# Exclusive phi meson electro-production for CLAS12

## 2020 CLAS12 Collaboration Meeting

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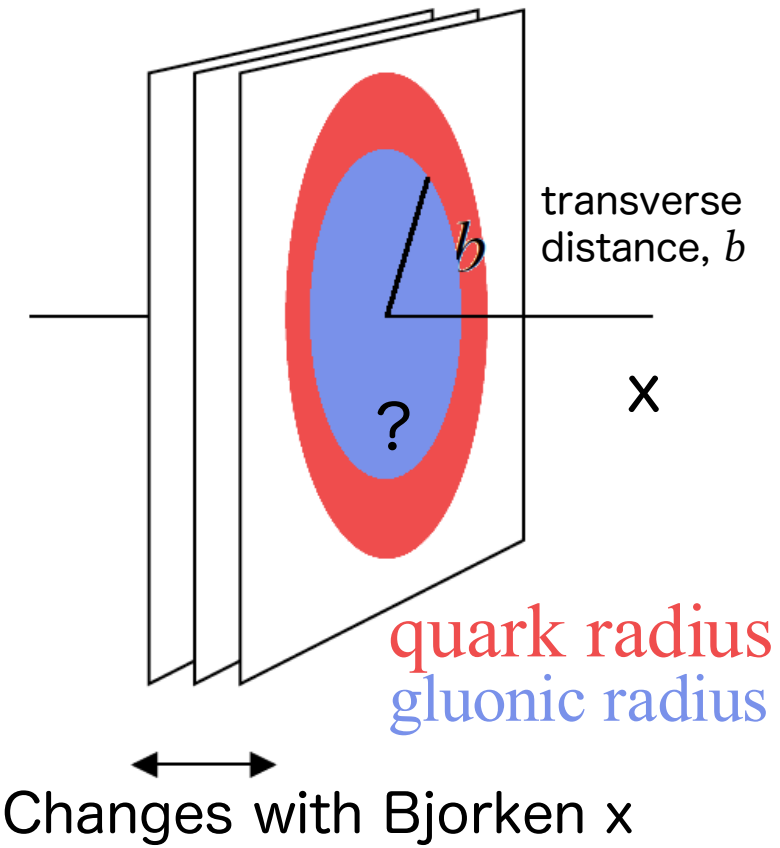
Virtual Meeting at Thomas Jefferson Lab, VA

# Outline

- Physics motivation
- Overview of the experiment
- Data Analysis
- Physics Observables
- Conclusion

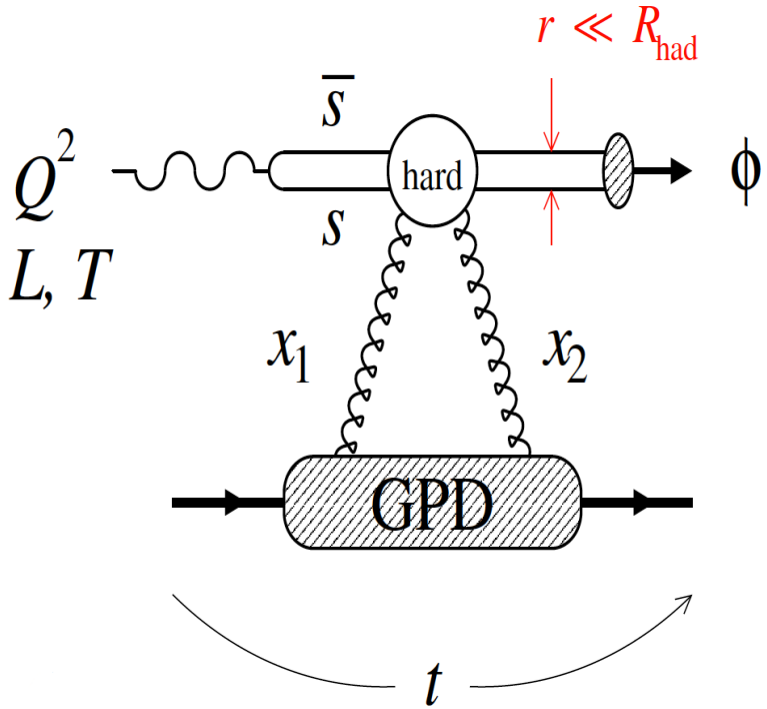
# Physics Motivation

- Understand the mechanisms of confinement using
  - **G**eneralized **P**arton **D**istribution (GPDs) functions
  - **D**eeply **V**irtual **M**eson **P**roduction (DVMP)
- GPDs provide information on the 3-D structure of the nucleon
  - 2D spatial + 1D longitudinal momentum distribution of quarks and gluons.
- Efforts to explore quark structure, but little is known about the gluonic structure.



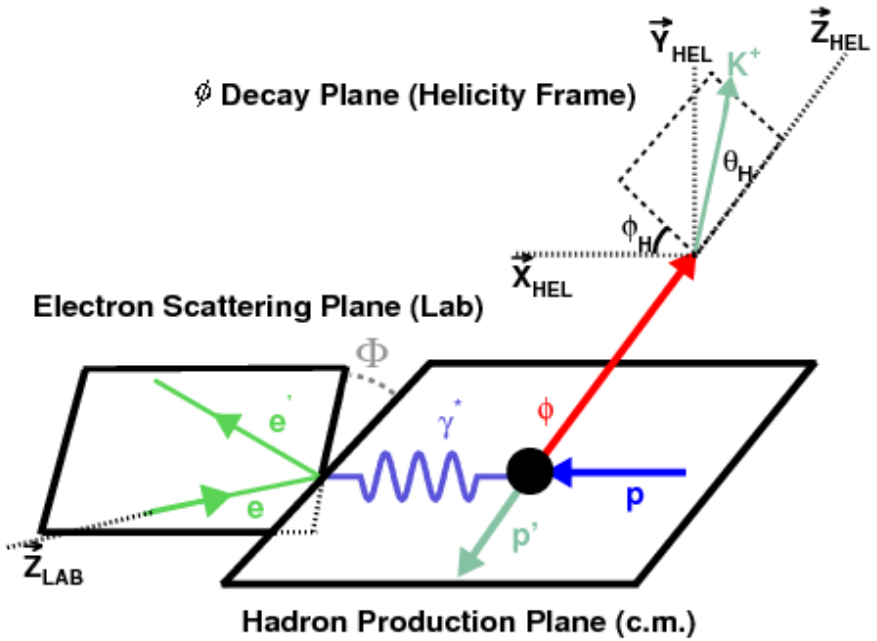
# Physics Motivation

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



# Exclusive $\phi$ Production $(ep \rightarrow ep\phi(1020) \rightarrow epK^+K^-)$

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




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

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



[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 ($ep \rightarrow ep\phi$)

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

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

$\lambda$ is the helicity state of the incident electron beam.

# Measuring the beam spin asymmetry will help test and validate various aspects of this analysis.

The measured beam spin asymmetry is defined as

$$BSA = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{A_{LU}^{sin(\phi)} sin(\phi)}{1 + A_{UU}^{cos(\phi)} cos(\phi) + A_{UU}^{cos(2\phi)} cos(2\phi)} \quad (2)$$

Effort is focused on determining $A_{LU} = \frac{\sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'}}{\sigma_T + \epsilon\sigma_L}$

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

$$A_{LU} \sim [H_T E - E_T H] \quad (3)$$

# JLAB is the home of CLAS12.

- Thomas Jefferson National Accelerator Facility in Newport News, Virginia
- 4 experimental Halls (A, B, C, and D)
- Data was taken during Fall 2018 with the Continuous Electron Beam Accelerator Large Acceptance Spectrometer (CLAS12) in Hall B.

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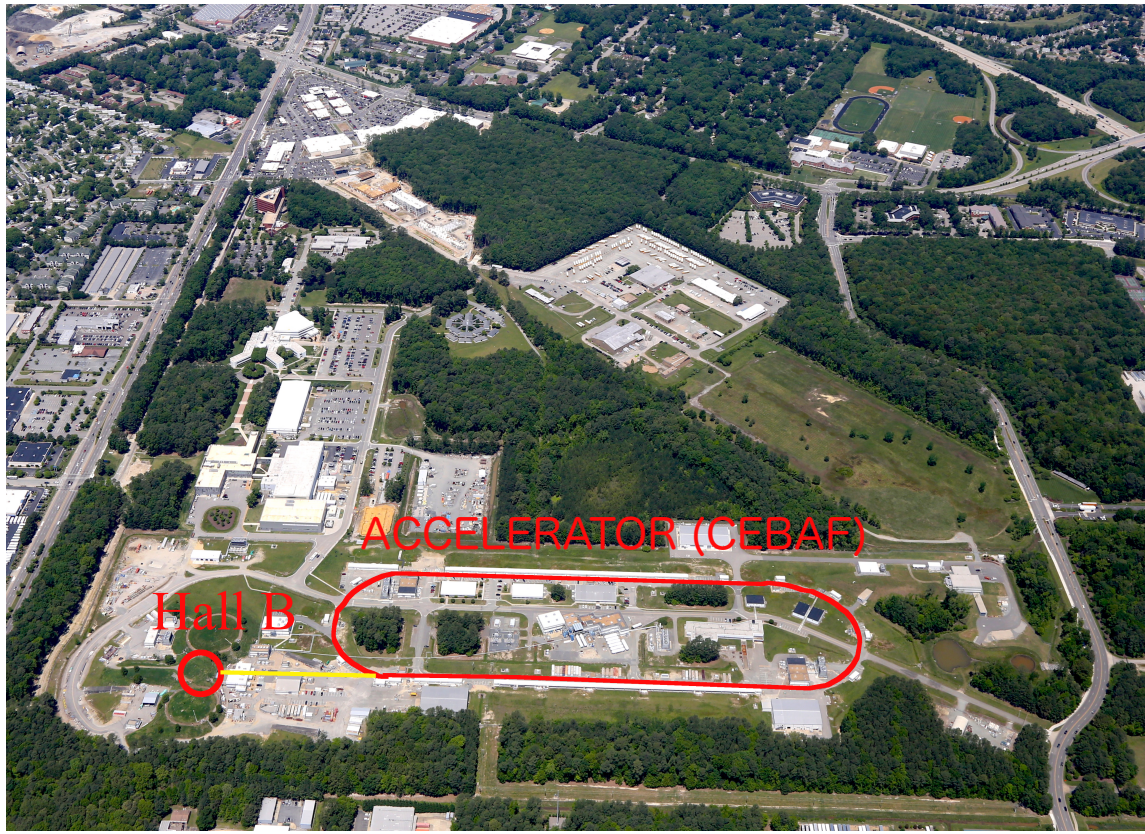
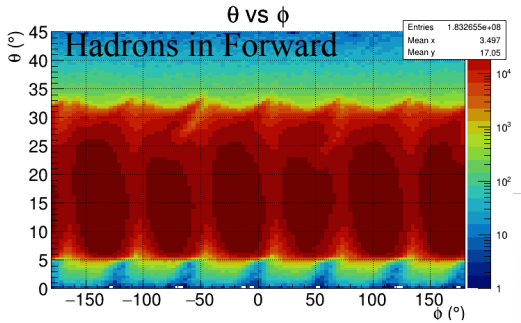
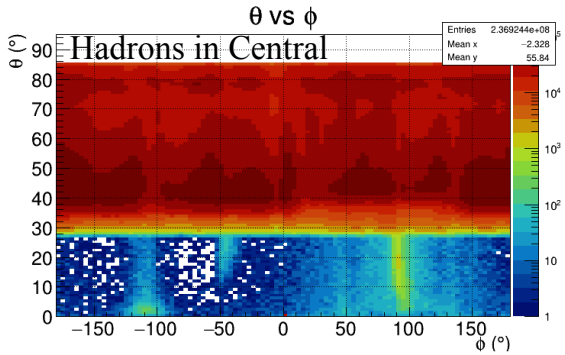
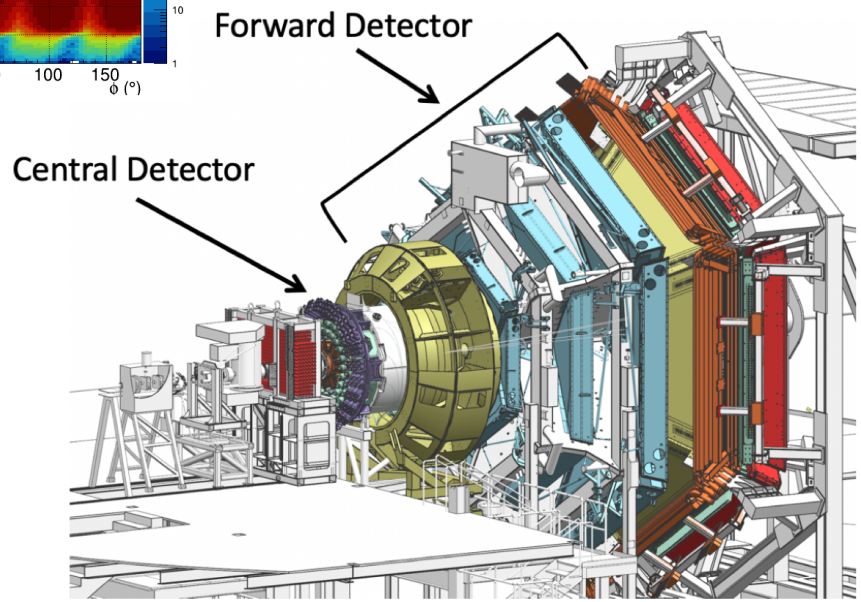


# CLAS12 is uniquely designed to provide coverage over a wide kinematic range for charged and neutral particles.



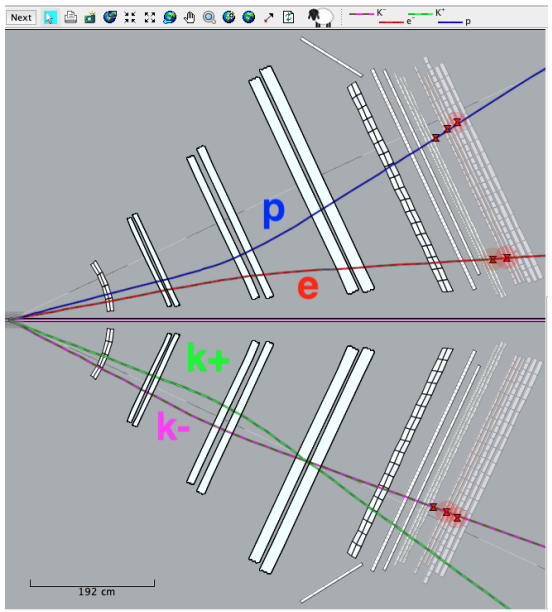

- Magnetic Fields – track reconstruction
- Cherenkov Counters – $e^-$ vs $\pi^-$ separator
- Drift Chambers – momentum for charge particles
- TOF Scintillators – time of flight and path length
- Calorimeters – energy reconstruction



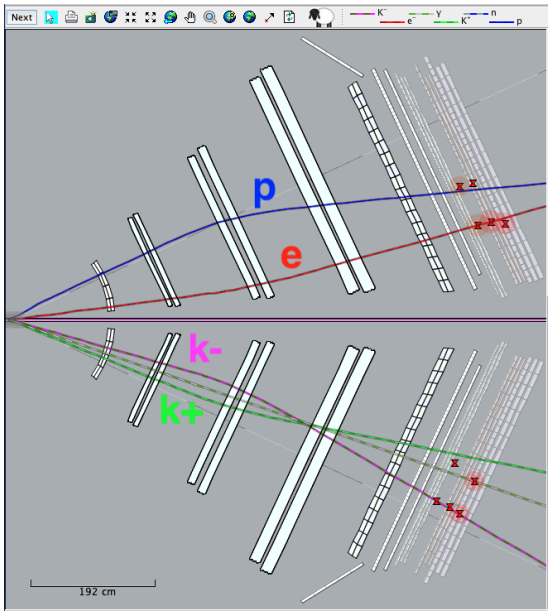

- 10.6 GeV Beam @ 50nA
- Unpolarized LH2 target
- Avg. Beam Pol. 87.4%.
- Torus Field ±100%
- Solenoid Field -100%

# Magnetic Field Polarity and Charged Particles

The torus polarity can create an inbending or outbending field.




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




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

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

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

- Analyze datasets from both mag. field settings.
- 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
- Requirement of being in the forward detector

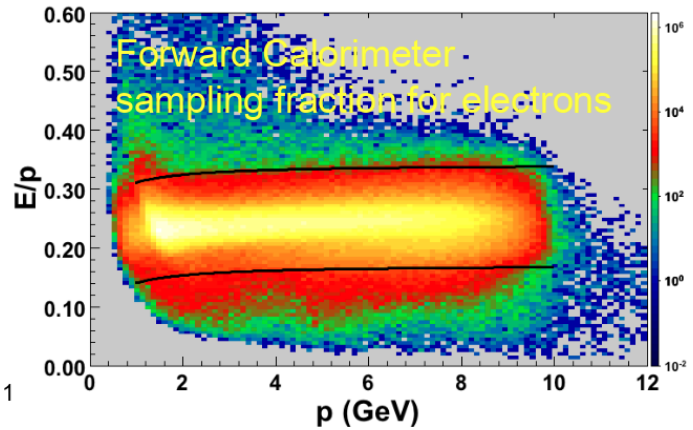



Figure: Example of the sampling fraction. Black lines are at the $3\sigma$ level from the mean $\sim 0.27$.

# After selecting the electron, one must identify the hadrons for this analysis.

- Charged particle ID
  - Momentum information from drift chambers $dp/p < 1\%$
  - Timing information from time-of-flight $\approx 60 - 160ps$
  - All hadrons in Forward Detector.

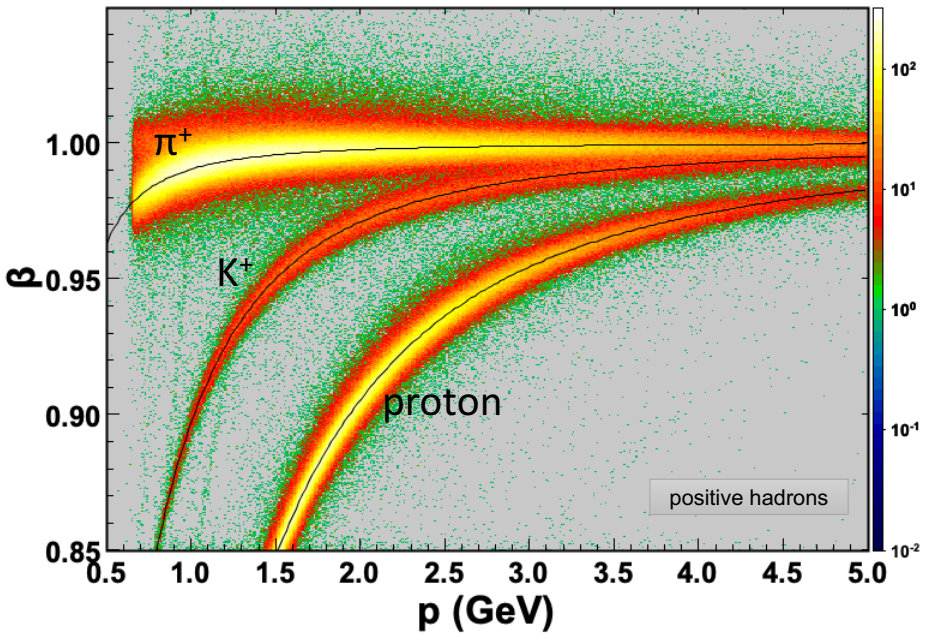
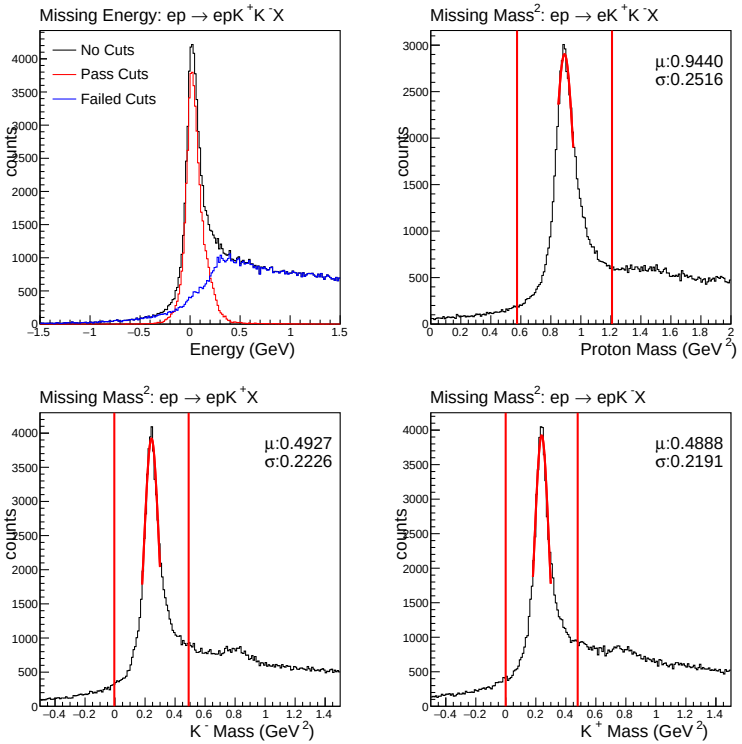



Figure: Proton, Kaons, and Pions $\beta$ vs p bands.

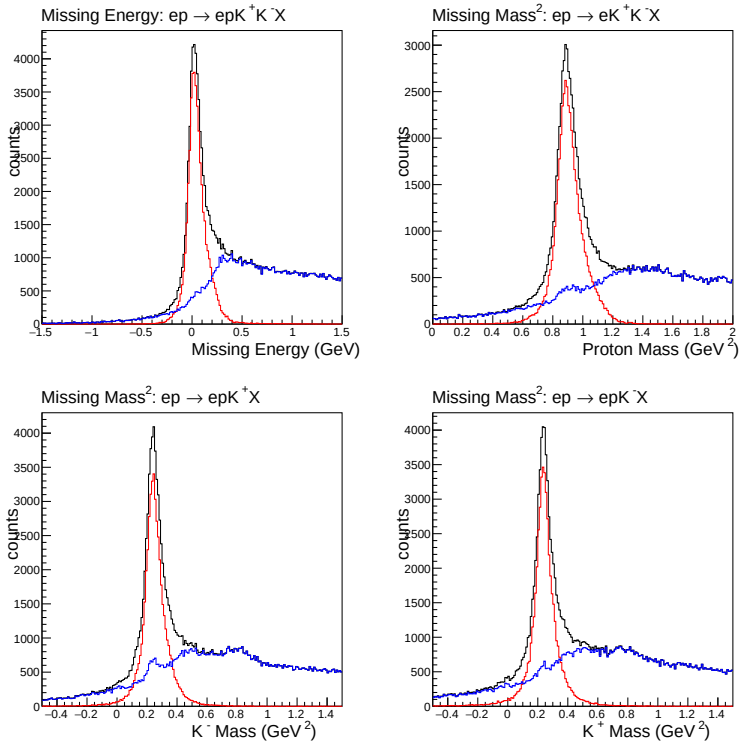
Once the particles in the final state are detected, we must define which events to analyze further.

- **Identify all final state particles** $e'p'K^+K^-$
- All hadrons are identified in the Forward Detector of CLAS12
- Apply exclusivity cuts for $ep \to ep\phi$
  - Missing energy cut at $\pm 4\sigma$
  - Missing Mass Squared on $eK^+K^-X$
  - Missing Mass Squared on $epK^+X$
  - Missing Mass Squared on $epK^-X$
  - $\Delta V_Z$ of Charged Kaons
  - Coplanarity cut of hadrons
  - Event Builder $\chi^2$ cut at $\pm 6\sigma$

# Exclusive Event Selection



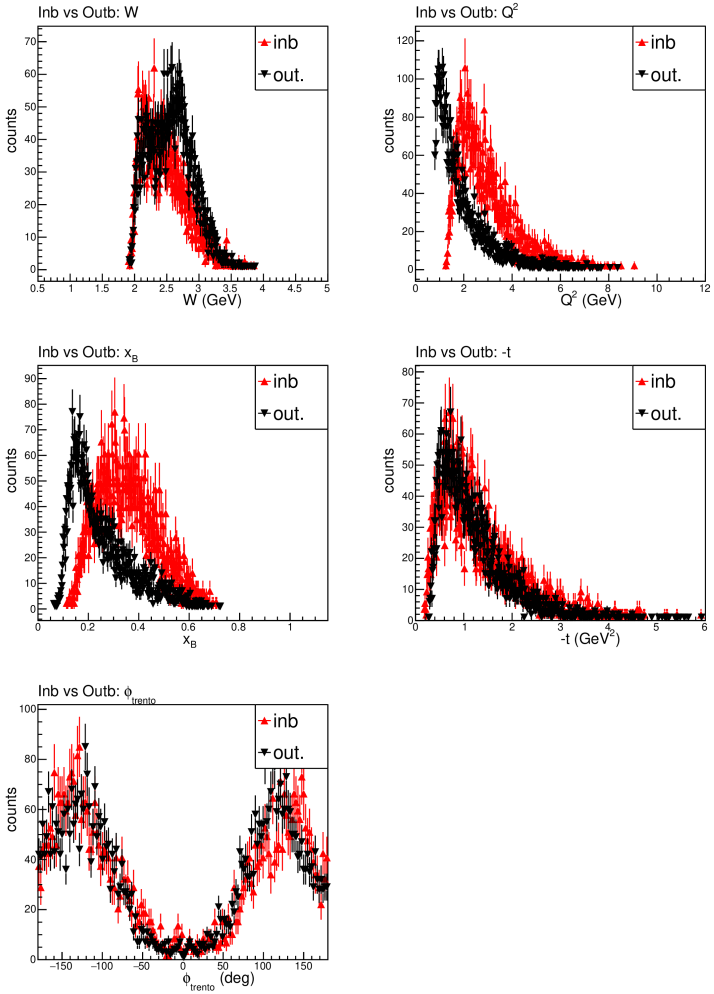

(a) Missing energy distribution with cuts on missing mass$^2$.



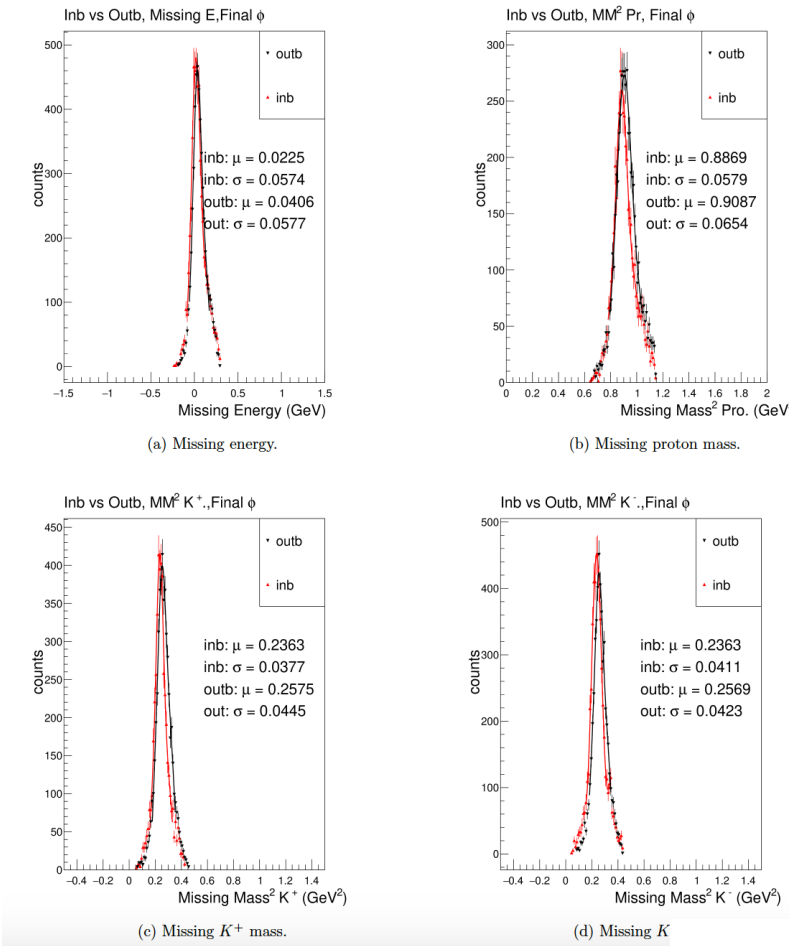

(b) All, pass, and fail for missing E, and mass$^2$.

Figure: Example of missing energy and missing mass squared exclusivity cuts. Red cut lines at $\sim 4\sigma$.

# Combining Inbending and Outbending Datasets.




(a) Compare kinematic variables. Outbending reaches lower $Q^2$.




(a) Missing energy. (b) Missing proton mass.

(c) Missing $K^+$ mass. (d) Missing $K$

(b) Missing E, and mass$^2$ of in/outbending data.

# Define selection of exclusive $\phi$ meson electroproduction based on fit to data.

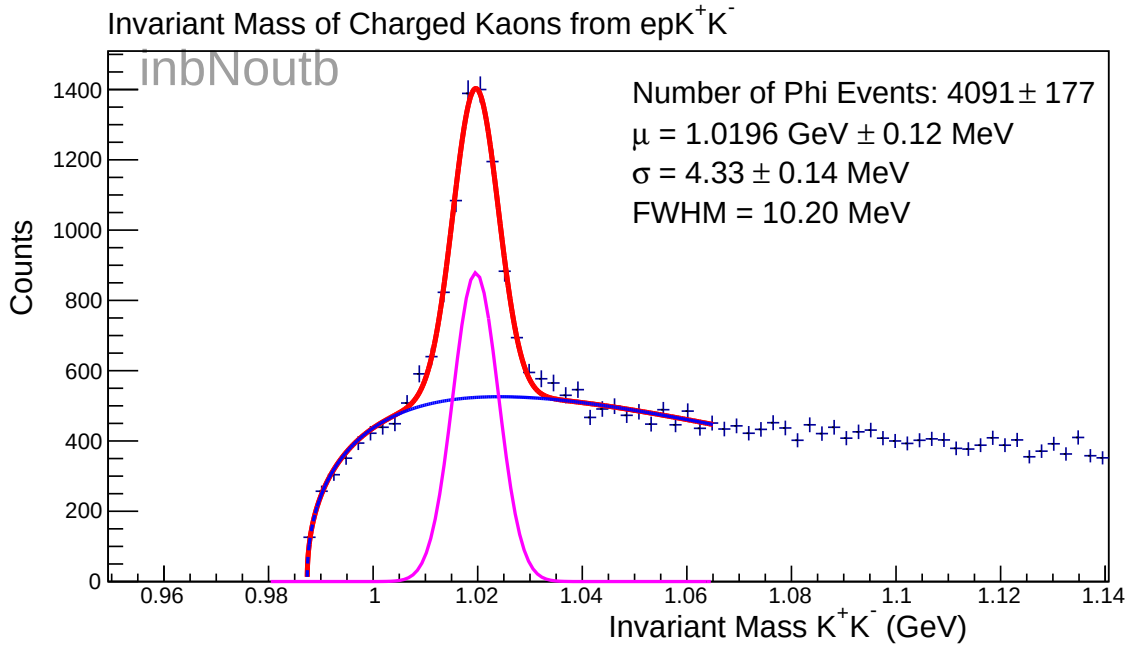


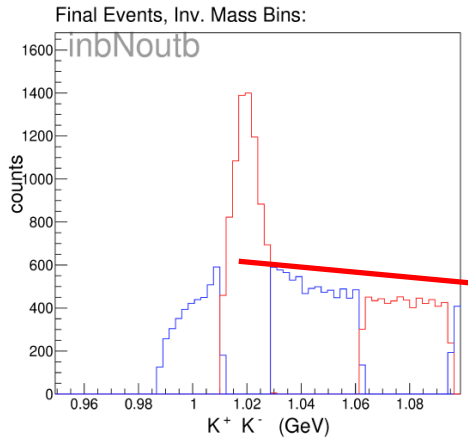

Figure: Invariant mass of $K^+K^-$ from the total available dataset with a fit red (signal+background), magenta (signal), and blue (background).

# Extract the BSA, integrated over kinematics $Q^2$, $x_B$, and $-t$, for events within the $\phi$ signal.

The asymmetry is extracted using a variety of techniques. The main one is...

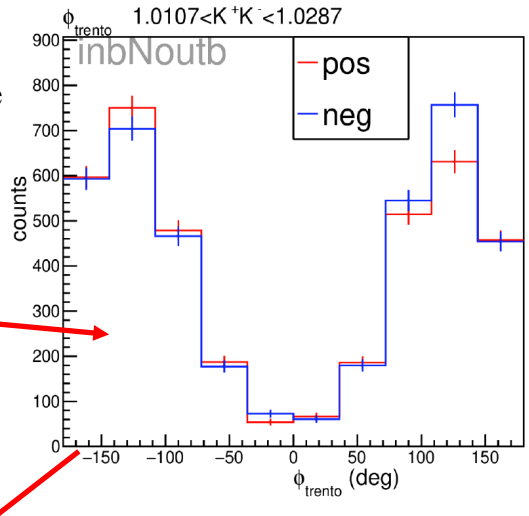
- Extract signal BSA by removing background asymmetry using sideband subtraction.
- Other methods used for determining events used as a cross check, i.e.
  - Calculate signal events for each $\phi_{Trento}$ bin using a fit to the $K^+K^-$ mass distribution for each helicity state.

# 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

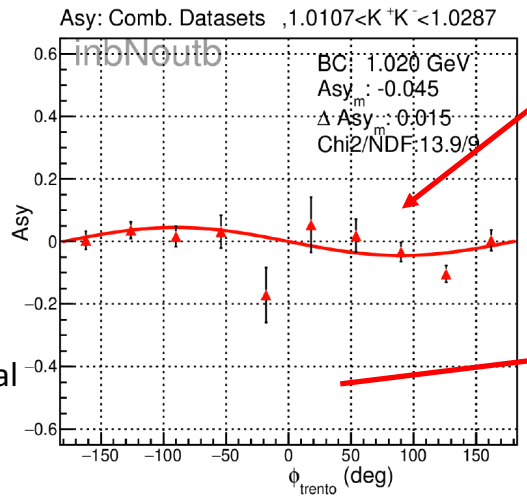
Signal Asymmetry, $A_s$, is calculated as:

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

$A_m$ : measured BSA

$A_b$: background BSA next to signal

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



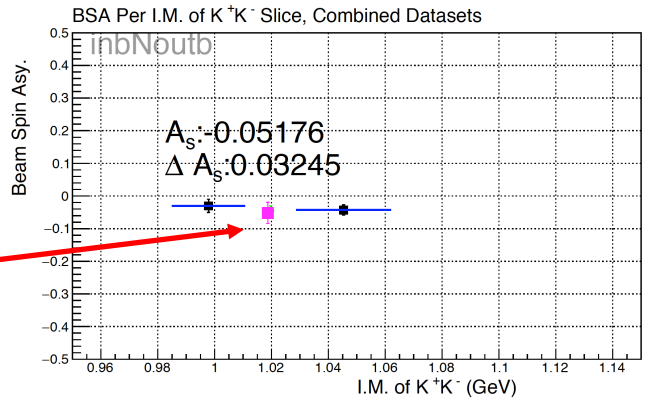
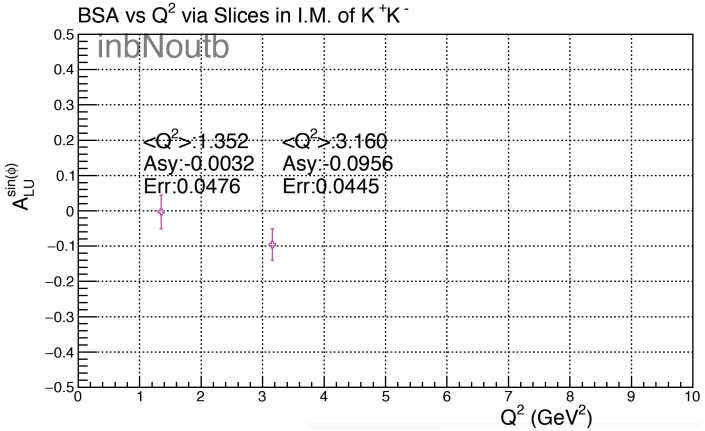
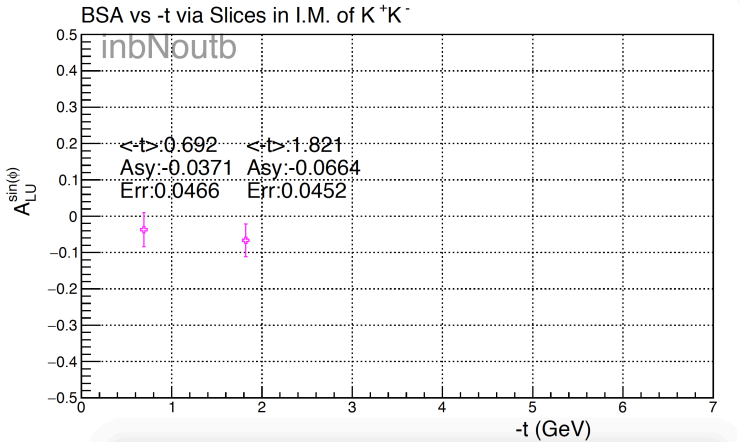
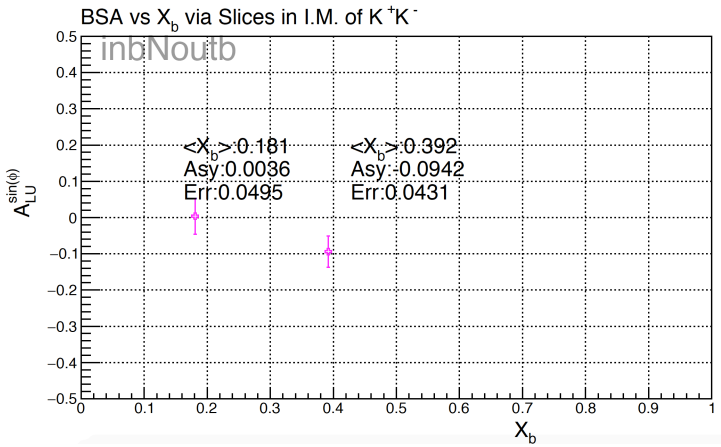




Figure: Determination of the BSA using sideband subtraction technique.

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




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

# Concluding Remarks

- With CLAS12 we have successful measurement of $\phi(1020)$ decay into charged Kaons using the total available data.
- Extract asymmetry with removal of competing resonances, i.e. $\Lambda(1520)$.
- Access to the full statistics will enable a rich analysis of the 3D structure of the nucleon.