Beam Spin Asymmetry for Deeply Virtual Exclusive π^0 Electroproduction with CLAS12

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CLAS Collaboration, 03/03/21

Generalized Parton Distributions (GPDs)

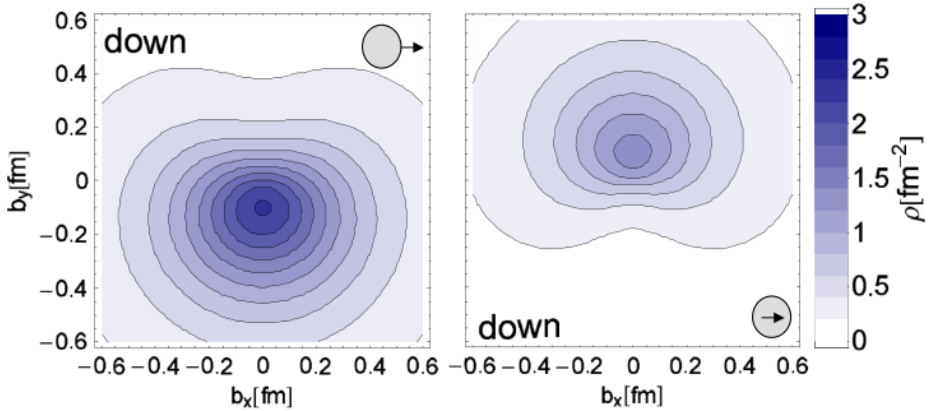
		Quark polarization		
		U	L	T
Nucleon polarization	U	H		$\bar{E}_T$
	L		$\tilde{H}$	
	T	E		H_T, $\tilde{H}_T$

Chiral-odd GPD results:

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

Chiral even GPDs:

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



Chiral-odd GPDs

- Proton anomalous tensor magnetic moment

$$\kappa_T^u = \int dx \bar{E}_T^u(x,\xi,t=0)$$

$$\kappa_T^d = \int dx \bar{E}_T^d(x,\xi,t=0)$$

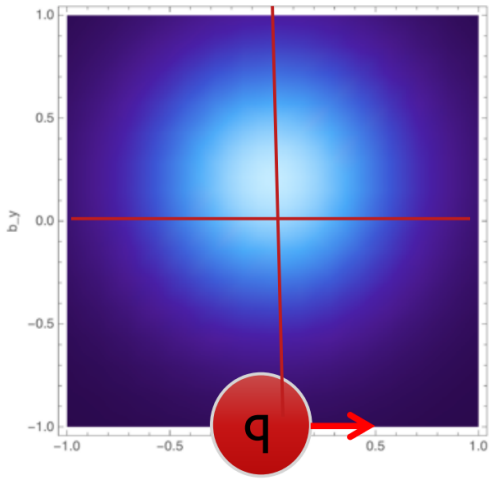
- Proton tensor charge

$$\delta_T^u = \int dx H_T^u(x,\xi,t=0)$$

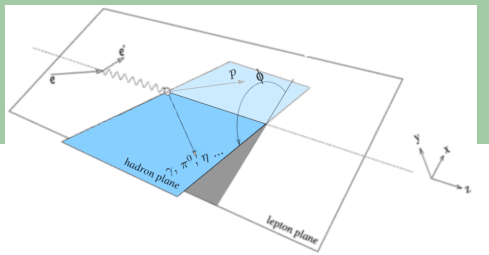
$$\delta_T^d = \int dx H_T^d(x,\xi,t=0)$$

- Density of transversity polarized quarks in an unpolarized proton in the transverse plane

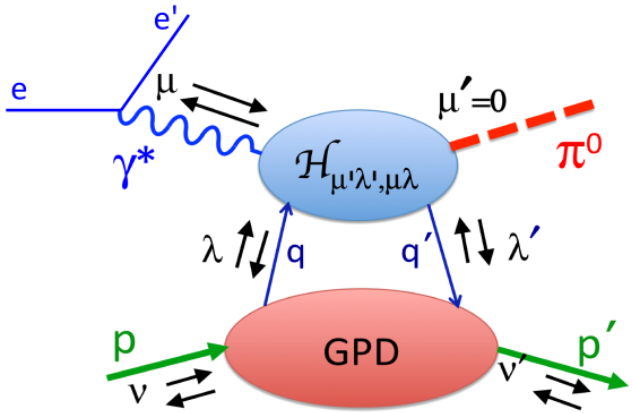
$$\delta(x,\vec{b}) = \frac{1}{2}[H(x,\vec{b}) - \frac{b_y}{m}\frac{\partial}{\partial b^2}\bar{E}_T(x,\vec{b})]$$



Access to the chiral-odd GPDs from experimental data



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



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

PHYSICAL REVIEW D **84,** 034007 (2011)

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

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THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Theoretical Physics

Transversity in hard exclusive electroproduction of pseudoscalar mesons

S.V. Goloskokov[1,a] and P. Kroll[2,3,b]

Goloskokov-Kroll model:

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

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

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

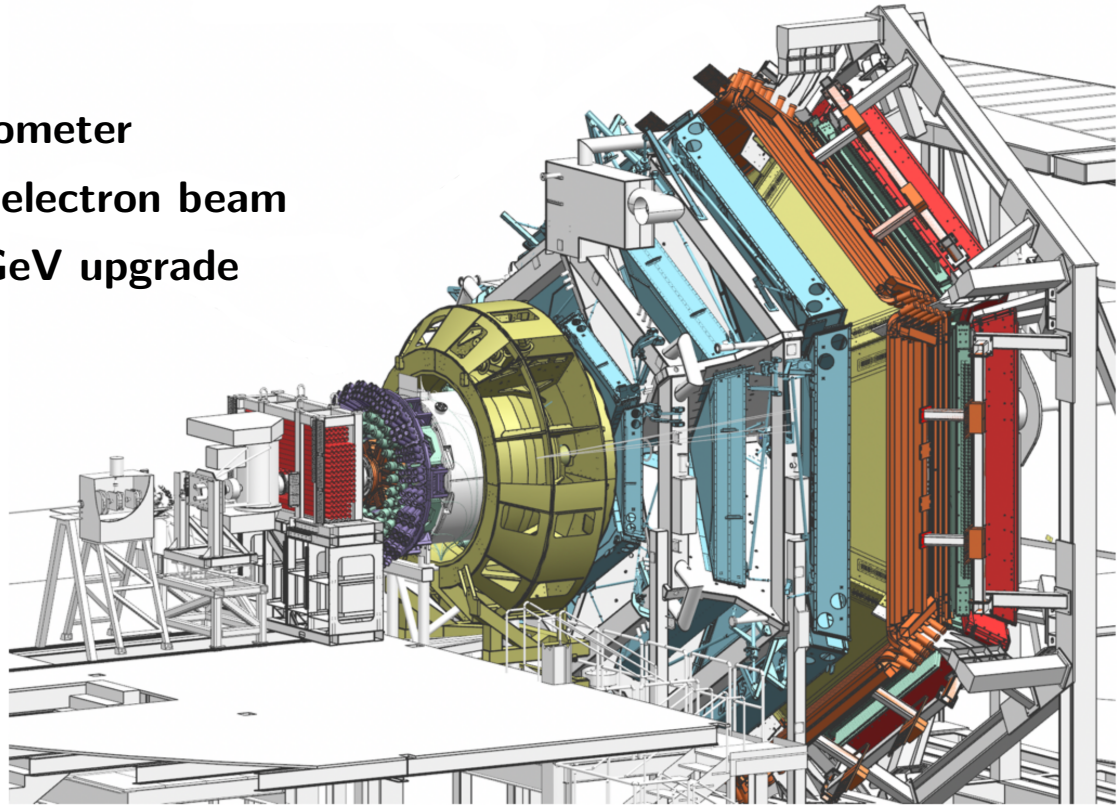
$$\sigma_{TT} \sim \frac{t'}{16m^2}\left|\langle\bar{E}_T\rangle\right|^2$$

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

CLAS12 First Experiment

V. Burkert et al., Nucl.Instrum.Meth.A 959 (2020) 163419

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

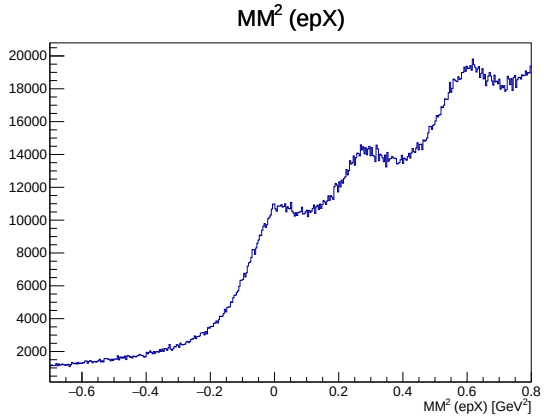


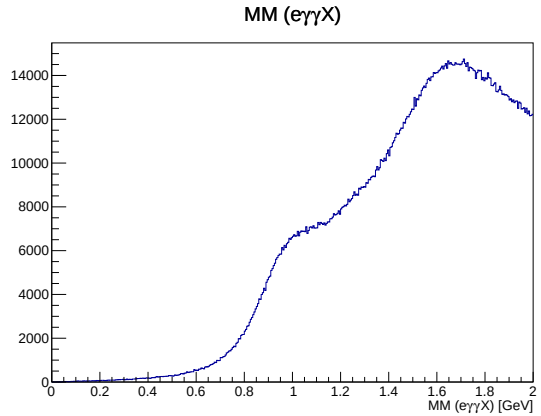
RGA fall 2018

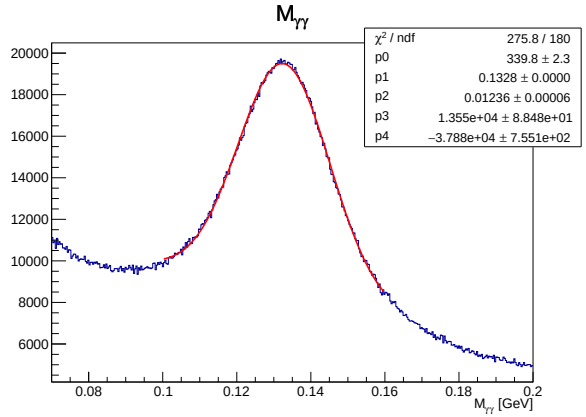
- **inbending:**
  - **174 runs**
  - **43.43 mC**
- **outbending:**
  - **185 runs**
  - **35.7 mC**

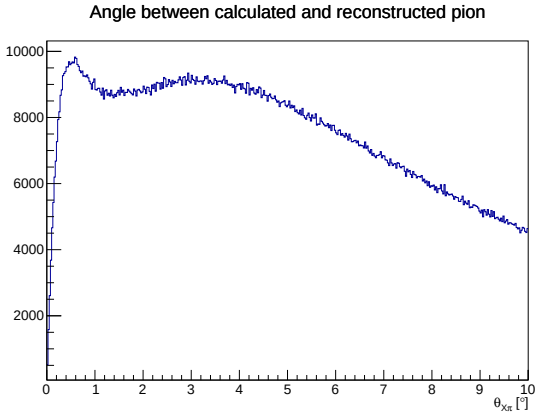
Exclusive distributions

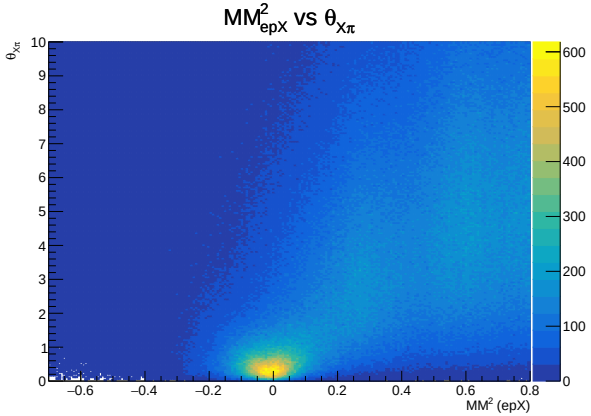
1. $e + p + \gamma + \gamma$ detected
2. loose π^0 mass cut









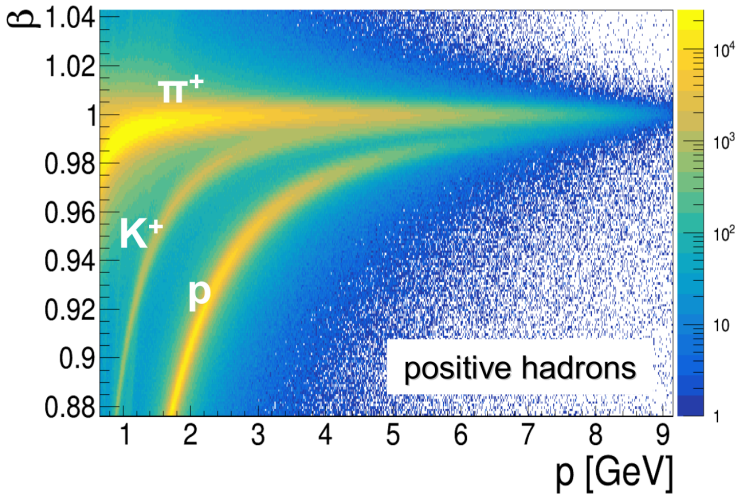


- The peaks for exclusive π^0 channels are visible but dominated by the background
- Invariant mass of two photons clearly shows the mass of the neutral pion and tighter cut of 3σ should be used to further improve selection

All cuts for exclusive π^0 electroproduction

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

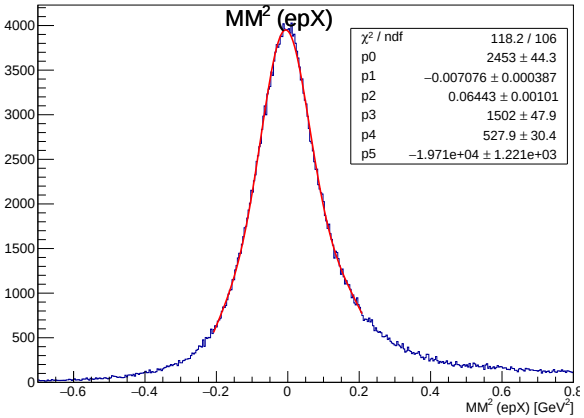
- **Electron (cuts based on RGA analysis note):**
  - Event Builder pid cut "pid==11"
  - NPHE cut
  - Vertex cut
  - DC fiducial cuts: region 1,2,3
  - EC fiducial cut
  - PCAL energy cut
  - EC sampling cut
- **Proton:**
  - Event Builder pid cut "pid==2212"
  - Δvertex cut
  - DC fiducial cuts: region 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 π^0 cut:**
  - $0.07 < M_{\gamma\gamma} < 0.2$ GeV

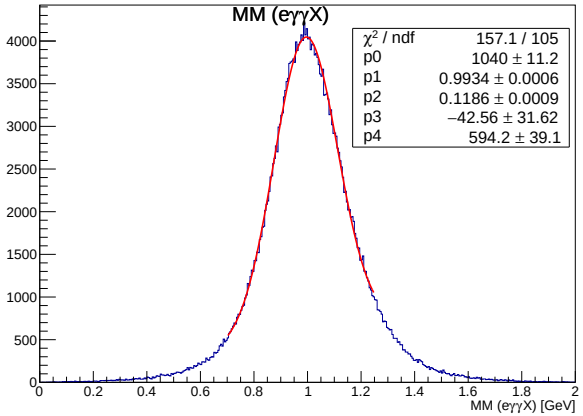


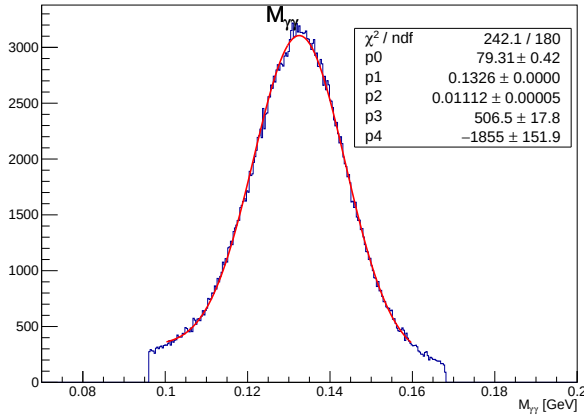
- **Exclusive cuts**
  - $|\Delta p_x| < 0.2$ GeV
  - $|\Delta p_y| < 0.2$ GeV
  - $\theta_{X\pi} < 2^\circ$
  - $MM^2(epX) < 0.5$ GeV^2
- **Tight π^0 cut:**
  - $0.096 < M_{\gamma\gamma} < 0.168$ GeV

Exclusive distributions

1. $e + p + \gamma + \gamma$ detected | 2. tight π^0 mass cut | 3. $|\Delta p_x| < 0.2$ GeV and $|\Delta p_y| < 0.2$ GeV | 3. $\theta_{X\pi} < 2^\circ$

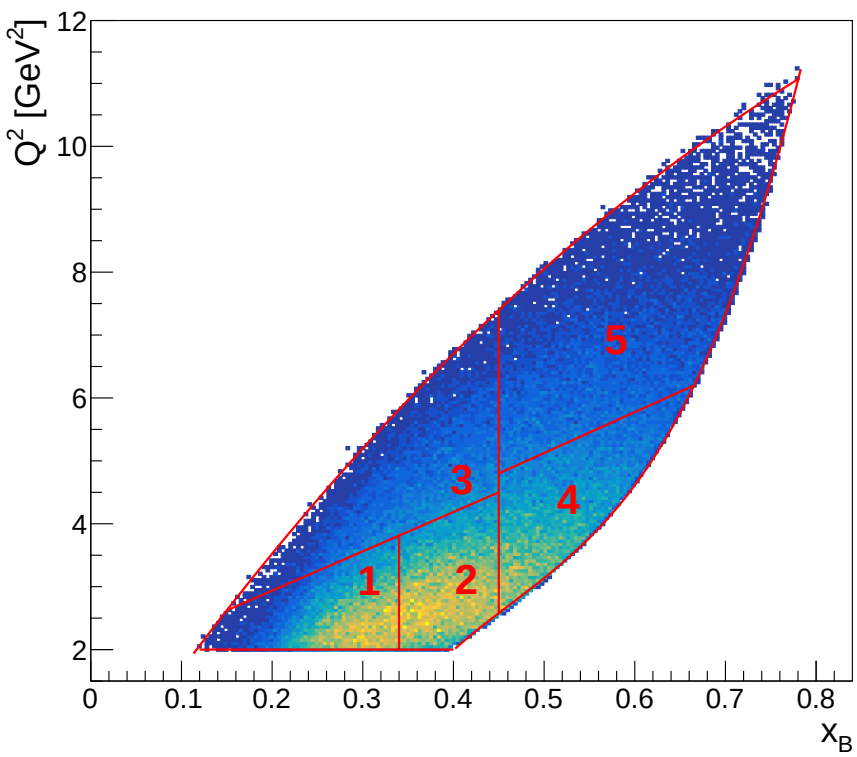


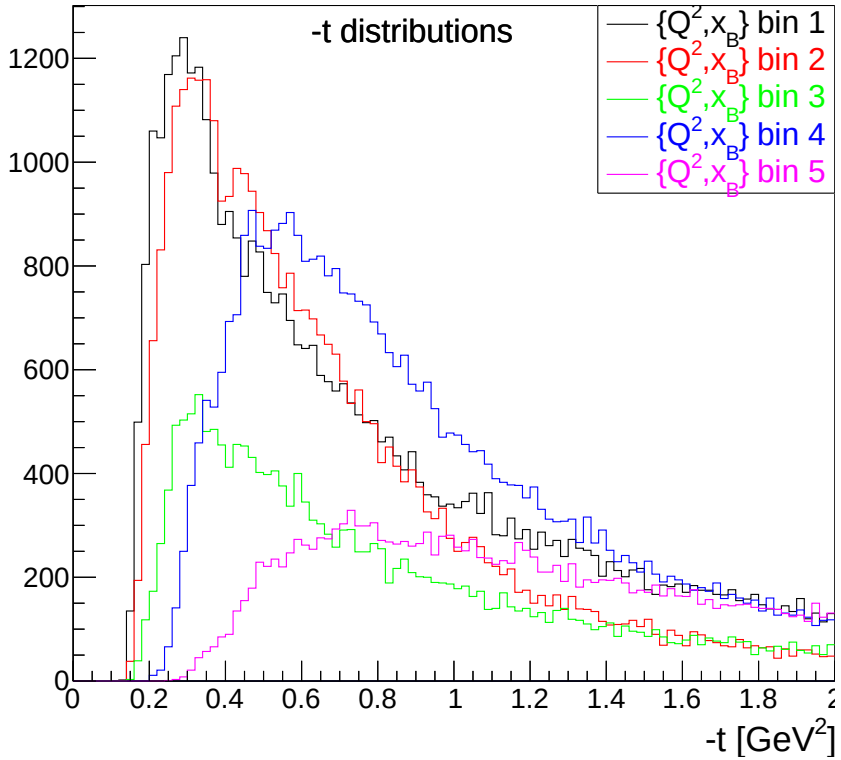




- With missing transverse momentum cuts and $\theta_{X\pi}$ cut exclusive peaks become very clean

Multidimensional binning



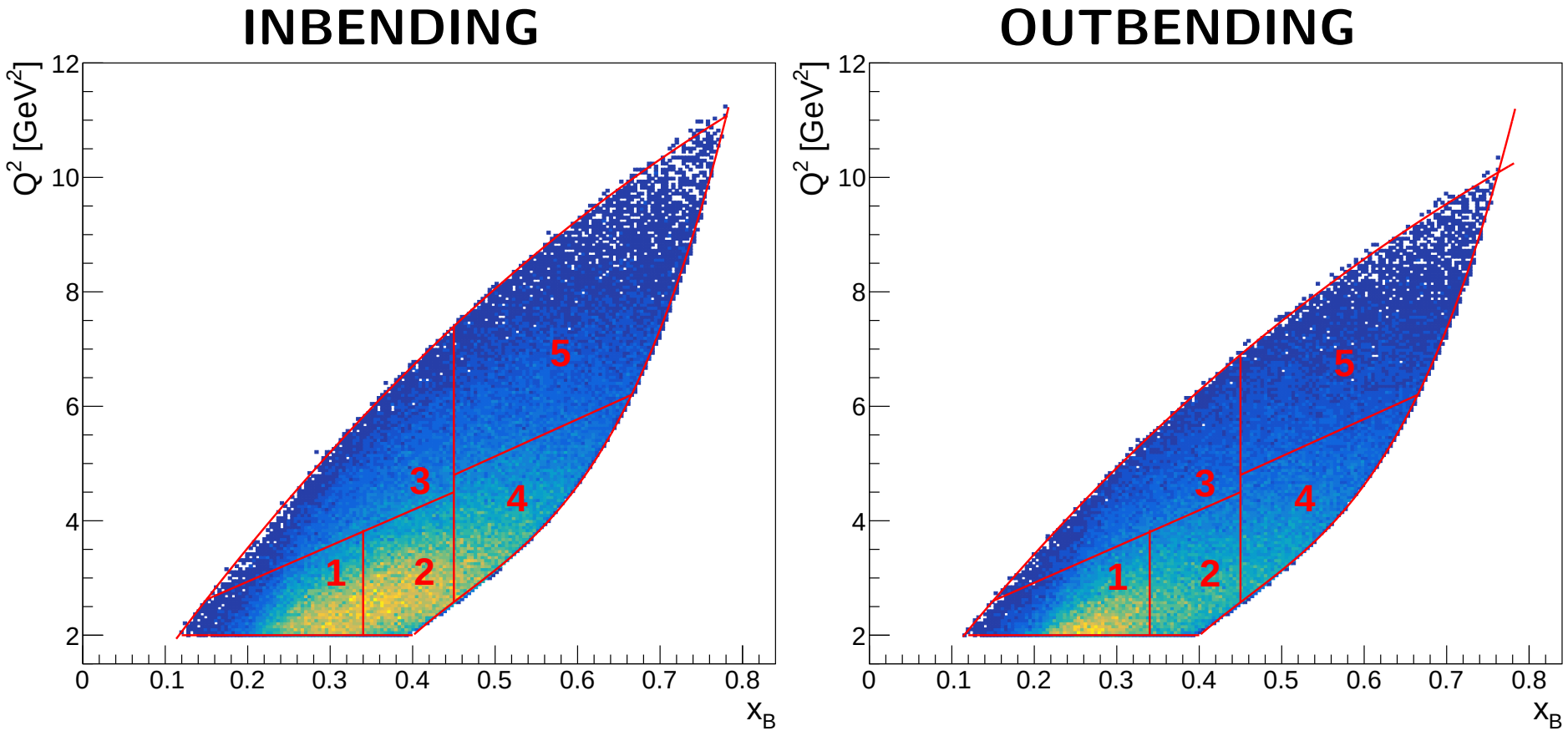


DIS cuts: $Q^2 > 2$ GeV^2 and $W > 2$ GeV

- 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 ϕ bins

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

Kinematic coverage for different torus configurations



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

Beam spin asymmetry

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

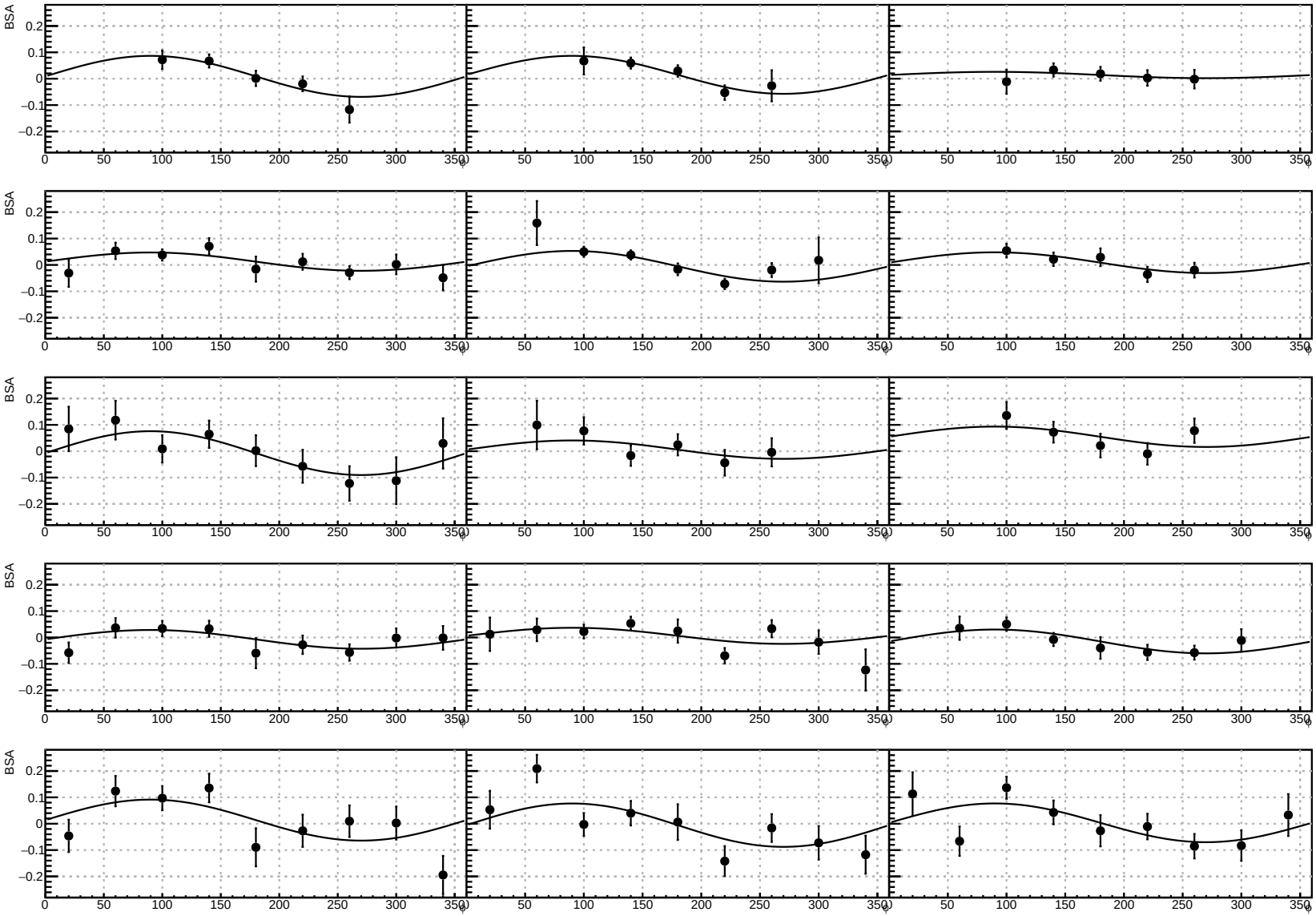
where Pb_i is an electron beam polarization for run periods and
n_i is the number of event after background subtraction

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

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

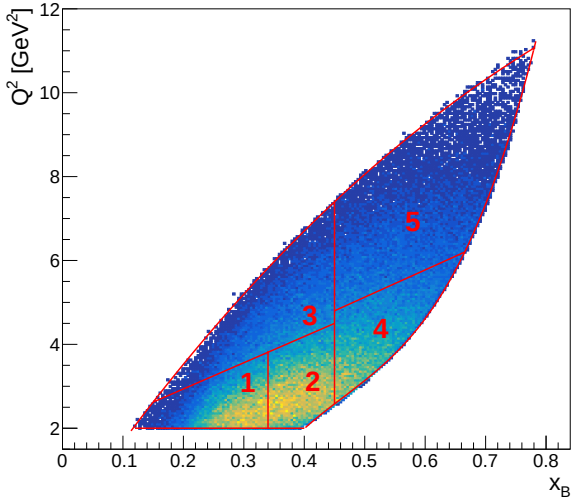
$$A_{LU}^{\sin\phi} = \sqrt{2\epsilon(1-\epsilon)}\frac{\sigma_{LT'}^{\sin\phi}}{\sigma_0}$$

Preliminary BSA from CLAS12 first experiment data [inbending]



Preliminary $\frac{\sigma_{LT'}}{\sigma_0}$ for Deeply Virtual π^0 Production from CLAS12 first experiment data

- beam spin asymmetry (BSA) extracted for **5** Q^2, x_B bins with FD proton
- the ratio $\frac{\sigma_{LT'}}{\sigma_0}$ can be extracted from BSA by dividing on $\sqrt{2\epsilon(1-\epsilon)}$
- the results are compared with Goloskokov-Kroll model calculations

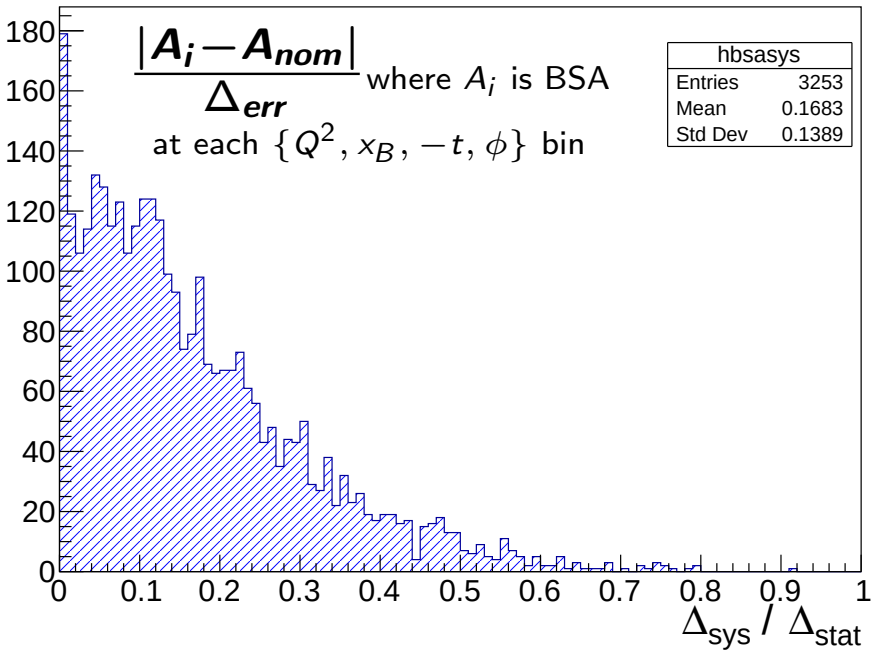


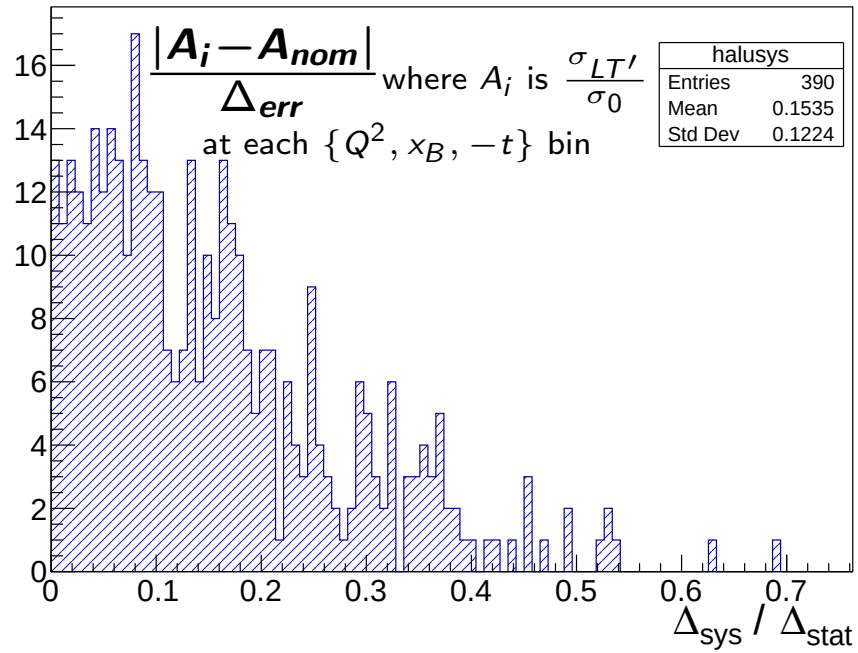
Systematic study of exclusive events selection

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

- 3 ΔP_x x 3 ΔP_y x 3 ΔP_x variations = **27 combinations**
- 27 BSA values extracted for each kinematic bin
- For each kinematic bin the systematic uncertainty is estimated as:

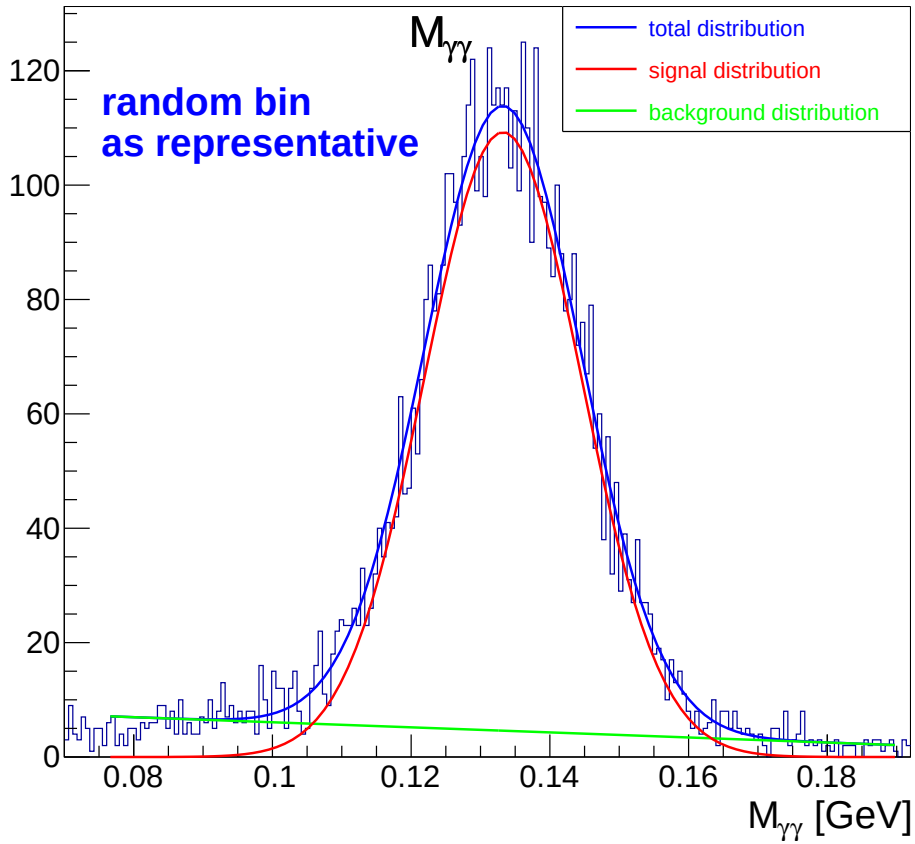
$$\Delta_{sys} = max(|\boldsymbol{A}_1 - \boldsymbol{A_{nom}}|, \ldots, |\boldsymbol{A}_{27} - \boldsymbol{A_{nom}}|)$$





Background treatment

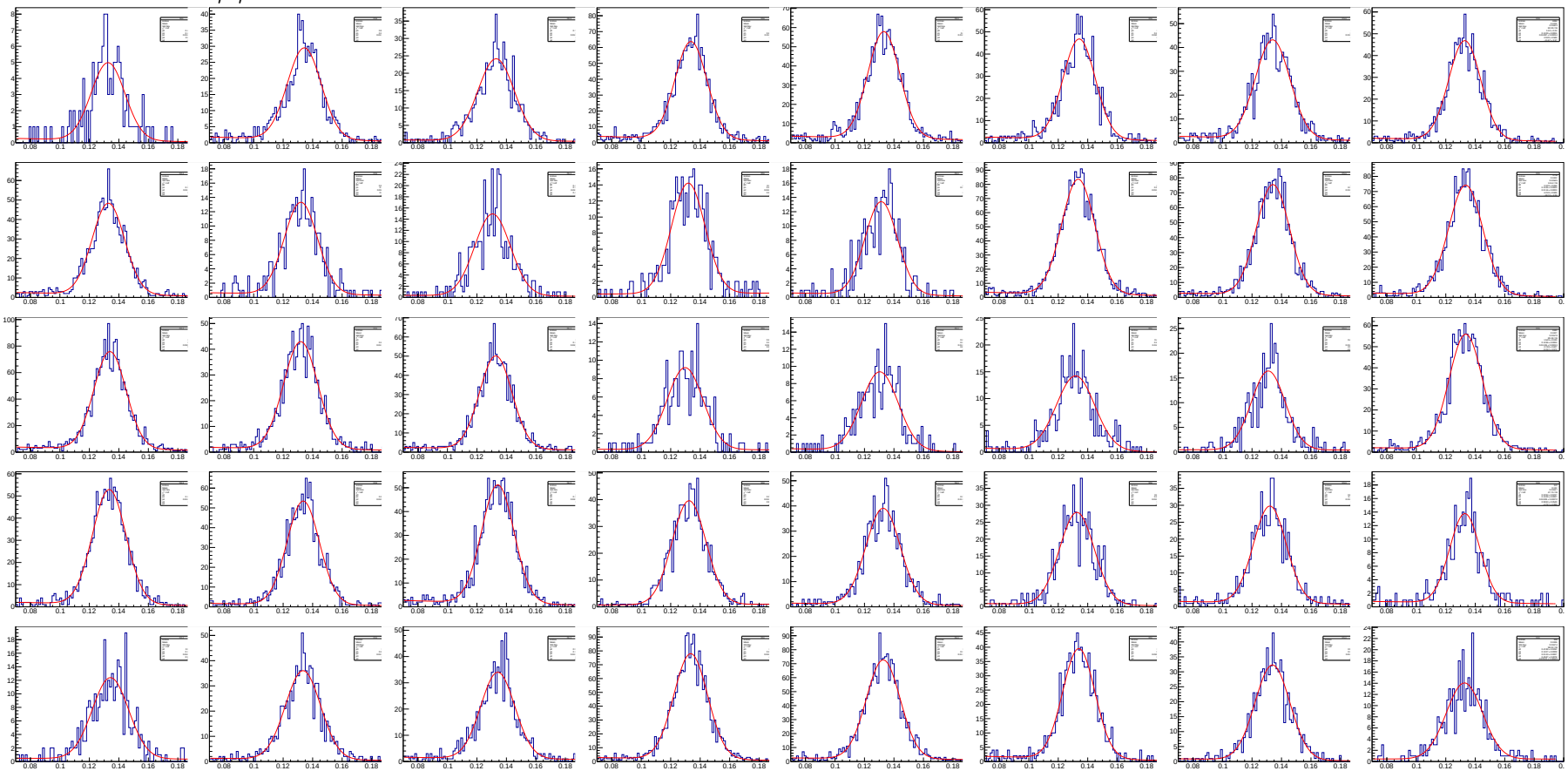
- **Background subtraction using invariant mass of two photons:**
  1. Sideband subtraction, assuming linear bebackground, counting events:
     - $|M_{\gamma\gamma} - 0.135| < 3\sigma$ as signal
     - $3\sigma < |M_{\gamma\gamma} - 0.135| < 5\sigma$ as background
  2. Fitting the peak and extracting the gaussian integral/error as signal



Bin by bin background subtraction

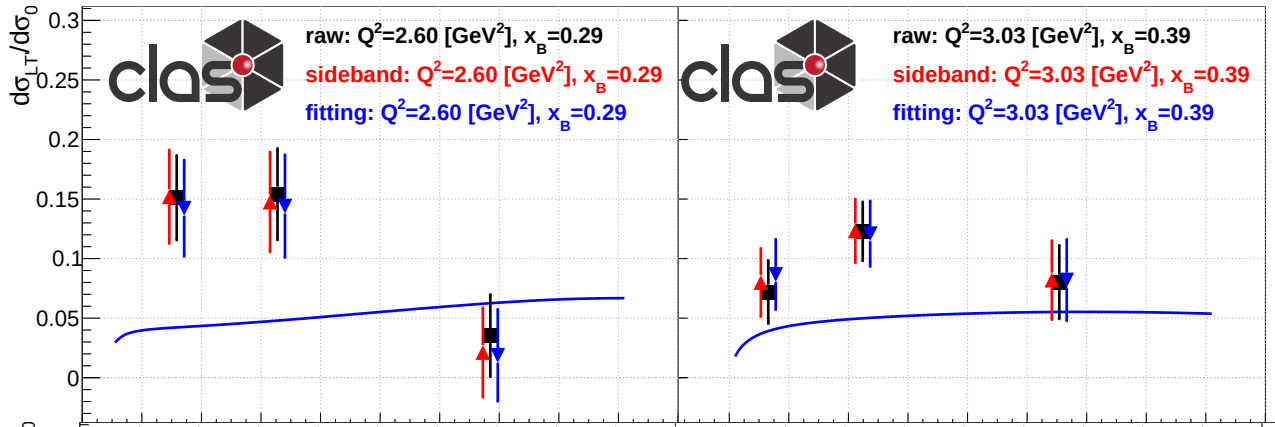
$$\left.\begin{array}{ll} 5 & \{Q^2, x_B\} \\ 3 & \{-t\} \\ 9 & \{\phi\} \\ 2 & \textbf{helicities} \end{array}\right\} \; 270 \textbf{ bins total}$$

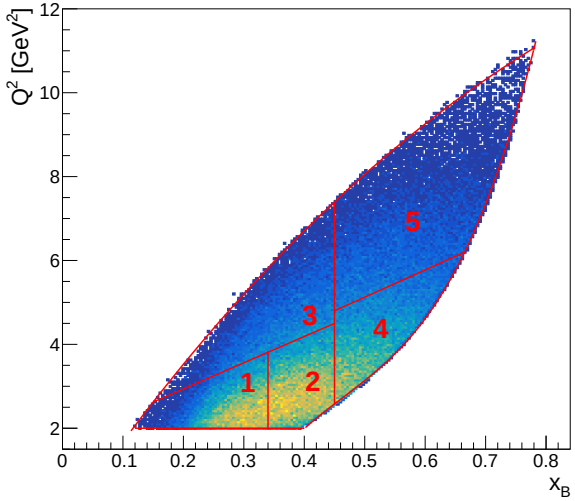
First 40 $M_{\gamma\gamma}$ distributions:

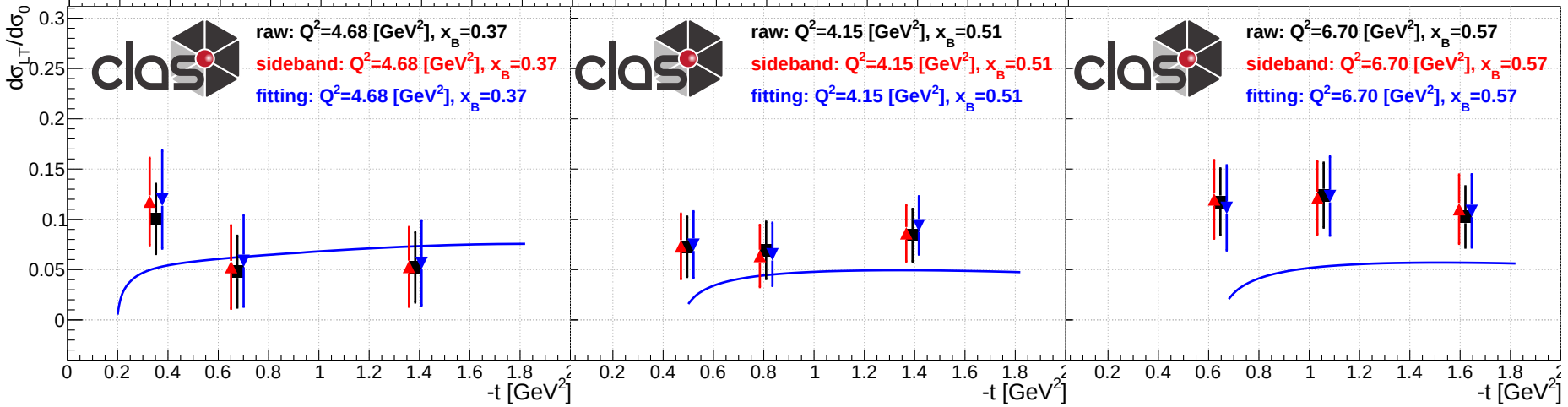


Systematic study of different background subtractions

- black points are results without subtraction at all
- difference between red and green points come from different BG treatments
- the difference is very small = **systematic uncertainty of BG subtraction**



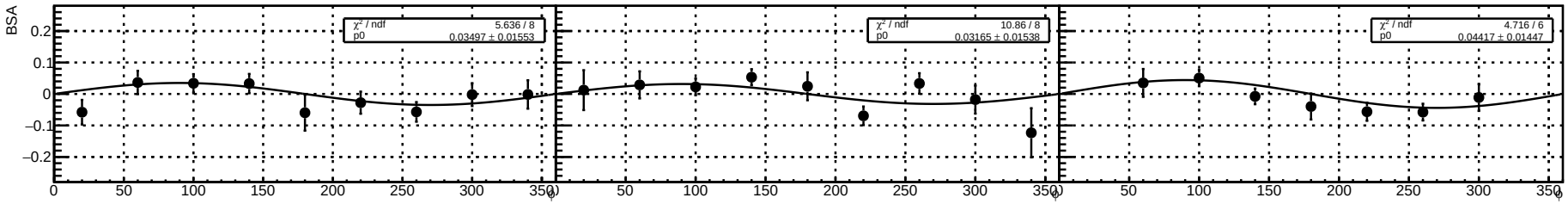




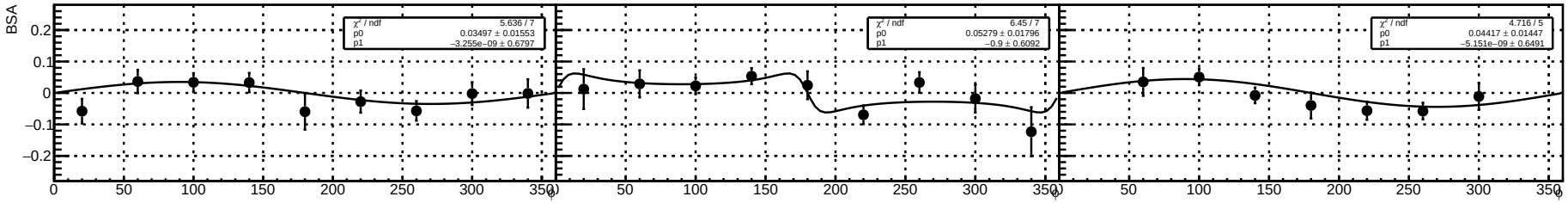
Systematic study of different fit functions

$3 < -t >$ bins for $< Q^2, x_B >$ bin 4 are shown below with different fit functions:

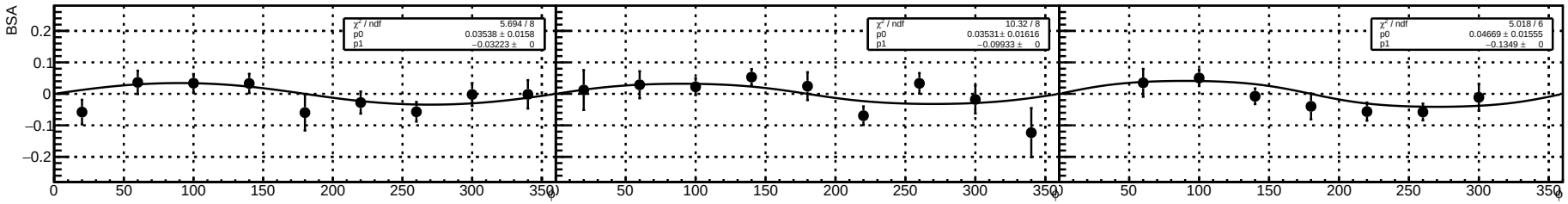
$f = \alpha \sin\phi$



$f = \frac{\alpha \sin\phi}{1+\beta \cos 2\phi}$, free α and β parameters, $0 < \beta < 1$

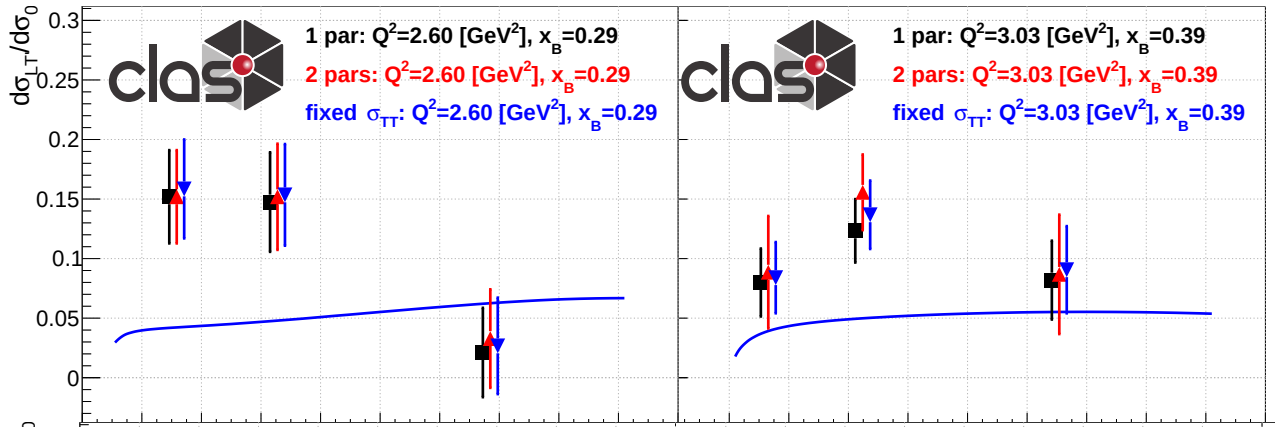


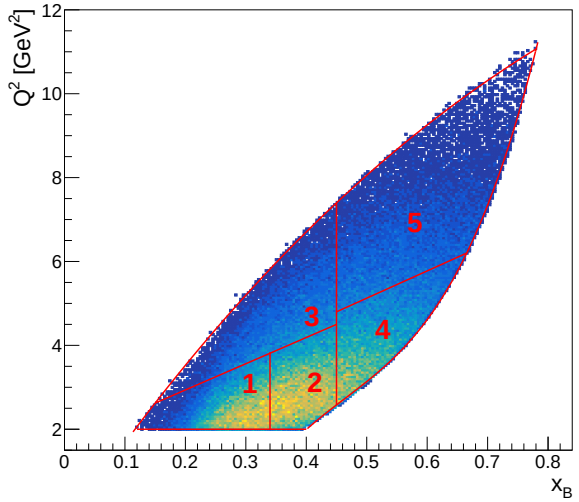
$f = \frac{\alpha \sin\phi}{1+\beta \cos 2\phi}$, β fixed using GK model calculations

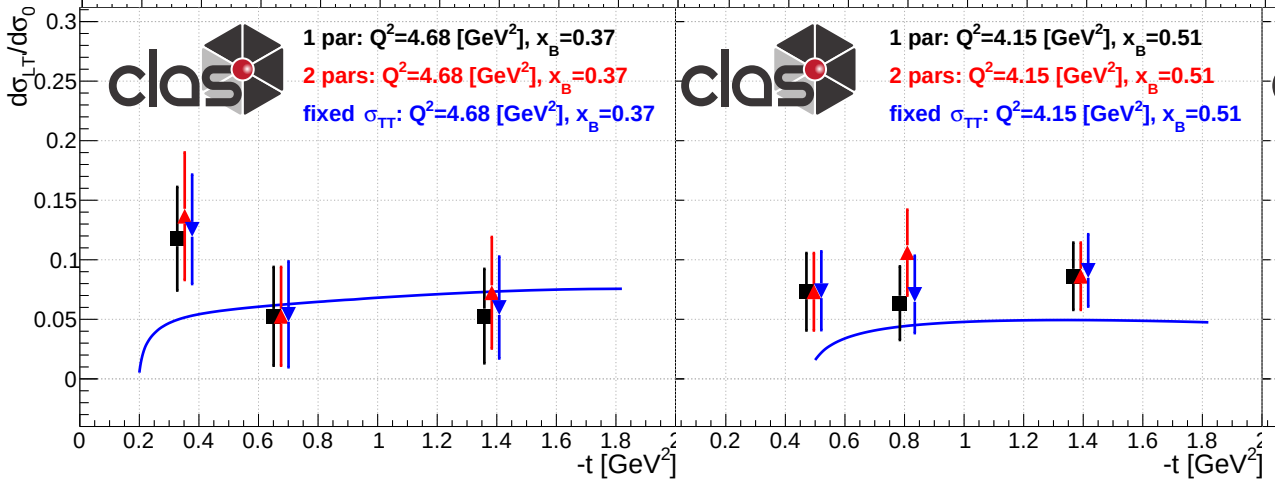


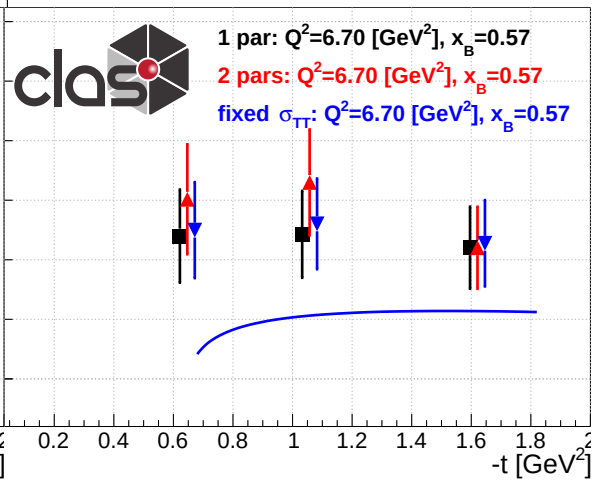
Systematic study of different fit functions

- the only non-negligible difference is observed at one kinematic bin
- the difference is still smaller than statistical error
- the fixed σ_{TT} version is the final version





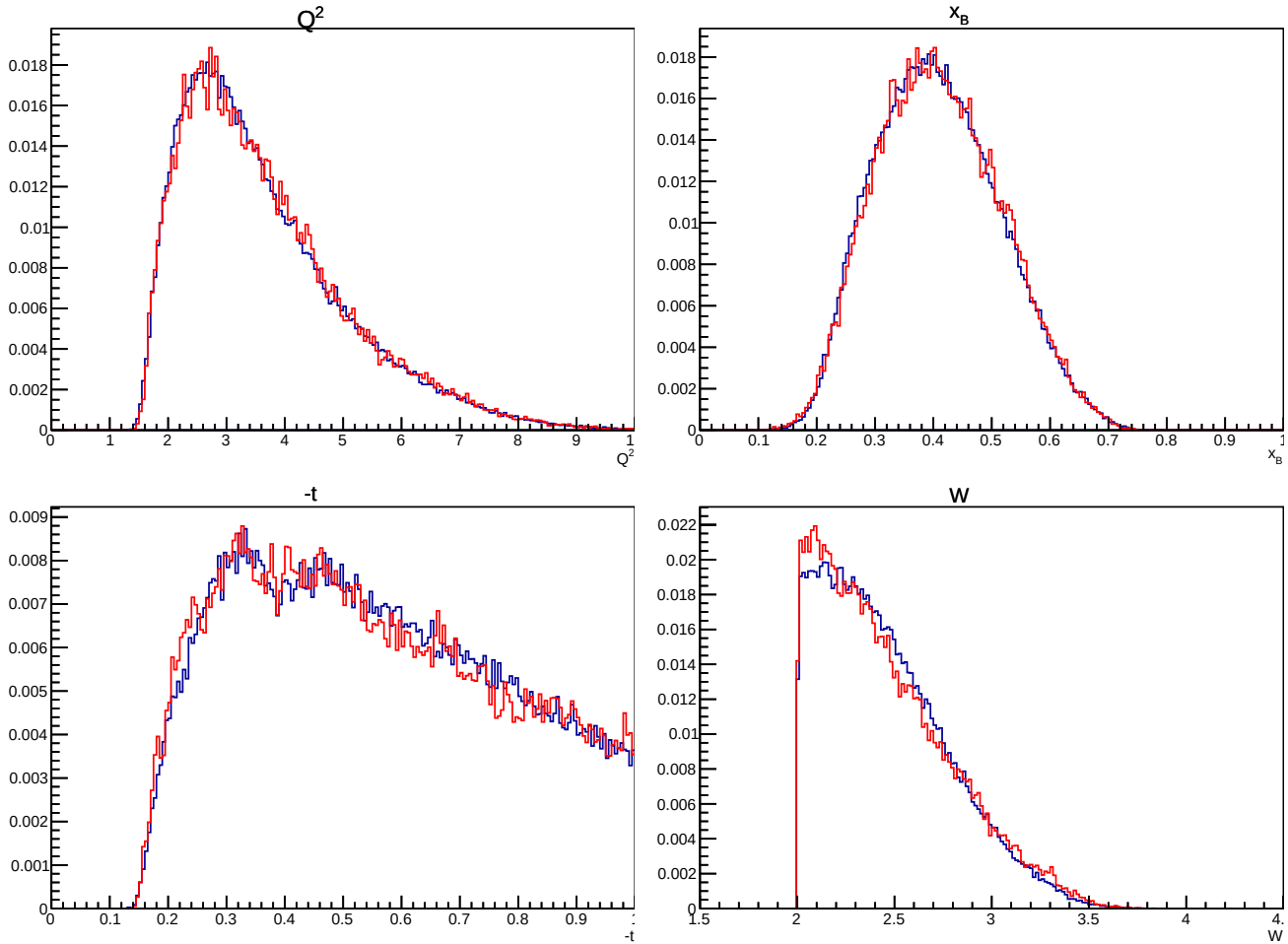




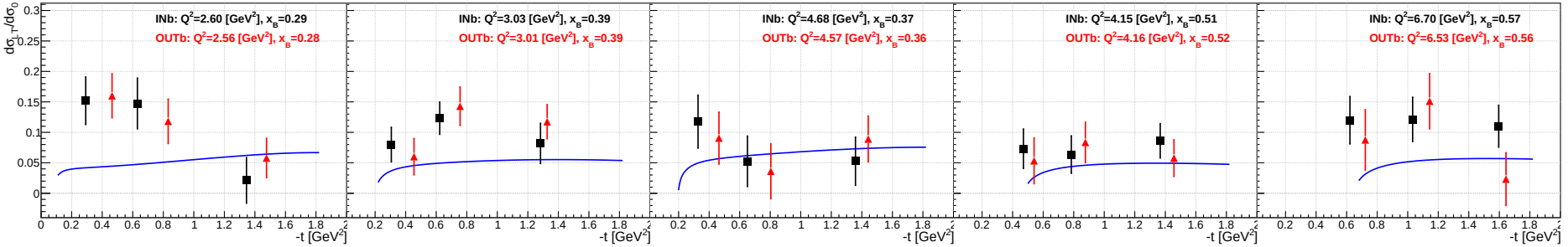
Systematic study of acceptance effects using Monte-Carlo simulation

MC
DATA

- The study of acceptance effects are **in progress** using Monte-Carlo simulation
- The generator driven by CLAS6 data and GK theoretical model is available
- MC sample provides reasonable kinematic coverage with experimental data



GPDs insight

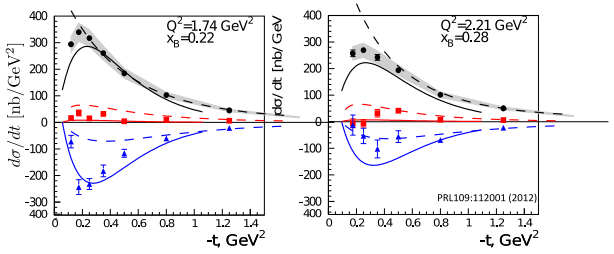


$$\sigma_{LT'} \sim \xi\sqrt{1-\xi^2}\,\frac{\sqrt{-t'}}{2m}\,\mathrm{Im}\left[\langle \boldsymbol{H_T}\rangle^*\langle\tilde{\boldsymbol{E}}\rangle\right]$$

Unpolarized cross section

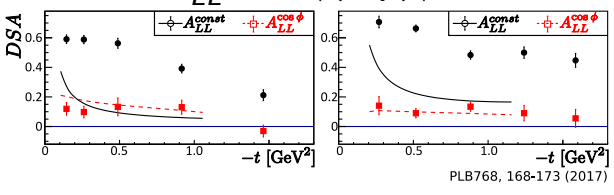
$$\sigma_T \sim (1-\xi^2)\,|\langle \boldsymbol{H_T}\rangle|^2 - \frac{t'}{8m^2}\,|\langle \bar{\boldsymbol{E}}_T\rangle|^2$$

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



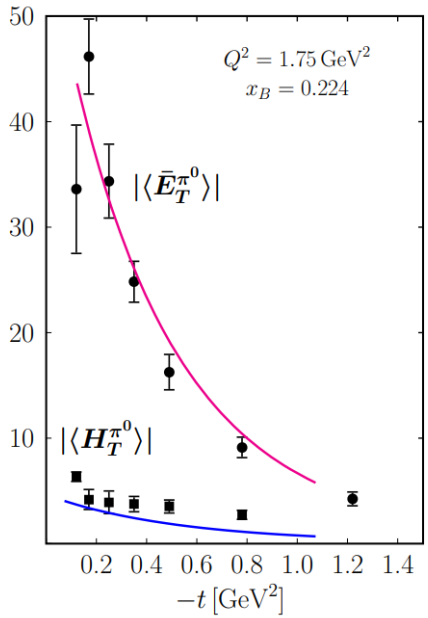
Double Spin Asymmetry

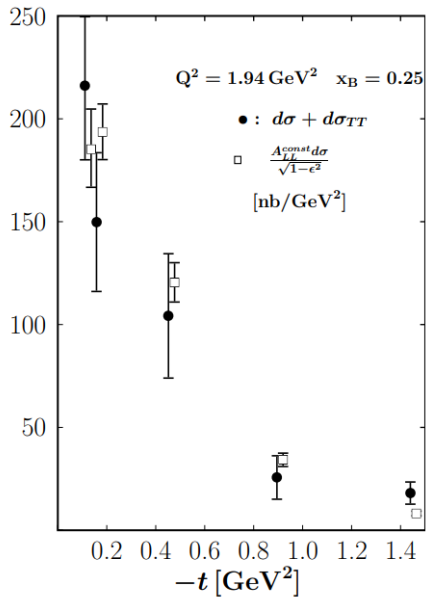
$$A_{LL}^{const} \sim |\langle \boldsymbol{H_T}\rangle|^2$$



H_T is underestimated in GK model

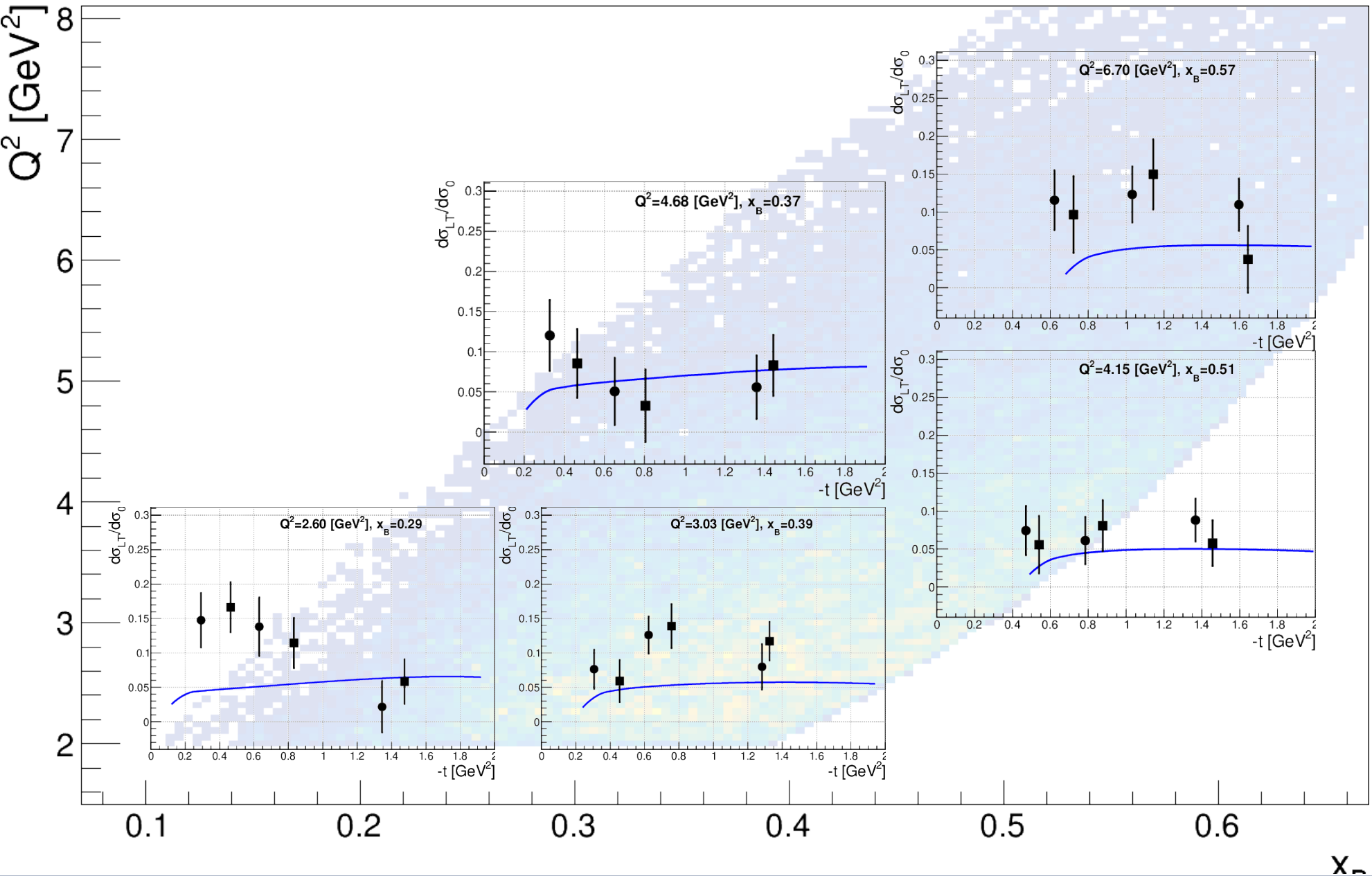
$$A_{LL}^{const} \sim |\langle \boldsymbol{H_T}\rangle|^2$$





Few-Body Syst 57, 1041–1050 (2016)

Preliminary $\frac{\sigma_{LT'}}{\sigma_0}$ for Deeply Virtual π^0 Production from CLAS12 first experiment data



Summary

- CLAS12 and polarized electron beam enables the extraction of BSA moments for exclusive π^0 electroproduction and extends our reach to the higher Q^2 kinematic regions
- The GK theoretical model calculations are available, and support sensitivity to chiral-odd GPD H_T
- Monte Carlo simulation study is in progress and soon to be finalized: event generator driven by CLAS6 data is available and provide reasonable agreement with experimental data. **Estimate: by mid April 2021.**
- Momentum corrections to be finalized. **Estimate: by April 2021.**
- Analysis note in preparation **Estimate: by June 2021.**

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