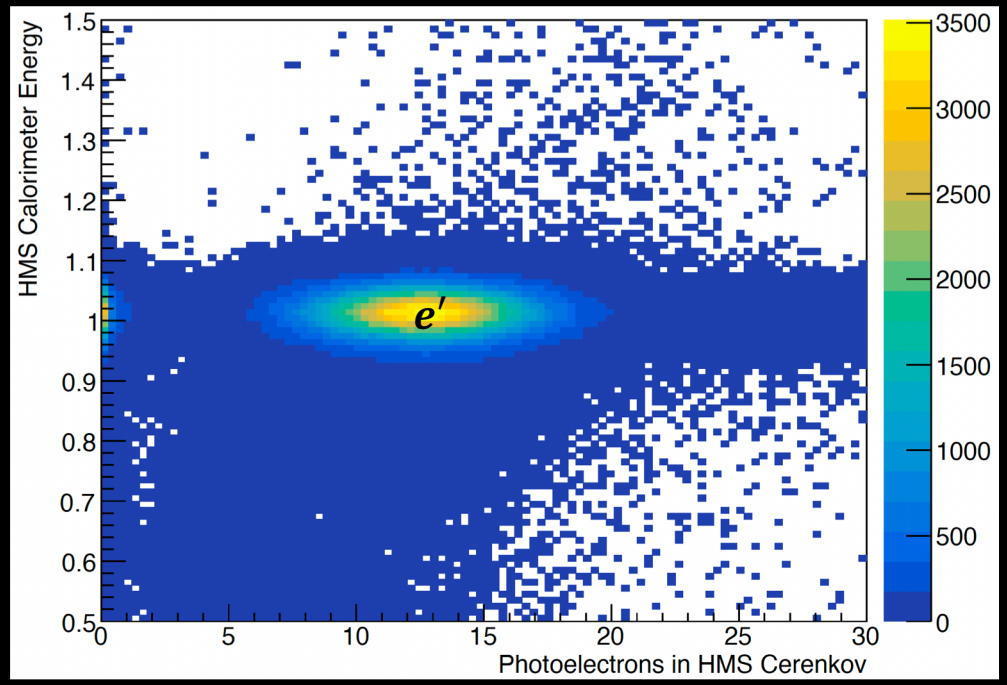
Azimuthal angle - ϕ

Particle ID

Pion Selection (SHMS)



Electron Selection (HMS)



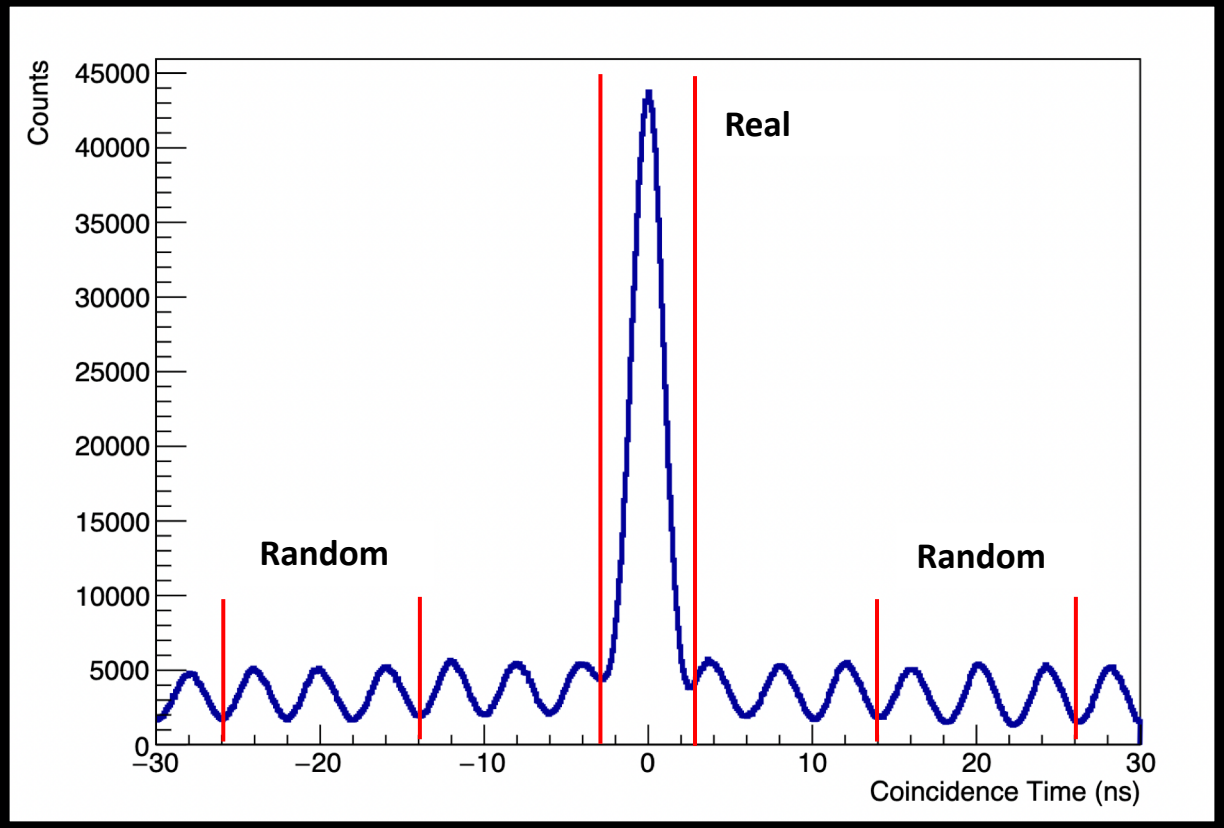
P.hgc.npeSum > 2.0	**H.cer.npeSum > 3.0**
P.aero.npeSum > 3.0	H.cal.etottracknorm > 0.7

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

Event Selection

- $e' - \pi^+$ Coincidence

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

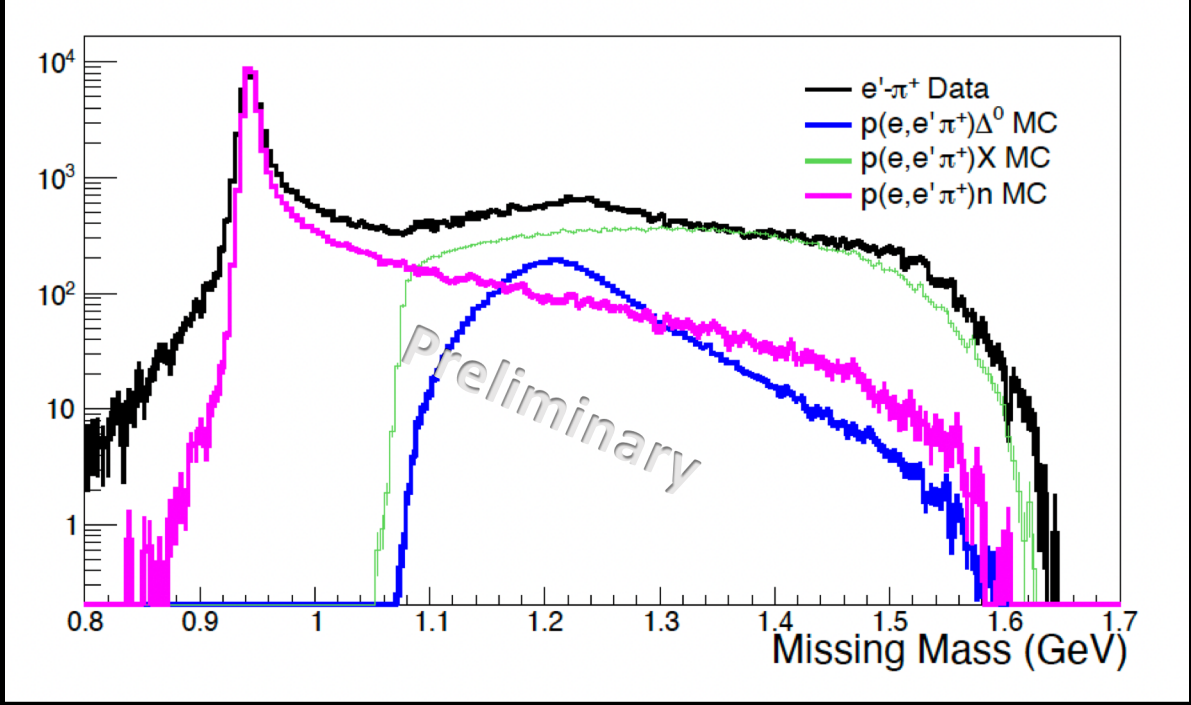


$$Q^2 = 2.115 \, , W = 2.95$$

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.

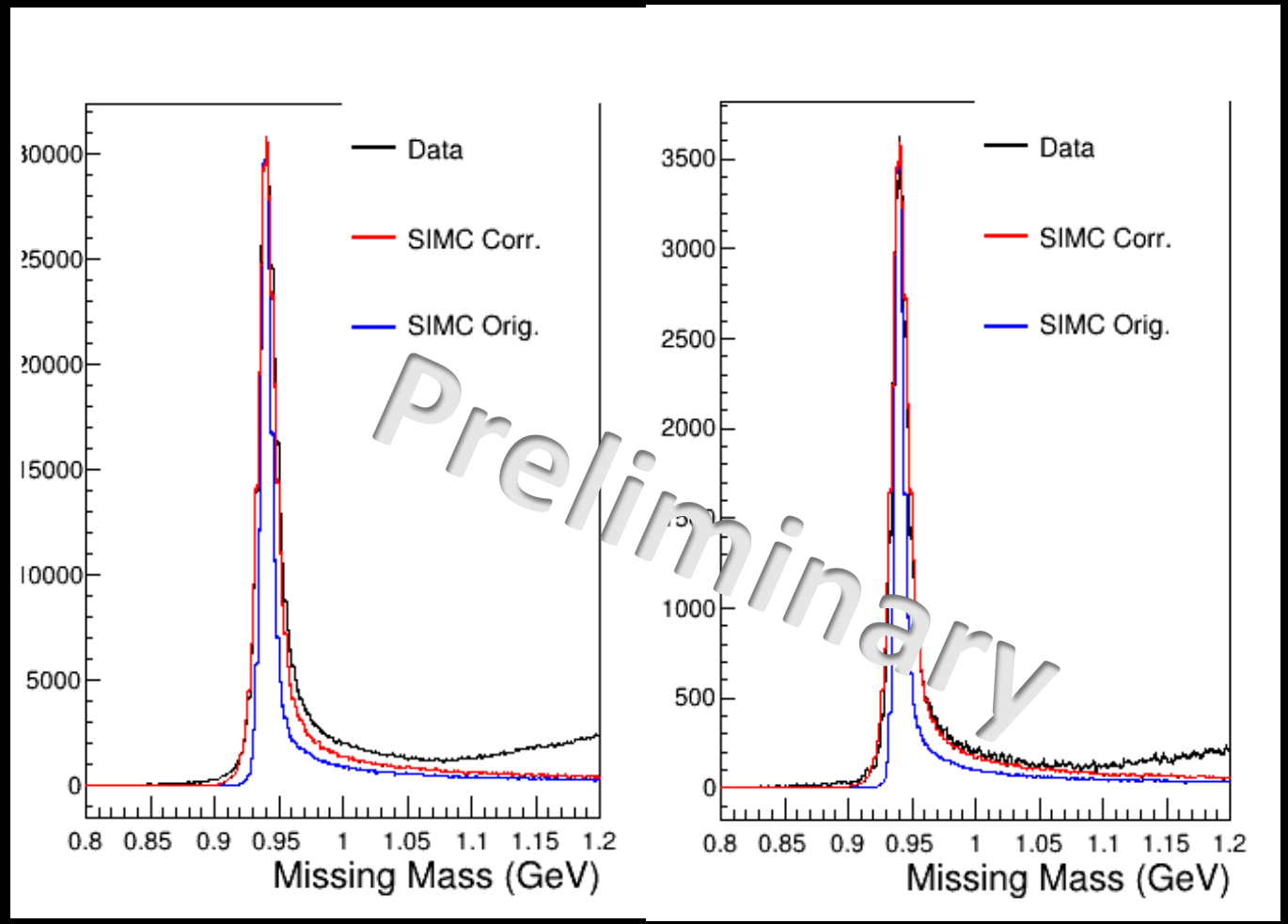


$p(e,e'\pi^+)X$ MC is subtracted by fitting it to the data in the region (1.45-1.60 GeV).

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

Monte Carlo Resolution Correction

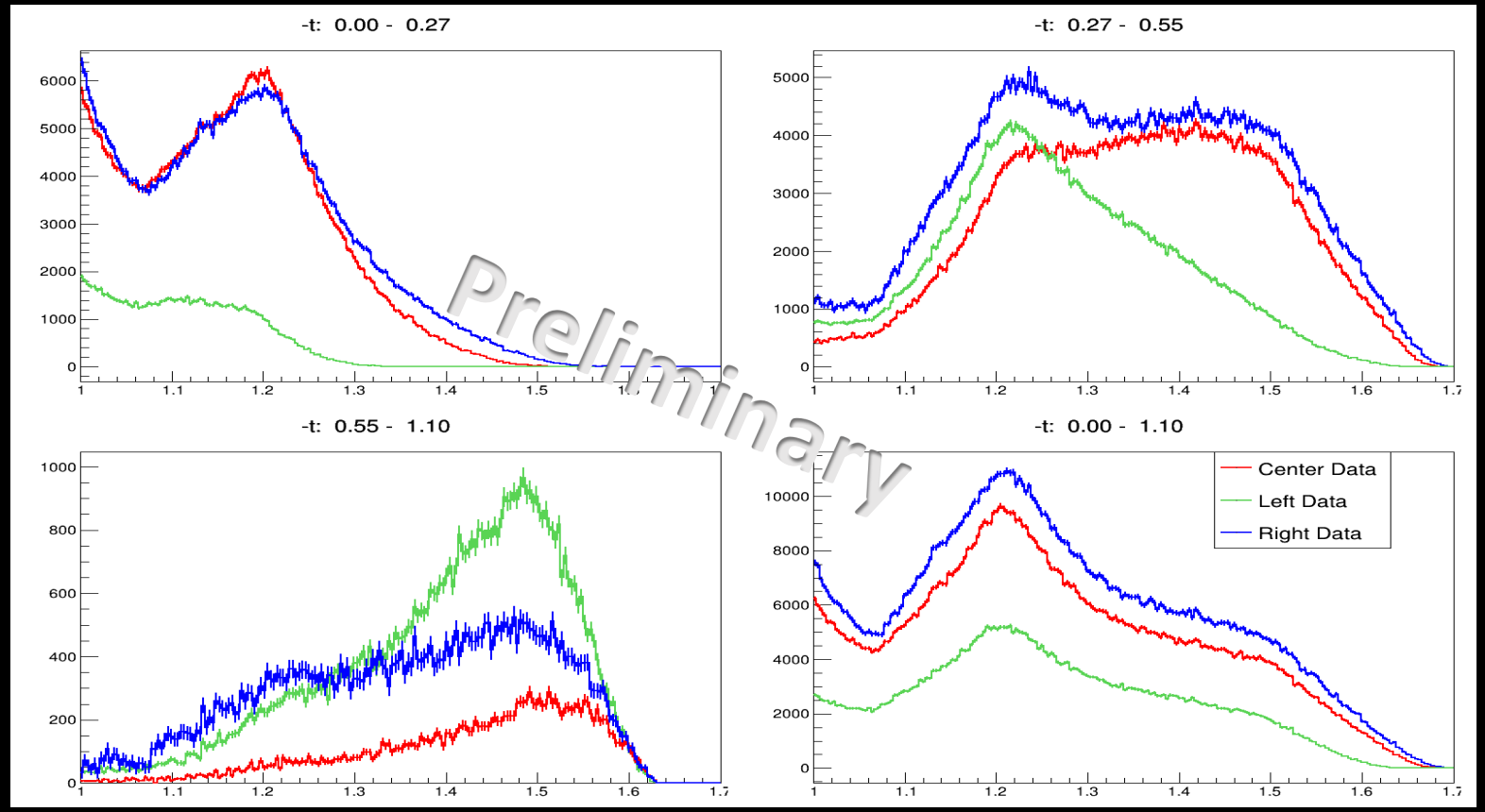
- Hall C Monte Carlo (SIMC) drift chamber resolution has been optimized.
  - MC is arbitrarily scaled to the data
- Resolution difference b/w data and MC vary for different kinematics.
  - A global correction factor is used (resmult = 3.5).
- A systematic uncertainty will be evaluated for remaining resolution difference.



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

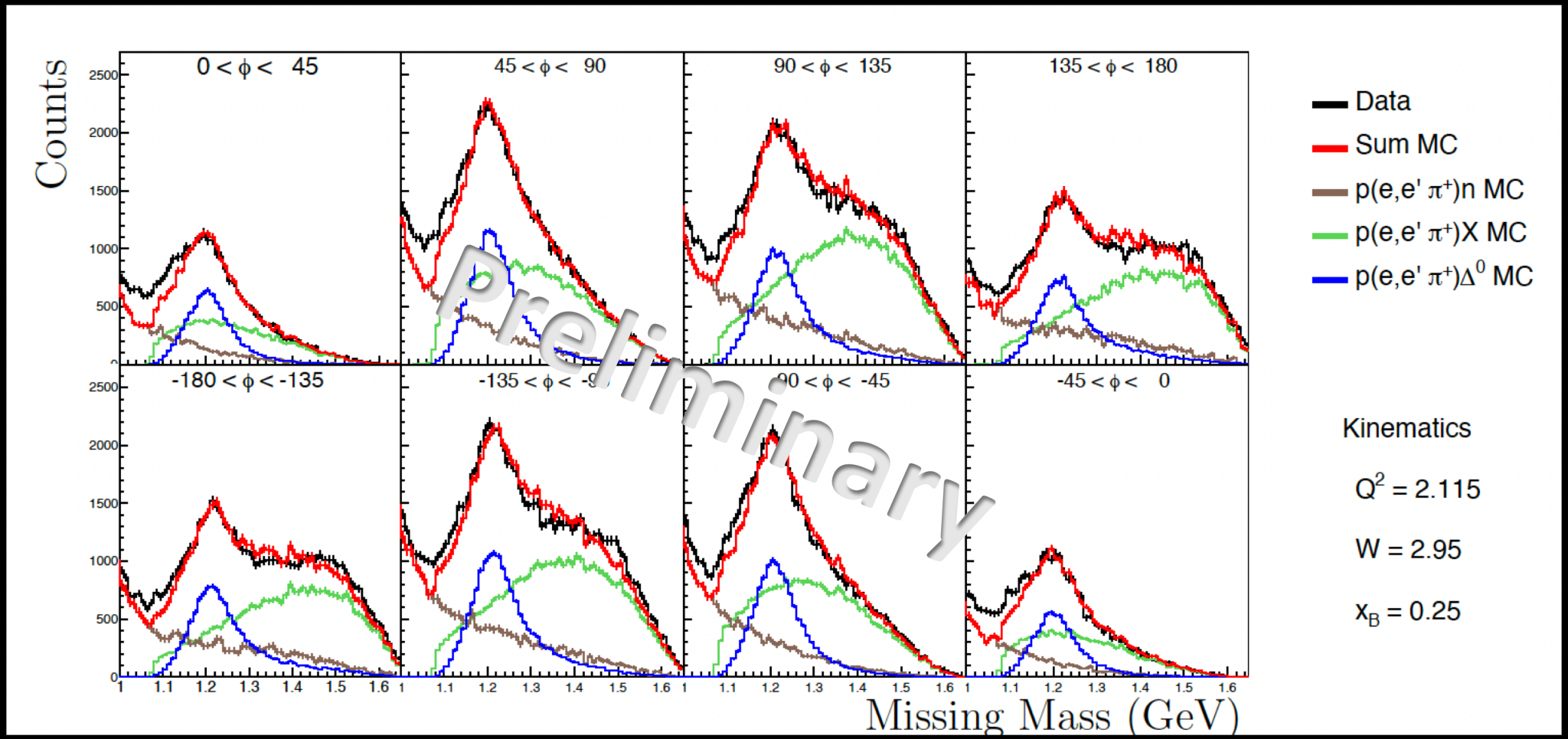
-*t* Binning

- The –*t* dependence is sensitive to different production mechanisms.
- Semi Inclusive background is dominant at higher –*t*



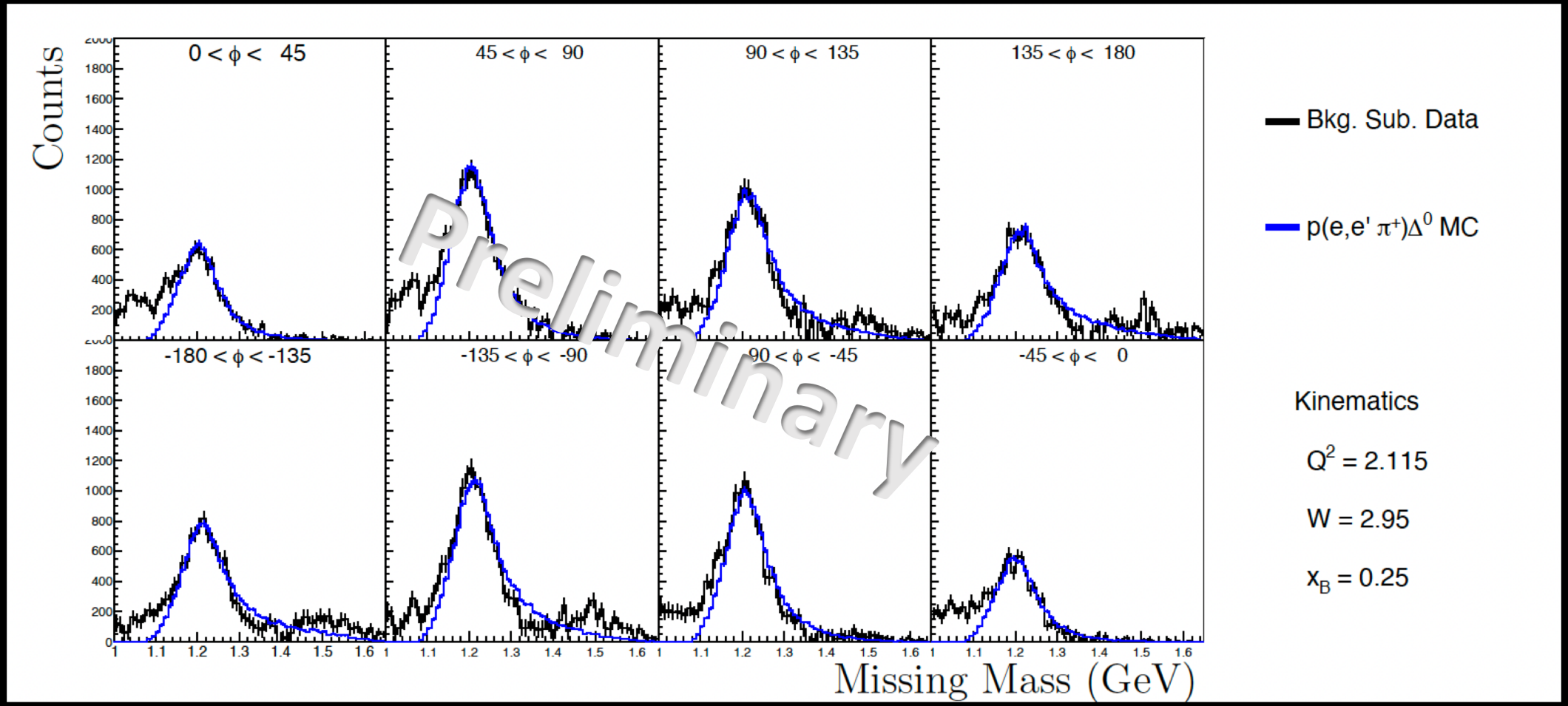
$Q^2 = 2.115\,, W = 2.95$

Δ^0 Shape Study – Combined Fit



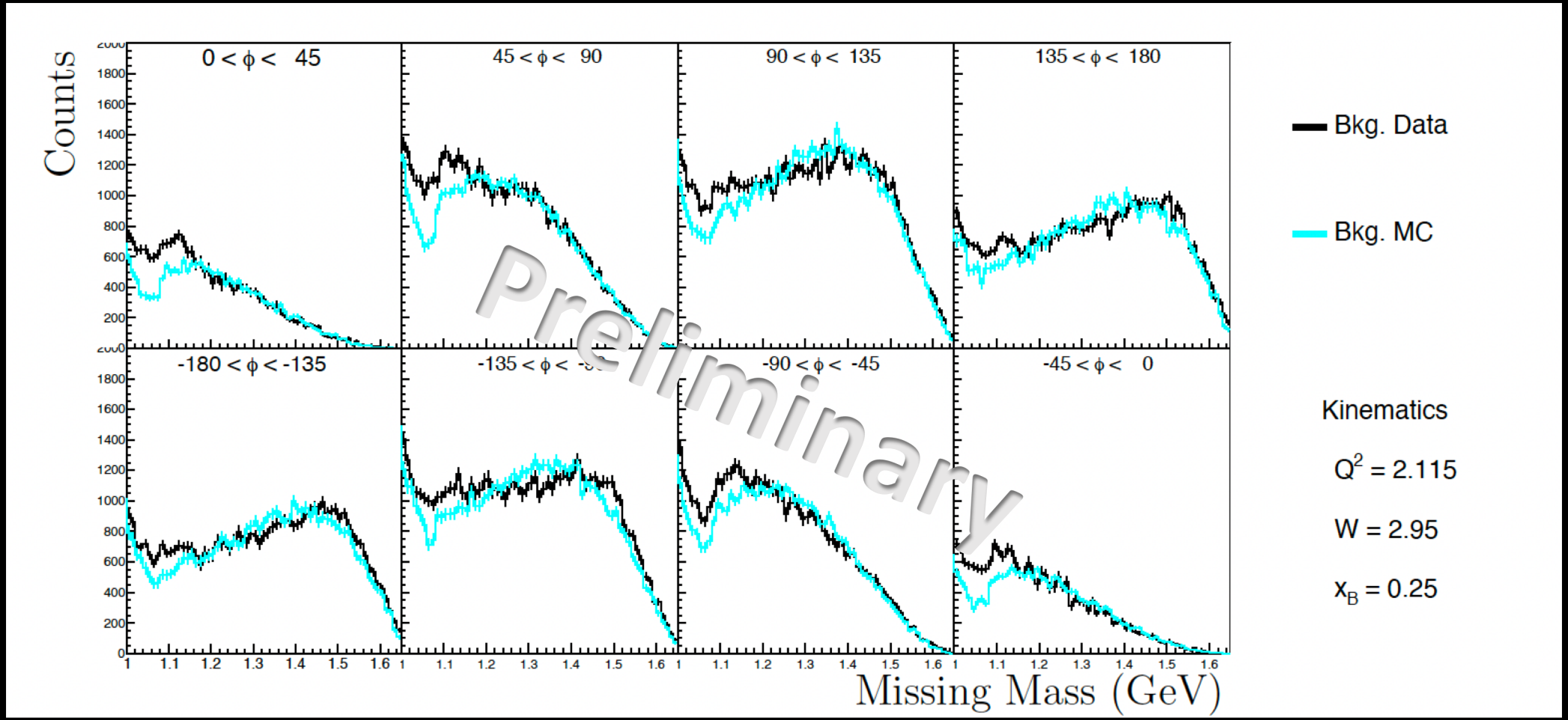
$Q^2 = 2.115\,, W = 2.95$

Δ^0 Shape Study – Signal Selection



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

Δ^0 Shape Study - Background Fit Check

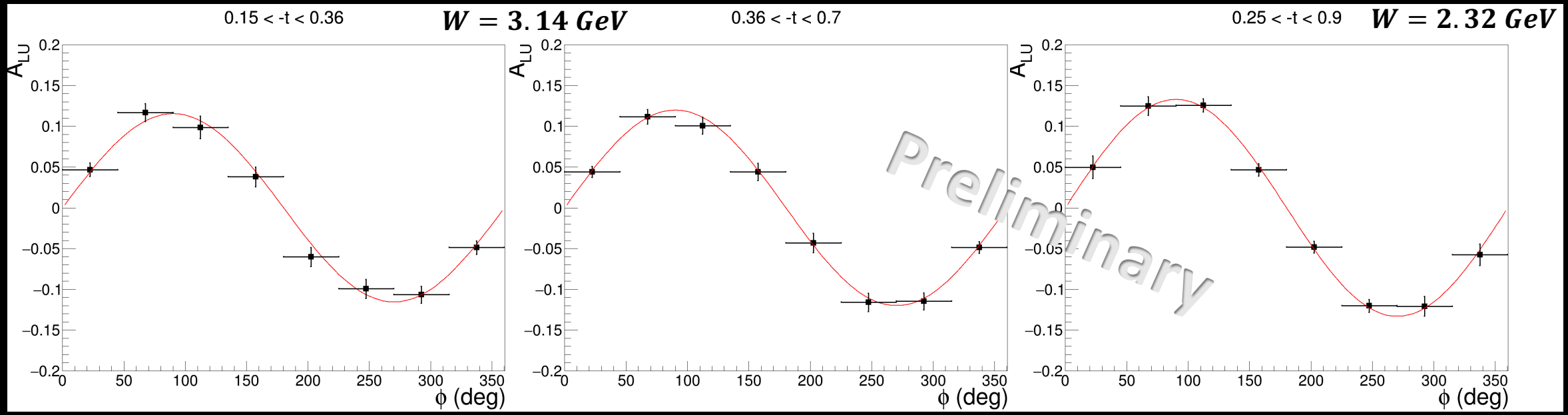


$Q^2 = 2.115, W = 2.95$

A_{LU} vs ϕ

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

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



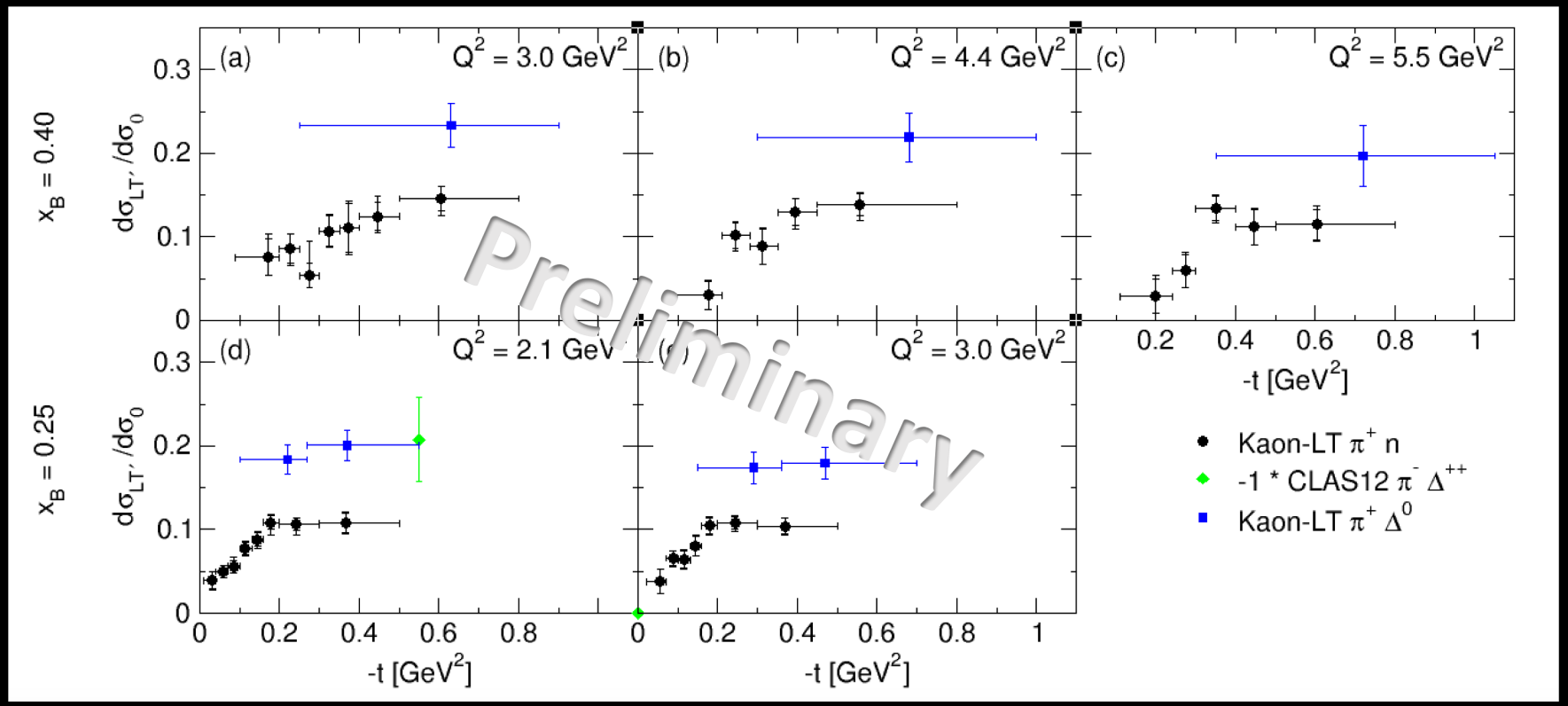
- Only statistical errors shown here.

$$Q^2 = 3.0\ GeV^2$$

$\sigma_{LT'}/\sigma_0$ vs -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.

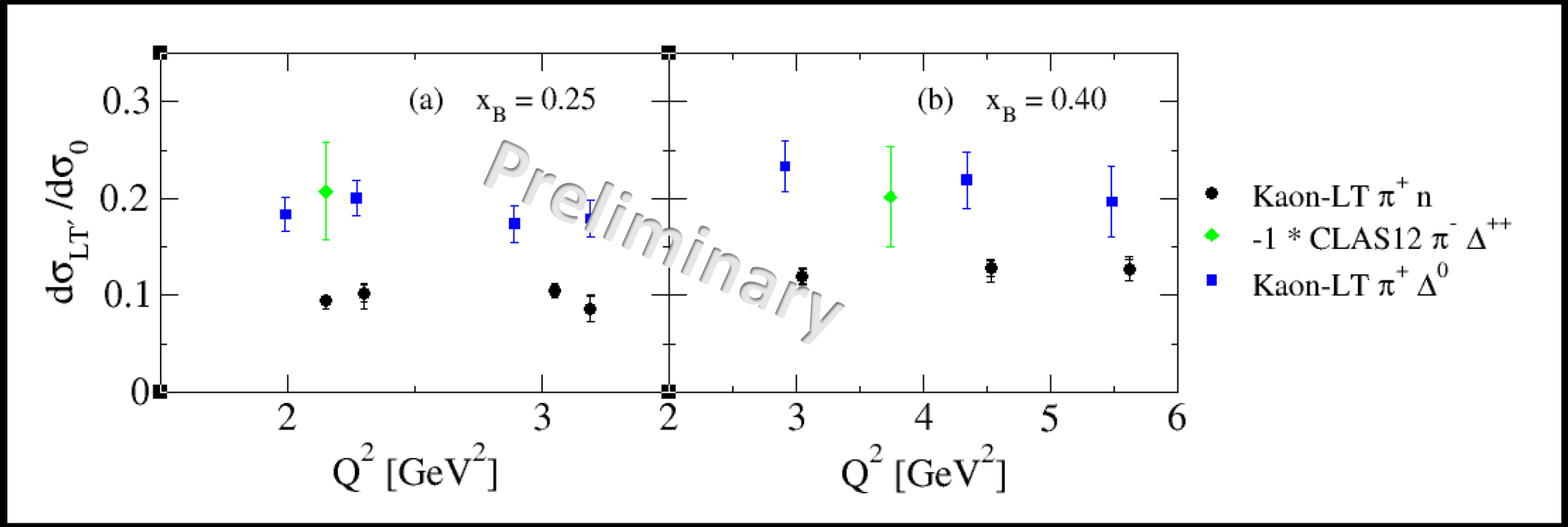
$$A_{LU} = \sqrt{2\epsilon(1-\epsilon)}\,\frac{d\sigma_{LT'}}{d\sigma_0}$$



- Only statistical errors shown here

$\sigma_{LT'}/\sigma_0$ vs 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 iso-spin symmetry



- Only statistical errors shown here

Summary

- Kaon-LT Experiment (E12-09-011) gives access to high statistic exclusive pion electroproduction data.
- **First measurement of Beam Spin Asymmetry for $p(e, e'\pi^+)\Delta^0$** is almost complete.
  - π^+ Δ^0 BSA is approximately double in magnitude $\pi^+ n$ (both from Kaon-LT)
  - π^+ Δ^0 BSA has opposite sign as compared to π^- Δ^{++} from CLAS12.
  - Currently evaluating systematic uncertainties.
- **Existing theory work needs experimental data to constrain their model before**
  - **Confirm hard-soft factorization**
  - **Extract transition GPDs**
- **A separate paper will be published on the π^+ Δ^0 beam spin asymmetry.**

Thank You !!!

This research is funded by Natural Sciences and Engineering Research Council of Canada (NSERC) FRN: SAPIN-2021-00026 and the National Science Foundation of USA (NSF), PHY1714133 and PHY2012430

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