Correlations in Partonic and Hadronic Interactions

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SIDIS Single Pion Beam Spin Asymmetry Measurements with CLAS 12

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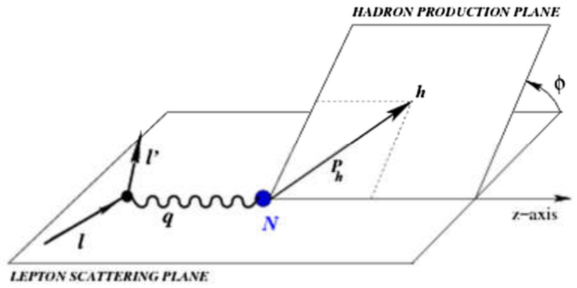
Physics Motivation

- The 3D nucleon structure in momentum space can be described by TMDs
- A way to acess these properties is the semi inclusive deep inelastic scattering



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

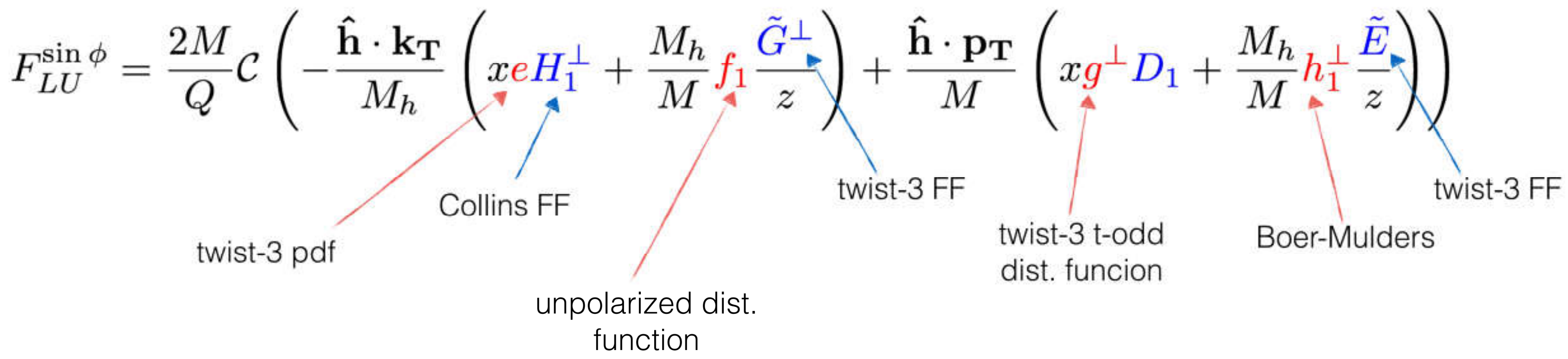
twist-3 FF

twist-3 t-odd
dist. funcion

Boer-Mulders

twist-3 FF

Physics Motivation



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

➔ 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

Additional constraints: i.e. from unpolarized structure functions

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}\mathcal{C}\left[-\frac{\hat{\mathbf{h}}\cdot\mathbf{p}_T}{M_h}\left(xhH_1^{\perp} + \frac{M_h}{M}f_1\frac{\tilde{D}^{\perp}}{z}\right) - \frac{\hat{\mathbf{h}}\cdot\mathbf{k}_T}{M}\left(xf^{\perp}D_1 + \frac{M_h}{M}h_1^{\perp}\frac{\tilde{H}}{z}\right)\right]$$

$$F_{UU}^{\cos 2\phi_h} = \mathcal{C}\left[-\frac{2(\hat{\mathbf{h}}\cdot\mathbf{p}_T)(\hat{\mathbf{h}}\cdot\mathbf{k}_T) - \mathbf{p}_T\cdot\mathbf{k}_T}{MM_h}h_1^{\perp}H_1^{\perp}\right].$$

Physics Motivation

and also from di-hadron SIDIS (Timothys talk)

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

Bacchetta,Radici, PRD69,074026 (2004), Aurore Courtoy, arXiv:1405.7659

+ constraints from other experiments (SIDIS + Drell-Yan)

➔ **A global fit is needed for a reliable extraction**

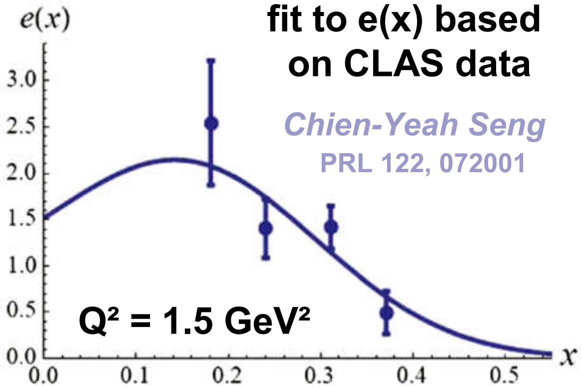
What can we learn from the extracted TMDs?

i.e. ***e(x)*** → Recent publication by Chien-Yeah Seng (PRL 122)

➔The chiral-odd, twist 3 distr. function ***e(x)*** is related to the nucleon sigma terms of the quark chromo magnetic dipole moment

→ Essential inputs for the CP-odd pion-nucleon couplings

→ Main contributors of long range CP-odd nuclear forces



$$\sigma_c^0 = (0.08 - 0.34)GeV^2$$

Physics Motivation

Goal of this study: Extract $F_{LU}^{\sin\phi}$ from single pion beam spin asymmetries

$$d\sigma = d\sigma_0(1 + A_{UU}^{\cos\phi}\cos\phi + A_{UU}^{\cos2\phi}\cos2\phi + \lambda_e A_{LU}^{\sin\phi}\sin\phi)$$

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

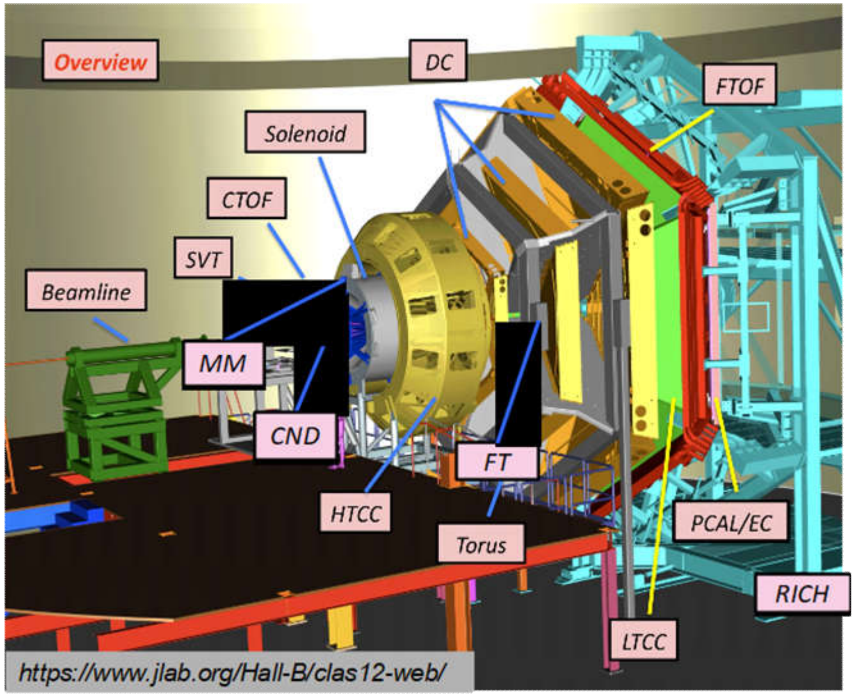
$$A_{LU}^{\sin\phi} = \sqrt{2\varepsilon(1-\varepsilon)}\,\frac{F_{LU}^{\sin\phi}}{F_{UU}}$$

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

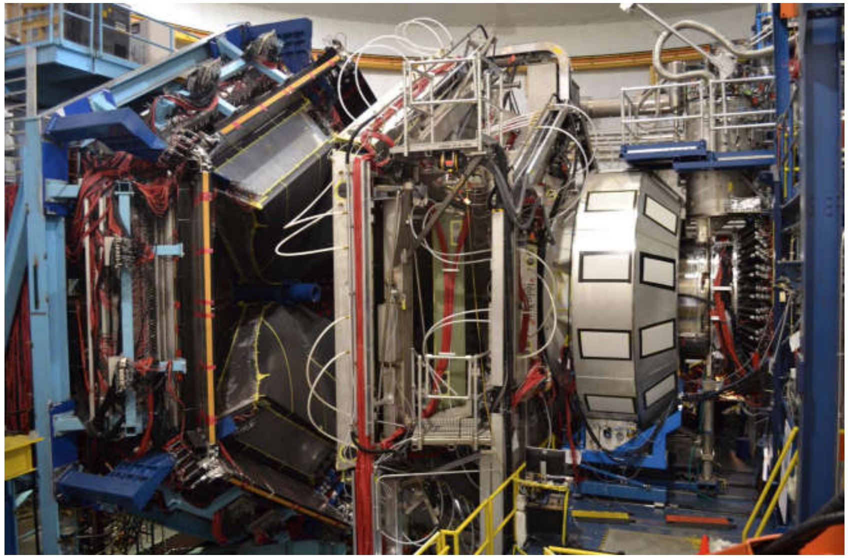
Advantages of CLAS12 → Significantly higher statistics

→ Extended kinematic coverage (Q^2, P_T)

Experimental Setup



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



➔ Data recorded with CLAS12 during fall of 2018

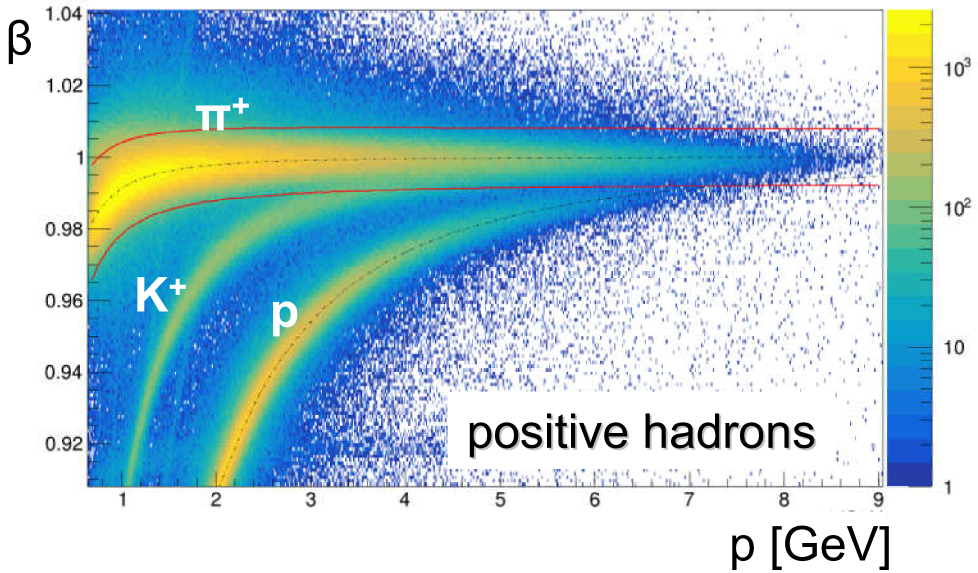
➔ 10.6 GeV electron beam ➔ 85 % average polarization ➔ liquid H_2 target

➔ Analysed data ~ 3 % 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**

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

→ 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:

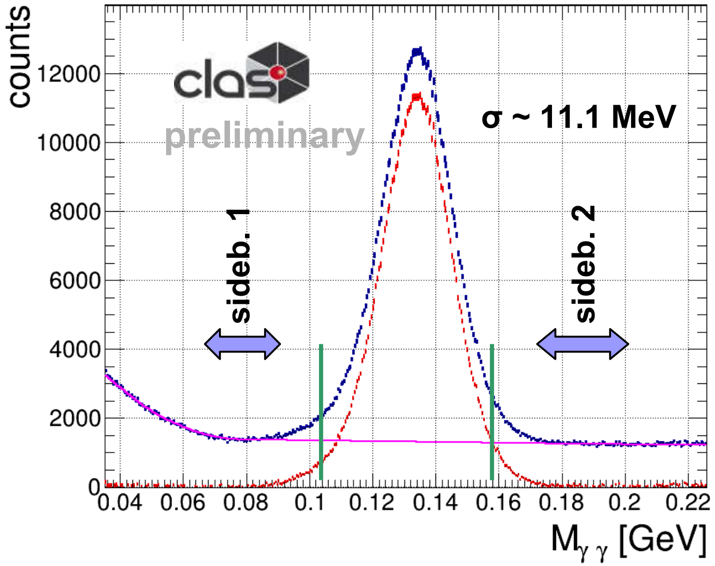
$E_\gamma > 0.6$ GeV $\alpha(e^-\gamma) > 8°$

all 2γ pairs

→ 2.2 σ cut around the peak positions

→ sidebands are used to estimate the asymmetry of the background

→ A sideband subtraction has been done



Kinematic cuts for all pions:

minimal electron energy: 2.0 GeV   minimal pion energy: 1.25 GeV

DIS cut: $Q^2 > 1$ GeV² $W > 2$ GeV

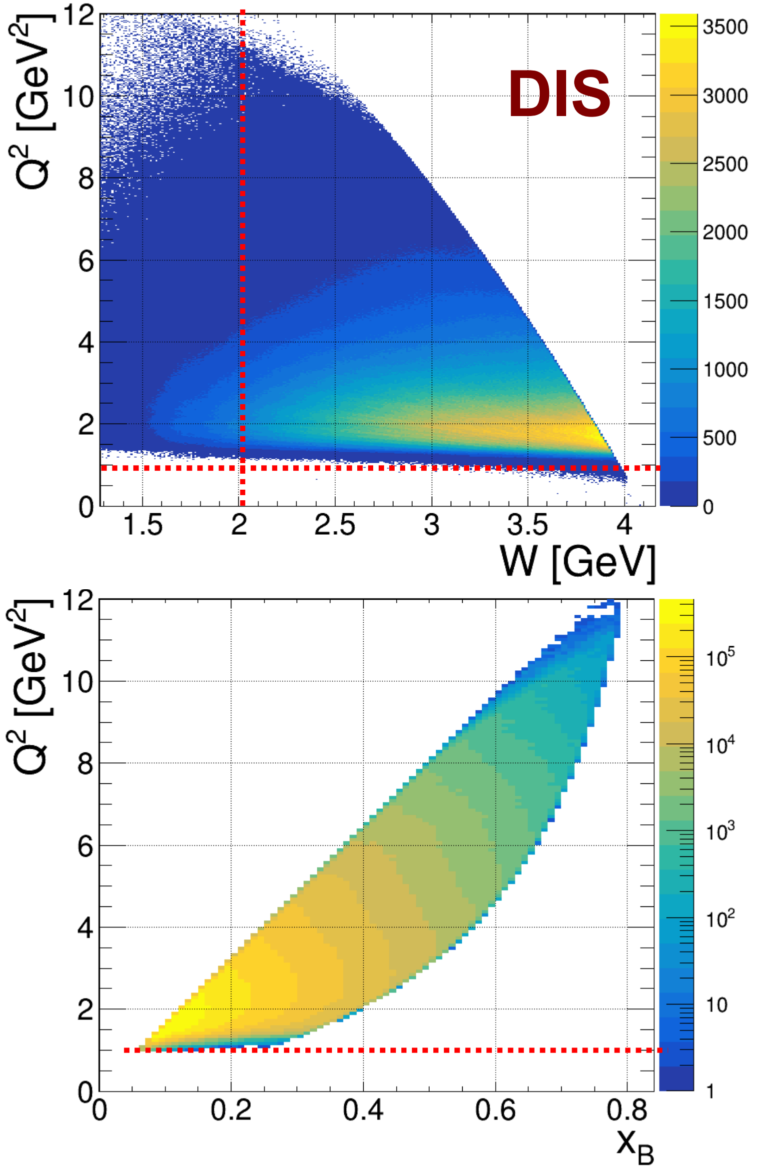
Additionally: Cut on the final state hadron momentum fraction z

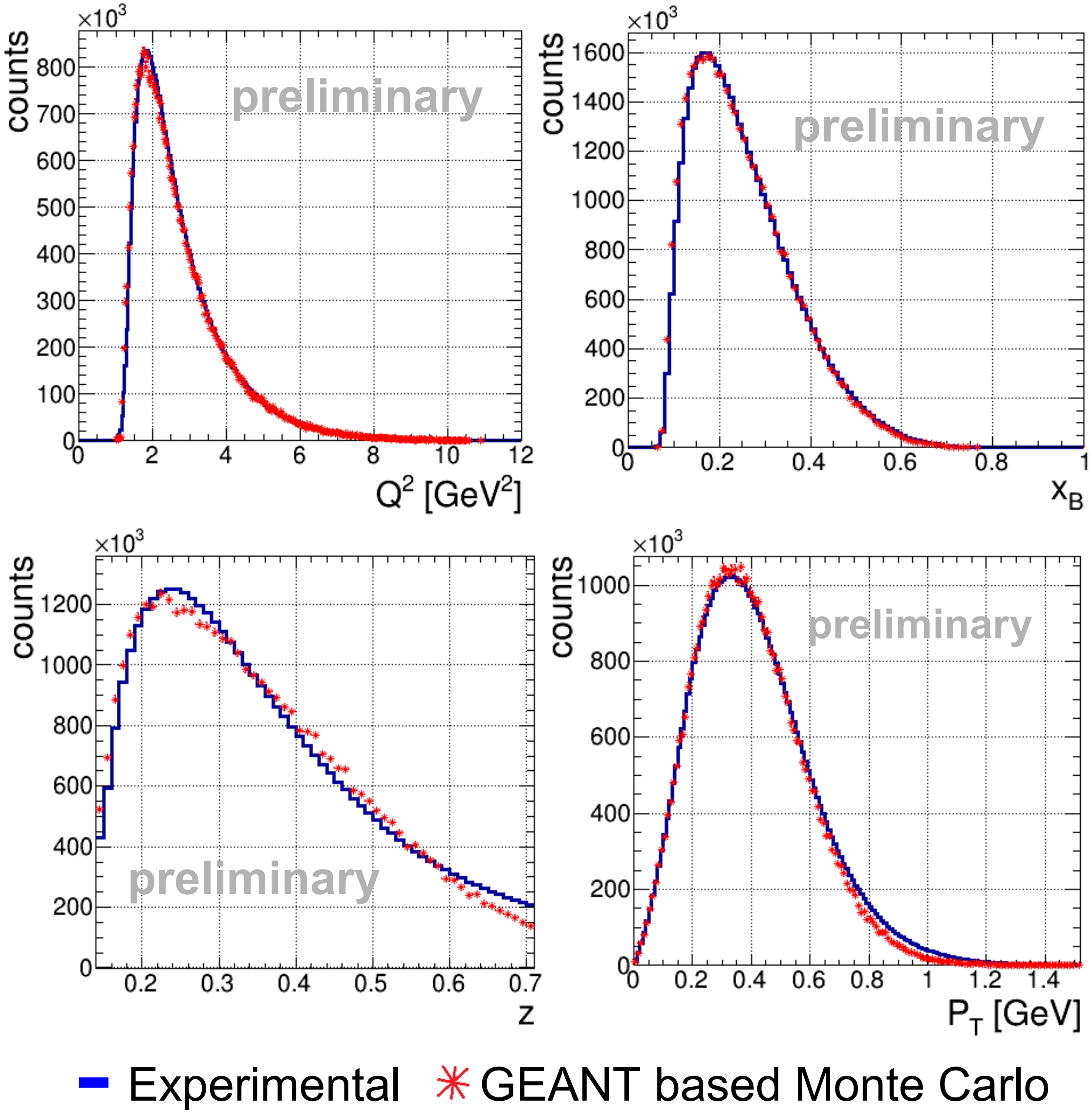
$$0.3 < z < 0.7$$

→ $z > 0.3$ 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)





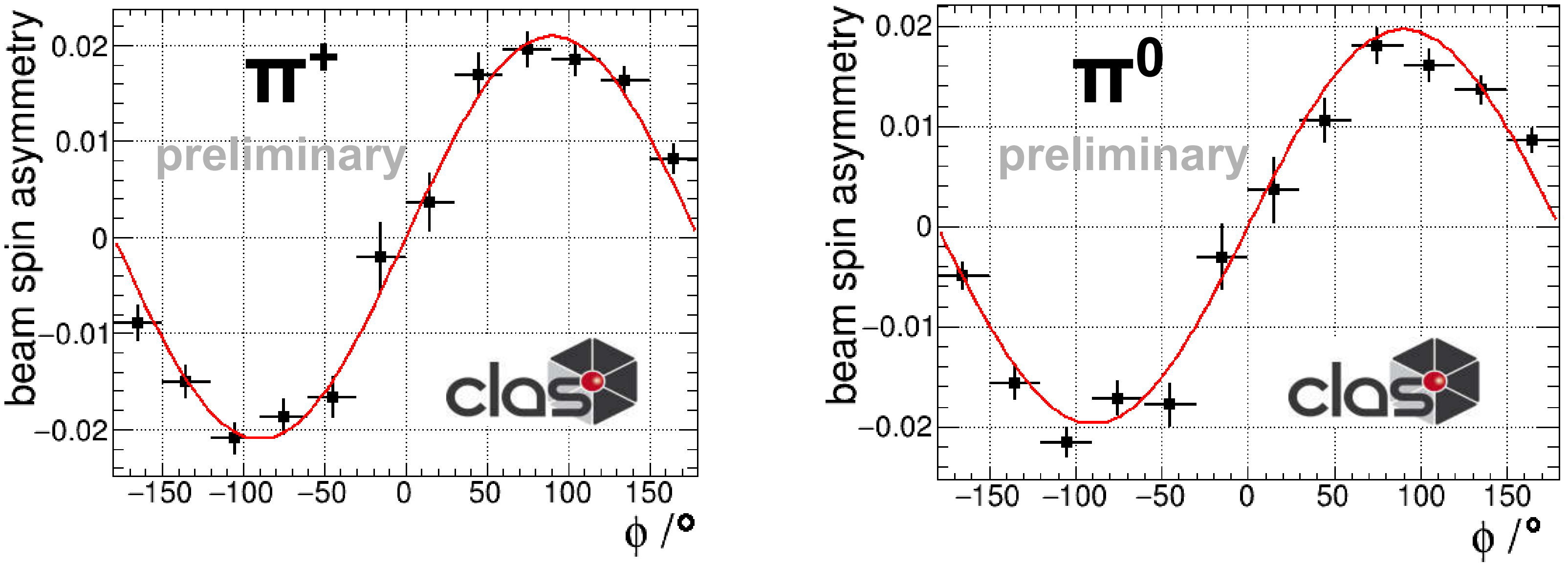
Beam spin asymmetry

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

P_e = 85 % : average e^- beam polarisation

Φ dependence without kinematic bins

$\langle Q^2 \rangle \sim 3.0\ \mathrm{GeV}^2$ $\langle x_B \rangle \sim 0.27$ $\langle z \rangle \sim 0.42$ $\langle P_T \rangle \sim 0.45$

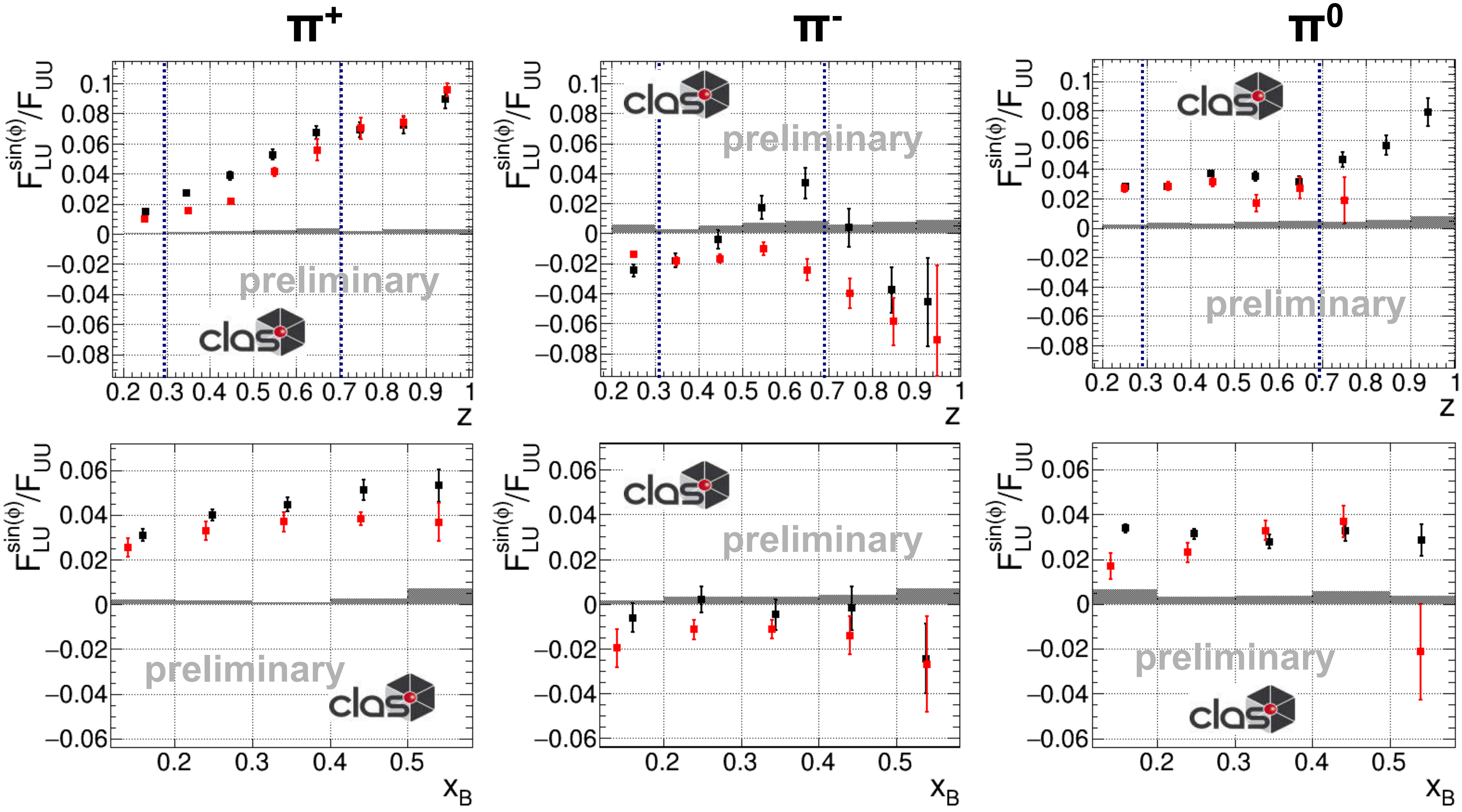


Extraction of the moments: a) A simple χ² fit of the ϕ dependence

b) Statistical extraction by minimizing

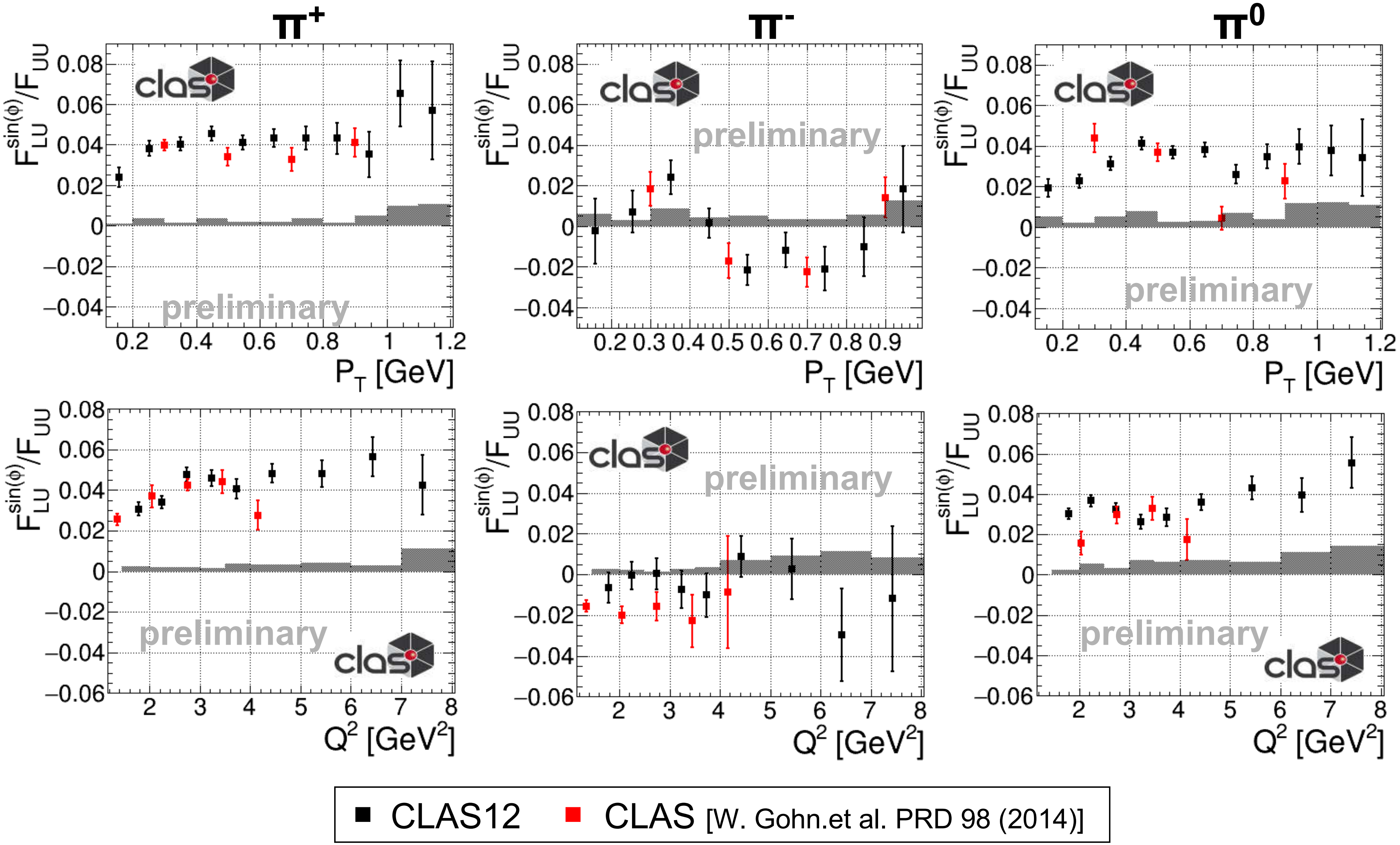
$$P = -\prod_{i=1}^{N} \left(1 + h \cdot P_e \cdot \frac{gauss(A_{LU}^{\sin(\phi)}, \sigma_1) \cdot \sin(\phi)}{1 + gauss(A_{UU}^{\cos(\phi)}, \sigma_2) \cdot \cos(\phi) + gauss(A_{UU}^{\cos(2\phi)}, \sigma_3) \cdot \cos(2\phi)} \right)$$

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



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

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



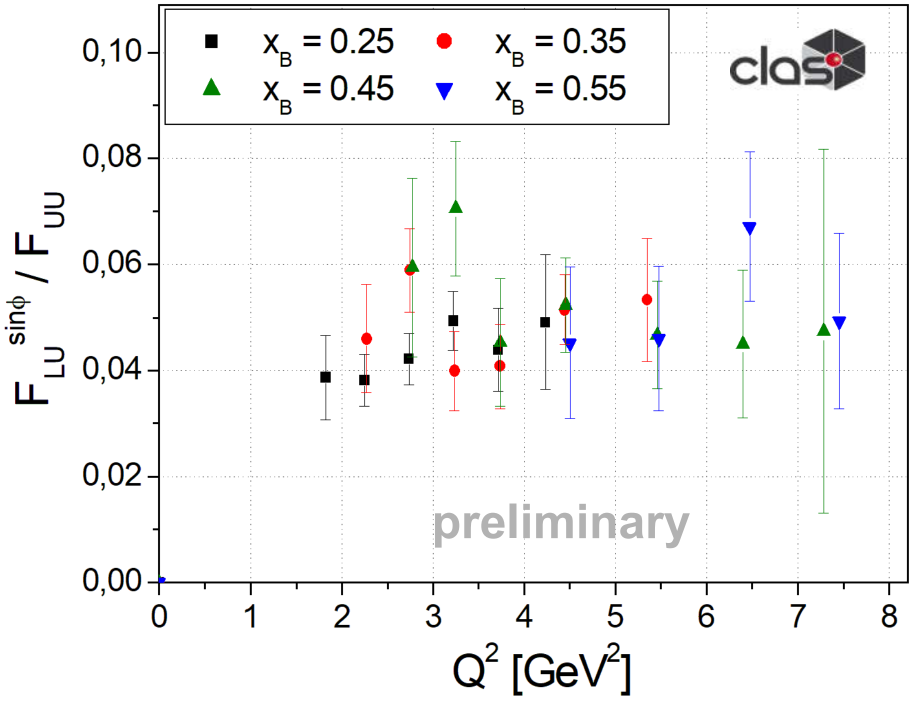
How do things change with a multidimensional binning?

Step 1: A two dimensional binning

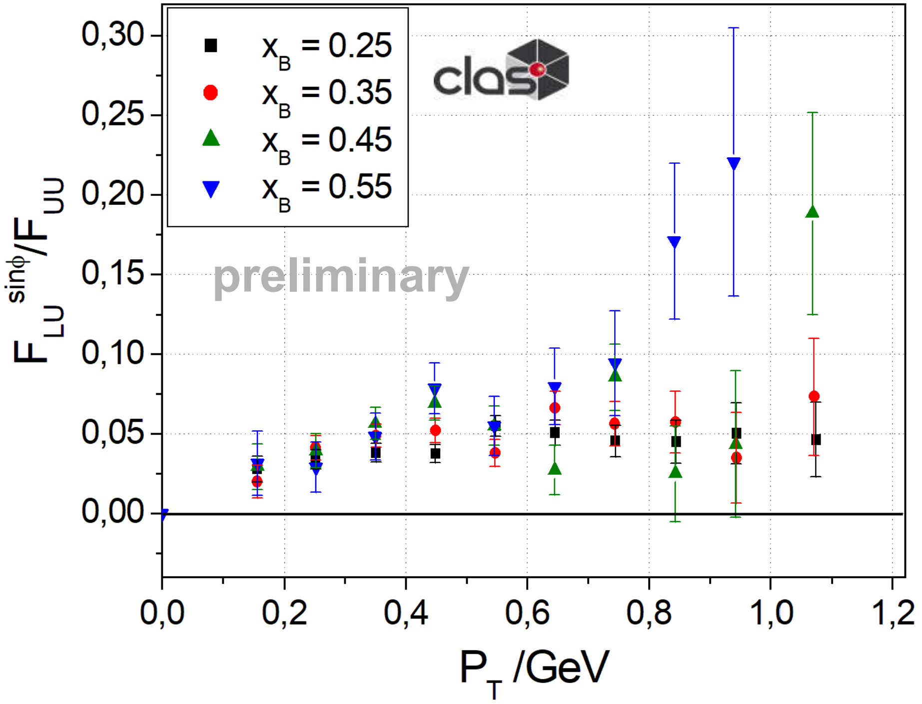
π^+

$0.3 < z < 0.7$

$0.0 \text{ GeV} < P_T < 1.4 \text{ GeV}$



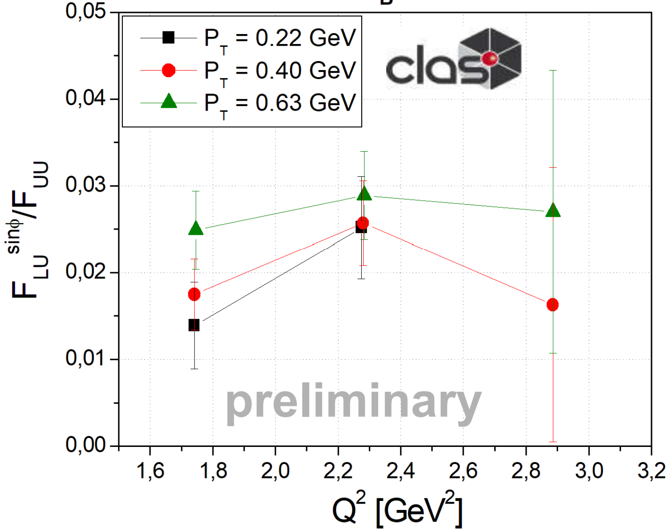
$1.0 \text{ GeV}^2 < Q^2 < 12 \text{ GeV}^2$



How do things change with a multidimensional binning?

Step 2: A multidimensional binning **in z, x_B, P_T and Q^2**

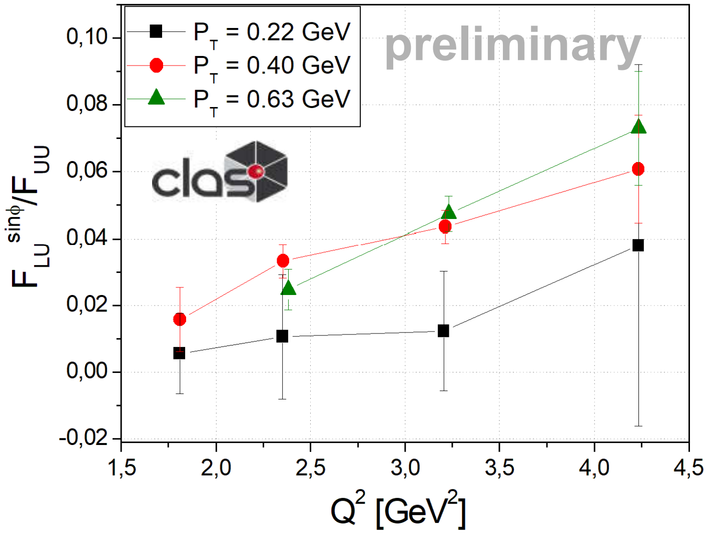
x_B = 0.17



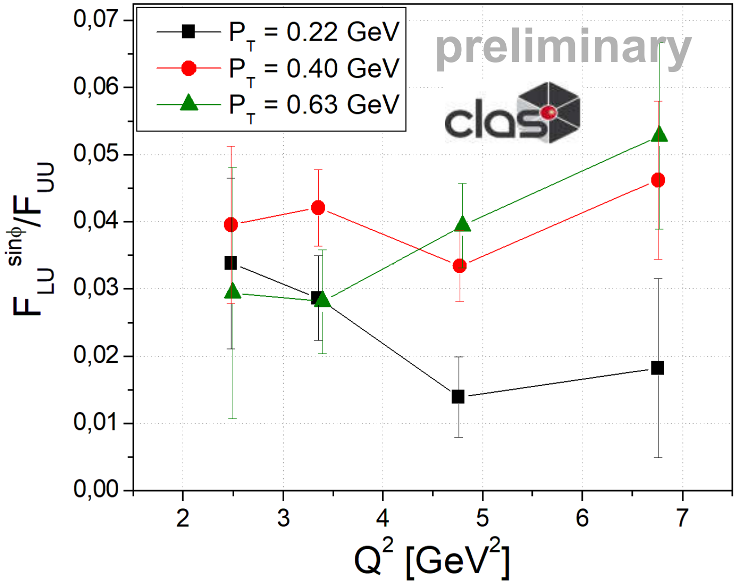
π^+

$0.3 < z < 0.4$

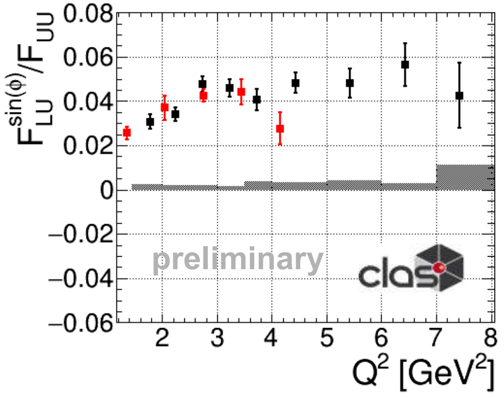
x_B = 0.24



x_B = 0.40



1 dimensional

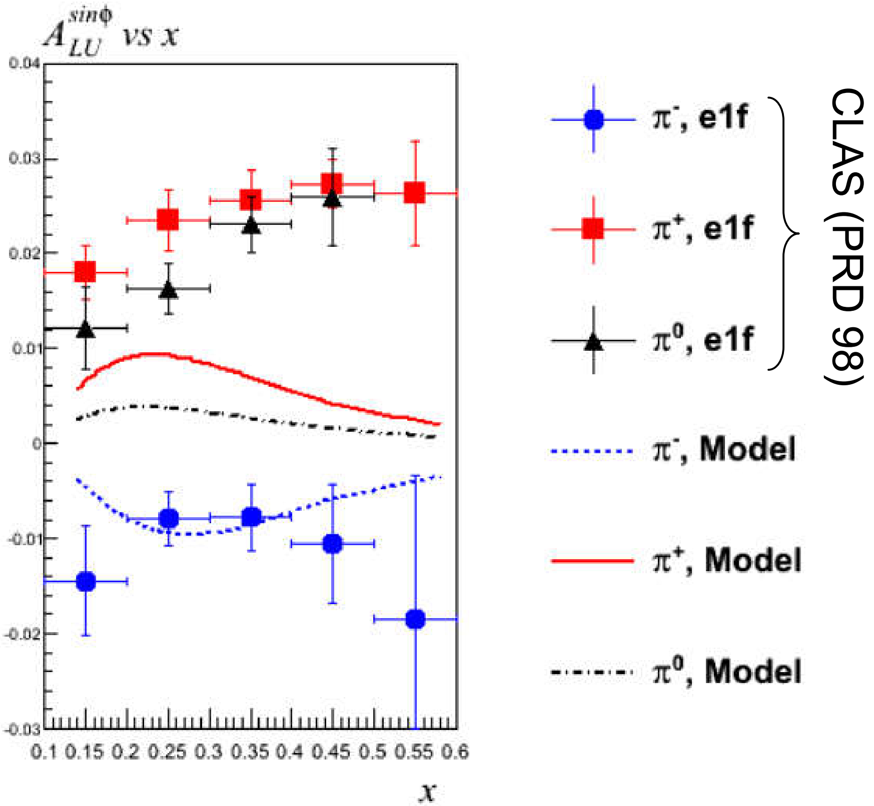


Comparison to theoretical predictions

A first theoretical model for single pion SIDIS was introduced in

P. Schweitzer, Phys. Rev. **D67**, 114010 (2003) [hep-ph/0303011]

A. V. Efremov, K. Goeke, and P. Schweitzer, Phys. Rev. **D73**, 094025 (2006) [hep-ph/0603054]



W. Gohn.et al. PRD 98 (2014)

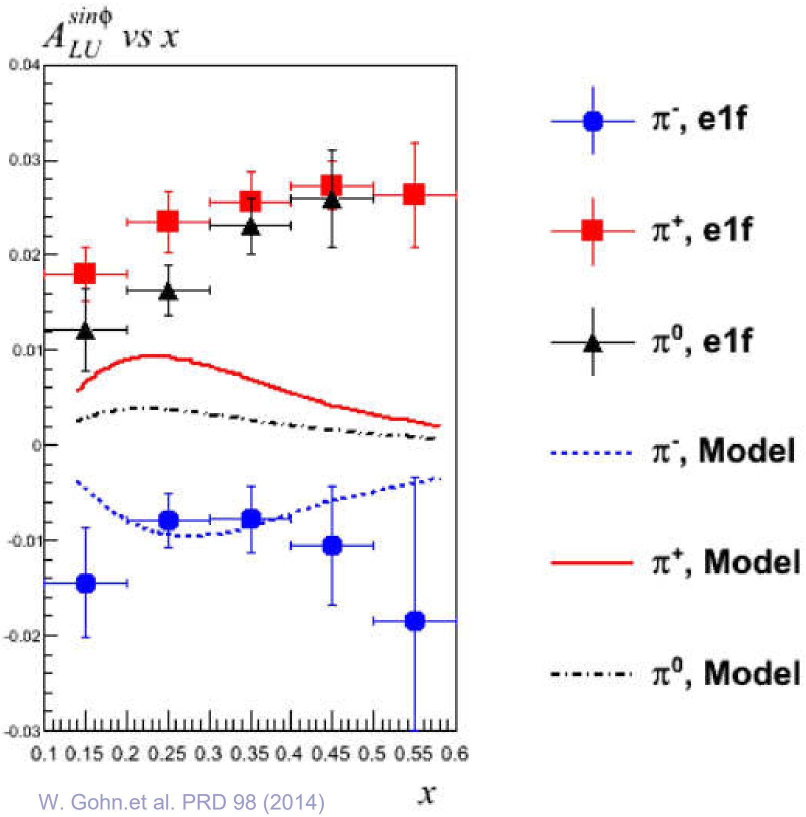
Simplifying assumption:

- only contribution from $e(x) \otimes H_1^\perp$

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

- signs are correctly reproduced
- ratio between π^+ and π^0 not
- magnitude at large x is too low

Comparison to theoretical predictions



W. Gohn.et al. PRD 98 (2014)

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

➔ Recent global fits show that the other terms can not be neglected

➔ Some of the TMDs and FF got better constrained

➔ Updated calculations, including all terms and the most recent TMDs and FF are in progress by P. Schweitzer et al.

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

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^-.
- The presented analysis is based on only ~ 3 % of the approved RGA beam time.
- The statistics provided by the pass 1 cooking this spring will enable a precise multidimensional analysis over an extended kinematic region.