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Multidimensional, high precision measurements of SIDIS pion BSA from the proton over a wide range of kinematics with CLAS12

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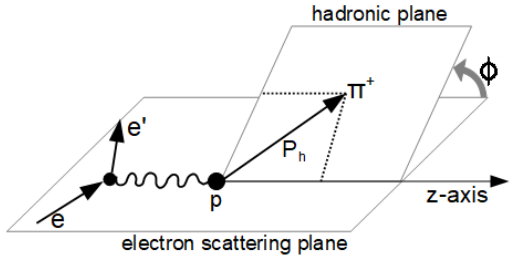
Physics Motivation

- The 3D nucleon structure in momentum space can be described by TMDs
- SIDIS provides an effective tool to probe the transverse momentum dependent partonic structure of the nucleon



SIDIS cross section for an unpolarized target:

→ Contains model independent structure functions

$$\frac{d\sigma}{dx_B\, dQ^2\, dz\, d\phi_h\, dp_{h\perp}^2} = K(x,y,Q^2)\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)F_{UU}^{\cos 2\phi_h} + \lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}\Big\}$$

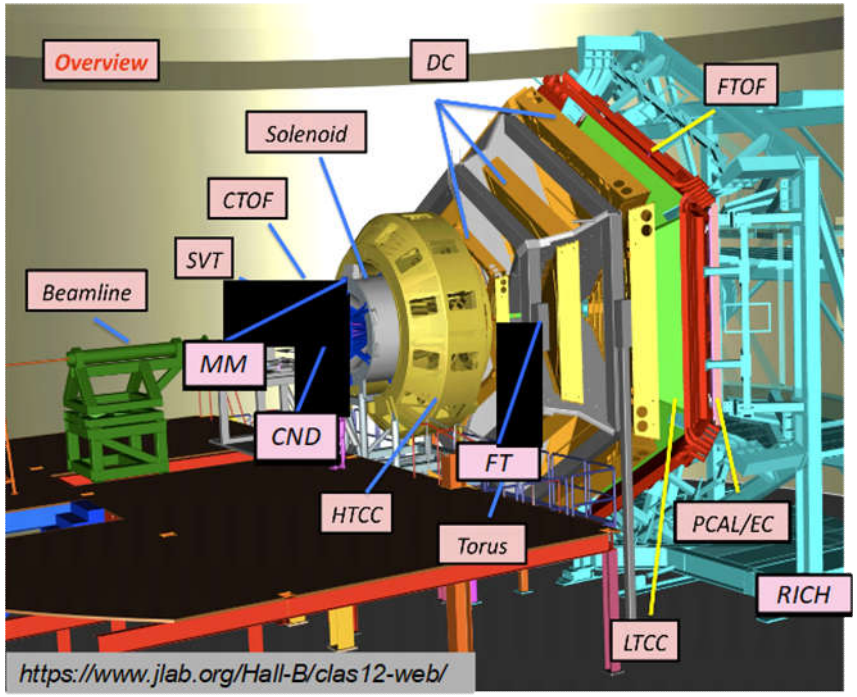
$$F_{LU}^{\sin\phi} = \frac{2M}{Q}\mathcal{C}\left(-\frac{\hat{\mathbf{h}}\cdot\mathbf{k_T}}{M_h}\left(xeH_1^{\perp} + \frac{M_h}{M}f_1\frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{\mathbf{h}}\cdot\mathbf{p_T}}{M}\left(xg^{\perp}D_1 + \frac{M_h}{M}h_1^{\perp}\frac{\tilde{E}}{z}\right)\right)$$

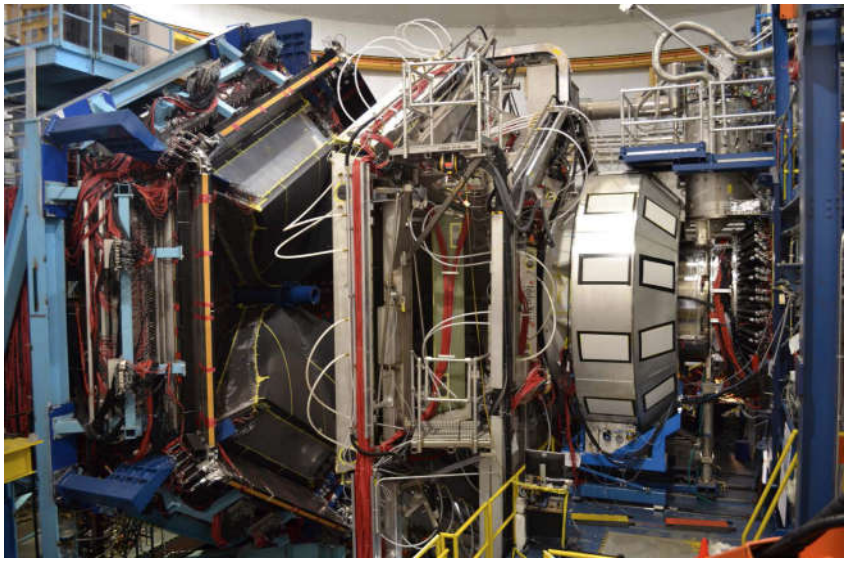
twist-3 pdf; Collins FF; unpolarized dist. function; twist-3 FF; twist-3 t-odd dist. funcion; Boer-Mulders; twist-3 FF

➔ A convolution of 4 TMDs and 4 fragmentation functions

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

CLAS12 Experimental Setup in Hall B @ JLAB





V. D. Burkert *et al.* (CLAS Collaboration), NIM A 959, 163419 (2020)

➔ Data recorded with CLAS12 during fall of 2018

➔ 10.6 GeV electron beam ➔ 86.3 % average polarization ➔ liquid H_2 target

➔ Analysed data ~ 15 % of the approved RG-A beam time

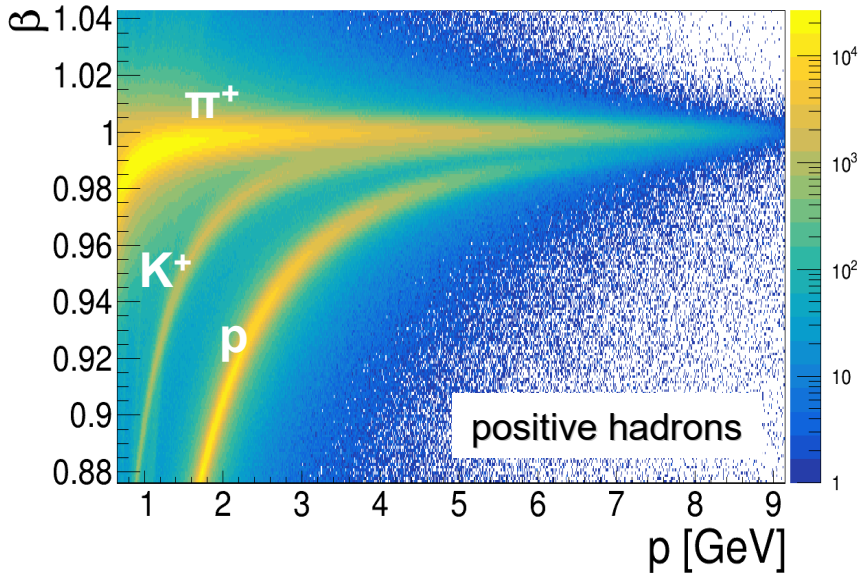
Particle ID and Kinematic Cuts

Electron ID

→ Based on the electromagnetic calorimeter and the cherenkov counters

Hadron ID

→ Based on β vs momentum correlation from TOF



Kinematic cuts: $1.25\ \text{GeV} < P_{\pi} < 5.0\ \text{GeV}$ $y < 0.75$

$Q^2 > 1\ \text{GeV}^2$ $W > 2\ \text{GeV}$

Cut on the eπX missing mass to remove exclusive events: $M_{miss} > 1.5\ \text{GeV}$

1 D study: $z > 0.3$ removes "target fragmentation region"

Observables

Goal of this study: Extract $F_{LU}^{\sin\phi} / F_{UU}$ from single π BSA

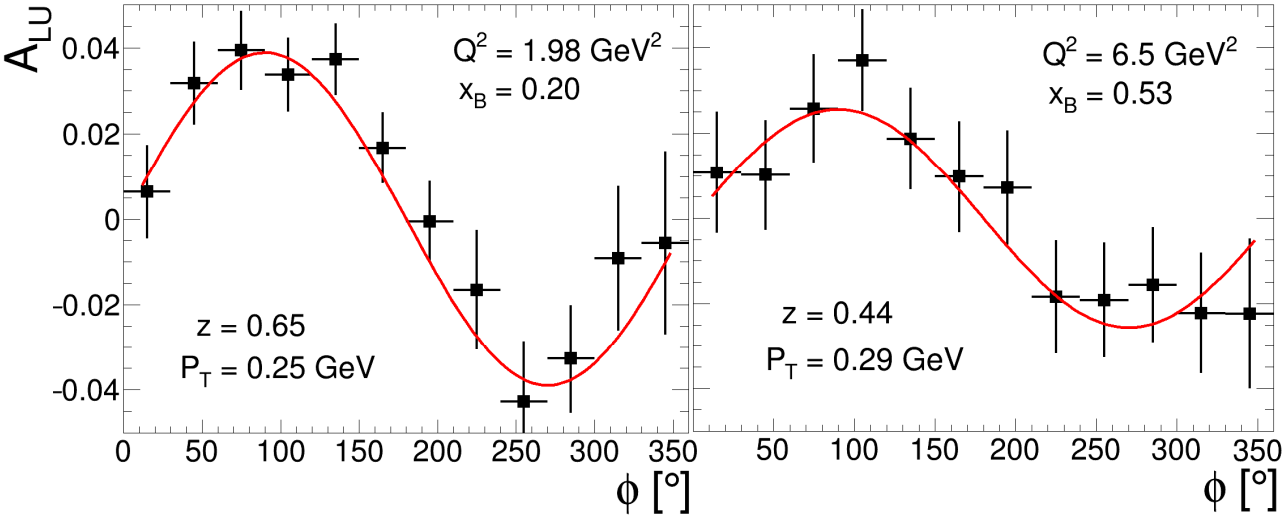
$$d\sigma = d\sigma_0 (1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos 2\phi} \cos 2\phi + \lambda_e A_{LU}^{\sin\phi} \sin\phi)$$

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

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

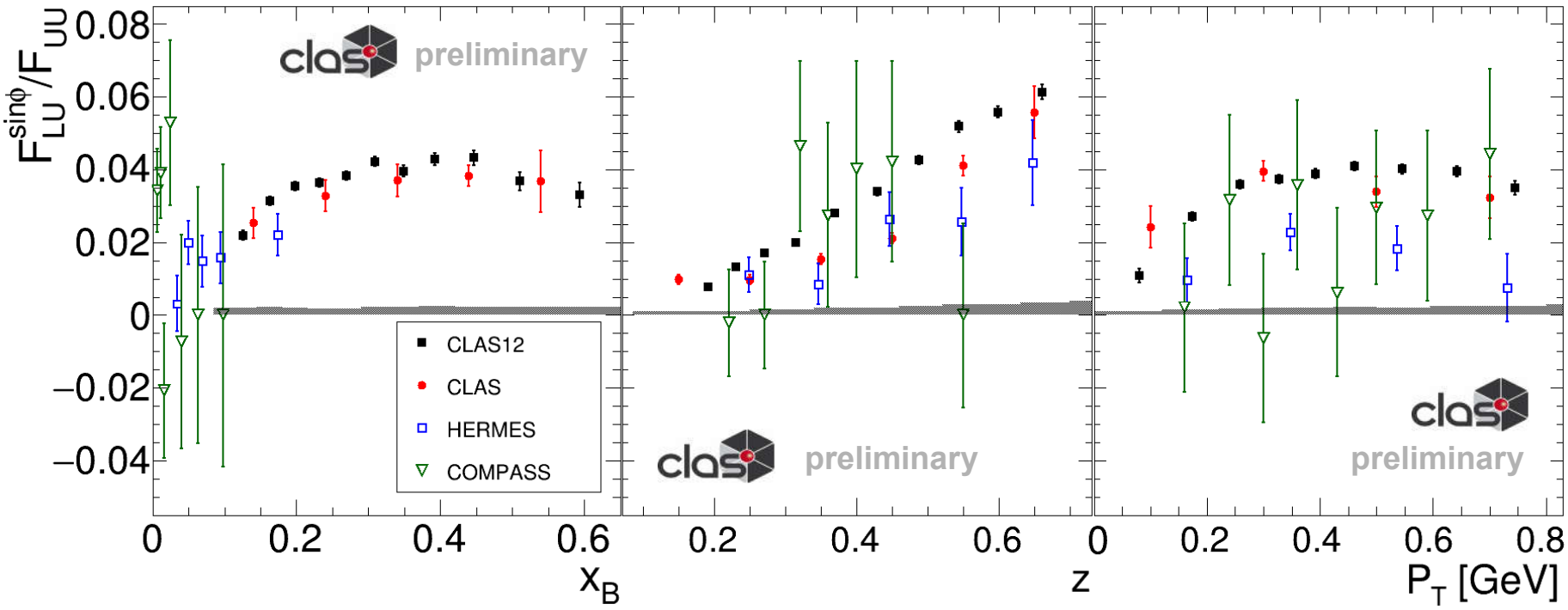
$$BSA_i = \frac{1}{P_e} \cdot \frac{N_i^+ - N_i^-}{N_i^+ + N_i^-}$$

π⁺:



One Dimensional Studies for π^+

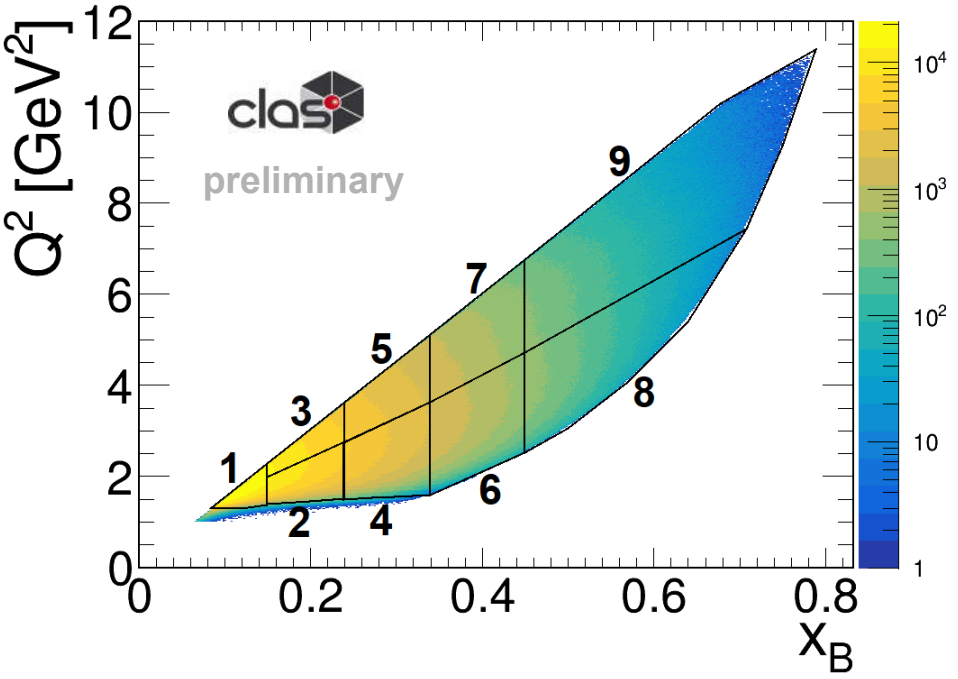
Several Measurements have been performed with CLAS, HERMES and COMPASS



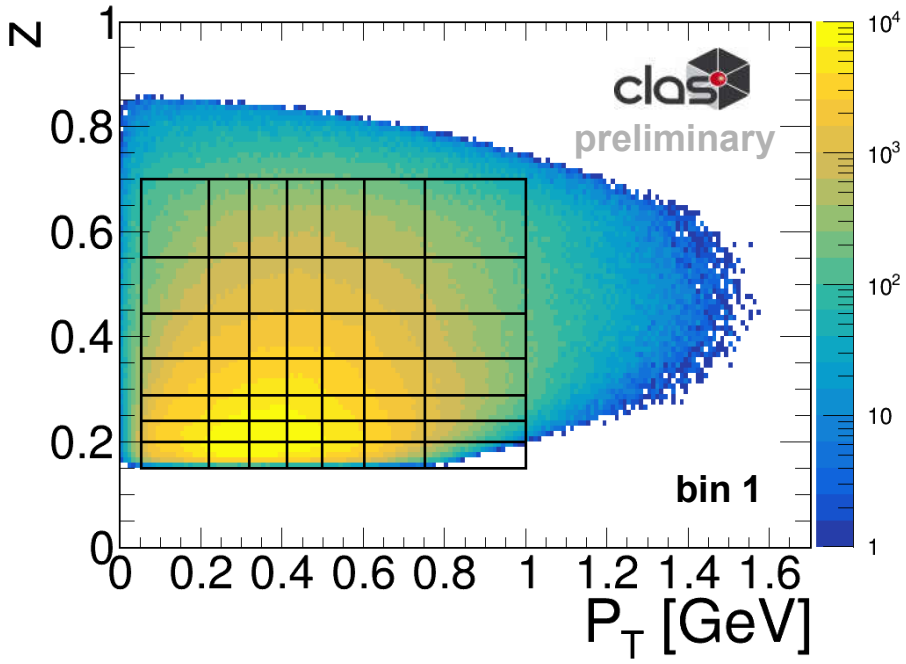
- CLAS12 [this work]
- CLAS [PRD 98 (2014)]
- HERMES [Phys. Let. B 797 (2019)]
- COMPASS [Nucl. Phys. B 886 (2014)]

Focus of this CLAS12 study: A multidimensional study in Q^2, x_B, z and P_T

A Fully Multidimensional Binning



9 bins in Q^2 - x_B



up to 7 x 7 bins in z - P_T
for each Q^2 - x_B bin

in total: 344 bins x 12 bins in Φ ~ 4130 BSA bins

Theoretical Models

The data is compared to 3 different TMD based models:

$$F_{LU}^{\sin\phi} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{h}\cdot k_T}{M_h}\left(x_B e H_1^{\perp} + \frac{M_h}{M} f_1 \frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{h}\cdot P_T}{M}\left(x_B g^{\perp} D_1 + \frac{M_h}{M} h_1^{\perp}\frac{\tilde{E}}{z}\right)\right]$$

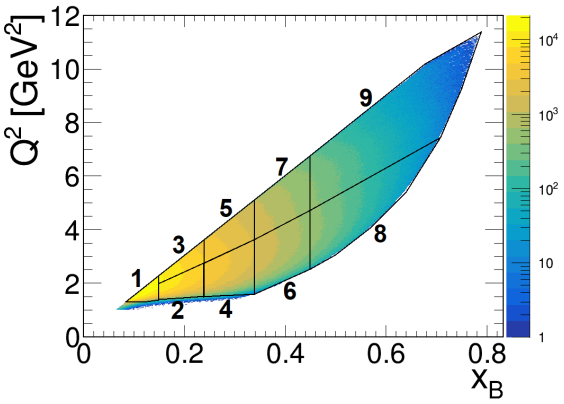
model 1 + 2: W. Mao and Z. Lu, Eur. Phys. J. C 73, 2557 (2013).
W. Mao and Z. Lu, Eur. Phys. J. C 74, 2910 (2014).
→ Calculations by C. Roberts and *Shu-Sheng* Xu

- ➔ Proton is described as an active quark plus spectator scalar and axial-vector diquarks.
- ➔ Different propagators for the axial-vector diquark and different masses of these correlations
- ➔ $eH_1^{\perp}$ and $g^{\perp}D_1$ terms

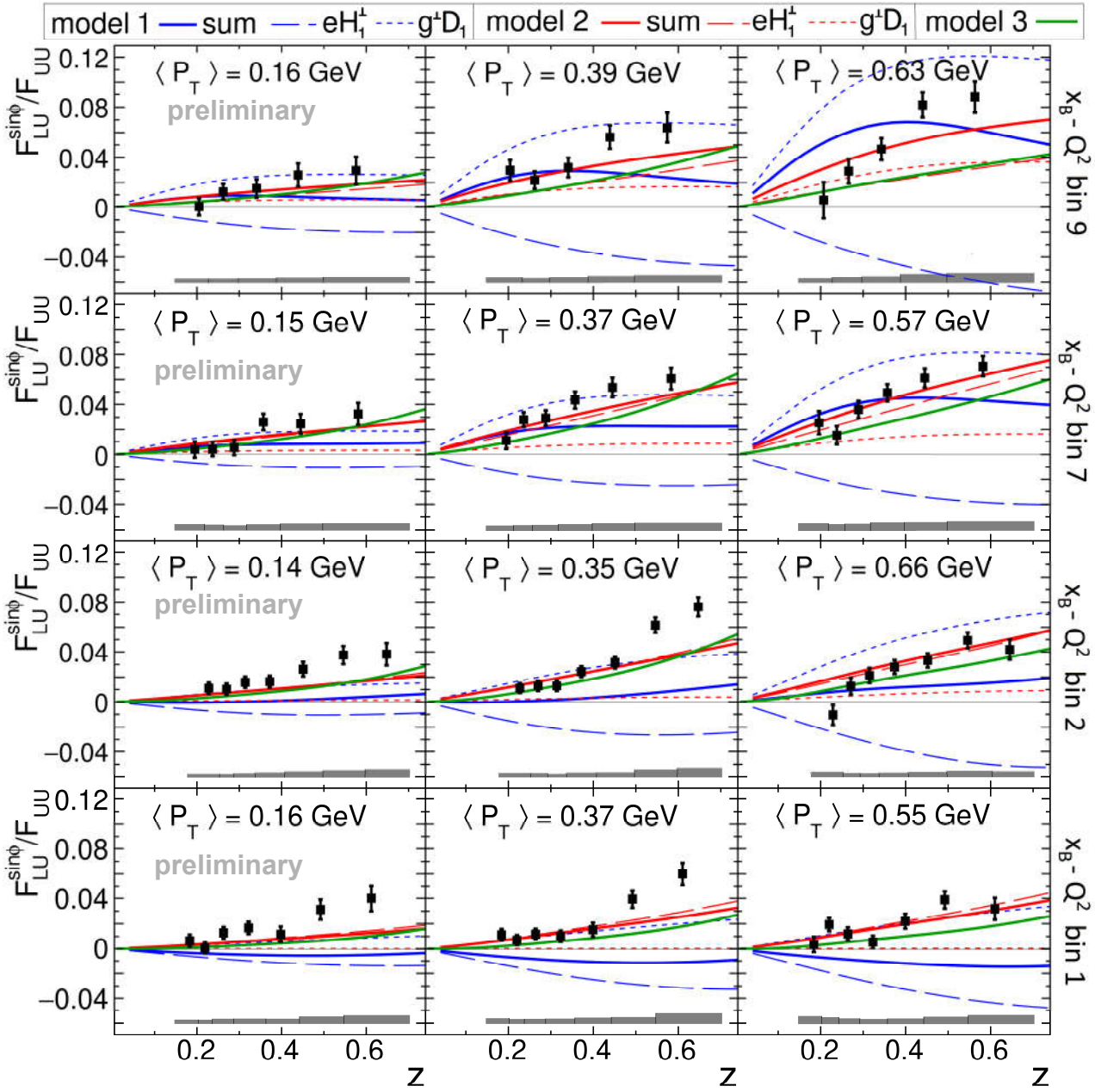
model 3: S. Bastami, K. Tezgin, A. Prokudin, P. Schweitzer (2020).

- ➔ Only $eH_1^{\perp}$ term
- ➔ *e*(*x*) based on the chiral quark soliton model
- ➔ Only model predicting the experimentally not measurable *δ*(*x*)-contribution in *e*(*x*) expected in QCD and related to the pion-nucleon sigma term

π^+ z Dependence



- model 1 $eH_1^\perp$
- model 1 $g^\perp D_1$
- model 1 sum
- model 2 $eH_1^\perp$
- model 2 $g^\perp D_1$
- model 2 sum
- model 3 $eH_1^\perp$



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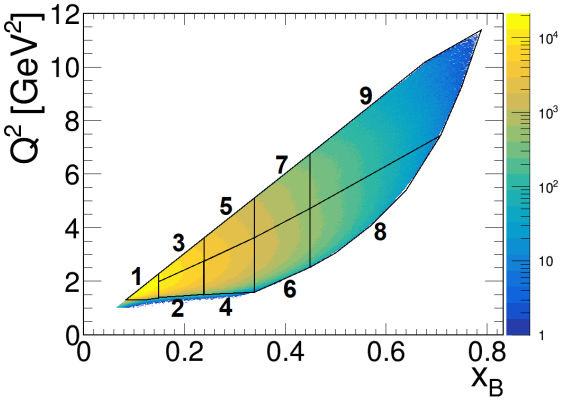
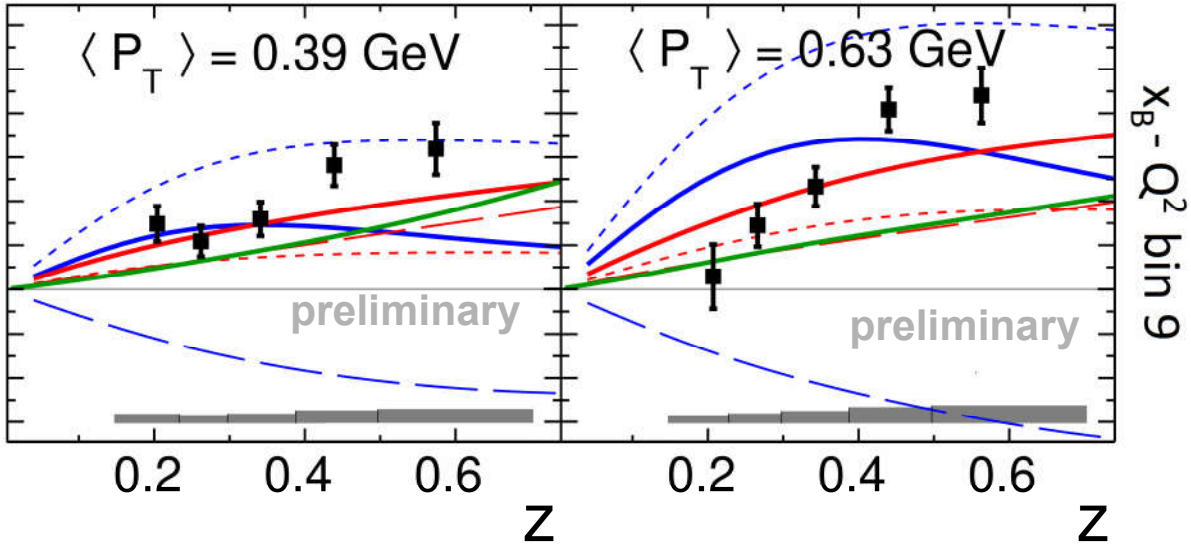
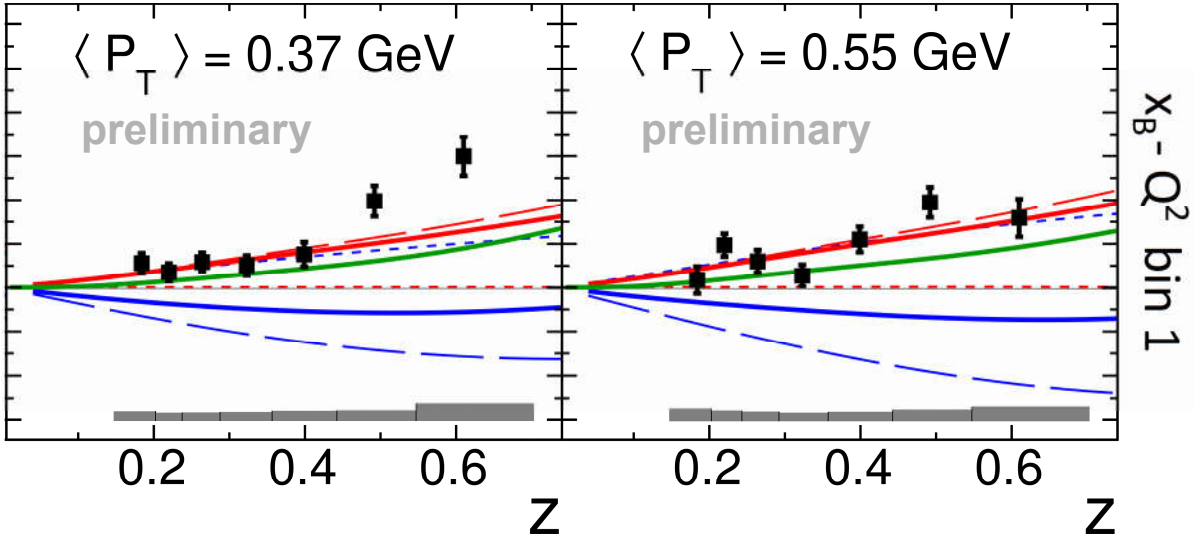
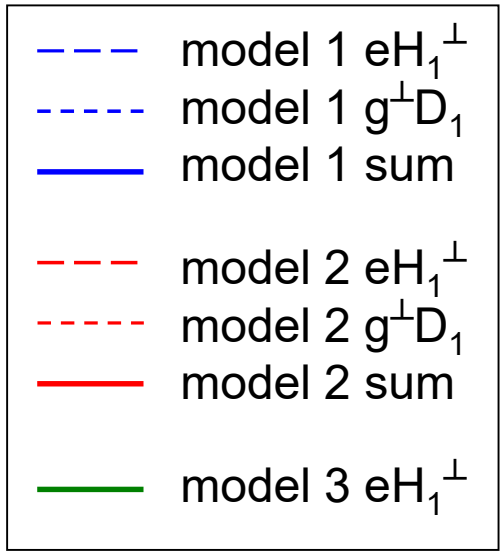
π^+ z Dependence

$$F_{LU}^{\sin\phi} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{h}\cdot k_T}{M_h}\left(x_B e H_1^{\perp} + \frac{M_h}{M} f_1 \frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{h}\cdot P_T}{M}\left(x_B g^{\perp} D_1 + \frac{M_h}{M} h_1^{\perp}\frac{\tilde{E}}{z}\right)\right]$$









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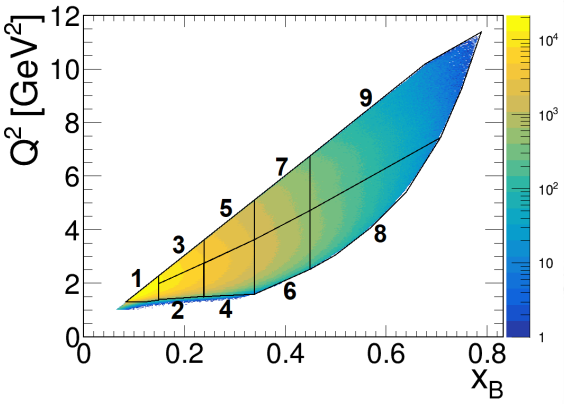
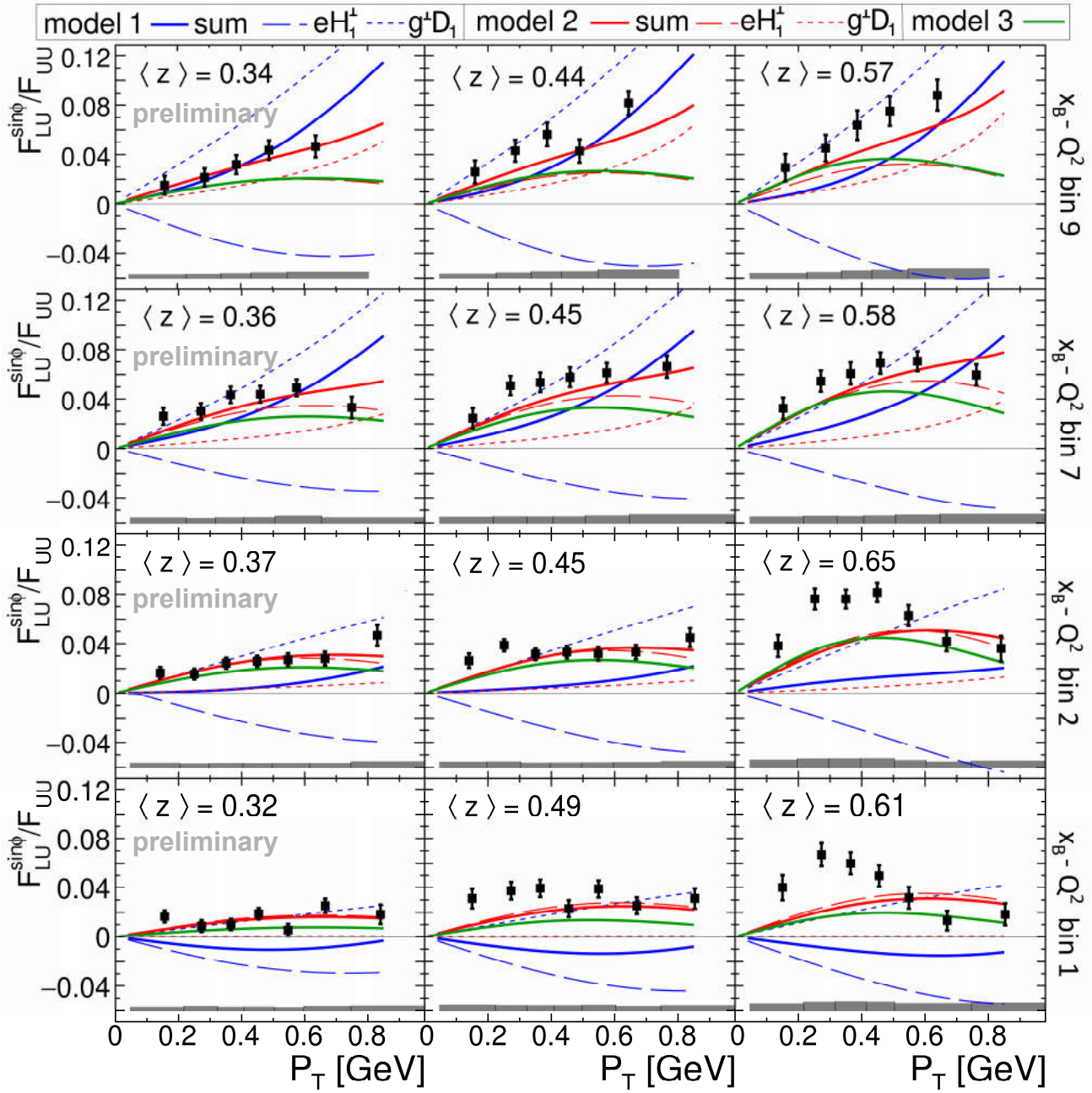
π^+ P_T Dependence



- model 1 $eH_1^\perp$
- model 1 $g^\perp D_1$
- model 1 sum
- model 2 $eH_1^\perp$
- model 2 $g^\perp D_1$
- model 2 sum
- model 3 $eH_1^\perp$



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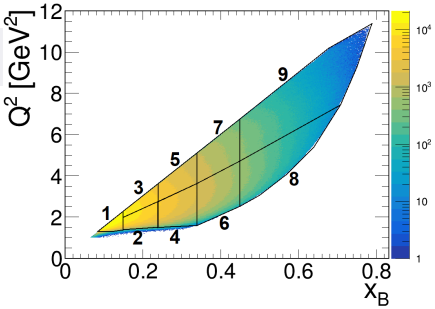
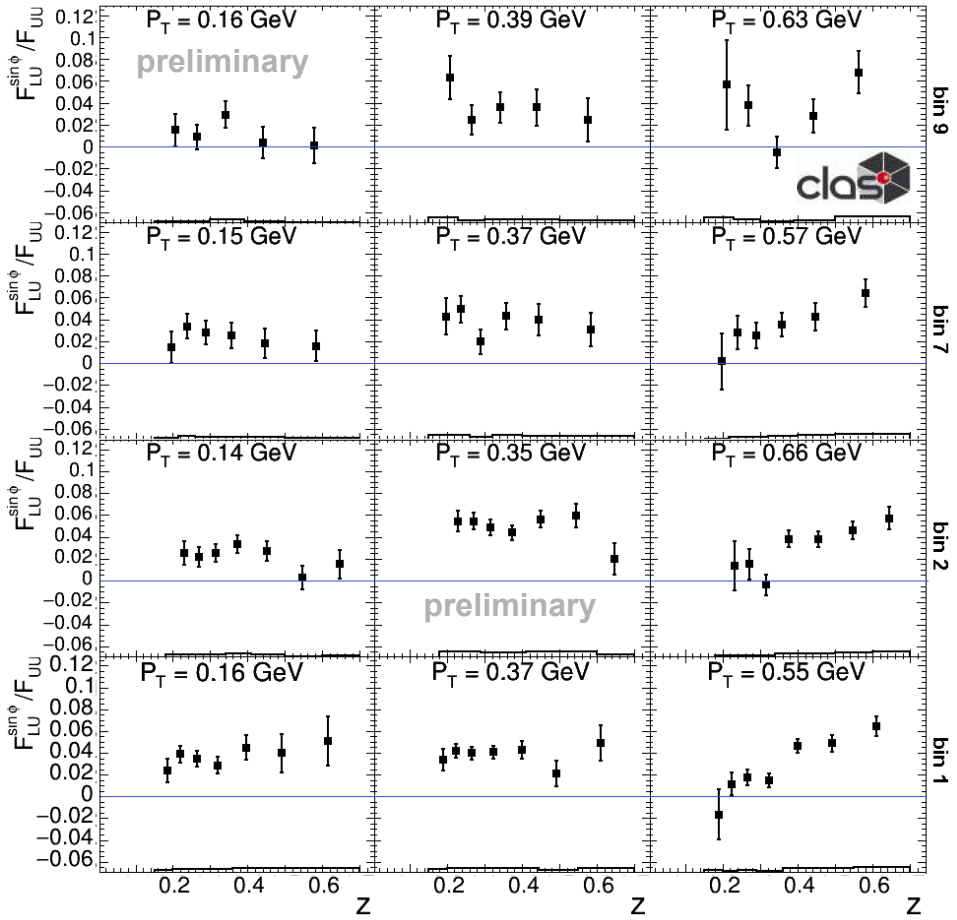
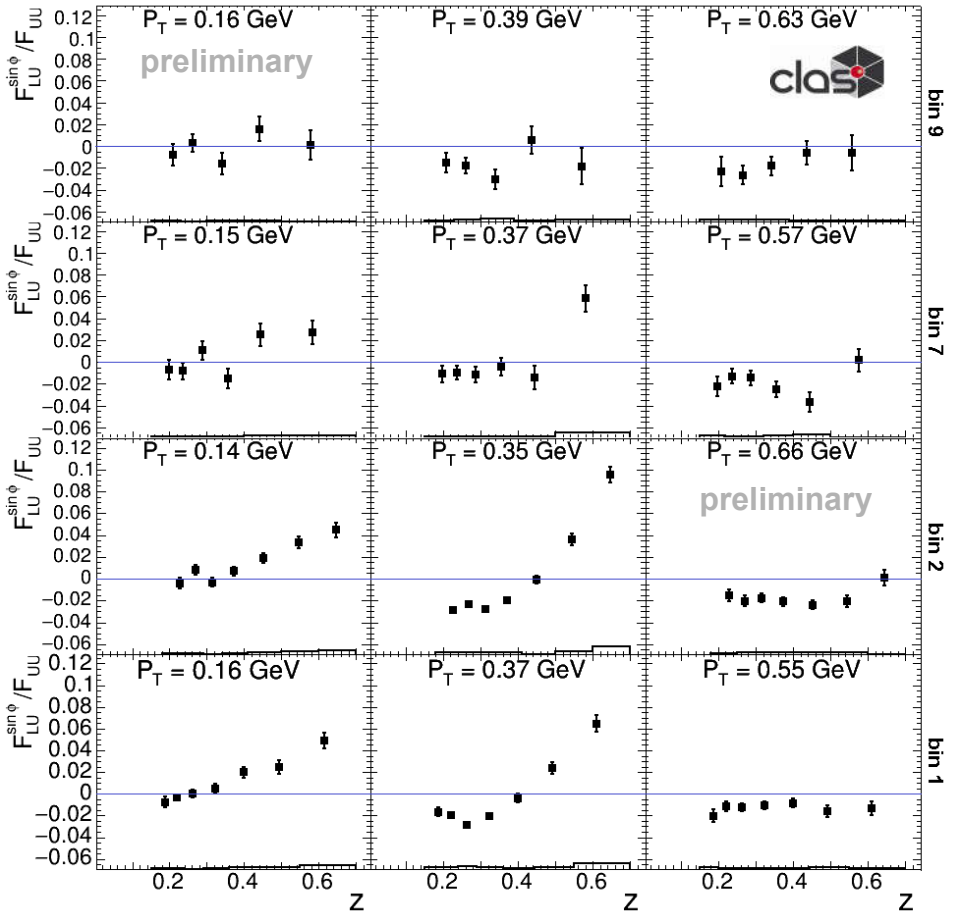
z Dependence for π^0 and π^-



π^0



π^-



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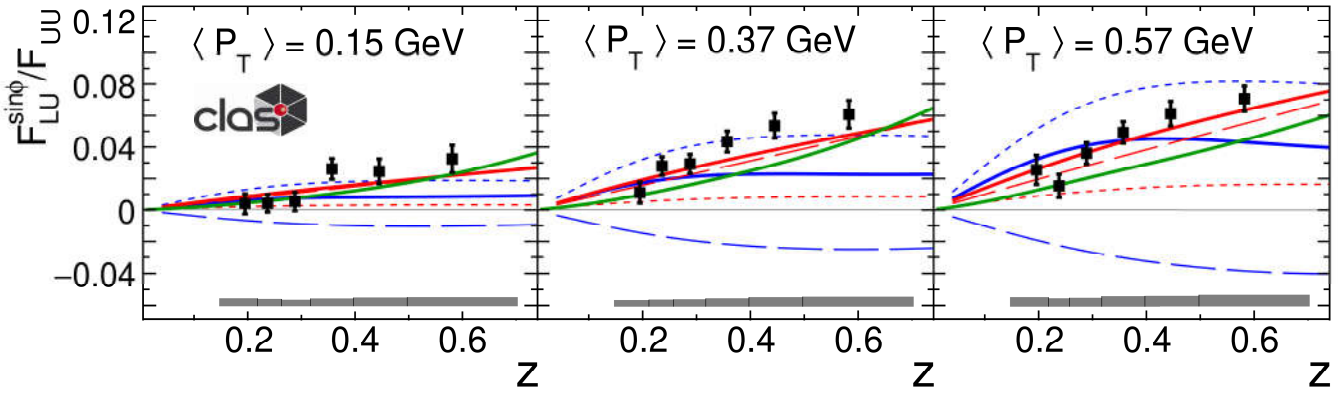
Comparison of the z Dependence for π^+, π^0 and π^-

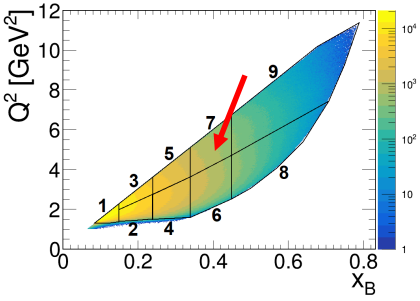
π^+



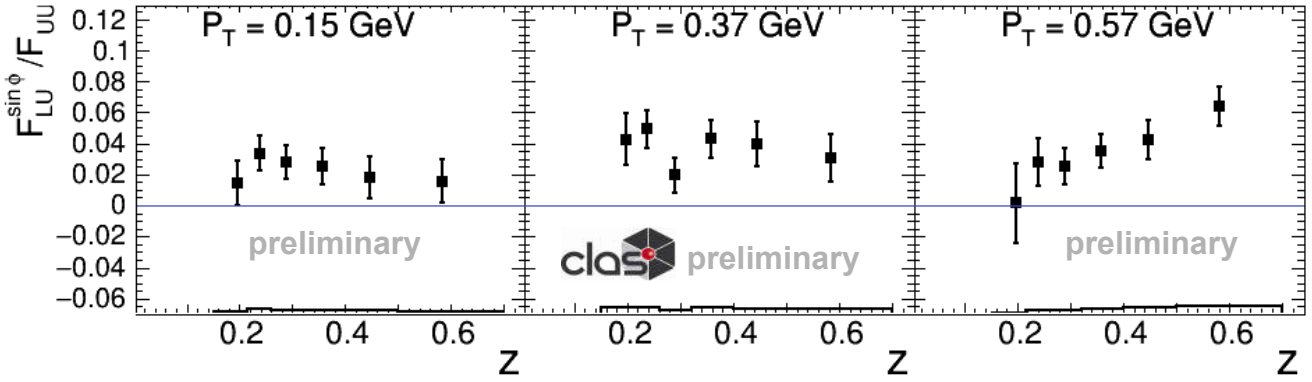
bin 7:

Q^2 = 4.8 GeV²

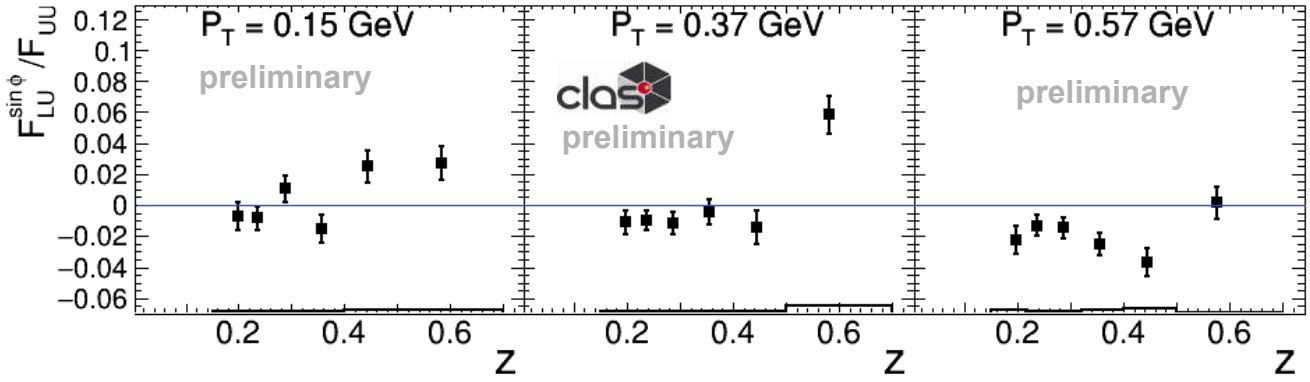
x_B = 0.39



π^0



π^-



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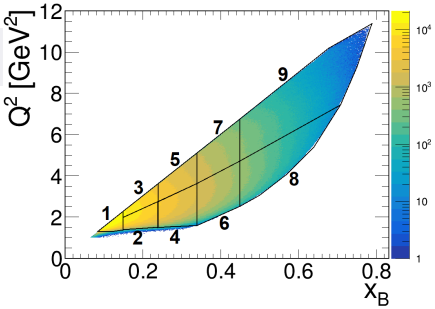
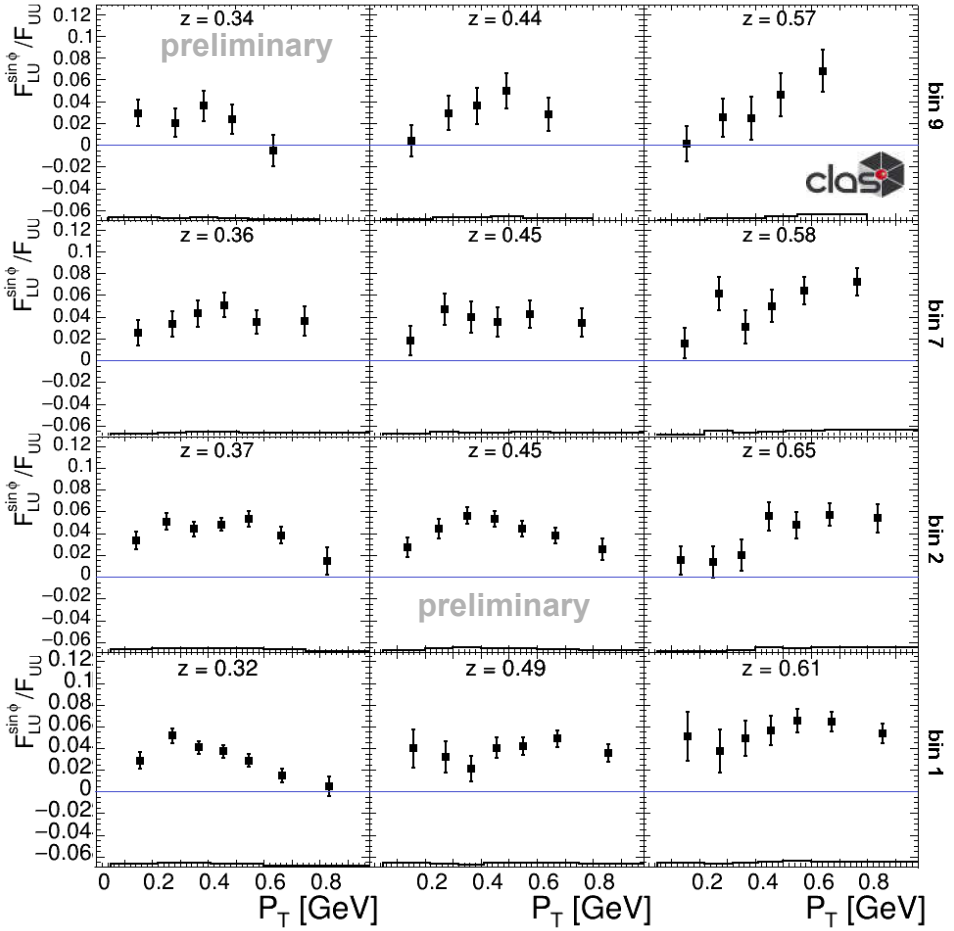
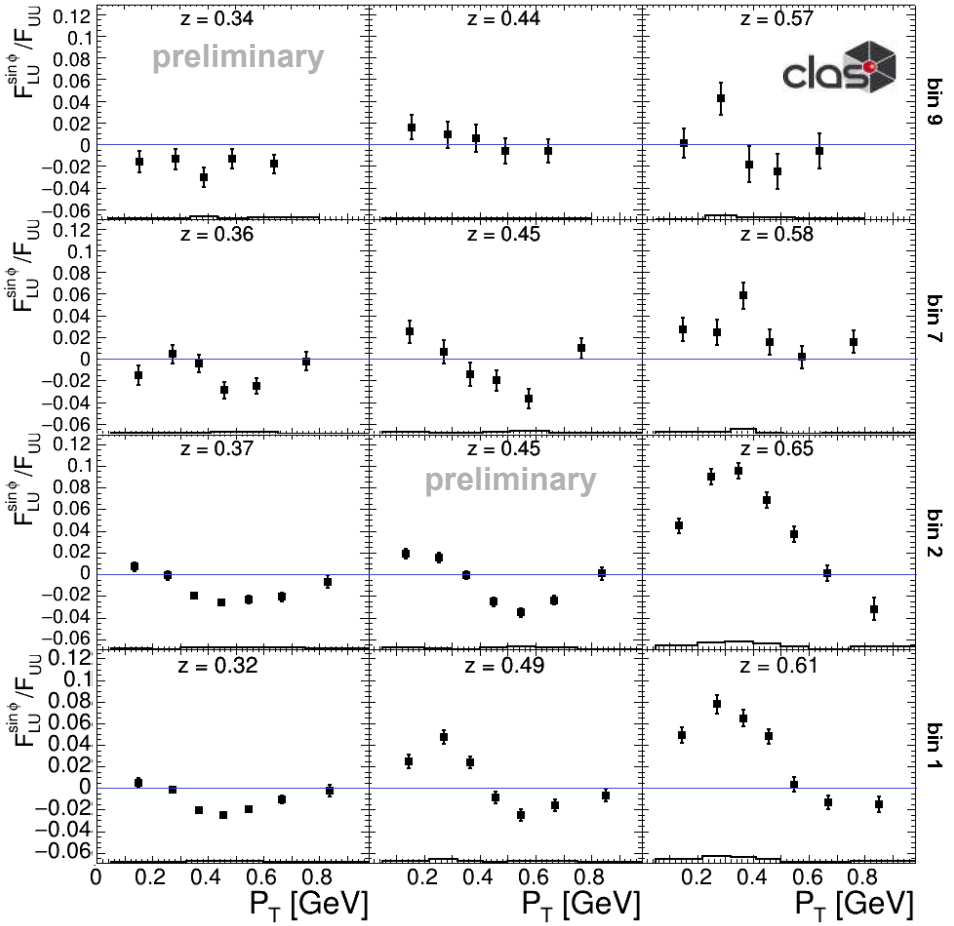
P_T Dependence for π^0 and π^-



π^0



π^-



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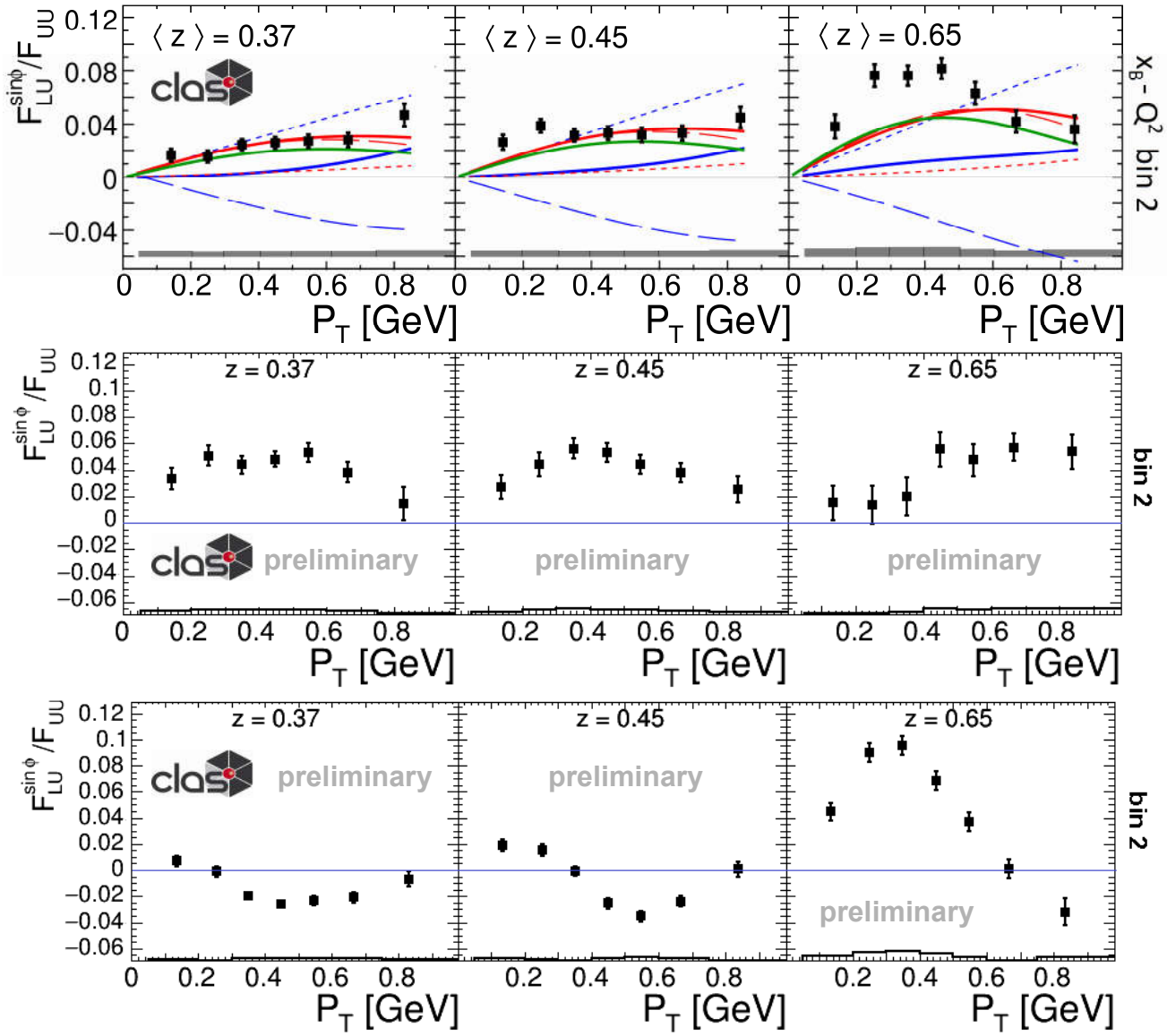
Comparison of the P_T Dependence for π^+, π^0 and π^-

π^+

π^0

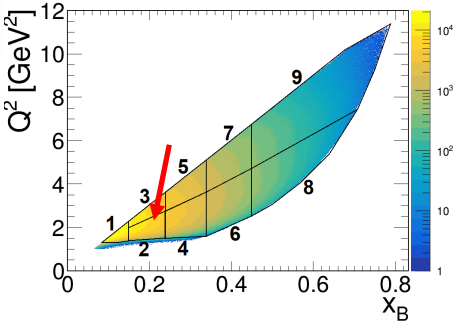
π^-



bin 2:

$Q^2 = 2.0$ GeV²

$x_B = 0.20$



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Conclusion and Outlook

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

- A fully differential binning in Q^2, x_B, z and P_T has been performed with a high precision extraction of the BSA
  - ➔ This study helps to distinguish between different reaction models
  - ➔ The kinematic dependence and the varying dominace of the different TMD and FF terms can be identified

- Existing models provide an overall good agreement
  - ➔ Model 2 indicates an importnat role of axial vector diquarks in the protons wave function

- CLAS12 SIDIS results will help to improve the results from global TMD fits and provide access to so far poorly known TMDs

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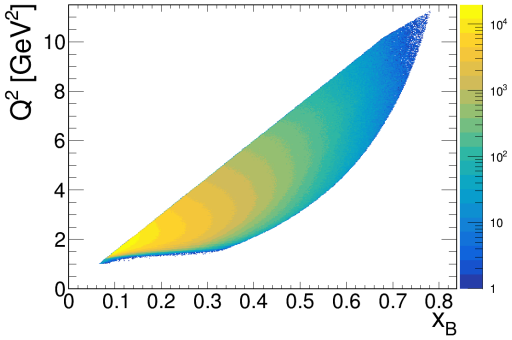
π^+ x_B Dependence

- averaged over Q^2



- model 1 sum
- model 2 sum
- model 3 $eH_1^{\perp}$

preliminary