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

International workshop on CLAS12 physics
and future perspectives at JLab

March 22, 2023

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(University of Connecticut)

Generalized Parton Distributions (GPDs)

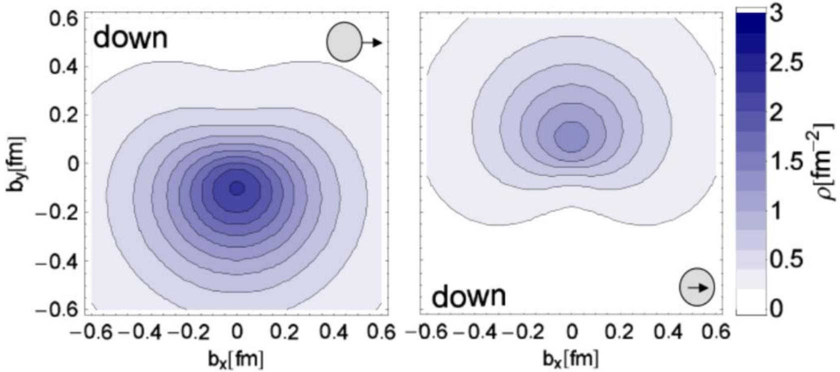
		Quark polarization		
		U	L	T
Nucleon polarization	U	H		$\bar{E}_T$
	L		$\tilde{H}$	
	T	E		$H_T, \tilde{H}_T$

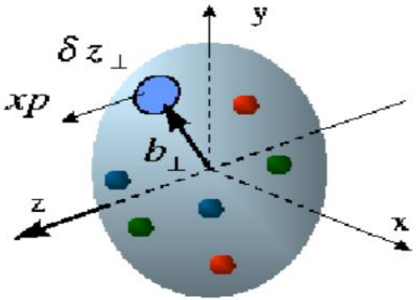
Chiral-odd GPD results:

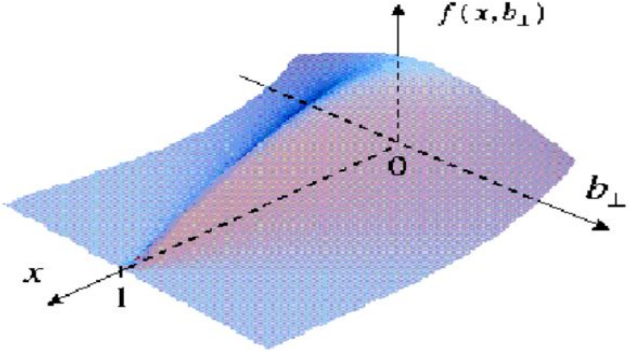
- Deeply virtual meson production
- Lattice QCD by Göckeler *et al*

Chiral even GPDs:

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







- 4 chiral-even GPDs: H, E, $\tilde{H}$, $\tilde{E}$
- 4 chiral-odd GPDs: H_T, E_T, $\tilde{H}_T$, $\tilde{E}_T$

	Meson	GPD flavor composition
$\tilde{H}$, $\tilde{E}$ / H_T, $\bar{E}_T$	π^+	$\Delta u - \Delta d$
	π^0	$2\Delta u + \Delta d$
	η	$2\Delta u - \Delta d$
H, E	ρ^0	$2u + d$
	ρ^+	$u - d$
	ω	$2u - d$

PDFs:

in the forward limit

$\xi = t = 0$:

$$H^q(x,0,0) = q(x)$$
$$\tilde{H}^q(x,0,0) = \Delta q(x)$$

Form Factors:

$$\int dx H^q(x,\xi,t) = F_1(t)$$
$$\int dx E^q(x,\xi,t) = F_2(t)$$
$$\int dx \tilde{H}^q(x,\xi,t) = G_A(t)$$
$$\int dx \tilde{E}^q(x,\xi,t) = G_P(t)$$

X. Ji, Phys. Rev. Lett. 78, 610 (1997):

$$J^q = \int x dx \left[H^q(x,\xi,0) + E^q(x,\xi,0)\right]$$

- Proton anomalous tensor magnetic moment

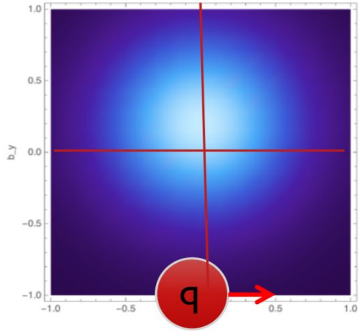
$$\kappa_T^u = \int dx \bar{E}_T^u(x,\xi,t=0)$$
$$\kappa_T^d = \int dx \bar{E}_T^d(x,\xi,t=0)$$

- Proton tensor charge

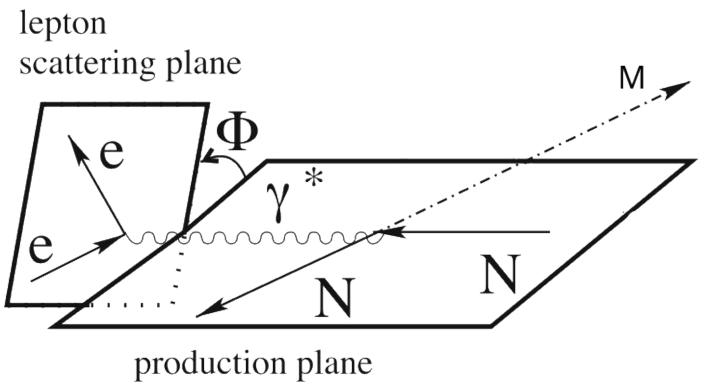
$$\delta_T^u = \int dx H_T^u(x,\xi,t=0)$$
$$\delta_T^d = \int dx H_T^d(x,\xi,t=0)$$

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

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



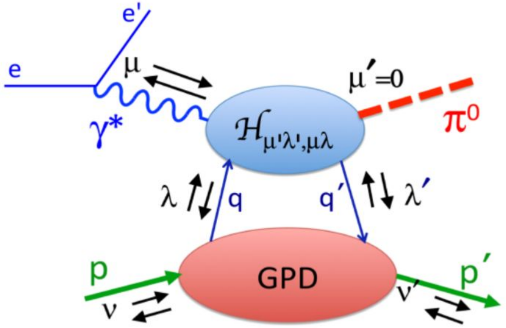
Experimental observables for exclusive meson production



$$\frac{d^4\sigma}{dQ^2\, dx_B\, dt\, d\Phi} = \Gamma(Q^2, x_B, E) \frac{1}{2\pi}\left\{\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} + \epsilon\frac{d\sigma_{TT}}{dt}\cos(2\Phi) + \sqrt{\epsilon(2\epsilon+1)}\frac{d\sigma_{LT}}{dt}\cos(\Phi) + \lambda\sqrt{2\epsilon(1-\epsilon)}\frac{d\sigma_{LT'}}{dt}\sin(\Phi)\right\}$$

where λ is the helicity state of the incident electron beam

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



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

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

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

Gary R. Goldstein,[1,*] J. Osvaldo Gonzalez Hernandez,[2,†] and Simonetta Liuti[2,‡]
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[2]*Department of Physics, University of Virginia, Charlottesville, Virginia 22901, USA*
(Received 16 February 2011; published 5 August 2011)

Goloskokov-Kroll model:

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

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

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

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

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

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

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Theoretical Physics

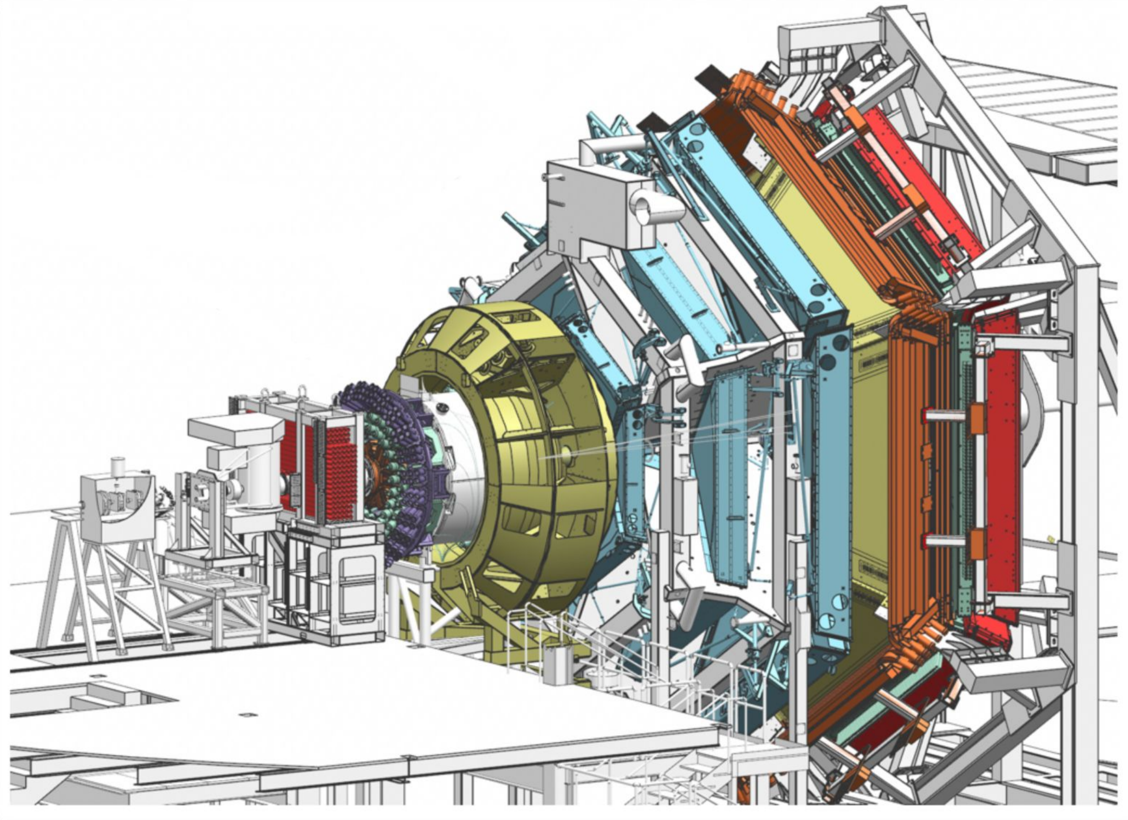
Transversity in hard exclusive electroproduction of pseudoscalar mesons

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

CLAS12 and exclusive π^0 production

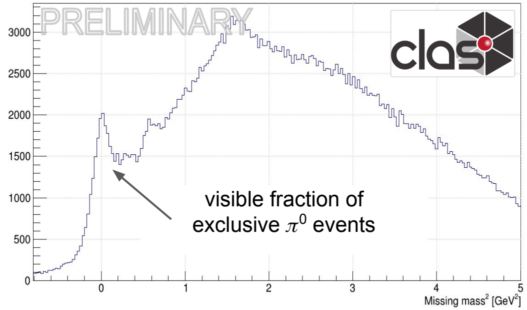
- CEBAF Large Acceptance Spectrometer
- First CLAS experiment since 12 GeV upgrade
- 10.6 GeV longitudinally polarized electron beam
- 86 % electron beam polarization
- Unpolarized liquid hydrogen fixed target
- Access to the Q^2 up to 10 GeV^2

$$ep \rightarrow e+p+\pi^0 \rightarrow e+p+\gamma+\gamma$$



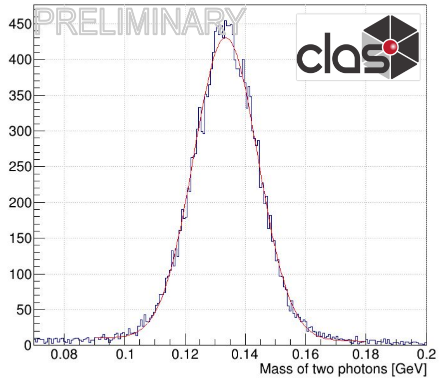
Exclusive π^0 selection

Raw $MM^2(epX)$ distribution

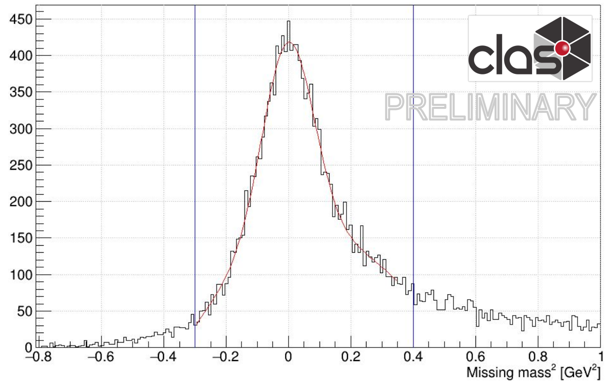


- All final state particle detected: electron, proton, two photons
- Reconstructed mass of two photons is used to identify π^0 candidates
- The momentum and energy conservation laws provide powerful constraints to suppress background: the plots show clear exclusive sample after application of exclusivity cuts

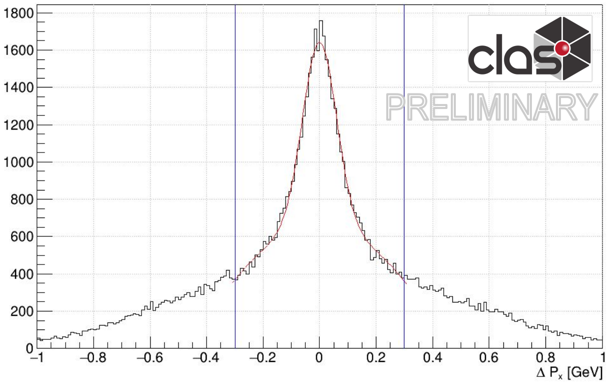
Mass of two photons



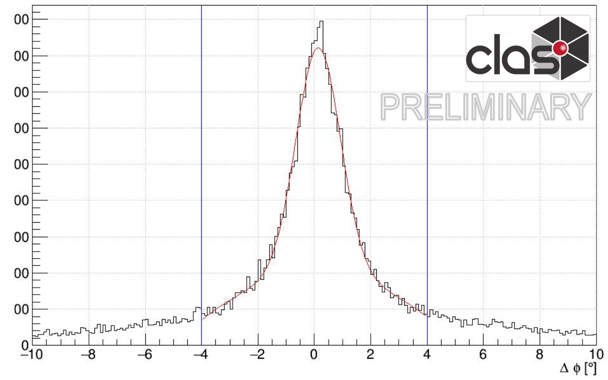
Missing mass^2 for ($ep \rightarrow epX$)



ΔP_x for ($ep \rightarrow ep\pi^0X$)



$\Delta\phi_{\pi X} = \phi_\pi - \phi_{epX}$

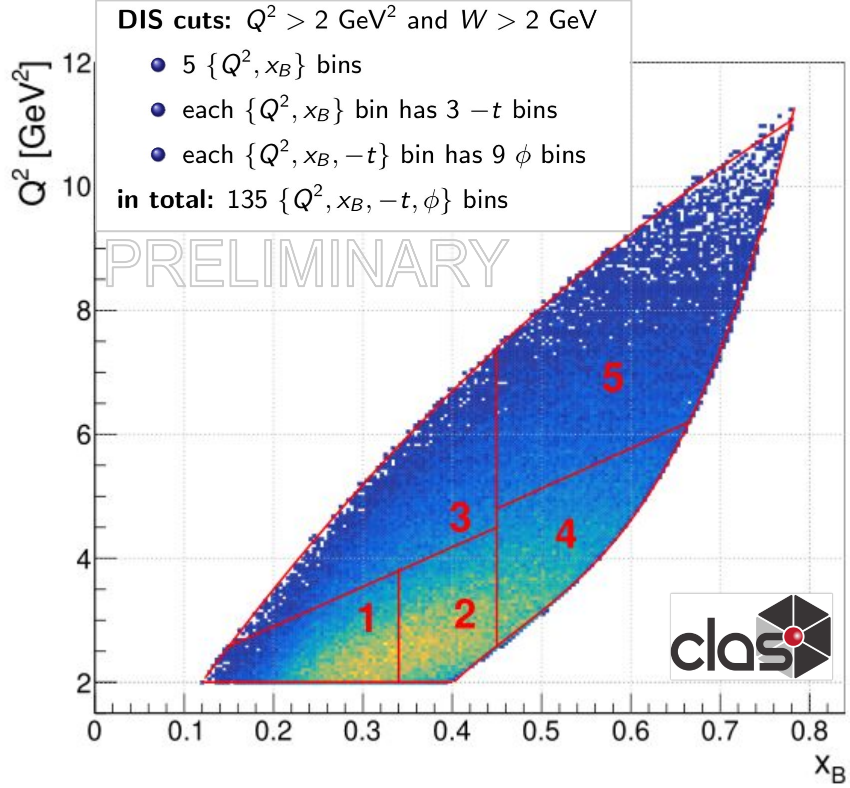


Exclusive π^0 kinematic coverage

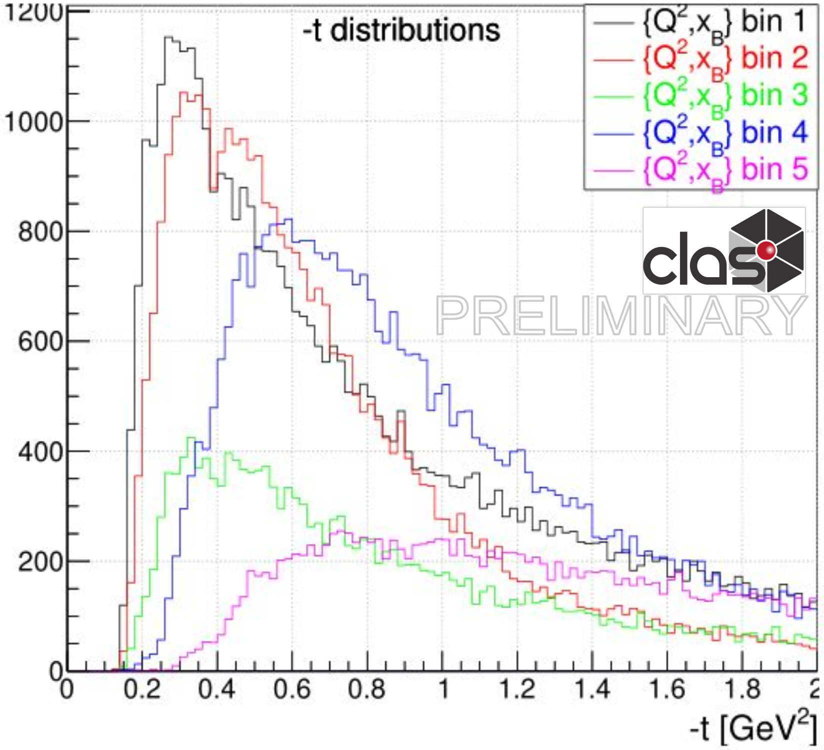
DIS cuts: $Q^2 > 2$ GeV^2 and $W > 2$ GeV

- 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 ϕ bins

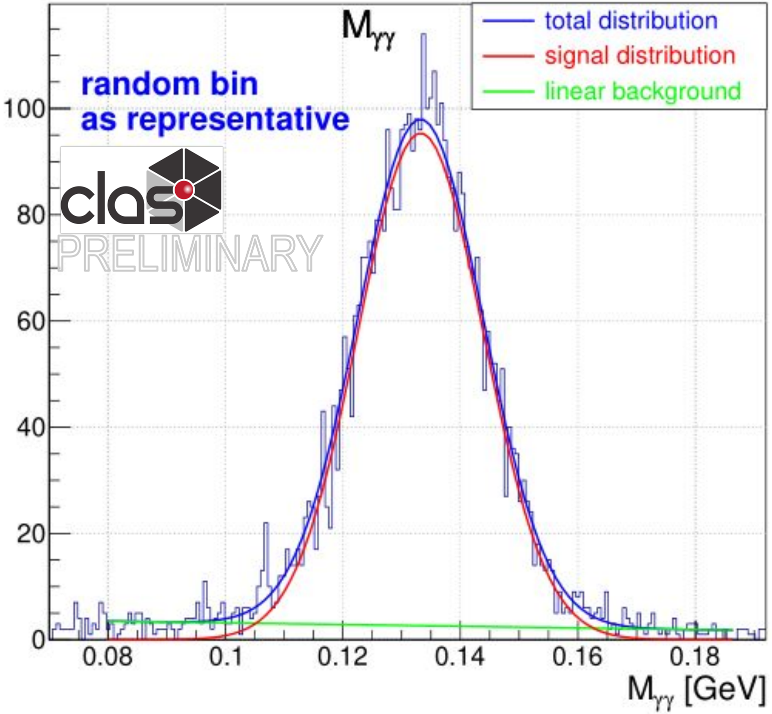
in total: 135 $\{Q^2, x_B, -t, \phi\}$ bins



(a) Q^2 vs x_B coverage

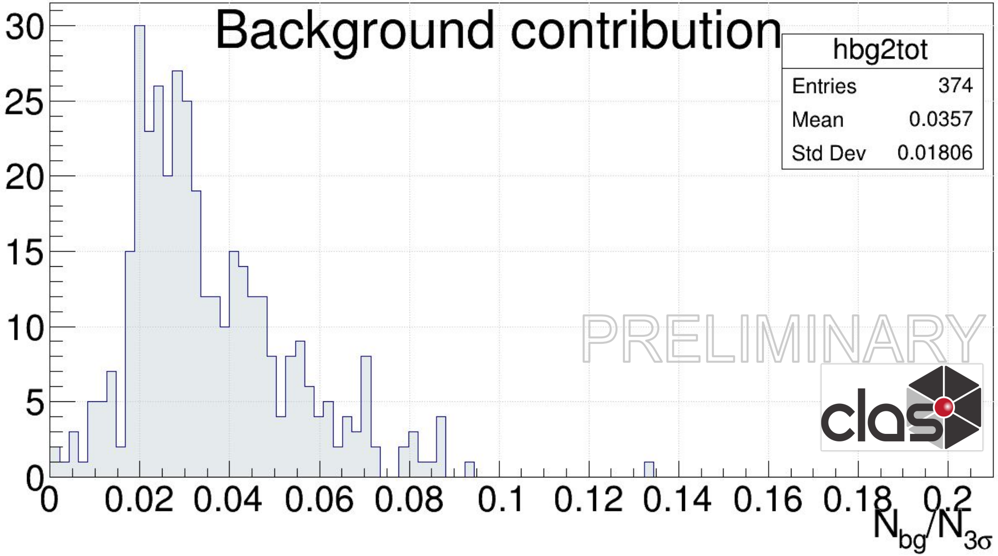


(b) $-t$ distributions for each $\{Q^2, x_B\}$ bin



Sideband background subtraction:

$$N_{signal} = N_{3\sigma} - N_{bg}$$



Exclusive π^0 Beam Spin Asymmetry

$$\mathrm{BSA} = \frac{1}{P_b}\frac{n^+ - n^-}{n^+ + n^-},$$

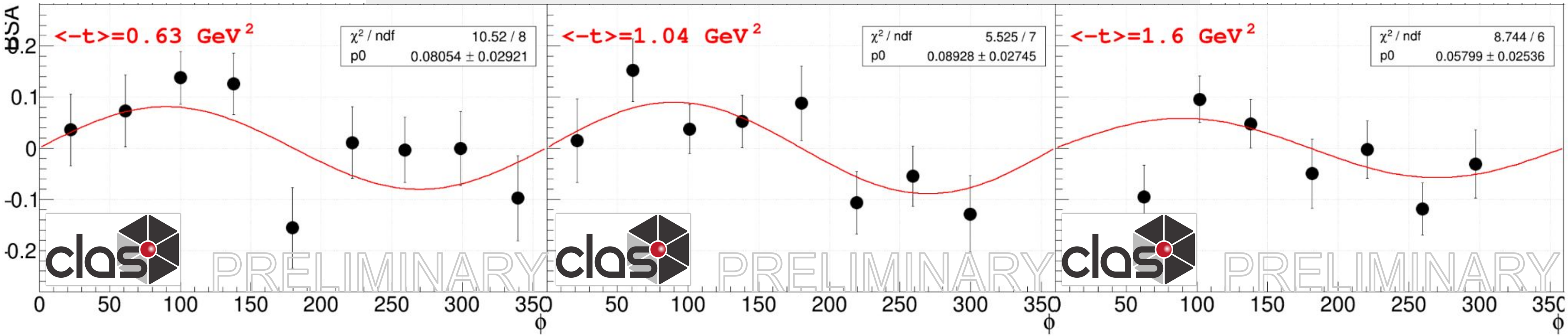
where P_b is an average electron beam polarization

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

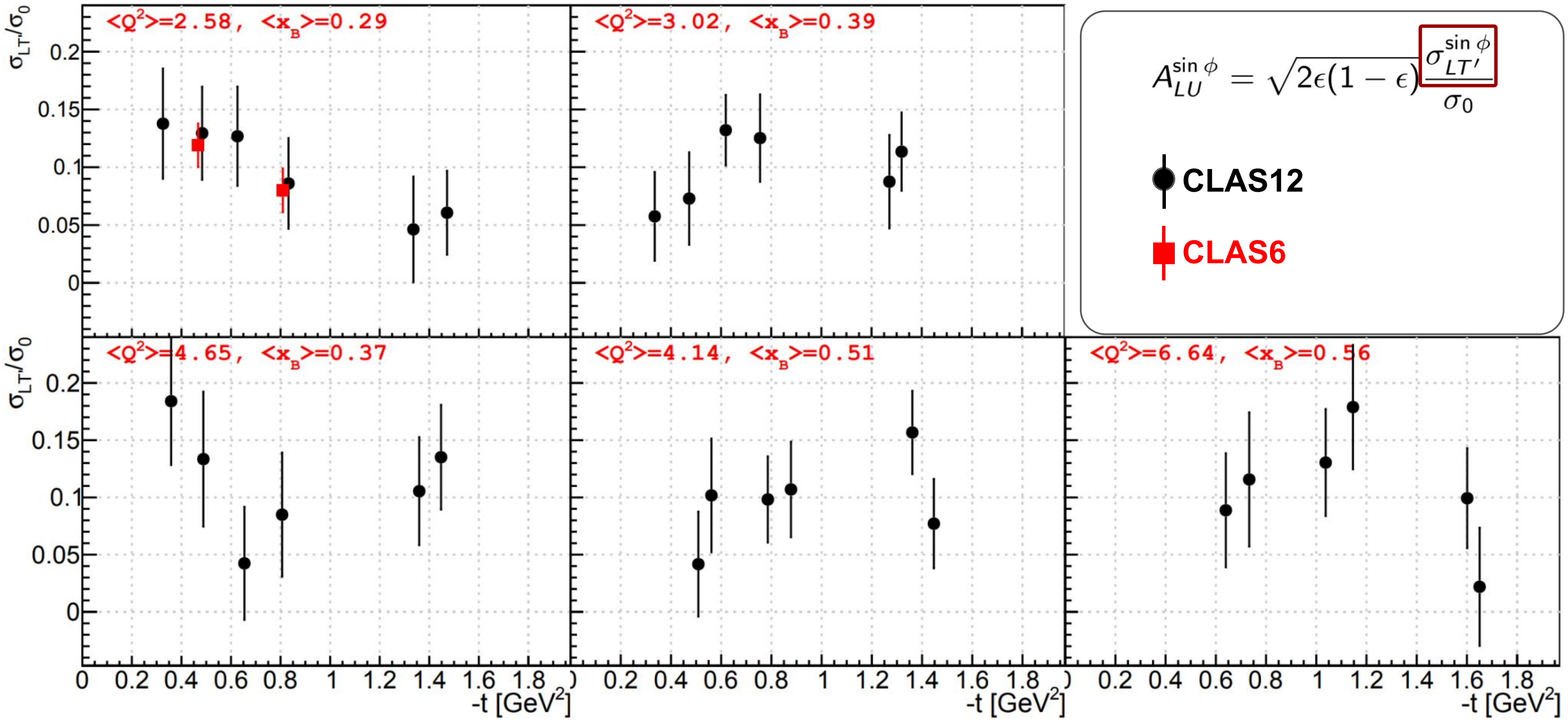
$$BSA = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} \propto A_{LU}^{\sin\phi}\sin\phi$$

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

Beam spin asymmetries for 3 <-t> bins in the 5th $\langle Q^2, x_B\rangle$ bin



Exclusive π^0 Beam Spin Asymmetry

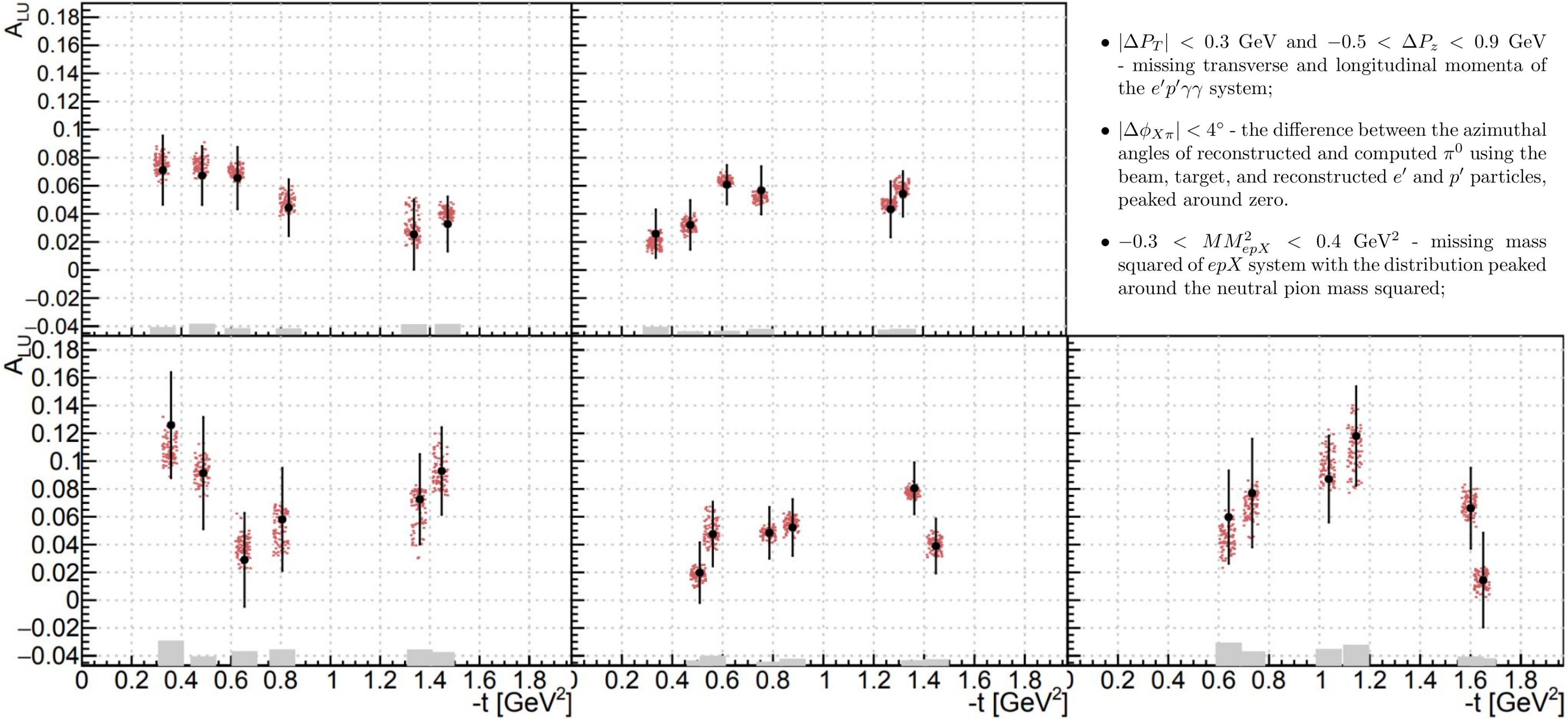


$$A_{LU}^{\sin\phi} = \sqrt{2\epsilon(1-\epsilon)}\frac{\sigma_{LT'}^{\sin\phi}}{\sigma_0}$$

CLAS12

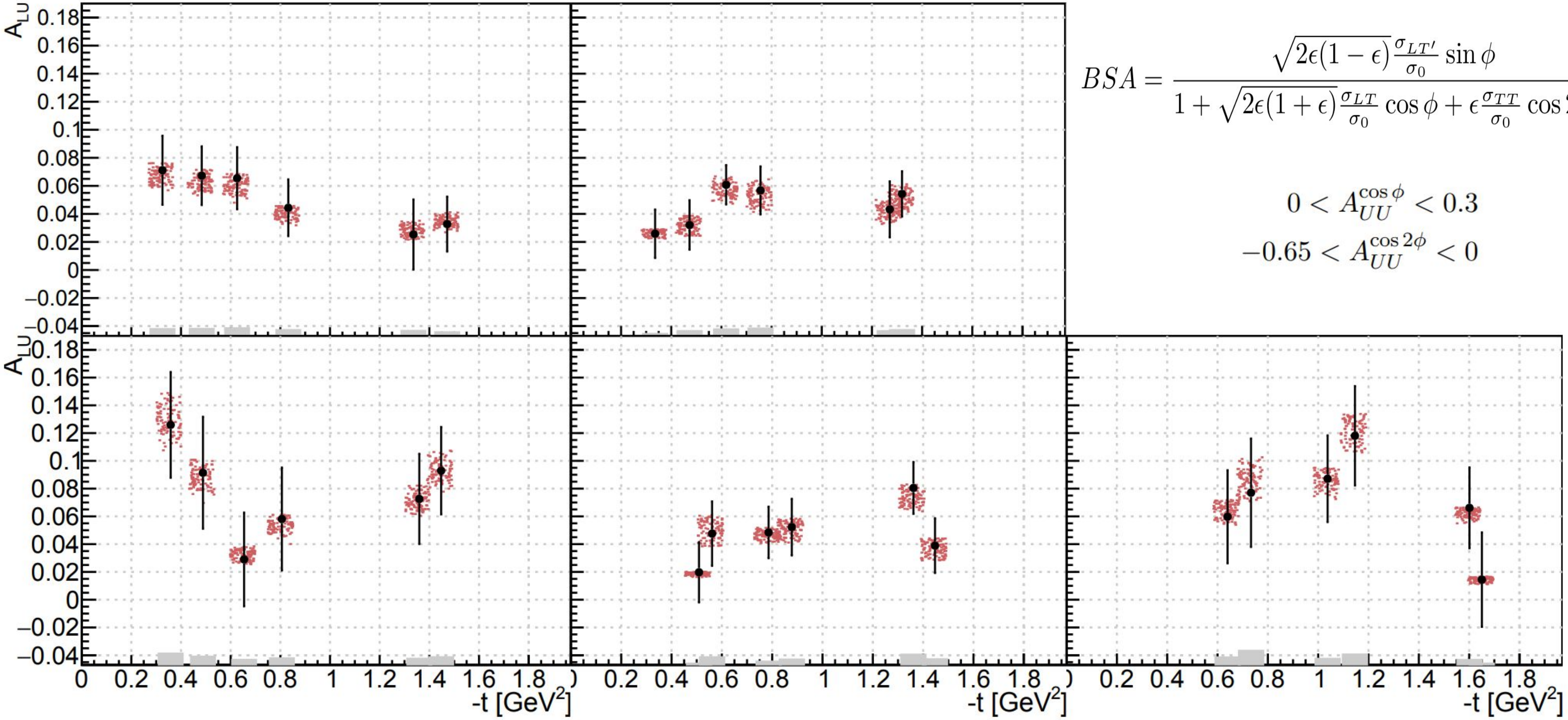
CLAS6

Systematics: exclusive selection



- $|\Delta P_T| < 0.3$ GeV and $-0.5 < \Delta P_z < 0.9$ GeV - missing transverse and longitudinal momenta of the $e'p'\gamma\gamma$ system;
- $|\Delta\phi_{X\pi}| < 4°$ - the difference between the azimuthal angles of reconstructed and computed π^0 using the beam, target, and reconstructed e' and p' particles, peaked around zero.
- $-0.3 < MM^2_{epX} < 0.4$ GeV^2 - missing mass squared of epX system with the distribution peaked around the neutral pion mass squared;

Systematics: fitting function

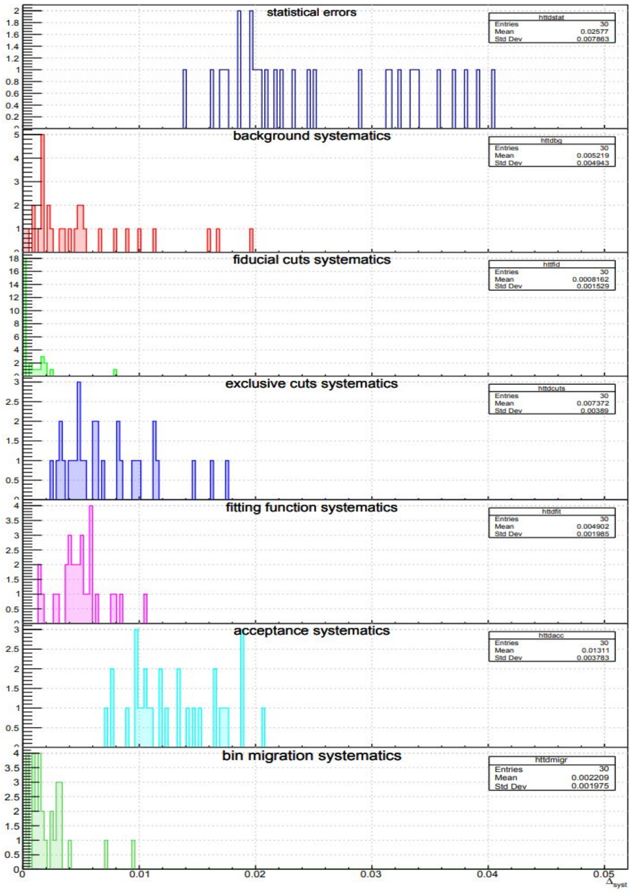


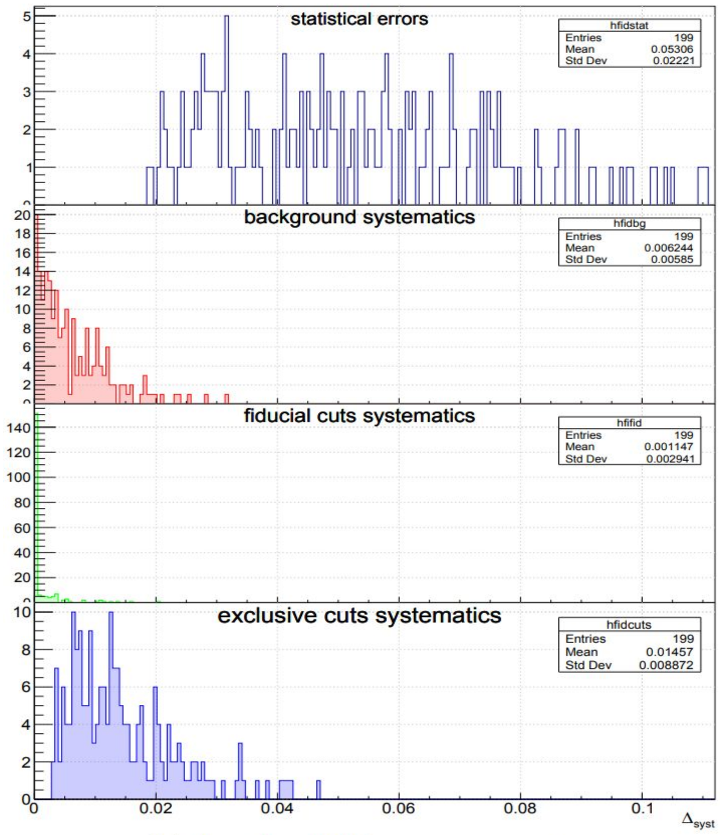
$$BSA = \frac{\sqrt{2\epsilon(1-\epsilon)}\frac{\sigma_{LT'}}{\sigma_0}\sin\phi}{1+\sqrt{2\epsilon(1+\epsilon)}\frac{\sigma_{LT}}{\sigma_0}\cos\phi+\epsilon\frac{\sigma_{TT}}{\sigma_0}\cos 2\phi}$$

$$0 < A_{UU}^{\cos\phi} < 0.3$$

$$-0.65 < A_{UU}^{\cos 2\phi} < 0$$

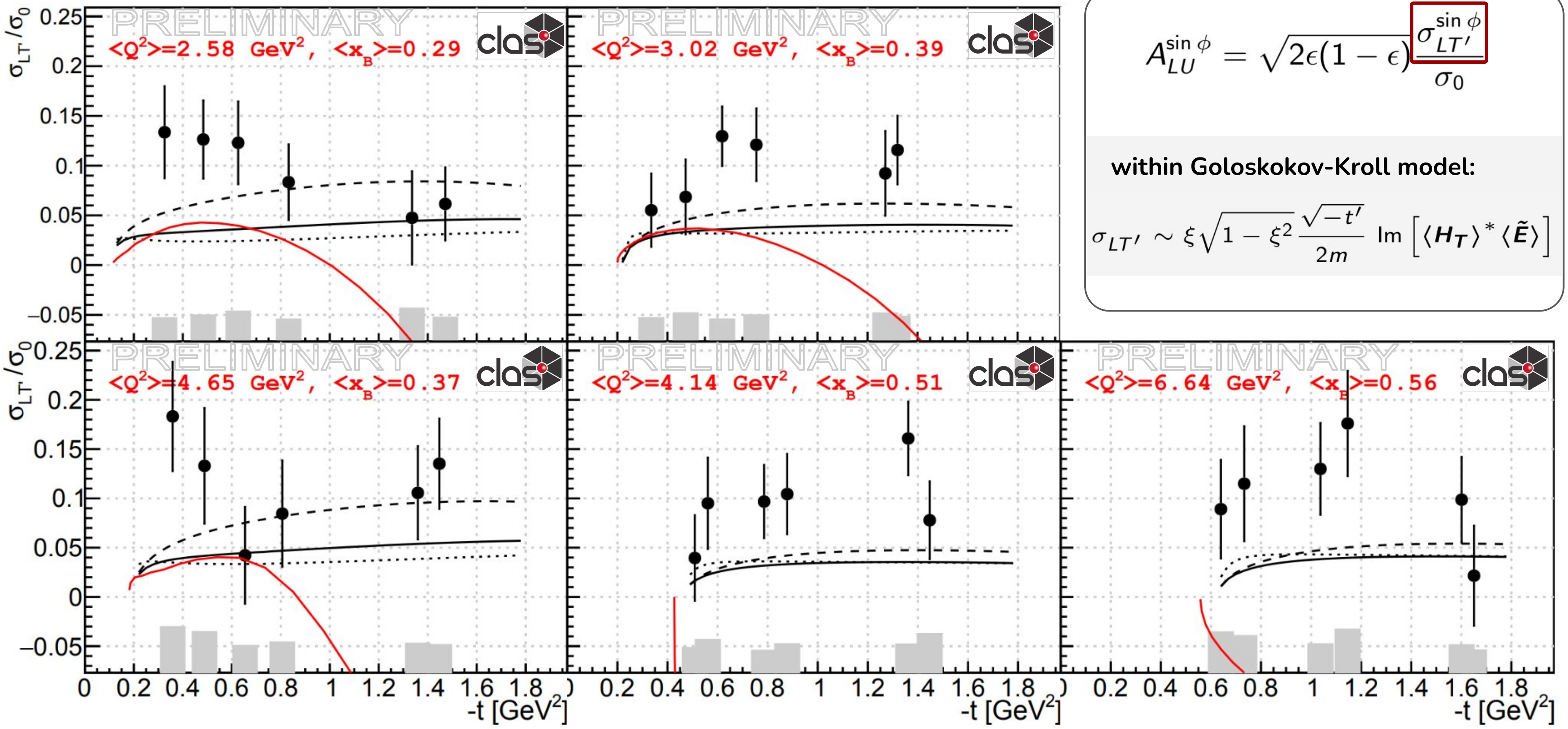
Systematics: overview





(b) for A_{LU} BSA measurements

Exclusive π^0 Beam Spin Asymmetry



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

within Goloskokov-Kroll model:

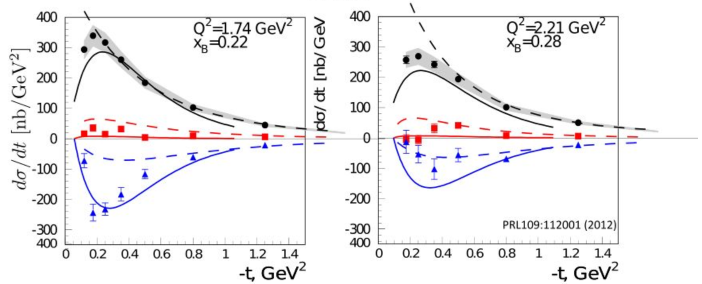
$$\sigma_{LT'} \sim \xi\sqrt{1-\xi^2}\frac{\sqrt{-t'}}{2m}\ \mathrm{Im}\left[\langle H_T\rangle^*\langle\tilde{E}\rangle\right]$$

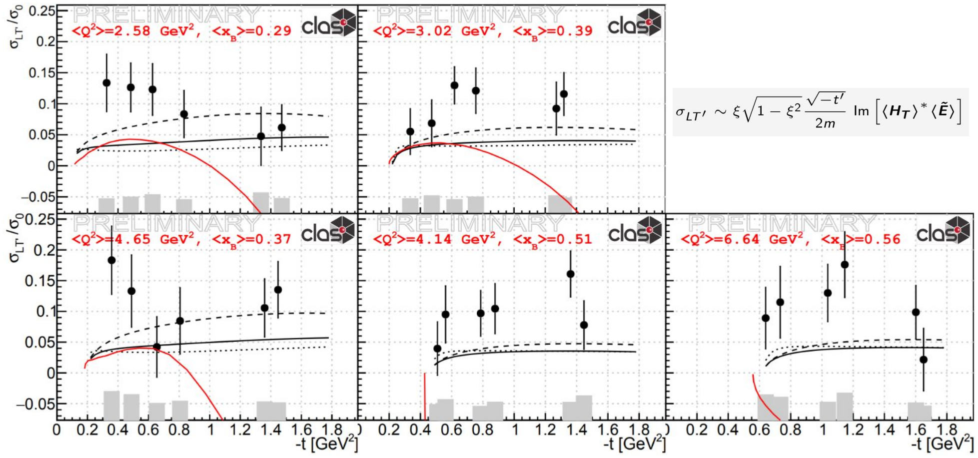
GPDs insight

Unpolarized structure functions

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

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

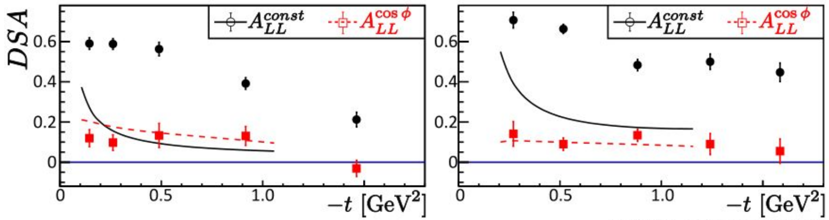




$$\sigma_{LT'} \sim \xi\sqrt{1-\xi^2}\,\frac{\sqrt{-t'}}{2m}\,\mathrm{Im}\left[\langle H_T\rangle^*\langle \tilde{E}\rangle\right]$$

Double spin asymmetry

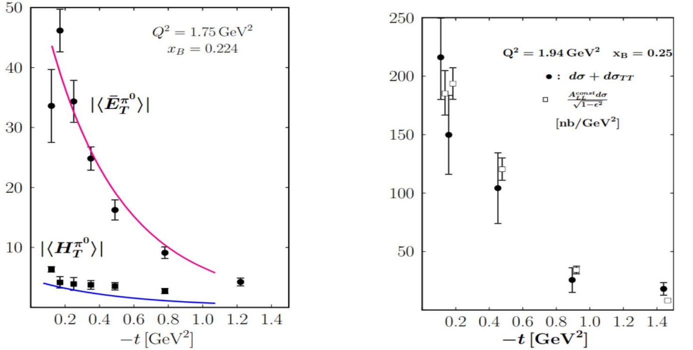
$$A_{LL}^{const} \sim |\langle H_T\rangle|^2$$



PLB768, 168-173 (2017)

H_T is underestimated in GK model

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



Few-Body Syst 57, 1041–1050 (2016)

Measurement of Exclusive π^0 Electroproduction Structure Functions and their Relationship to Transverse Generalized Parton Distributions

I. Bedlinskiy *et al.* (CLAS Collaboration)
Phys. Rev. Lett. **109**, 112001 – Published 10 September 2012

Rosenbluth Separation of the π^0 Electroproduction Cross Section

M. Defurne *et al.* (Jefferson Lab Hall A Collaboration)
Phys. Rev. Lett. **117**, 262001 – Published 23 December 2016

Exclusive η electroproduction at $W > 2$ GeV with CLAS and transversity generalized parton distributions

I. Bedlinskiy *et al.* (CLAS Collaboration)
Phys. Rev. C **95**, 035202 – Published 10 March 2017

Rosenbluth Separation of the π^0 Electroproduction Cross Section Off the Neutron

M. Mazouz *et al.* (Jefferson Lab Hall A Collaboration)
Phys. Rev. Lett. **118**, 222002 – Published 1 June 2017

Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/physletb

A multidimensional study of the structure function ratio $\sigma_{LT'}/\sigma_0$ from hard exclusive π^+ electro-production off protons in the GPD regime

S. Diehl[ah,f,*], A. Kim[f], K. Joo[f]

Measurement of $ep \to ep\pi^0$ beam spin asymmetries above the resonance region

R. De Masi *et al.* (CLAS Collaboration)
Phys. Rev. C **77**, 042201(R) – Published 14 April 2008

Physics Letters B
Volume 789, 10 February 2019, Pages 426-431

Measurement of the beam spin asymmetry of $\vec{e}p \to e'p'\eta$ in the deep-inelastic regime with CLAS

B. Zhao[a b], A. Kim[a], K. Joo[a], I. Bedlinskiy[c], W. Kim[d], V. Kubarovsky[e f], M. Ungaro[e],

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Target and double spin asymmetries of deeply virtual π^0 production with a longitudinally polarized proton target and CLAS

A. Kim[b,a,*], H. Avakian[c], V. Burkert[c], K. Joo[a], W. Kim[b]

1 Beam Spin Asymmetry Measurements of Deeply Virtual π^0 Production with CLAS12

2 A. Kim,[1] K. Joo,[1] and S. Diehl[2,1]
3 (The CLAS Collaboration)
4 [1]University of Connecticut, Storrs, Connecticut 06269
5 [2]II. Physikalisches Institut der Universität Giessen, 35392 Gießen, Germany

- The preliminary Beam Spin Asymmetry for deeply virtual exclusive π^0 electroproduction was measured with CLAS12 and longitudinally polarized electron beam
- New CLAS12 measurements extend experimental reach up to 10 GeV^2, twice the range compared to CLAS6 data
- Sizable extracted BSA moments indicate significant contributions from chiral-odd GPDs
- Chiral-odd based theoretical models will benefit from additional constraints provided by new measurements in a wide kinematic range