Exclusive Phi Production Beam Spin Asymmetry Measurements with CLAS12

CLAS12 Fall Collaboration Meeting

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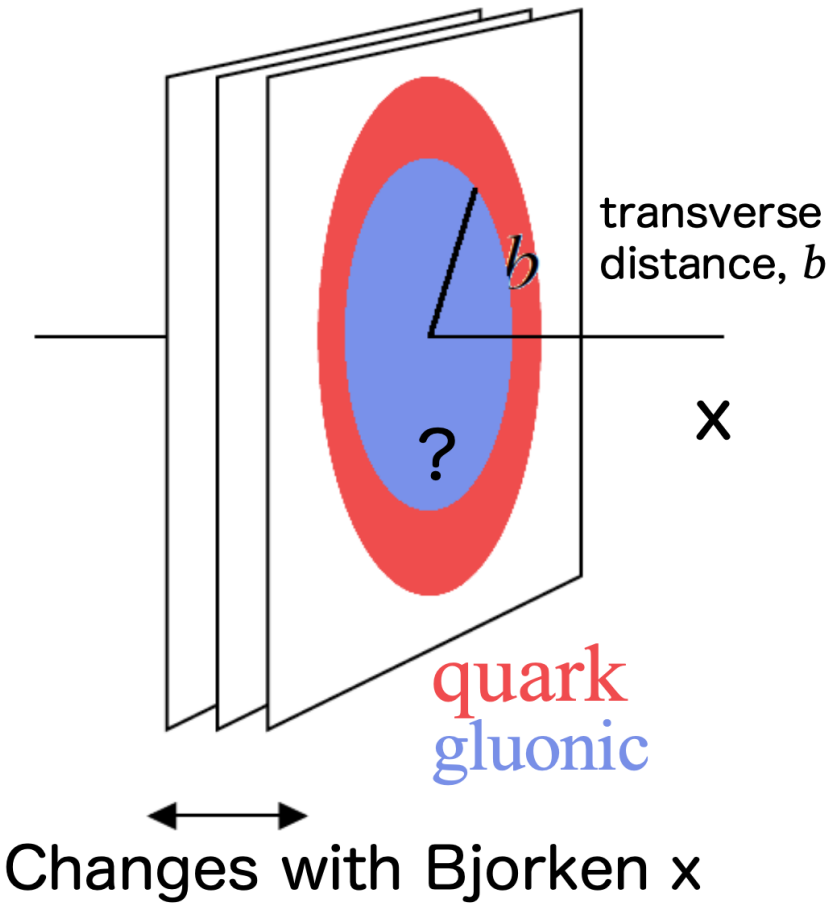
UCONN

Outline

- Physics Motivation
- Experimental Setup
- Data Analysis
- Conclusion

Physics Motivation

- Generalized parton distributions (GPDs) for 3-D structure of nucleon
  - longitudinal momentum distributions and transverse spatial distributions of quark and gluons.
- Efforts to explore quark structure, but little is known about the gluonic structure.

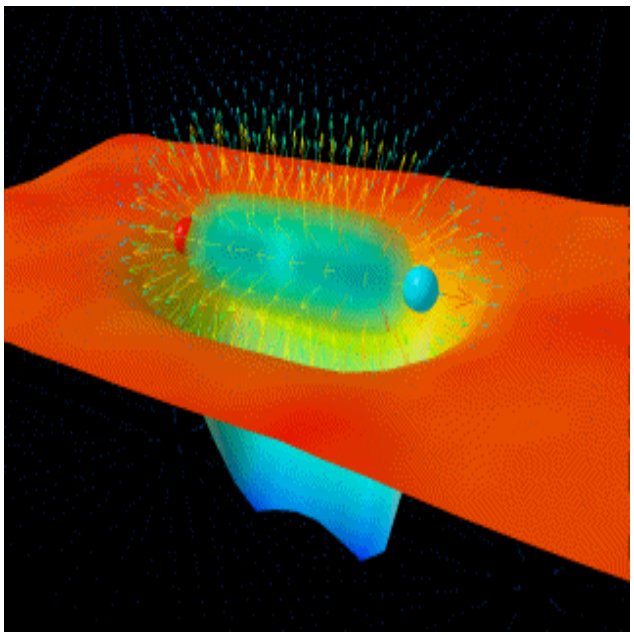


Mechanisms of Confinement

The mechanism of confinement - the phenomenon that there are no free quarks existing in nature - has been an ongoing research endeavor since the inception of QCD.

Candidate mechanisms include

- formation of gluon flux tube between quarks



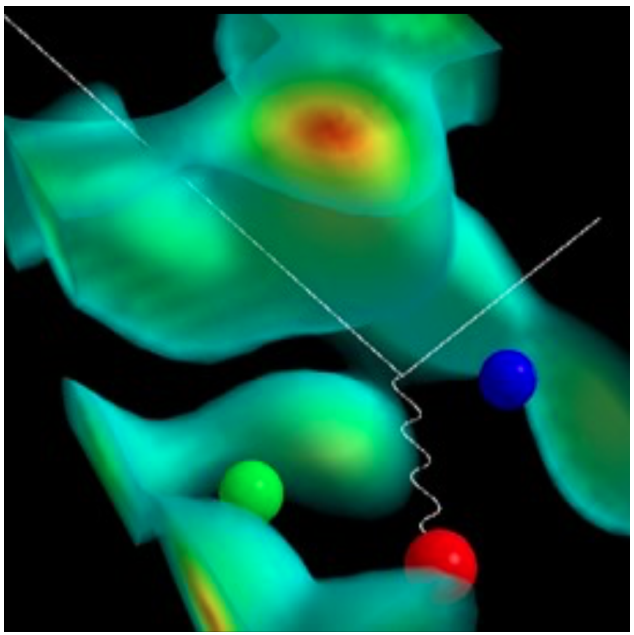
Flux tube formed between two quarks (red and blue spheres), vacuum is suppressed. [1]

Mechanisms of Confinement

The mechanism of confinement - the phenomenon that there are no free quarks existing in nature - has been an ongoing research endeavor since the inception of QCD.

Candidate mechanisms include

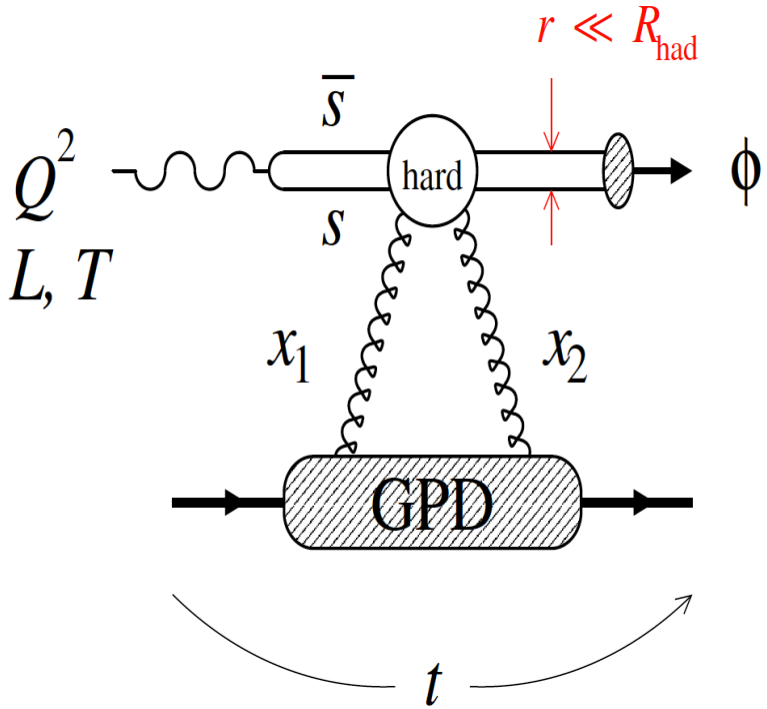
- formation of gluon flux tube between quarks
- the QCD vacuum screening against the propagation of free quarks



Quarks (spheres) located on instanton fluctuation, being probed by photon (white curve line) [1]

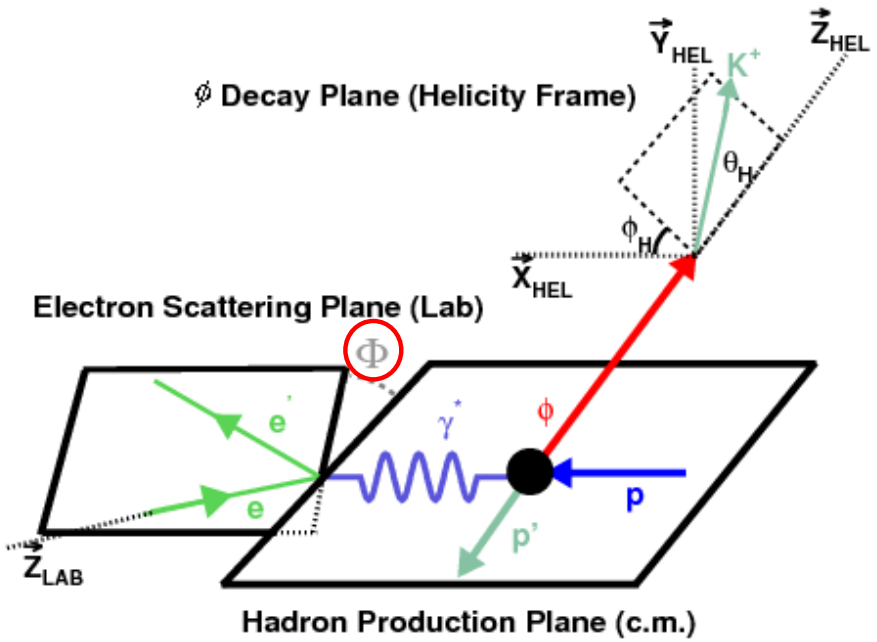
Physics Motivation

- Access gluonic GPDs
  - ϕ $(s\bar{s})$
  - J/ψ $(c\bar{c})$
- At JLAB 12 GeV kinematics
  - J/ψ can only be accessed at threshold relatively large t_{min}
  - ϕ production can be measured at low $t \ll 1$ GeV^2 where GPD formalism is relevant.



Exclusive ϕ Production ($ep \rightarrow e'p'\phi(1020) \rightarrow e'p'K^+K^-$)

Here the angle, Φ, is the angle between the lepton and hadron plane which is defined by the electron and proton, respectively.



$$Q^2 = (e - e')^2 \qquad W^2 = m_p - Q^2 + 2m_p\nu$$

$$\nu = E_e - E_{e'} \qquad x_B = \frac{Q^2}{2m_p\nu} \qquad t = (P - P')^2$$

$\Phi \equiv \phi_{Trento}$ → angle between leptonic and hadronic plane

[1] J. P. Santoro et al. Electroproduction of phi(1020) mesons at 1.4 < Q^2 <3.8 GeV^2 measured with the CLAS spectrometer

Differential Cross Section ($ep \to e'p'\phi$)

Differential cross section for $ep \to e'p'\phi$ for an unpolarized proton with polarized electron beam can be written in the form

$$\begin{aligned}\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} = \Gamma(Q^2, x_B, E) \\ \frac{1}{2\pi}\Bigg\{ \boxed{\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}} + \epsilon \boxed{\frac{d\sigma_{TT}}{dt}} cos(2\phi) \\ + \sqrt{\epsilon(2\epsilon+1)} \boxed{\frac{d\sigma_{LT}}{dt}} cos(\phi) \\ + \textcircled{\lambda} \sqrt{2\epsilon(1-\epsilon)} \boxed{\frac{d\sigma_{LT'}}{dt}} sin(\phi) \Bigg\}\end{aligned} \tag{1}$$

λ is the helicity state of the incident electron beam (± 1).

Measuring the beam spin asymmetry is the main focus of this work.

The **b**eam **s**pin **a**symmetry (BSA) is defined as

$$BSA = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \leftarrow \text{Measurable!}$$

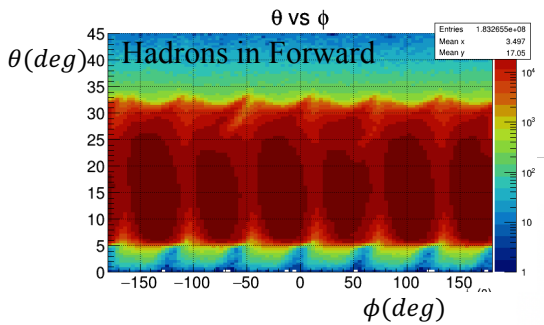
$$BSA = \frac{\boxed{A_{LU}^{sin(\phi)}} sin(\phi)}{1 + A_{UU}^{cos(\phi)} cos(\phi) + A_{UU}^{cos(2\phi)} cos(2\phi)}$$

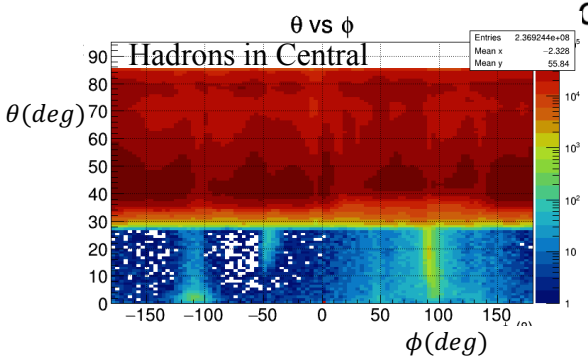
Effort is focused on determining $A_{LU}^{sin(\phi)} \sim \sigma_{LT'}$

- Extracting A_{LU} provides access to parton helicity flip (H_T, E_T) and helicity *non*-flip GPDs (H, E)...

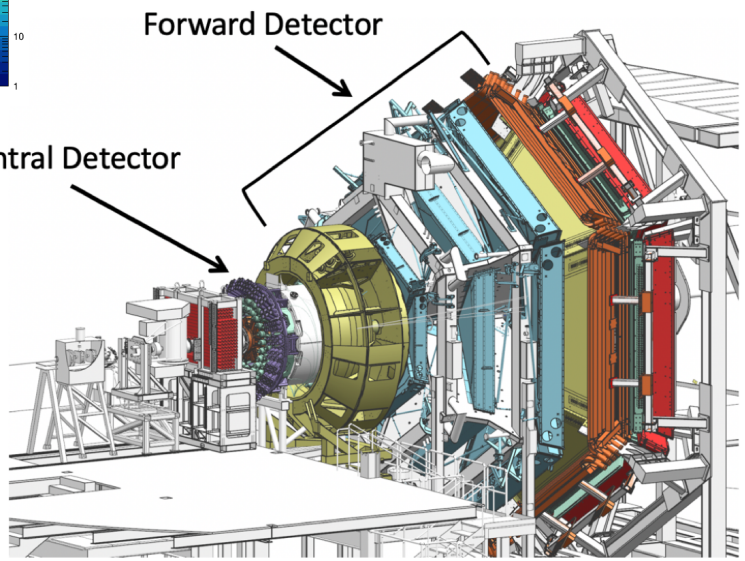
$$A_{LU}^{sin(\phi)} \sim \Im\mathfrak{m}\left(H_T E - E_T H\right)$$

CLAS12 is uniquely designed to provide coverage over a wide kinematic range for charged and neutral particles





- Magnetic Fields – track reconstruction
- Cherenkov Counters – e^- vs π^- separator
- Drift Chambers – momentum for charge particles
- TOF Scintillators – time of flight and path length
- Calorimeters – energy reconstruction



- 10.6 GeV Beam @ 50nA
- Unpolarized LH2 target
- Polarized Beam
- Torus Field ±100%
- Solenoid Field -100%
- NIM paper [2]

Outline

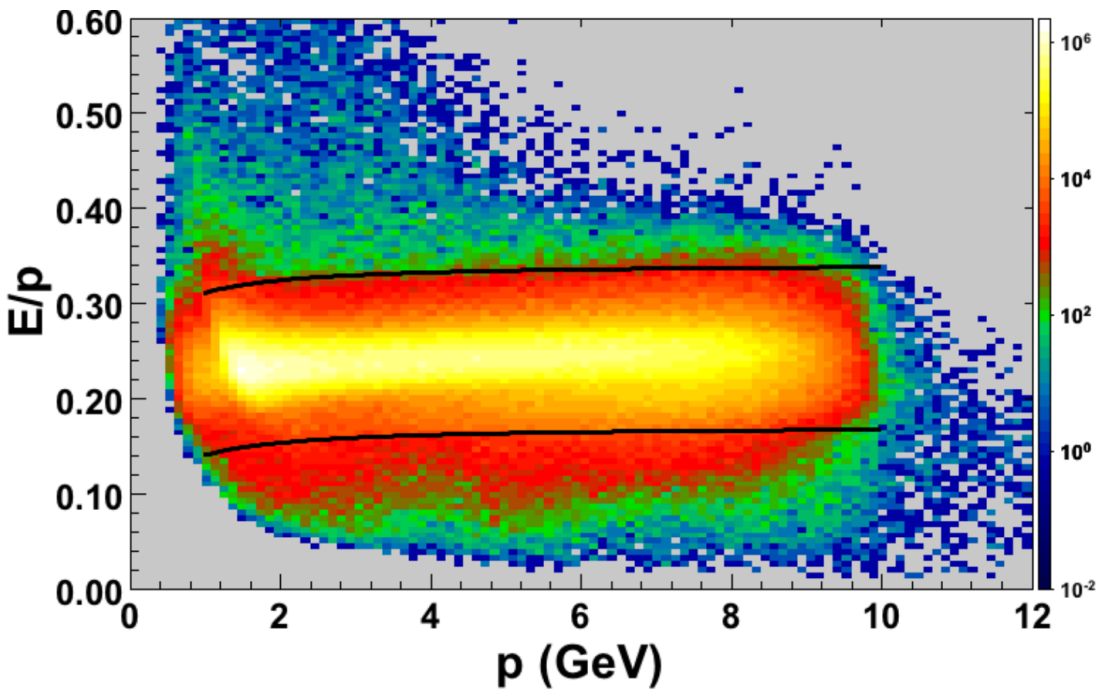
- Physics Motivation
- Experimental Setup
- Data Analysis
- Results

Focus on the data analysis for $ep \to e'p'\phi$ through $e'p'K^+K^-$

- Analyze ~20% of available data
- Electron ID
- Hadron ID
- Event selection $ep \to e'p'\phi$
- Beam Spin Asymmetry Extraction

Electron ID requires multiple cuts to select a clean sample of events

- Sampling fraction cut
- Minimum energy deposited in calorimeter
- Number of photoelectrons produced in Cherenkov counters
- Preshower calorimeter and drift chamber fiducial cuts



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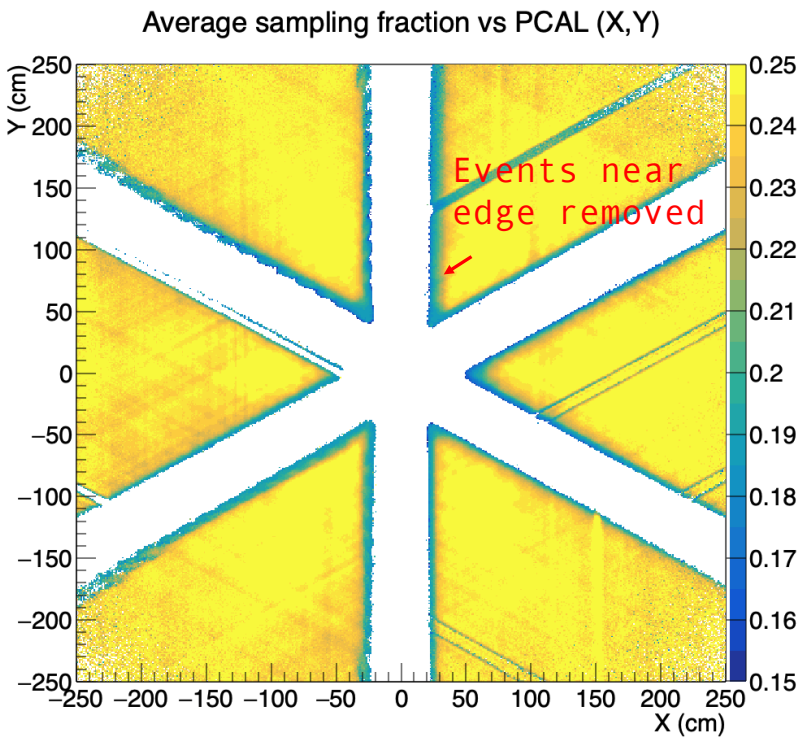
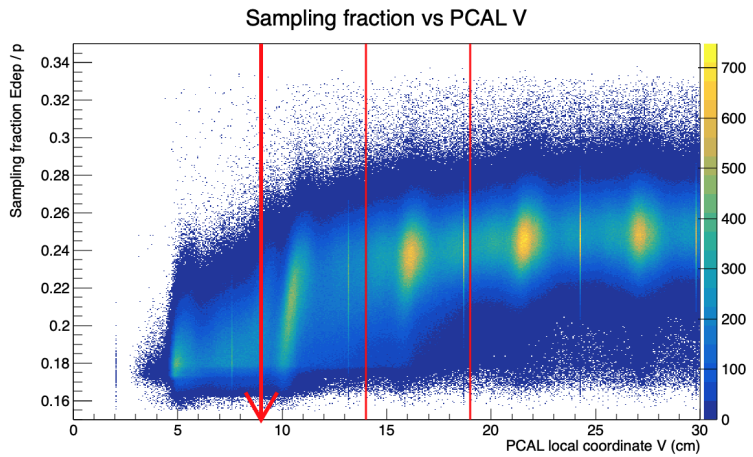
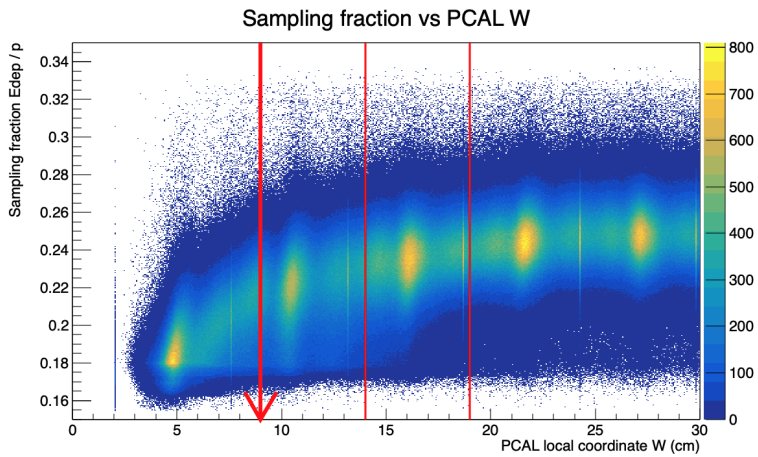
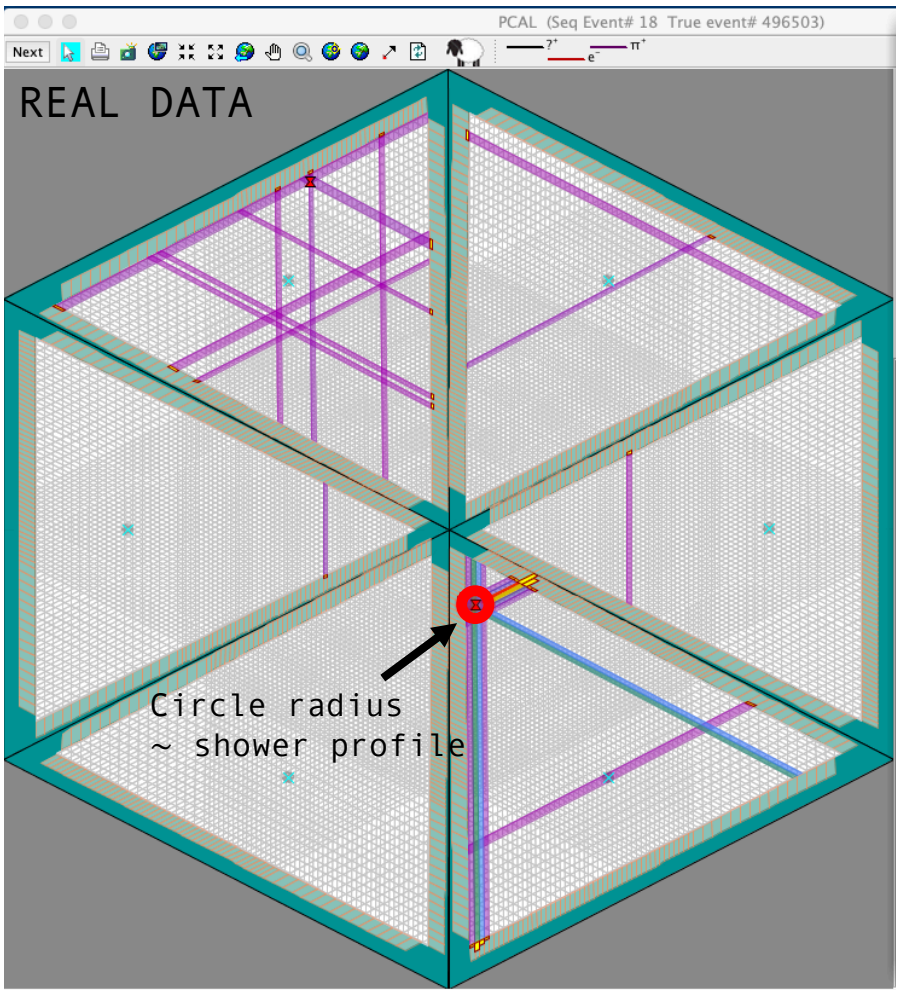






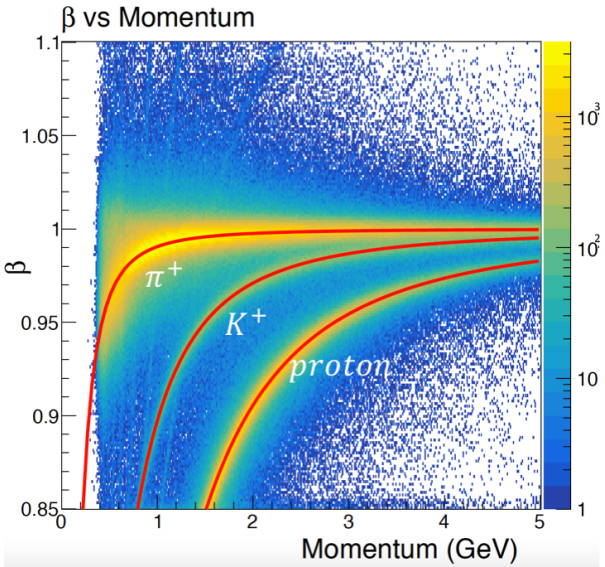
- At the edge of the calorimeter the deposited energy may not be fully contained → drop in sampling fraction
- Apply cut in the local PCAL coordinates of the calorimeter.

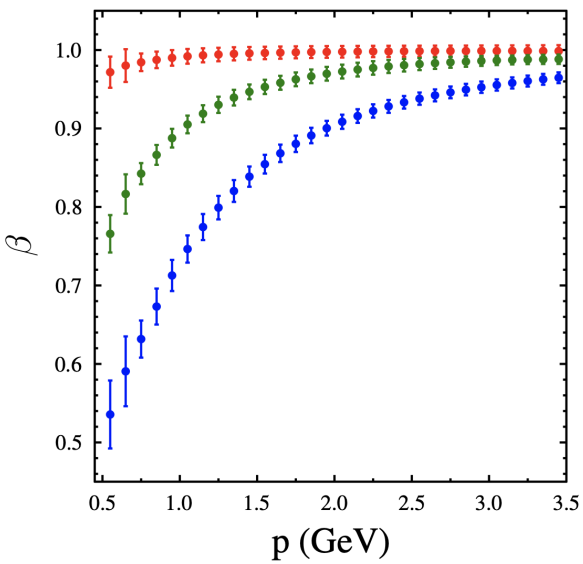
Electron ID requires multiple cuts to select a clean sample of events



After selecting the electron, identify the hadrons

- Require track hits in
  - Drift Chambers
  - Time-of-Flight Detector
- Identification based on minimizing time: $\Delta t = (t_{measured} - t_{hypothesis})$
- Track assigned to the particle that best fits the hypothesis
- Fiducial volume drift chamber position based cuts





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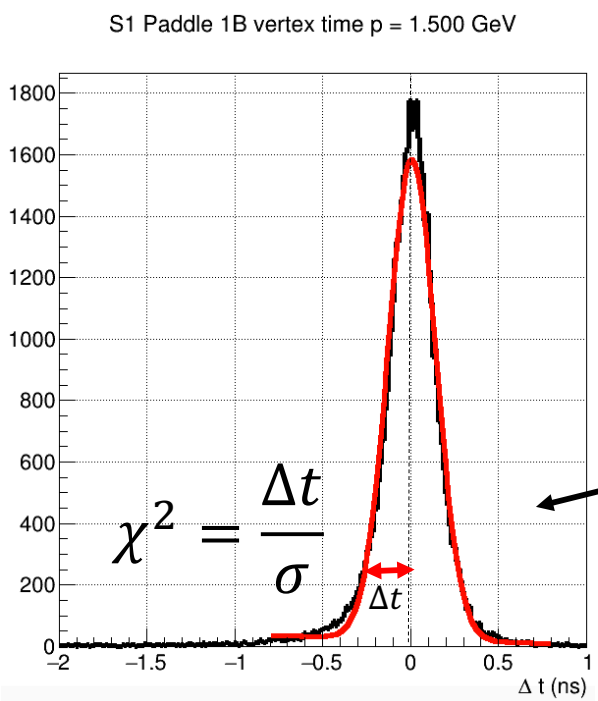
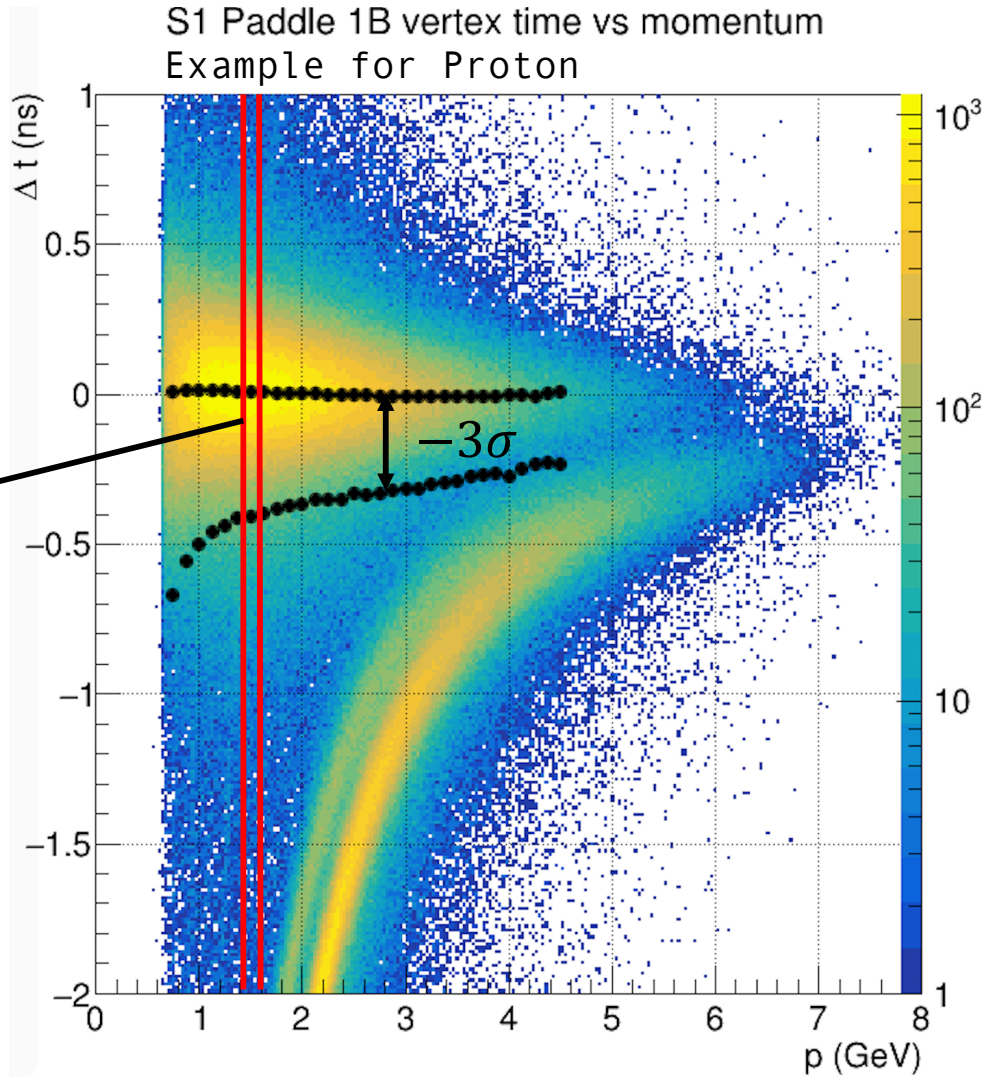
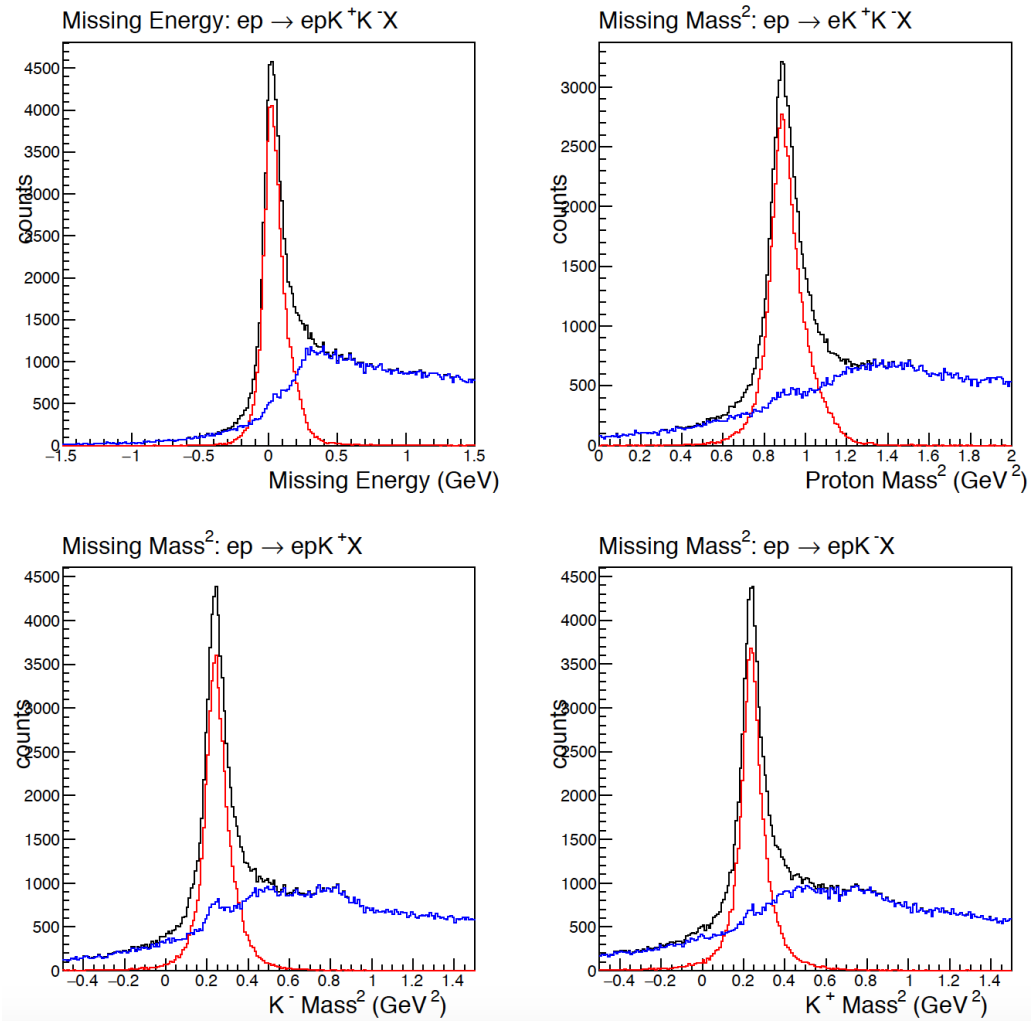




- Particle ID assigned by first finding the best hypothesis to minimize time of flight.
- Cut on $\chi^2 > -3$ - based on the *ratio* of the distance Δt is from the mean to $\sigma(p)$

Exclusive Event Selection

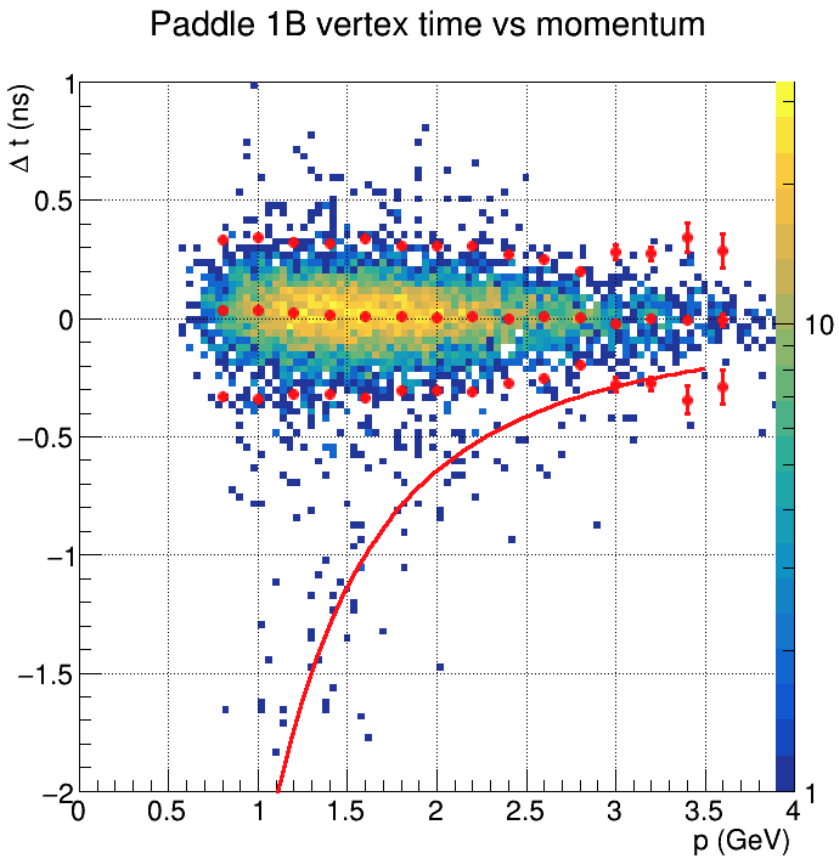
Applying exclusivity cuts helps to remove background events



All, pass, and fail for missing E, and mass^2.

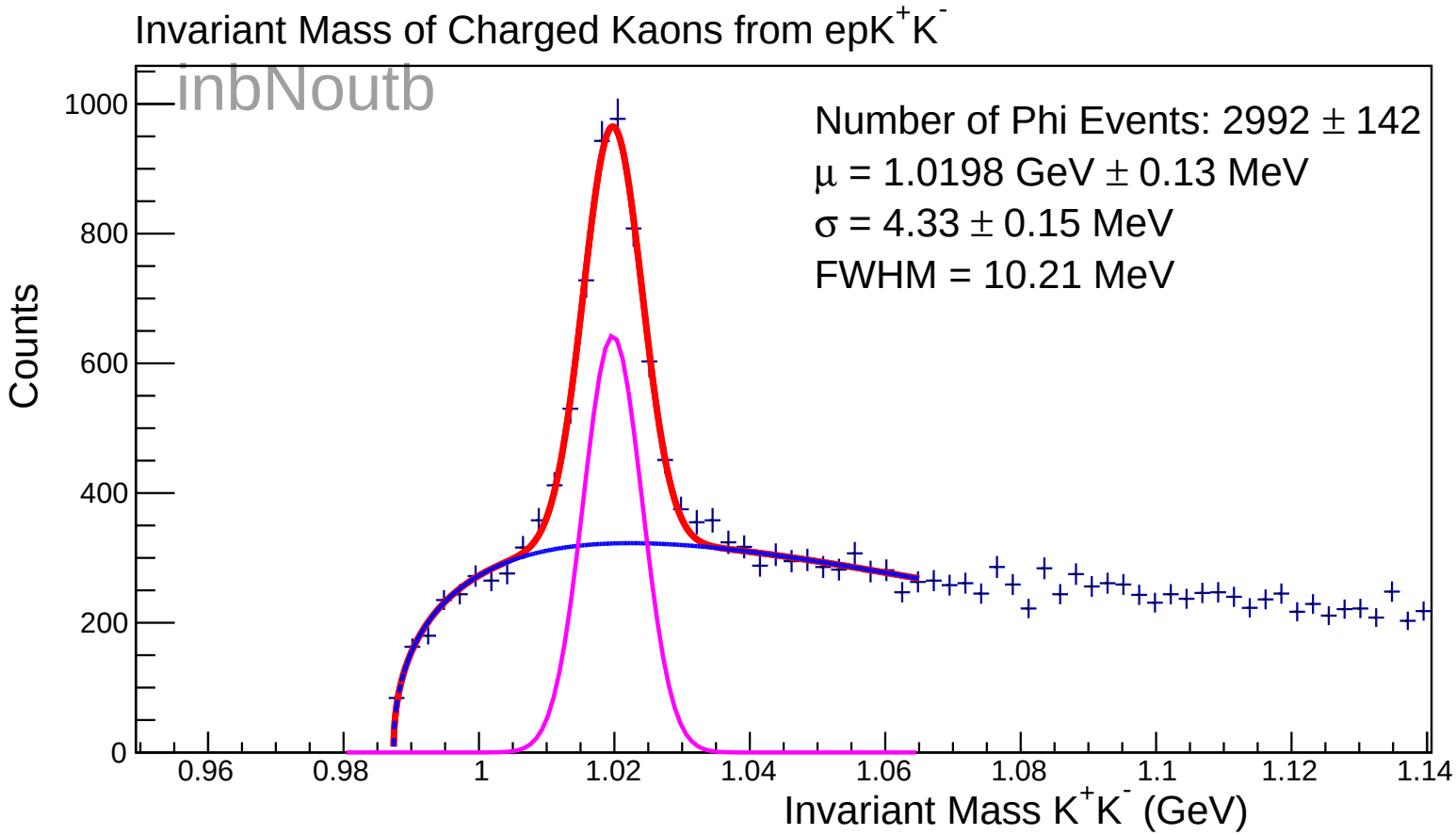
Exclusive Event Selection

Exclusivity cuts significantly reduce contamination of positive pions as kaons .



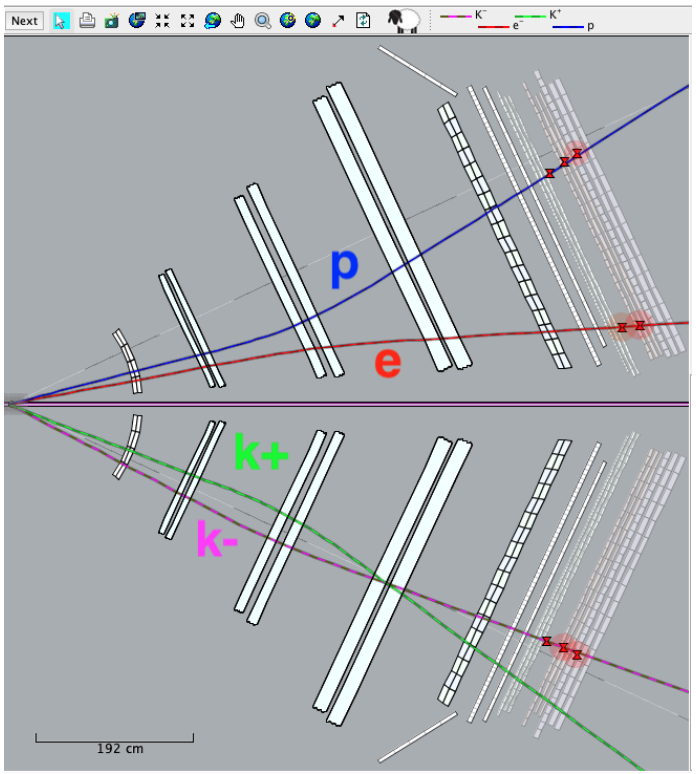
Δt vs p for Kaon$^+$ without EB pid with all exclusivity cuts applied.

Selection of exclusive ϕ meson electroproduction based on fit to data.

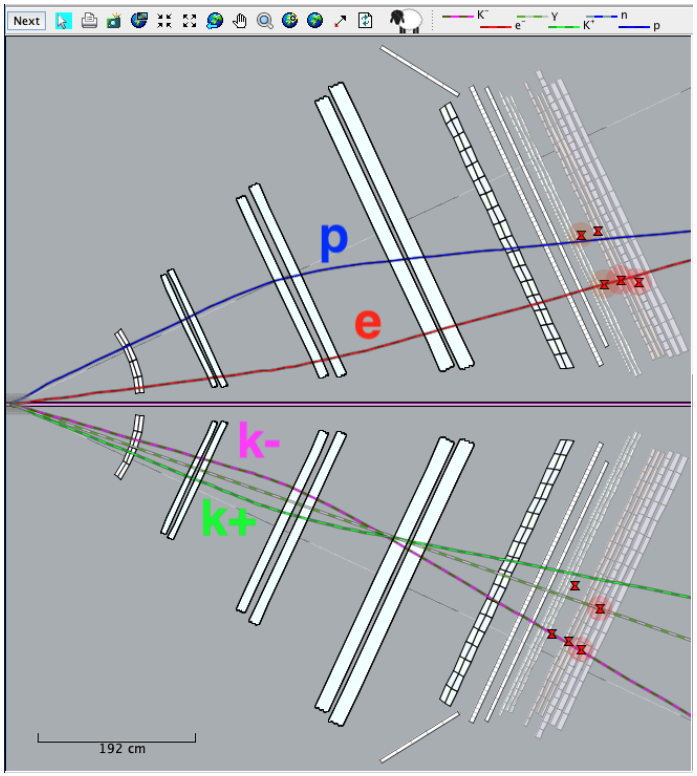


K^+K^- invariant mass spectrum from the combined datasets.

Selected exclusive ϕ meson event in detector.



(a) Negative "inbending" field (torus -1)

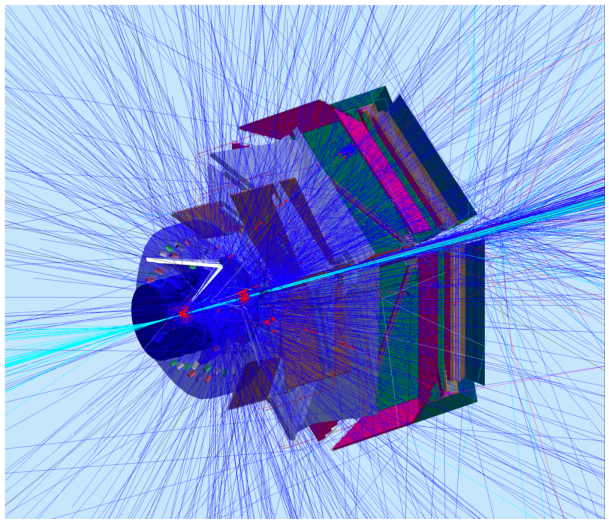


(b) Negative "outbending" field (torus +1)

Figure: Inbending vs outbending. Proton curvature reverses between the two configurations. (**Real** ϕ events!)

Simulating Vector ϕ Meson Electroproduction

- Empirical paramterization of the exclusive ϕ vector meson was developed.
  - dipole vs exponential t-dependence
- Particle interactions with detector performed using Geant4-MC (GEMC)
- Find agreement between model and results from Nature
  - match resolution between data and simulation.
  - similarities in final state kinematic distributions

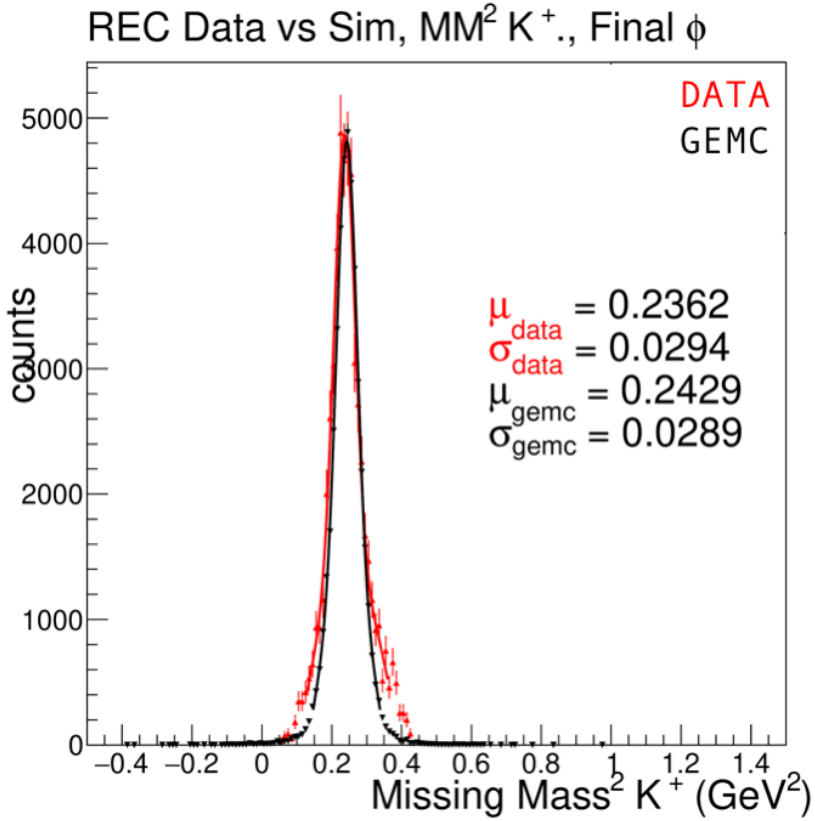


Rendering of the CLAS12 detector from GEMC with reconstructed tracks.

Resolution Agreement

Resolutions are modified to reproduce distributions in data.

- Smear GEMC reconstructed p, θ, ϕ of particles informed by simulation.
- Compare results of calculated masses between GEMC and data.

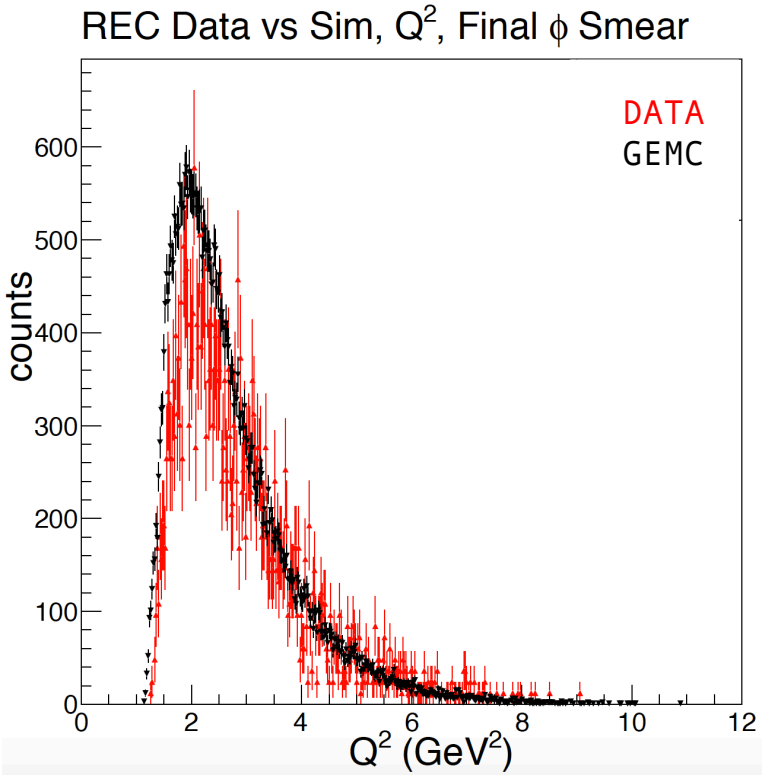


Smearing p, θ, ϕ from GEMC broadens peak width for calculated K^+.

ϕ Production Model

Model is parameterized based on available data from fixed-target experiments.

- The power-like t-depedence (i.e. dipole model) yielded better agreement to data.
- Tuning of model parameters was required
  - Reduce dependency on cross section at production threshold $\rightarrow$ **insight** into production mechanism.



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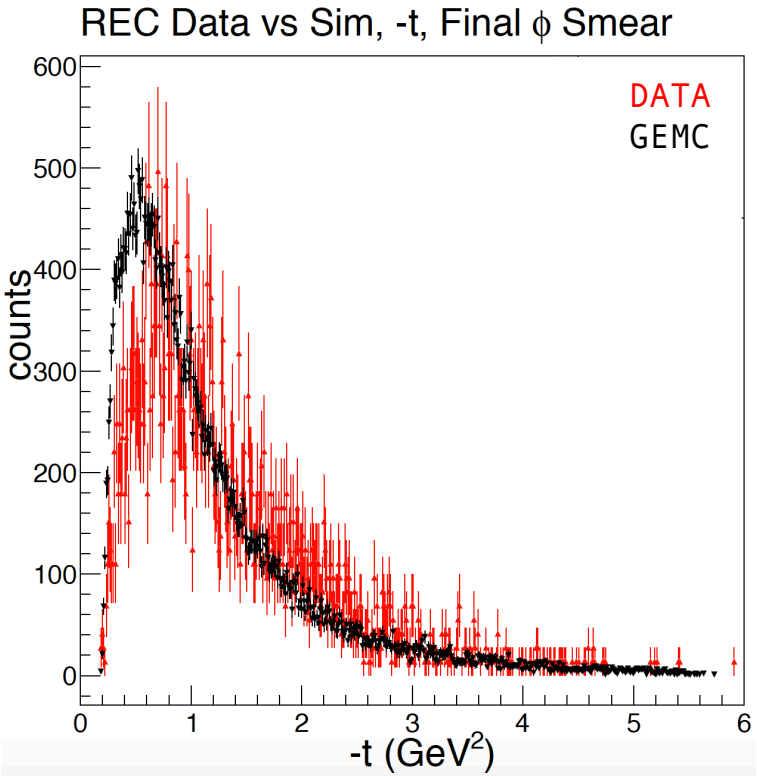
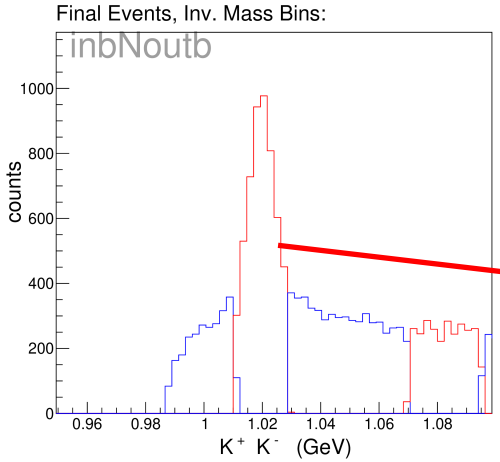
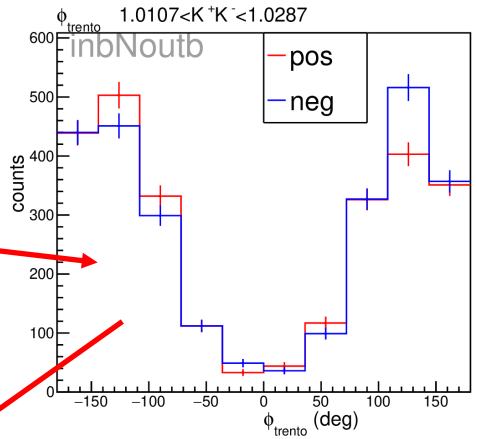


Beam Spin Asymmetry via Sideband Subtraction

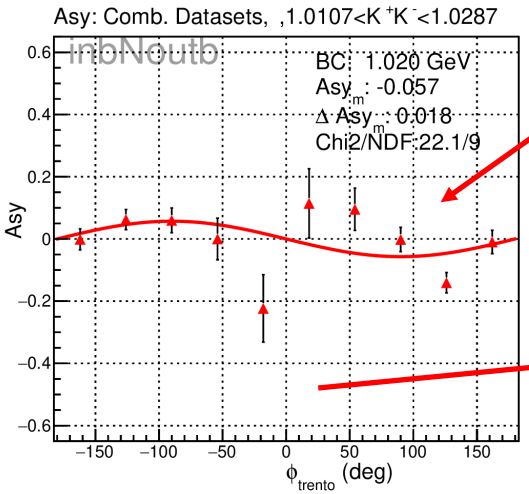


- Average polarization, P_B, is 87%.
- $N^{\pm}$, number of events for positive or negative helicity events.

$$BSA = \frac{1}{< P_B >} \frac{N^+ - N^-}{N^+ + N^-}$$



Binning based on Figure-of-Merit of Signal to Background



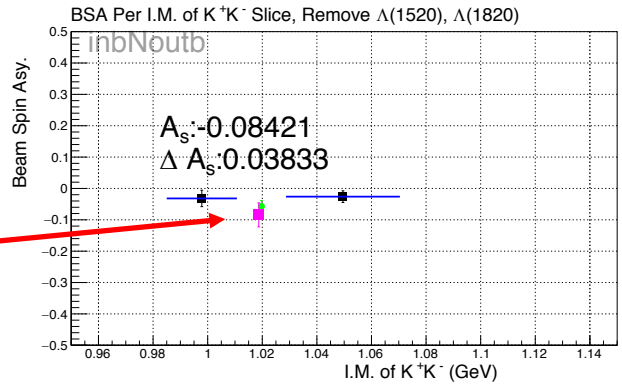
Signal Asymmetry, A_s, is calculated as:

$$A_s = A_m + \frac{B}{S}(A_m - A_b)$$

A_m : measured BSA

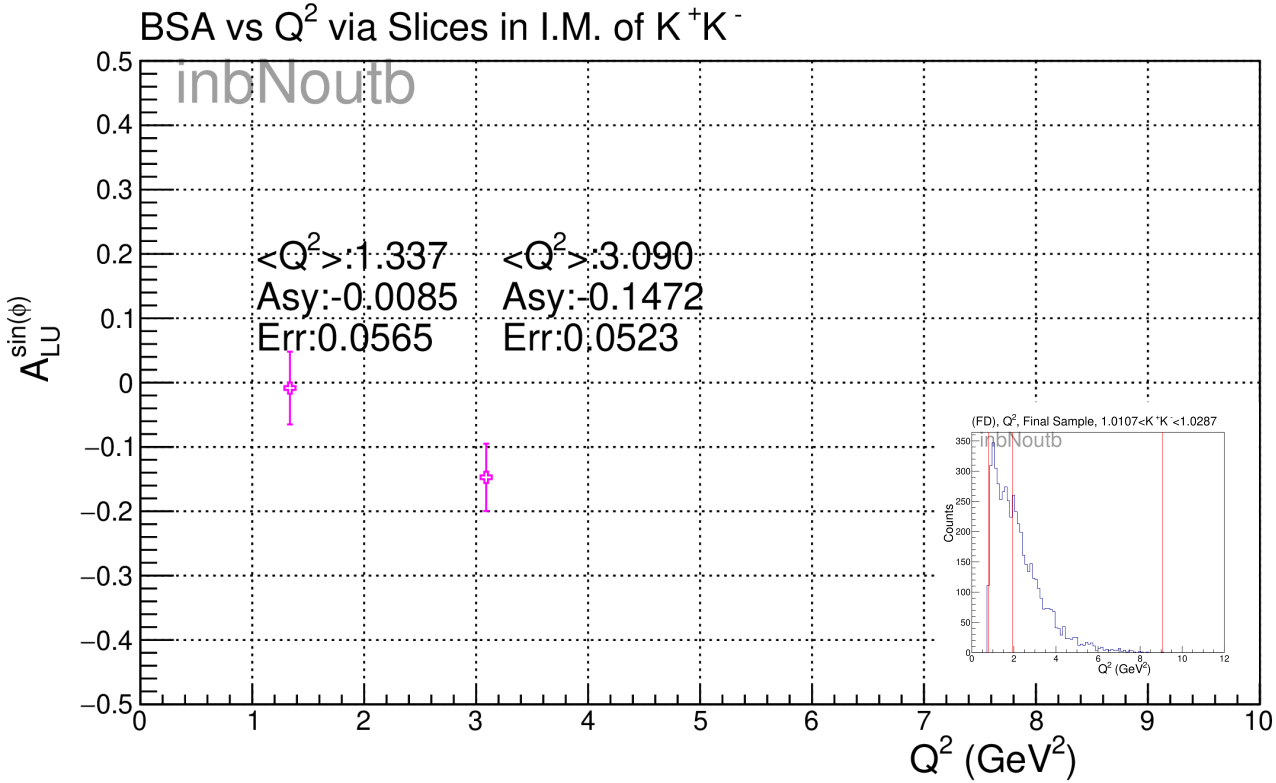
A_b: background BSA next to signal

$\frac{B}{S}$: background to signal ratio



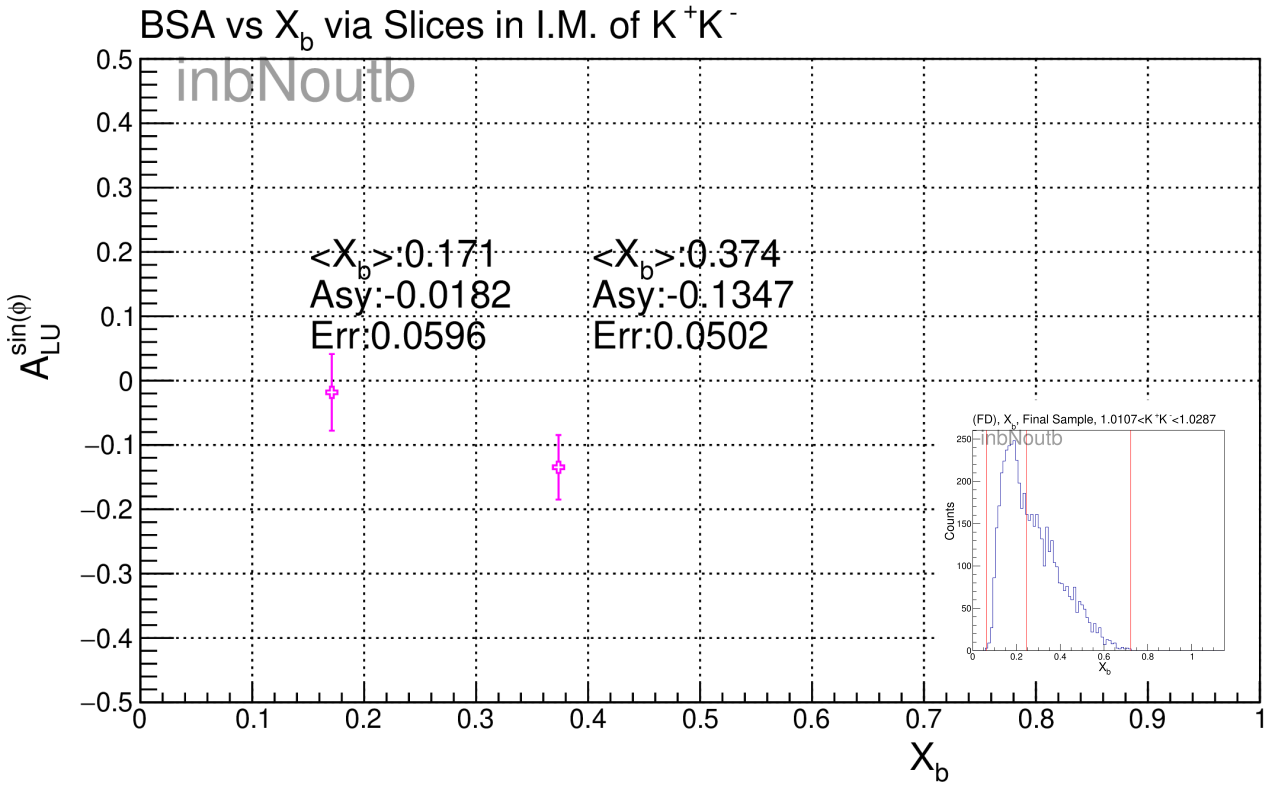
Determination of the BSA using sideband subtraction technique.

Calculate asymmetry over Q^2, x_B, $-t$, and W. kinematics.



Bins in Q^2, x_B, $-t$, and W are constructed with equal binning size.

Calculate asymmetry over Q^2, x_B, $-t$, and W. kinematics.



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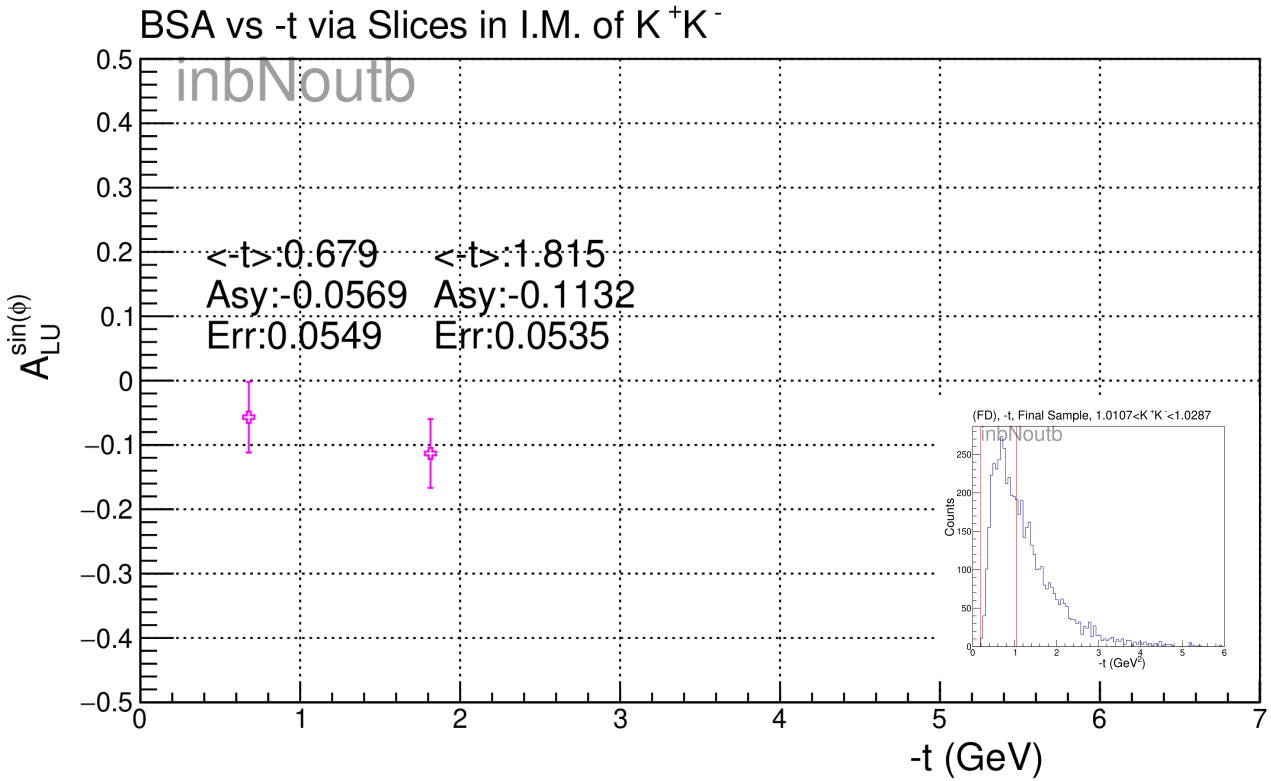

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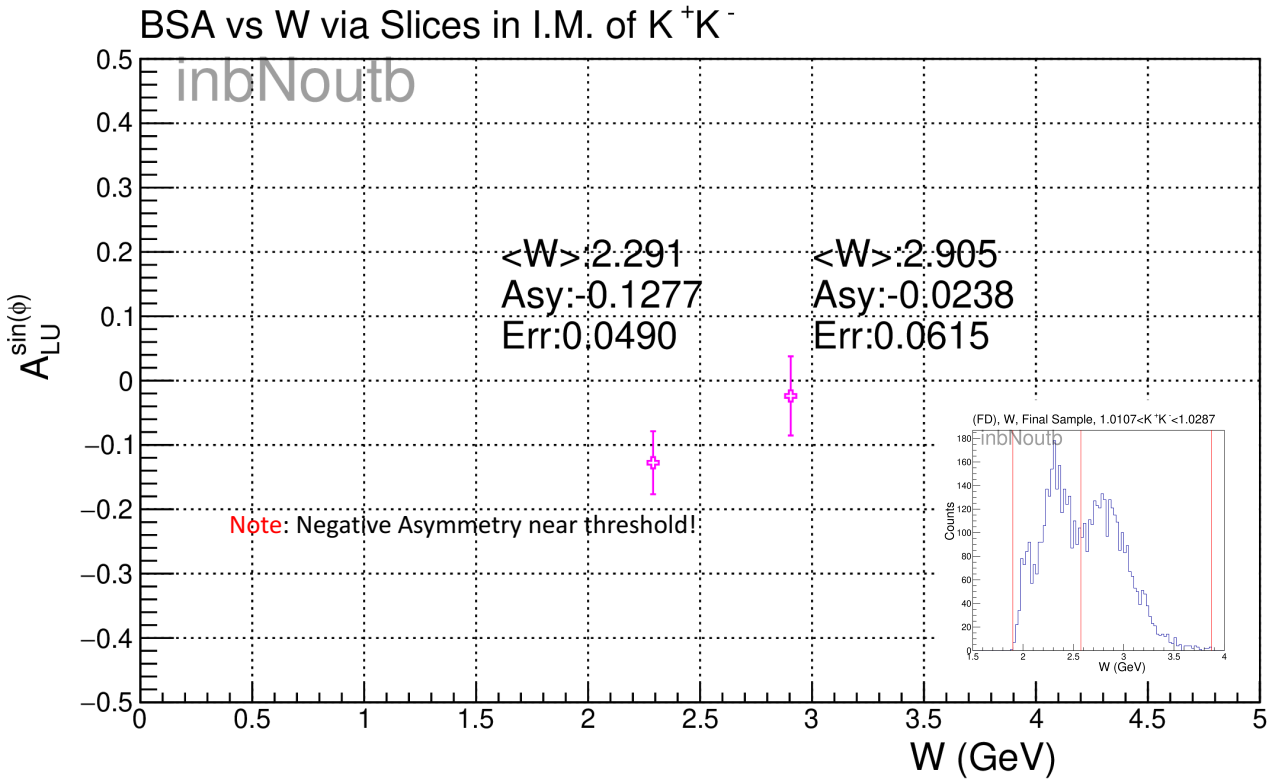

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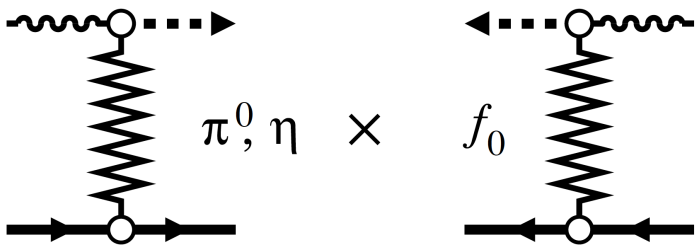
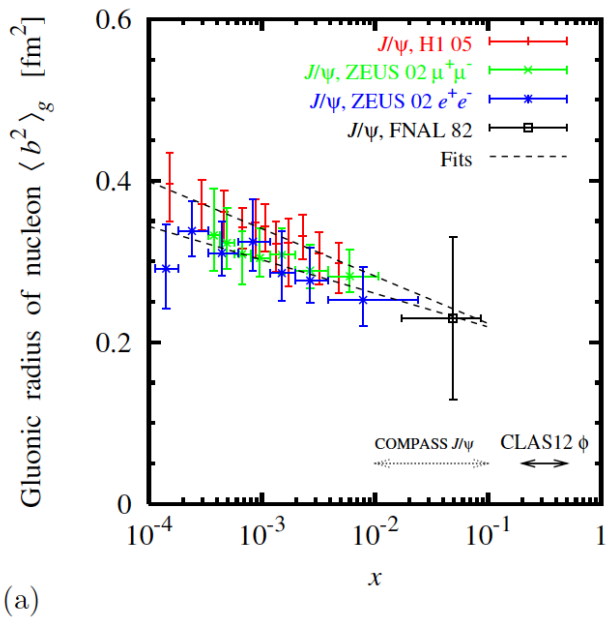
Conclusion

- Measured a non-zero **b**eam **s**pin **a**symmetry (BSA).
  - Negative BSA and adjustment to Monte-Carlo model imply enhancement of scalar-pseudoscalar exchange mechanisms at threshold.
- **Pioneering** in validating the gluon contribution of transversity GPDs to the BSA.
  - recall: $A_{LU}^{sin(\phi)} \sim Im\,(H_T E - E_T H)$
- **Validated** results across separate but similar analyses.



Left - pseudo-scalar π^0, η exchange mechanism. Right - scalar, f_0, exchange mechanism

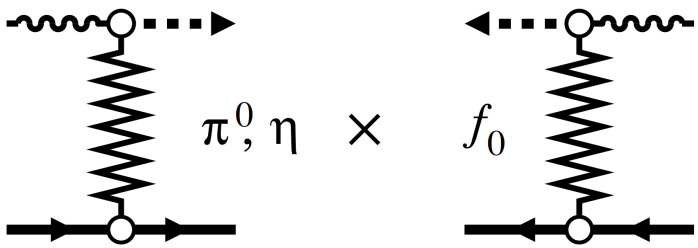


(a)

Future work will be done at large x [3].

Going Forward...

- test new event generator based on scalar-pseudoscalar exchange mechanisms,
- improve statistics with analysis of full dataset for BSA,
- incorporate multivariate analysis techniques for final state extraction,
- draft preliminary publication paper.



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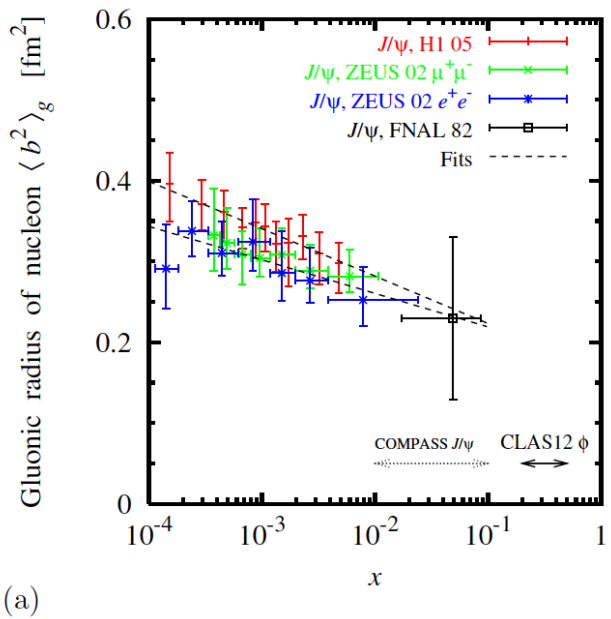

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Thank You!

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Derek B. Leinweber. "Visializations of Quantum Chromodynamics". In: (2003).

V.D. Burkert et al. "The CLAS12 Spectrometer at Jefferson Laboratory". In: *Nucl. Instrum. Meth. A* 959 (2020), p. 163419. DOI: 10.1016/j.nima.2020.163419.

CLAS Collaboration. "Proposal to Jefferson Lab PAC39 Exclusive Phi Meson Electroproduction with CLAS12". In: (). URL: https://www.jlab.org/exp_prog/proposals/12/PR12-12-007.pdf.