

# Beam Spin Asymmetry for Deeply Virtual Exclusive $\pi^0$ Electroproduction with CLAS12

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CLAS Collaboration Meeting  
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## Generalized Parton Distributions (GPDs)

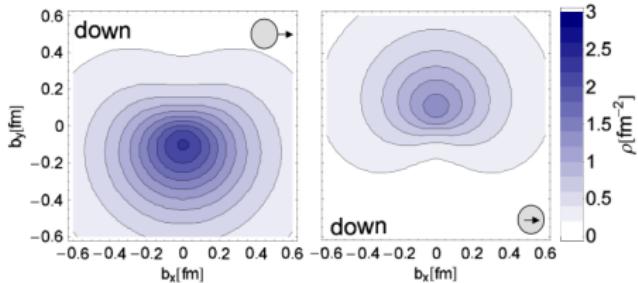
		Quark polarization			
		U	L	T	
Nucleon polarization	U	$H$	$\bar{E}_T$		
	L	$\tilde{H}$			
	T	$E$	$H_T, \tilde{H}_T$		

Chiral even GPDs:

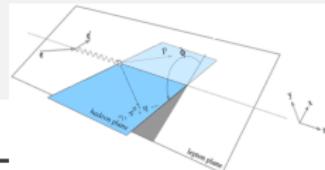
- DVCS on unpolarized and polarized targets with polarized beam by HERMES, JLAB and COMPASS

Chiral-odd GPD results:

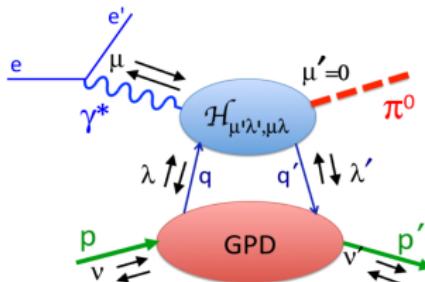
- Deeply virtual meson production
- Lattice QCD by Göckeler *et al*



# Access to the chiral-odd GPDs from experimental data



$$\sigma = \sigma_0 + \sqrt{2\epsilon(1+\epsilon)}\sigma_{LT}^{\cos\phi}\cos\phi + \epsilon\sigma_{TT}^{\cos 2\phi}\cos 2\phi + \lambda_e\sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'}^{\sin\phi}\sin\phi$$



$$\langle F \rangle = \sum_{\lambda} \int_{-1}^1 dx \mathcal{H}_{0\lambda,\mu\lambda}(x, \xi, Q^2, t) F(x, \xi, t)$$

## Goloskokov-Kroll model:

$$\sigma_L \sim \left\{ (1 - \xi^2) |\langle \tilde{H} \rangle|^2 - 2\xi^2 \text{Re} [\langle \tilde{H} \rangle^* \langle \tilde{E} \rangle] - \frac{t'}{4m^2} \xi^2 |\langle \tilde{E} \rangle|^2 \right\}$$

$$\sigma_T \sim \left[ (1 - \xi^2) |\langle H_T \rangle|^2 - \frac{t'}{8m^2} |\langle \bar{E}_T \rangle|^2 \right]$$

$$\sigma_{LT} \sim \xi \sqrt{1 - \xi^2} \frac{\sqrt{-t'}}{2m} \text{Re} [\langle H_T \rangle^* \langle \tilde{E} \rangle]$$

$$\sigma_{TT} \sim \frac{t'}{16m^2} |\langle \bar{E}_T \rangle|^2$$

$$\sigma_{LT'} \sim \xi \sqrt{1 - \xi^2} \frac{\sqrt{-t'}}{2m} \text{Im} [\langle H_T \rangle^* \langle \tilde{E} \rangle]$$

PHYSICAL REVIEW D 84, 034007 (2011)

### Flexible parametrization of generalized parton distributions from deeply virtual Compton scattering observables

Gary R. Goldstein,<sup>1,a</sup> J. Osvaldo Gonzalez Hernandez,<sup>2,†</sup> and Simonetta Luti<sup>2,‡</sup>

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<sup>2</sup>Department of Physics, University of Virginia, Charlottesville, Virginia 22901, USA

(Received 16 February 2011; published 5 August 2011)

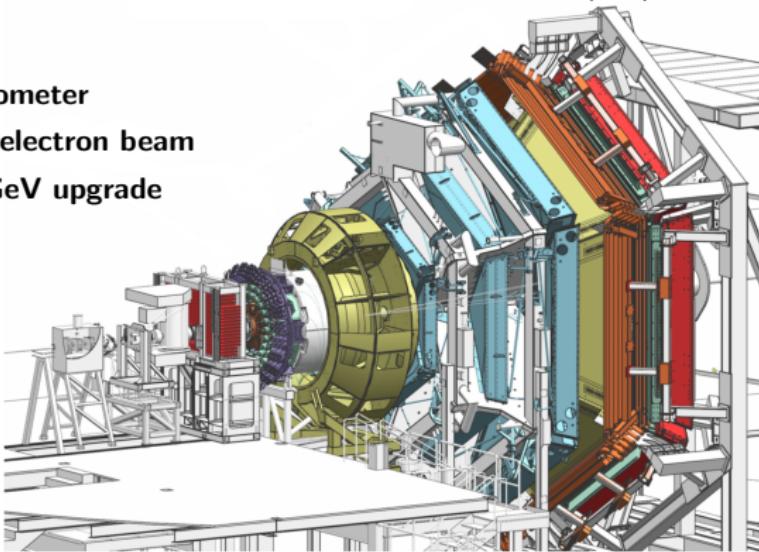
Eur. Phys. J. A (2011) 47: 112  
DOI 10.1140/epja/i2011-11112-6

Regular Article – Theoretical Physics

### Transversity in hard exclusive electroproduction of pseudoscalar mesons

S.V. Goloskokov<sup>1,a</sup> and P. Kroll<sup>2,3,b</sup>

- CEBAF Large Acceptance Spectrometer
- 10.6 GeV longitudinally polarized electron beam
- First CLAS experiment since 12 GeV upgrade
- 86% electron polarization
- Liquid hydrogen target
- All final state particles detected
- Access  $Q^2$  range up to 10  $\text{GeV}^2$



## RGA fall 2018

- inbending:

- 174 runs
- 43.43 mC

- outbending:

- 185 runs
- 35.7 mC

## PID cuts for exclusive $\pi^0$ electroproduction

All final state particles events selection  $e + p + \gamma + \gamma$ :

- **Electron (cuts based on RGA analysis note):**

- Event Builder pid cut "pid==11"
- NPHE cut
- Vertex cut
- DC fiducial cuts: region 1,2,3
- EC fiducial cut
- PCAL energy cut
- EC sampling cut

- **Proton:**

- Event Builder pid cut "pid==2212"
- $\Delta$ vertex cut
- DC fiducial cuts: region 1,2,3
- **Forward Detector only**

- **Photons:**

- Event Builder pid cut "pid==22"
- Forward Detector only
- Photon sector is different from electron sector
- Hits in, at least, two ECAL layers

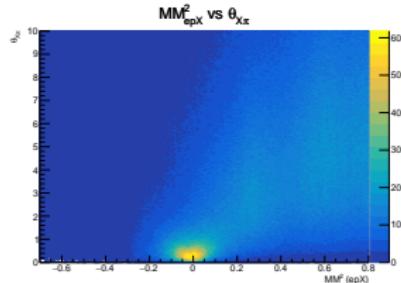
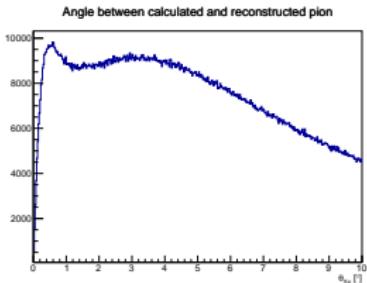
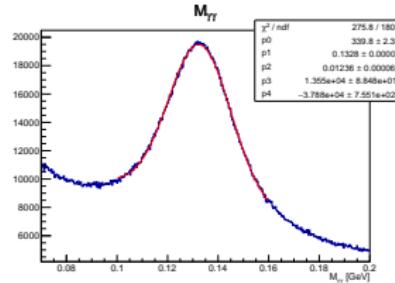
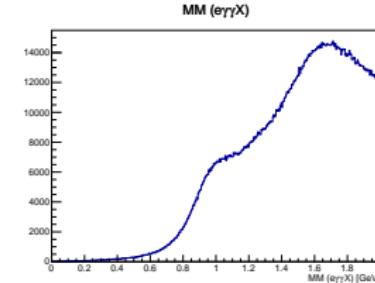
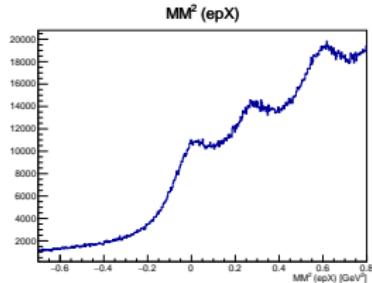
- **Loose  $\pi^0$  cut:**

- $0.07 < M_{\gamma\gamma} < 0.2$  GeV

# Exclusive distributions

1.  $e + p + \gamma + \gamma$  detected

2. loose  $\pi^0$  mass cut



- The peaks for exclusive  $\pi^0$  channels are visible but dominated by the background
- Invariant mass of two photons clearly shows the mass of the neutral pion and tighter cut of  $3\sigma$  should be used to further improve selection

# All cuts for exclusive $\pi^0$ electroproduction

All final state particles events selection  $e + p + \gamma + \gamma$ :

- Electron (cuts based on RGA analysis note):

- Event Builder pid cut "pid==11"
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- Proton:

- Event Builder pid cut "pid==2212"
- Avertex cut
- DC fiducial cuts: region 1,2,3
- Forward Detector only

- Photons:

- Event Builder pid cut "pid==22"
- Forward Detector only
- Photon sector is different from electron sector
- Hits in, at least, two ECAL layers

- Loose  $\pi^0$  cut:

- $0.07 < M_{\gamma\gamma} < 0.2 \text{ GeV}$

- Exclusive cuts

- $|\Delta p_x| < 0.2 \text{ GeV}$
- $|\Delta p_y| < 0.2 \text{ GeV}$
- $\theta_{X\pi} < 2^\circ$
- $MM^2(epX) < 0.5 \text{ GeV}^2$

- Tight  $\pi^0$  cut:

- $0.096 < M_{\gamma\gamma} < 0.168 \text{ GeV}$

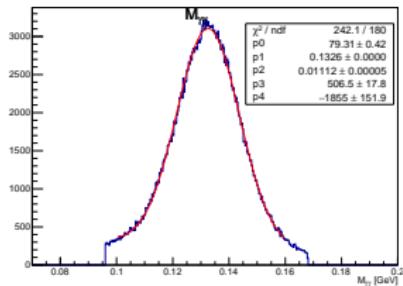
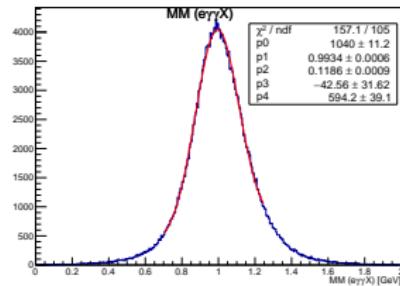
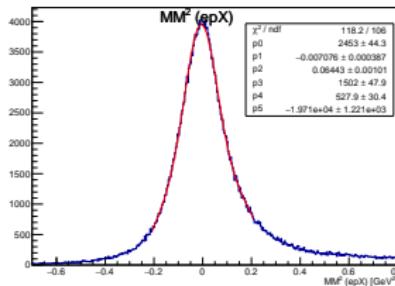
## Exclusive distributions

1.  $e + p + \gamma + \gamma$  detected

2. tight  $\pi^0$  mass cut

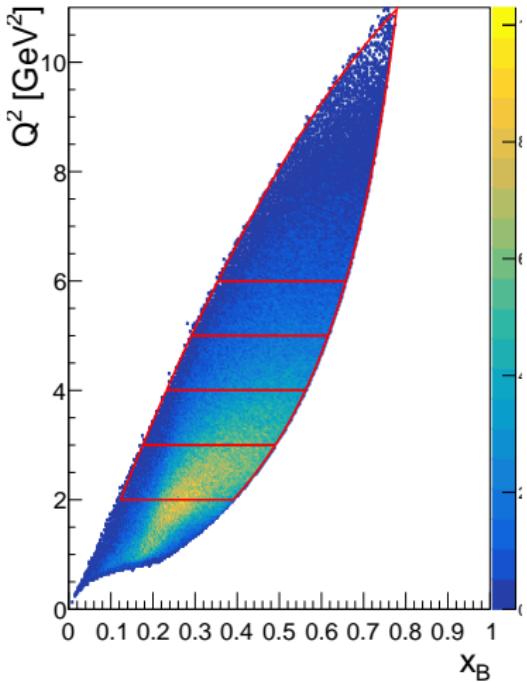
3.  $|\Delta p_x| < 0.2$  GeV and  $|\Delta p_y| < 0.2$  GeV

3.  $\theta_{X\pi} < 2^\circ$



- With missing transverse momentum cuts and  $\theta_{X\pi}$  cut exclusive peaks become very clean
- Finally, the cut on  $MM^2(epX)$  can be added:  $|MM^2| < 0.5$  GeV<sup>2</sup> which is a conservative cut

## Kinematic coverage, binning



**CLAS12 allows:**

- azimuthal dependence analysis
- multidimensional binning
- extended kinematic coverage

**DIS cuts:**  $Q^2 > 2$  GeV $^2$  and  $W > 2$  GeV

- 5  $\{Q^2, x_B\}$  bins
- each  $\{Q^2, x_B\}$  bin has  $3 - t$  bins
- each  $\{Q^2, x_B, -t\}$  bin has 9  $\phi$  bins

**in total:** 135  $\{Q^2, x_B, -t, \phi\}$  bins

## Beam spin asymmetry

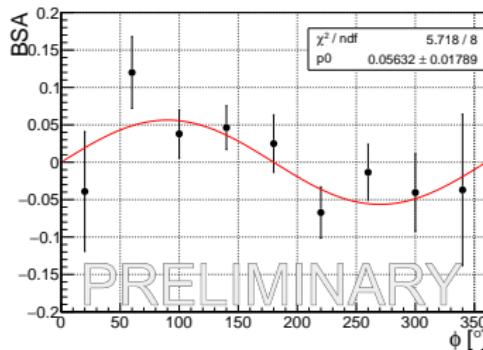
$$BSA = \frac{\sum \frac{1}{Pb_i} n_i^+ - \sum \frac{1}{Pb_i} n_i^-}{n^+ + n^-}$$

where  $Pb_i$  is an electron beam polarization for run periods

$$\sigma = \sigma_0 + \sqrt{2\epsilon(1+\epsilon)}\sigma_{LT}^{\cos\phi} \cos\phi + \epsilon\sigma_{TT}^{\cos 2\phi} \cos 2\phi + \lambda_e \sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'}^{\sin\phi} \sin\phi$$

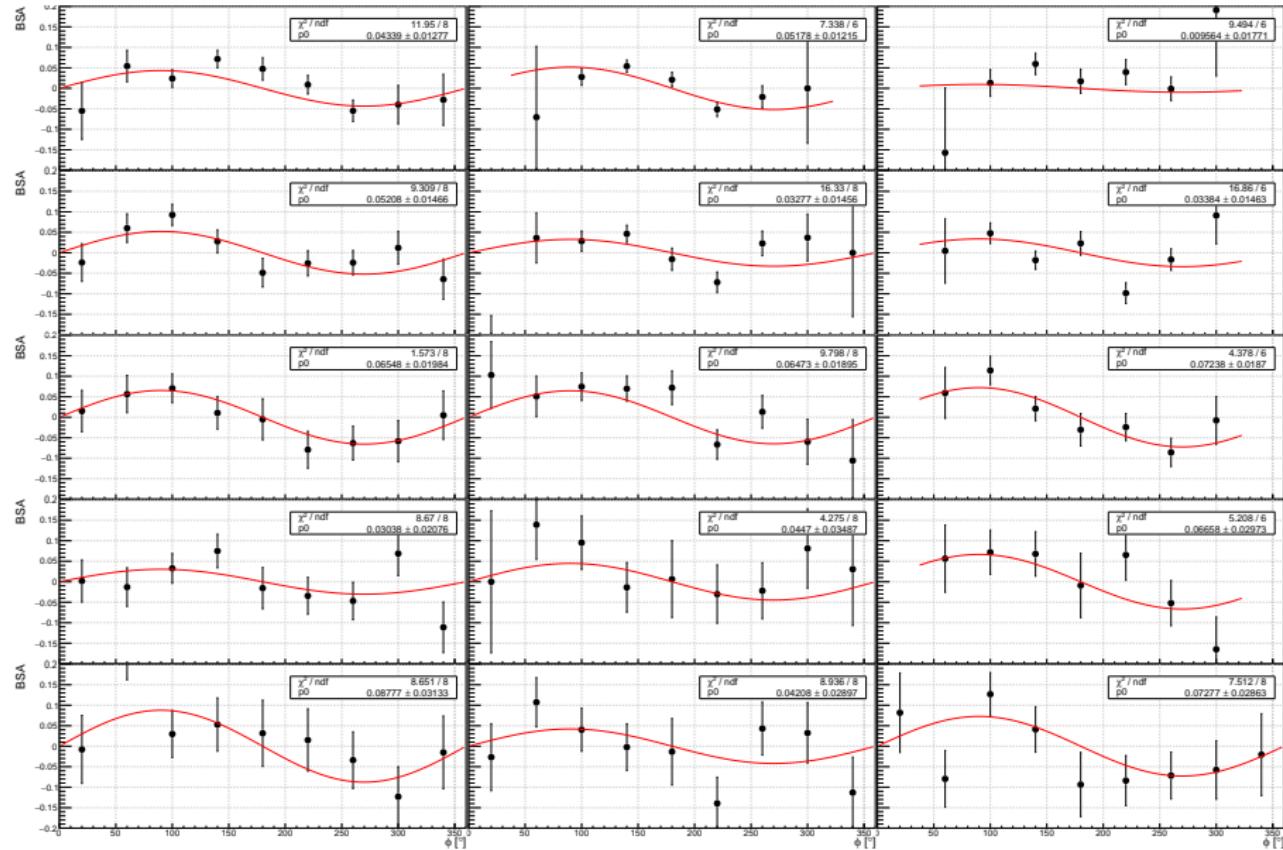
$$BSA = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} \propto A_{LU}^{\sin\phi} \sin\phi$$

$$A_{LU}^{\sin\phi} = \sqrt{2\epsilon(1-\epsilon)} \frac{\sigma_{LT'}^{\sin\phi}}{\sigma_0}$$



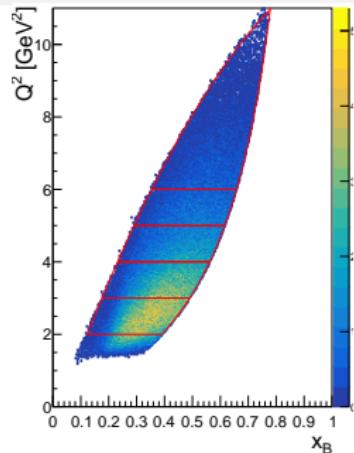
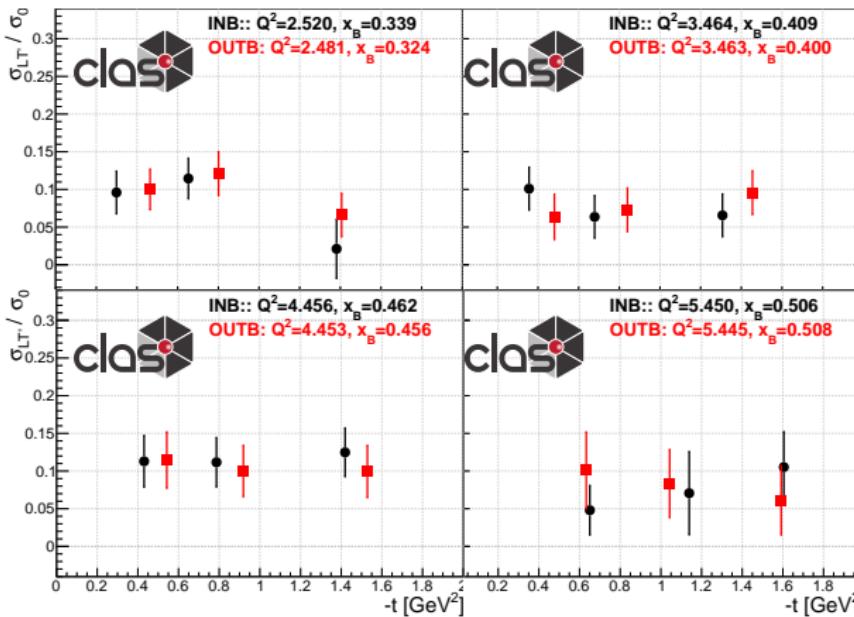
The Beam Spin Asymmetry as a function of  $\phi$   
for one of the kinematic bins

# Preliminary BSA from CLAS12 first experiment data [inbending]



# Preliminary $\frac{\sigma_{LT'}}{\sigma_0}$ from CLAS12 first experiment data

- beam spin asymmetry (BSA) extracted for 5  $Q^2$ ,  $x_B$  bins with FD proton
- the ratio of structure functions  $\frac{\sigma_{LT'}}{\sigma_0}$  can be extracted from BSA by dividing on  $\sqrt{2\epsilon(1-\epsilon)}$

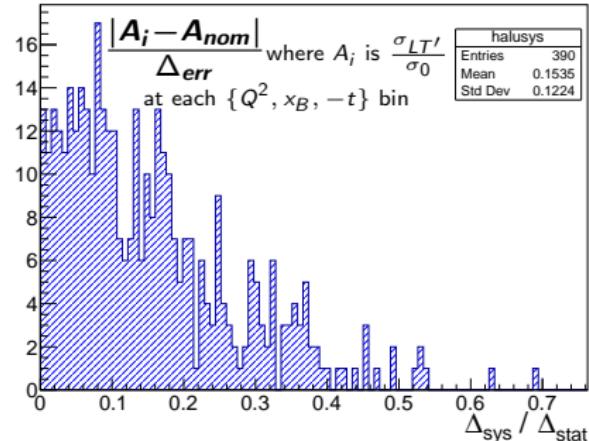
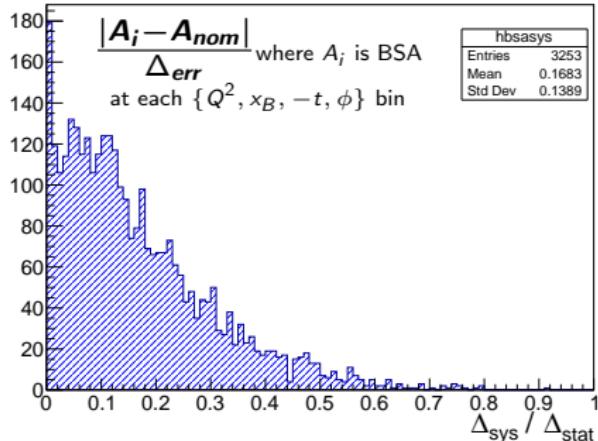


## Systematic studies of exclusive events selection

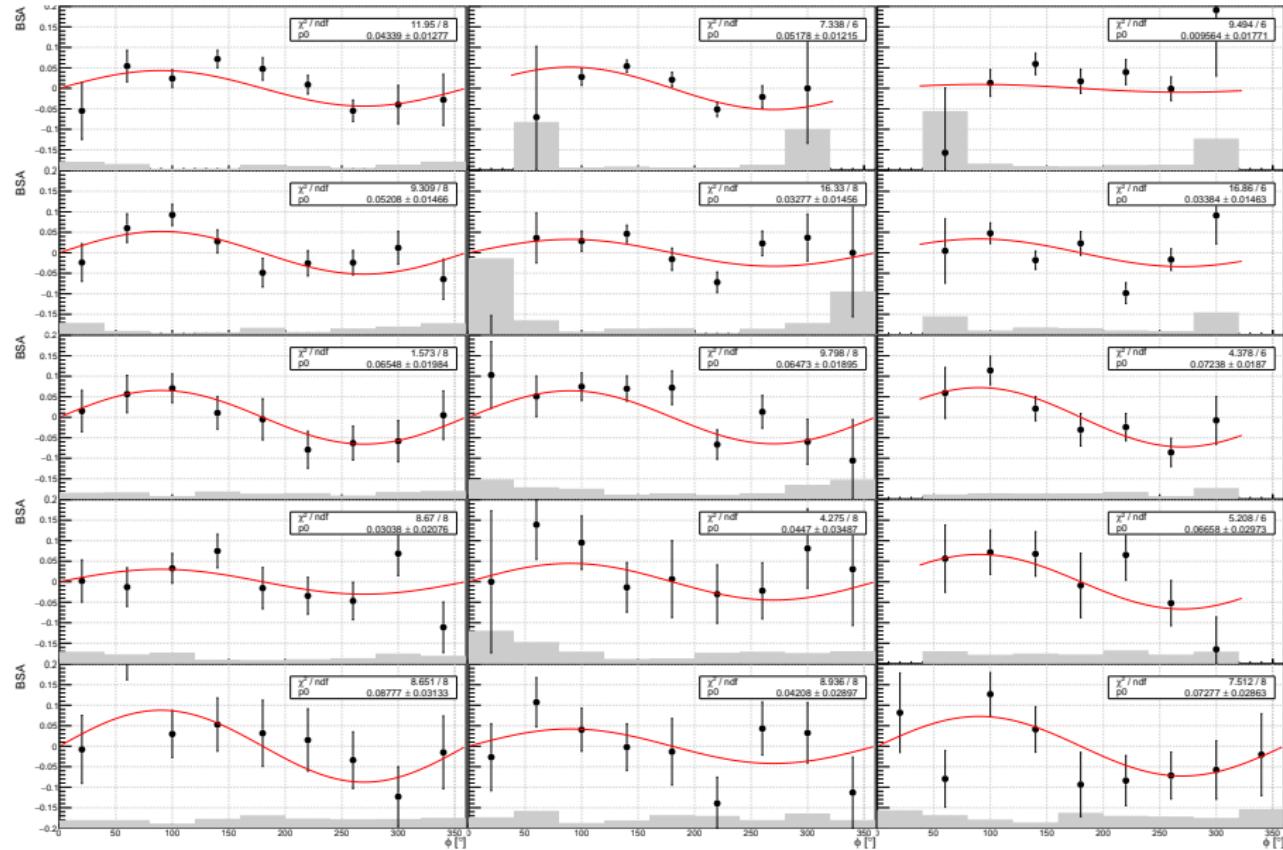
$$|\Delta P_x| \begin{cases} < 0.18 \text{ GeV} \\ < 0.2 \text{ GeV} \\ < 0.22 \text{ GeV} \end{cases} \quad |\Delta P_y| \begin{cases} < 0.18 \text{ GeV} \\ < 0.2 \text{ GeV} \\ < 0.22 \text{ GeV} \end{cases} \quad \theta_{X\pi} \begin{cases} < 1.8^\circ \\ < 2^\circ \\ < 2.2^\circ \end{cases}$$

- $3 \Delta P_x \times 3 \Delta P_y \times 3 \Delta P_z$  variations = **27 combinations**
- 27 BSA values extracted for each kinematic bin
- For each kinematic bin the systematic uncertainty is estimated as:

$$\Delta_{\text{sys}} = \max(|A_1 - A_{\text{nom}}|, \dots, |A_{27} - A_{\text{nom}}|)$$

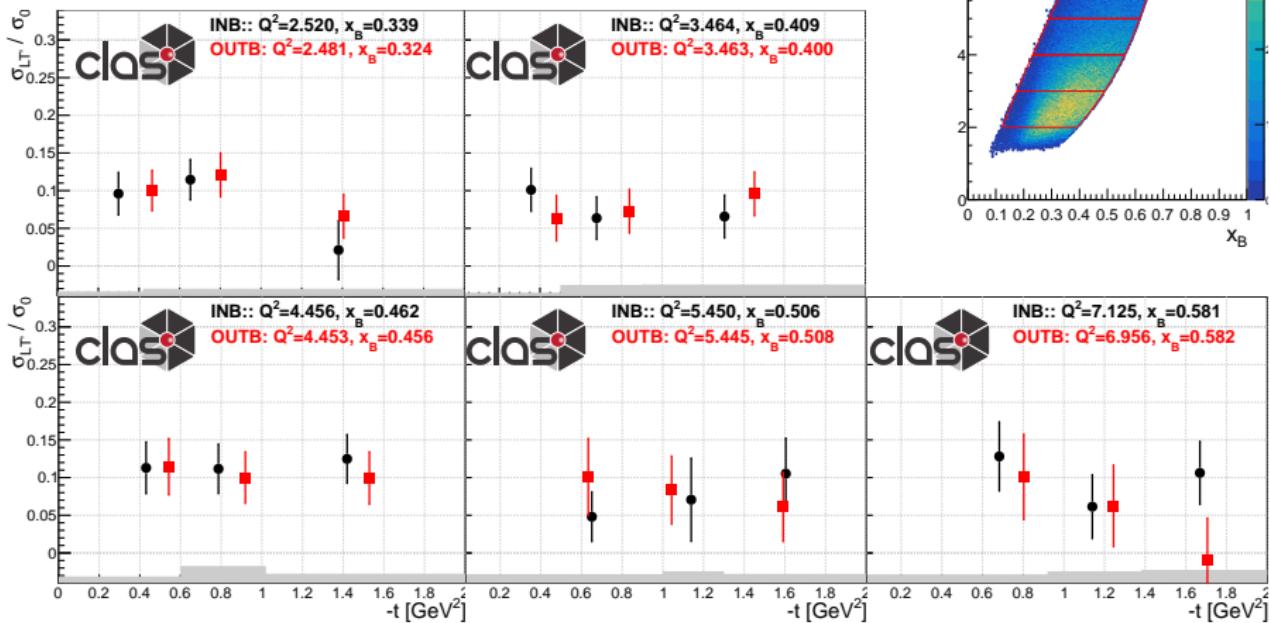


# Preliminary BSA from CLAS12 first experiment data [inbending]



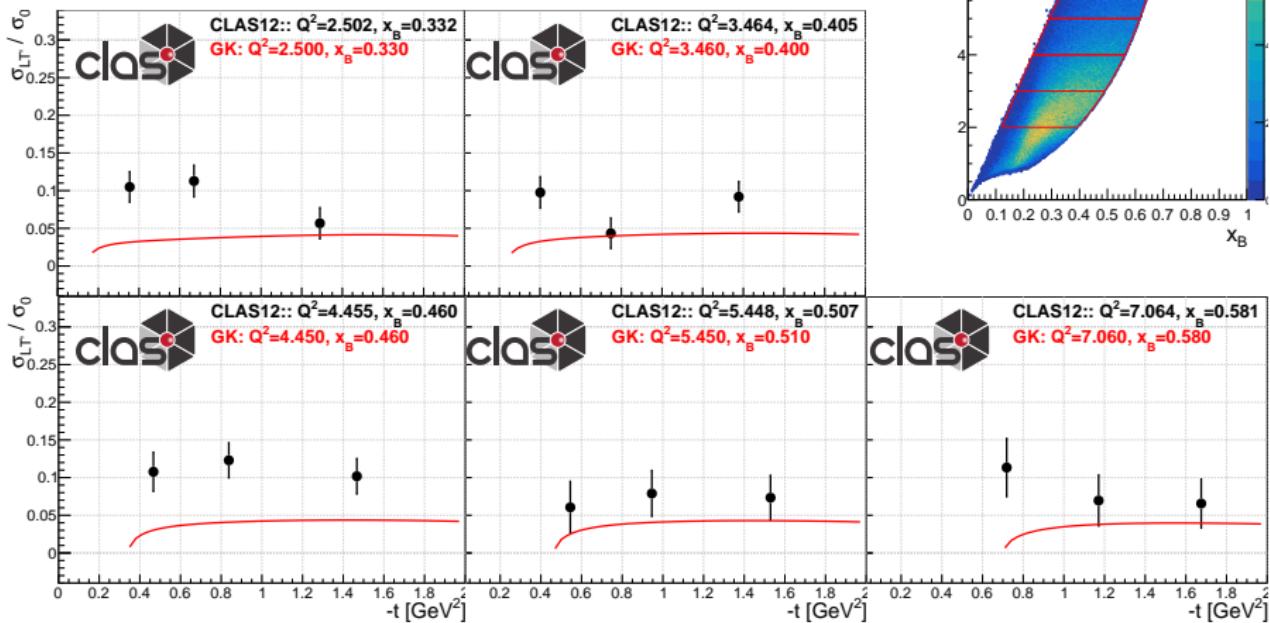
# Preliminary $\frac{\sigma_{LT'}}{\sigma_0}$ from CLAS12 first experiment data

- beam spin asymmetry (BSA) extracted for 5  $Q^2$ ,  $x_B$  bins with FD proton
- the ratio of structure functions  $\frac{\sigma_{LT'}}{\sigma_0}$  can be extracted from BSA by dividing on  $\sqrt{2\epsilon(1-\epsilon)}$



# Preliminary $\frac{\sigma_{LT'}}{\sigma_0}$ from CLAS12 first experiment data

- combining **INBENDING** and **OUTBENDING** data
- the results are compared with theoretical calculations based on Goloskokov-Kroll (GK) model

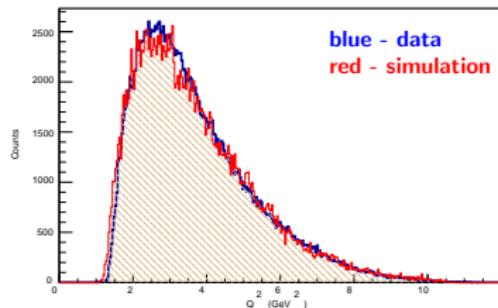


# Checklist.

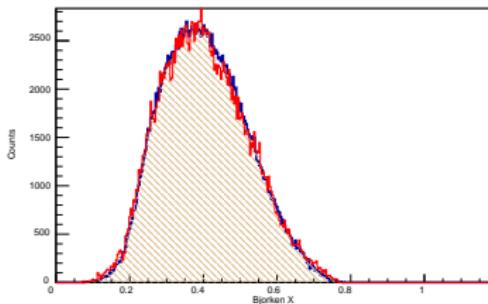
- Finalize systematic studies
  - Exclusive events selection: exclusivity cut, PID etc
  - Fitting procedure, additional fitting parameters
  - Acceptance and large kinematic bins
    - Simulation
- Cross check analysis (guidelines appreciated)
- Study kinematic binning schemes
- Finalize analysis note [overleaf here]
- Draft preliminary version of the paper

# Simulation

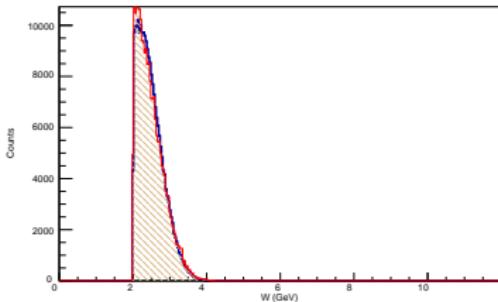
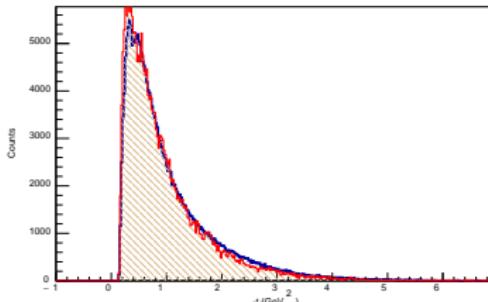
- GEMC simulation for inbending and outbending data
- **aao\_norad** generator: [github here](#)
  - Structure functions based on GK model
  - Parameterized using CLAS6 data by Valery

Q<sup>2</sup>, After Excl. Cuts, FD + Scaled Sim.

Bjorken X, After Excl. Cuts, FD + Scaled Sim.



W Distribution, After Excl. Cuts, FD + Scaled Sim.

Momentum transfer to Nucleon ( $t$ ), After Excl. Cuts, FD + Scaled Sim.

## Summary

- CLAS12 and polarized electron beam enables the extraction of BSA moments for exclusive  $\pi^0$  electroproduction
- 10.6 GeV electron beam extends our reach to the higher  $Q^2$  kinematic regions
- $\frac{\sigma_{LT'}}{\sigma_0}$  is positive and large, compatible with previously observed BSA moments
- These data will provide further insight into chiral-odd GPDs and constrain their parameterizations

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 Jefferson Lab

The logo for Jefferson Lab, which includes a stylized red and black swoosh graphic followed by the text "Jefferson Lab".