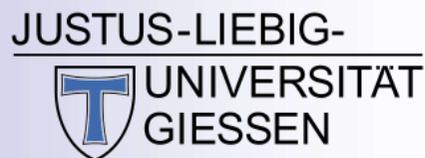




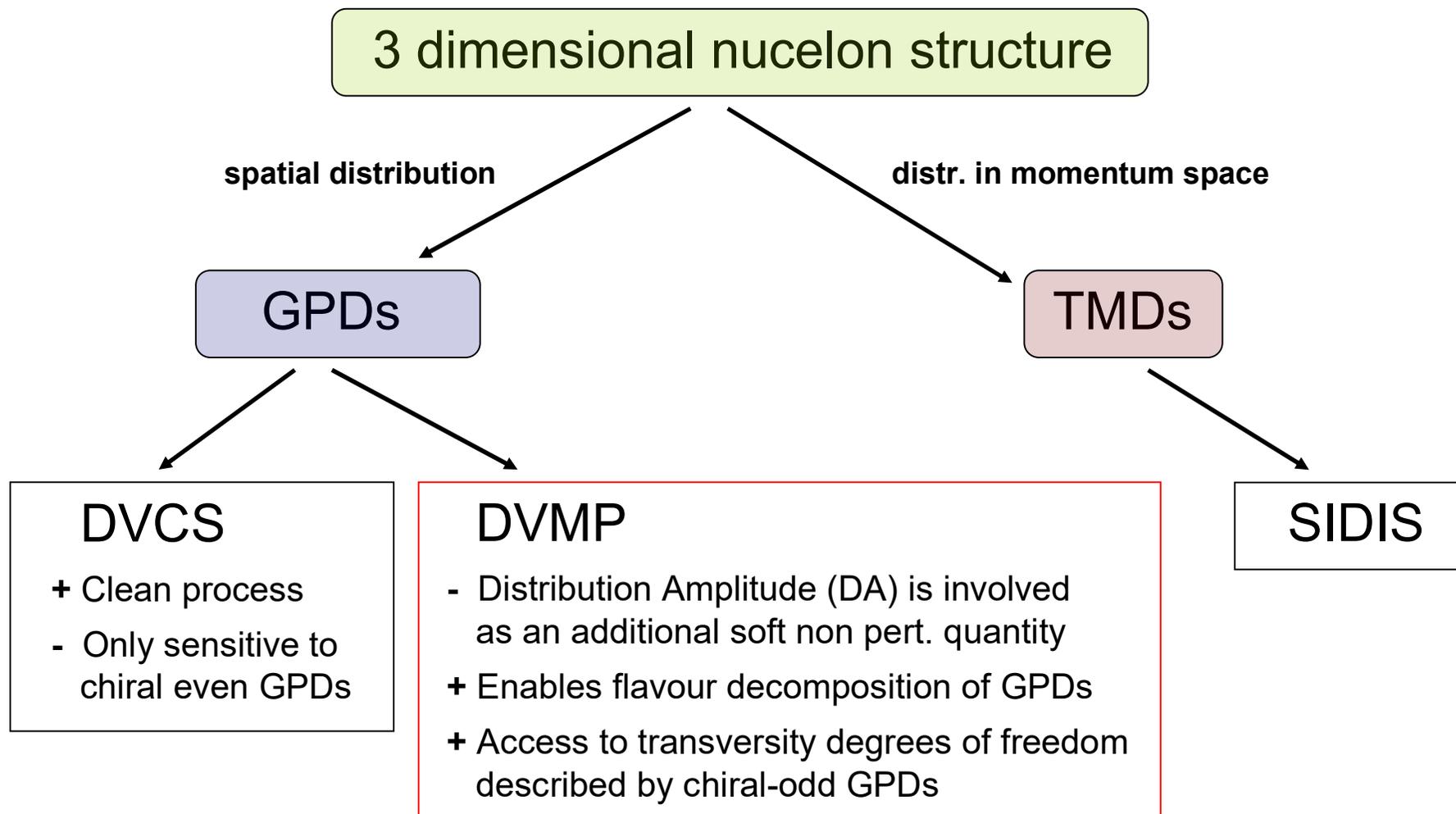
# TDA measurements based on hard exclusive pion electroproduction with CLAS at JLAB



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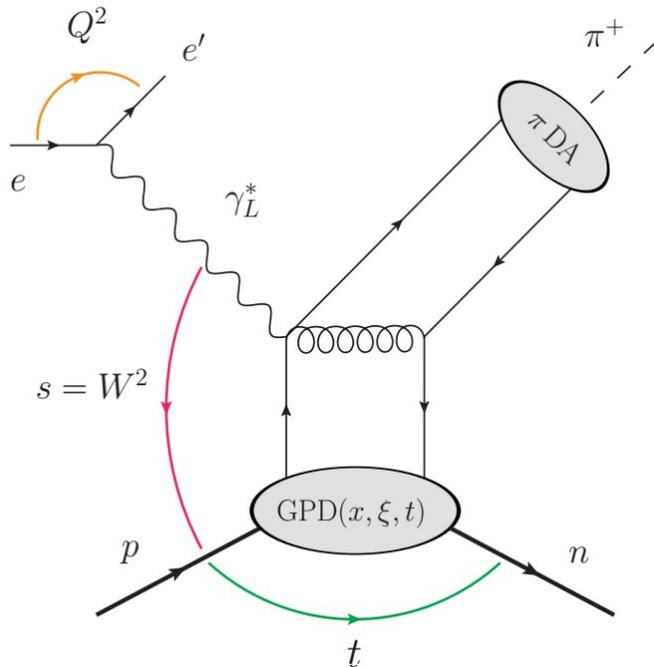
# Physics motivation



# Hard exclusive $\pi^+$ electroproduction $ep \rightarrow en\pi^+$

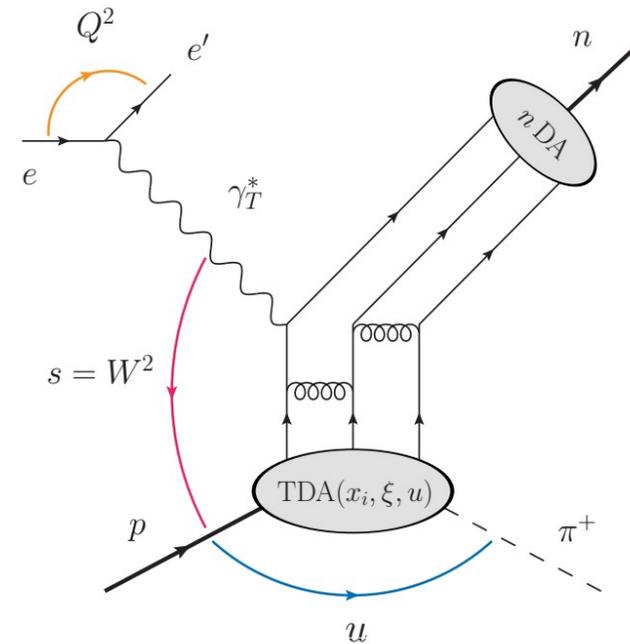
colinear factorization theorem

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



$\pi^+$  in forward region

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



$\pi^+$  in backward region

## Physics motivation

**GPDs:** describe hadronic structural information in terms of quark and gluon degrees of freedom

- tool to study the nature and origin of the nucleon spin
- interpretation in the impact parameter space as spatial femto-photographs of the hadron structure in the transverse plane

**Baryon to meson TDAs:** encoded physical picture close to GPDs

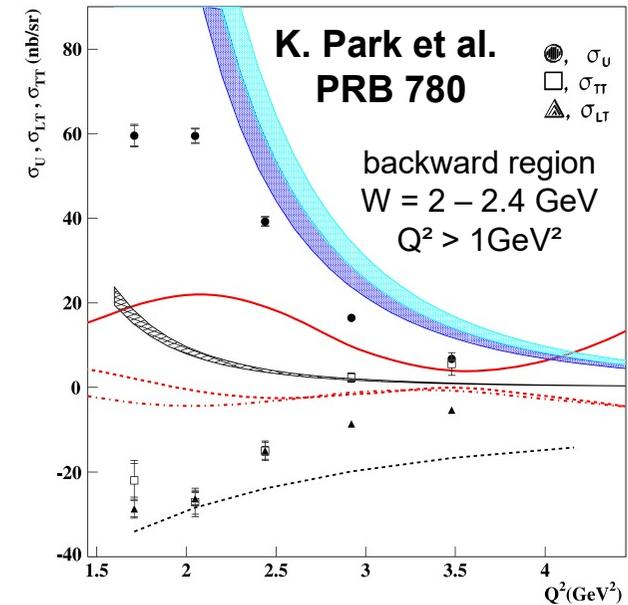
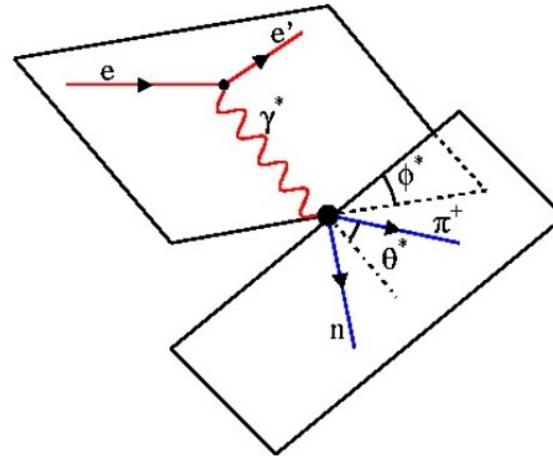
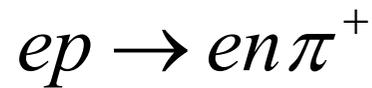
- probe partonic correlations between states of different baryonic charge
- access to non-minimal Fock components of baryon light-cone wave functions

Fourier transforming TDAs to the impact parameter space:

- Femto-photography of hadrons from a new perspective
- Spatial imaging of the structure of the pion cloud inside the nucleon

**Aim:** Investigate the GPD and TDA kinematic regime and study the transition from the GPD to the TDA formalism

# Hard exclusive $\pi^+$ electroproduction



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

$$\frac{d\sigma_\nu}{d\Omega_\pi} = \frac{d\sigma_T}{d\Omega_\pi} + \epsilon_L \frac{d\sigma_L}{d\Omega_\pi} + \sqrt{2\epsilon_L(1+\epsilon)} \frac{d\sigma_{TL}}{d\Omega_\pi} \cos(\phi_\pi) + \epsilon \frac{d\sigma_{TT}}{d\Omega_\pi} \cos(2\phi_\pi) + h\sqrt{2\epsilon_L(1-\epsilon)} \frac{d\sigma_{TL'}}{d\Omega_\pi} \sin(\phi_\pi)$$



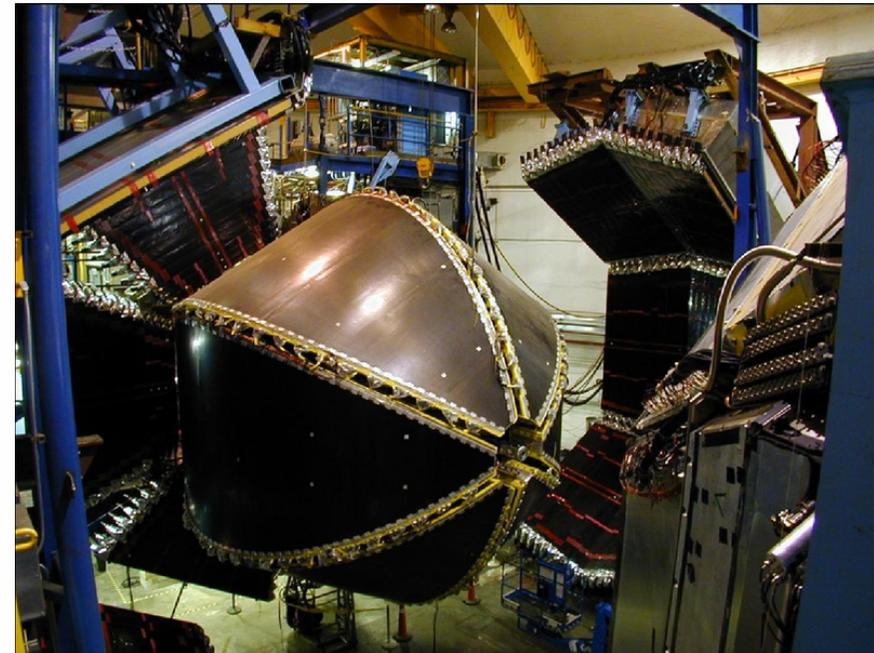
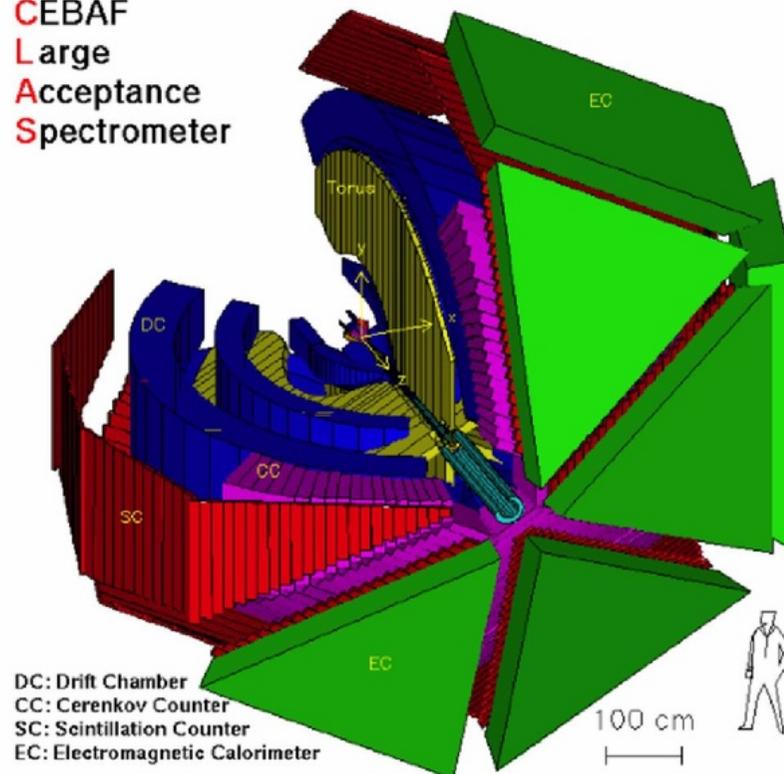
$$\frac{d^4\sigma}{dQ^2 dx_B d\phi dt} = \sigma_0 + A_{UU}^{\cos(2\phi)} \cdot \cos(2\phi) + A_{UU}^{\cos(\phi)} \cdot \cos(\phi) + h_L \cdot A_{LU}^{\sin(\phi)} \cdot \sin(\phi)$$



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

## Experimental Setup

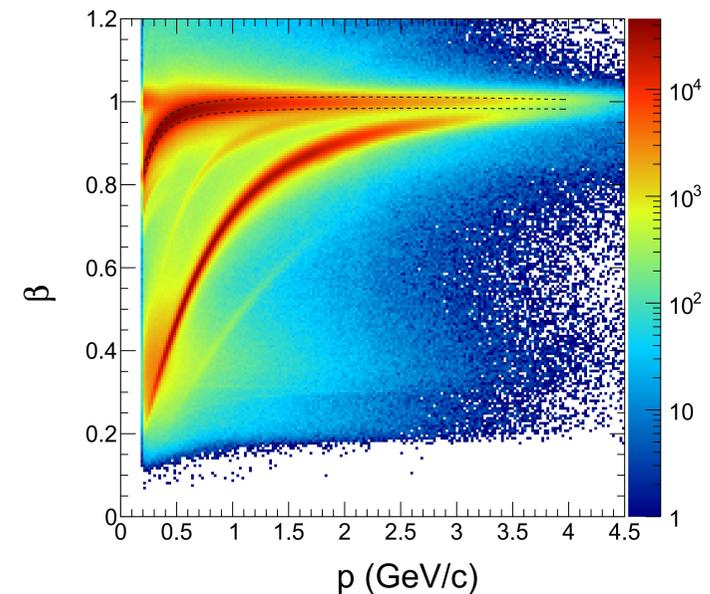
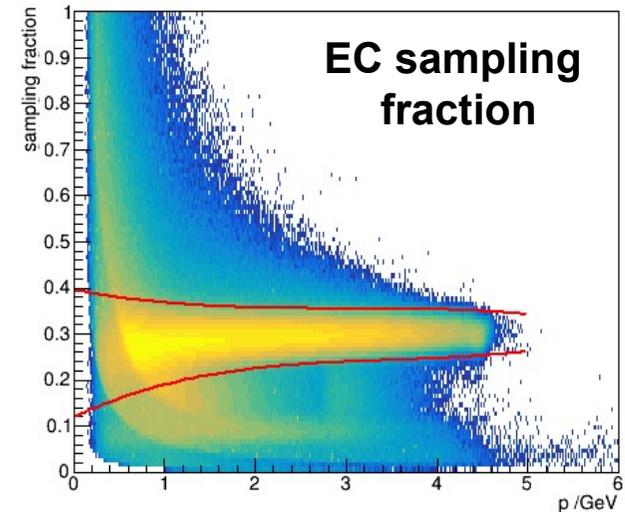
CEBAF  
Large  
Acceptance  
Spectrometer



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

## Particle identification

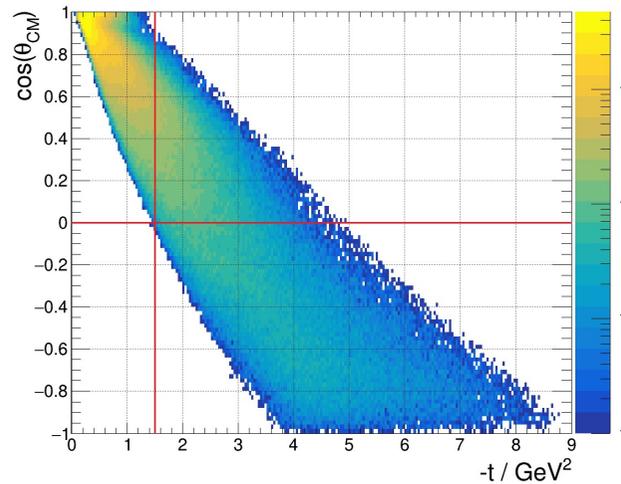
- **Electron ID** based on electromagnetic calorimeter and Cherenkov counters
- **$\pi^+$  ID** based on a maximum likelihood particle selection from TOF based  $\beta$  vs  $p$  correlation



# Kinematic regions and exclusivity cuts

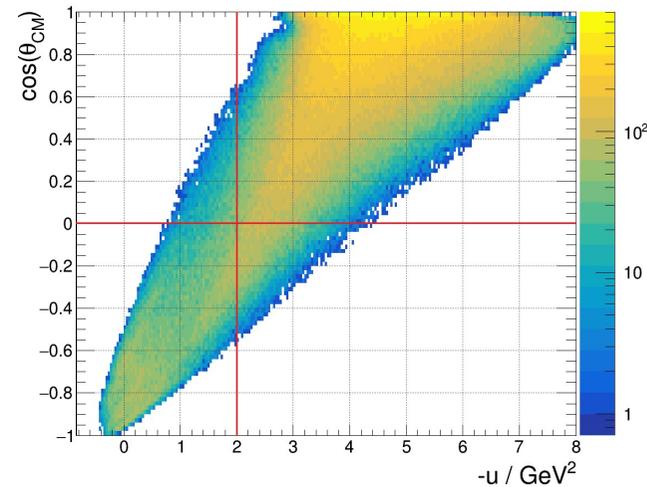
forward region „small  $t$ “

$-t < 1.5 \text{ GeV}^2$   
 $\cos(\theta) > 0$

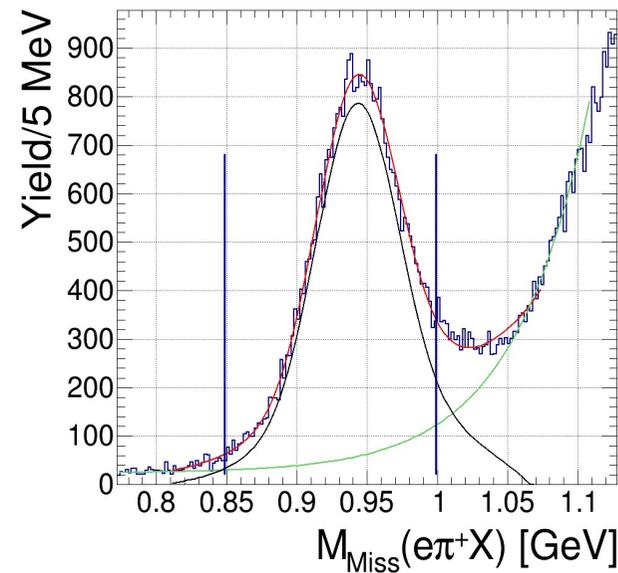
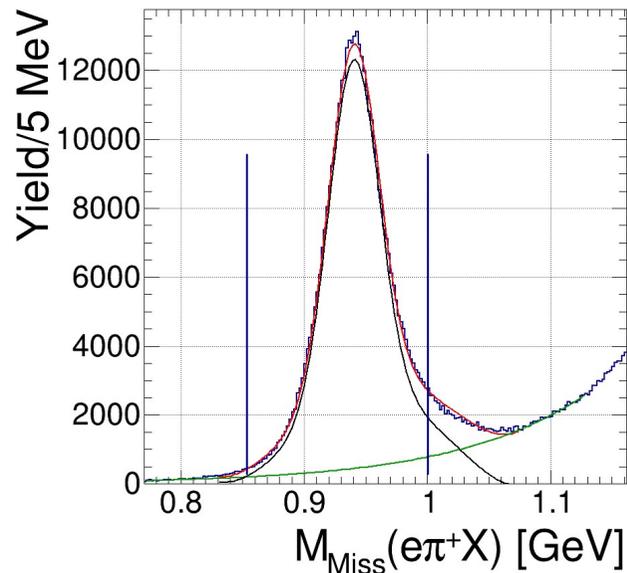


backward region „small  $u$ “

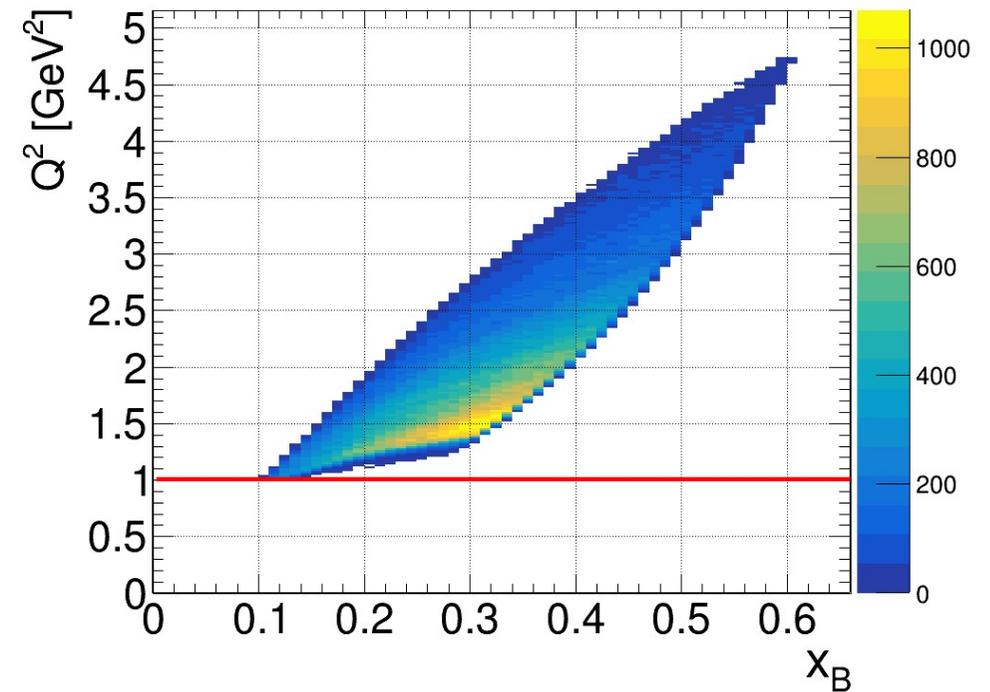
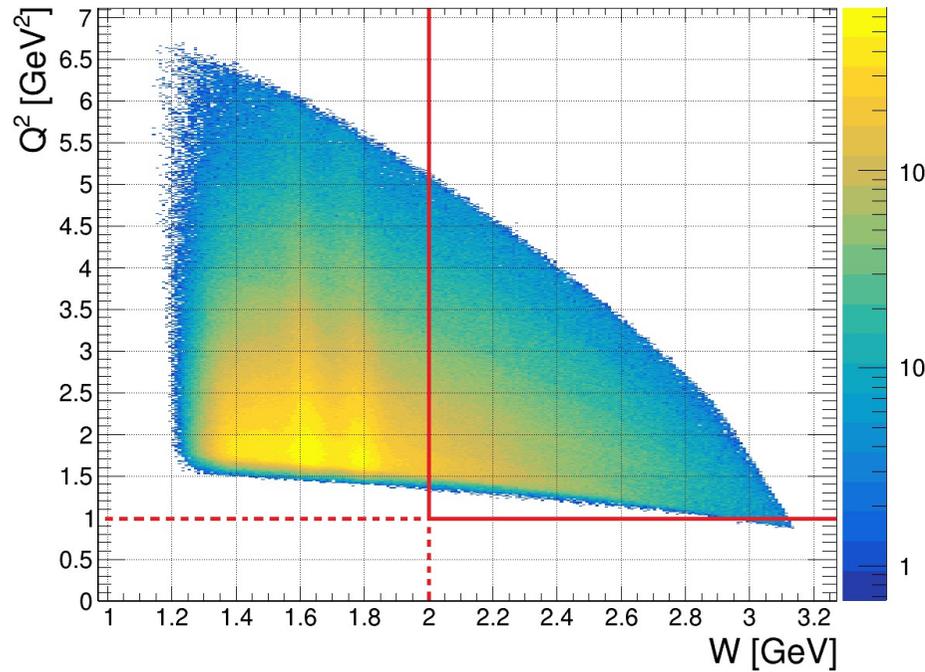
$-u < 2.0 \text{ GeV}^2$   
 $\cos(\theta) < 0$



missing  
mass



## Kinematic coverage and cuts

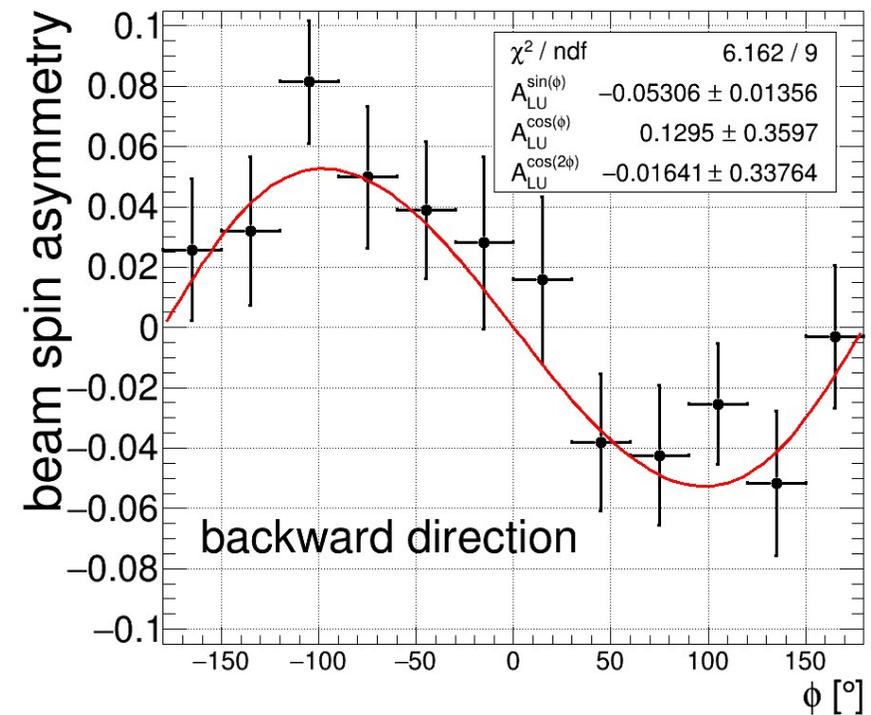
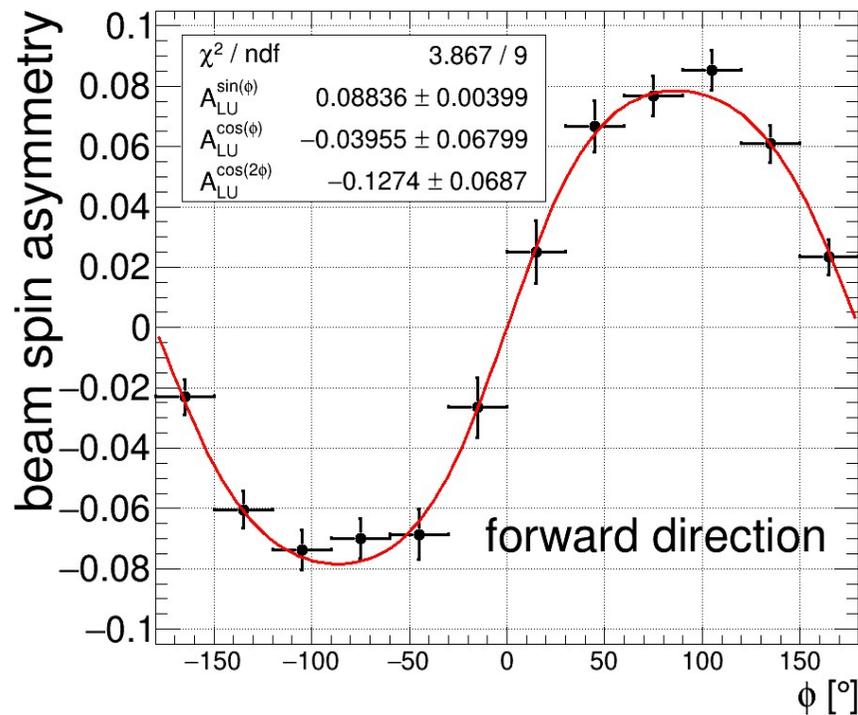


**DIS cut:  $W > 2$  GeV  $Q^2 > 1$  GeV<sup>2</sup>**

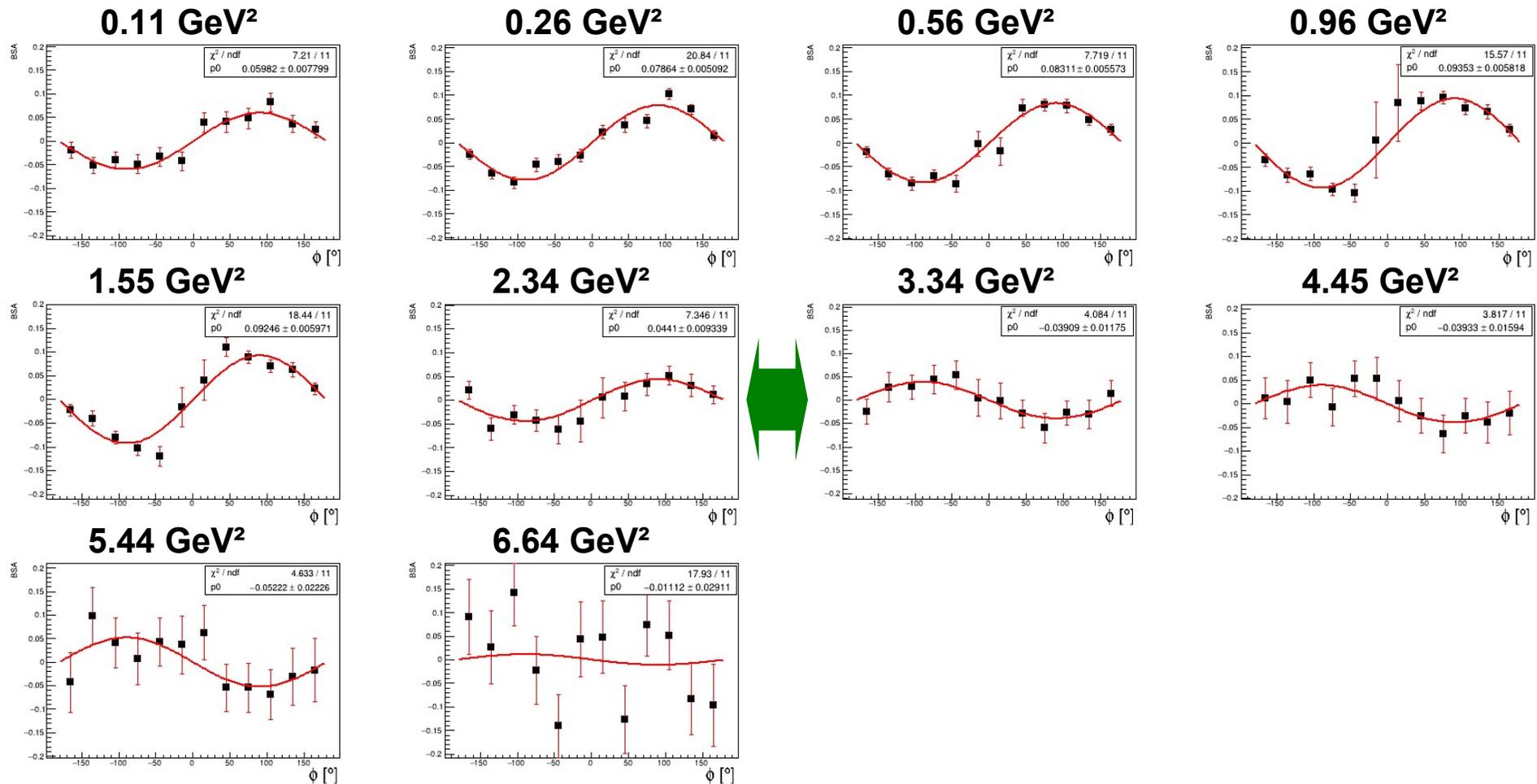
## Beam spin asymmetry

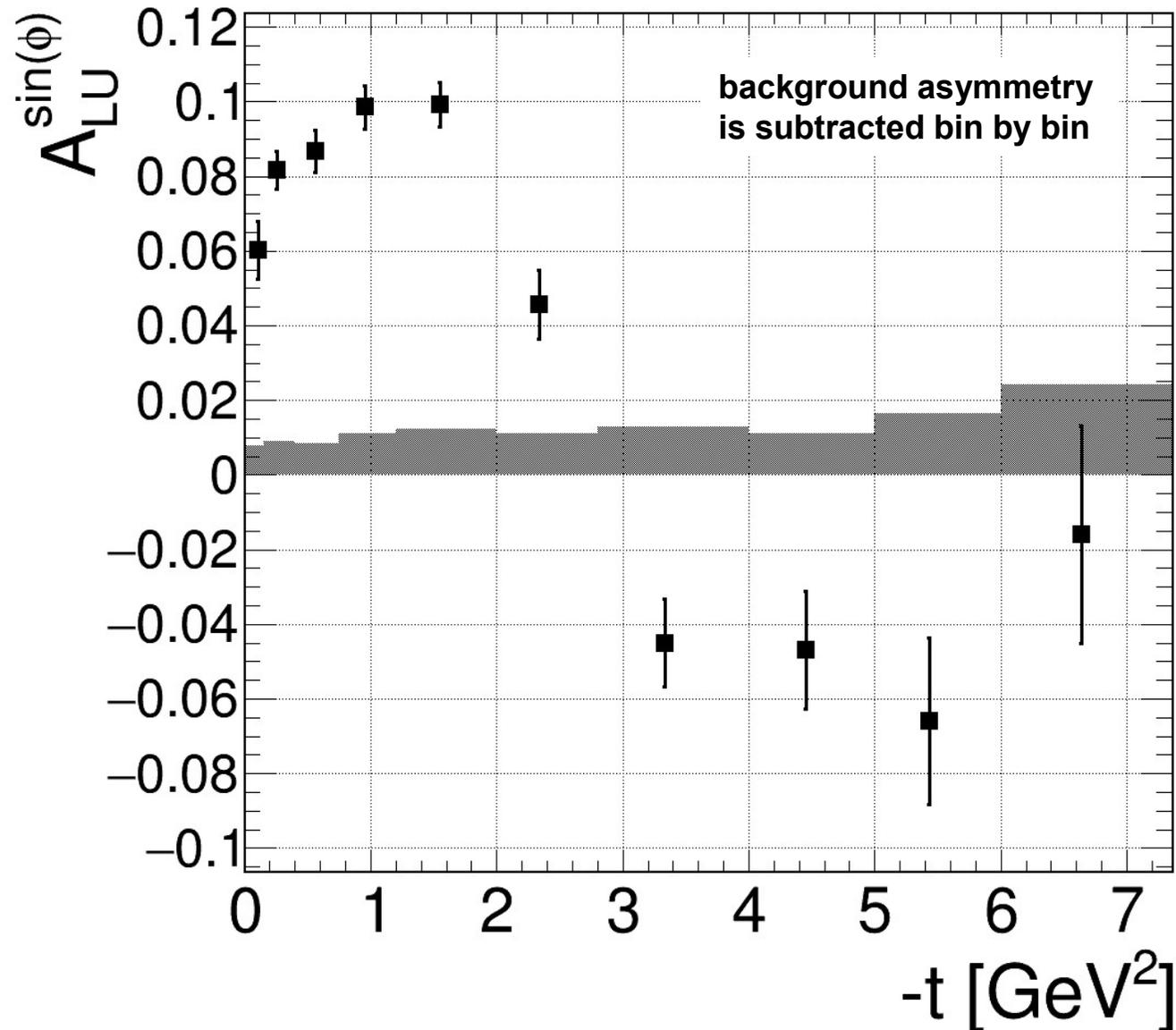
$$BSA_i = \frac{1}{P_e} \cdot \frac{N_i^+ - N_i^-}{N_i^+ + N_i^-} \quad P_e = 75 \% : \text{average } e^- \text{ beam polarisation}$$

Integrated over all kinematic variables in forward / backward region:

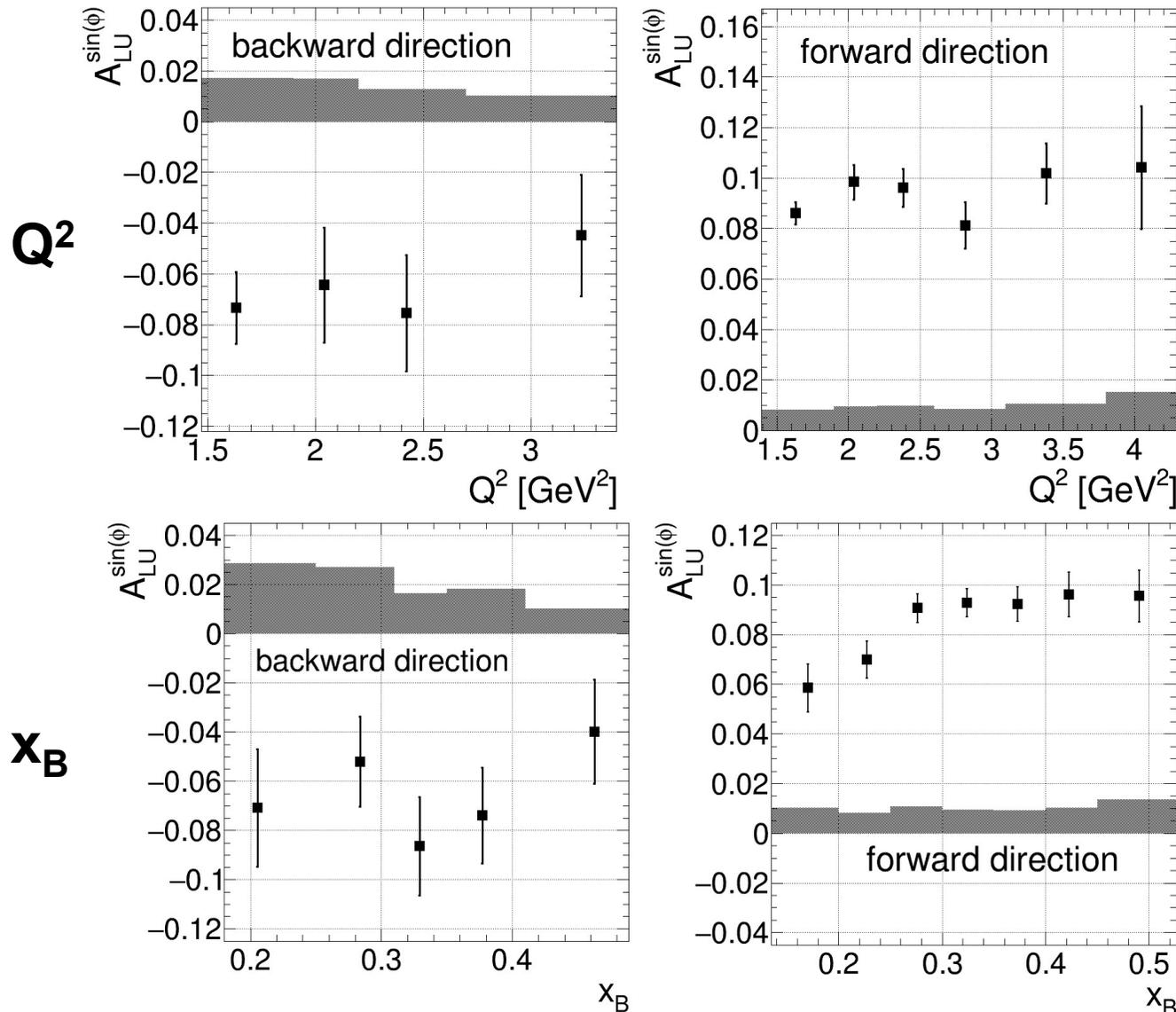


# BSA for different -t bins



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

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



BSA vanishes in leading twist in forward and backward region

decrease with  $1/Q^2$  for large  $Q^2$  expected

**forward region:**  
factorisation is delayed

**backward region:**  
hint for early settlement of factorisation

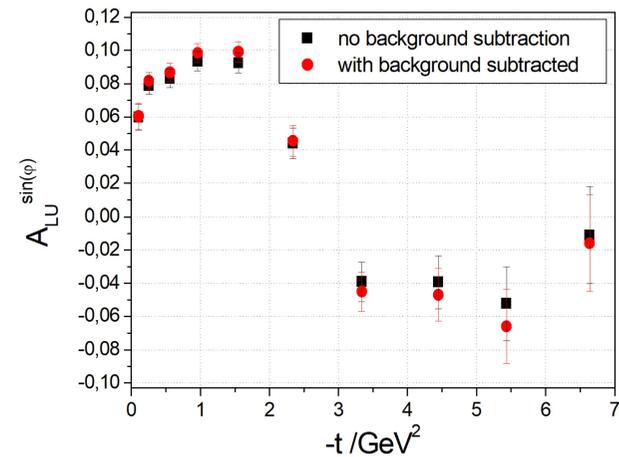
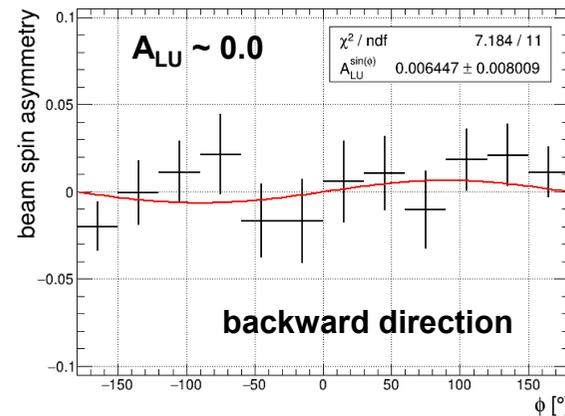
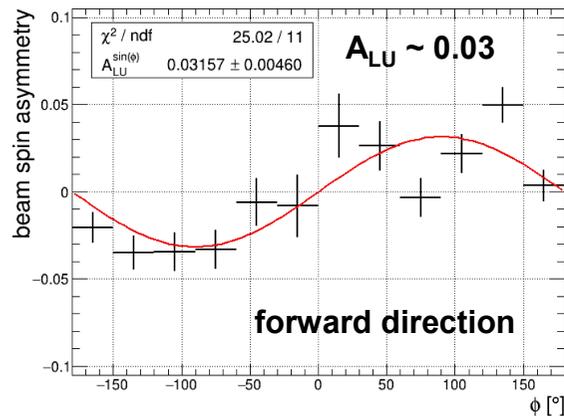
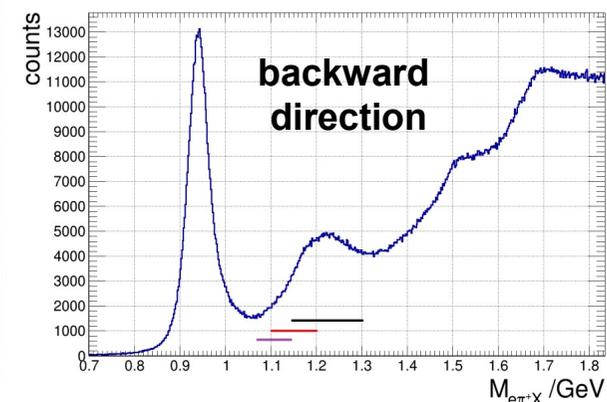
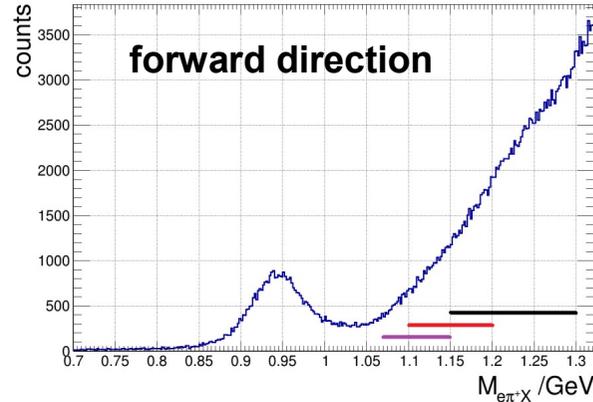
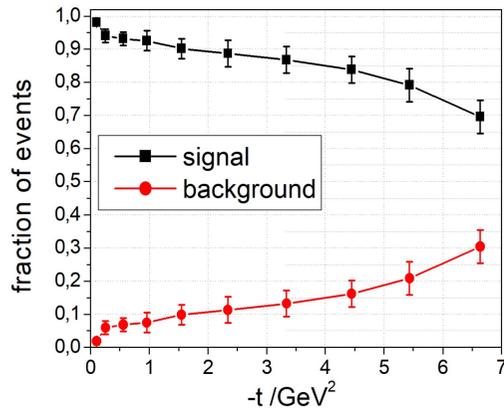
also shown for  $\omega$   
W. Li et al. arXiv: 1712.03214

## Summary and Conclusion

- $A_{LU}^{\sin(\phi)}$  moment from the hard exclusive  $\pi^+$  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.
- Measurements with higher statistics will be performed with CLAS12 to test the  $1/Q^2$  scaling for the exclusive  $\pi^+$  channel and to access different reactions.
- The crossed reaction  $\bar{N}N \rightarrow \gamma^* \pi$  will be accessible with PANDA at FAIR.

# Influence of the background asymmetry

- The background asymmetry has been determined and subtracted for each bin



$$A_{LU\text{-real}}^{\sin(\phi)} = \frac{A_{LU\text{-measured}}^{\sin(\phi)} - A_{LU\text{-backg.}}^{\sin(\phi)} * \text{background}}{\text{signal}}$$