2020 JLUO Annual Meeting

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SIDIS Single Pion and Di-hadron Beam Spin Asymmetry Measurements with CLAS12

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

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Transverse Momentum Distributions

Goal: A deeper understanding of the momentum distributions inside the nucleon

➔ 3 dimensionel **T**ransverse **M**omentum **D**istributions (**TMD**)

$$f(x, \vec{k}_T)$$

CLAS12:

Access TMDs with SIDIS

➔ single hadron SIDIS

➔ di-hadron SIDIS

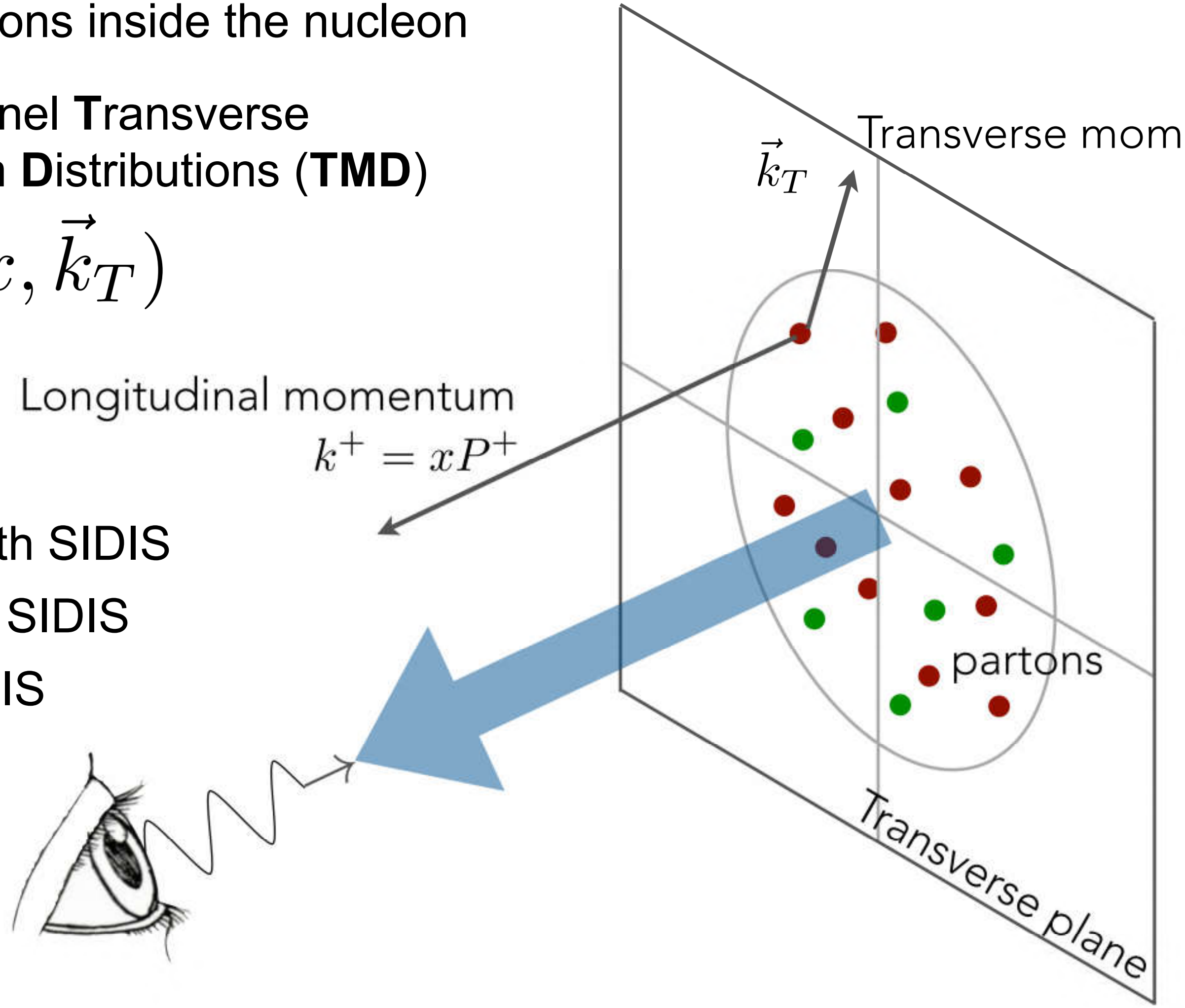
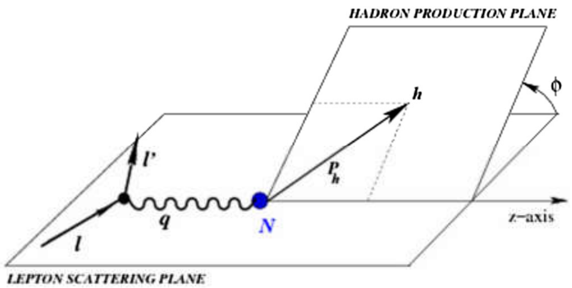


figure: A. Bacchetta

SIDIS and its Relation to TMDs



SIDIS single hadron cross section for an unpolarized target:

→ Contains model independent structure functions

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

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

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

- e: twist-3 pdf
- $H_1^\perp$: Collins FF
- f_1: unpolarized dist. function
- $\tilde{G}^\perp$: twist-3 FF
- $g^\perp$: twist-3 t-odd dist. funcion
- $h_1^\perp$: Boer-Mulders
- $\tilde{E}$: twist-3 FF

➔ A convolution of 4 TMDs and 4 fragmentation functions

➔ Each term contains a twist 3 component

➔ The results can be used in a global fit to constrain the TMDs and FF

Di-hadron SIDIS

Additional constraints can be obtained from **di-hadron SIDIS:**

➔ The PDF e(x) is coupled to the interference fragmentation function H_1

➔ e p → e` π^+ π^- X provides a clean access to e(x)

➔ e(x) is related to the scalar-charge of the nucleon and the pion-nucleon sigma terms

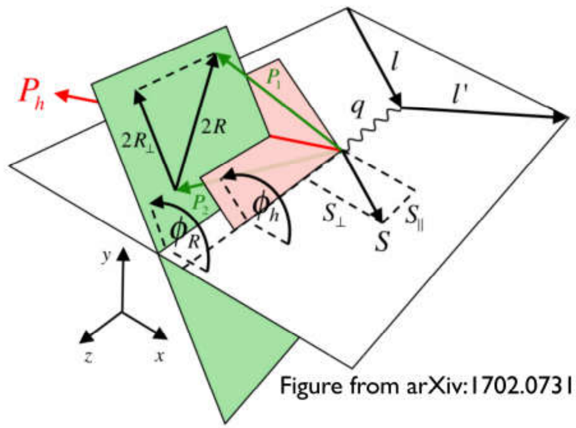


Figure from arXiv:1702.07317

$$\overrightarrow{P_h} = \overrightarrow{P_\pi^+} + \overrightarrow{P_\pi^-}, \qquad \vec{R} = \overrightarrow{P_\pi^+} - \overrightarrow{P_\pi^-}$$

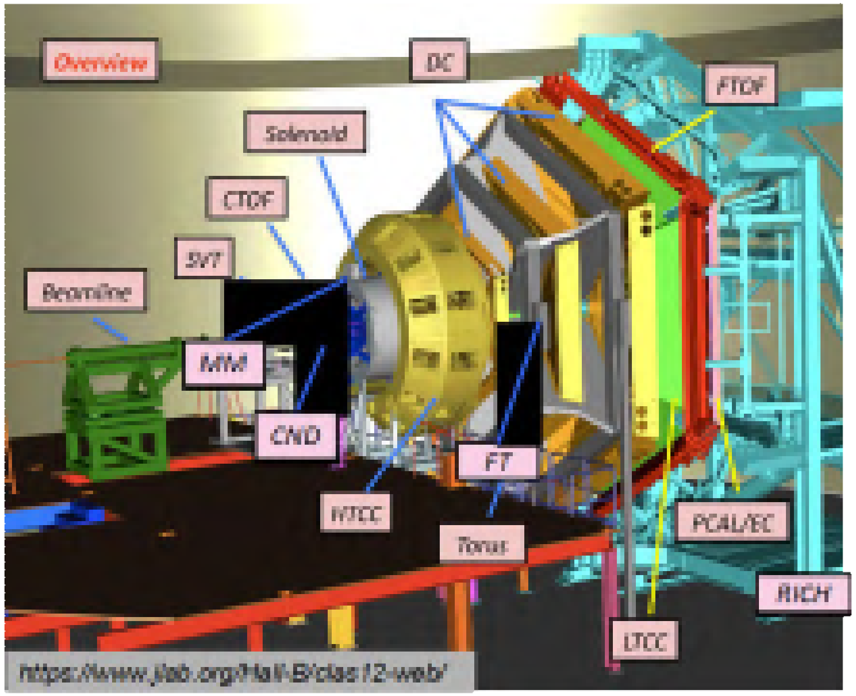
$$F_{LU}^{\sin\phi_R} = -x\frac{|\vec{R}|\sin\theta}{Q}\left[\frac{M}{M_{\pi\pi}} x e^q(x) H_1^{\sphericalangle q}(z, cos\theta, M_{\pi\pi}) + \frac{1}{z} f_1^q(x)\tilde{G}(z, \cos\theta, M_{\pi\pi})\right]$$

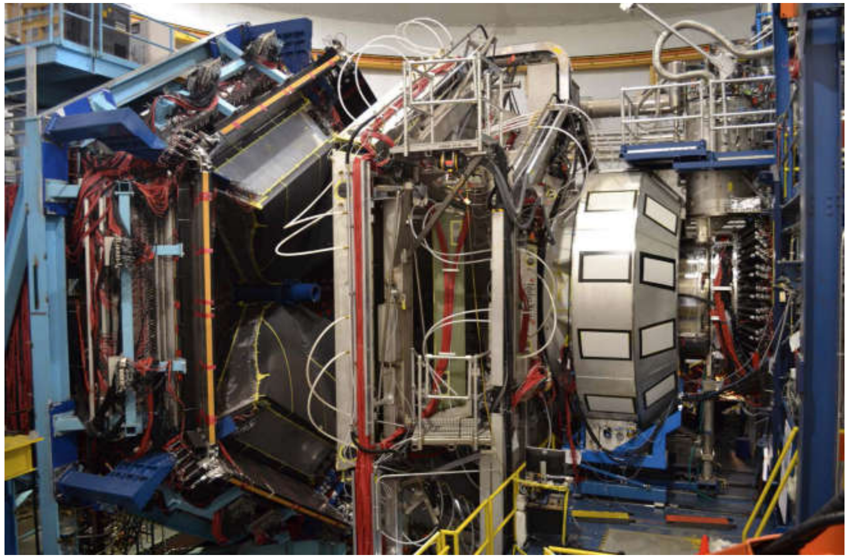
➔ Dihadron SIDS allows the study of DiFFs with no single hadron analog

e.g. G_1 describes the azimuthal dependence of an unpolarized hadron pair on the helicity of the outgoing quark.

$$A_{LU}^{\rightrightarrows}(x, y, z, M_h^2) = \frac{1}{M_h}\frac{\langle P_{h\perp}\sin(\varphi_h - \varphi_R)\rangle}{\langle 1\rangle} = \lambda_l \frac{C'(y)}{A'(y)} \frac{\sum_a e_a^2\, f_1^a(x)\, z\, G_1^{\perp a}(z, M_h^2)}{\sum_a e_a^2\, f_1^a(x)\, D_1^a(z, M_h^2)}$$

CLAS12 Experimental Setup in Hall B





➔ Data recorded with CLAS12 during fall of 2018

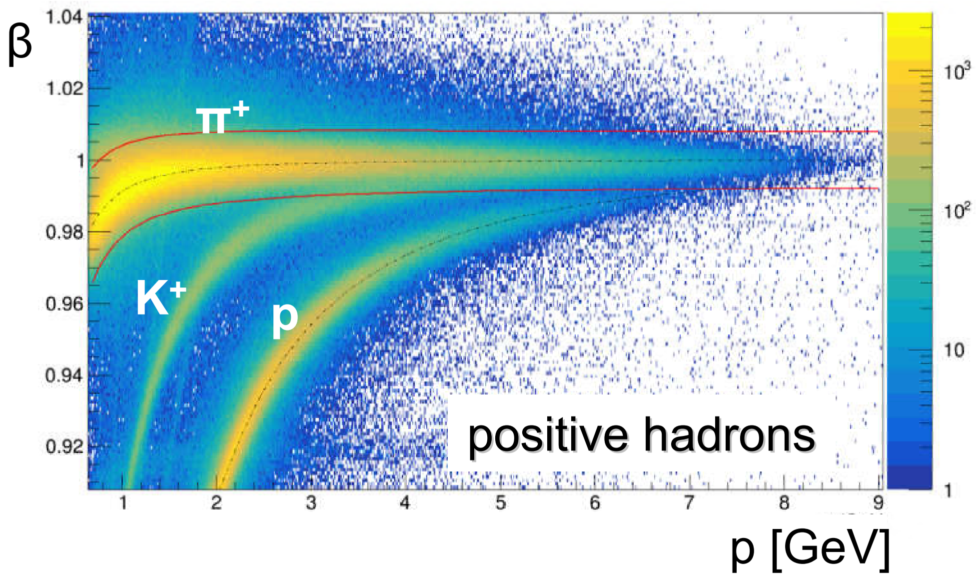
➔ 10.6 GeV electron beam ➔ 87 % average polarization ➔ liquid H_2 target

➔ Analysed data ~ 20 % of the approved RG-A beam time

Particle ID

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

Hadron ID → Based on β vs momentum correlation from TOF



→ **Maximum likelihood particle ID**

→ Assign particle to the species with the highest probability

→ Check if particle is within a certain confidence level

Photon ID → Based on the electromagnetic calorimeter

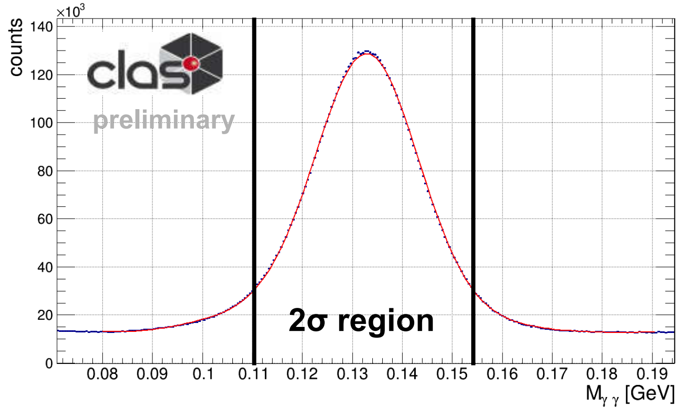
Single Pion SIDIS: Event selection and kinematic cuts

π^0 selection:

$E_\gamma > 0.6$ GeV $\alpha(e^-\gamma) > 8°$ all 2γ pairs

→ 2 σ cut around the peak positions

→ sidebands are used to estimate the asymmetry of the background



Kinematic cuts for all pions:

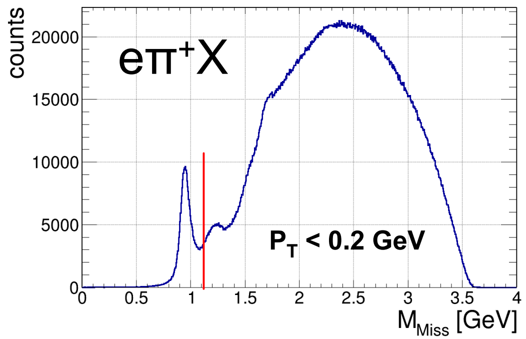
$P_{min}(e^-)$ ~ 2.1 GeV (y < 0.8) $P_{min}(\pi) = 1.25$ GeV

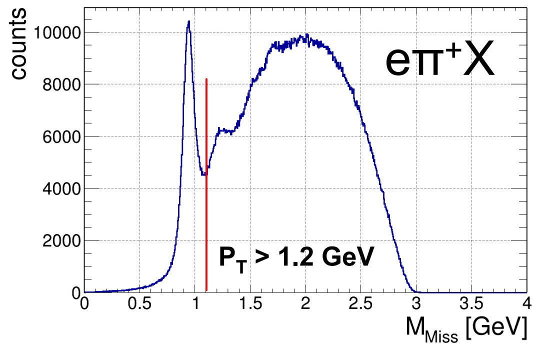
DIS cut: $Q^2 > 1$ GeV²   W > 2 GeV

Cut on the final state hadron momentum fraction:

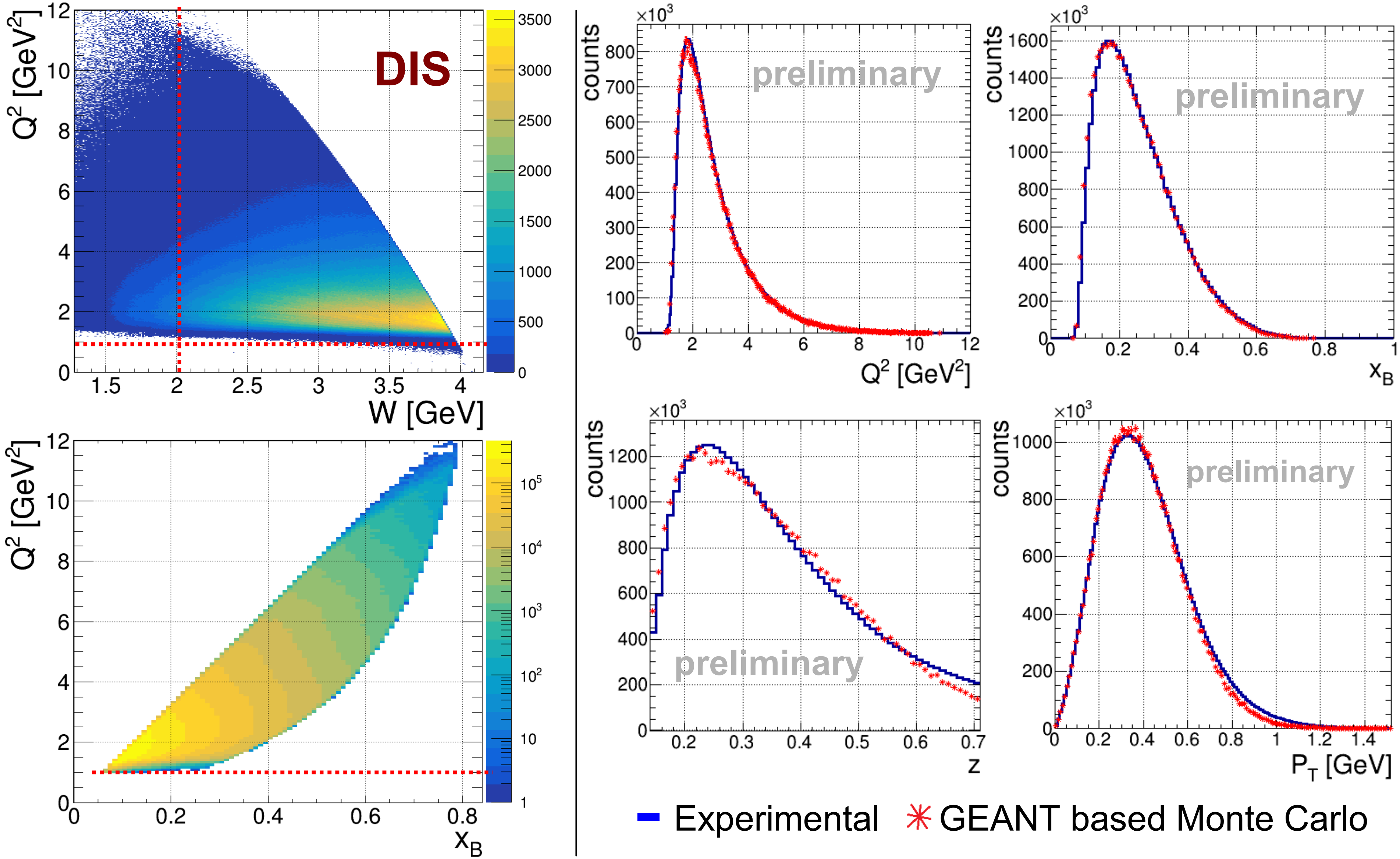
→ z > 0.3 removes "target fragmentation region"

Cut on the eπX missing mass to remove exclusive events: → $M_{miss} > 1.1$ GeV





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



Single Pion SIDIS

Goal: Extract $F_{LU}^{\sin\phi} / F_{UU}$ from single pion beam spin asymmetries

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

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

$$A_{LU}^{\sin\phi} = \sqrt{2\varepsilon(1-\varepsilon)} \frac{F_{LU}^{\sin\phi}}{F_{UU}}$$

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

Advantages of CLAS12 →
- Significantly higher statistics
- Extended kinematic coverage (Q^2, P_T)

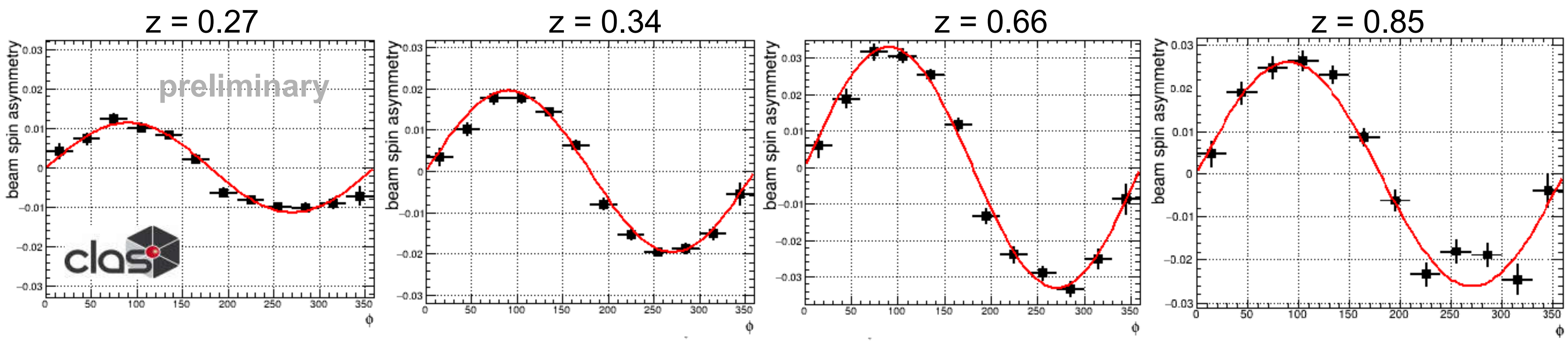
Beam Spin Asymmetry

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

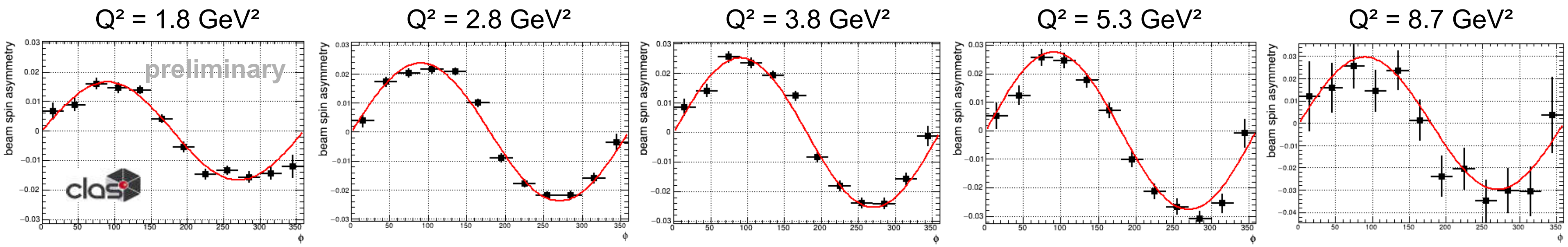
P_e = 87 % : average e^- beam polarisation

π^+

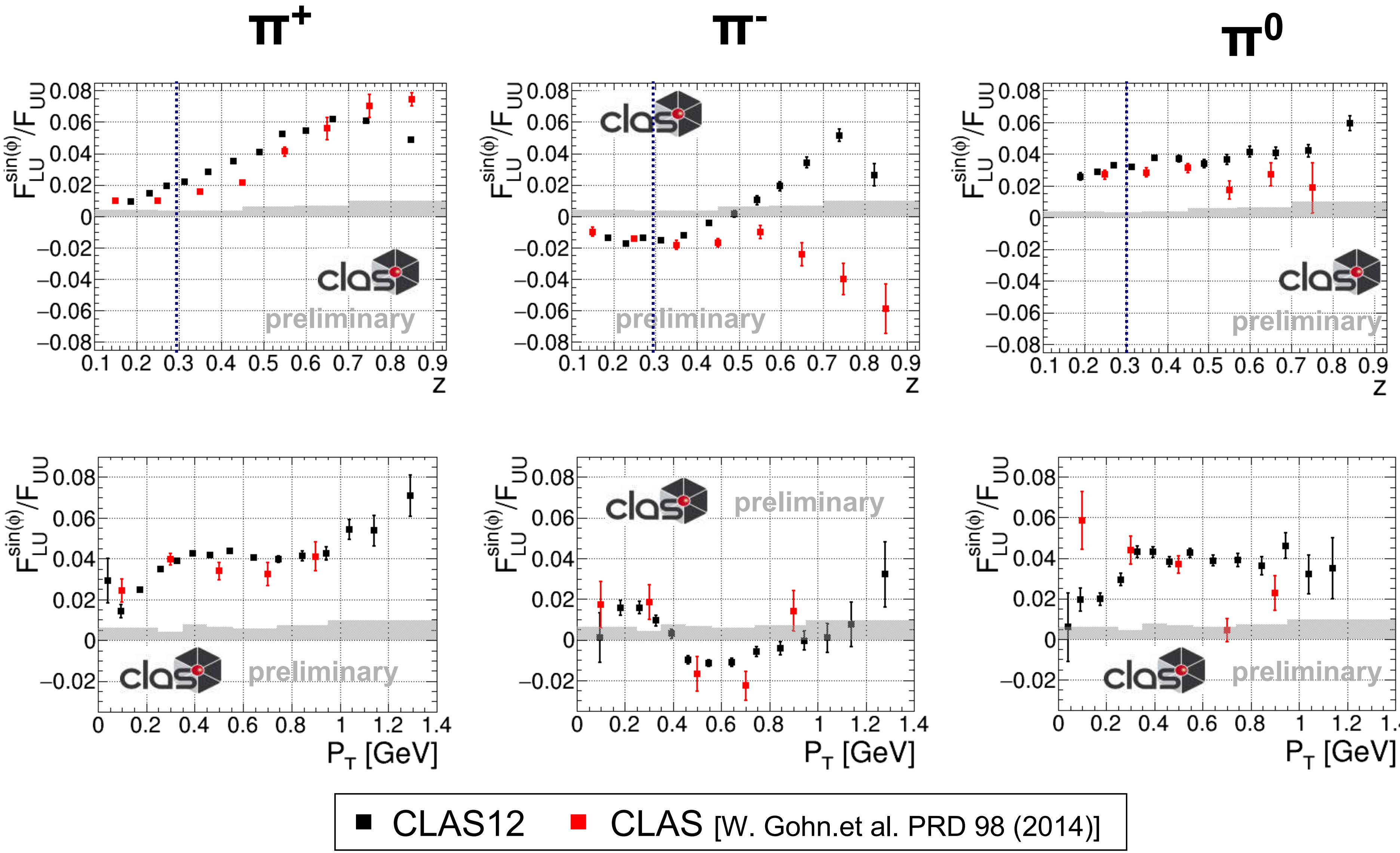
z binning:



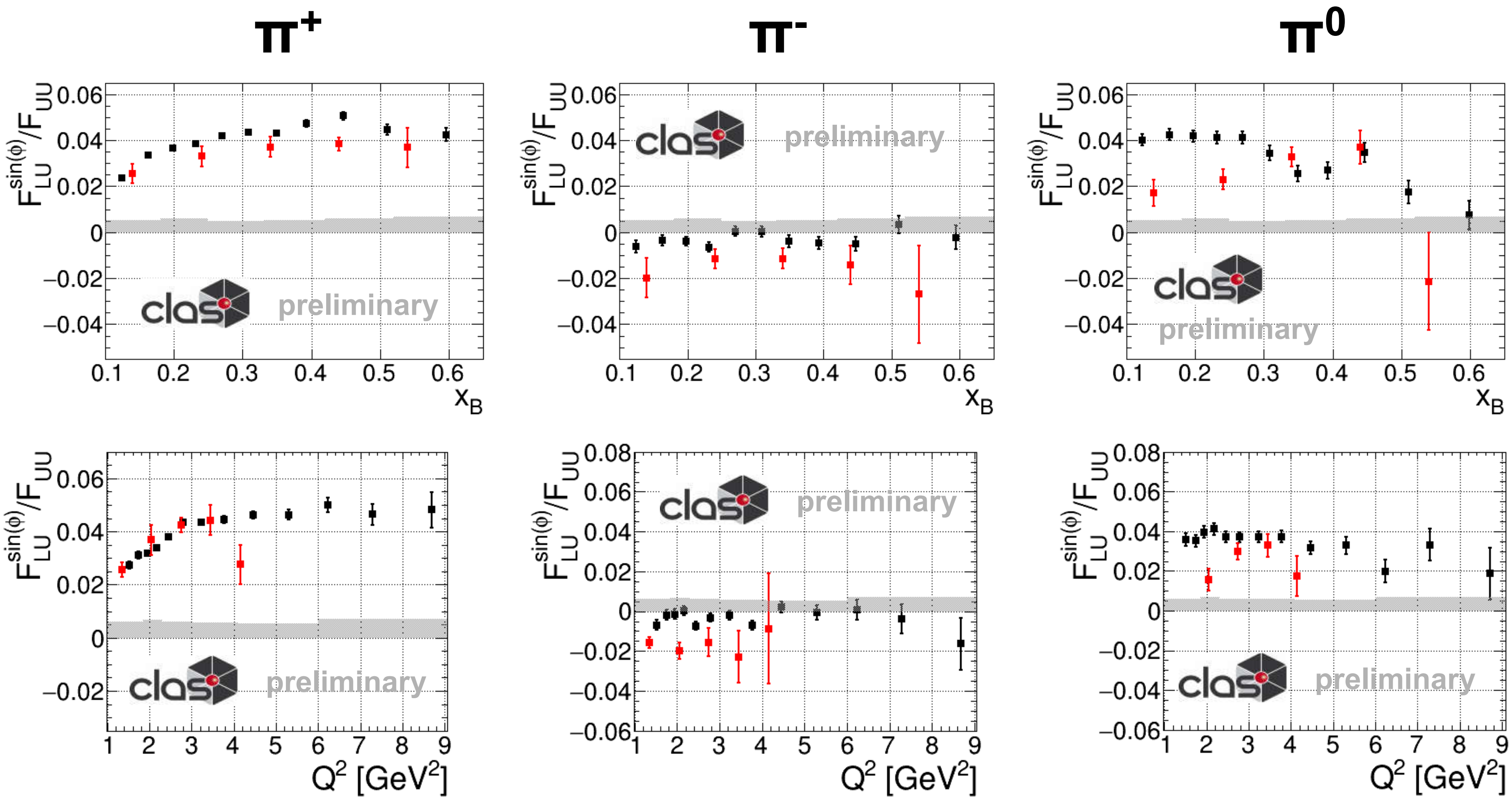
Q² binning:



$F_{LU}^{\sin\phi} / F_{UU}$ for a **z** and **P_T** binning



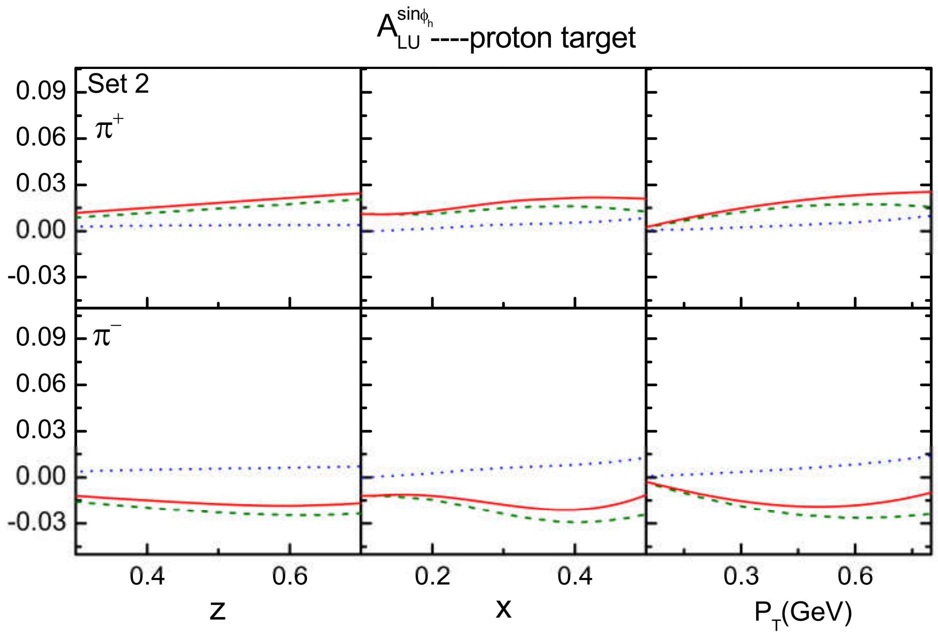
$F_{LU}^{\sin\phi} / F_{UU}$ for a x_B and Q^2 binning



■ CLAS12 ■ CLAS [W. Gohn.et al. PRD 98 (2014)]

Comparison to Theoretical Predictions

Predictions for the 12 GeV JLAB data:



Wenjuan Mao, Zhun Lu
Eur. Phys. J. C (2014) 74:2910
DOI 10.1140/epjc/s10052-014-2910-7

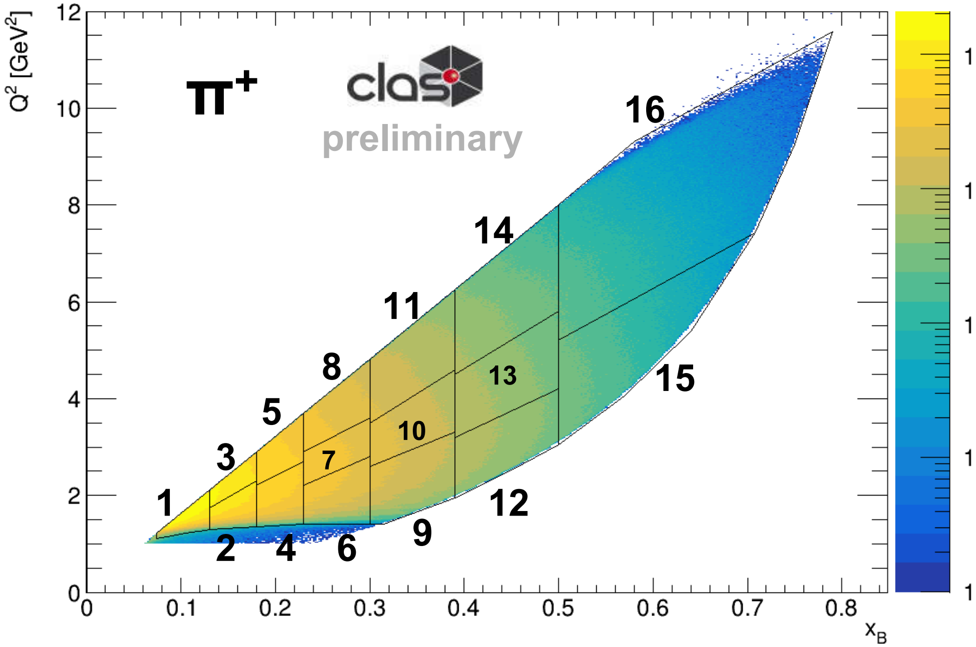
➔ Prediction reproduces several charakteristics of our results

➔ Updated calculations from different collaborators are in progress

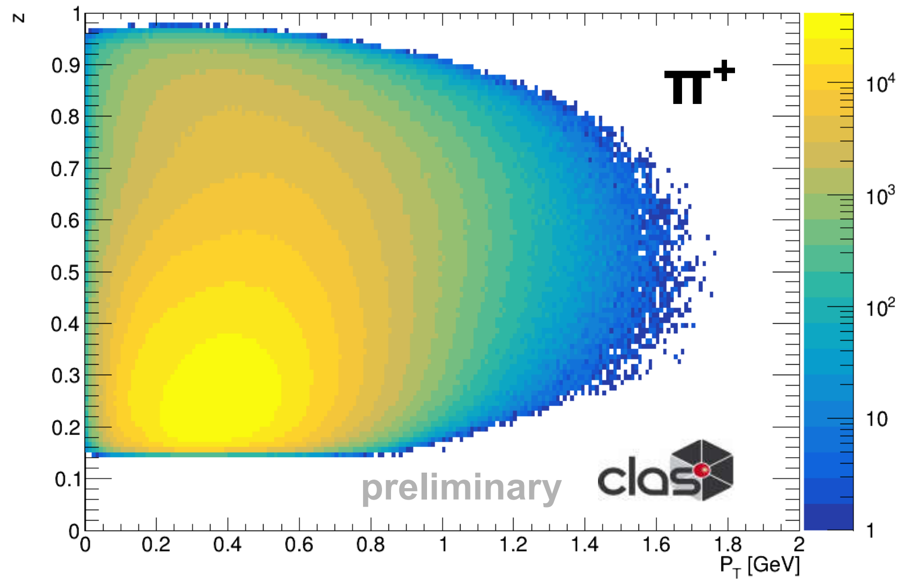
➔ A multidimensional binning will enable a much better comparability with the calculations

A Fully Multidimensional Binning

- With the available statistics, a fully multidimensional binning in Q², x_B, z and P_T becomes possible for the first time



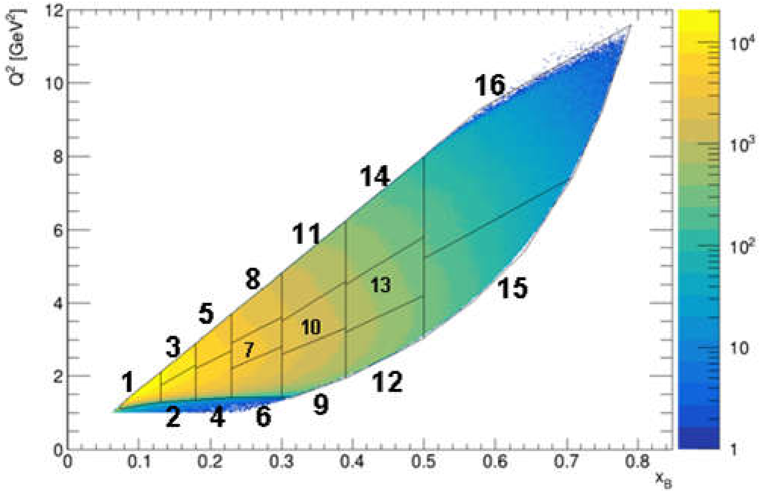
16 bin in Q² - x_B

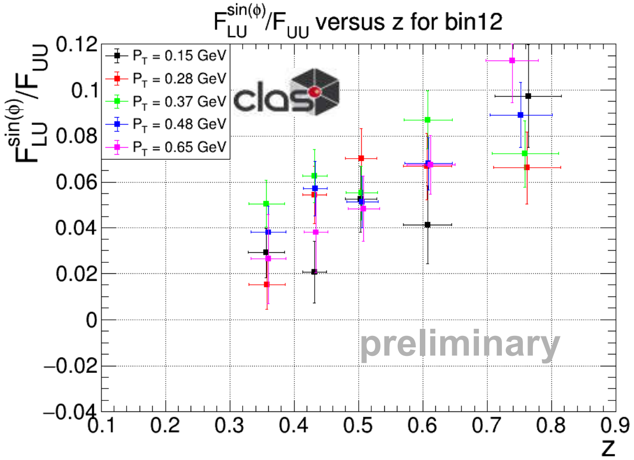


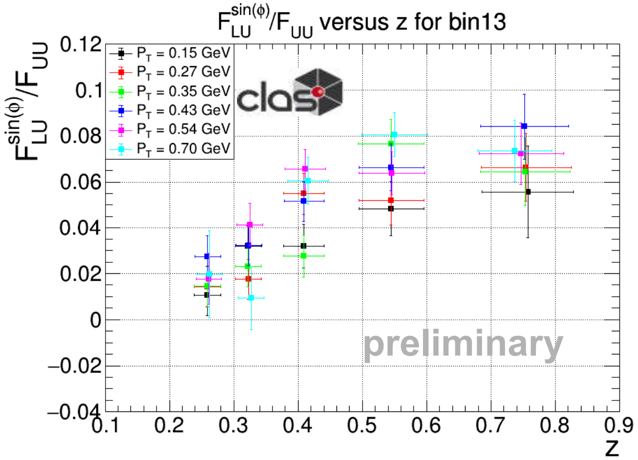
up to 7 x 7 bins in z - P_T
for each Q² - x_B bin

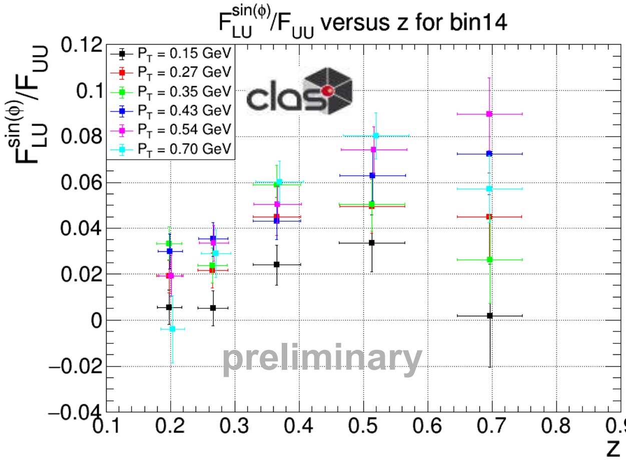
in total: 583 bins x 12 bins in Φ ~ 7000 BSA bins

π^+: z Dependence for Increasing Q^2 and Fixed x_B



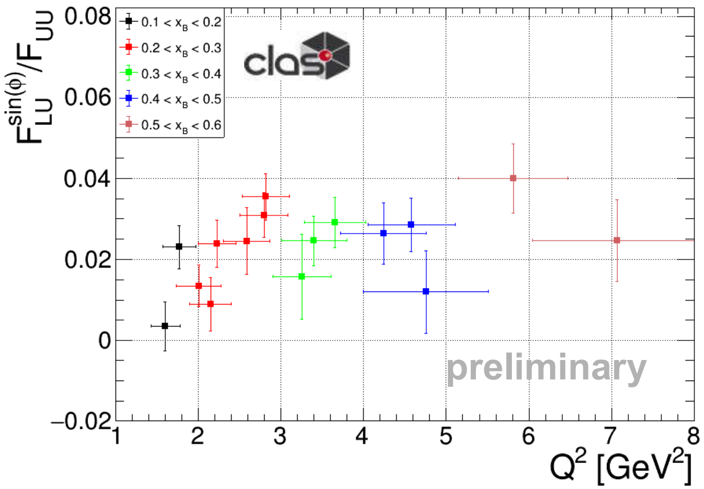




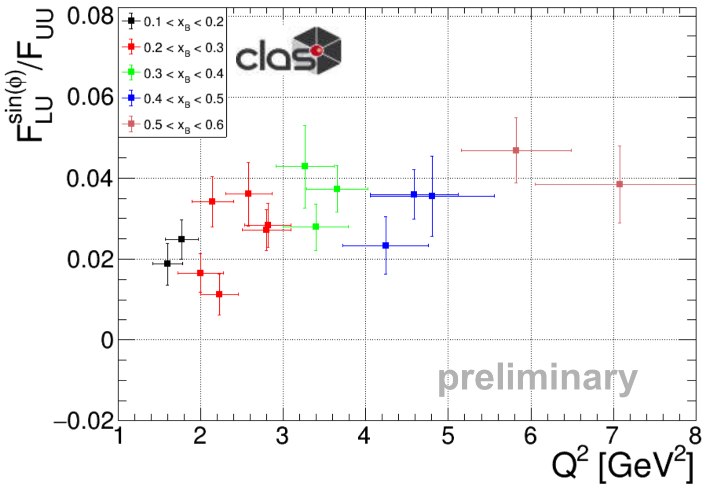


π^+: Q^2 Dependence ($0.3 < z < 0.4$, x_B fixed)

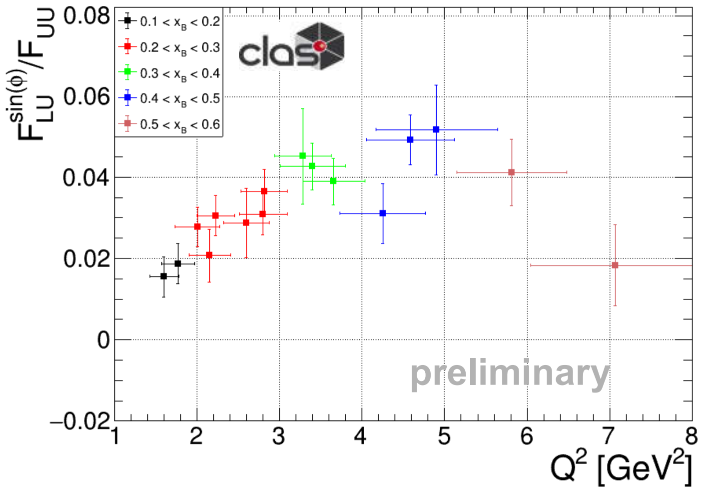
0.2 GeV < P_T < 0.3 GeV



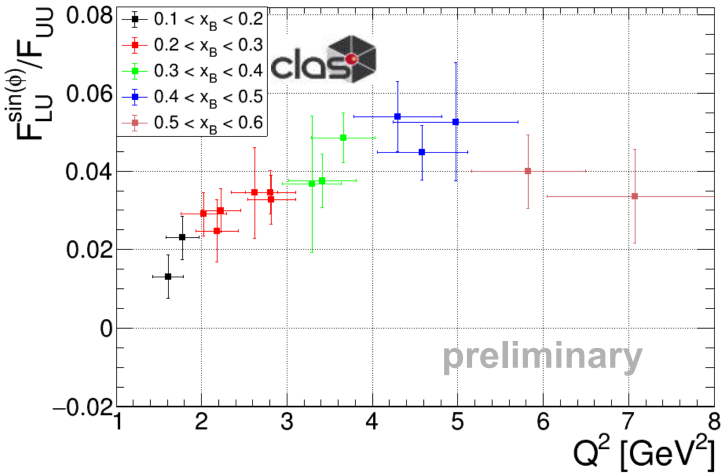
0.3 GeV < P_T < 0.4 GeV



0.4 GeV < P_T < 0.5 GeV



0.5 GeV < P_T < 0.6 GeV



Di-hadron SIDIS

Final state with two charged pions: **e p → e` π⁺ π⁻ X**

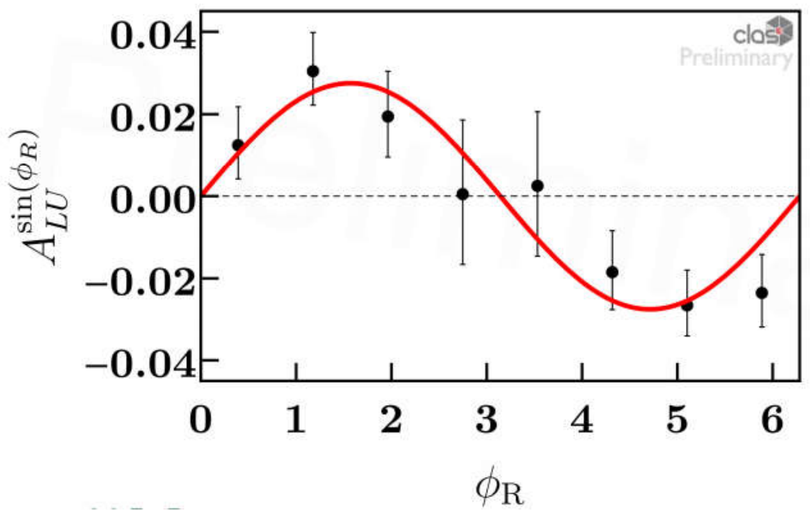
Kinematic cuts: $Q^2 > 1.0$ GeV² W > 2.0 GeV y < 0.8

$P_{min}(\pi) = 1.25$ GeV z < 0.95 $x_F > 0$ $M_{miss} > 1.6$ GeV

➔ Simultaneous fit to all 3 modulations

$$A_r \sin(\phi_R) + A_{hr} \sin(\phi_H - \phi_R) + A_h \sin(\phi_H)$$

➔ BSA example for $0.22 < x_B < 0.25$



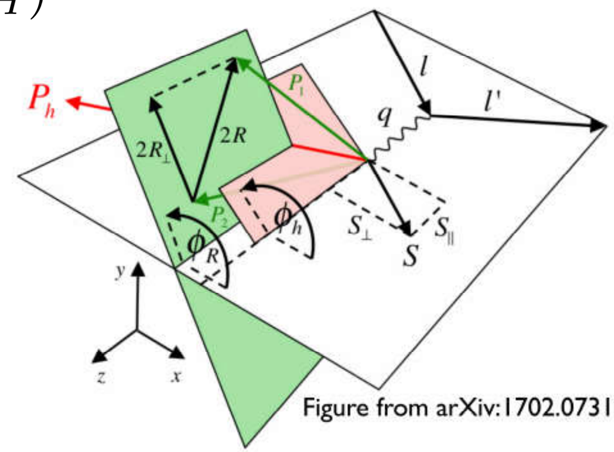
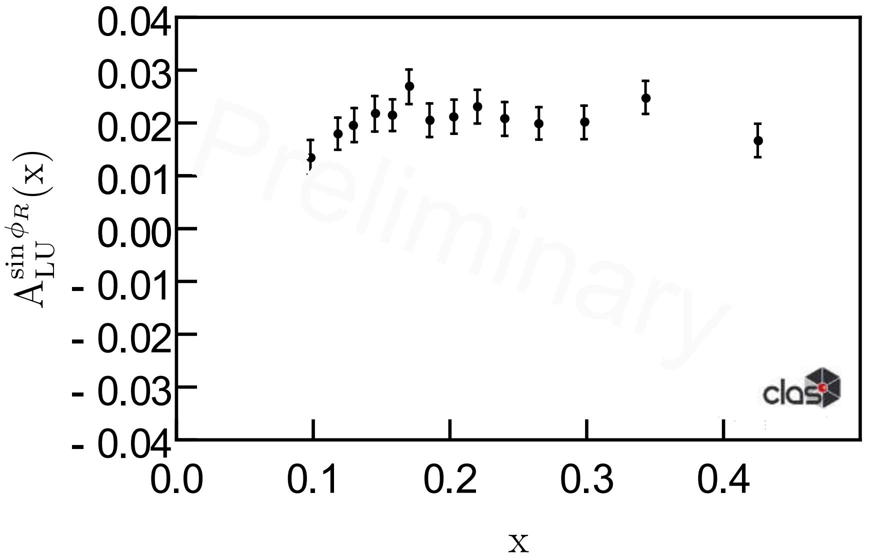


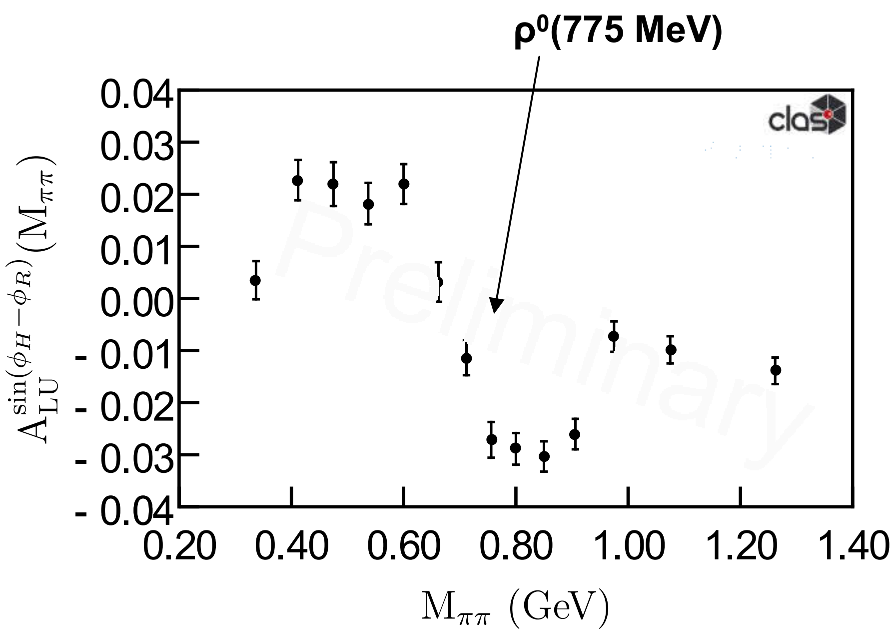
Figure from arXiv:1702.07317

$$\overrightarrow{P_h} = \overrightarrow{P_\pi^+} + \overrightarrow{P_\pi^-}, \qquad \vec{R} = \overrightarrow{P_\pi^+} - \overrightarrow{P_\pi^-}$$

analysis by T. Hayward, C. Dilks

Di-hadron Beam Spin Asymmetry





➔ **Sensitive to the PDF e(x)**

➔ **Sensitive to G_1**

- No asymmetry corrections and systematics included!

analysis by T. Hayward, C. Dilks

Conclusion and Outlook

- CLAS12 enables the extraction of SIDIS pion BSA moments with high accuracy in an extended kinematic range.
- $F_{LU}^{\sin\phi} / F_{UU}$ is positive for π^+ and π^0 and close to zero or slightly negative for π^-.
- Di-hadron BSA in Φ_R shows non-zero values for $A_{LU}(x)$
  ➔ Sensitive to e(x)
- The fully multidimensional analysis of the single pion SIDIS enables the decomposition of different effects
- CLAS12 SIDIS results will significantly improve the results from global TMD fits and provide access to so far poorly known TMDs