



EMMI Rapid Reaction Task Force meeting

“Impact of Vector Mesons on the Studies of the 3D Structure of the Nucleon”



Impact of vector mesons on the TMD extraction from semi-inclusive deep inelastic scattering with CLAS12 at JLAB

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June 16, 2024

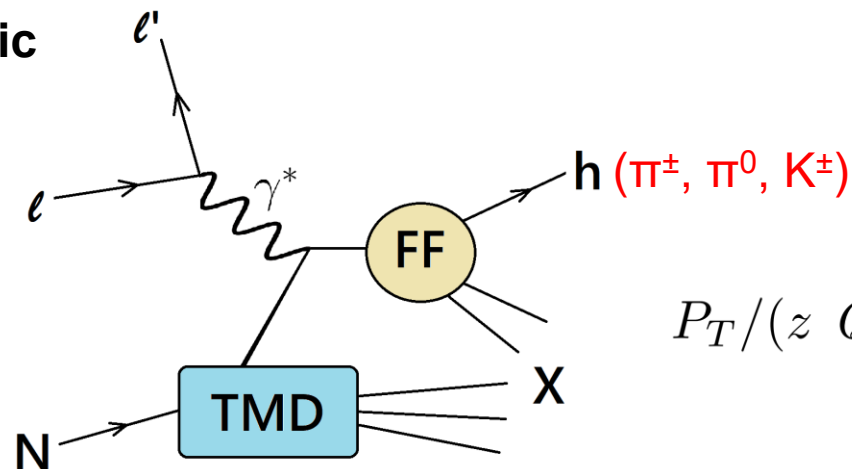
Transverse Momentum Distributions (TMDs)

TMDs: Spin-dependent 3D **momentum space** images

quark pol.

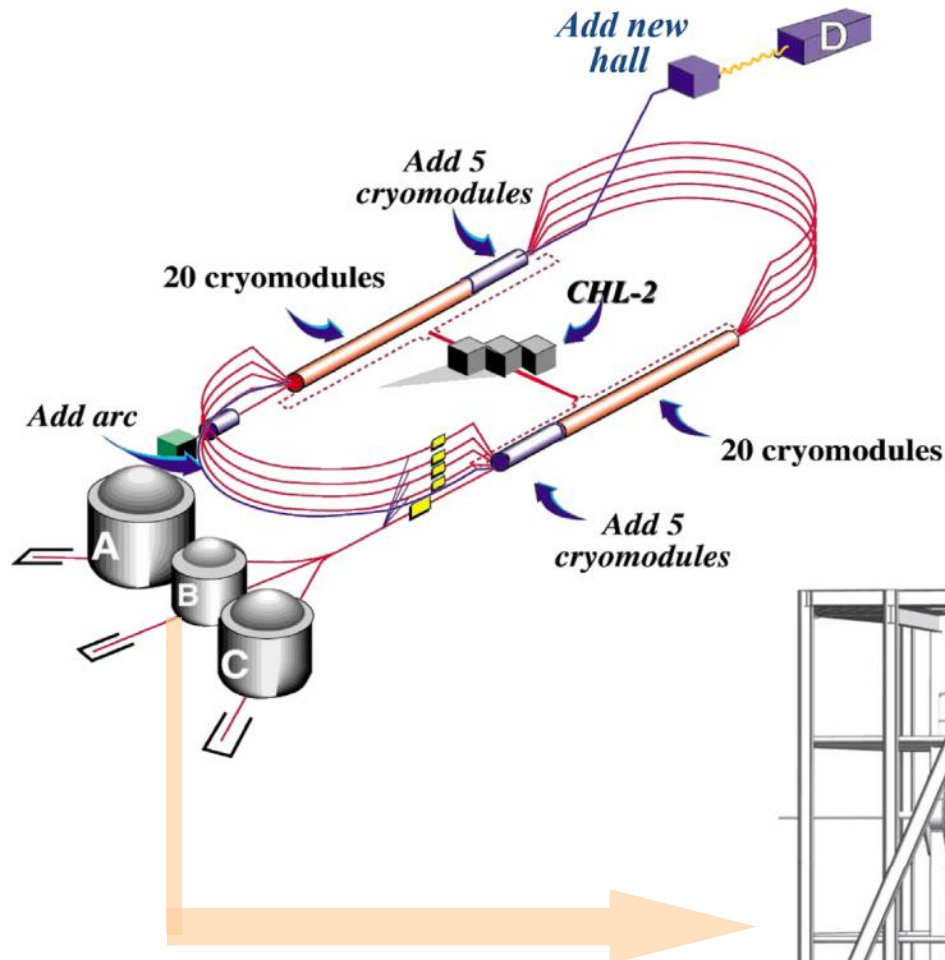
	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_T^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

TMDs can be accessed in
semi-inclusive deep-inelastic
scattering (SIDIS)

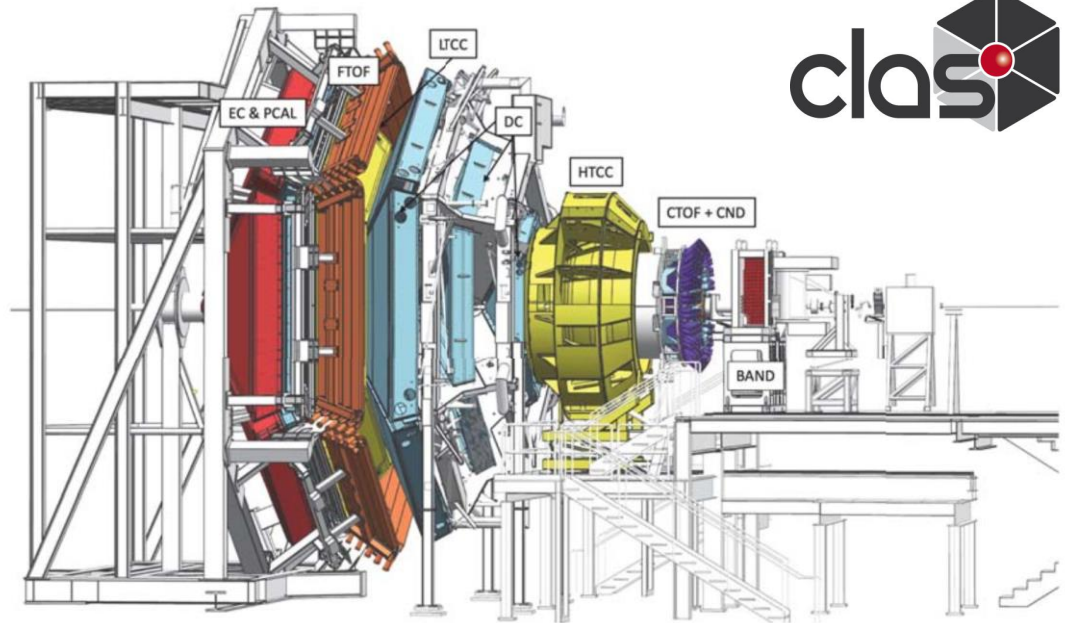


$$P_T/(z Q) \ll 1$$

CLAS12 at JLAB



- CLAS12 operation since 2017
- Data taking since 2018
- Up to 10.6 GeV longitudinally polarized electron beam and different targets



V. Burkert et al., Nucl. Instr. Meth. A 959, 163419 (2020)

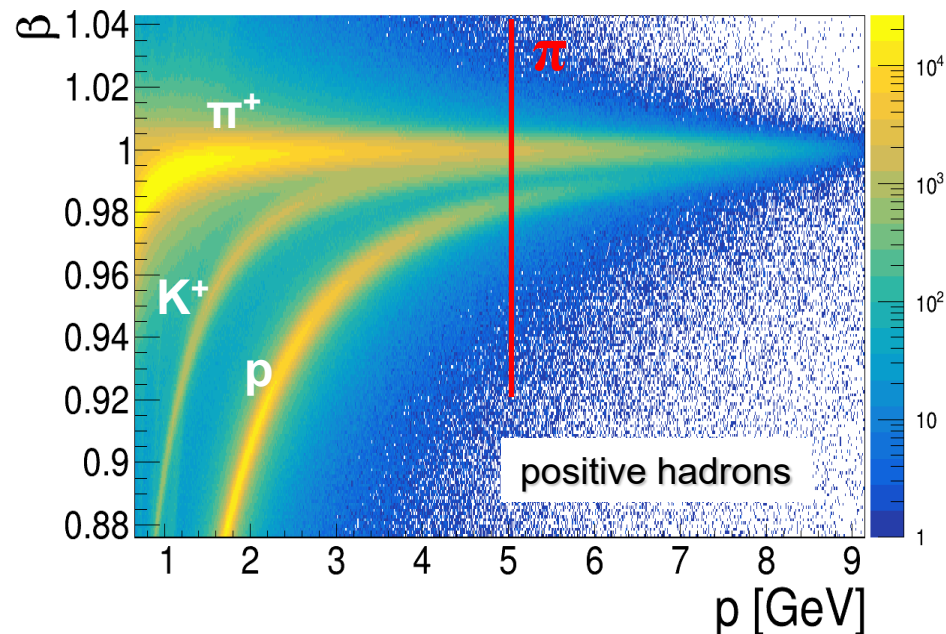
CLAS12 at JLAB: Particle ID

Electron ID

→ Based on the electromagnetic calorimeter and the cherenkov counters

Hadron ID

→ Based on β vs momentum correlation from TOF + RICH in 1(2) of 6 sectors



Single Hadron SIDIS Beam Spin Asymmetries

RG-A: - Longitudinally polarized 10.6 GeV and 10.2 GeV electron beam
 (~ 86 % average polarization) - Unpolarized H₂ target

$$\frac{d\sigma}{dx dQ^2 dz dP_{h\perp}^2 d\phi_h} \sim F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)} \cos \phi_h F_{UU}^{\cos \phi_h} + \epsilon \cos 2\phi_h F_{UU}^{\cos 2\phi_h} + \lambda_e \sqrt{2\epsilon(1-\epsilon)} \sin \phi_h \underline{F_{LU}^{\sin \phi_h}}$$

$$F_{LU}^{\sin \phi} = \frac{2M}{Q} \mathcal{C} \left(-\frac{\hat{\mathbf{h}} \cdot \mathbf{k}_T}{M_h} \left(x \overset{\text{Collins FF}}{\color{blue}e} \overset{\text{twist-3 pdf}}{\color{blue}H_1^\perp} + \frac{M_h}{M} \overset{\text{unpolarized dist. function}}{\color{green}f_1} \frac{\tilde{G}^\perp}{z} \right) + \frac{\hat{\mathbf{h}} \cdot \mathbf{p}_T}{M} \left(x \overset{\text{twist-3 t-odd dist. function}}{\color{green}g^\perp} \overset{\text{twist-3 FF}}{\color{blue}D_1} + \frac{M_h}{M} \overset{\text{Boer-Mulders}}{\color{green}h_1^\perp} \frac{\tilde{E}}{z} \right) \right) \rightarrow \text{TMDs and FFs}$$

$$A_{LU}(x_B, Q^2, z, P_T, \phi) = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{\sqrt{2\epsilon(1-\epsilon)} \frac{F_{LU}^{\sin \phi}}{F_{UU}} \sin \phi}{1 + \sqrt{2\epsilon(1+\epsilon)} \frac{F_{UU}^{\cos \phi}}{F_{UU}} \cos \phi + \epsilon \frac{F_{UU}^{\cos 2\phi}}{F_{UU}} \cos 2\phi}$$

Single π^+ Beam Spin Asymmetries

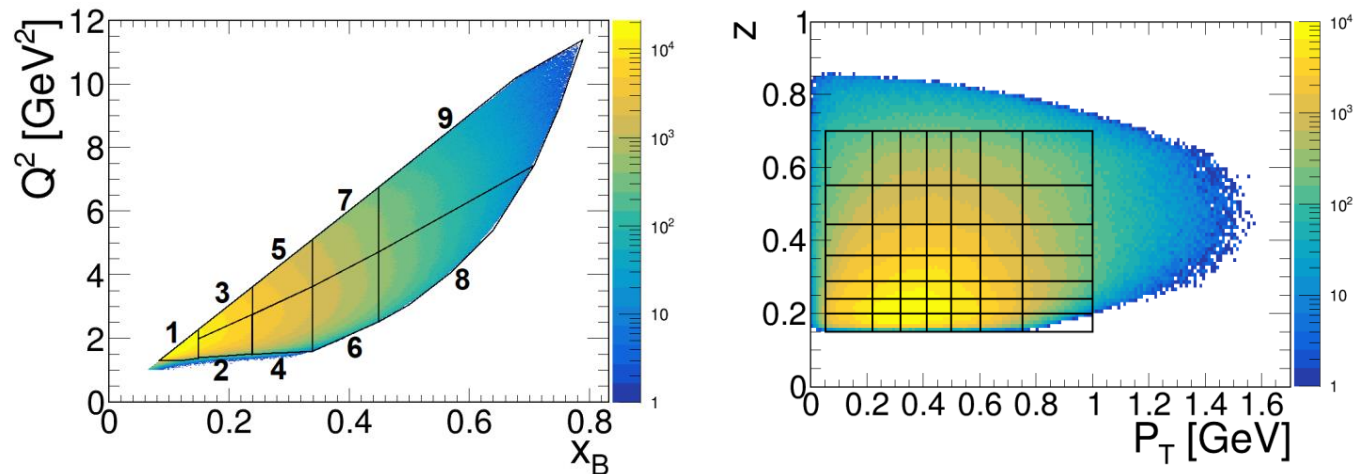
CLAS12: A multidimensional study in Q^2 , x_B , z and P_T for $\pi^\pm$, π^0 and $K^\pm$

$e\pi^+X$

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

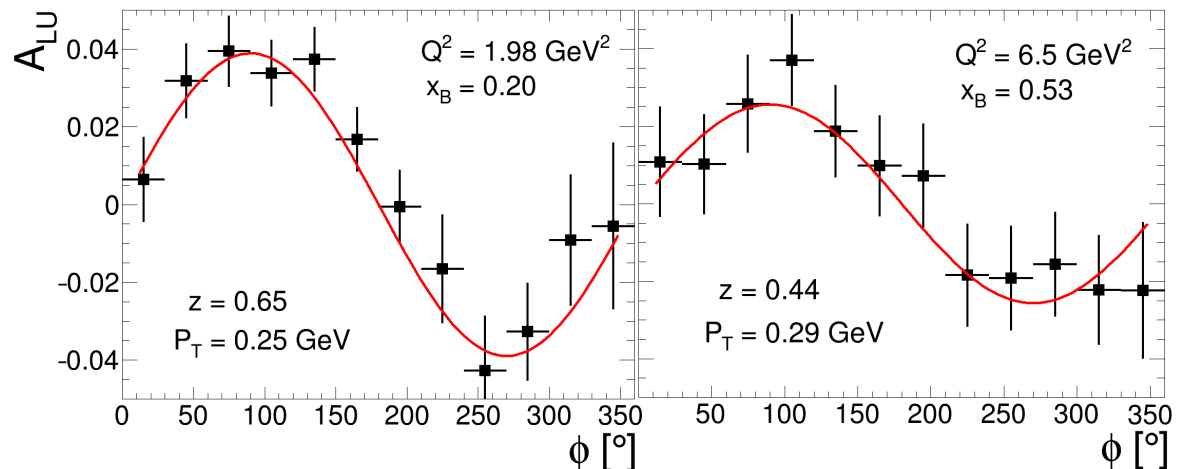
$$W > 2 \text{ GeV}$$

$$M_{e\pi X} > 1.5 \text{ GeV}$$



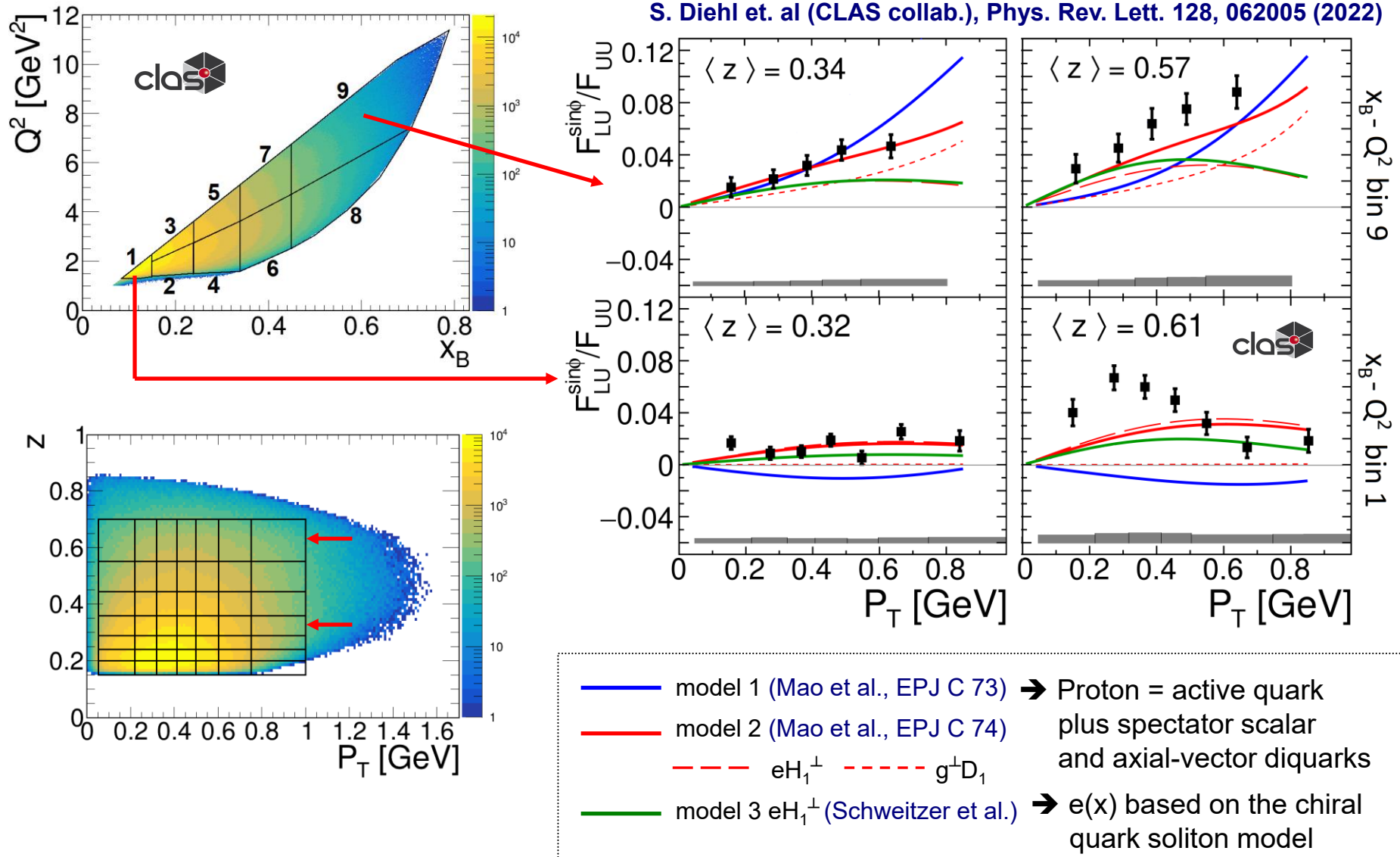
in total: 344 bins $\times$ 12 bins in $\phi \rightarrow \sim 4130$ BSA bins

S. Diehl et al.
(CLAS collab.)
Phys. Rev. Lett.
128, 062005 (2022)

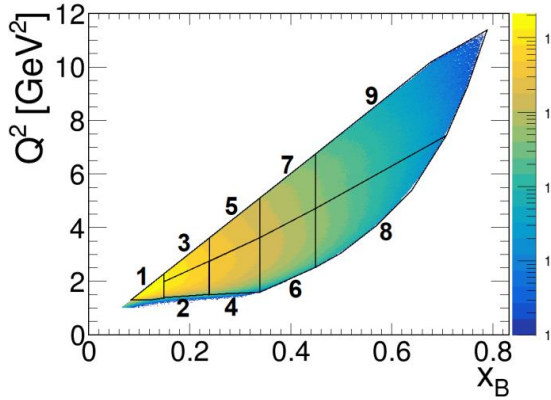


Multidimensional (4D) Single π^+ SIDIS with CLAS12

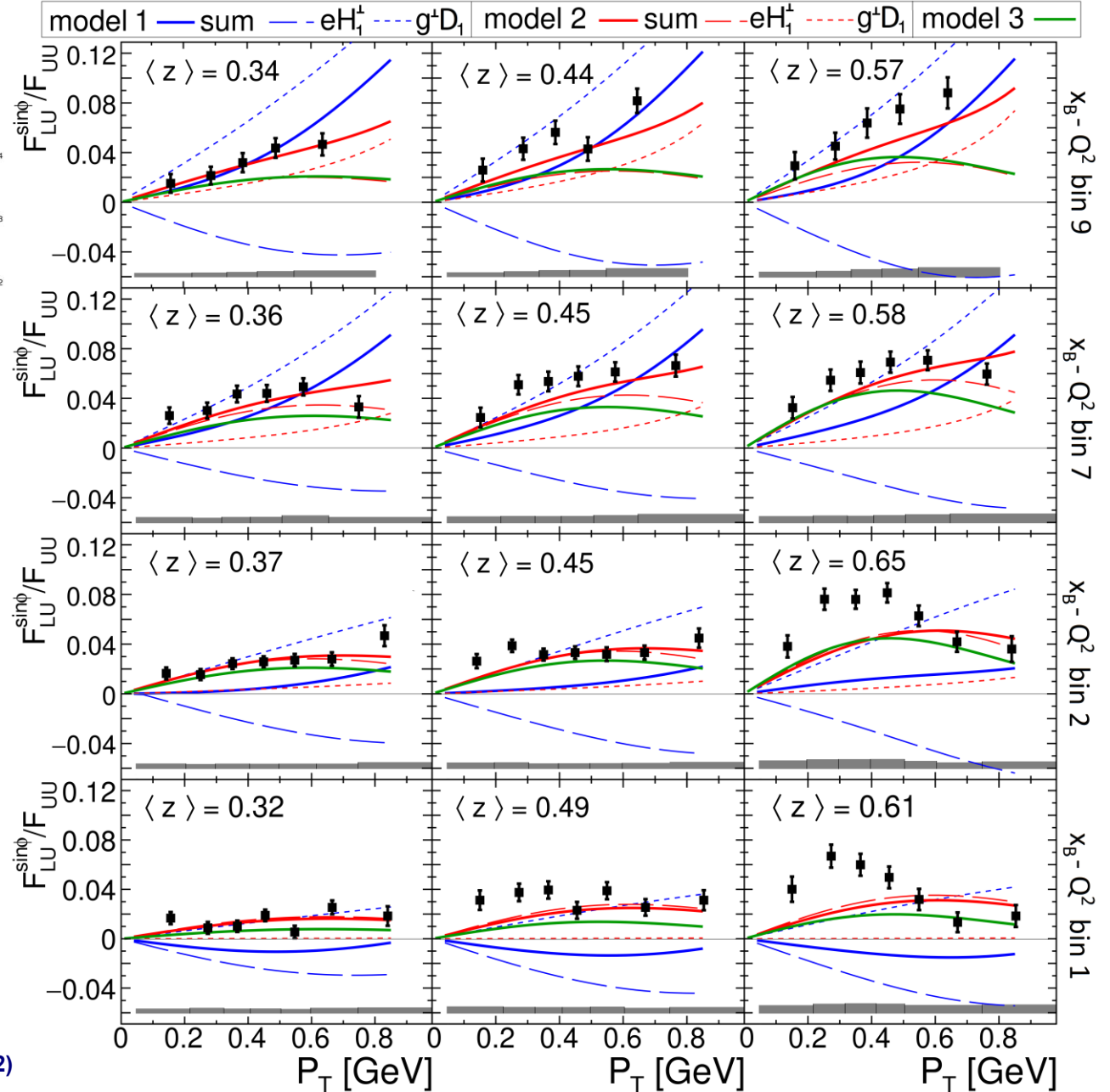
S. Diehl et. al (CLAS collab.), Phys. Rev. Lett. 128, 062005 (2022)



$\pi^+ P_T$ 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 $eH_1^\perp$

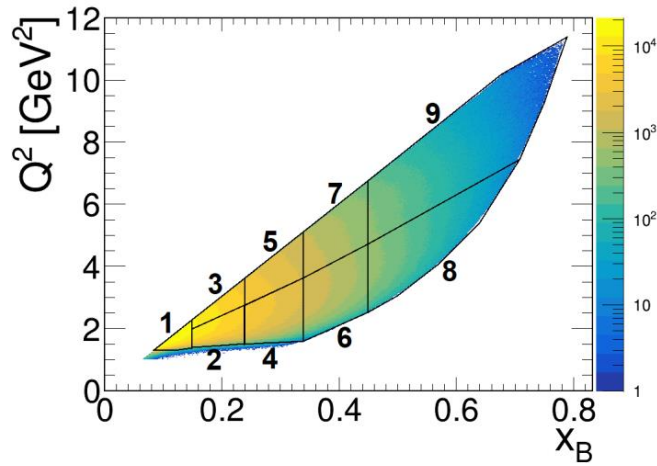


S. Diehl et. al
(CLAS collab.)
Phys. Rev. Lett.
128, 062005 (2022)

Flavour Effects in Single Pion SIDIS

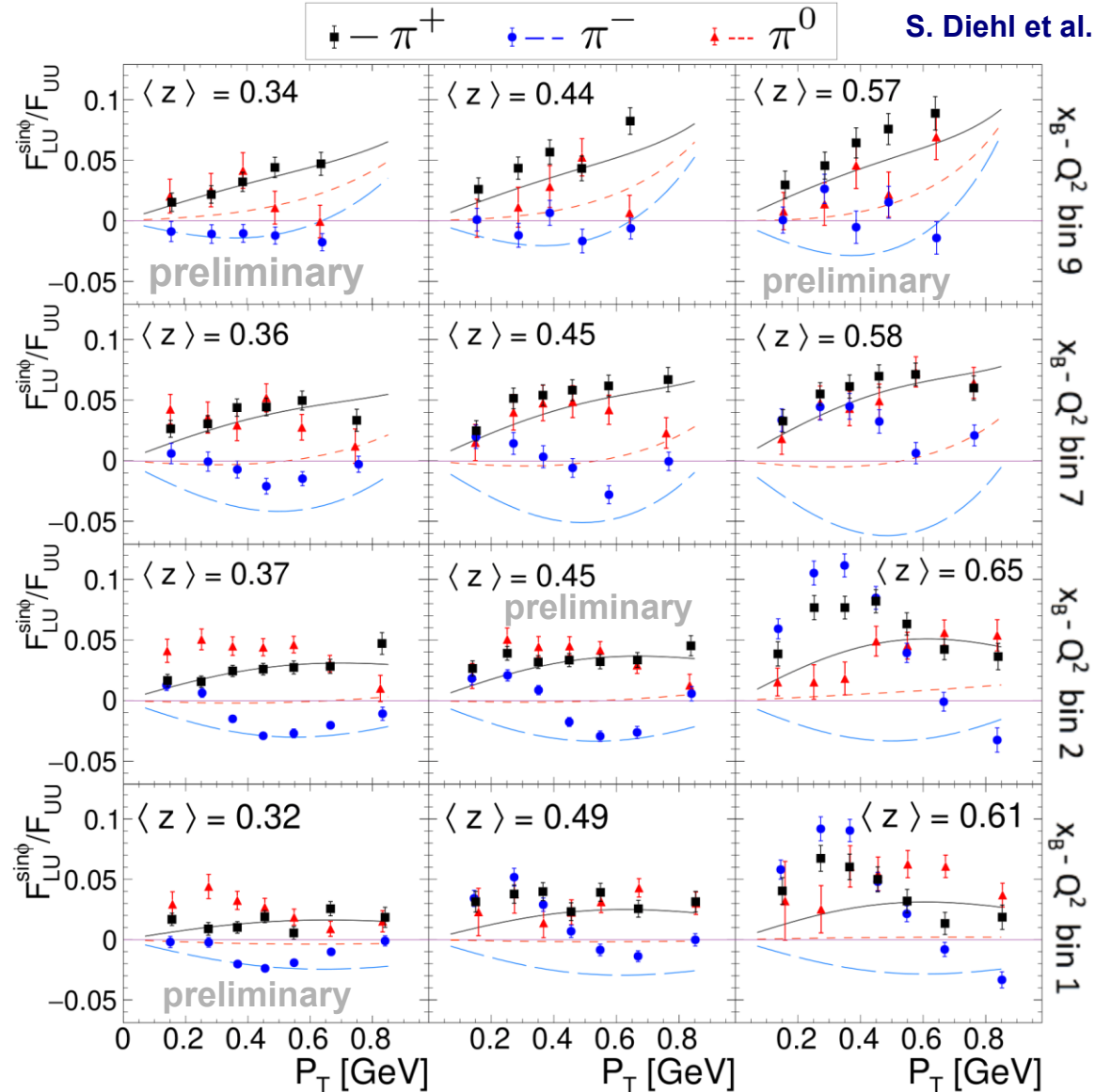


S. Diehl et al.



■ π^+
■ π^0
■ π^-

— model 2 prediction
- - -
- - -

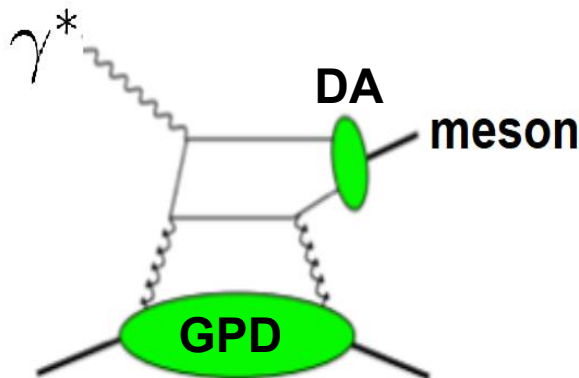


Exclusive Contributions to the SIDIS Sample

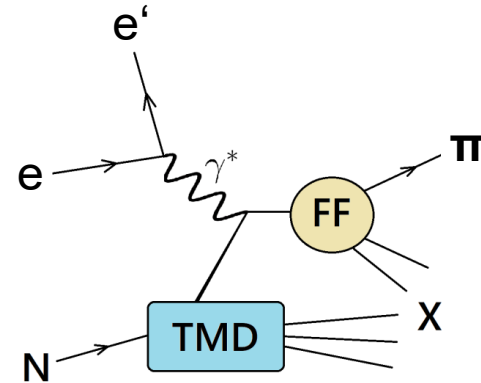
- A TMD based description is only valid for pions from current fragmentation

BUT: The $e\pi X$ sample contains also pions from exclusive processes

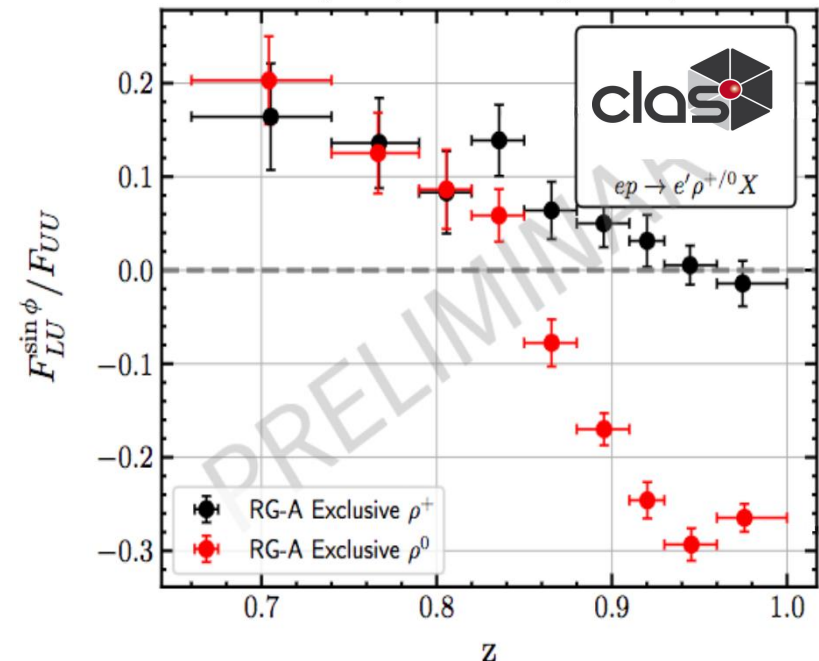
$$e p \rightarrow e' p \rho^0 \rightarrow e' p \pi^+ \pi^-$$



- ➔ Especially dominant at low $-t$ / high z
- ➔ Different mechanism in this region (gluon contributions to the GPDs)

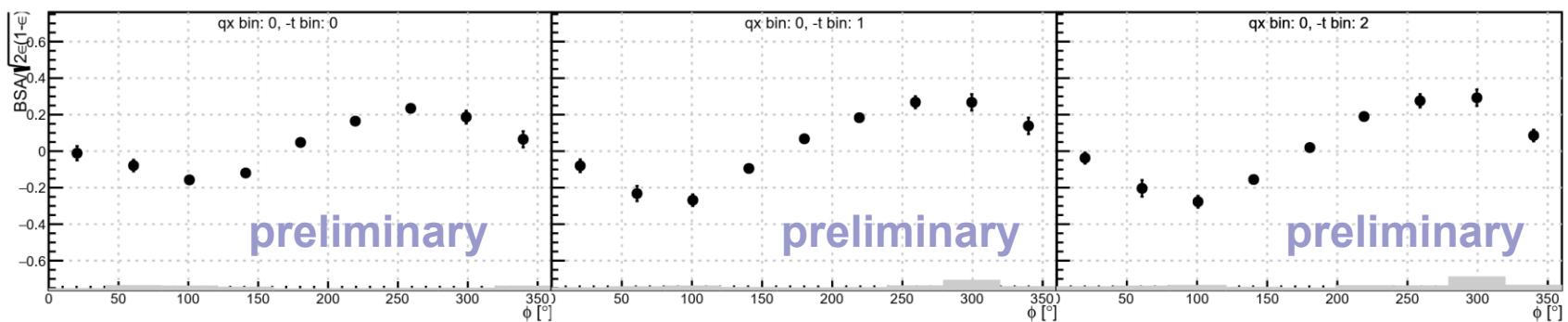
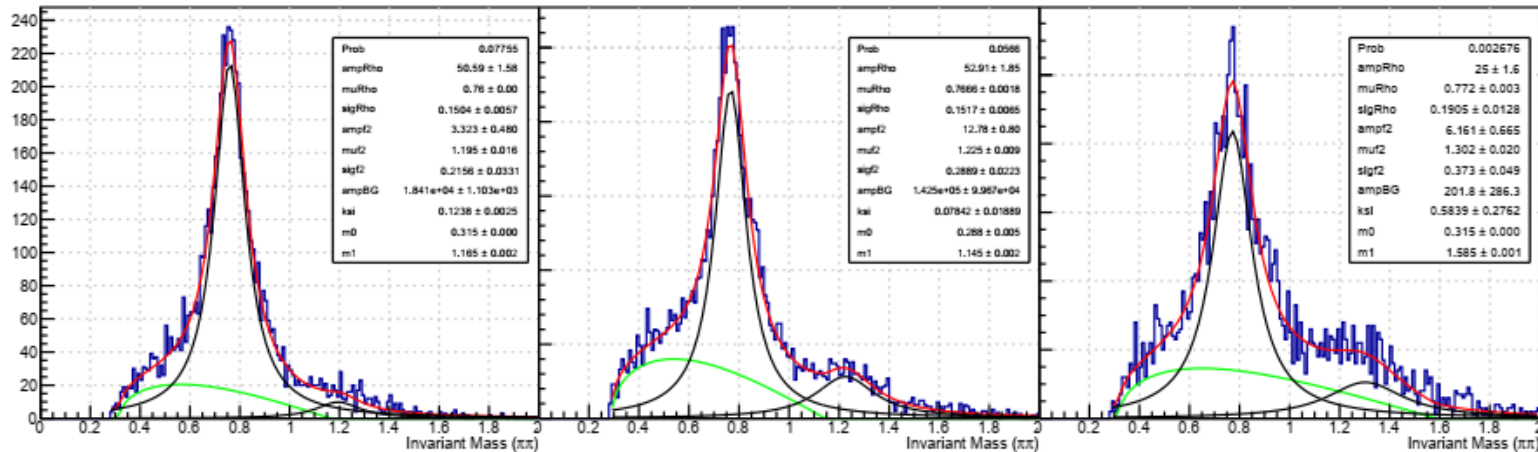


G. Matousek (Duke) & N. Trotta (UConn)



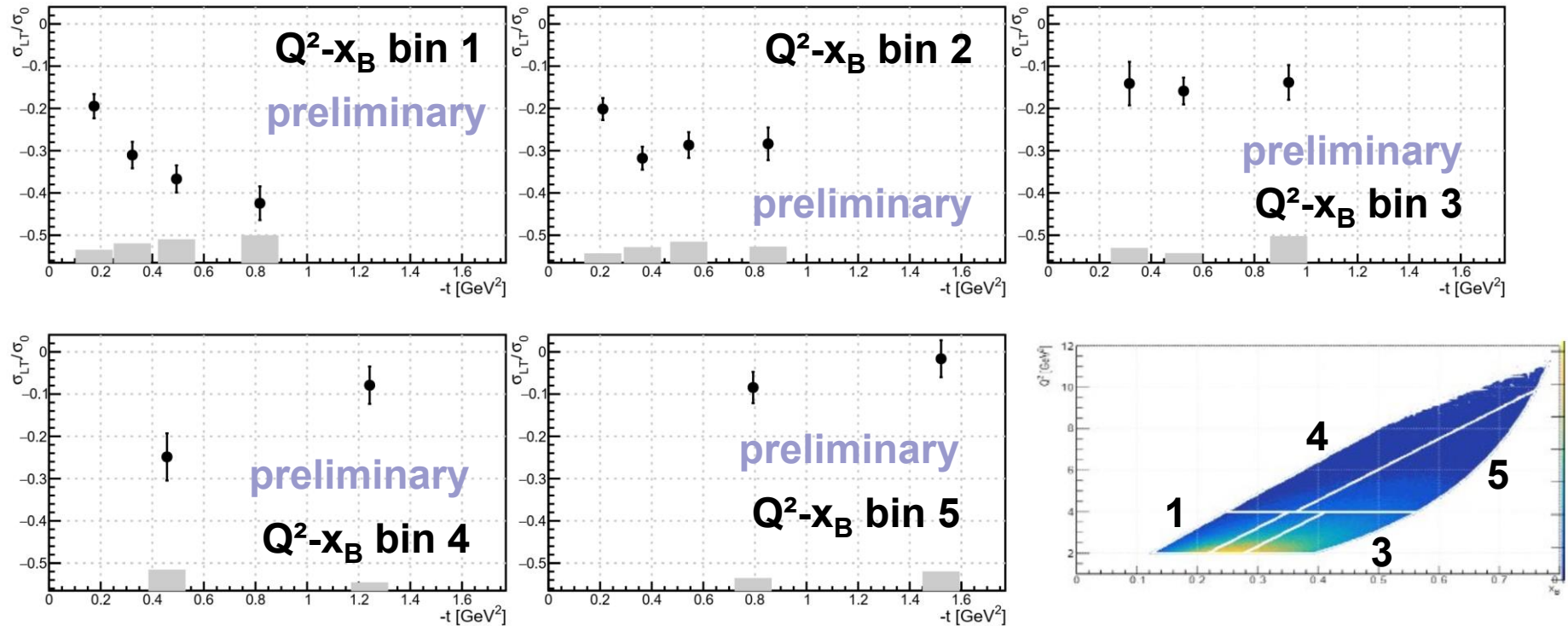
Hard Exclusive ρ^0 Production

$$e p \rightarrow e' p \rho^0 \rightarrow e' p \pi^+ \pi^- \quad Q^2 > 1 \text{ GeV}^2, W > 2 \text{ GeV}, -t < 1.5 \text{ GeV}^2$$



N. Trotta, A. Kima, S. Diehl, K. Joo (CLAS Collab), Beam spin asymmetry measurements of deeply virtual exclusive ρ^0 production with CLAS12, to be submitted to PLB (2026)

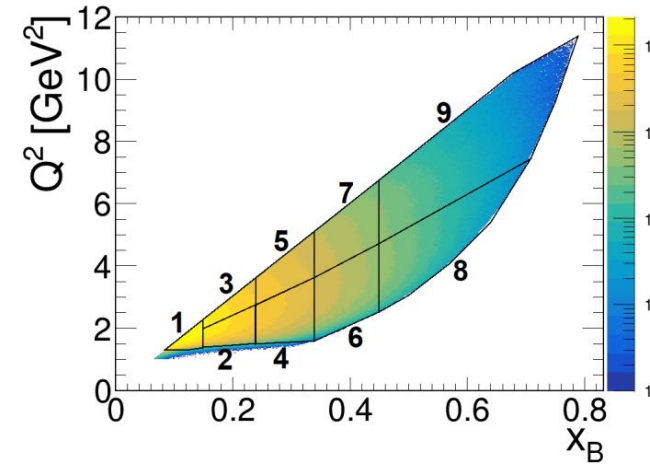
Hard Exclusive ρ^0 Production



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Exclusive ρ^0 Effects in π^- SIDIS

$e\pi^- X$

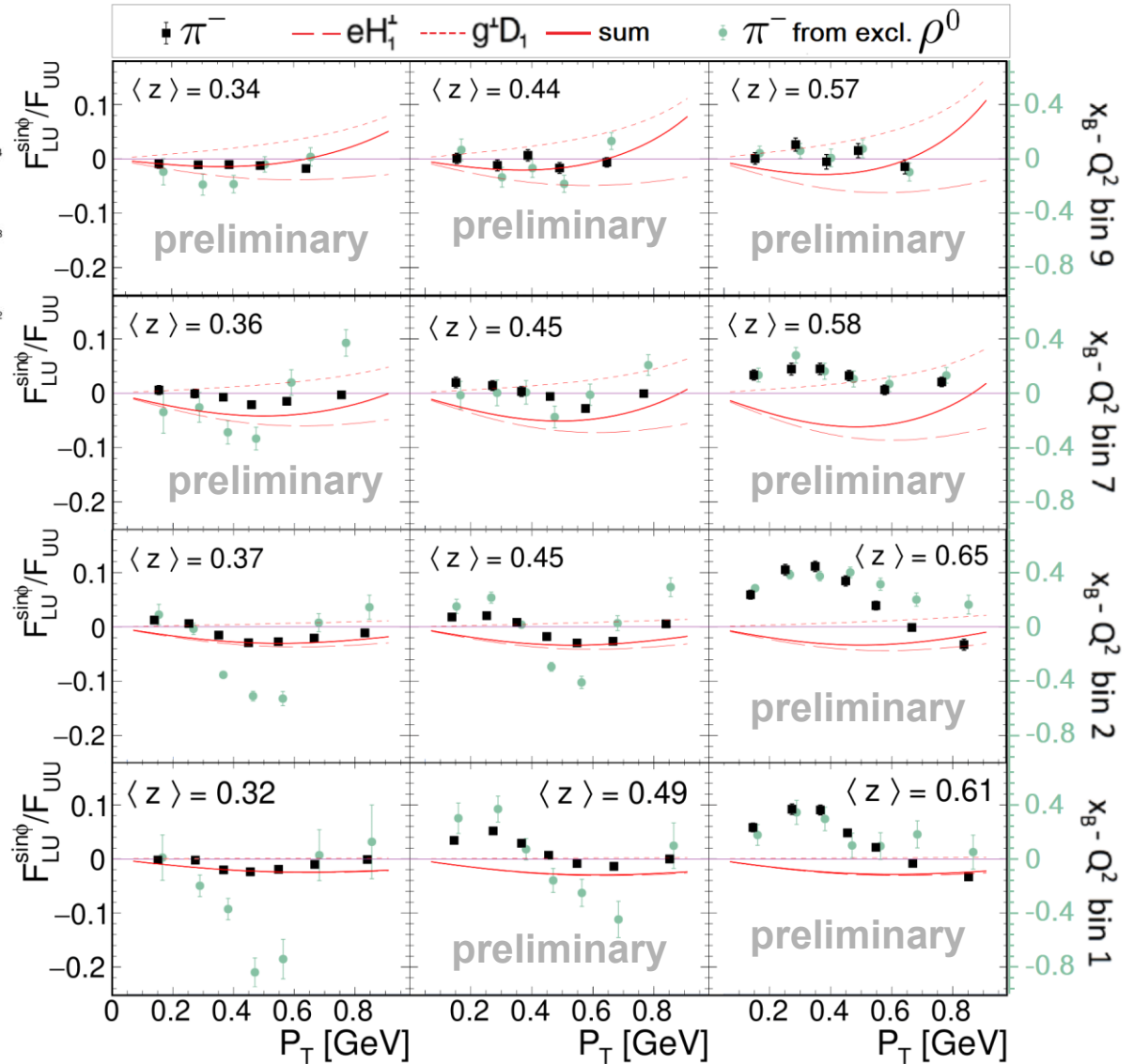


■ π^-

— TMD model 2

■ π^- from excl. ρ^0

→ π^- from excl. ρ^0 show similar BSA as the whole SIDIS sample



Summary and Outlook

- ➡ CLAS12 provides several orders of magnitude higher luminosity than any previous lepton scattering experiment
- ➡ High precision data in the valence region has been recorded
- ➡ BSA from charged pions show structures which can not be explained with TMD based models
- ➡ Similar structures are present for charged pions originating from exclusive ρ^0 events
- ➡ **Precise multidimensional ρ^0 MC** is needed to subtract these contributions
- ➡ We need a **multidimensional SDME extraction for ρ^0**