CLAS collaboration meeting, JLAB

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SIDIS π^+ Beam Spin Asymmetry Measurements with CLAS 12

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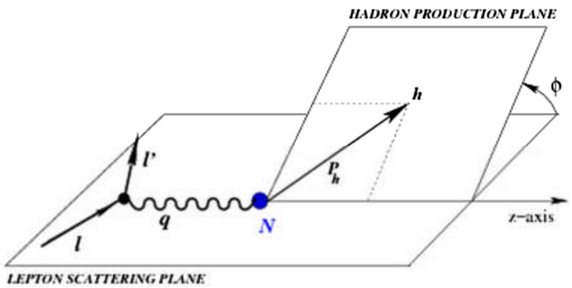
Physics Motivation

- 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

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

twist-3 pdf

Collins FF

unpolarized dist. function

twist-3 FF

twist-3 t-odd dist. funcion

Boer-Mulders

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

Additional constraints: i.e. from unpolarized structure functions

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

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

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

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

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

Physics Motivation

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

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

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

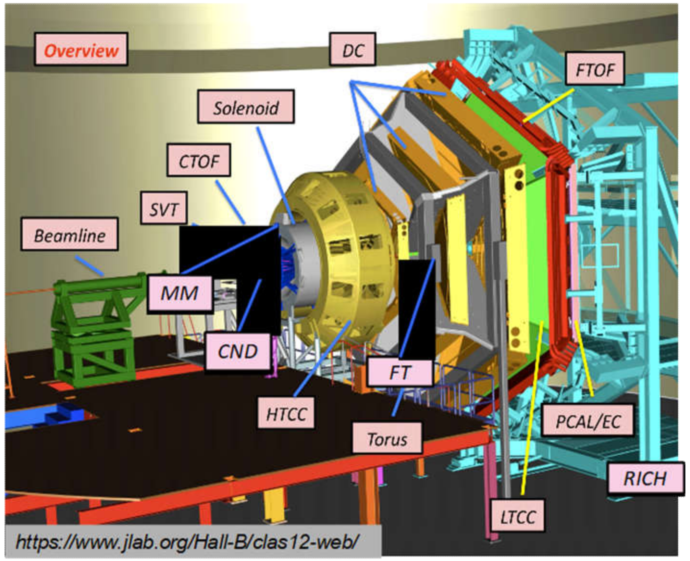
$$A_{LU}^{\sin\phi} = \sqrt{2\varepsilon(1-\varepsilon)} \frac{F_{LU}^{\sin\phi}}{F_{UU}}$$

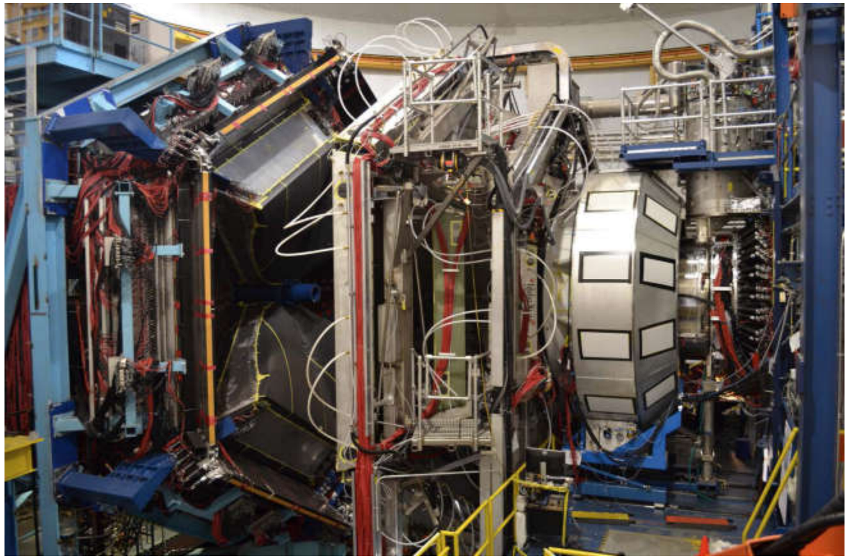
Past: Measurements have been performed with CLAS, HERMES and COMPASS

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

Goal for the first CLAS12 publication: A multidimensional study in Q^2, x_B, z and P_T

Experimental Setup and available dataset





RG-A data from fall 2018:

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

Plots shown in this presentation: ~ 3 % of the approved RG-A beam time (DNP 2019)
inbending torus field

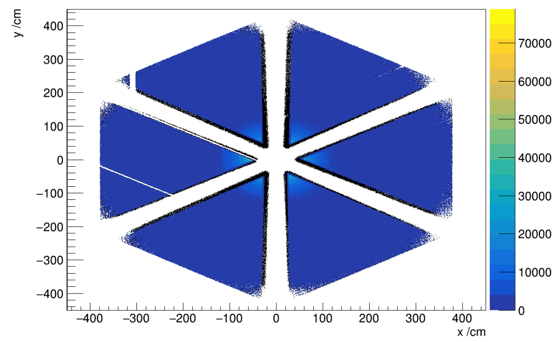
Data for first publication: complete fall 2018 inbending dataset (~ 3 x more)
outbending data can be used to extend the kinematic region

Electron ID

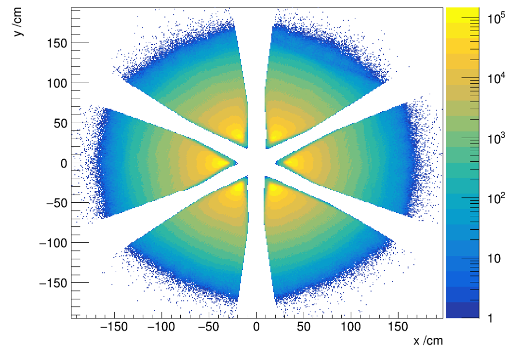
1. **1.** PCAL fiducial cuts

2. **2.** DC fiducial cuts for the 3 regions

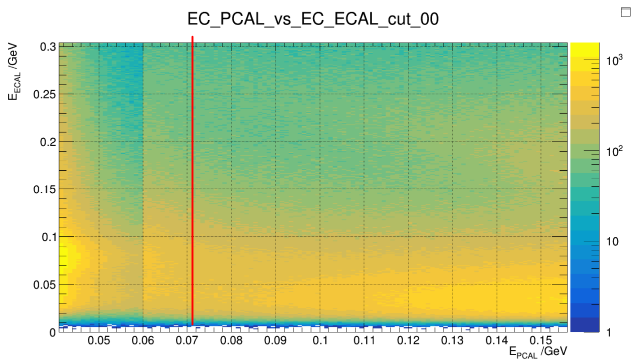
PCAL



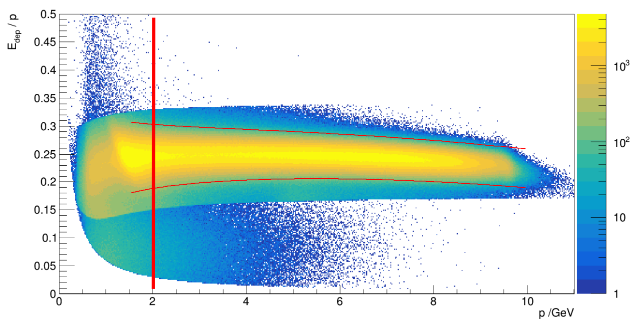
DC region 1



3. **3.** PCAL energy deposition > 0.07 GeV
eventbuilder: > 0.06 GeV

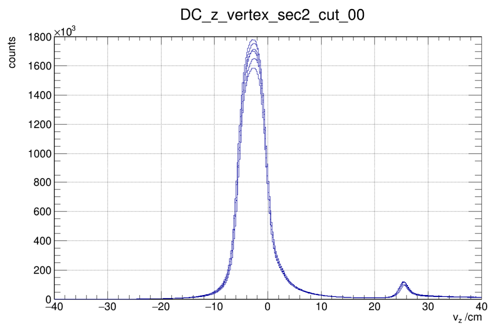


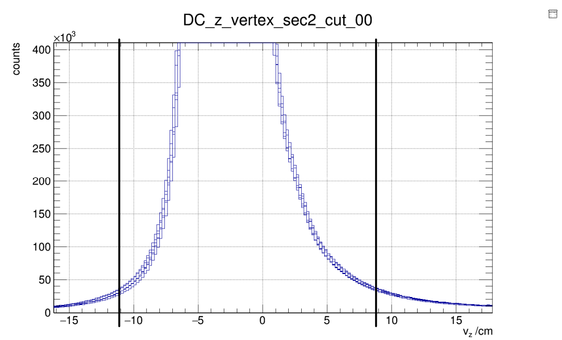
4. **4.** Calorimeter sampling fraction: 3 sigma region



5. **5.** p_e > 2.0 GeV

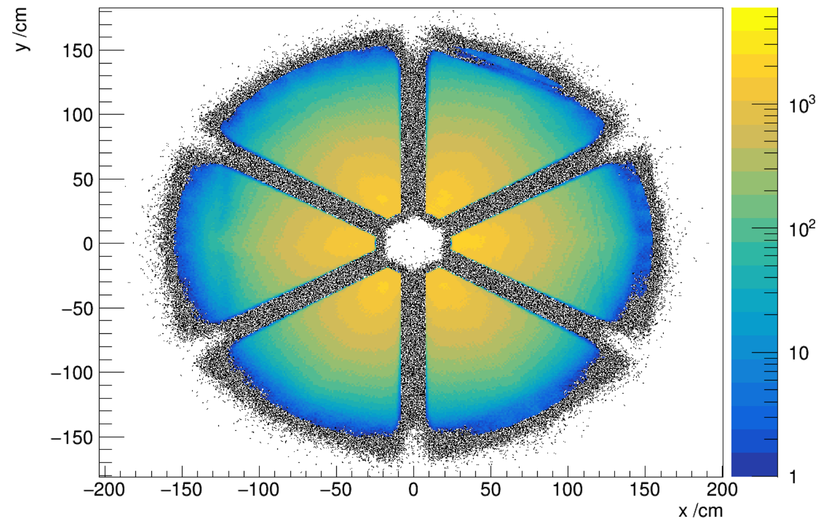
6. **6.** z-vertex cut [-11, +9]
➔ 2 % level of the maximum





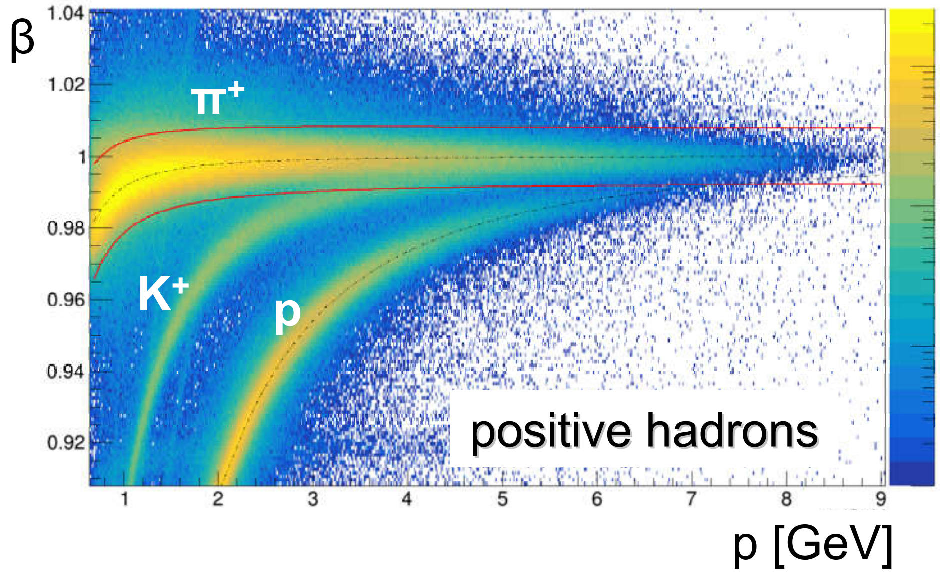
Hadron ID

1. DC fiducial cuts for the 3 regions



2. Final selection based on TOF

→ Maximum likelyhood PID from eventbuilder with $|\chi^2_{PID}| < 2.0$



Kinematic cuts

$P_{min}(e^-)$ = 2.0 GeV ($y < 0.8$) $P_{min}(\pi^+)$ = 1.25 GeV

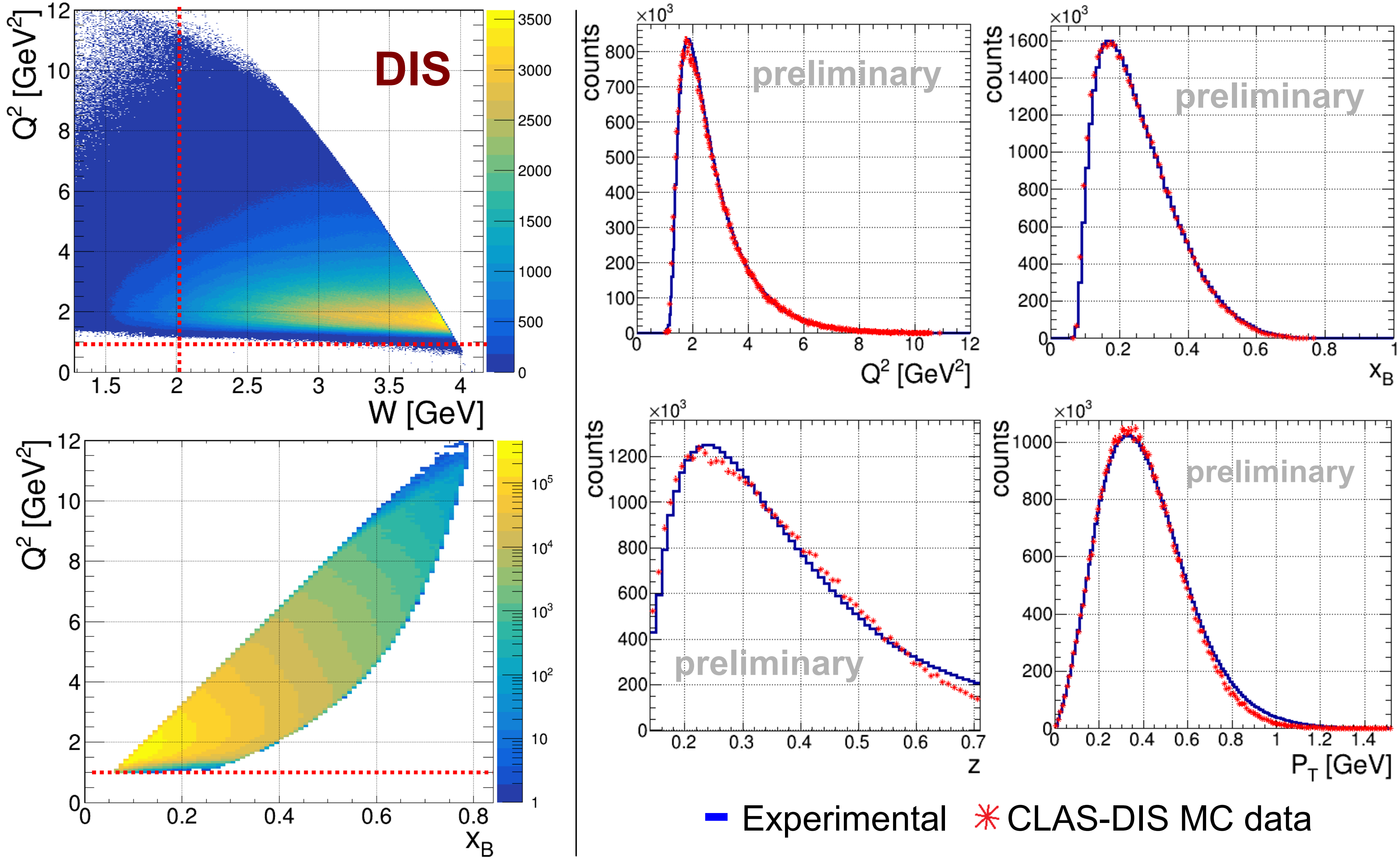
DIS cut: $Q^2 > 1$ GeV² $W > 2$ GeV

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^+



Beam spin asymmetry

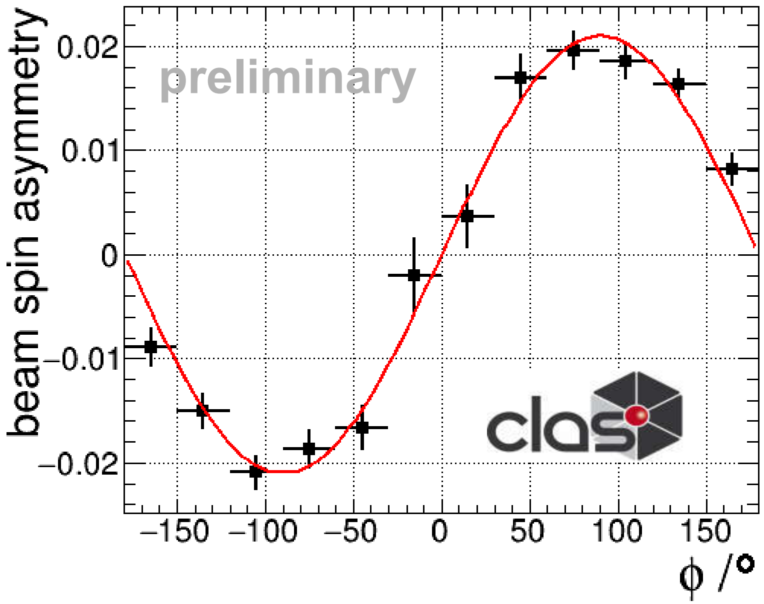
$$BSA_i = \frac{1}{P_e} \cdot \frac{N_i^+ - N_i^-}{N_i^+ + N_i^-}$$

P_e = 85 % : average e^- beam polarisation

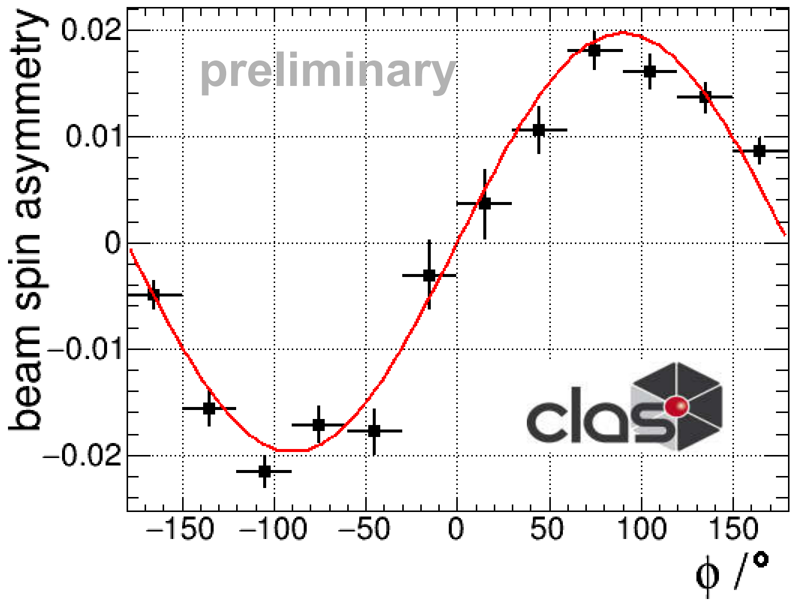
Φ dependence without kinematic bins

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

π^+

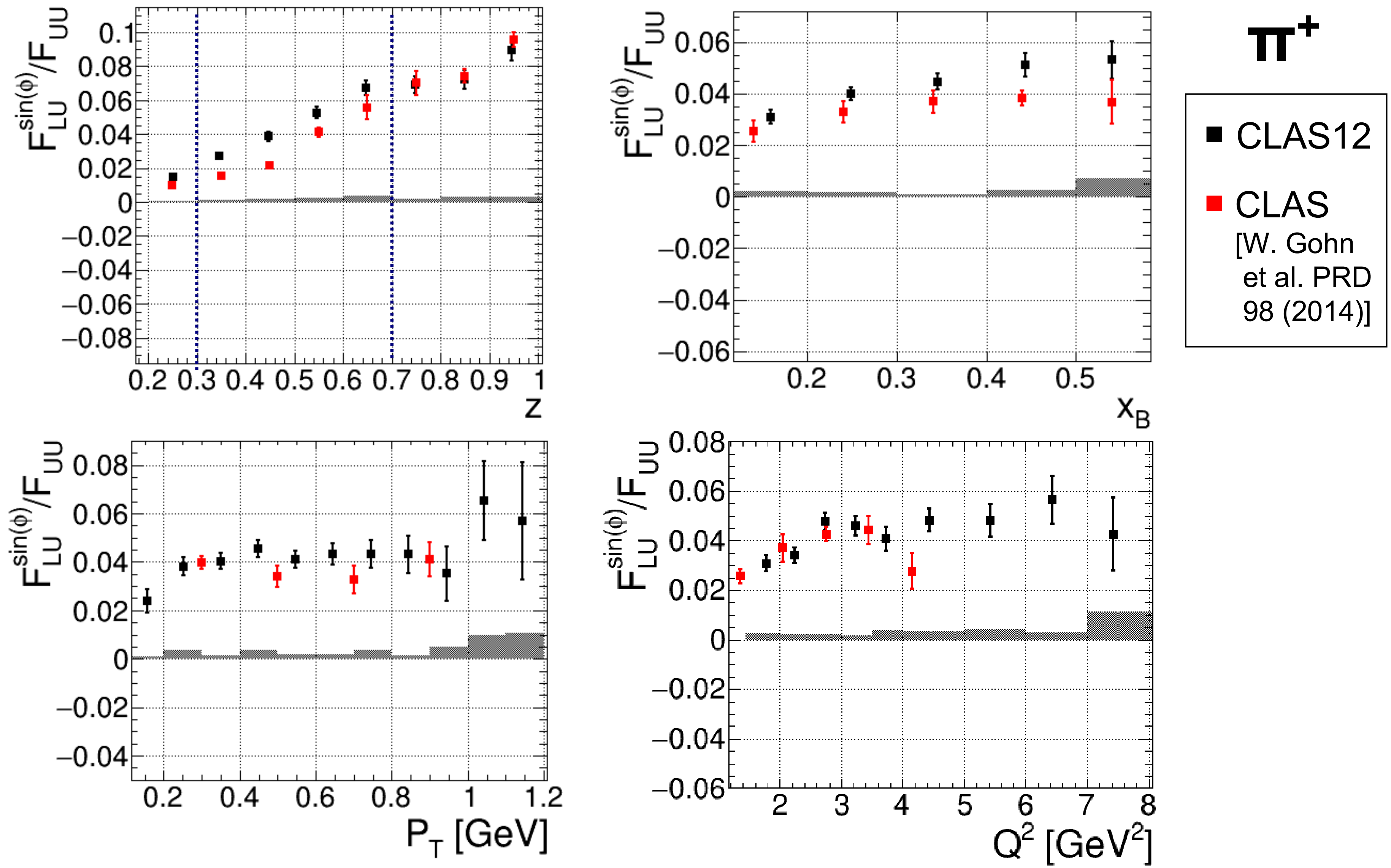


π^0



➔ Clear sinoid shape can be observed

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



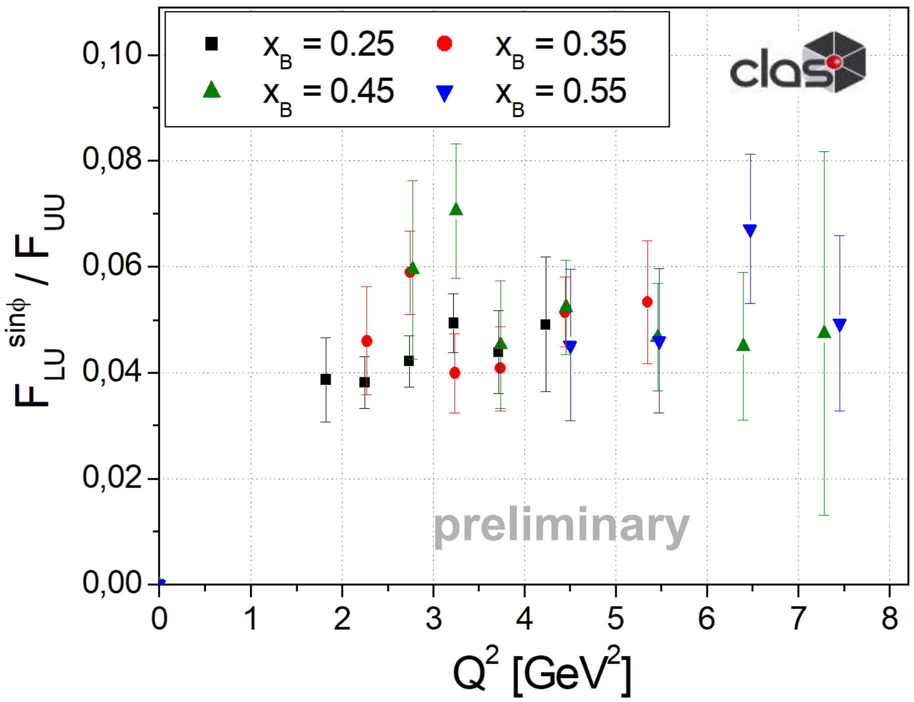
A multidimensional study

π^+

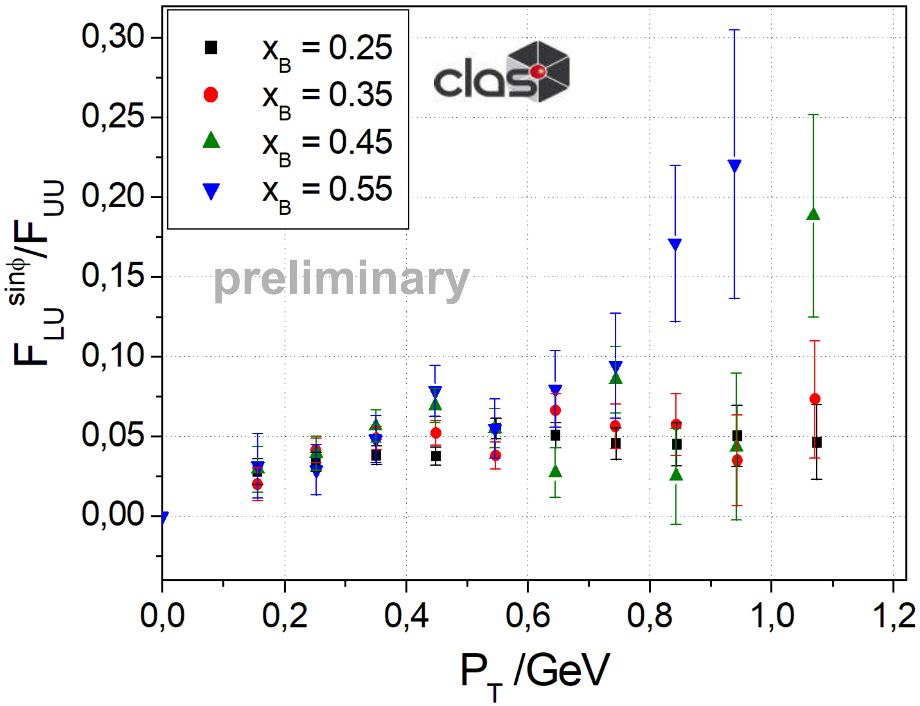
Step 1: A two dimensional binning

$0.3 < z < 0.7$

0.0 GeV < P_T < 1.4 GeV



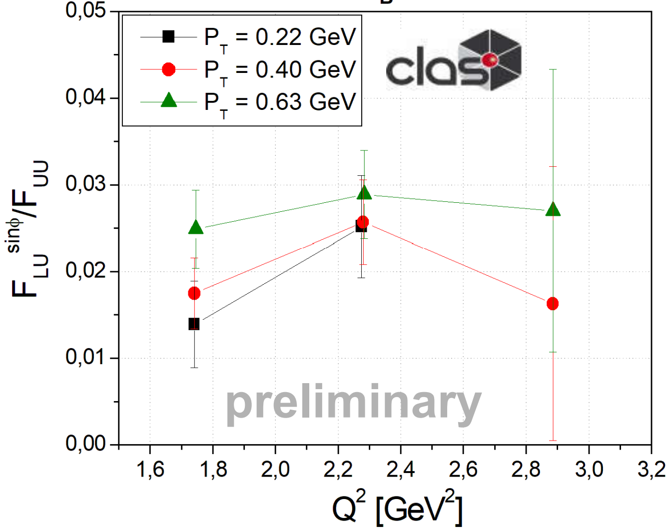
1.0 GeV² < Q² < 12 GeV²



A multidimensional study

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

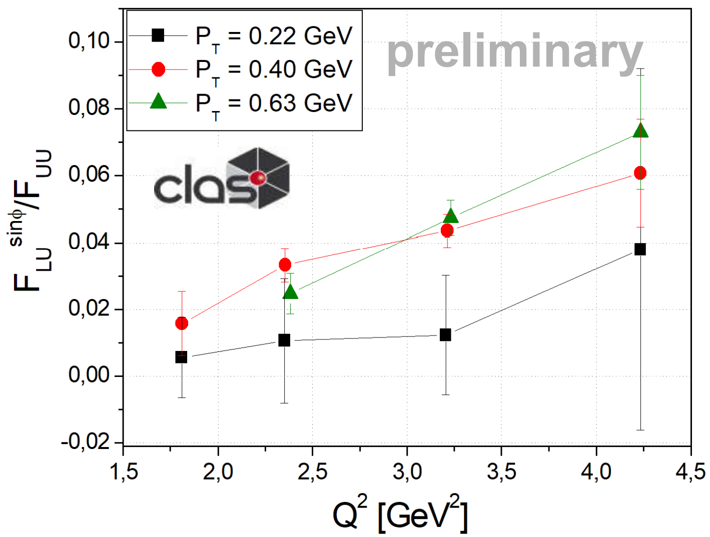
x_B = 0.17



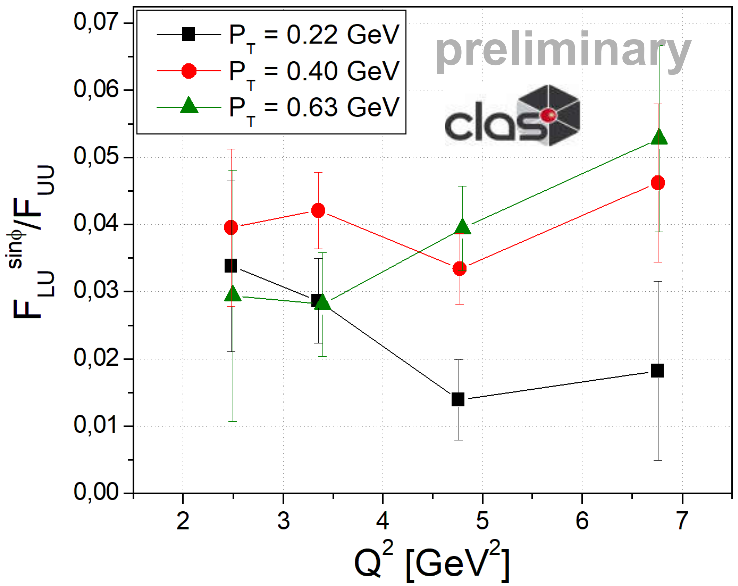
π^+

0.3 < z < 0.4

x_B = 0.24



x_B = 0.40

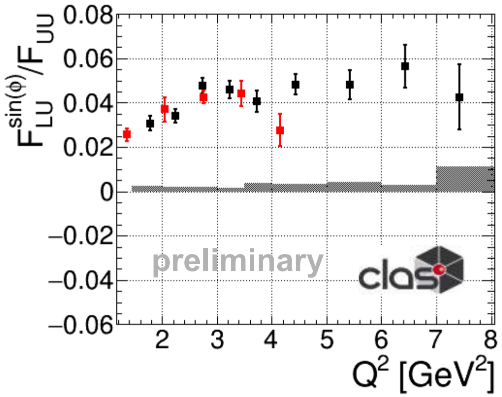


Behaviour at large Q^2:

➔ Decrease for small P_T

➔ Increase for large P_T

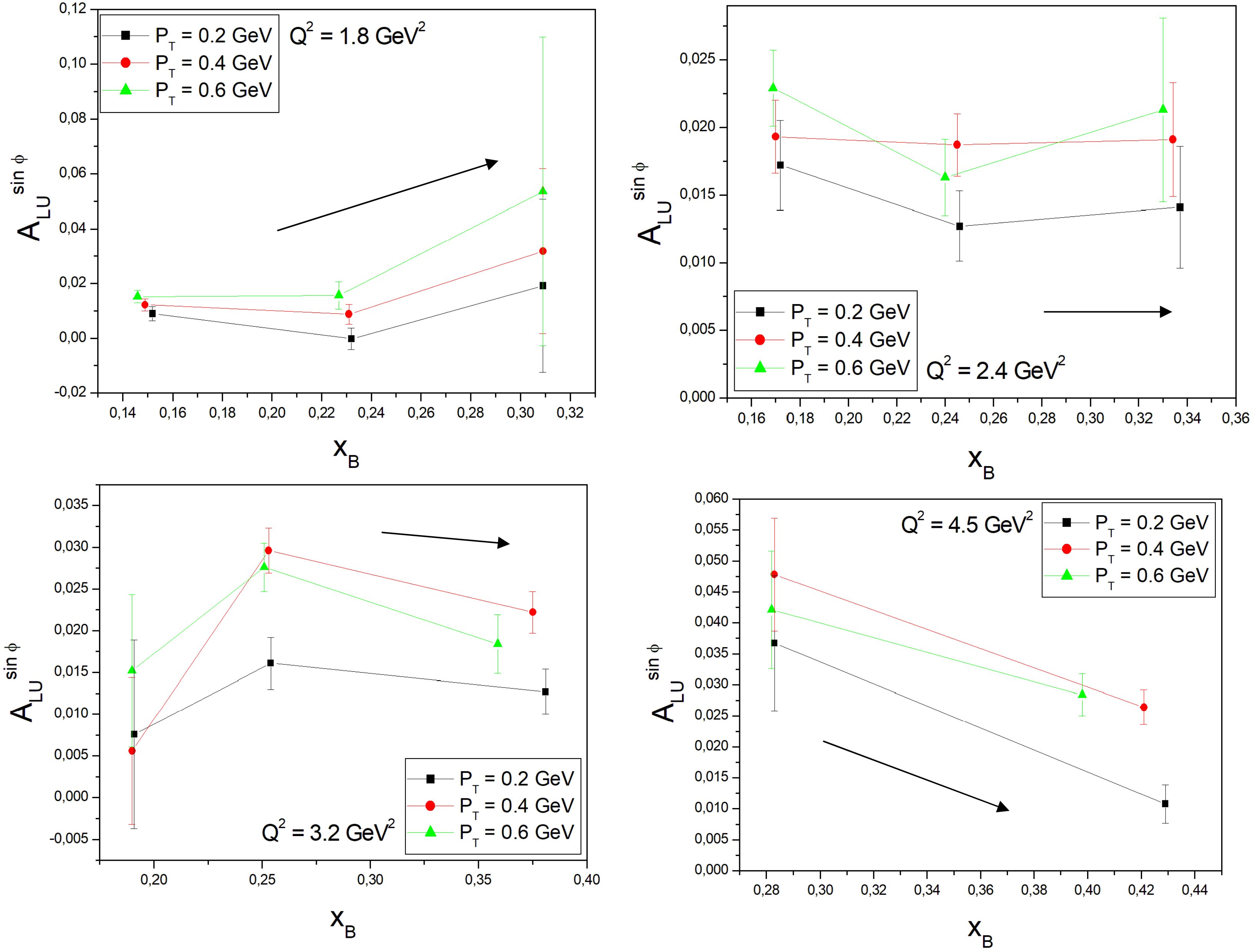
1 dimensional



A multidimensional study

0.3 < z < 0.4

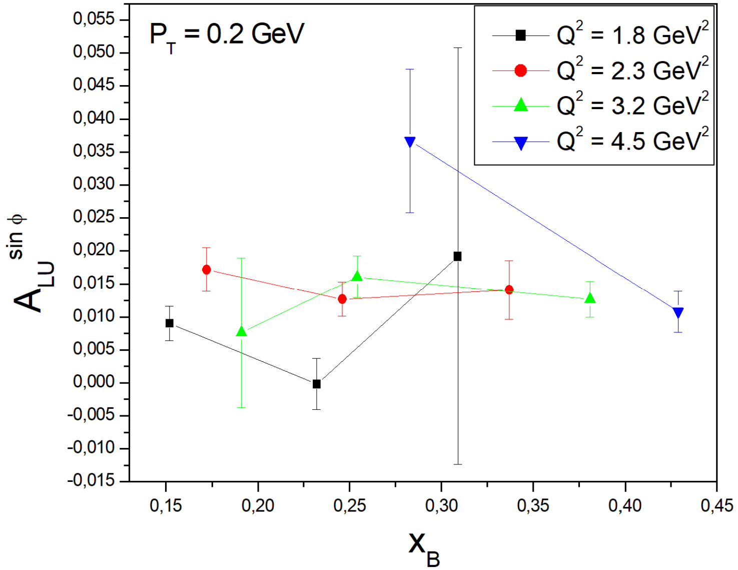
π^+

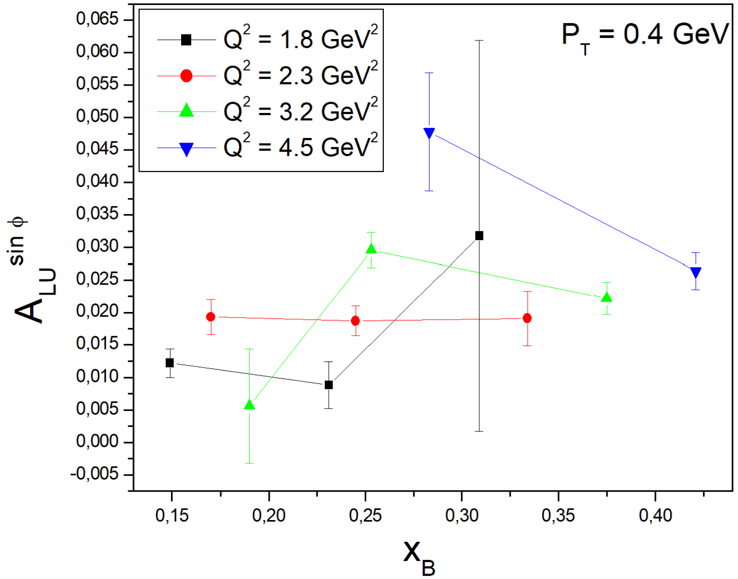


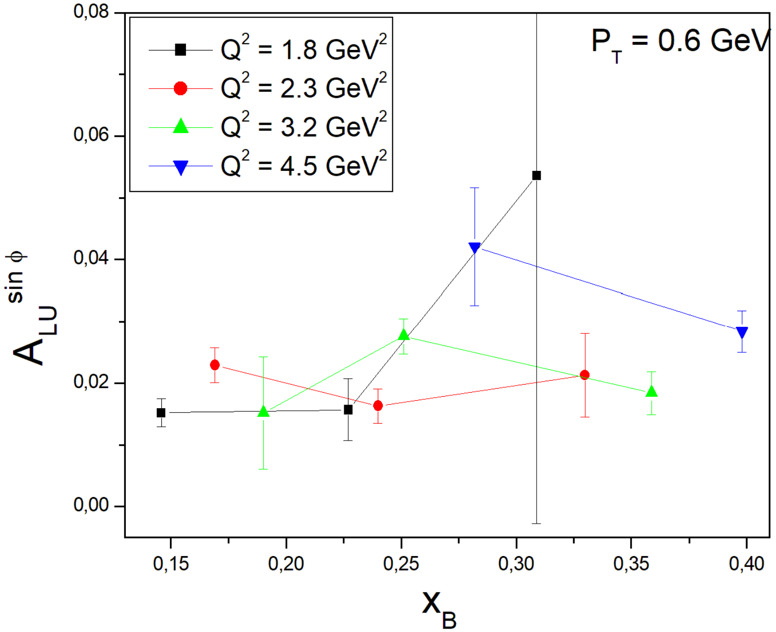
A multidimensional study

$0.3 < z < 0.4$

π^+







Conclusion on x_B:

➔ Increase for small Q^2 independent of P_T

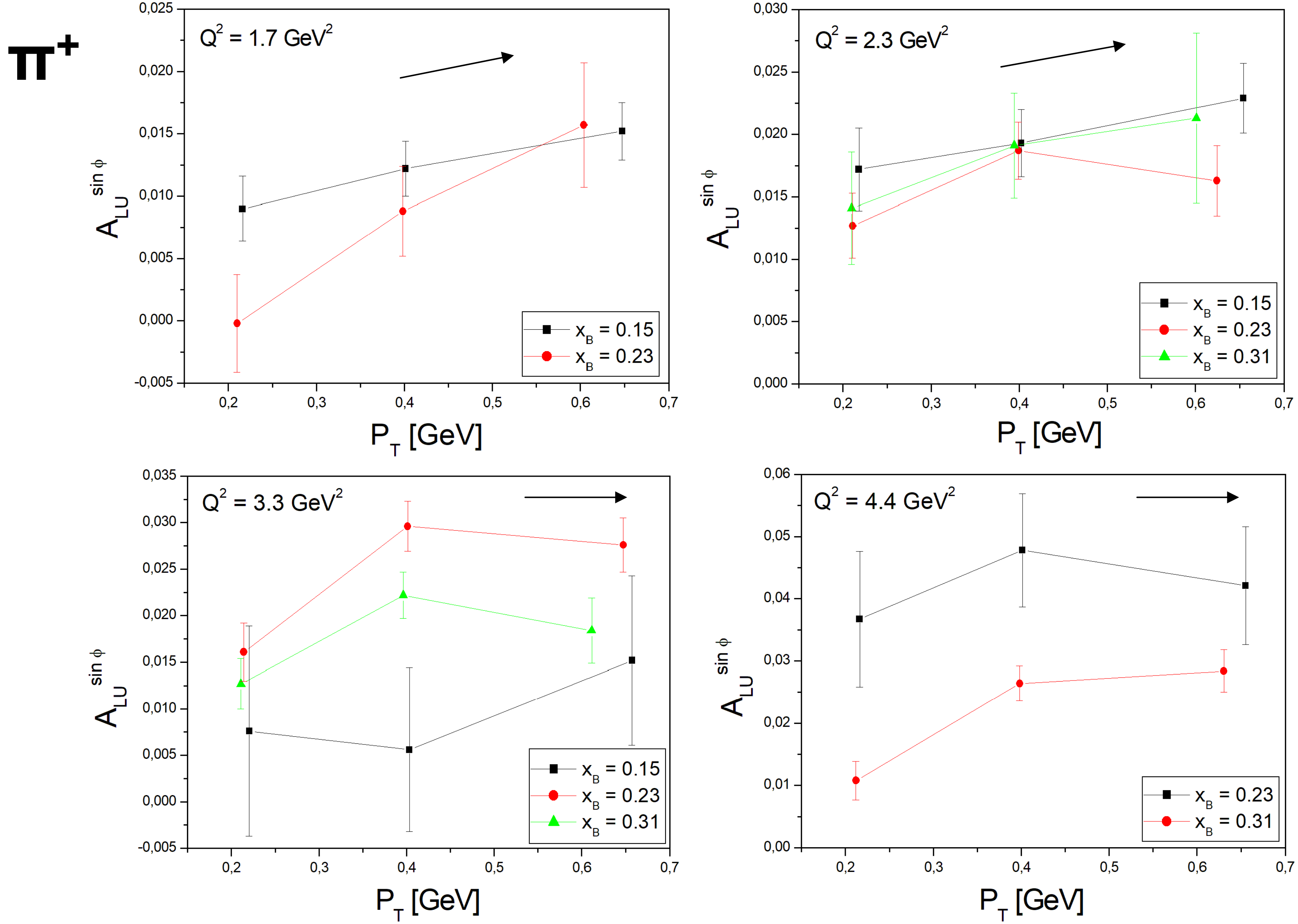
➔ Decrease at large Q^2 independent of P_T

➔ Nearly flat at intermediate Q^2

➔ Slope and magnitude are dominated by Q^2

A multidimensional study

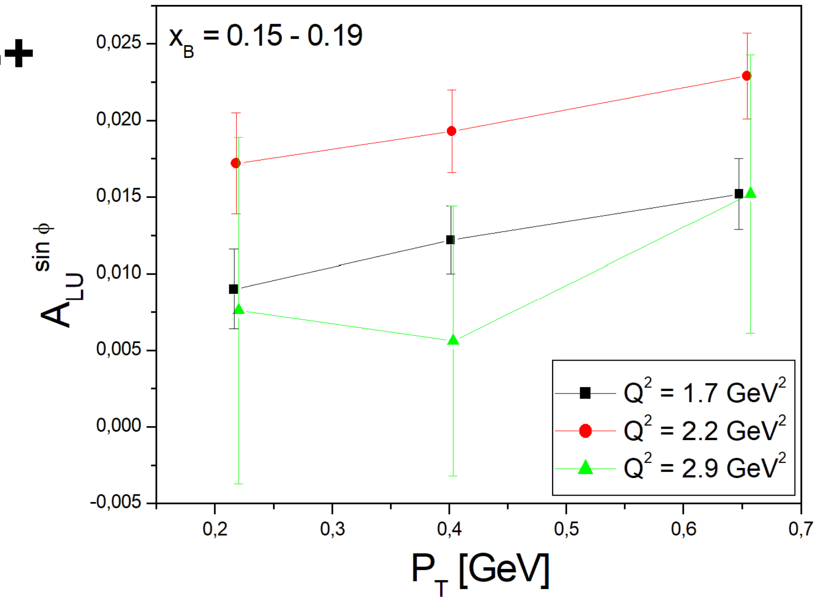
$0.3 < z < 0.4$

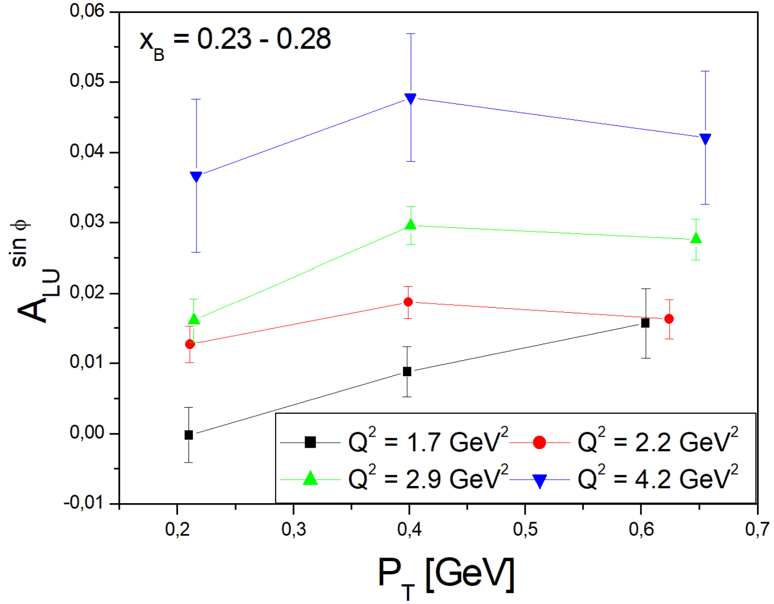


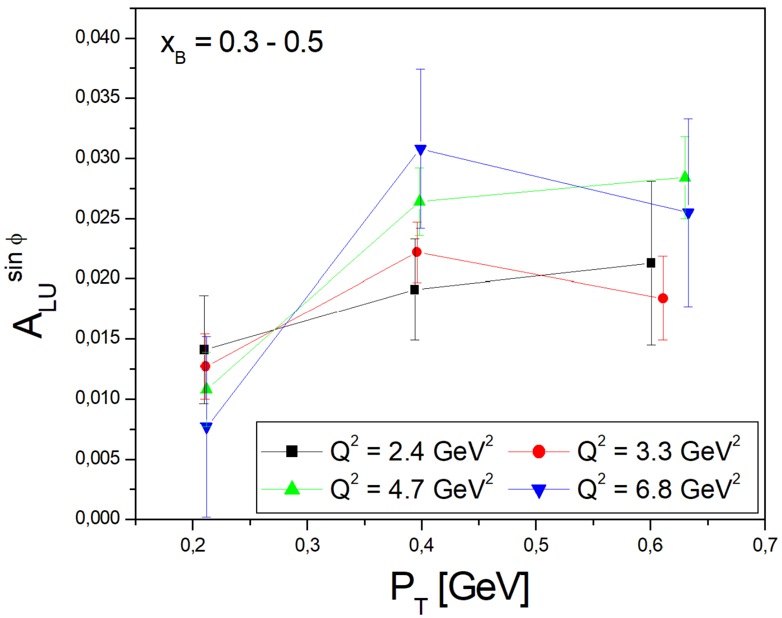
A multidimensional study

0.3 < z < 0.4

π^+







Conclusion on P_T:

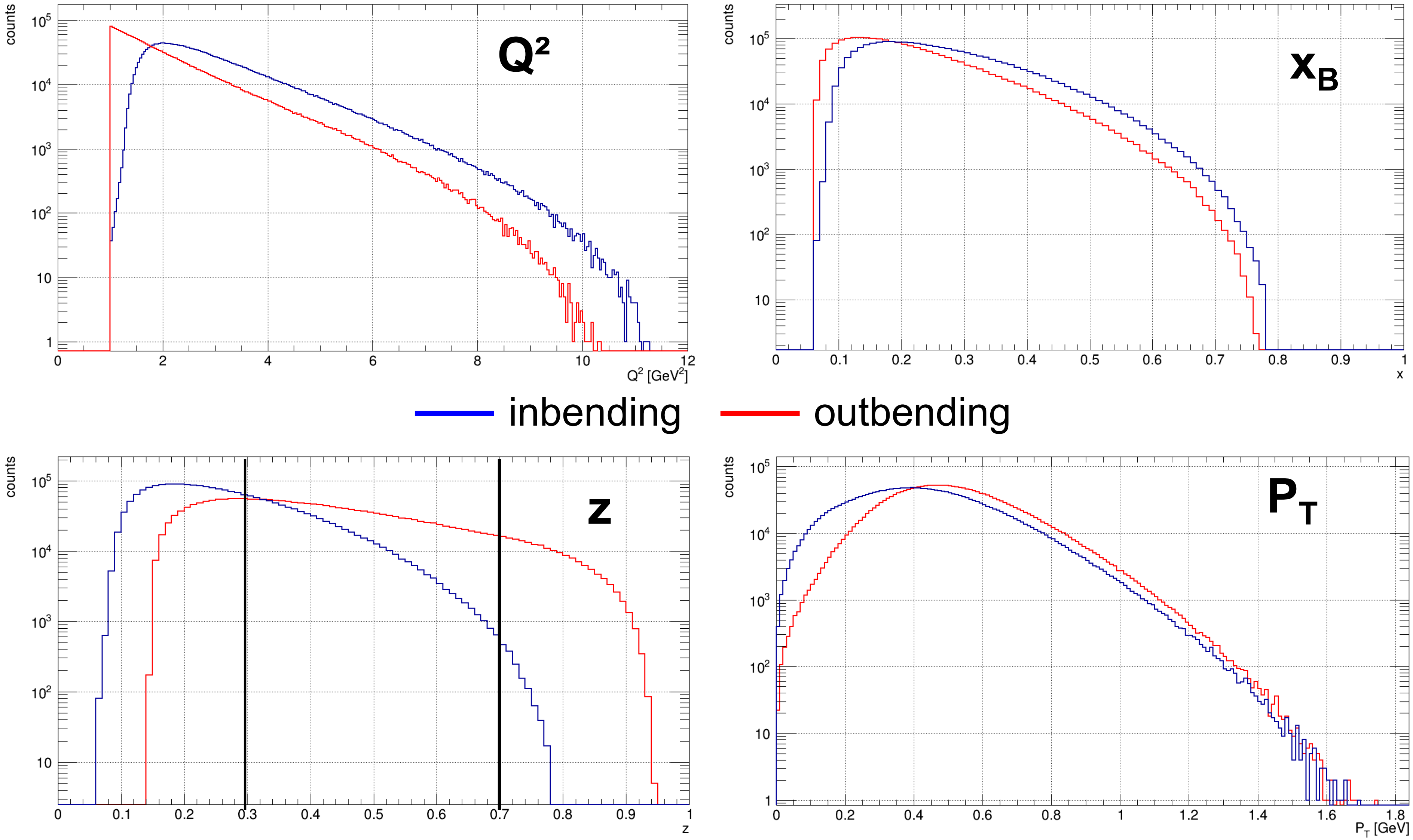
➔ Increase up to high P_T if Q² and x_B are small

➔ Flat behaviour at large P_T for intermediate Q_2 and x_B

➔ Slight decrease at large P_T for large Q_2 and x_B

➔ Slope and magnitude influenced by Q² and x_B

Kinematic coverage: outbending vs inbending



Possible sources of systematic uncertainty:

→ Uncertainty of the beam polarisation

→ Fiducial cuts and particle ID refinements
(strictness of the PID / contamination in the pion sample)

→ Acceptance Effects

→ Extraction method and higher order moments

→ Detector inefficiencies / sector dependence

→ Radiative effects

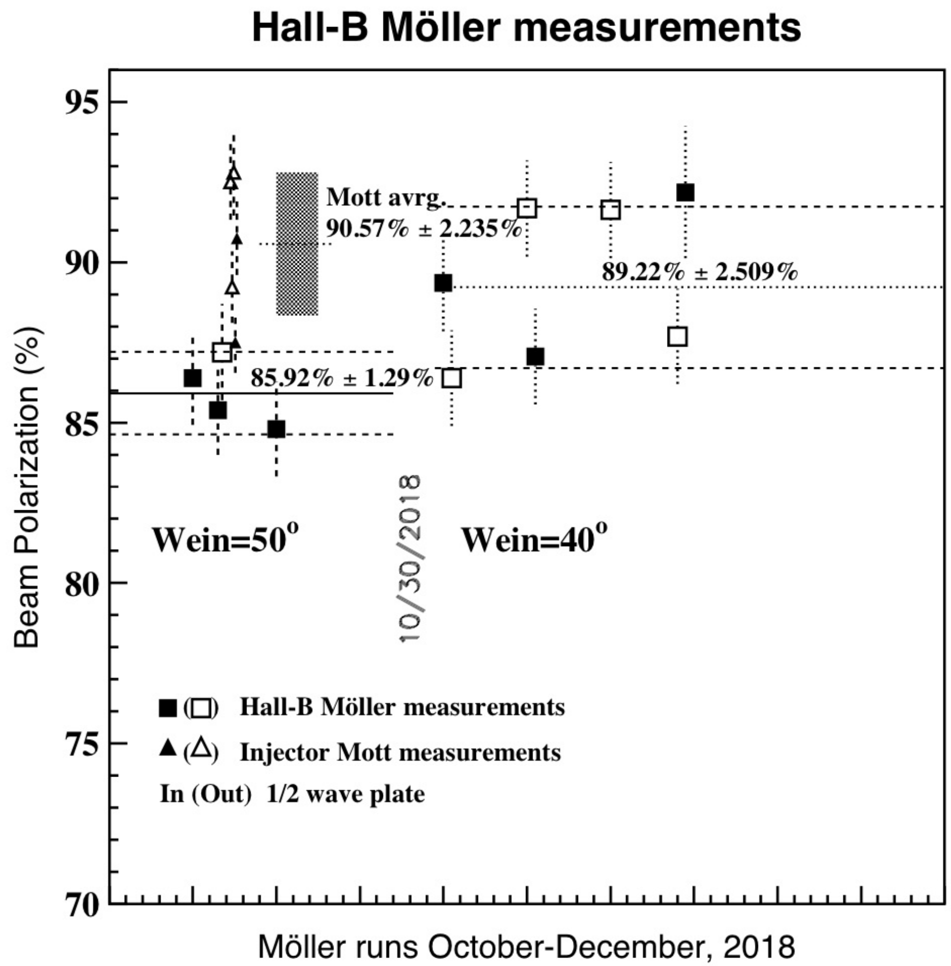
→ Binning / resolution effects

Systematics: Beam Polarisation

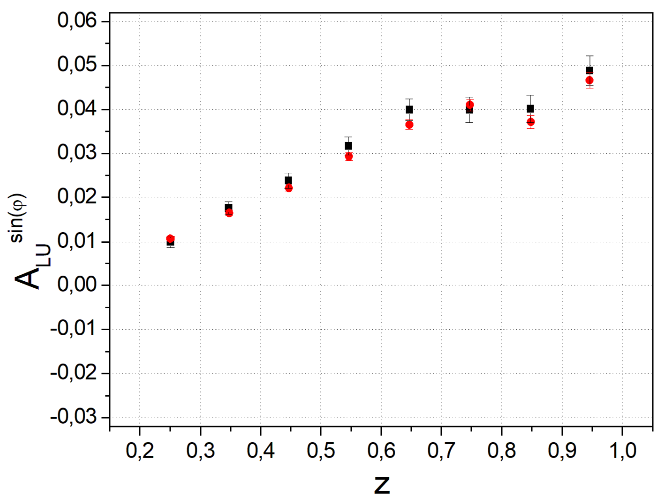
Available measurements:

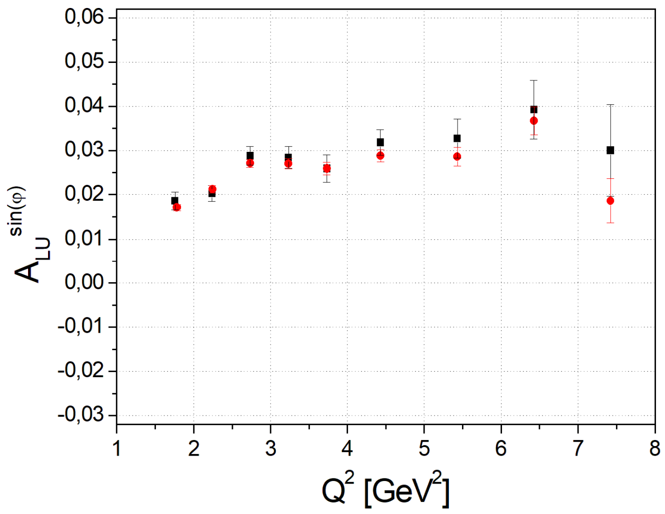
- Change of the beam polarisation has to be considered.

~3% systematic uncertainty from the measurement.

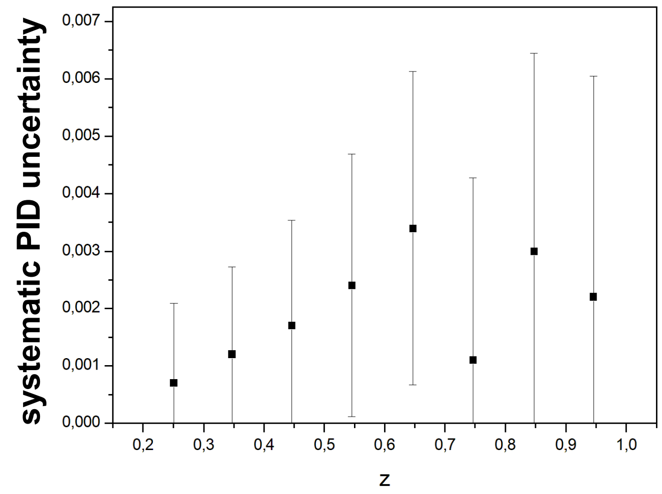


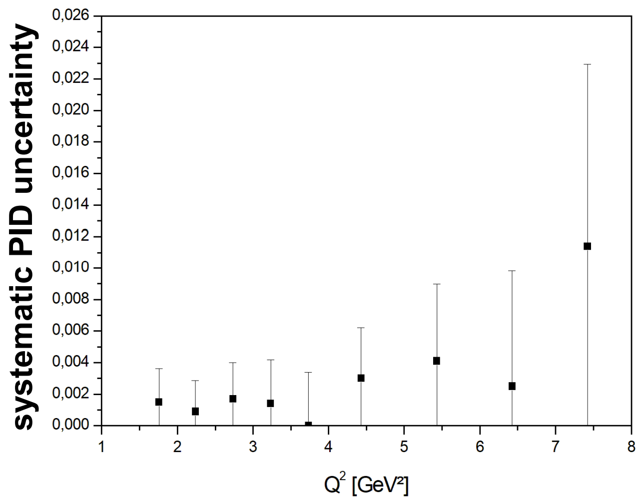
Systemtics: Uncertainty from the PID





red: eventbuilder
black: redefined PID

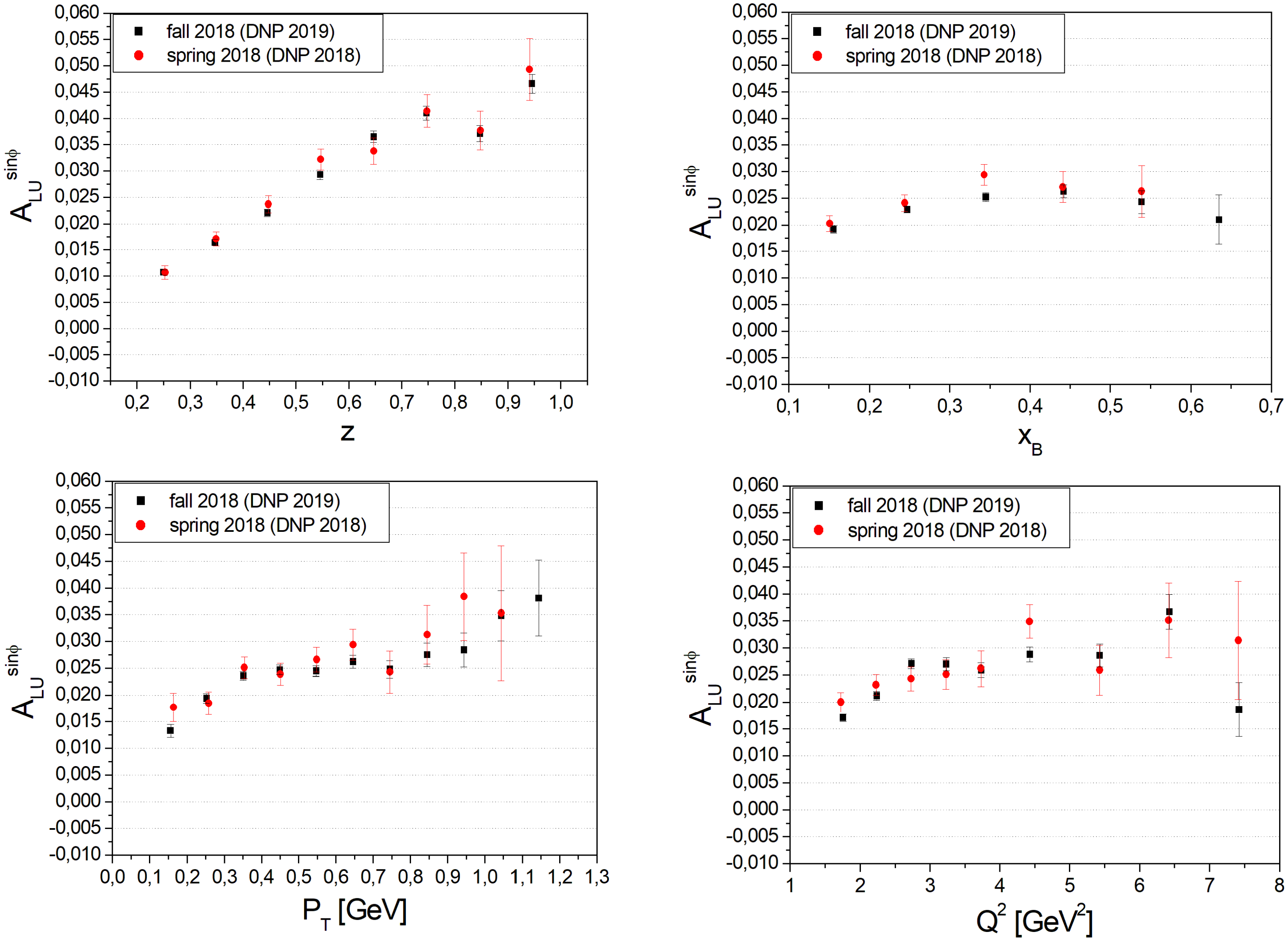




→ Small effect (requires final statistics for precise results)

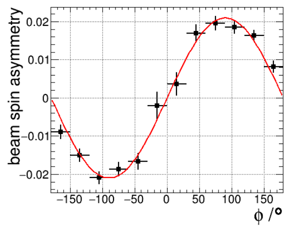
Systematics: Dependence of the result on the data quality

π^+



Comparison of different extraction methods

Method 1: χ^2 fit of the BSA calculated for 12 ϕ bins



a) 1 moment only: $$BSA = A_{LU}^{\sin\phi} \cdot \sin(\phi)$$

b) all 3 moments: $$BSA = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{A_{LU}^{\sin\phi} \sin\phi}{1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos(2\phi)} \cos(2\phi)}$$

+ fast   + result can be visualized   - using all 3 moments not reliable for low stat.

Method 2: Statsitical extraction (unbinned in ϕ)

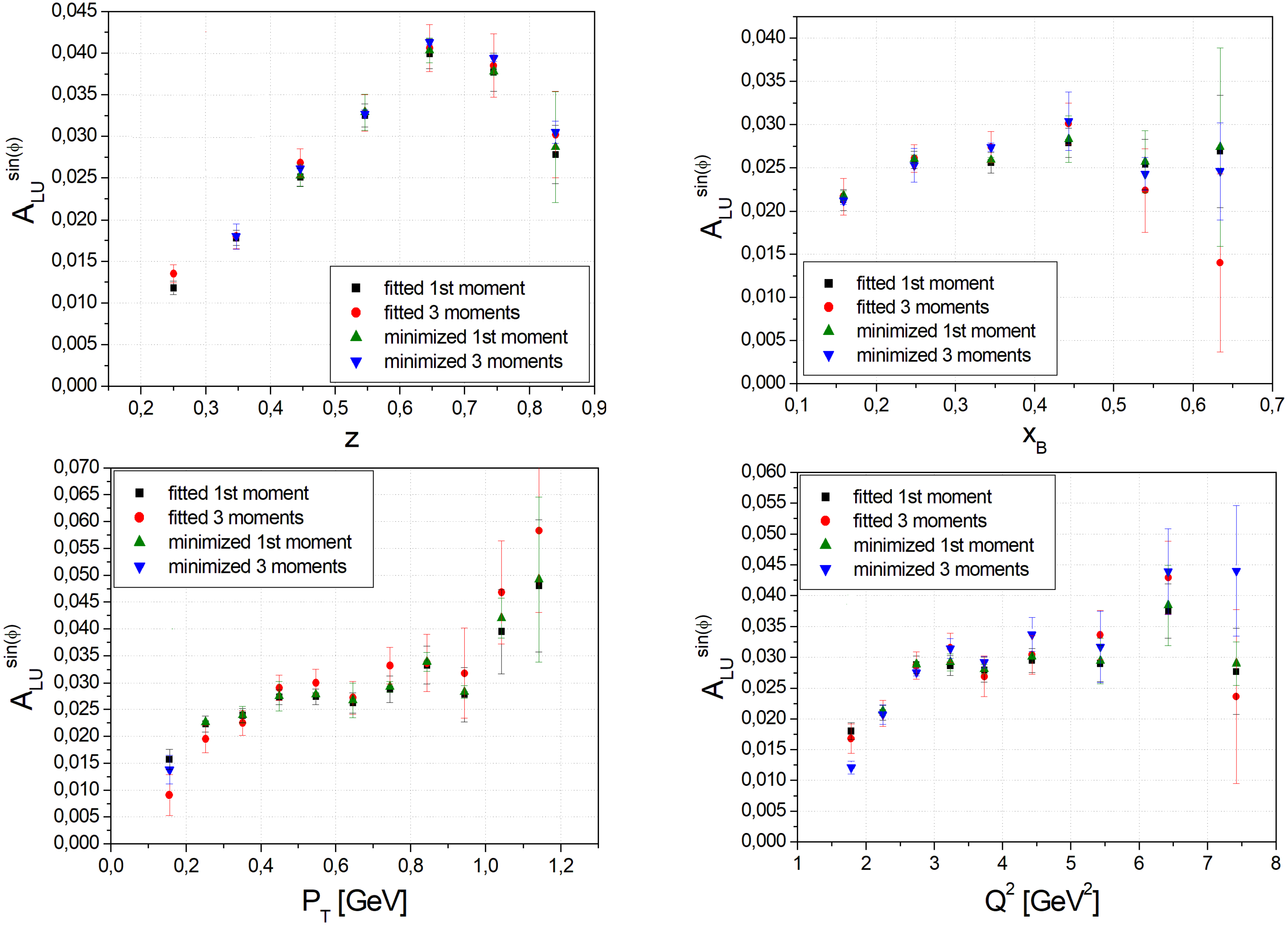
a) 1 moment only: $$P = -\prod_{i=1}^{N} (1 + h \cdot P_e \cdot gauss(A_{LU}^{\sin(\phi)}, \sigma) \cdot \sin(\phi))$$

b) all 3 moments: $$P = -\prod_{i=1}^{N} \left(1 + h \cdot P_e \cdot \frac{gauss(A_{LU}^{\sin(\phi)}, \sigma_1) \cdot \sin(\phi)}{1 + gauss(A_{UU}^{\cos(\phi)}, \sigma_2) \cdot \cos(\phi) + gauss(A_{UU}^{\cos(2\phi)}, \sigma_3) \cdot \cos(2\phi)} \right)$$

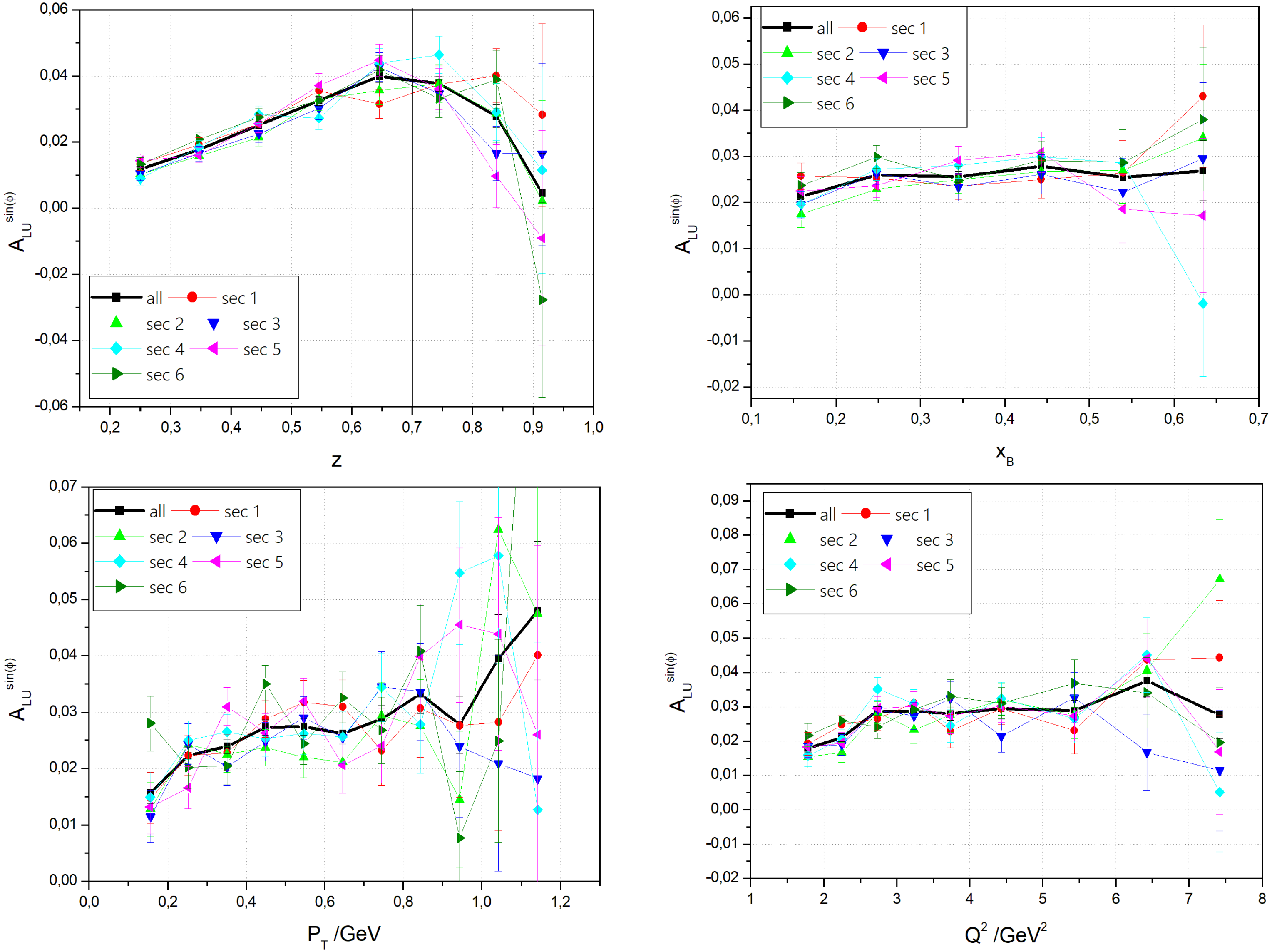
➔ Minimize P

+ partly a reduced error   + more reliable for low stat.   - slow   - no direct visualisation of the quality
+ does not depend on the phi binning   + less sensitive to possible holes in the phi coverage

π^+ - Comparison of all 4 extraction variants



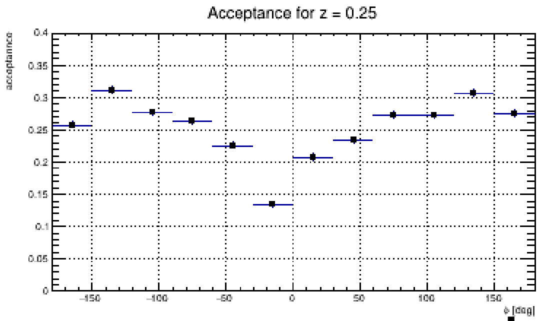
Systematics: Comparison of the sector dependence (π^+ sector)



Systematics: Acceptance effects

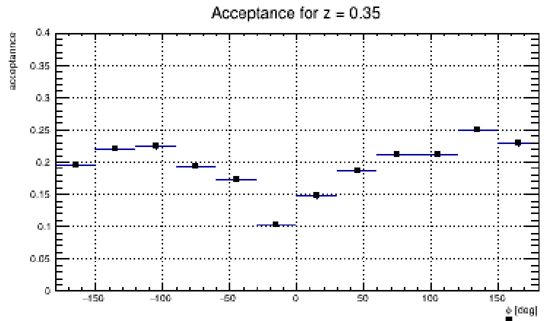
π^+ ϕ acceptance, based on SIDIS MC

z = 0.25



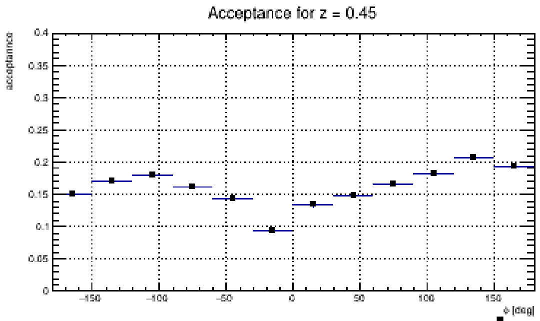
ϕ

z = 0.35



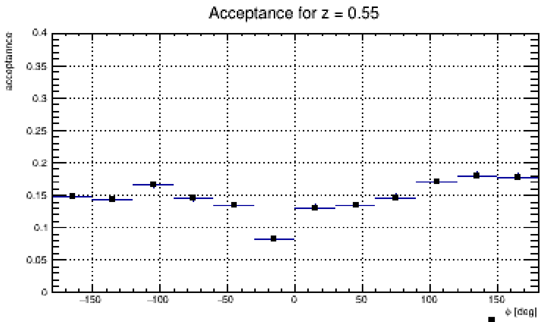
ϕ

z = 0.45



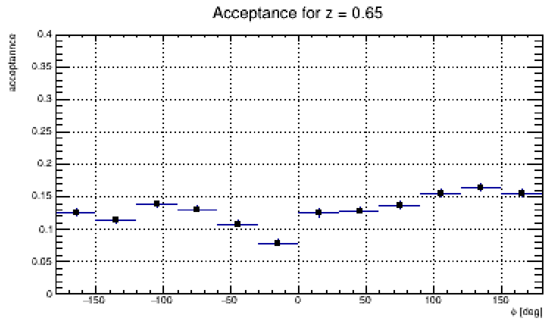
ϕ

z = 0.55



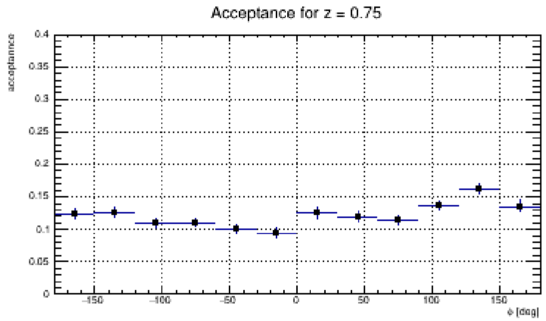
ϕ

z = 0.65



ϕ

z = 0.75



ϕ

- Smooth acceptance curves
- If they exist, acceptance effects due to the finite bin size only around ϕ = 0

Systematics: acceptance effects

MC for π⁺:

genearated

(with experimental BSA)

fit to exp. result:

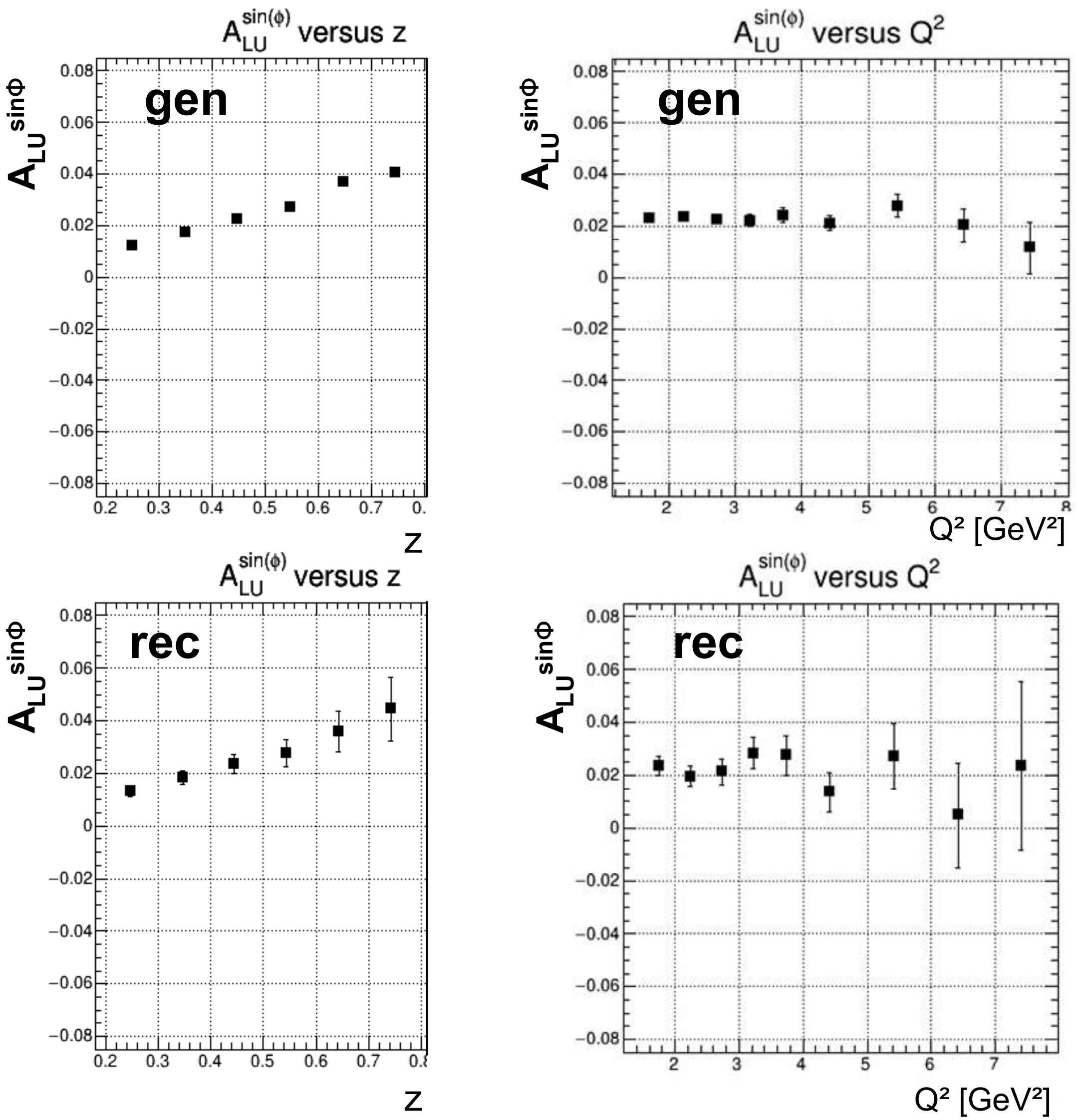
$A_{LU}^{\sin\phi} = -0.00285 + 0.05787 * z_{gen}$

~ 60 – 80 million events

reconstructed:

➔ no variation within statistical uncertainty

➔ for a pricise study 500 – 1000 million MC events will be produced (CLAS DIS).

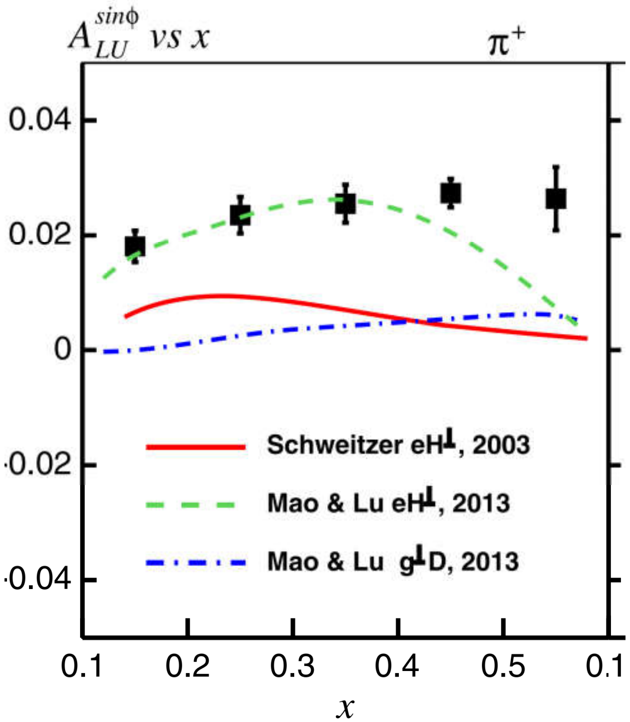


Comparison to theoretical predictions

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 $e(x) \otimes H_1^{\perp}$

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

- sign is correctly reproduced
- magnitude at large x is too low

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

➔ Some of the TMDs and FF got better constrained

Comparison to theoretical predictions

Newer predictions (2014):

On the beam spin asymmetries of electroproduction of charged hadrons off the nucleon targets

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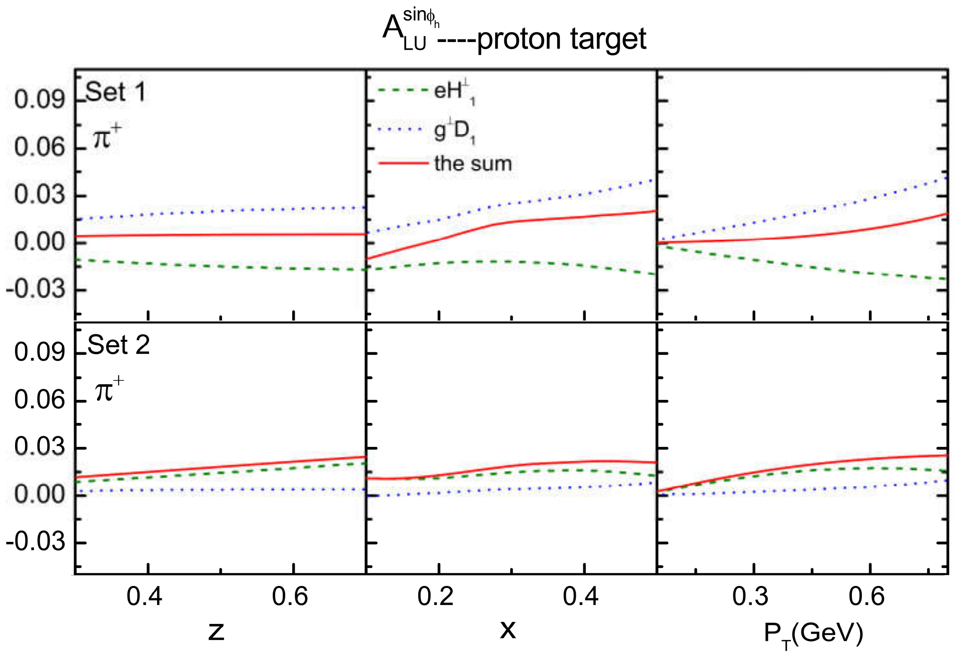
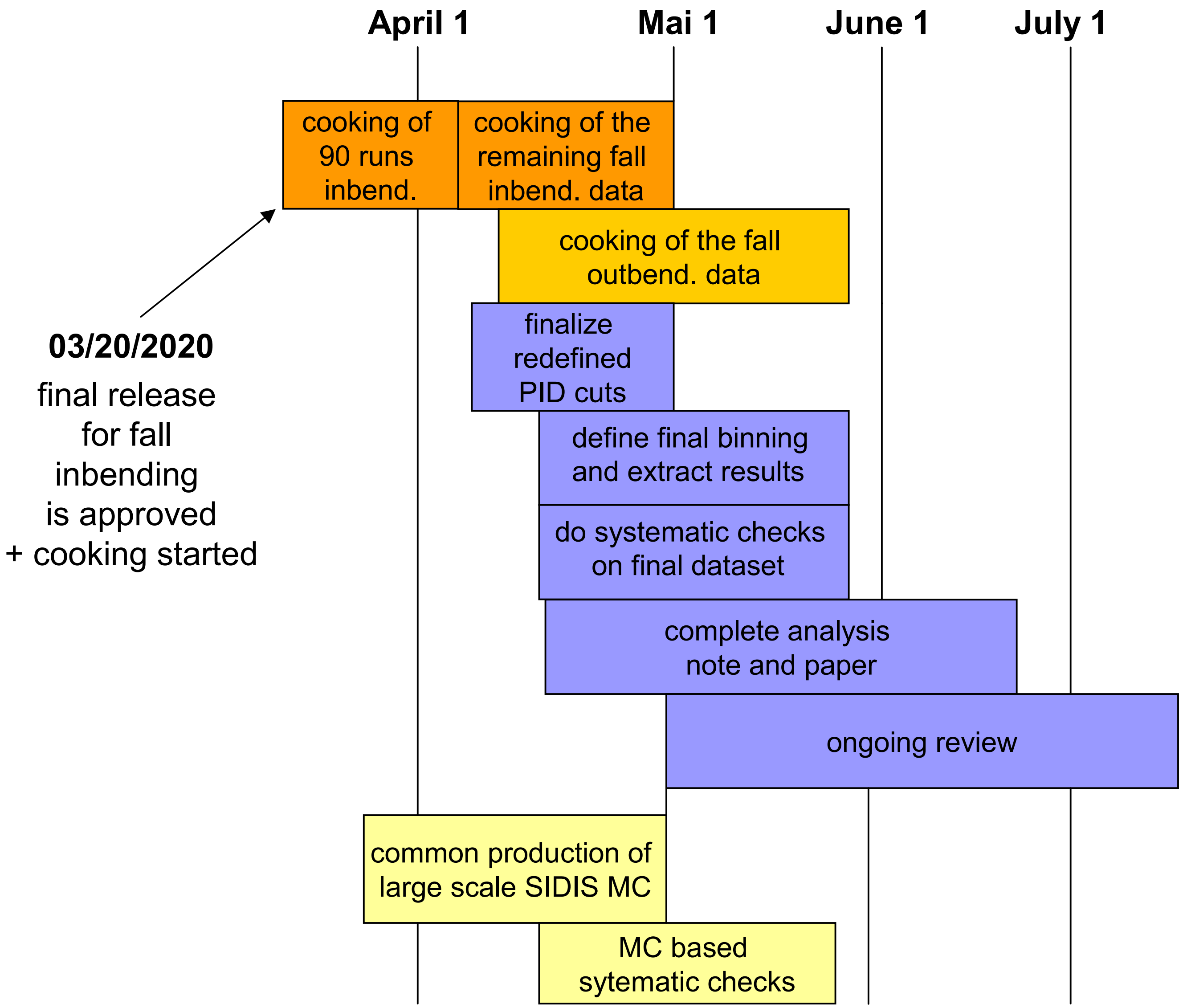


Fig. 5 Predictions on the beam SSAs for charged pions (*left panel*), charged kaons (*central panel*), and proton/antiprotons (*right panel*) in SIDIS at JLab with a 12 GeV electron beam scattered off a proton target. The upper panels show the results calculated from the TMD DFs in Set 1 and the lower panels show the results calculated from the TMD DFs in Set 2. The *dashed, dotted and solid curves* show the asymmetries from the $eH_1^\perp$ term, the $g^\perp D_1$ term and the sum of the two terms, respectively

➔ Updated calculations, including all known 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

Timelines and path towards a first publication



Conclusion and Outlook

- All analysis methods have been developed and tested on the DNP data
- Adjustment of cuts etc. will start as soon as the first bunch of the final data is avaialble (next week)
- MC production will be done in parallel on OSG (common SIDIS MC)
- The goal for the first publication is to show a multidimensional binning for π^+
  → A multidimensional binning will be available for the first time and is very importnant for global TMD fits.
- The analysis note and the paper are under preparation

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