April 14, 2021

Hard exclusive π^+ electro-production BSA off the proton in the GPD and TDA regimes

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for the CLAS collaboration

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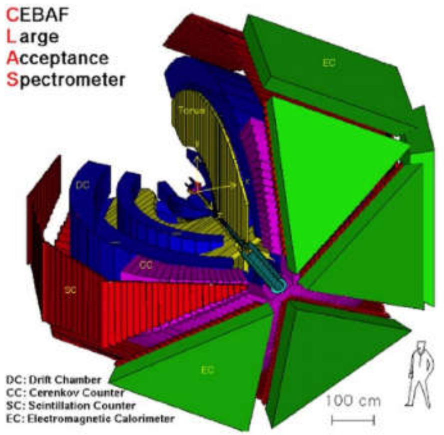
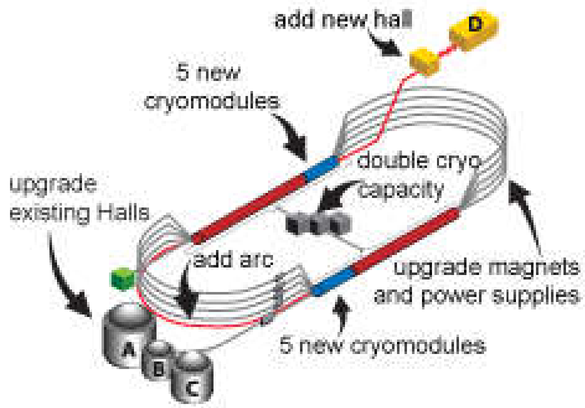
Outline

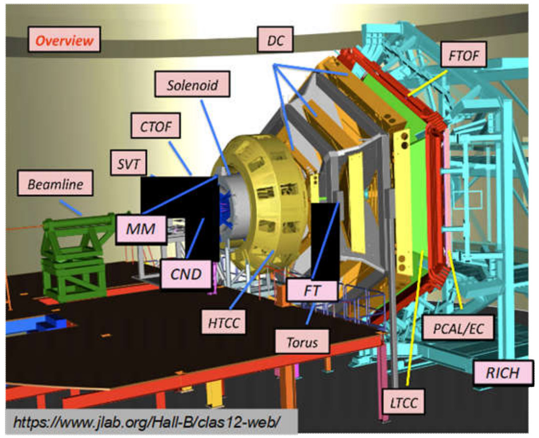
First part

Extraction of beam-spin asymmetries from the hard exclusive π^+ channel off protons in a wide range of kinematics

S. Diehl *et al.* (CLAS Collaboration) Phys. Rev. Lett. 125, 182001 (2020)







Second part

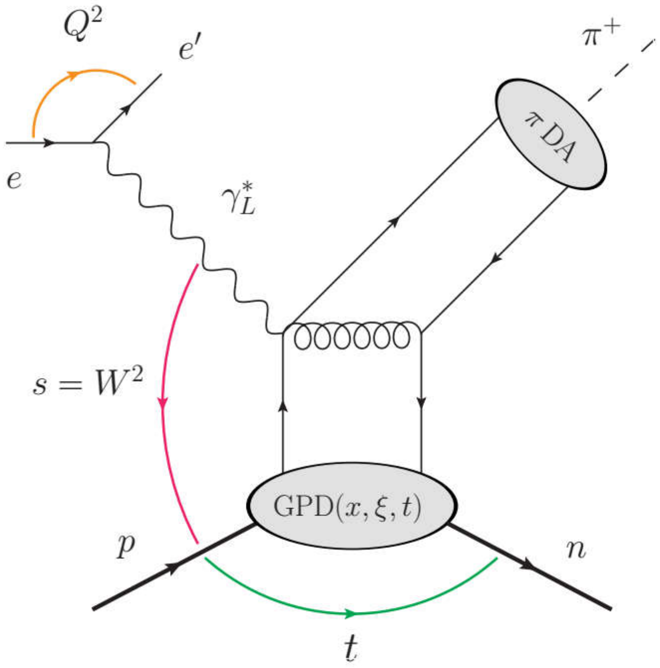
A multidimensional study of π^+ BSA in the GPD regime with CLAS12

Hard Exclusive π⁺ Electroproduction

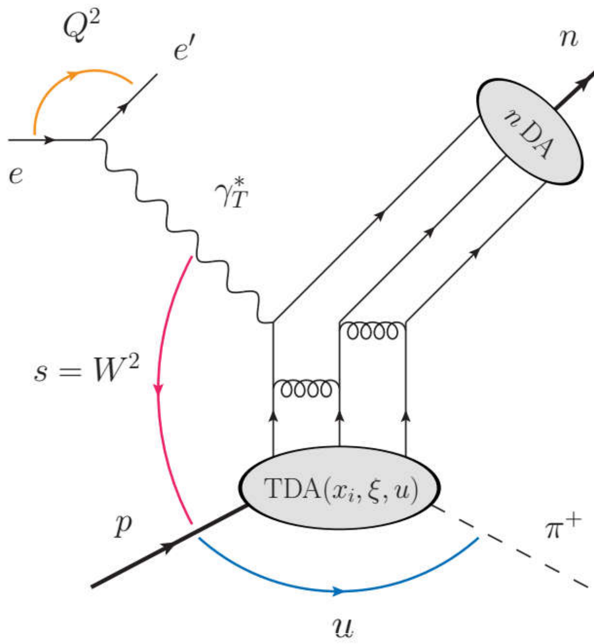
colinear factorization theorem

GPD based description
large Q^2 and s
small t channel contribution

TDA based description
large Q^2 and s
small u channel contribution



meson in forward region

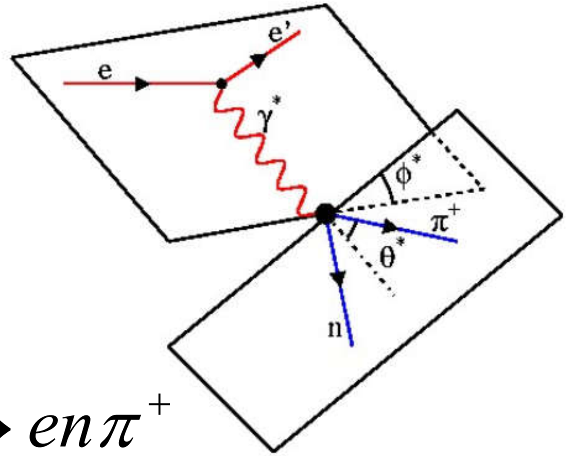


meson in backward region

Hard Exclusive π⁺ Electroproduction and BSA

Cross section (longitudinally pol. beam and unpol. target):

$$2\pi \frac{d^2\sigma}{dt d\phi} = \frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt} + \epsilon \cdot cos(2\phi) \frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)} \cdot cos(\phi) \frac{d\sigma_{LT}}{dt} + h \cdot \sqrt{2\epsilon(1-\epsilon)} \cdot sin(\phi) \frac{d\sigma_{LT'}}{dt}$$



$$ep \to en\pi^+$$

$$\sigma = \sigma_0(1 + A_{UU}^{\cos(2\phi)} \cos(2\phi) + A_{UU}^{\cos(\phi)} \cos(\phi) + h A_{LU}^{\sin(\phi)} \sin(\phi))$$

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

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

Theoretical Interpretation in the GPD Regime

$$ep \rightarrow en\pi^+$$

t / Q² << 1: GPD based description

Goldstein, Hernandez, Liuti
Phys. Rev. D 84, 034007 (2011)

Goloskokov, Kroll
Eur. Phys. J. A. 47: 112 (2011)

quark pol. / nucleon pol.

N/q	U	L	T
U	H		$\bar{E}_T$
L		$\widetilde{H}$	$\widetilde{E}_T$
T	E	$\widetilde{E}$	$H_T, \widetilde{H}_T$

4 chiral even GPDs

4 chiral odd GPDs

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

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

H_T is related to the protons tensor charge

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

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

$\bar{E}_T$ is related to the protons anomalous tensor magnetic moment

Theoretical Interpretation

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

$\sigma_{LT'}$: Product of chiral-odd and chiral-even GPDs

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

$$\widetilde{E} = \widetilde{E}_{generic} + pole\ term$$
$$\widetilde{H} = \widetilde{H}_{generic} + pole\ term$$

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

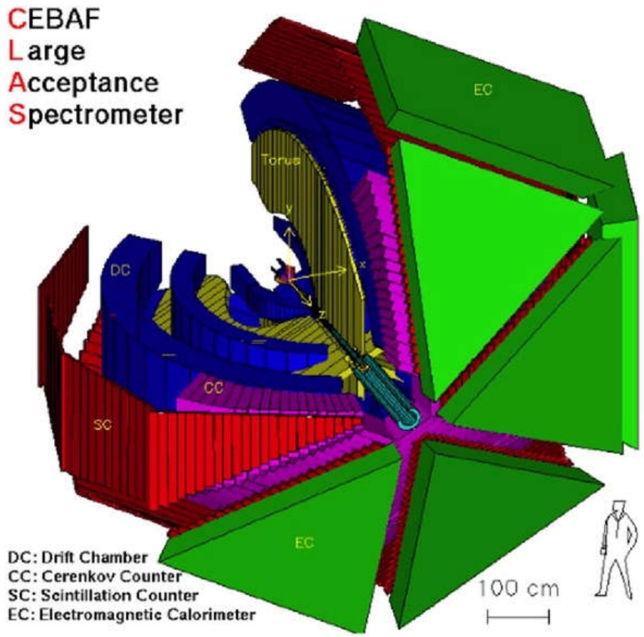
$$\sigma_T \sim \left[\left(1-\xi^2\right)\left|\langle H_T\rangle\right|^2 - \frac{t'}{8m^2}\left|\langle\bar{E}_T\rangle\right|^2\right]$$

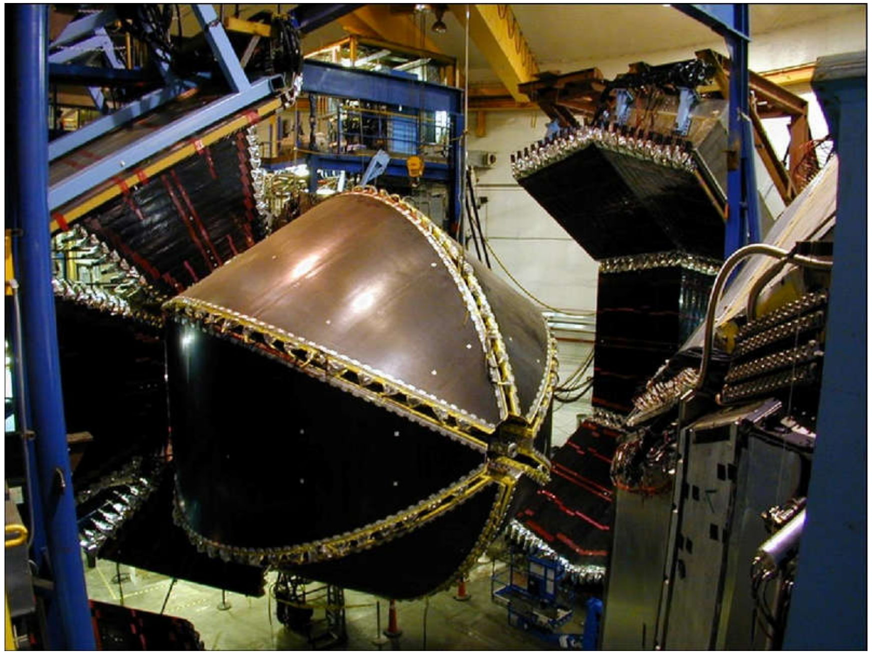
➔ **π^+:** Chiral odd GPDs are significantly amplified by the pion pole term in $\sigma_{LT'}$

➔ Polarized π^+ observables show an increased sensitivity to chiral-odd GPDs

➔ $\bar{E}_T \sim F_u - F_d \sim 0$ for π^+ ➔ Strong sensitivity to the poorly known GPD H_T

The CLAS Detector at JLAB





- data recorded in 2003
- 5.5 GeV longitudinally polarized electron beam
- unpolarized hydrogen target

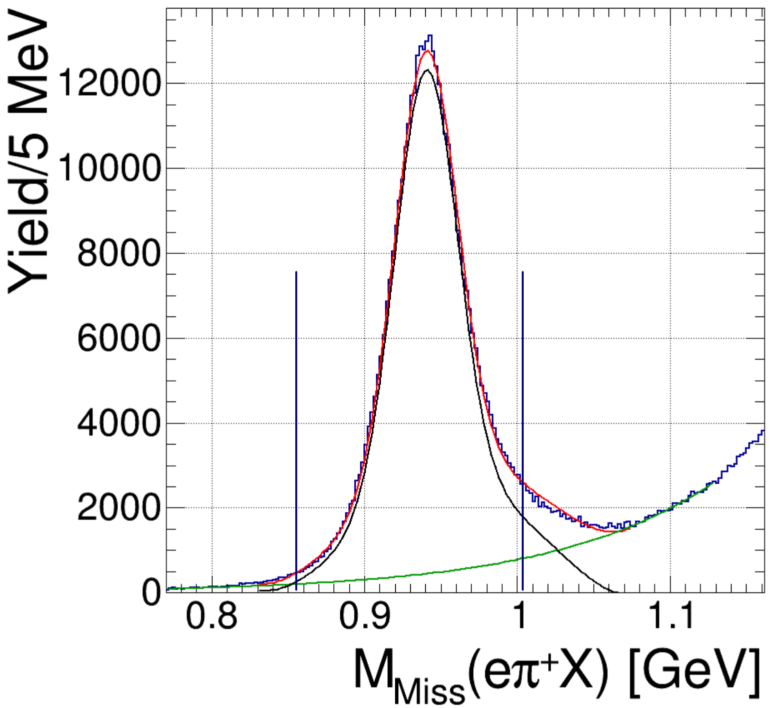
- **Electron ID** based on electromagnetic calorimeter and Cherenkov counters
- **π ID** from a TOF based maximum likelyhood particle selection

Hard Exclusive π⁺ Electroproduction with CLAS

$$ep \rightarrow en\pi^{+}$$

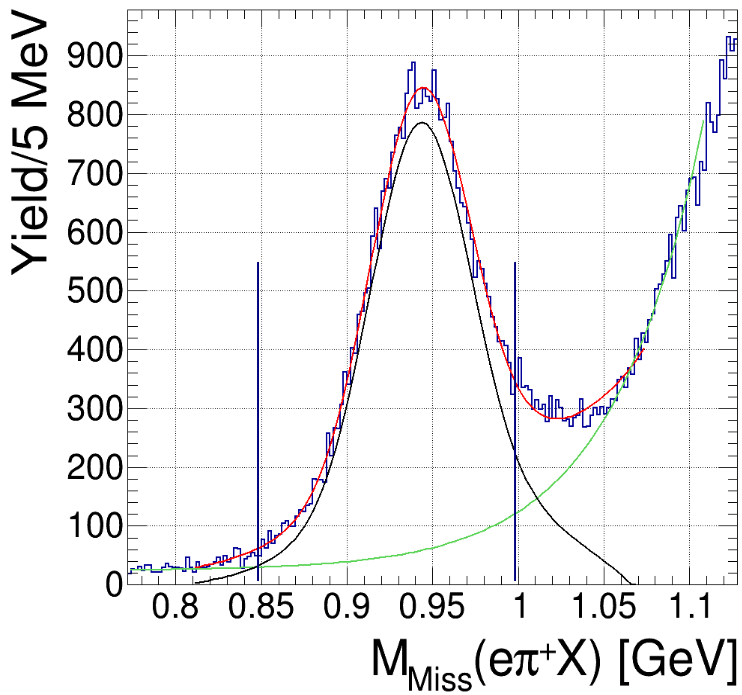
forward

$-t < 1.5$ GeV² cos(θ) > 0

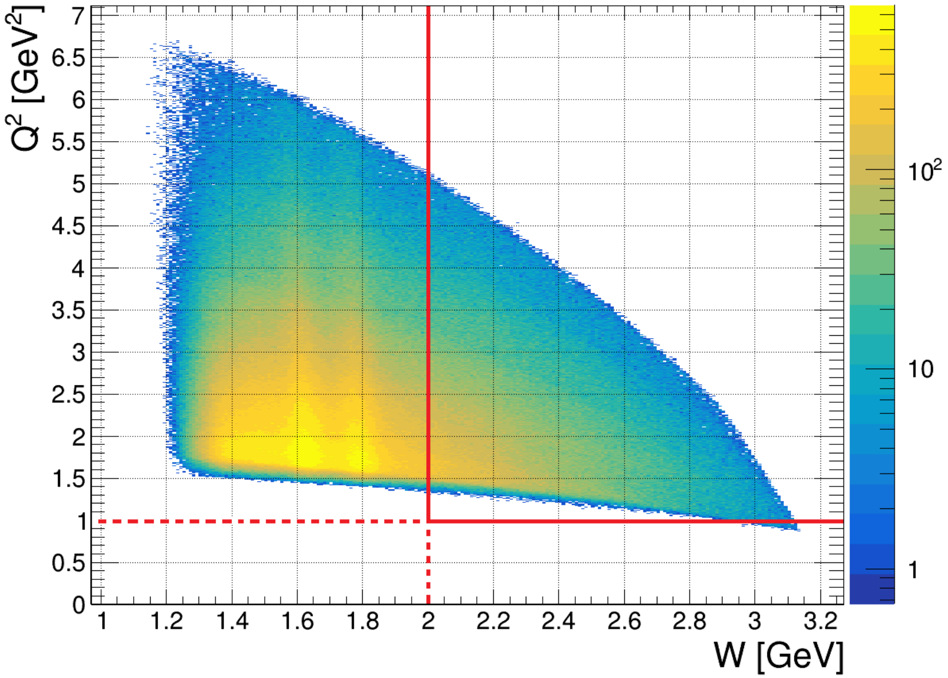


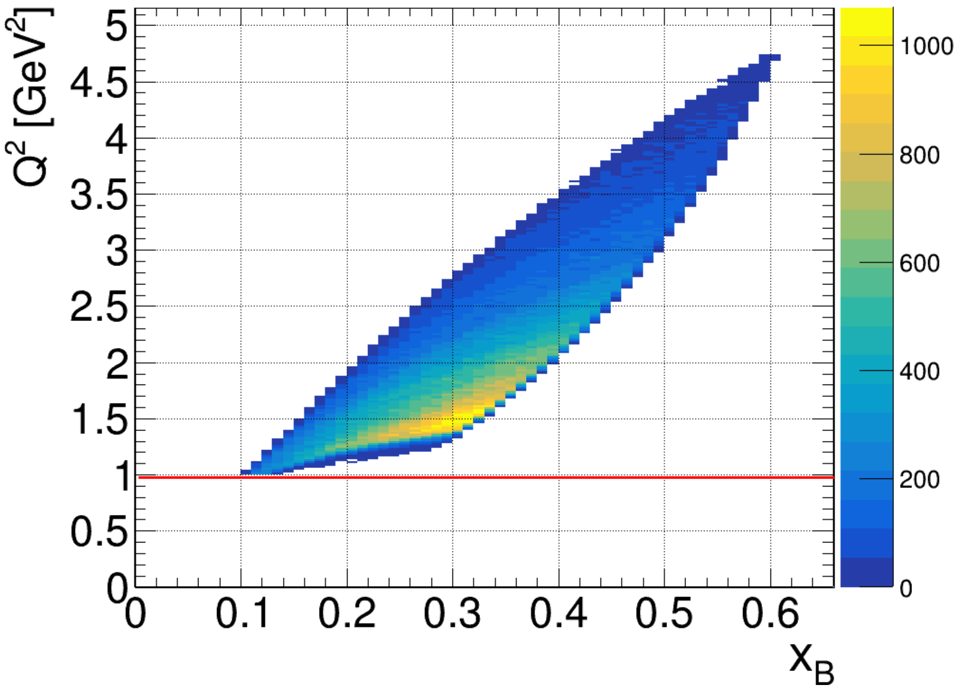
backward

$-u < 2.0$ GeV² cos(θ) < 0



Kinematics accessible with CLAS (E_{beam} = 5.5 GeV)



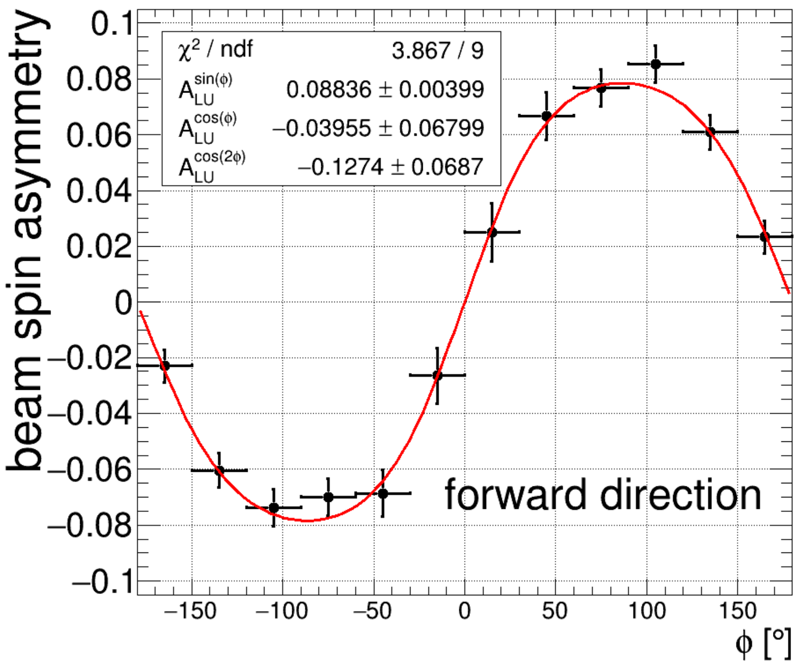


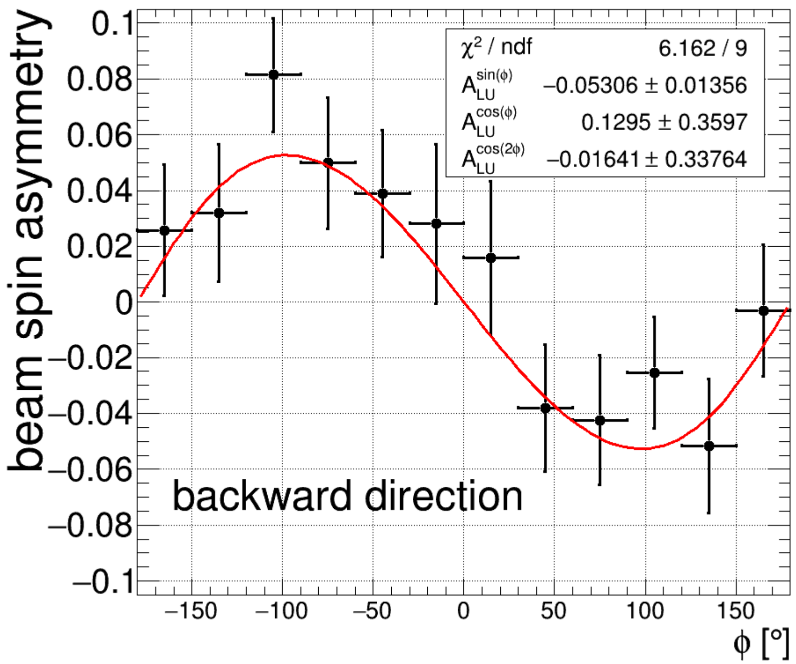
DIS cuts: W > 2 GeV $Q^2 > 1$ GeV²

Beam Spin Asymmetry in Forward and Backward Direction

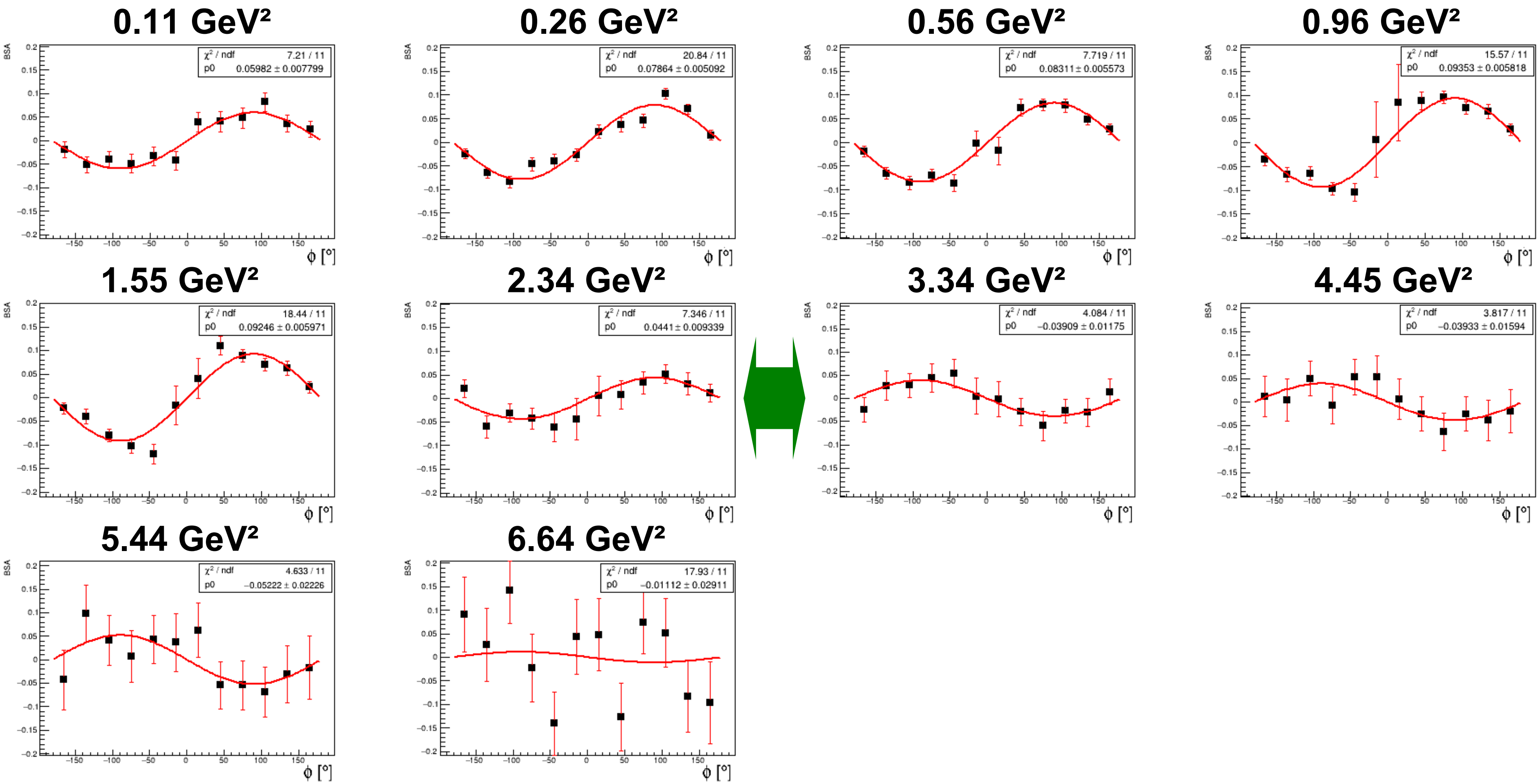
$$BSA_i = \frac{1}{P_e} \cdot \frac{N_i^+ - N_i^-}{N_i^+ + N_i^-}$$

P_e = 75 % : average e^- beam polarisation

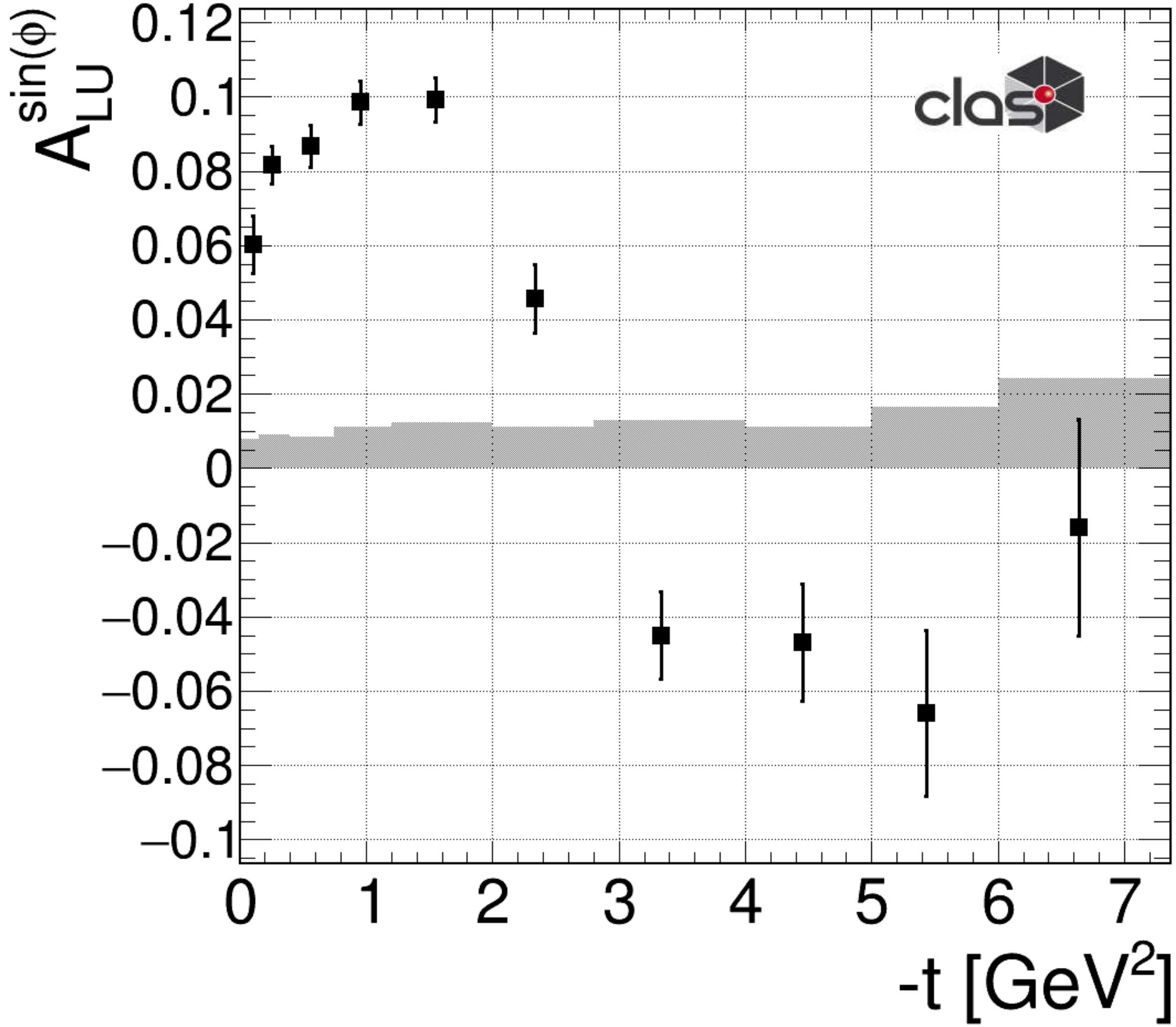




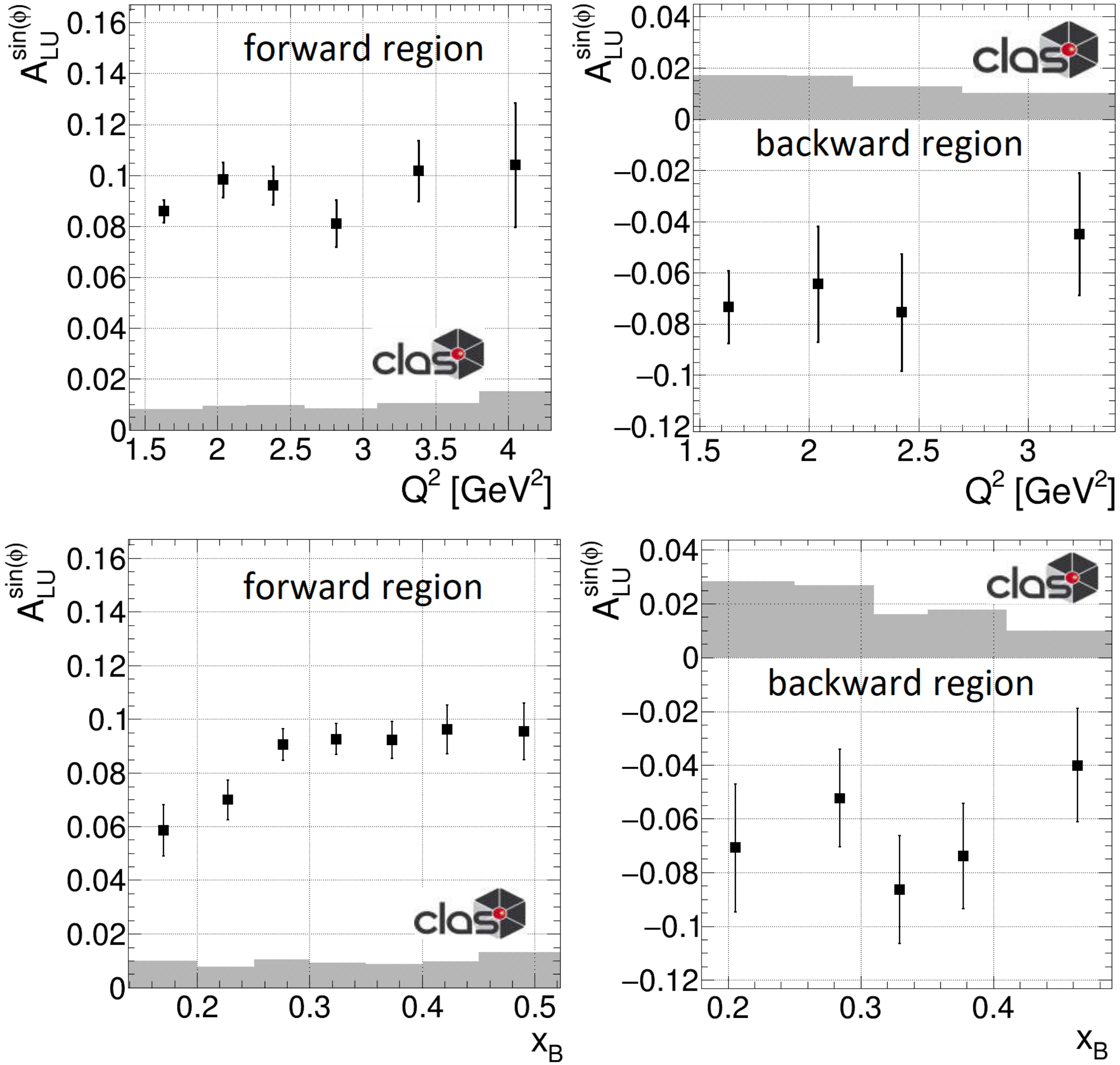
BSA for Different -t Bins



-t Dependence of $A_{LU}^{\sin(\phi)}$



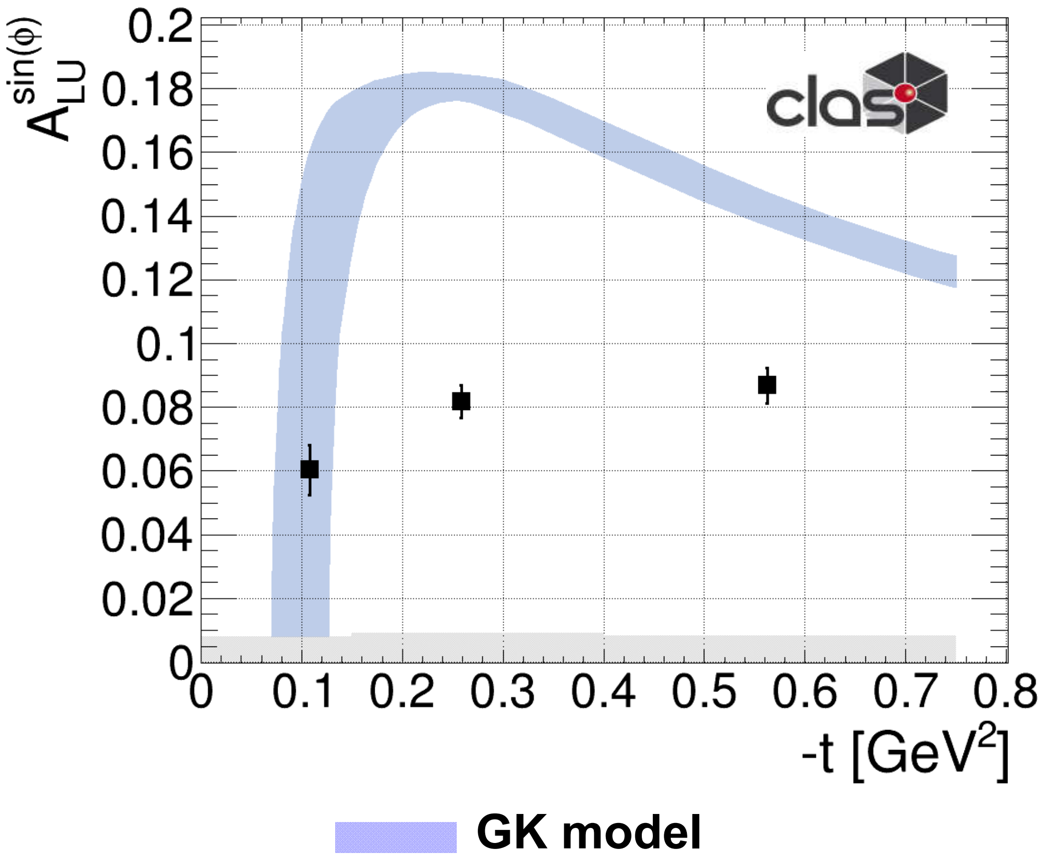
Q^2 and x_B Dependence of $A_{LU}^{\sin(\phi)}$



Comparison to the Prediction of the GK Model

➔ GPD-based model by Goloskokov and Kroll

➔ Valid for $-t/Q^2 << 1$



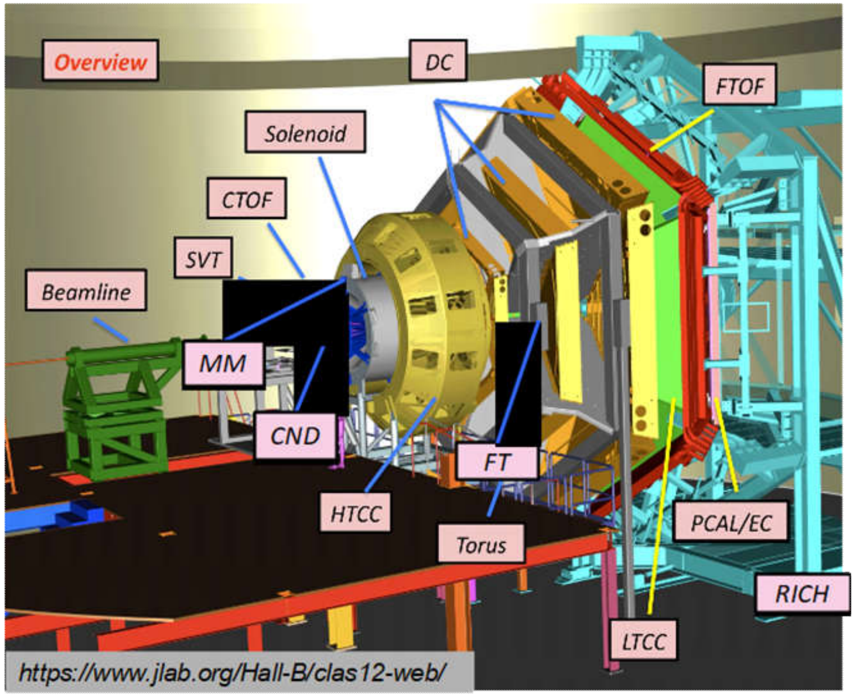
$$A_{LU}^{\sin\phi} \sim \frac{\sigma_{LT'}}{\sigma_T + \epsilon\sigma_L}$$

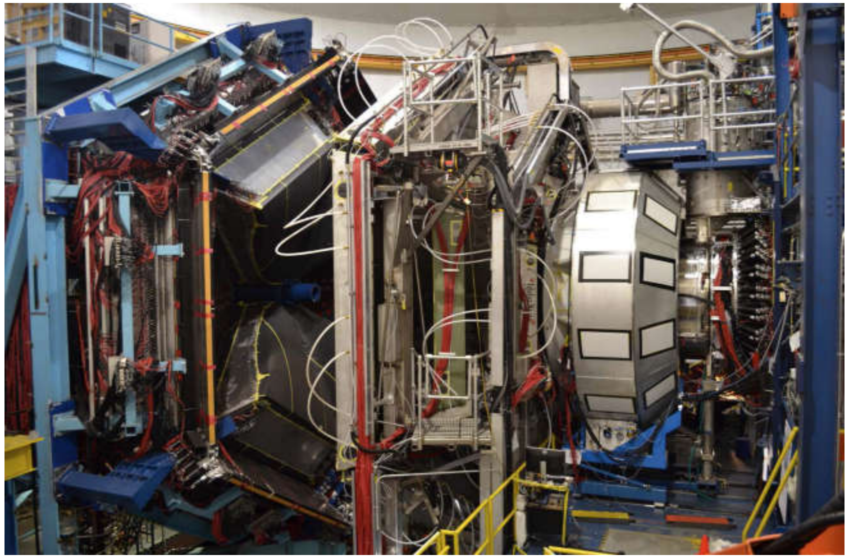
$$\sim \frac{\sqrt{-t'}\ Im\left[\langle H_T\rangle^* \langle \widetilde{E}\rangle\right]}{|\langle H_T\rangle|^2 + \epsilon\sigma_L}$$

➔ Discrepancy caused by the interplay between the pion pole term and the poorly known GPD H_T

➔ Measurement integarted over Q^2 and x_B

A Multidimensional Study in the GPD Regime with CLAS12



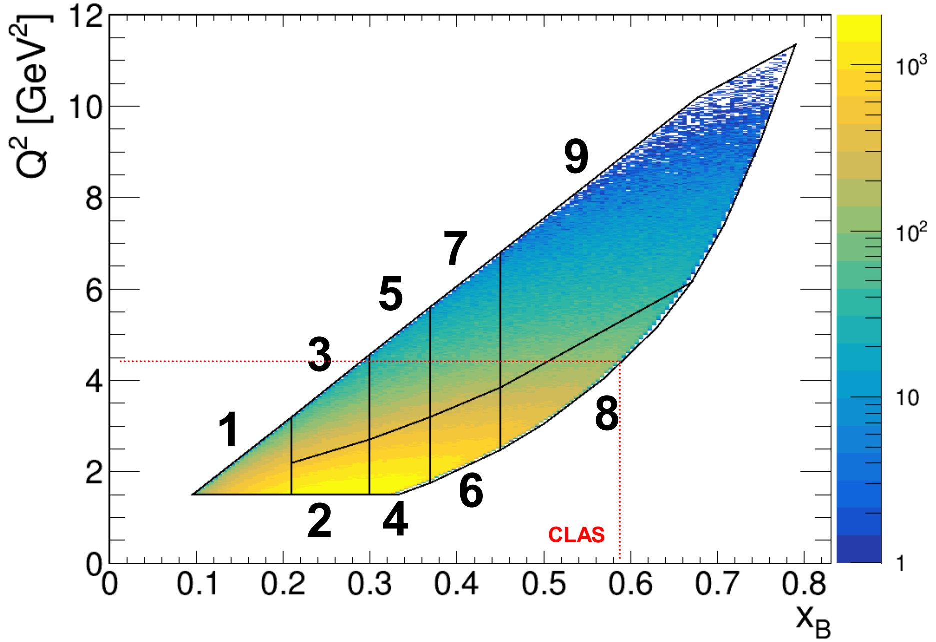


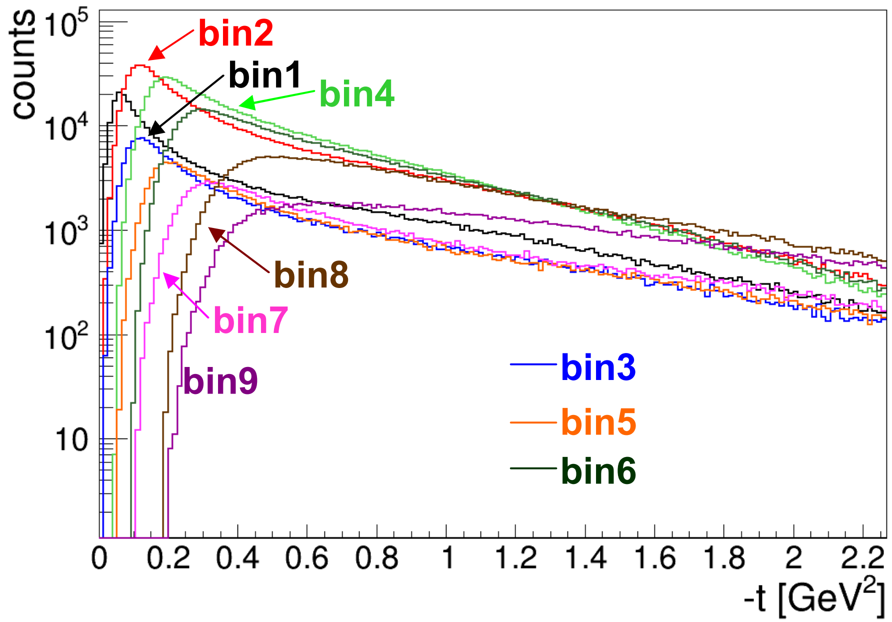
➔ Data recorded with CLAS12 during fall of 2018

➔ 10.6 GeV electron beam ➔ 86.3 % average polarization ➔ liquid H_2 target

➔ Analysed data ~ 15 % of the approved RG-A beam time

Multidimensional Binning





9 bins in Q^2 - x_B

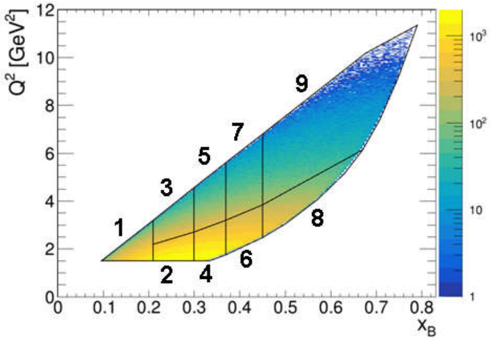
4 - 6 bins in $-t < 1.0$ GeV² (1.2 GeV²)

Advantages of CLAS12 vs CLAS

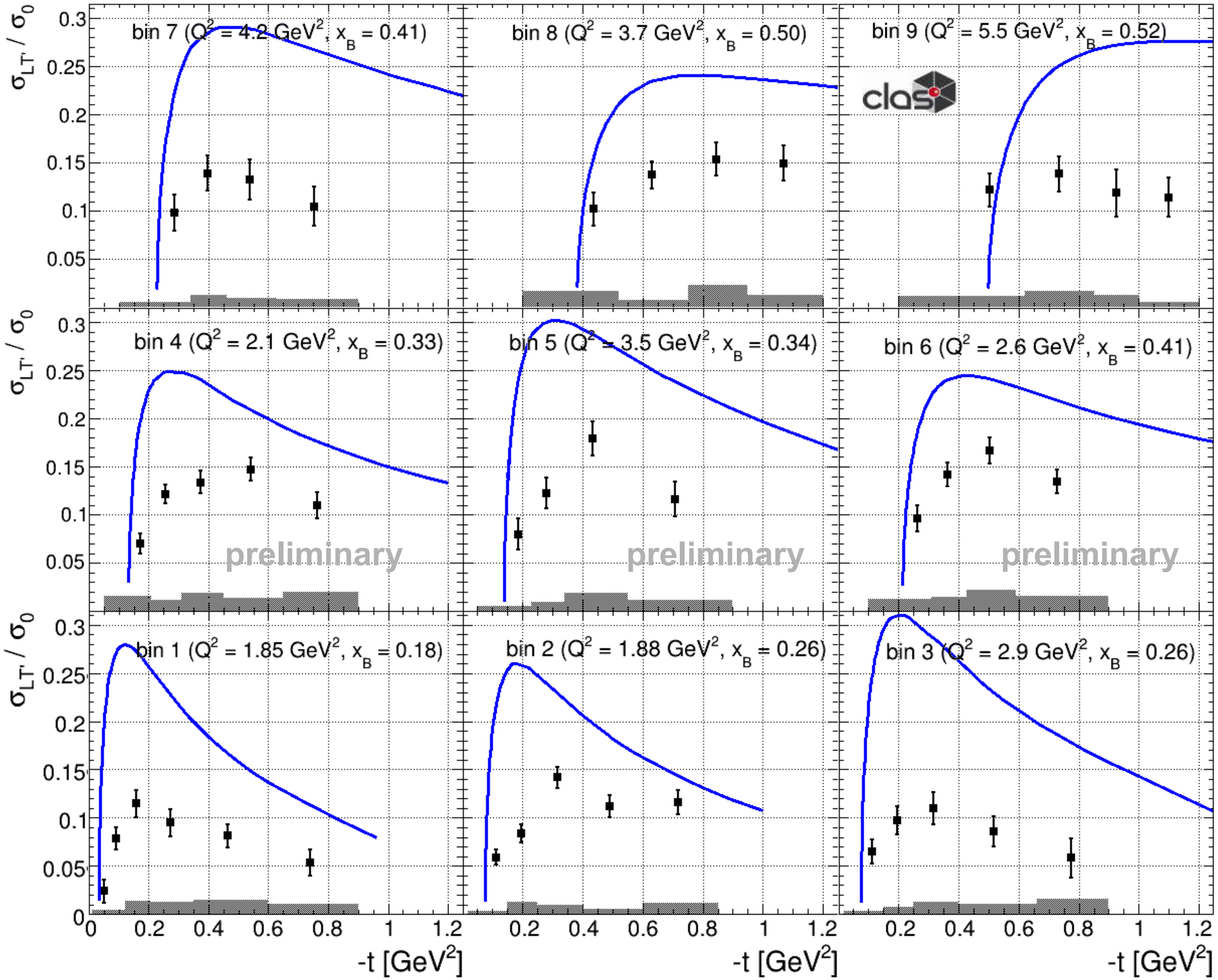
- Increased range in Q^2 and x_B
- Significantly higher statistics

Results and Comparison to the GK Model

preliminary



GK model



Summary

- $A_{LU}^{\sin(\phi)}$ moment from the hard exclusive π^+ channel has been extracted for the first time over a large range of kinematics with CLAS.

- The results show a clear sign change from forward to backward angles, which may indicate a transition from the GPD to the TDA regime.

- A high precision study of the BSA in the GPD regime has been performed with CLAS12.

  ➔ The results will help to further constrain the poorly known GPD H_T