DVMP group meeting January 2020

January 24, 2020

Extraction of $A_{LU}^{\sin(\phi)}$ from the hard exclusive π^+ channel in a wide range of kinematics with CLAS at JLAB

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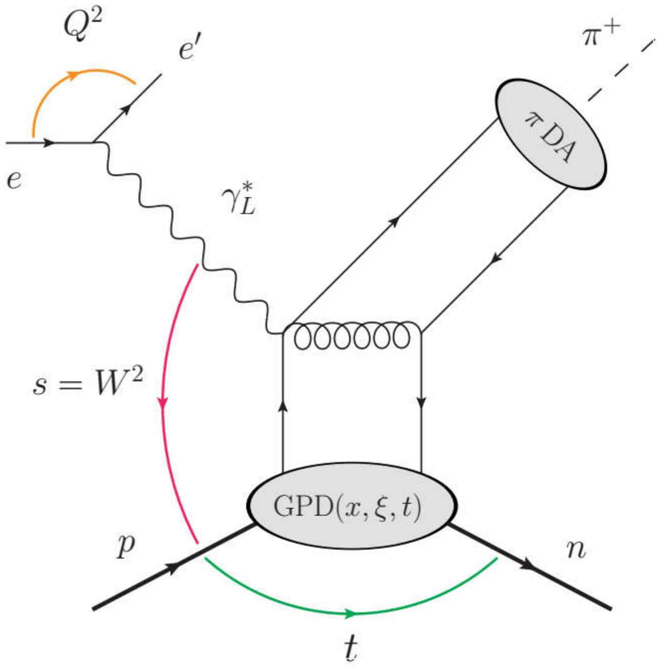
Hard exclusive π⁺ electroproduction $ep \to en\pi^+$

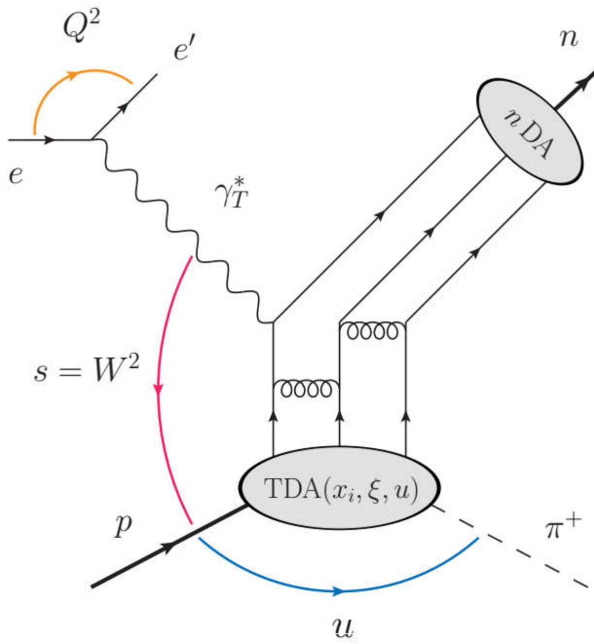
colinear factorization theorem

GPD based description
large Q² and s
small t channel contribution

TDA based description
large Q² and s
small u channel contribution



π⁺ in forward region

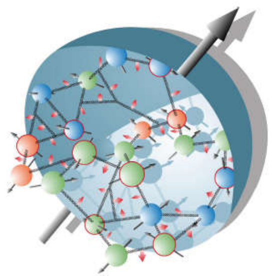


π⁺ in backward region

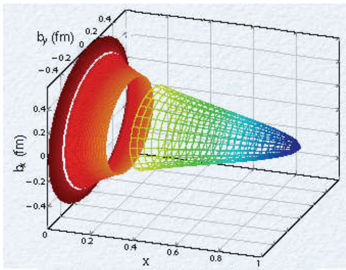
Physics motivation

GPDs

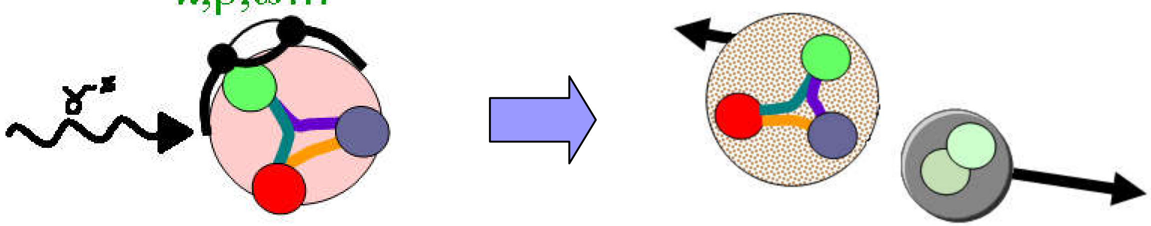
- ➔ Light-cone matrix elements of non-local bilinear quark and gluon operators
- ➔ Describe hadronic structural information in terms of quark and gluon degrees of freedom
- ➔ Spin-dependent 2D transverse coordinate space + 1D longitudinal momentum space images of the nucleon



  - ➔ Tool to study the nature and origin of the nucleon spin
  - ➔ Impact parameter space: spatial femto-photographs of the hadron structure in the transverse plane



courtesy of Z.E. Meziani

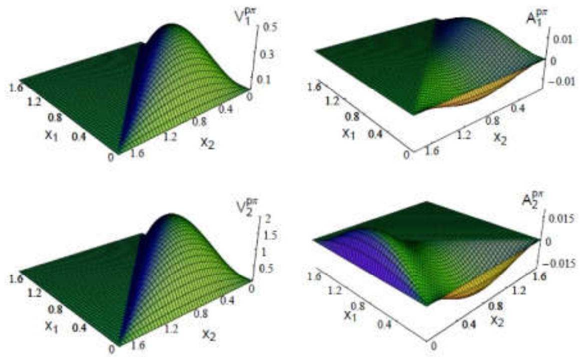


"knocking a pion out of a proton"

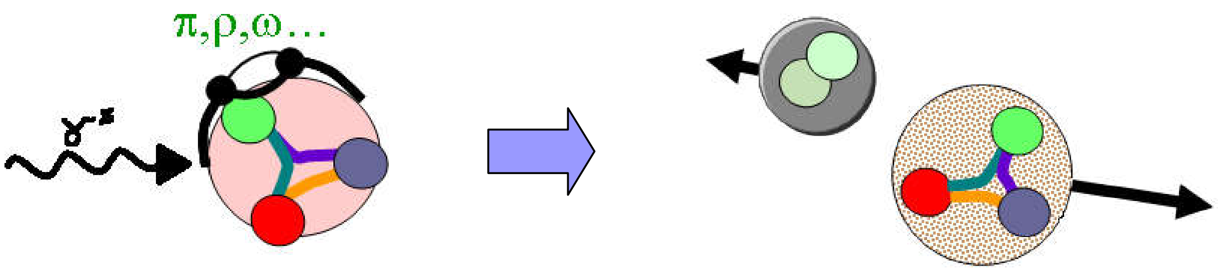
Physics motivation

Baryon to meson TDAs

- ➔ Light-cone matrix elements of non-local three quark operators
- ➔ Encoded physical picture close to GPDs
- ➔ Probe partonic correlations between states of different baryonic charge
  - ➔ Access to non-minimal Fock components of baryon light-cone wave functions



- ➔ Impact parameter space: Femto-photography of hadrons from a new perspective
  - ➔ Spatial imaging of the structure of the pion cloud inside the nucleon

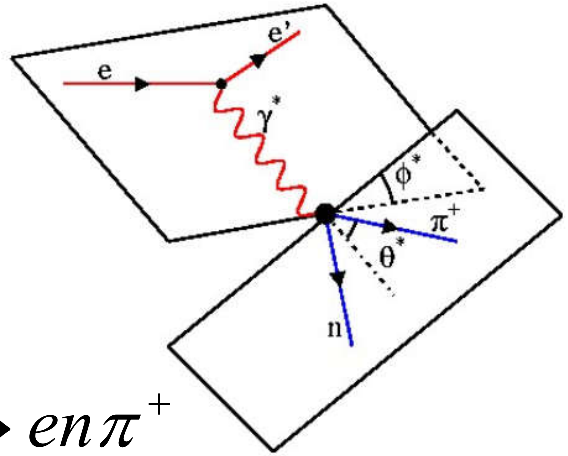


"knocking a proton out of a proton"

Hard exclusive π+ electroproduction

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

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



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

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

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

Theoretical prediction in the forward kinemtic regime

t / Q² << 1: GPD based description

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

Golosokov, 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, $\widetilde{H}_T$

GPDs: - Constructed by double distributions

- Costrained by the latest results from lattice QCD and transversity parton dsitribution functions

chiral even GPDs: all contributions are included

chiral odd GPDs: emphasis on H_T and $\overline{E}_T = 2\widetilde{H}_T + E_T$

➔ Pion pole contribution is considered for longitudinally and transversely polarized virtual photons

Theoretical prediction in the forward kinemtic regime

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

$$A_{LU}^{\sin\phi} = \sqrt{2\varepsilon(1-\varepsilon)} \frac{\frac{d\sigma_{LT'}}{dt}}{\frac{d\sigma_T}{dt} + \varepsilon \frac{d\sigma_L}{dt}} \sim \frac{\sigma_{LT'}}{\sigma_u}$$

$\sigma_{LT'}$: - convolution of GPDs with subprocess amplitudes
- product of chiral-odd and chiral-even GPDs

$$\sigma_{LT'} \sim Im\left[< \overline{E}_T >^* < \widetilde{H} > + < H_T >^* < \widetilde{E} >\right]$$

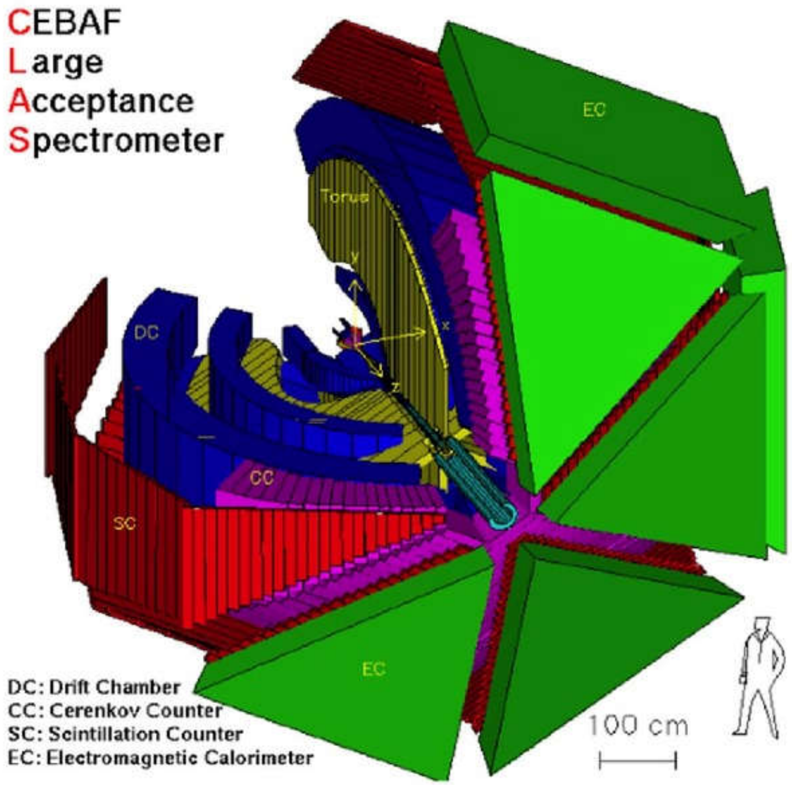
$$\widetilde{E} = \widetilde{E}_{generic} + pole\ term$$
$$\widetilde{H} = \widetilde{H}_{generic} + pole\ term$$

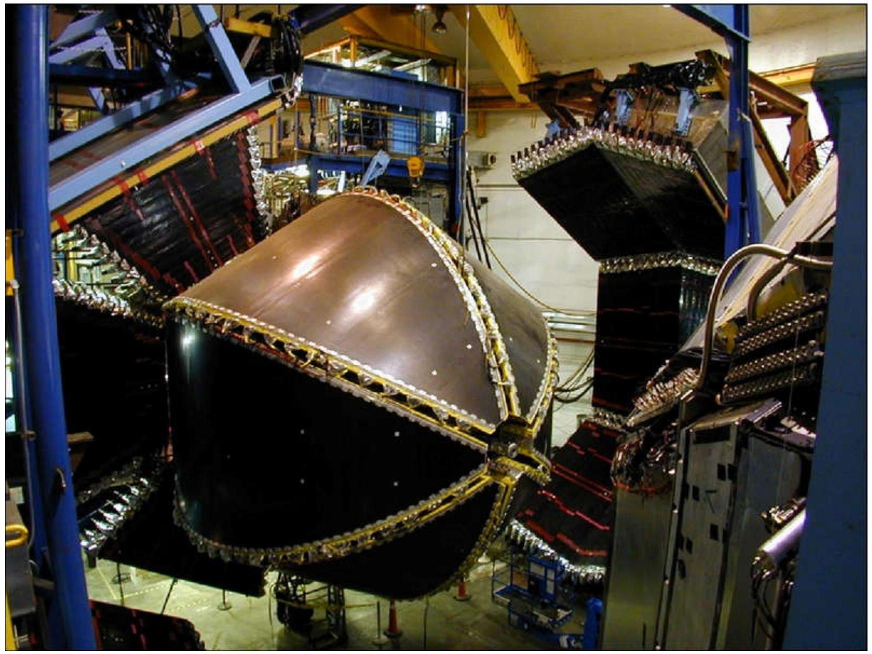
➔ Imaginary part of small chiral odd GPDs is significantly amplified by the pion pole term

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

$\sigma_{LT'}$ ~ $Im[< H_T >^* < \widetilde{E} >]$ $\widetilde{E}$ is dominated by the pion pole

Experimental Setup

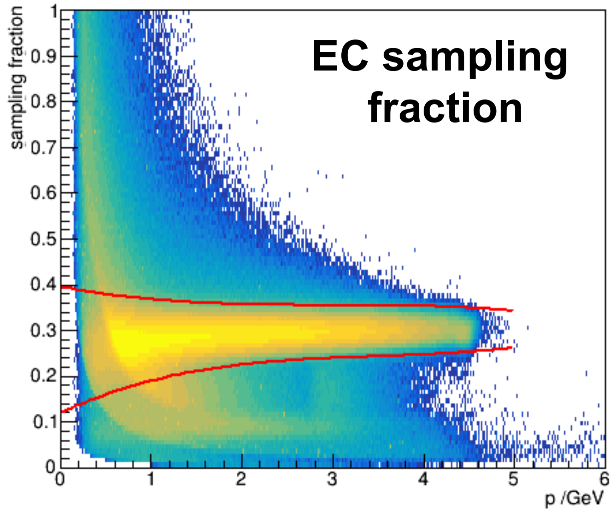




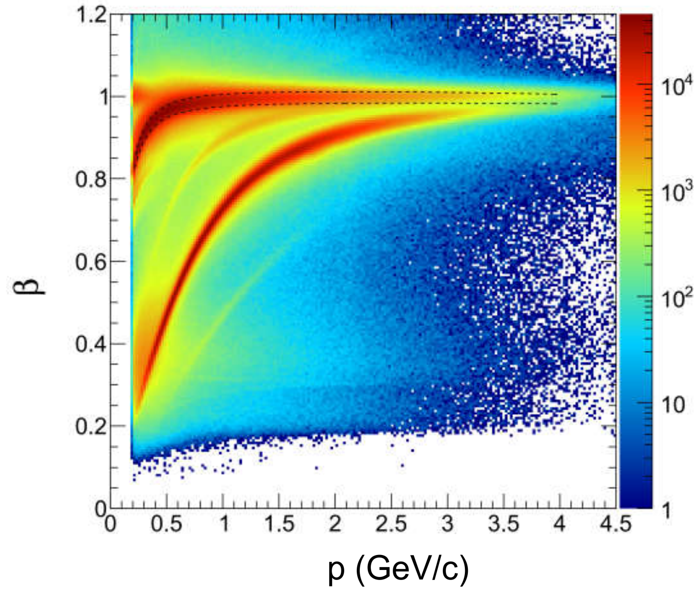
- **CLAS (e1f run period)**
- **5.5 GeV longitudinally polarized electron beam**
- **unpolarized hydrogen target**

Particle identification

- **Electron ID** based on electromagnetic calorimeter and Cherenkov counters



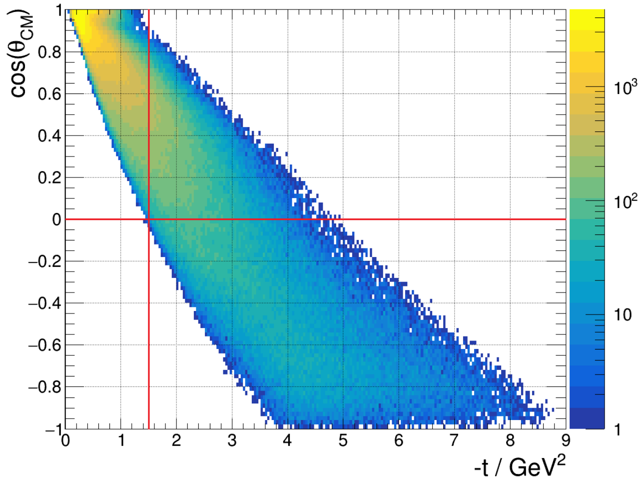
- **π^+ ID** based on a maximum likelyhood particle selection from TOF based β vs p correlation

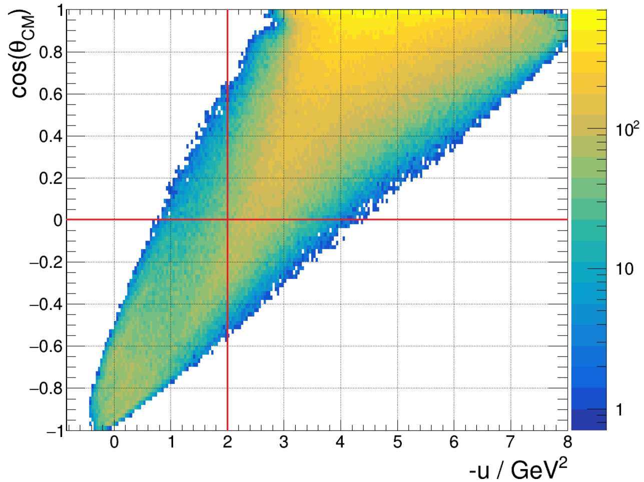


Kinematic regions and exclusivity cuts

forward region „small t“ | **backward region „small u“**

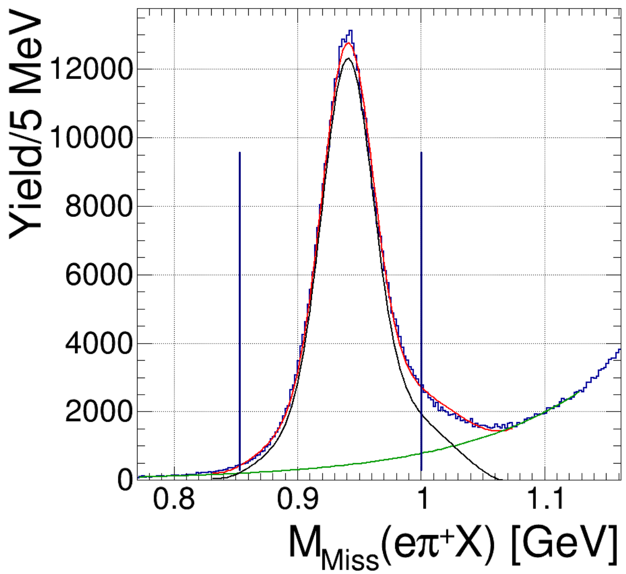
-t < 1.5 GeV²
cos(θ) > 0

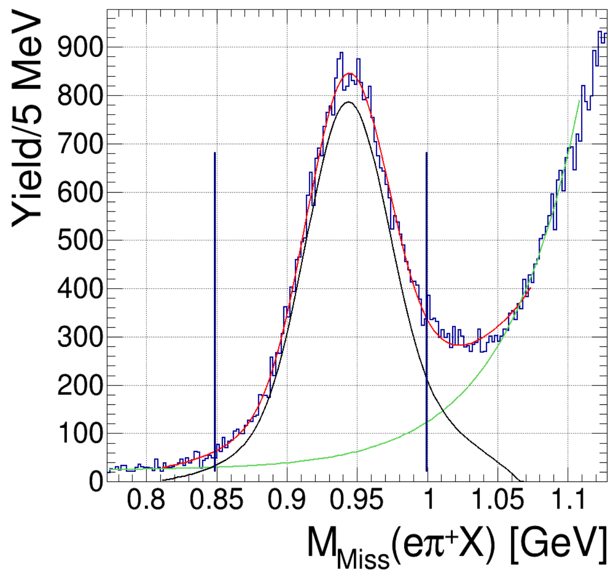




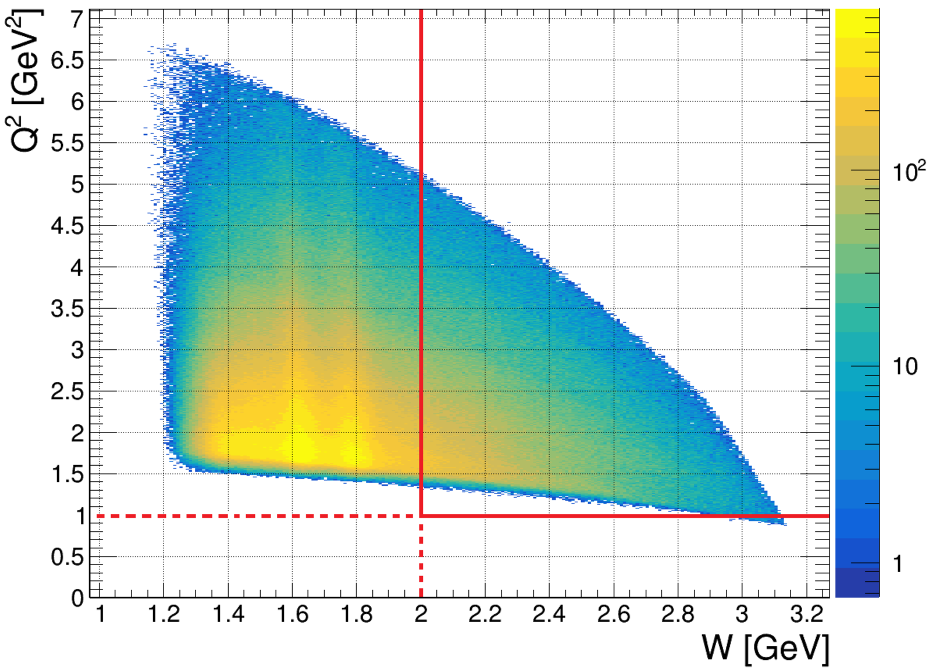
-u < 2.0 GeV²
cos(θ) < 0

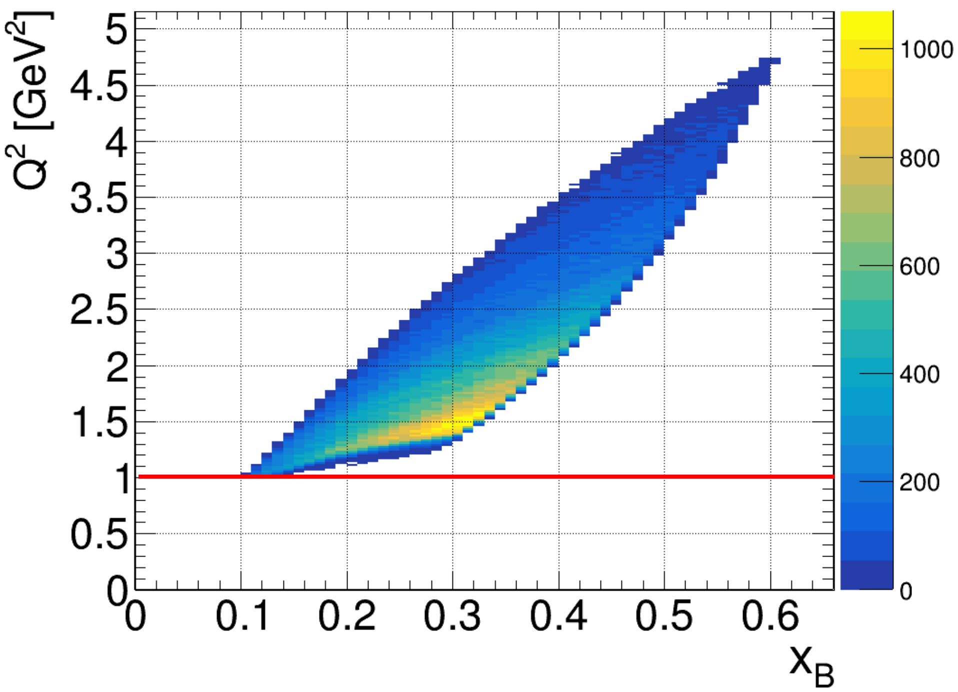
missing mass





Kinematic coverage and cuts





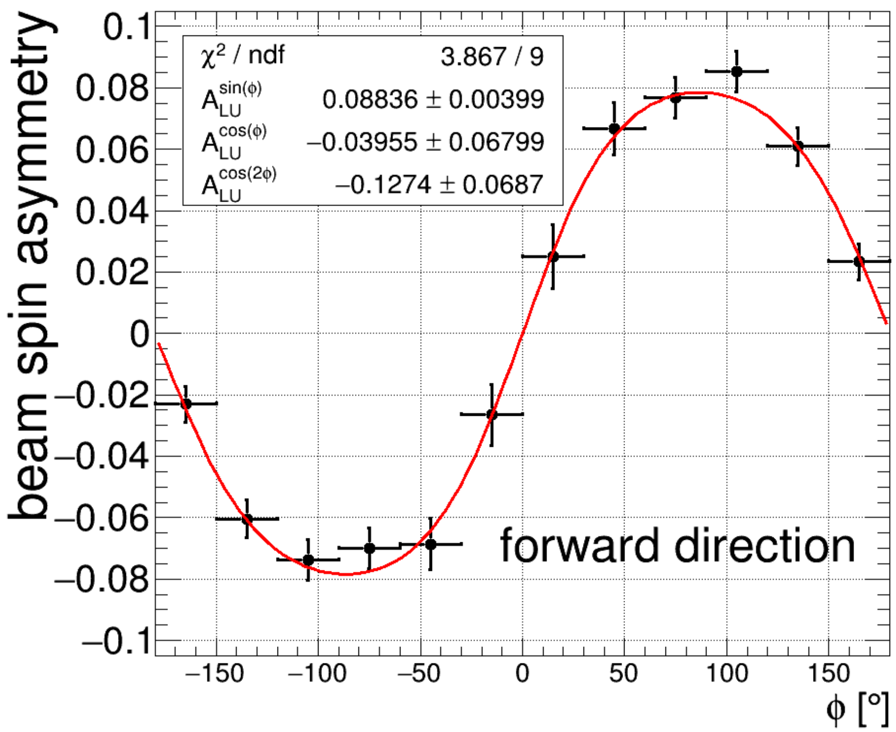
DIS cut: W > 2 GeV $Q^2 > 1$ GeV²

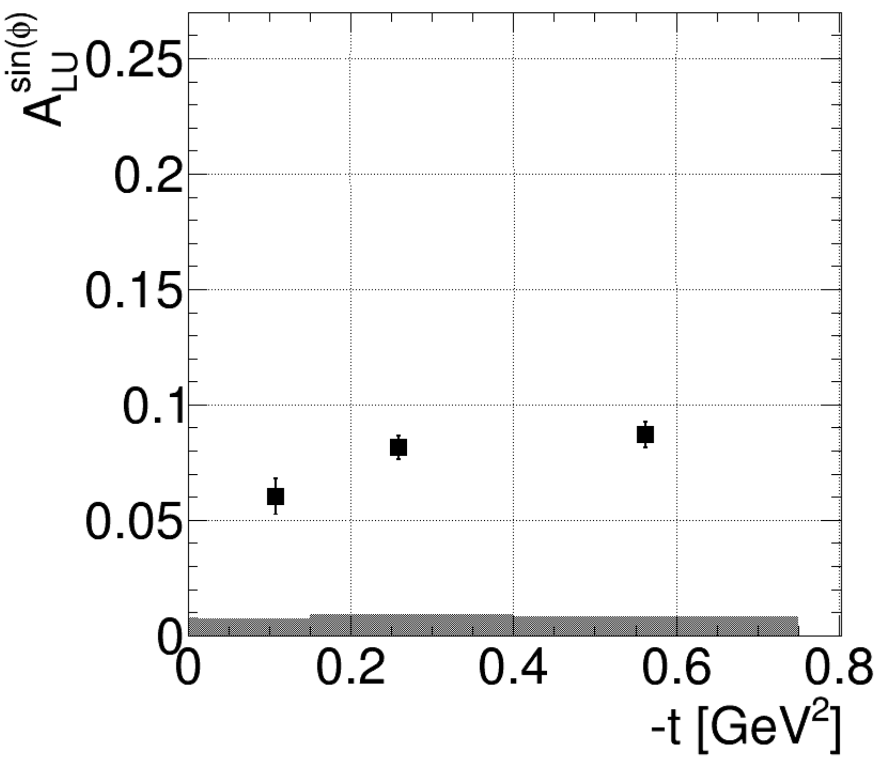
Beam spin asymmetry

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

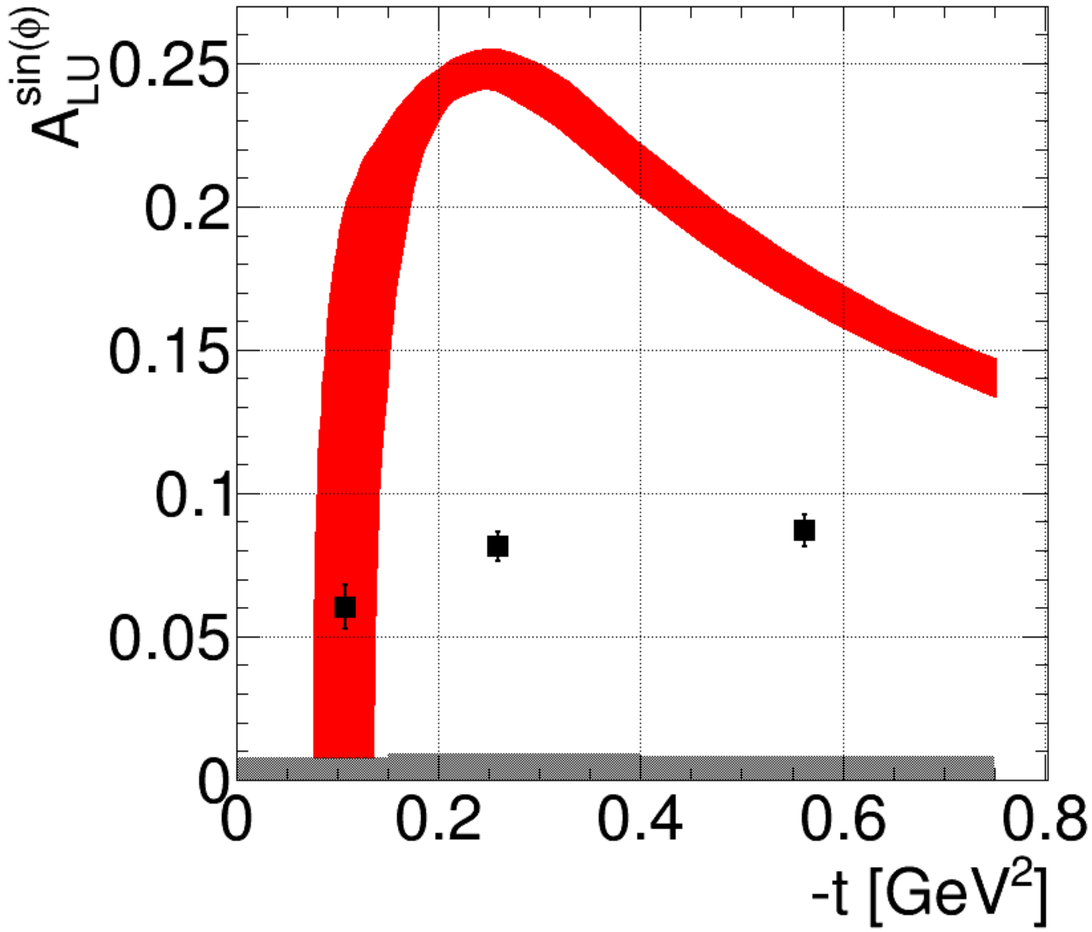
P_e = 75 % : average e⁻ beam polarisation

1.0 GeV² < Q² < 4.5 GeV², 0.1 < x_B < 0.6





Comparison to the GK model predictions

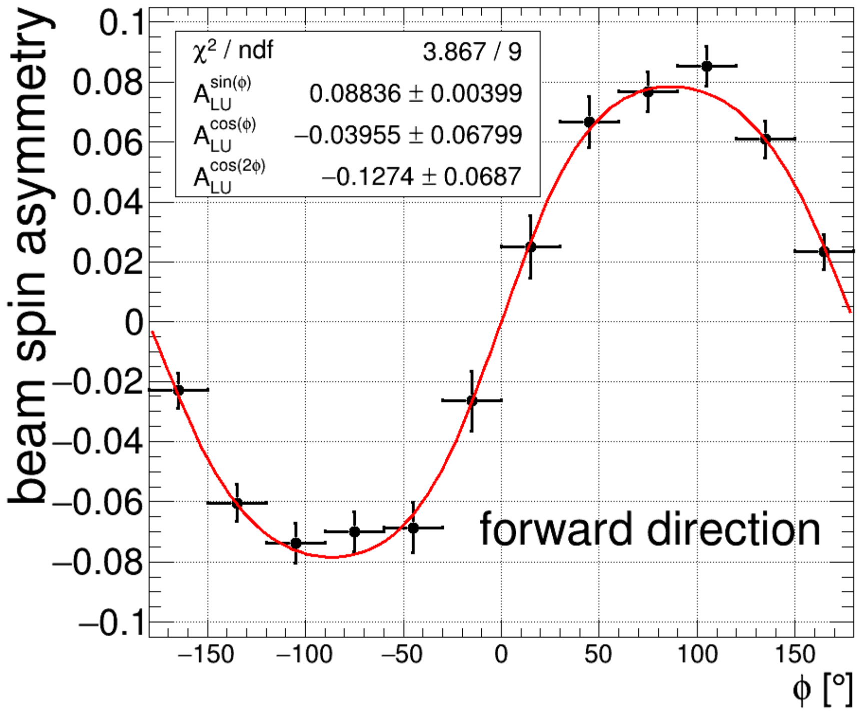


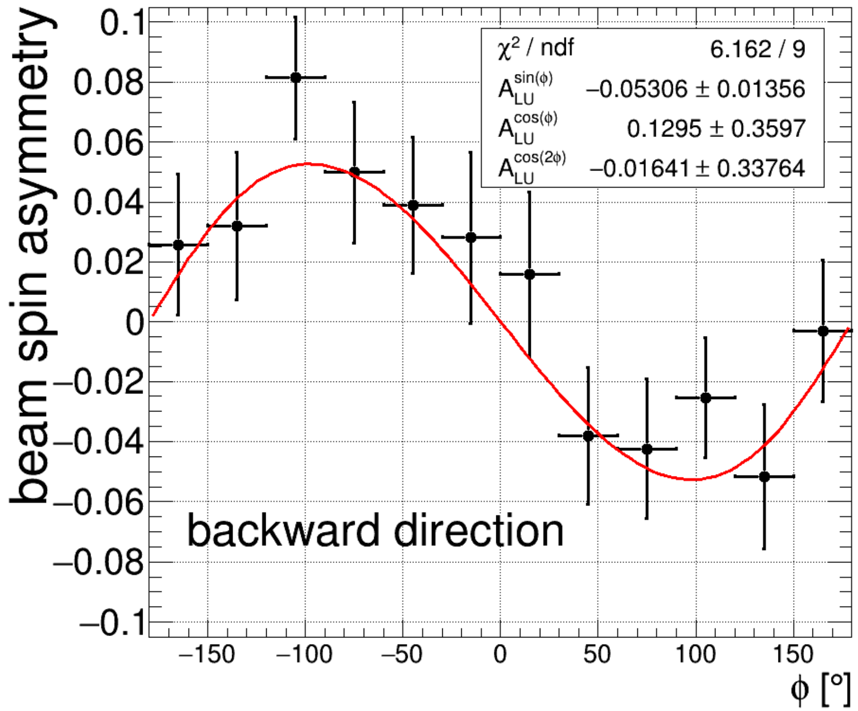
Discrepancy caused by the interplay between the pion pole term and the poorly known GPDs H_T and $\overline{E}_T$

π^+ data in combination with π^0 and η data is essential to better constrain these GPDs

Extension of the kinematic range

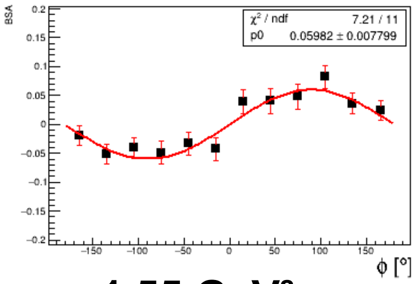
1.0 GeV² < Q^2 < 4.5 GeV², 0.1 < x_B < 0.6



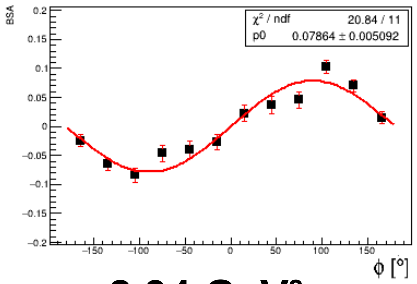


BSA for different -t bins

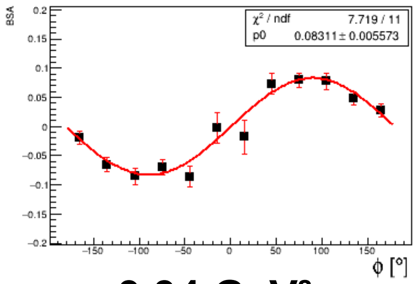
0.11 GeV²



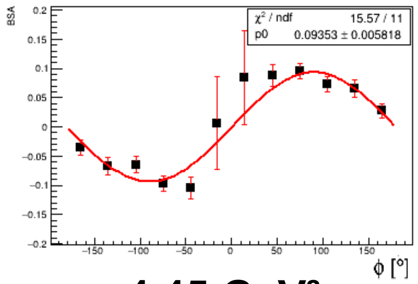
0.26 GeV²



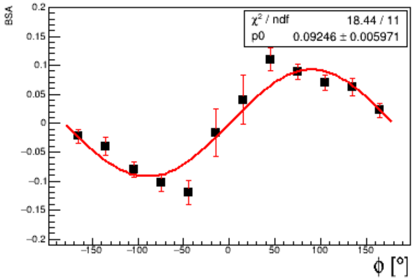
0.56 GeV²



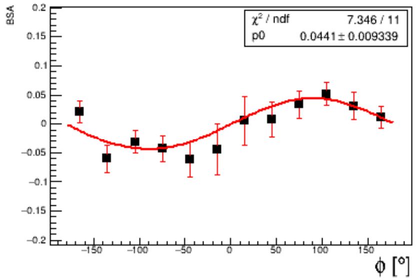
0.96 GeV²



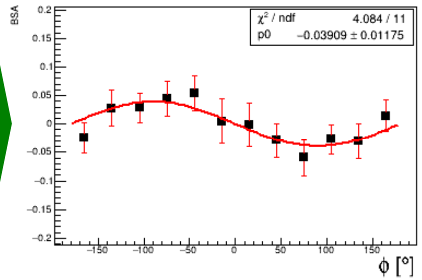
1.55 GeV²



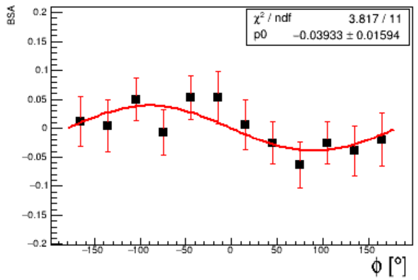
2.34 GeV²



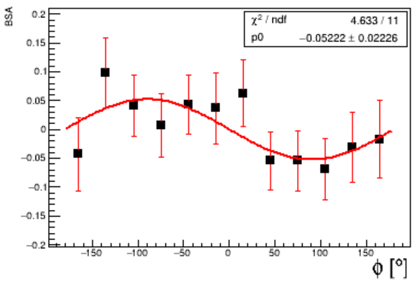
3.34 GeV²



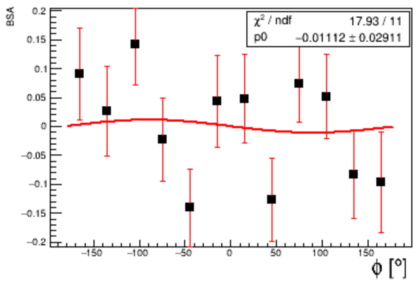
4.45 GeV²



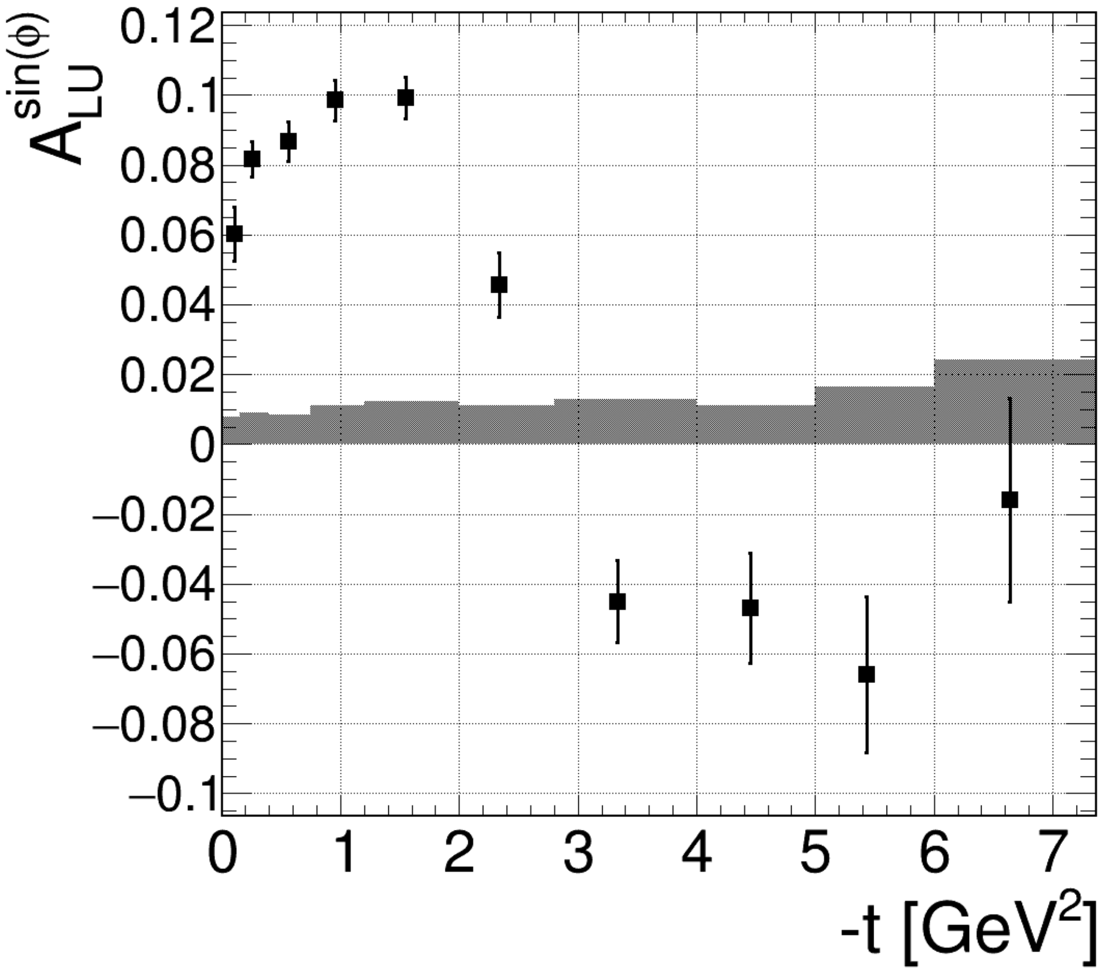
5.44 GeV²



6.64 GeV²



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



Theoretical description for large t (small u):

TDA model with

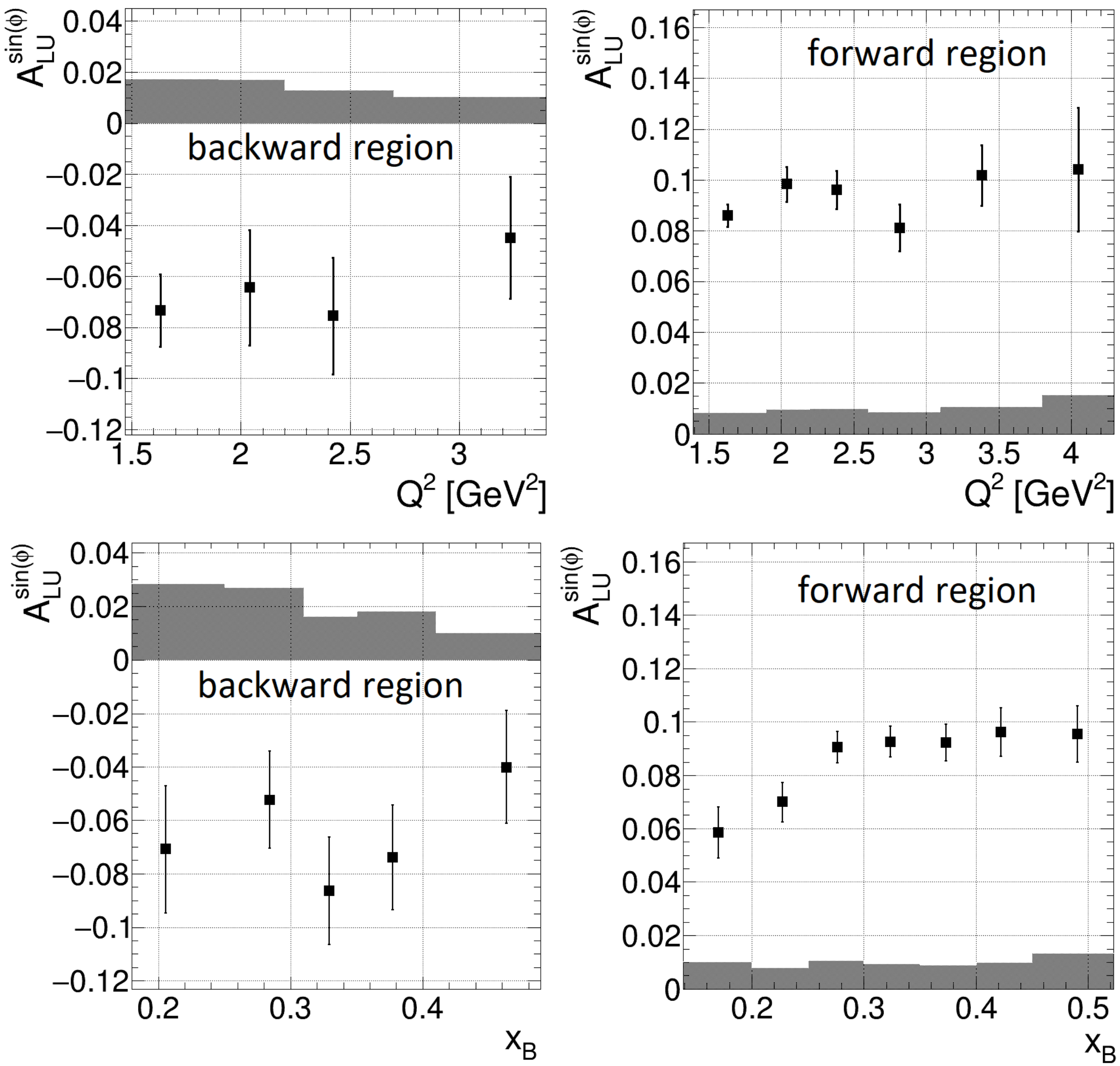
- dominant leading twist transverse amplitude
- next-to leading twist sub-dominant longitudinal amplitude (twist-4 nucleon DAs or twist-4 nucleon-to pion TDAs)

➔ Calculations not available yet

Q² and x_B dependence of $A_{LU}^{\sin(\phi)}$

Q²

x_B



Sign change present for all Q² and x_B bins

forward direction:

flat Q² behaviour due to approximate Bjorken scaling

backward direction:

effect not significant

Summary and Conclusion

- $A_{LU}^{\sin(\phi)}$ moment from the hard exclusive π^+ channel has been extracted for the first time over a large range of kinematics.
- The results show a clear sign change from forward to backward angles, which may indicate a transition from the GPD to the TDA regime.
- Asymmetry moments are proportional to interference terms which amplify small contributions.
- The results will help to constrain the poorly known chiral-odd GPDs and to further develope the TDA modell.
- The crossed reaction $\bar{N}N \rightarrow \gamma^*\pi$ will be accessible with PANDA at FAIR.

Physics motivation

3 dimensional nucelon structure

transverse position
+ long. momentum
distribution

trans. + long.
momentum distr.

GPDs

TDAs

TMDs

DVCS

+ Clean process
- Only sensitive to chiral even GPDs

DVMP

+ Enables flavour decomposition
+ Access to chiral-odd GPDs
- Distribution Amplitude (DA) is involved as an additional soft non pert. quantity

SIDIS

Drell-Yan process