The 52nd Reimei Workshop
"Hadronic Resonances and Dense Nuclear Matter"

January 9 - 11, 2019

Extraction of beam spin asymmetry moments from deeply virtual meson production with CLAS and CLAS12 at JLAB

Stefan Diehl

University of Connecticut

Justus Liebig University Giessen

Jefferson Loaboratory

Newport News

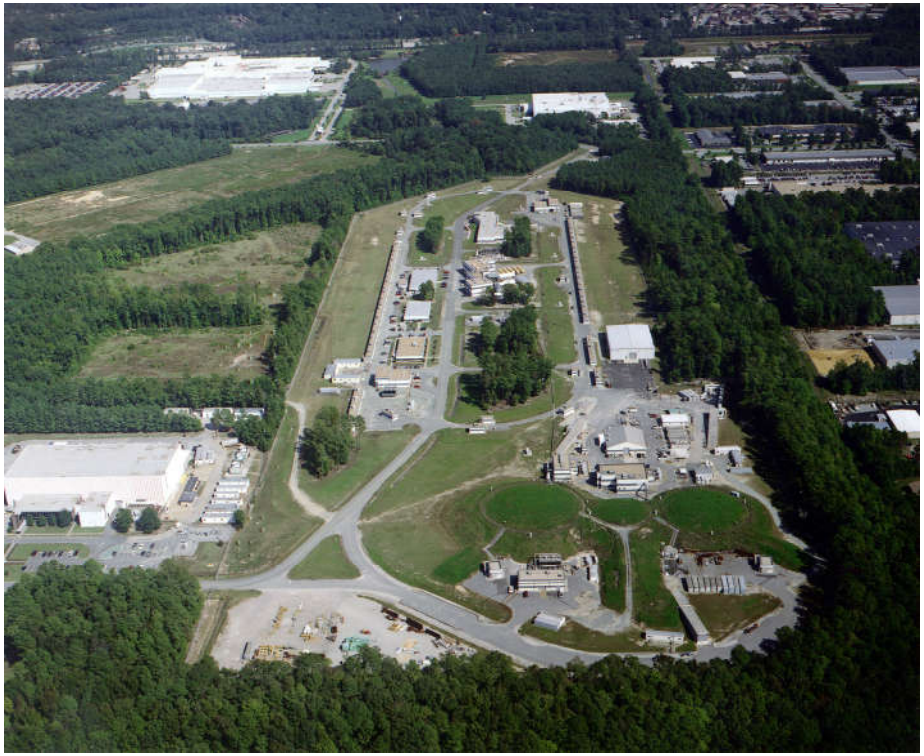
Virginia, USA

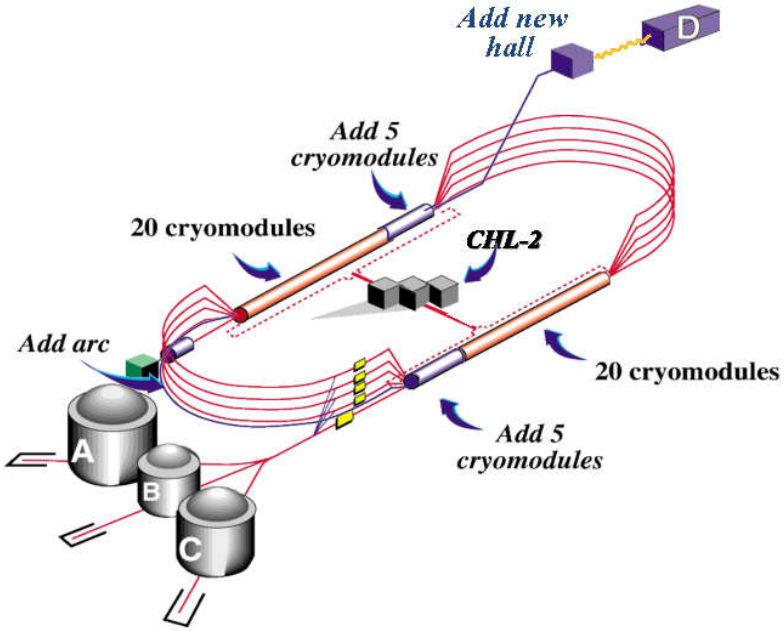
until 2014:

6 GeV polarized electron beam
3 experimental halls

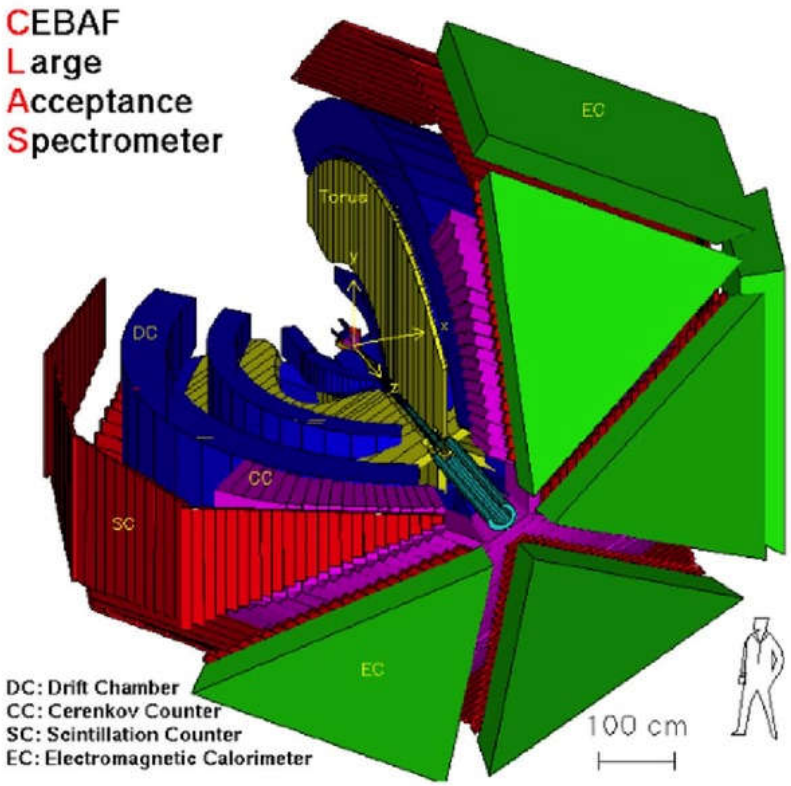
since 2017:

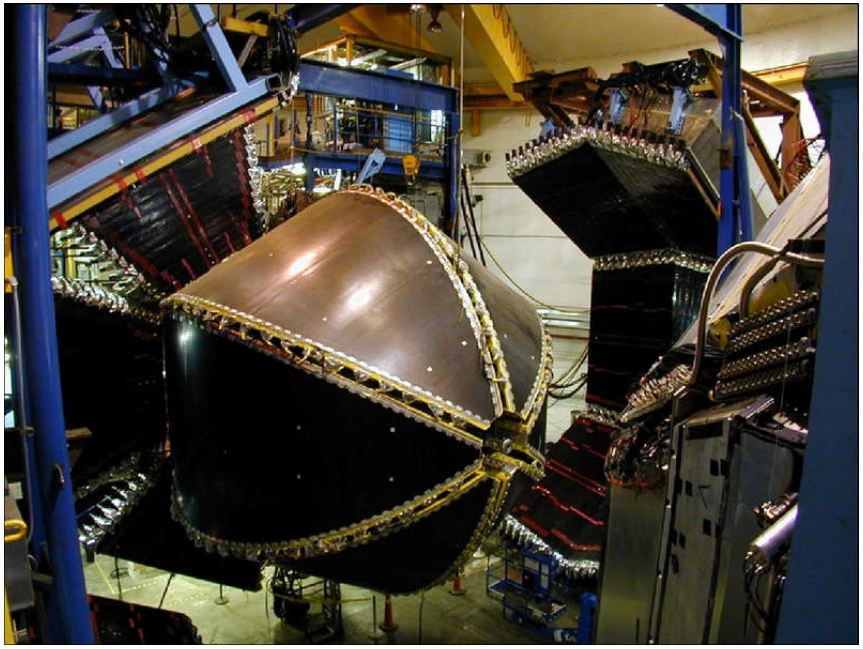
10.6 GeV polarized electron beam
4 experimental halls





Hall B until 2014: CLAS detector





Hall B since 2017: CLAS 12

(constructed 2014 – 2017)

Forward Detector:

- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter/ RICH detector
- Forward Time-of-Flight
- E.M. calorimeter

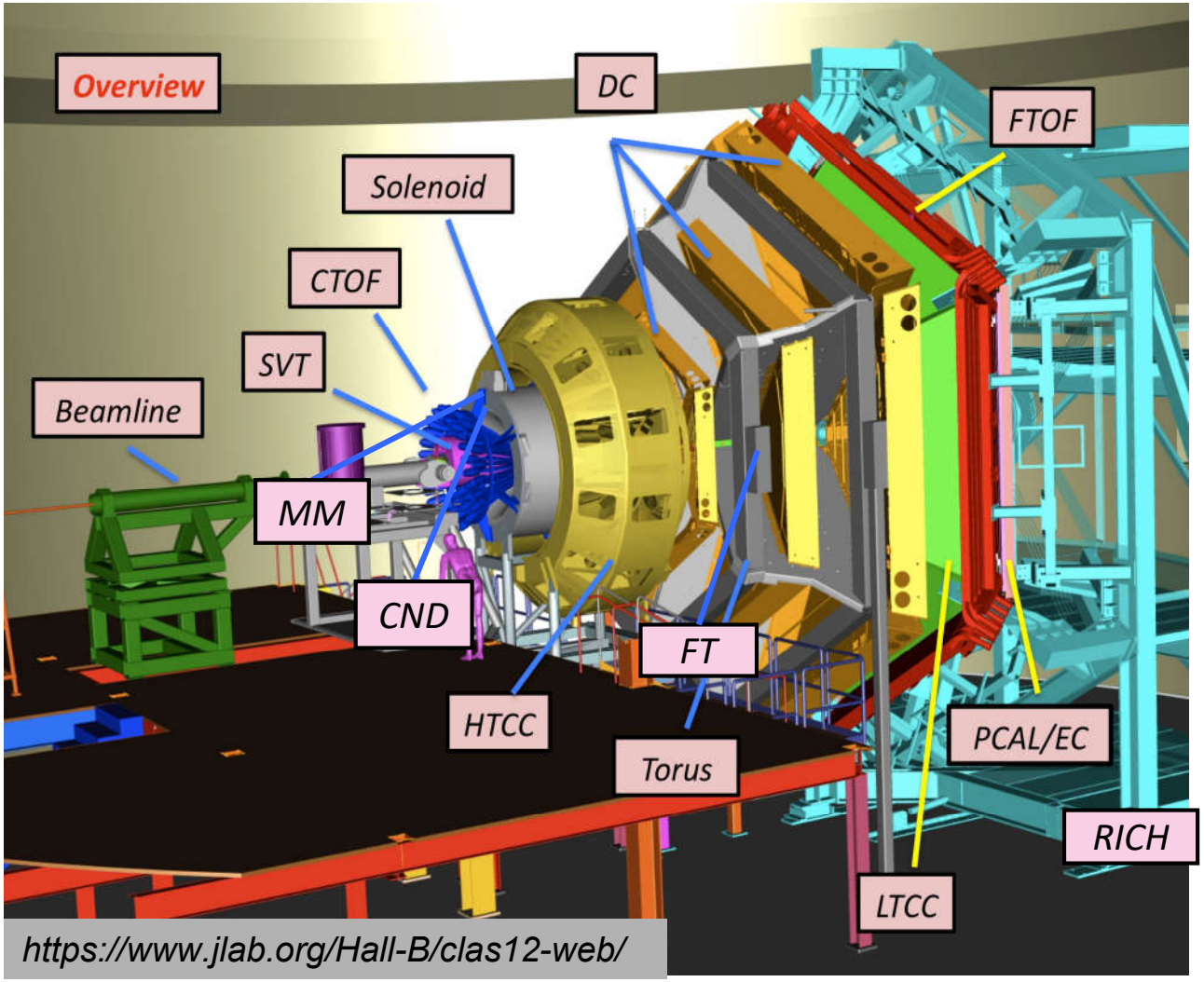
Central Detector:

- SOLENOID magnet
- Micromegas Tracker
- Barrel Silicon Tracker
- Central Time-of-Flight
- Neutron detector

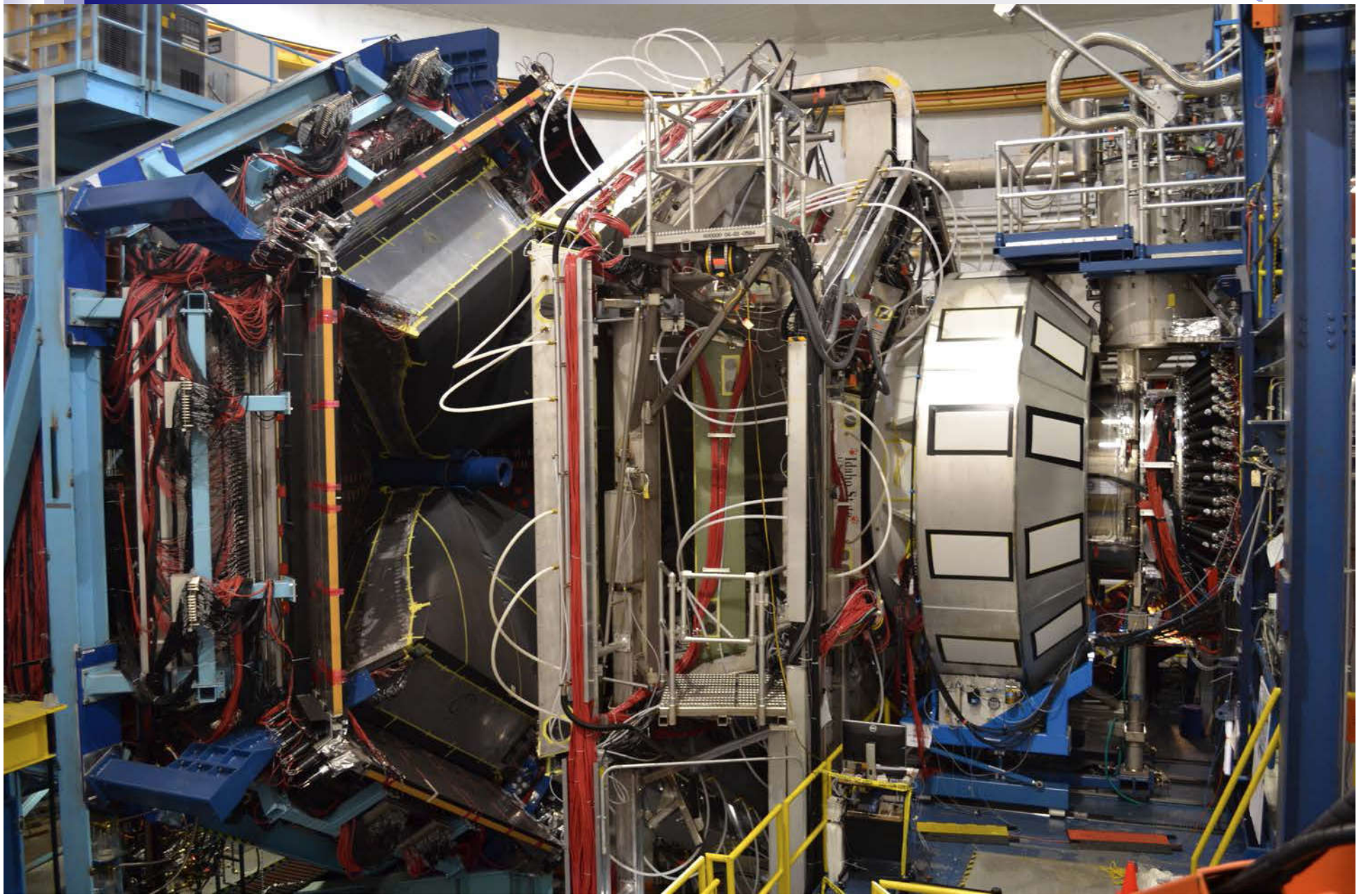
Extended Setup:

- Forward Tagger

~100,000 readout channels



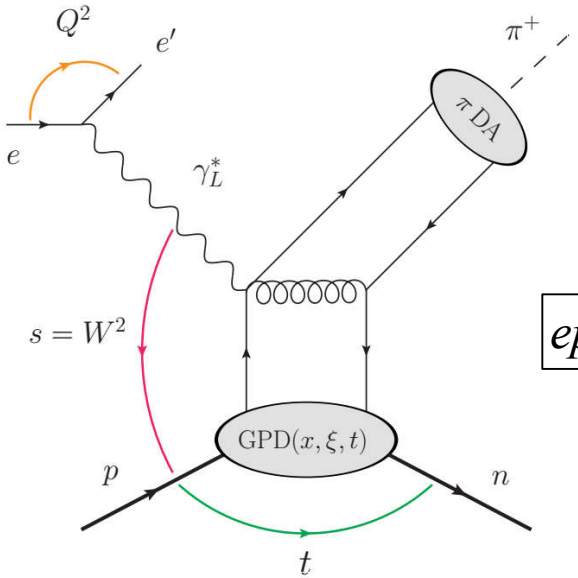
https://www.jlab.org/Hall-B/clas12-web/



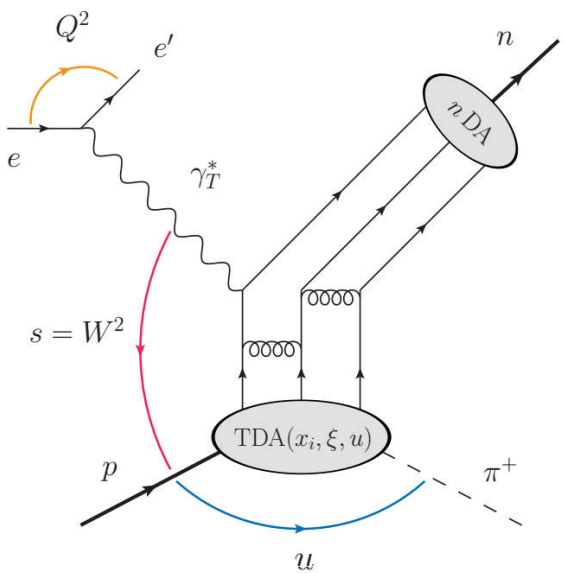
Extraction of $A_{LU}^{\sin(\varphi)}$ from the hard exclusive π^+ channel

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

Physics motivation



$ep \to en\pi^+$



forward region

small t / large u channel contribution

backward region

small u / large t channel contribution

Theory: Common features between baryon to meson TDAs, nucleon DAs and GPDs

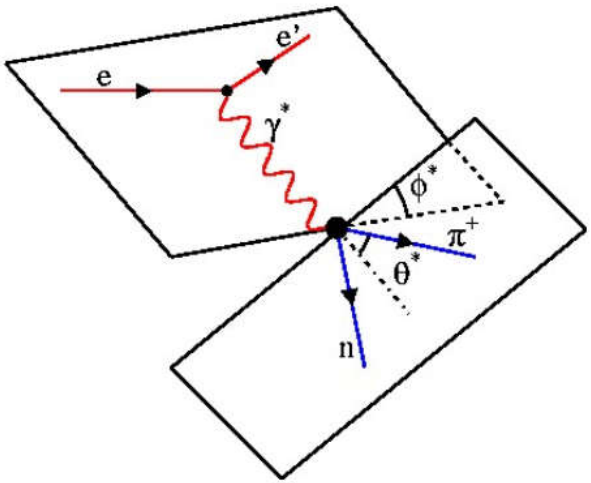
→ Partonic correlations inside a nucleon with the momentum distribution of the nucleon's baryon density

→ Similar to GPDs, a Fourier transformed TDA ($_T \to$ **b**) allows an impact-parameter interpretation for TDAs in the transverse plane

Aim: Study the transition from the GPD to the TDA formalism

Hard exclusive π⁺ electroproduction

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



Cross section:

$$\frac{d^4\sigma}{dQ^2 dx_B d\phi dt} \sim \sigma_T + \varepsilon_L \sigma_L + \varepsilon \cdot \sigma_{TT} \cdot \cos(2\phi) + \sqrt{2 \cdot \varepsilon_L \cdot (1+\varepsilon)} \cdot \sigma_{LT} \cdot \cos(\phi) + h \cdot \sqrt{2 \cdot \varepsilon_L \cdot (1-\varepsilon)} \cdot \sigma_{LT'} \cdot \sin(\phi)$$

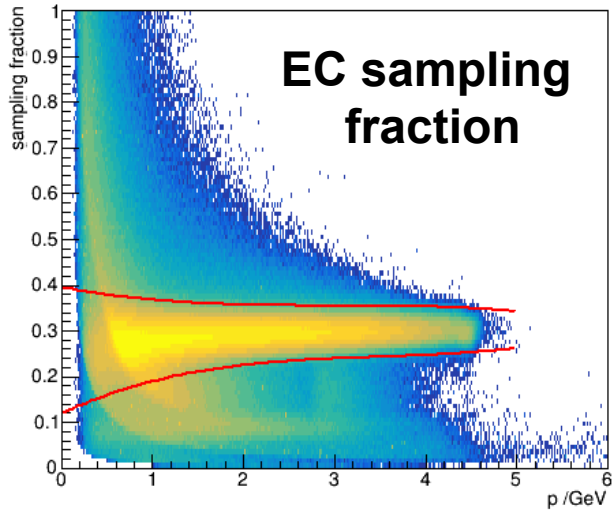
$$\Rightarrow \quad d\sigma = d\sigma_0 (1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos 2\phi} \cos 2\phi + \lambda_e A_{LU}^{\sin\phi} \sin\phi)$$

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

Particle identification

Electron ID

→ Based on the electromagnetic calorimeter and the cherenkov counters

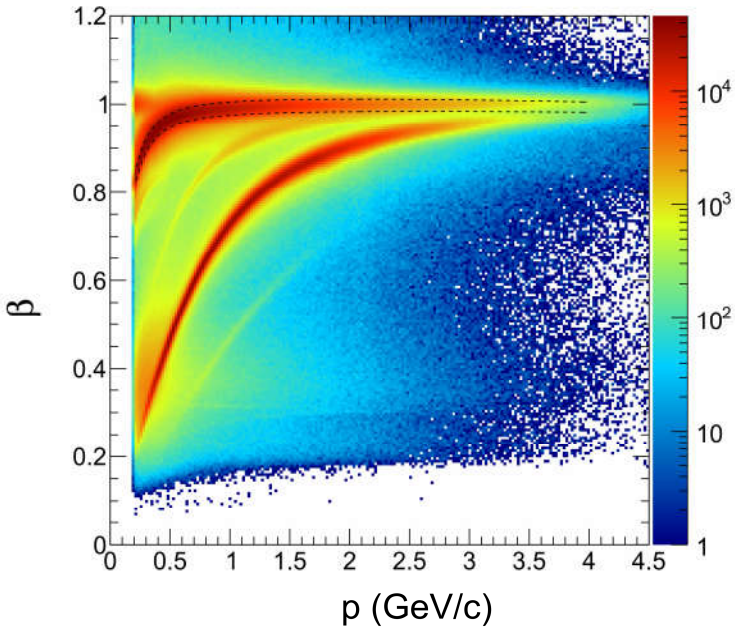


π^+ ID

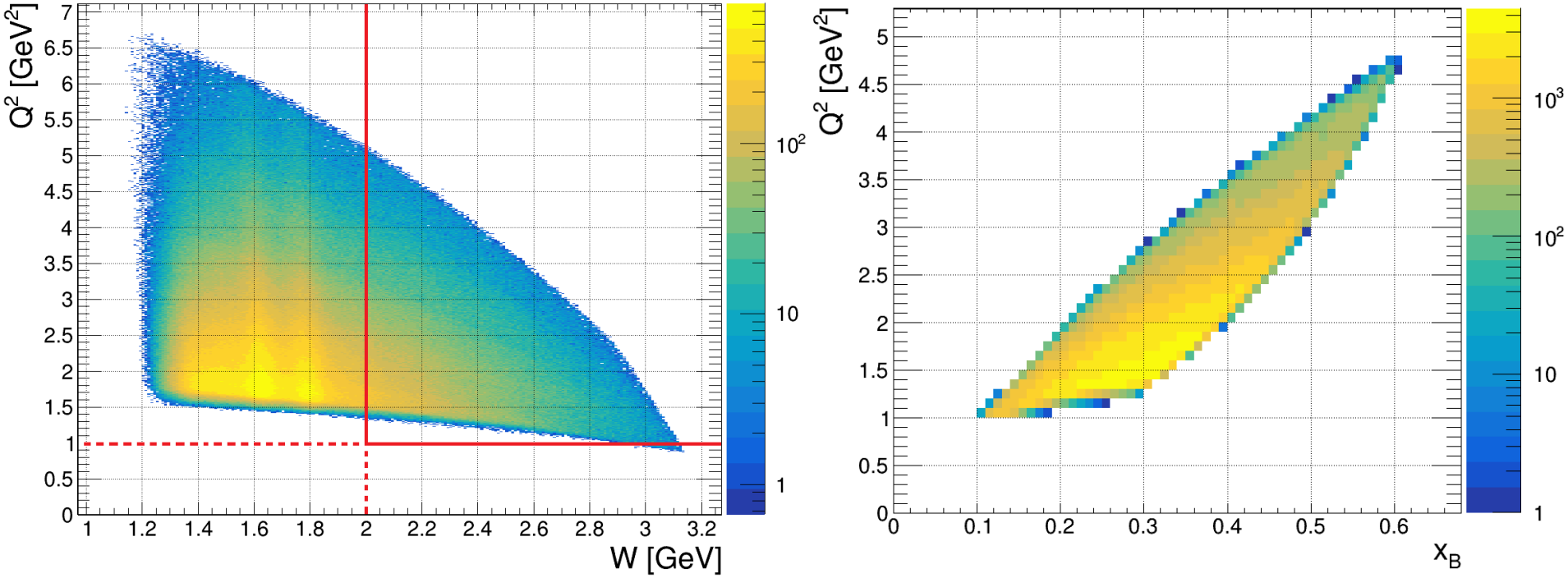
→ Positive charge

→ Fiducial cuts on the hit position in the drift chambers

→ Particle selection based on β vs p correlation



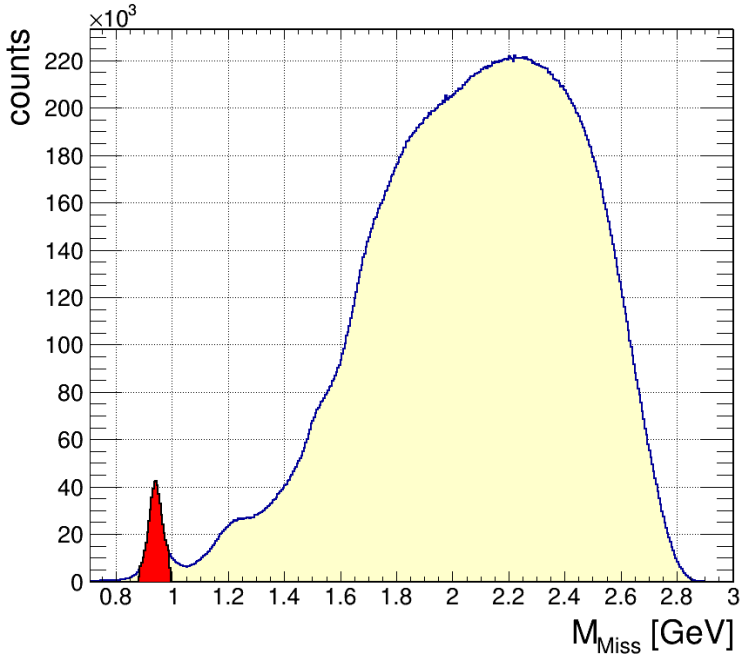
Kinematic coverage and cuts

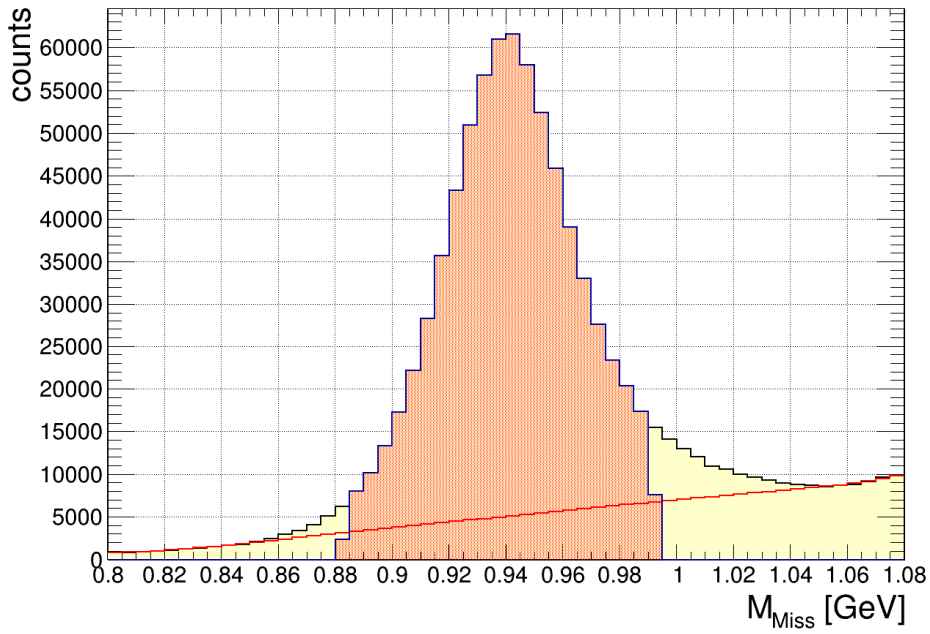


DIS cut: W > 2 GeV Q² > 1 GeV²

Selection of exclusive events

e π^+ X

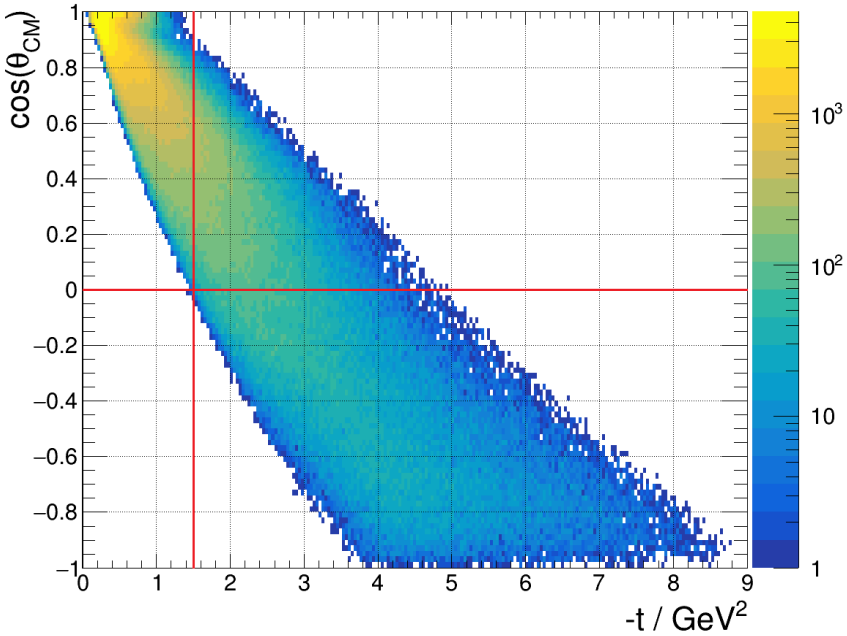




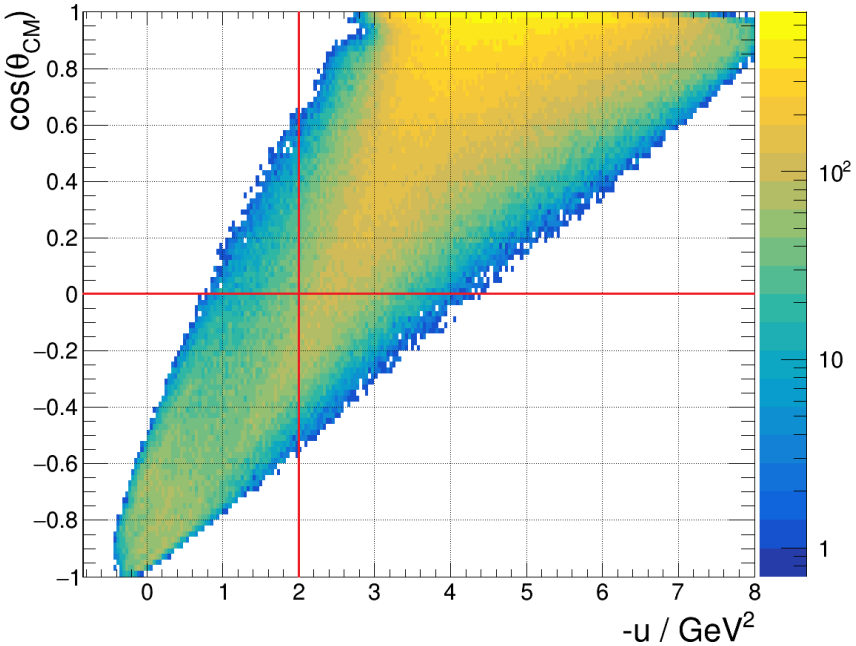
- 3 σ cut on the missing neutron peak
- ≤ 10% background

Separation of forward and backward region

forward region
„small t“



backward region
„small u“



$-t < 1.5\ \mathrm{GeV}^2$

$\cos(\theta) > 0$

$-u < 2.0\ \mathrm{GeV}^2$

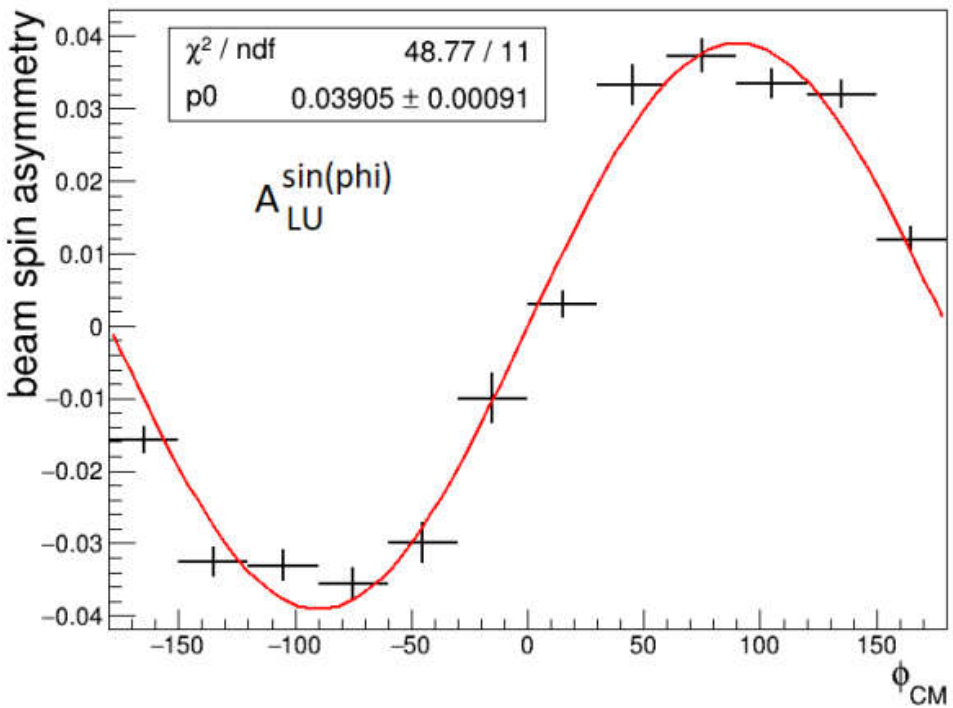
$\cos(\theta) < 0$

Beam spin asymmetry

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

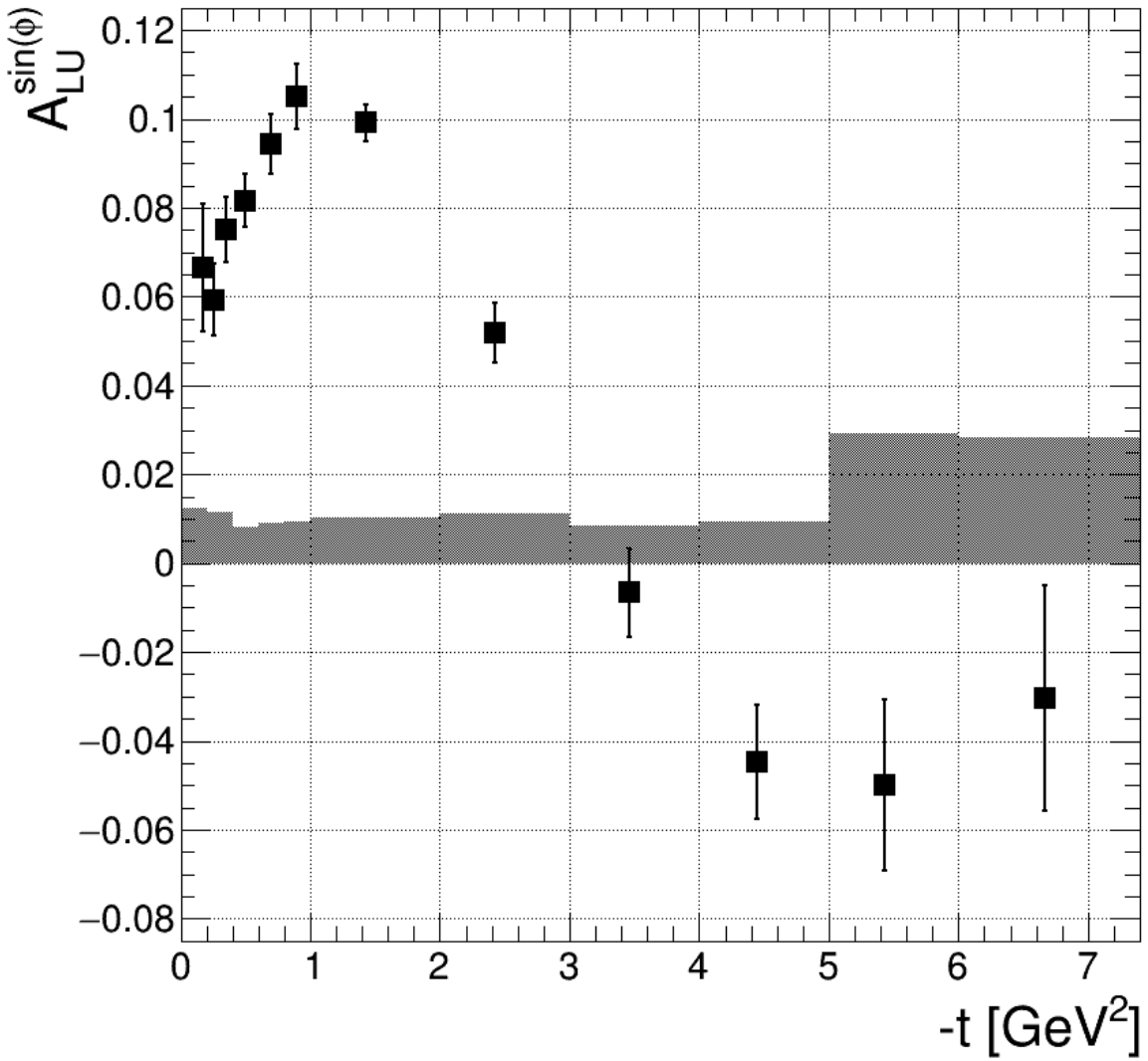
P_e = 75 % : average e^- beam polarisation

Integrated over all kinematic variables in the forward region:



$$A_{LU}^{\sin\varphi} \sin\varphi$$

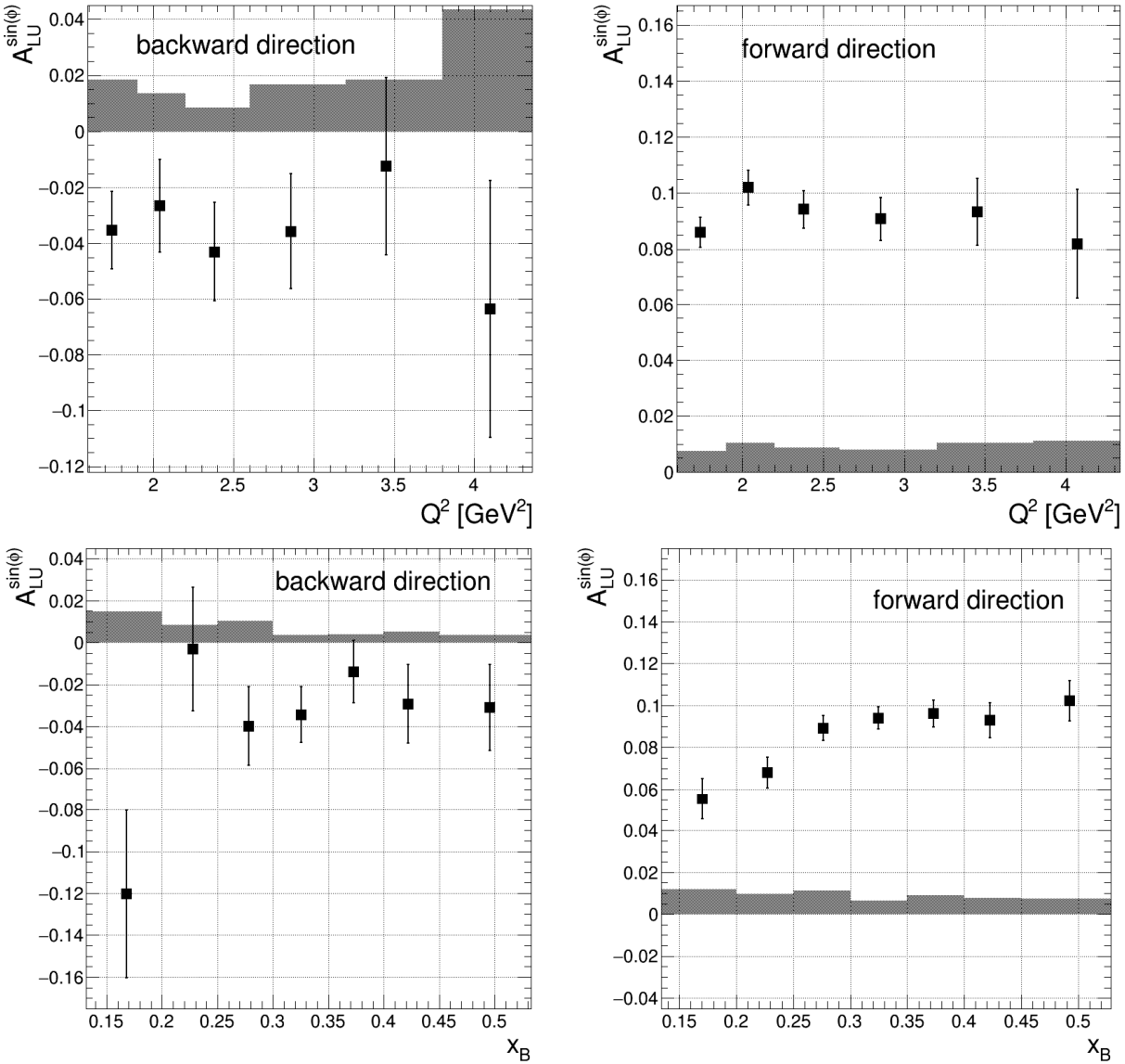
Results


$A_{LU}^{\sin(\phi)}$
0.12
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
0
1
2
3
4
5
6
7
-t [GeV^2]

Results

Q^2

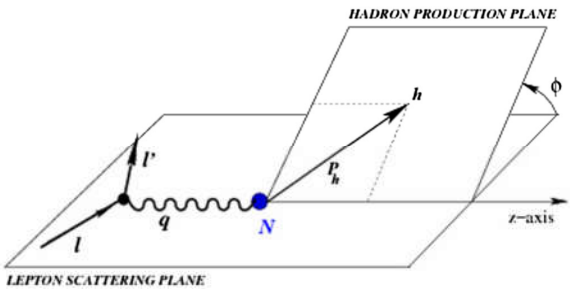
x_B



SIDIS Pion Beam Spin Asymmetries with CLAS12 at 10.6 GeV

Physics Motivation

- The 3D nucleon structure can be described by GPDs and TDAs
- A way to acess these properties is the semi inclusive deep inelastic scattering



The SIDIS cross section for an unpolarized target:

→ Contains model independent structure functions

$$\frac{d\sigma}{dx_B\, dQ^2\, dz\, d\phi_h\, dp_{h\perp}^2} = K(x,y,Q^2)\Big\{F_{UU,T} + \varepsilon F_{UU,L}$$

$$+\sqrt{2\,\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)F_{UU}^{\cos 2\phi_h} + \lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\sin\phi_h \underline{F_{LU}^{\sin\phi_h}}\Big\}$$

$$F_{LU}^{\sin\phi} = \frac{2M}{Q}\mathcal{C}\left(-\frac{\hat{\mathbf{h}}\cdot\mathbf{k_T}}{M_h}\left(xeH_1^{\perp} + \frac{M_h}{M}f_1\frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{\mathbf{h}}\cdot\mathbf{p_T}}{M}\left(xg^{\perp}D_1 + \frac{M_h}{M}h_1^{\perp}\frac{\tilde{E}}{z}\right)\right)$$

twist-3 pdf

Collins FF

unpolarized dist. function

twist-3 FF

twist-3 t-odd dist. funcion

Boer-Mulders

twist-3 FF

⇨ **Twist 3 component in every term**

Physics Motivation

In a simplified way, it can be expressed as:

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

where the moments $A_{UU}^{\cos\phi}$, $A_{UU}^{\cos 2\phi}$, $A_{LU}^{\sin\phi}$ are directly related to the structure functions of the cross section

Focus of this study: $A_{LU}^{\sin\phi}$

→ Only moment which depends on the beam helicity

→ Helicity dependence arises from the asymmetric part of the leptonic tensor and its coupling to the hadronic tensor

→ Directly correlated with the structure function $F_{LU}^{\sin\phi}$

➔ Provides information about the quark gluon correlations in the proton

Physics Motivation and Extraction

- BSA is a good tool to extract $A_{LU}^{\sin\phi}$

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

➔ Helicity independent acceptance terms cancel out in the ratio!

Past: Measurements have been performed with CLAS, HERMES and COMPASS

<u>Advantages of CLAS12:</u>

➔ Significantly higher statistics

➔ Extended kinematic coverage (Q^2, p_T)

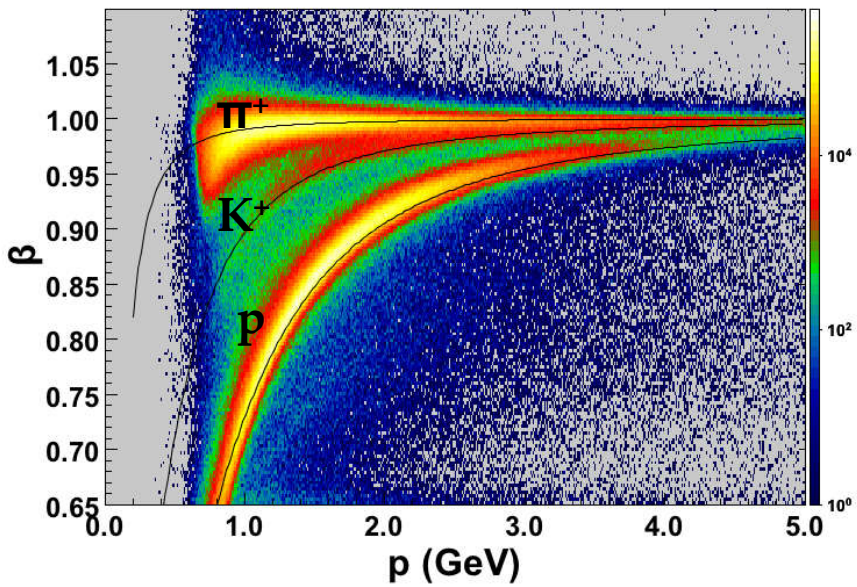
Particle ID

Electron ID → Based on the electromagnetic calorimeter and the cherenkov counters

Hadron ID → Charge corresponding to the selected hadron

→ Fiducial cuts on the hit position in the drift chambers

→ Particle selection based on β vs p correlation



→ **Maximum likelihood particle ID**

$$P(\beta) = \frac{1}{\sqrt{2\pi}\sigma} \cdot \exp\left(-\frac{1}{2}\left(\frac{\beta - \mu}{\sigma} \right)^2 \right)$$

→ Assign particle to species with the highest probability

→ Check if particle is within a certain confidence level

➔ Provides a cleaner particle ID for inclusive measurements

Event selection and kinematic cuts

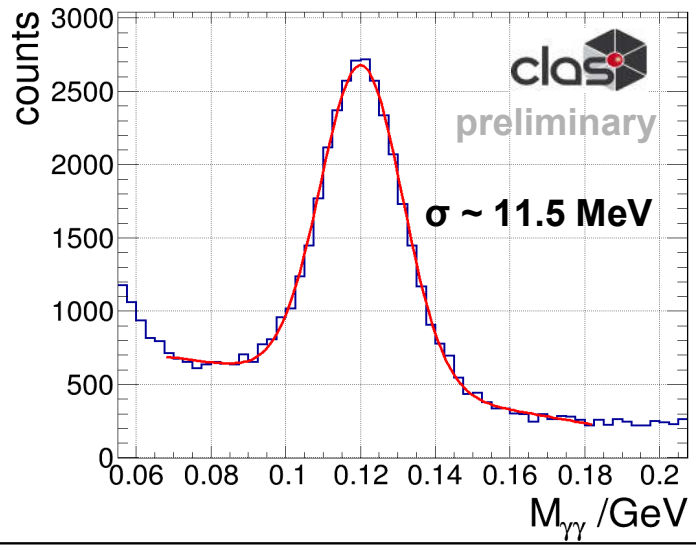
π^0 selection:

$E_\gamma > 0.6$ GeV, all 2γ pairs

SIDIS simulations show:

background dominated by SIDIS π^0

→ 3 σ cut around the peak positions



Kinematic cuts for all pions:

minimal electron energy: 2.0 GeV minimal pion energy: 1.5 GeV

DIS cut: $Q^2 > 1$ GeV² $W > 2$ GeV

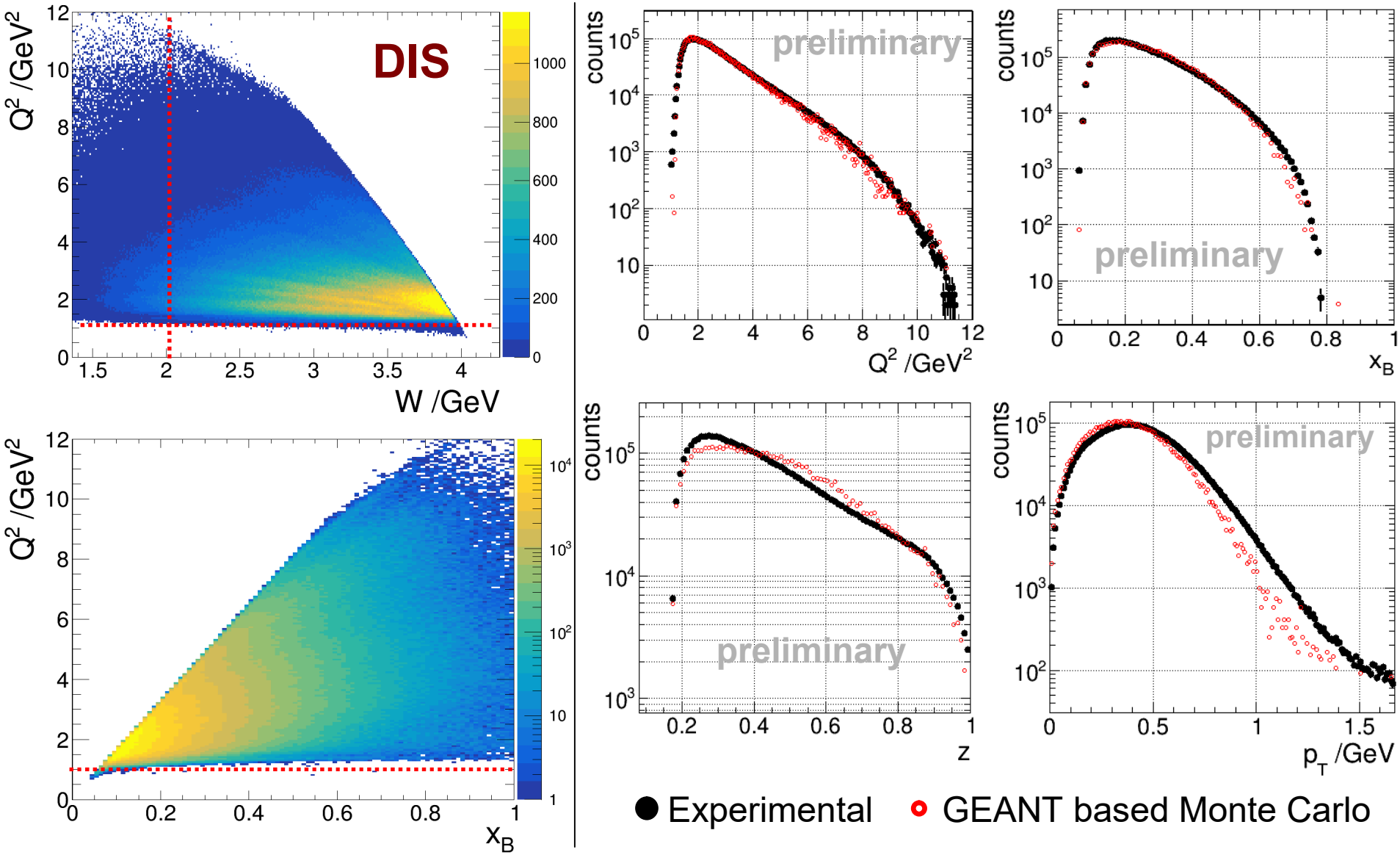
Additionally: Cut on the final state hadron momentum fraction z

$$0.3 < z < 0.7$$

→ $z > 0.3$ removes the "target fragmentation region"

→ $z < 0.7$ removes contamination by pions from exclusive channels

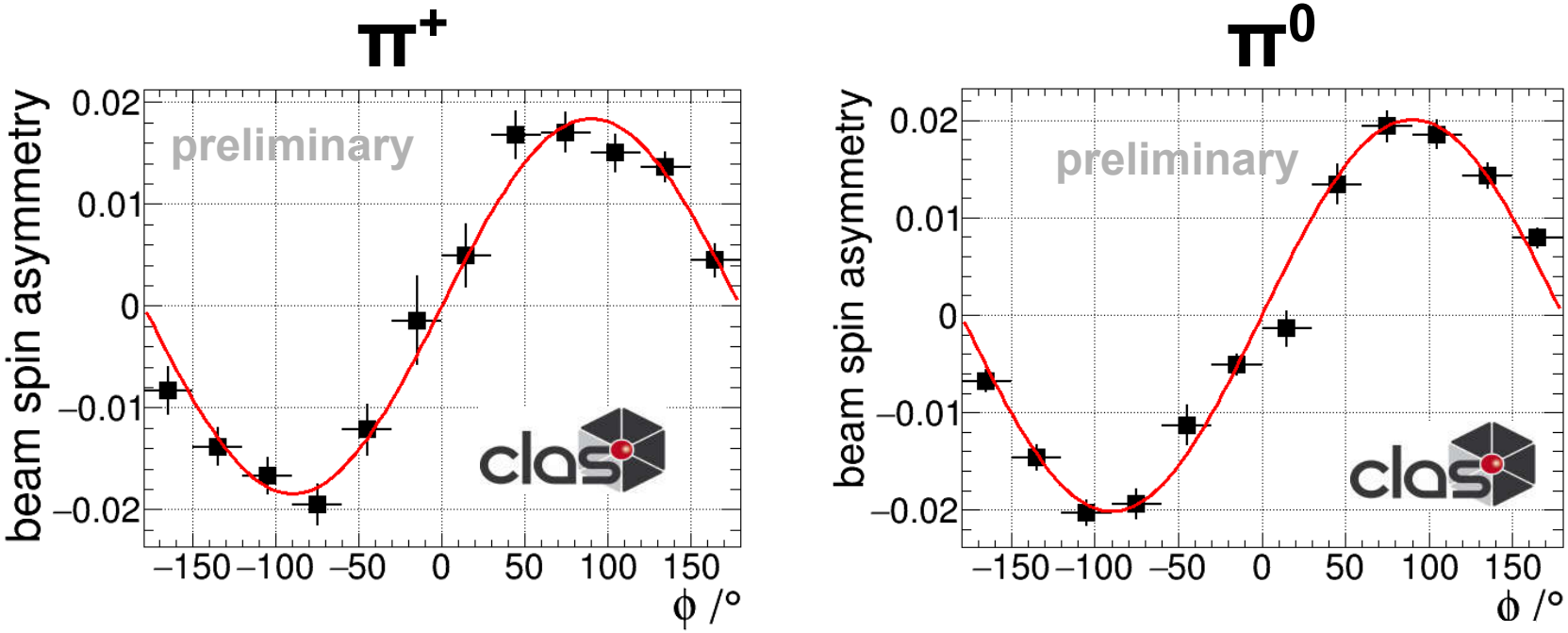
Kinematic coverage for π^+ (similar for π^- and π^0)



Integrated beam spin asymmetry

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

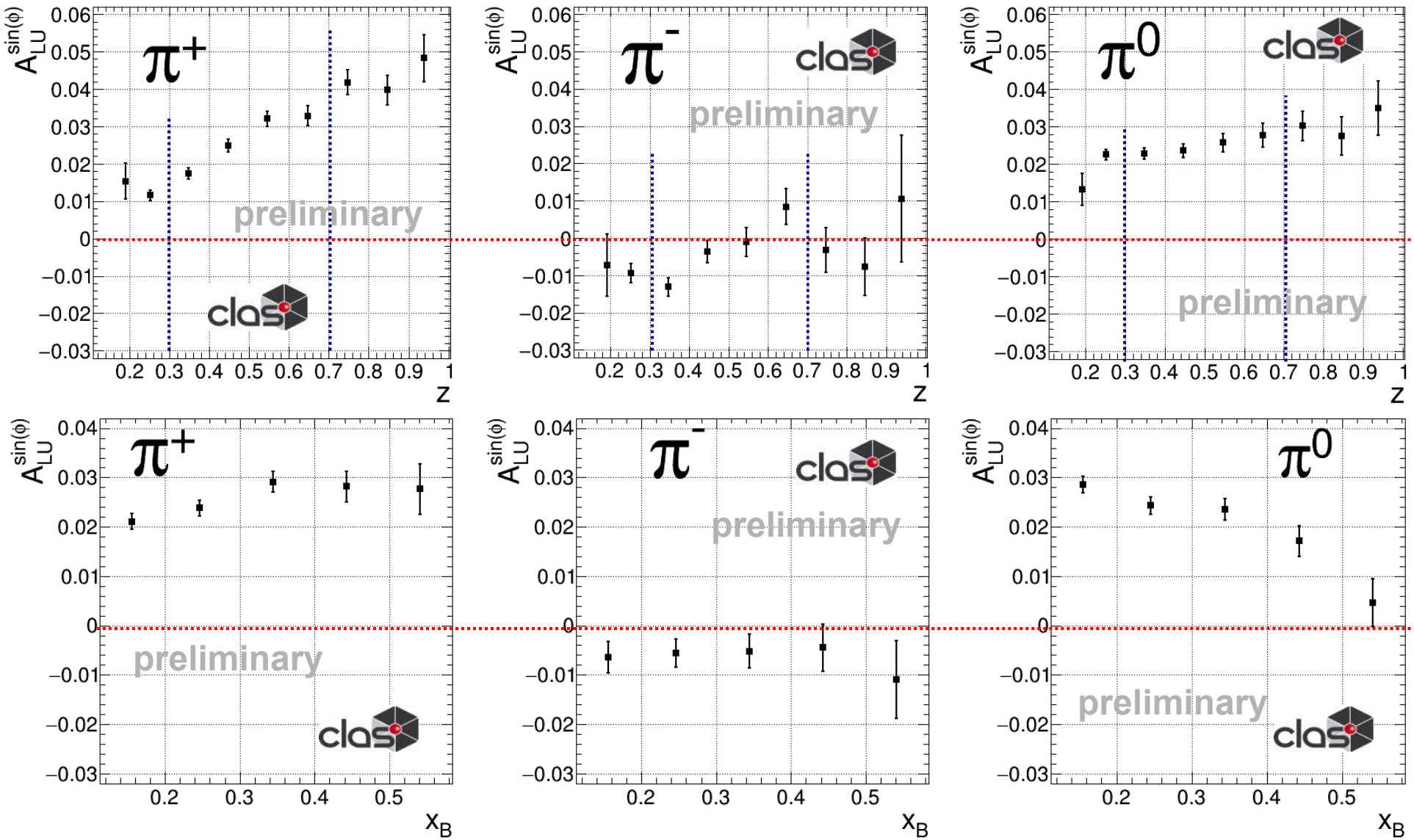
P_e = 85 % : average e^- beam polarisation



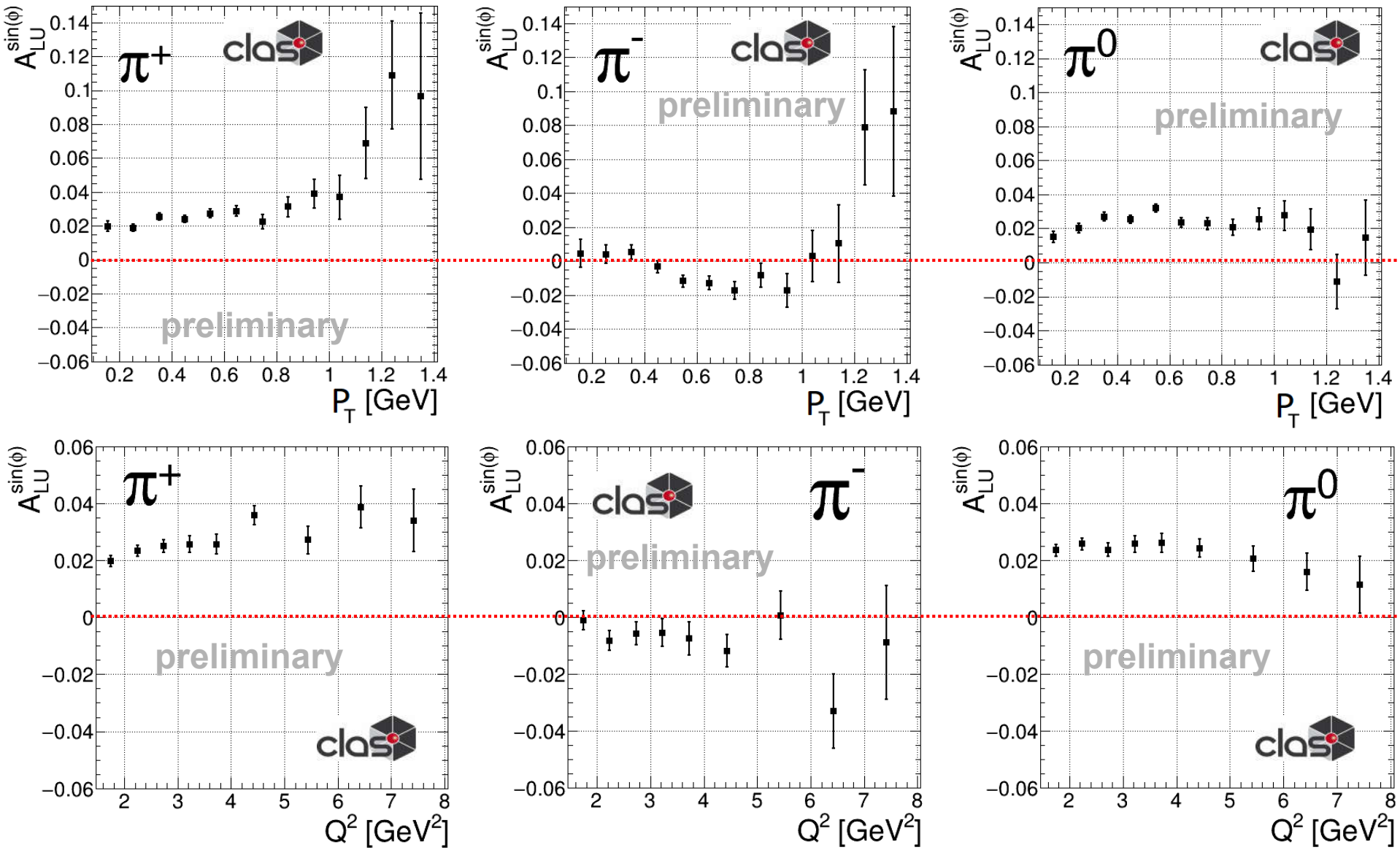
➔ Clear sinoid shape can be observed, according to $A_{LU}^{\sin\varphi} \sin\varphi$

➔ No systematics considered so far

$A_{LU}^{\sin(\varphi)}$ for a **z** and **x_B** binning



$A_{LU}^{\sin(\varphi)}$ for a P_T and Q^2 binning



Summary and Conclusion

- Based on CLAS data, the $A_{LU}^{\sin(\Phi)}$ moment from the hard exclusive π^+ channel above the resonance region has been measured for the first time with nearly full coverage from forward to backward angles
- The results show a clear sign change from forward angle to backward angle, which may indicate a transition from the GPD to the TDA regime.

- CLAS12 enables the extraction of SIDIS pion BSA moments with high accuracy in an extended kinematic range

- Qualitative agreement with previous experiments

- The presented analysis is based on only close to 2 % of the approved RG-A beamtime