Q^2-dependence of SIDIS observables

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CLAS Collaboration Meeting

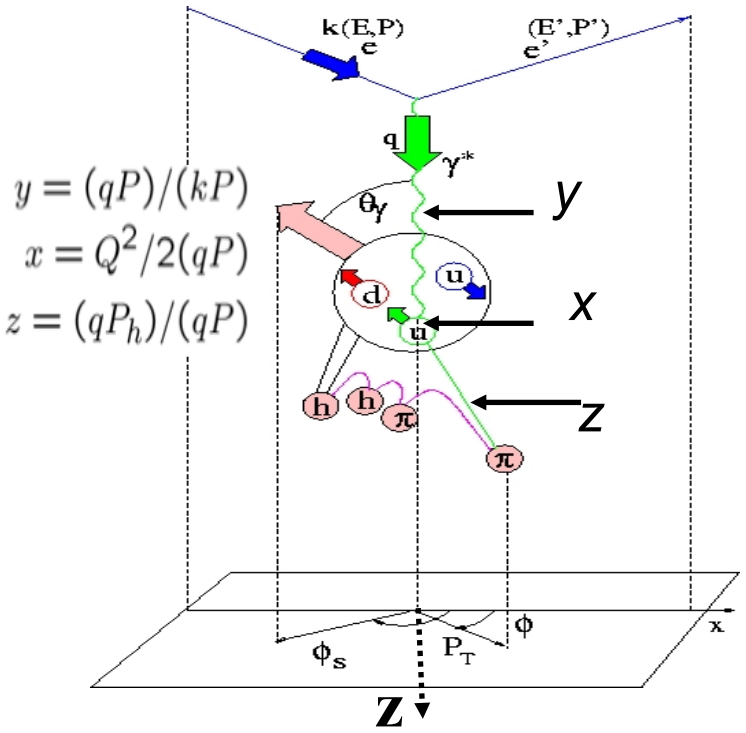
from Tuesday, 13 November 2018 at **01:30** to Friday, 16 November 2018

Outline

- Introduction
- Evolution of TMDs →critical for 3D formalism
- Studies of Q^2-dependence & multidimensional binning
- Evolution studies and higher twist TMDs
- Understanding of systematics of measurements and the role of MC
- Conclusions

TMD means Transverse Momentum Dependent PDF with most important dependences making it different from other PDFs its dependence on transverse momentum and Q^2(evolution)!!!

SIDIS kinematical plane and observables



$$y = (qP)/(kP)$$
$$x = Q^2/2(qP)$$
$$z = (qP_h)/(qP)$$

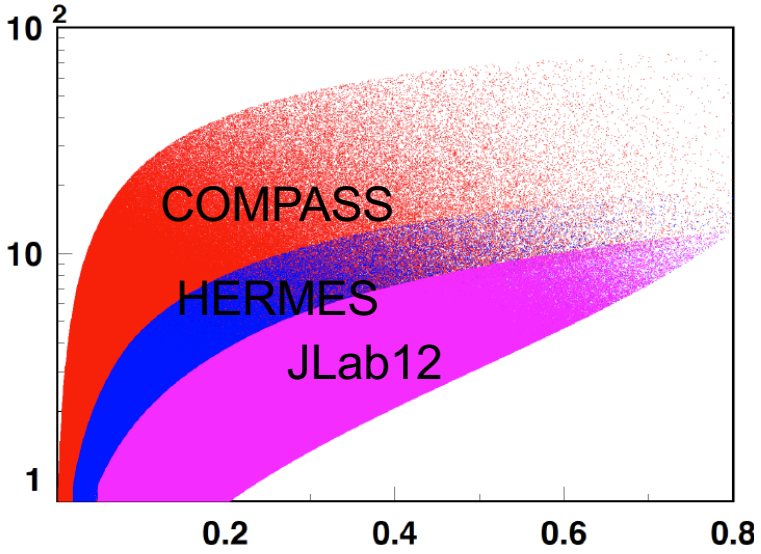
hermes

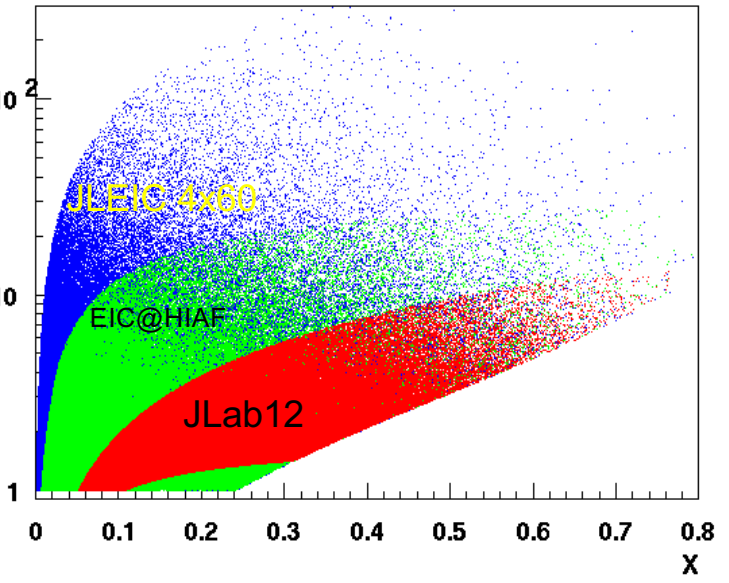
COMPASS

Jefferson La

EIC²
EIC Center at Jefferson Lab

EIC





$$\sigma = F_{UU} + P_t F_{UL}^{\sin\phi} \sin 2\phi + P_b F_{LU}^{\sin\phi} \sin\phi \ldots$$

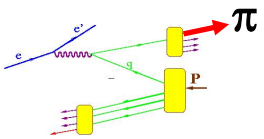
$$F_{XY}^{h}(x,z,P_T,Q^2) \propto \sum H^q \times f^q(x,k_T,..) \otimes D^{q\to h}(z,p_T,..) + Y(Q^2,P_T) + \mathcal{O}(M/Q)$$

$$\otimes \equiv \int d^2\vec{k}_T d^2\vec{p}_T \delta^{(2)}(z\vec{k}_T + \vec{p}_T - \vec{P}_T)$$

beam polarization

target polarization

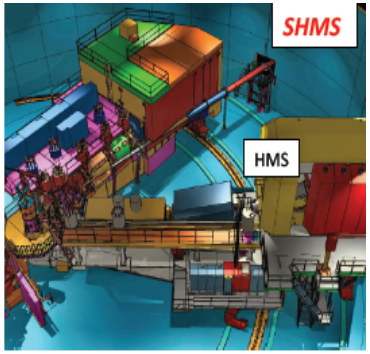
corrections for the region of large kT~Q

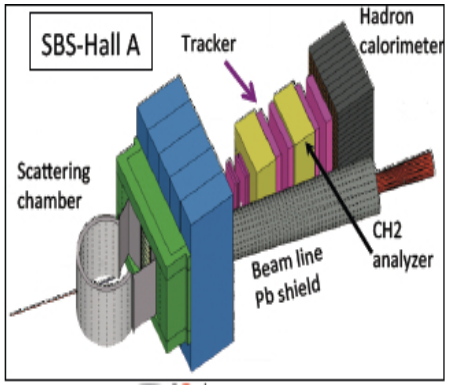


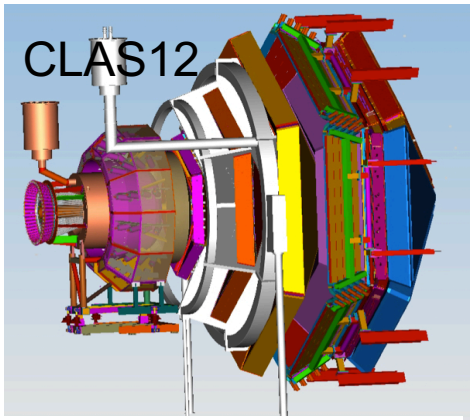
SIDIS at JLab12

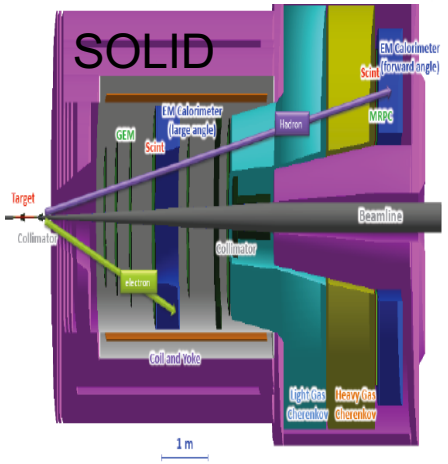
	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

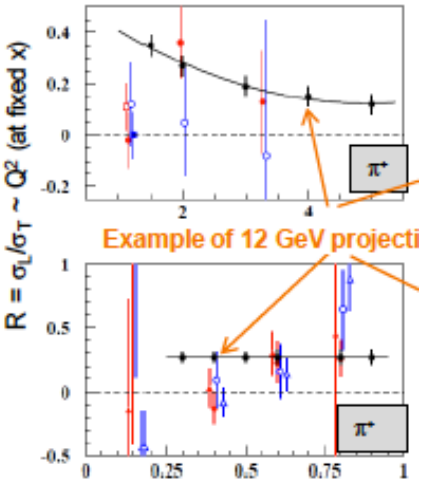
Complementary measurements with different targets

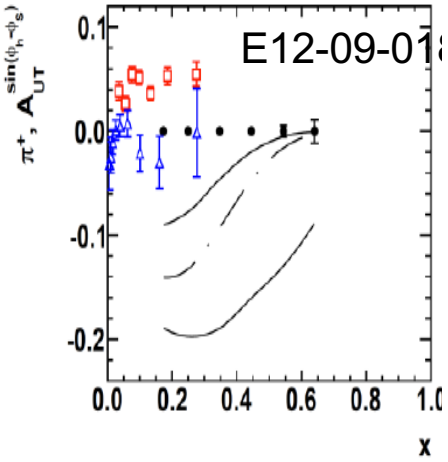


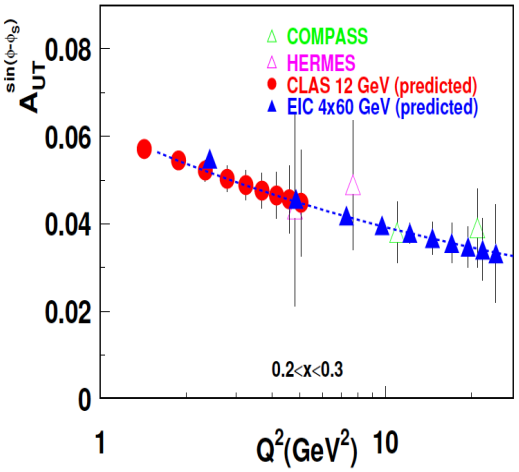


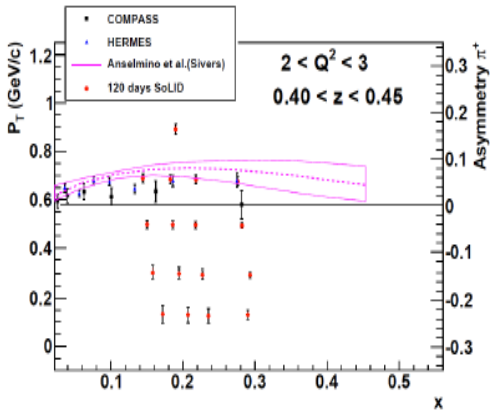












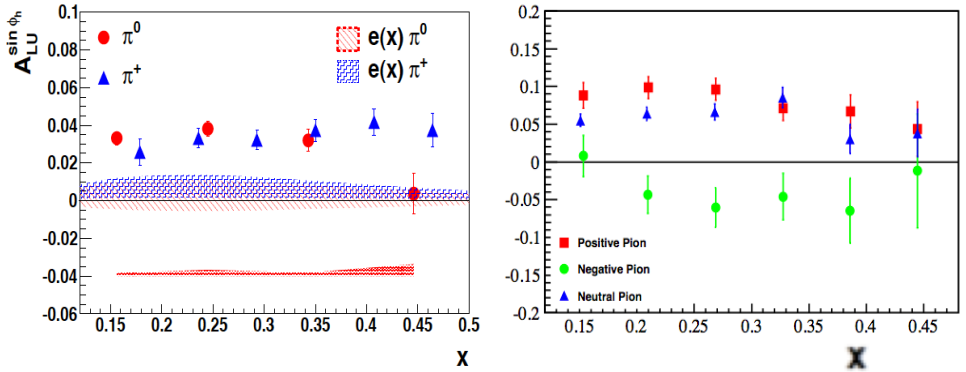
Combination of high resolution measurements from spectrometers combined with large acceptance data from CLAS12 and SOLID would allow to study TMDs in details in the valence region

Quark-gluon correlations: flavor dependence

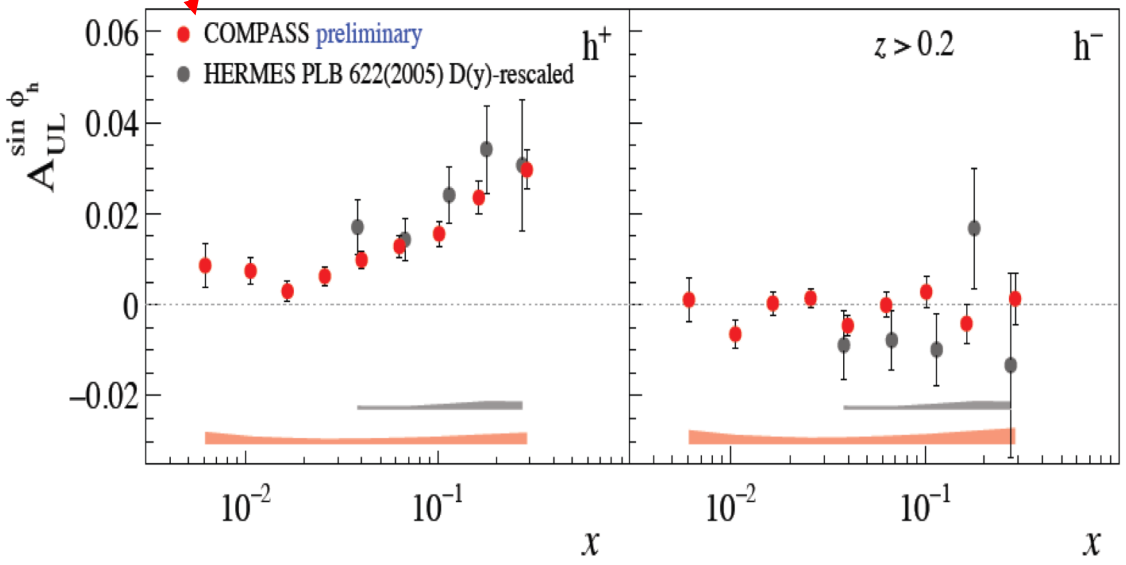
Higher Twist PDFs

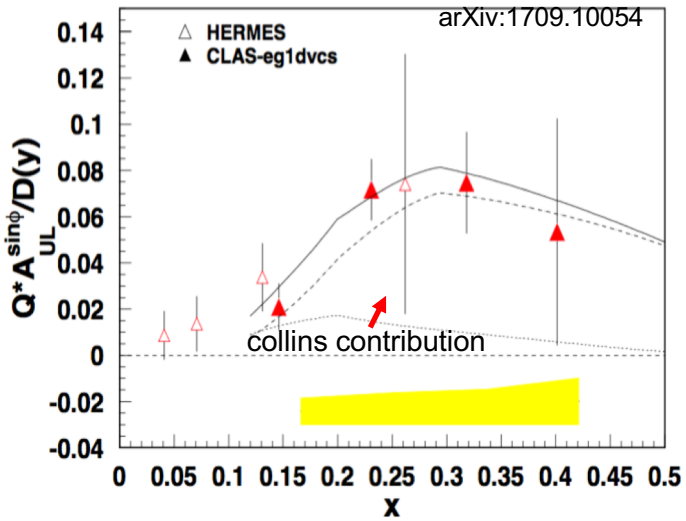
N/q	U	L	T
U	$f^{\perp}$	$g^{\perp}$	h, e
L	$f_L^{\perp}$	$g_L^{\perp}$	h_L, e_L
T	$f_T, f_T^{\perp}$	$g_T, g_T^{\perp}$	$h_T, e_T, h_T^{\perp}, e_T^{\perp}$

1) roughly equal $\pi^+\pi^0$ SSA
2) π^- SSA much smaller, consistent with 0 or<0



CLAS/HERMES

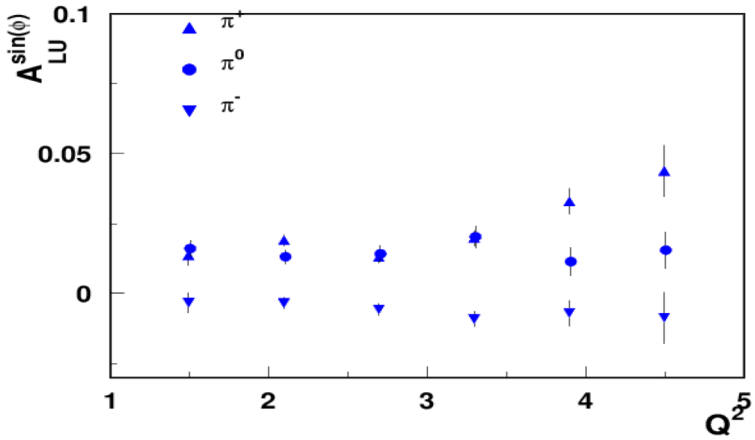




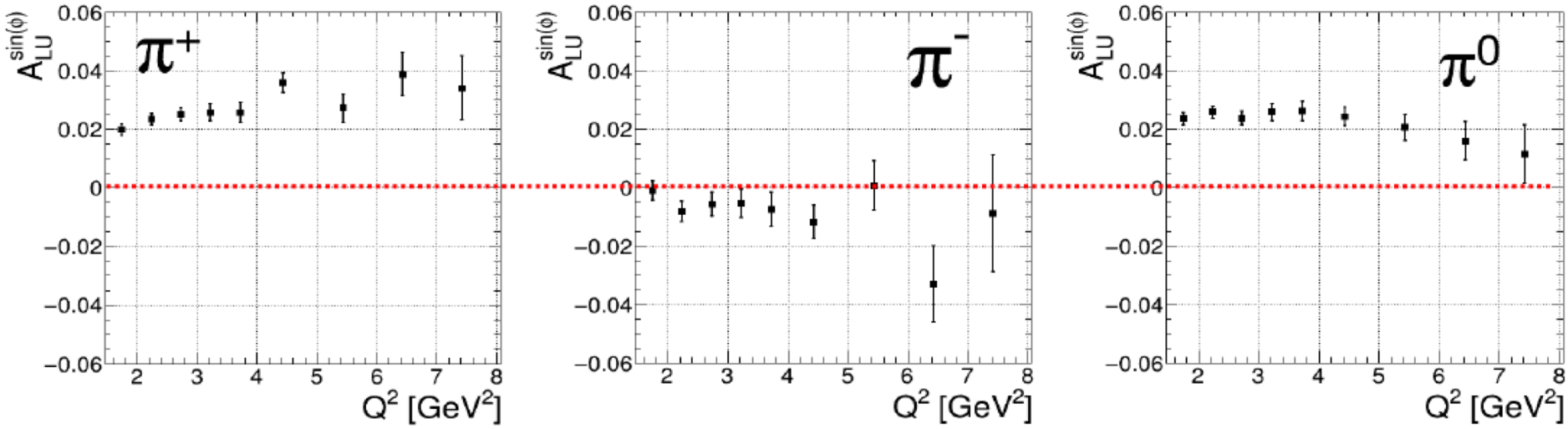
- Significant longitudinal beam and target SSA measured at HERMES, JLab and COMPASS may be related to higher twist distribution functions
- sinϕ modulations for $\pi^+\pi^0$ consistent with dominance of Sivers mechanism
- Subleading asymmetries comparable with leading ones (1/Q terms should be accounted)

First look at CLAS12 data

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



S.Diehl



With only 2% of expected unpolarized target data, clas12 already provides a superior measurement
Will require fine multidimensional binning to study Q^2-dependence

A_{LU} structure

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} \sim \frac{\alpha^2}{xyQ^2}\;(2-y)\sqrt{1-y-\tfrac{1}{4}\gamma^2y^2}\;\lambda_e\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$\gamma = \frac{2Mx}{Q}$$

$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(xh_LH_1^\perp + \frac{M_h}{M}\,g_{1L}\frac{\tilde{G}^\perp}{z}\right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(xf_L^\perp D_1 - \frac{M_h}{M}\,h_{1L}^\perp\frac{\tilde{H}}{z}\right)\right]$$

distribution functions

fragmentation functions

$$F_{XY}^h(x,z,P_T,Q^2) \propto \sum H^q \times f^q(x,k_T,..) \otimes D^{q\to h}(z,p_T,..) + Y(Q^2,P_T) + \mathcal{O}\big(M/Q\big)$$

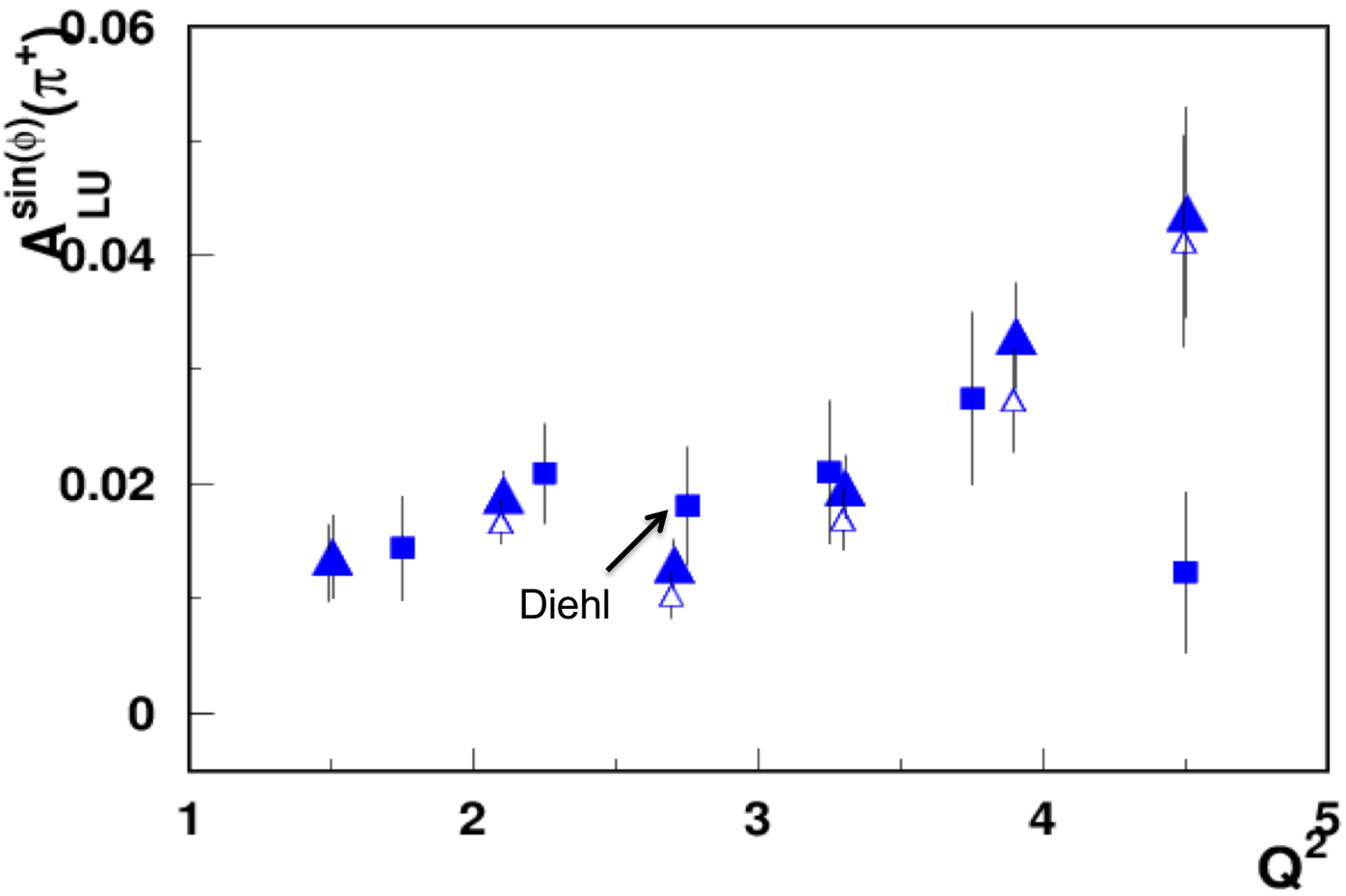
$$\int d^2\vec{k}_T d^2\vec{p}_T \delta^{(2)}(z\vec{k}_T + \vec{p}_T - \vec{P}_T)$$

- universal quantities are the distribution and fragmentation functions,
- kinematic factors should be factored out
- binning should be defined using minimization of the errors in extraction

Q^2-dependence: Kinematic factors

θ_e>10
Eπ>1.2

0.3<z<0.8
1.1<M_X
2<W<4
0.05<y<0.8



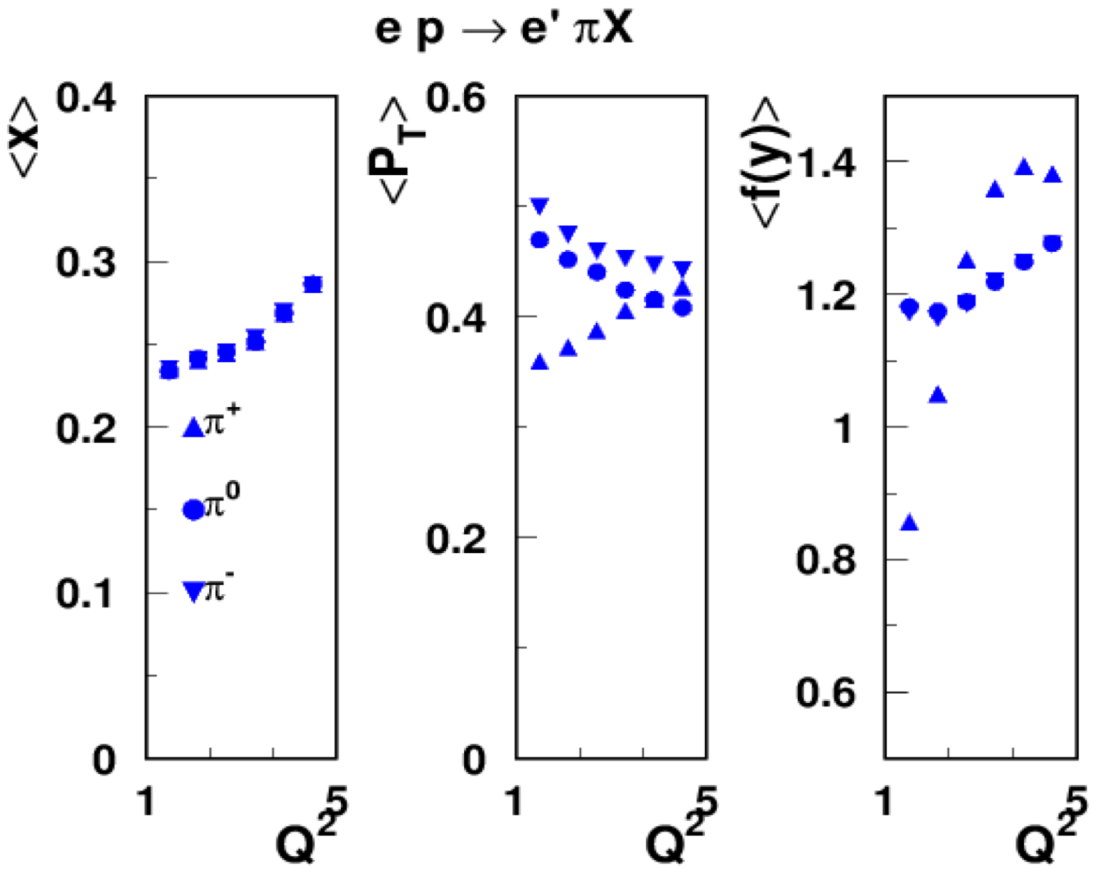
Asymmetry tend to increase at large Q^2?

Q^2-dependence: Kinematic factors

f(y)= $(2-y)\sqrt{1-y-\frac{1}{4}\gamma^2 y^2}$

θ_e>8
Eπ>1.2

0.2<x<0.3
0.3<z<0.8
1.1<M_X
2<W<4
0.05<y<0.8



Structure Function tend to increase at large Q^2?

Q^2-dependence: Kinematic factors

f(y)= $(2-y)\sqrt{1-y-\frac{1}{4}\gamma^2 y^2}$

θ_e>8
Eπ>1.2

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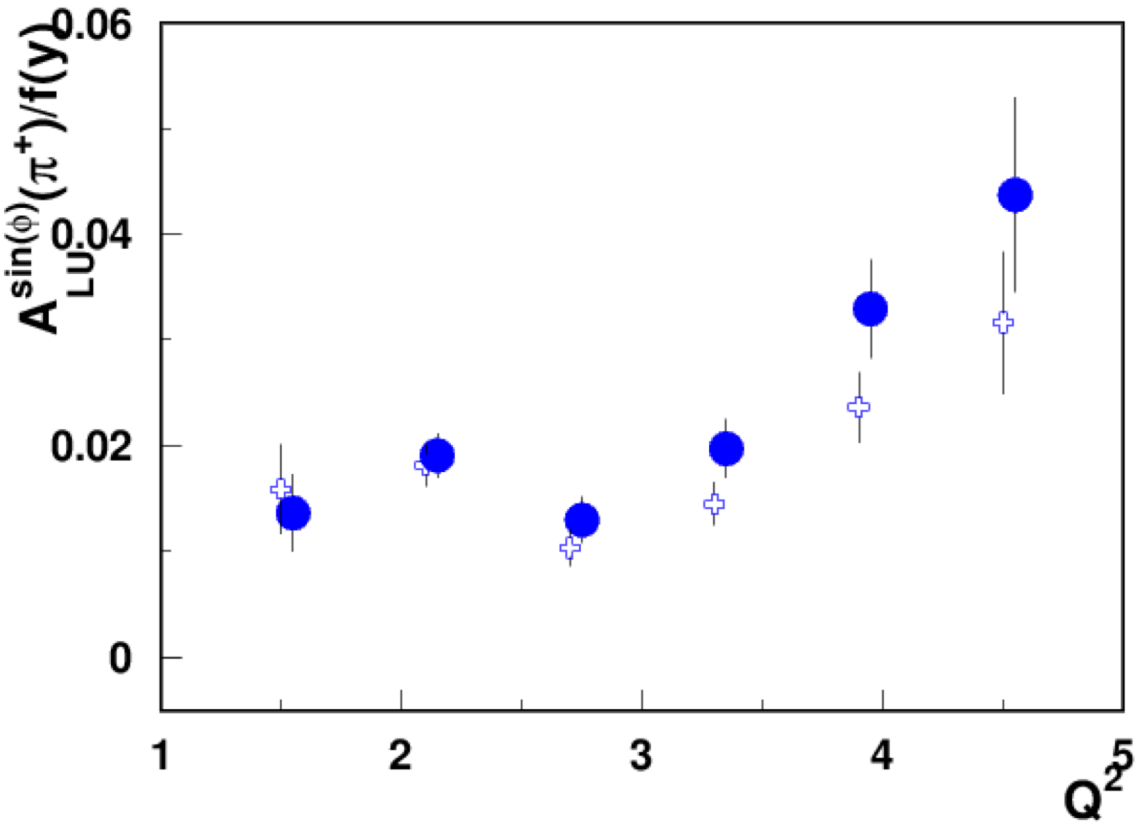

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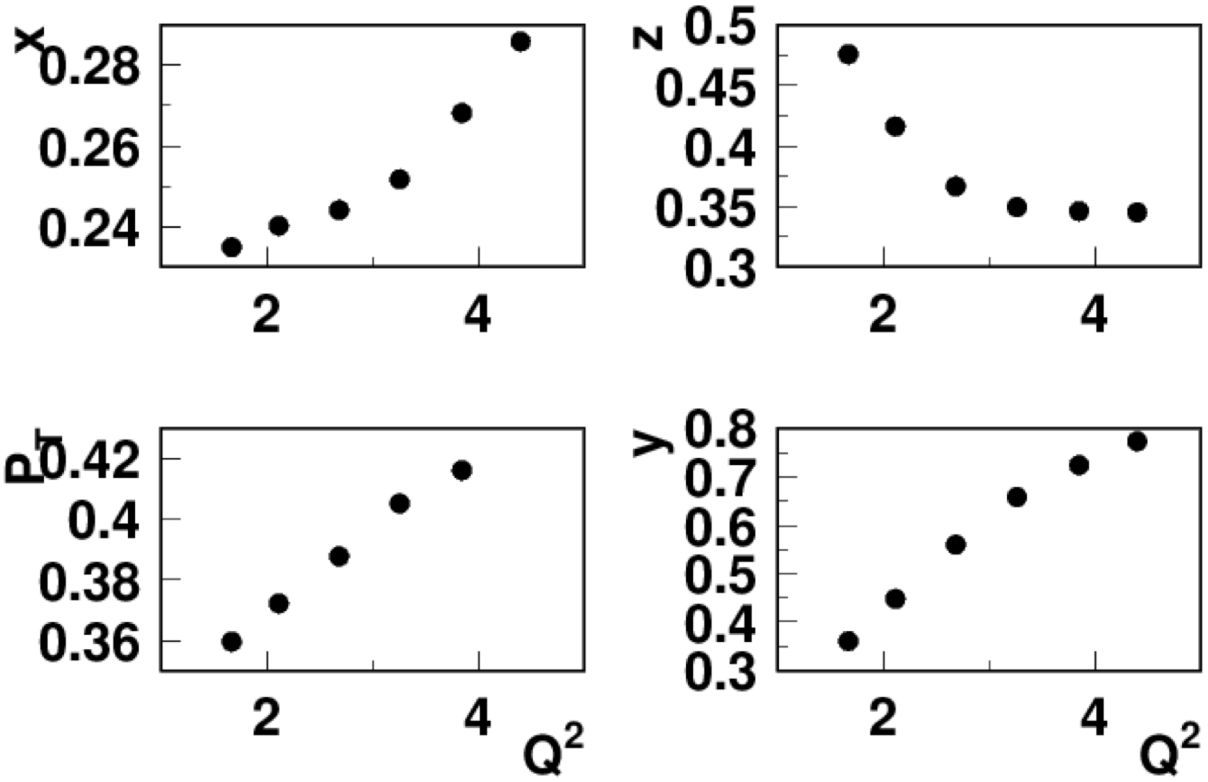
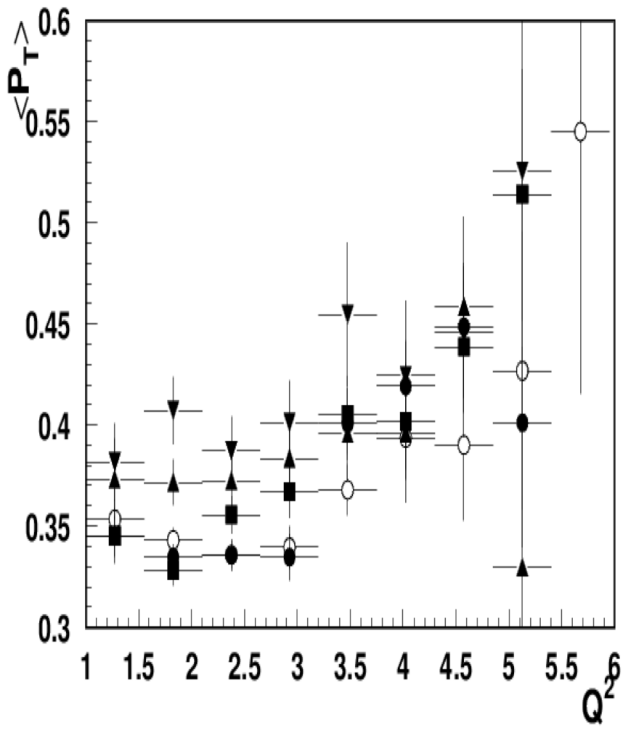


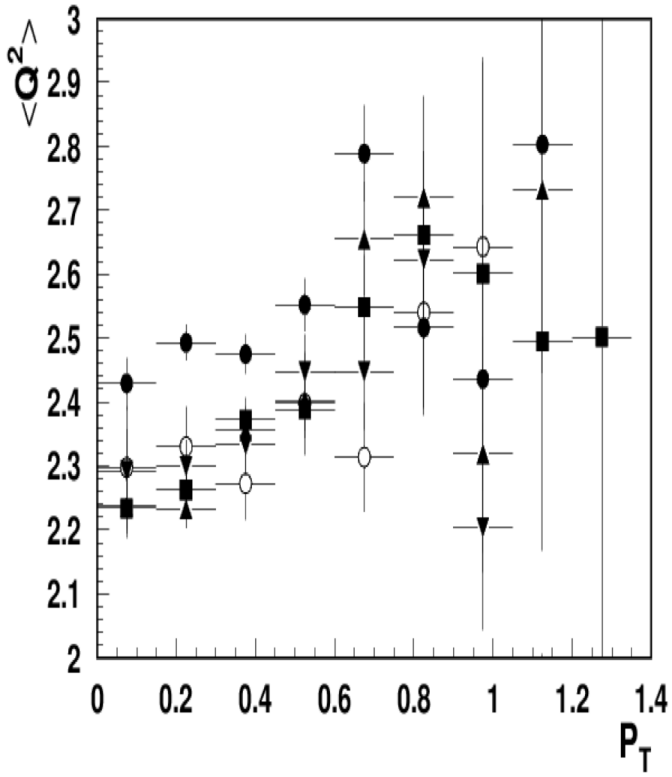
Strong variations of kinematical variables vs Q^2 even for small bins in x,Q^2

Q^2-dependence: Kinematic factors

θ_e>8
Eπ>1.2

0.2<x<0.3
5 bins in z ->0.3<z<0.8
1.1<M_X
2<W<4
0.05<y<0.8





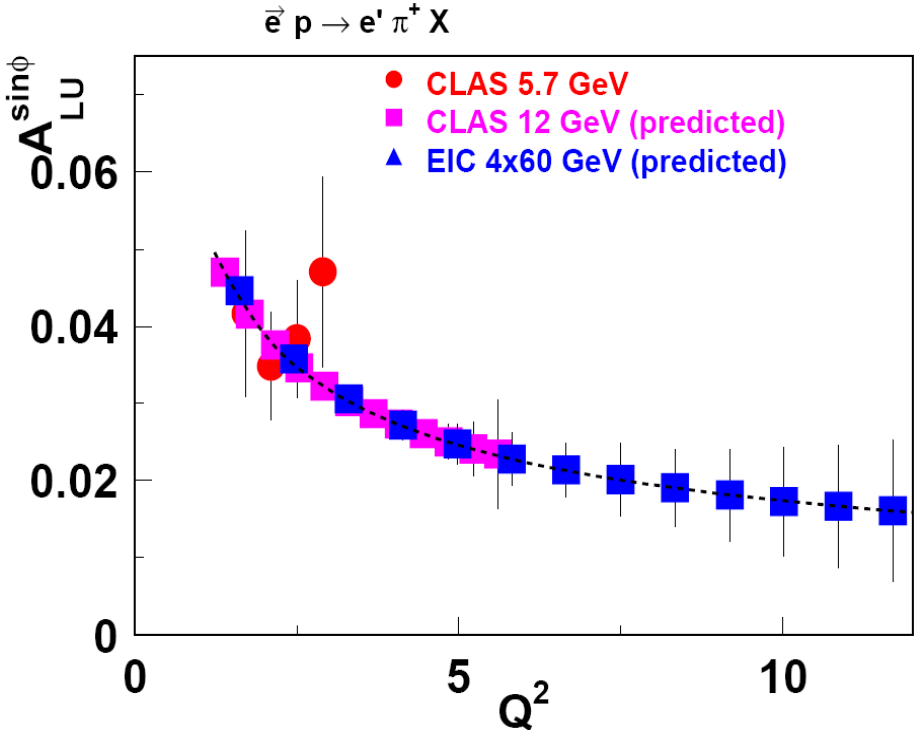
May need finer binning in all involved variables to study P_T and Q^2 dependences

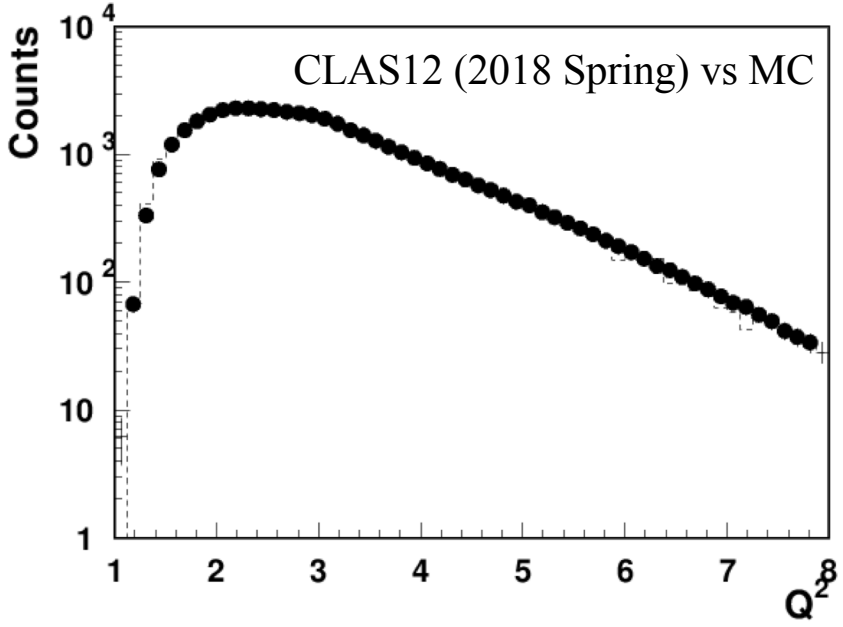
From JLab12 to EIC

N/q	U	L	T
U	$f^{\perp}$	$g^{\perp}$	h, e
L	$f_L^{\perp}$	$g_L^{\perp}$	h_L, e_L
T	$f_T, f_T^{\perp}$	$g_T, g_T^{\perp}$	$h_T, e_T, h_T^{\perp}, e_T^{\perp}$

$$A_{LU} \propto g^{\perp}(x) D_1(z)$$

JLab@12GeV (25/50/75)
→$0.1<x_B<0.7$: valence quarks
EIC $\sqrt{s}$ = 140, 50, 15 GeV
→$10^{-4}<x_B<0.3$: gluons and quarks, higher P_T and Q^2.

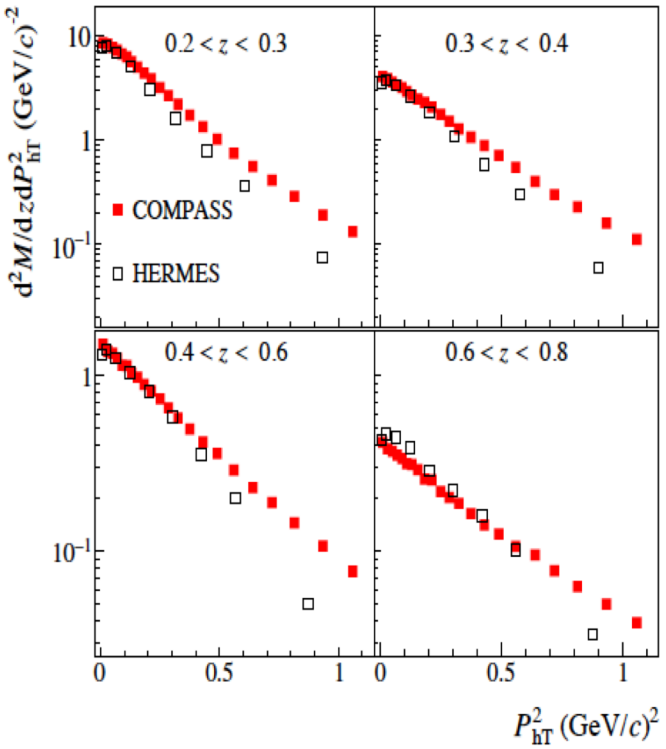


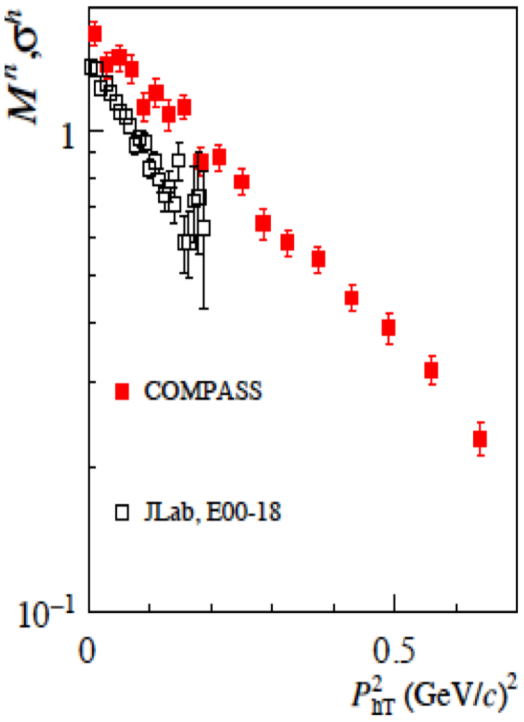


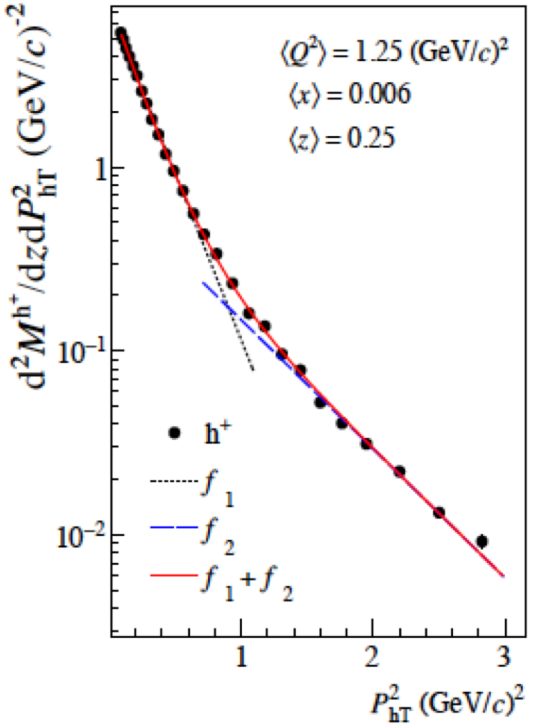
- Understanding of quark-gluon correlations is crucial for precision studies of the structure of the nucleon.
- At medium energies all experiments measure very significant HT contributions
- Large HT effects may indicate the breakdown of the theory
- Overlap of EIC and JLab12 in the valence region will be crucial for the TMD program

Multiplicities of hadrons in SIDIS

COMPASS:1709.07374







- Lower the beam energy, less phase space for high P_T
- P_T-weighting may be hard to control

- What is the origin of the tail?
- Is there a problem with the perturbative part (Sato) or with high P_T-part of TMD?

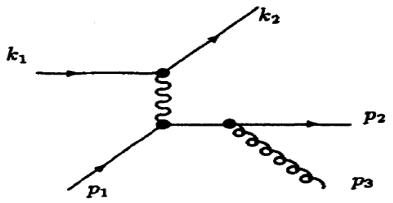
Azimuthal asymmetries in SIDIS

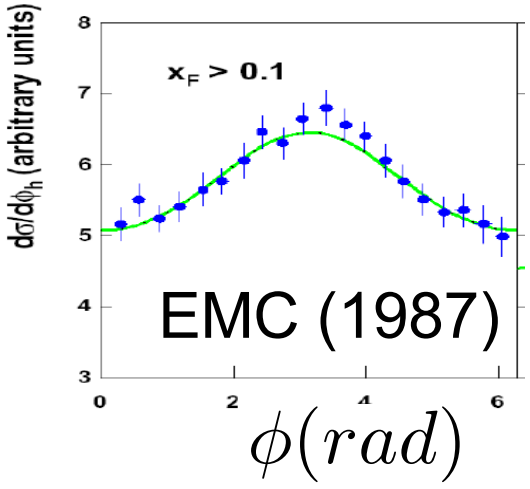
$$\frac{d\sigma}{dx_B\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{x_B y Q^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x_B}\right)\left\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h}\right.$$
$$\left. + \varepsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + \lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}\right\},$$

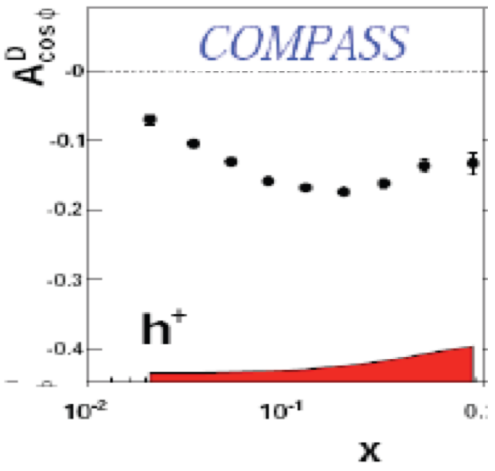
Non-perturbative vs perturbative

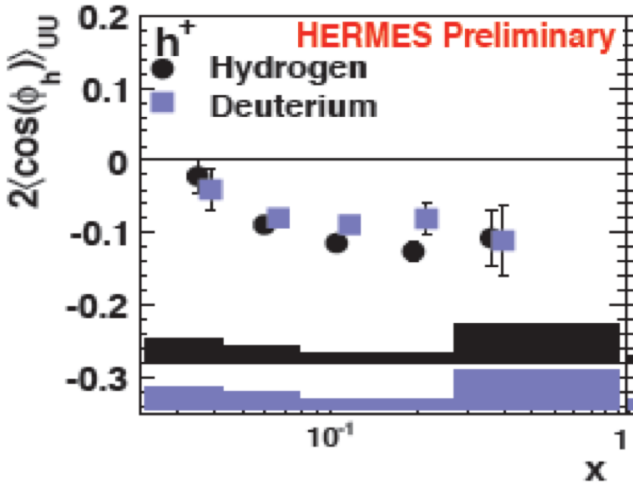
Cahn 1978

Georgi & Politzer, Mendez 1978









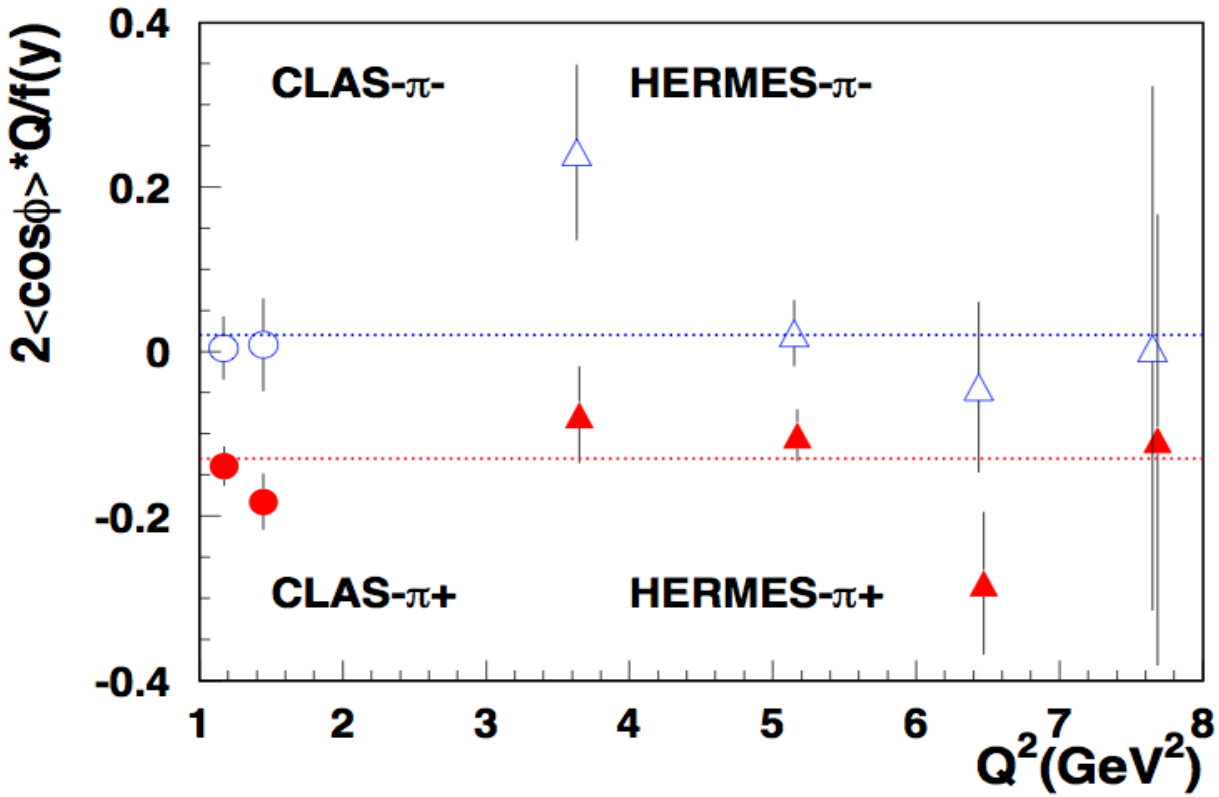
Large cosϕ modulations observed by EMC were reproduced in electroproduction of hadrons in SIDIS with unpolarized targets at COMPASS and HERMES

Comparing with HERMES

$$F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(x h\,H_1^{\perp} + \frac{M_h}{M}\,f_1\frac{\tilde{D}^{\perp}}{z}\right) - \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(x f^{\perp} D_1 + \frac{M_h}{M}\,h_1^{\perp}\frac{\tilde{H}}{z}\right)\right]$$

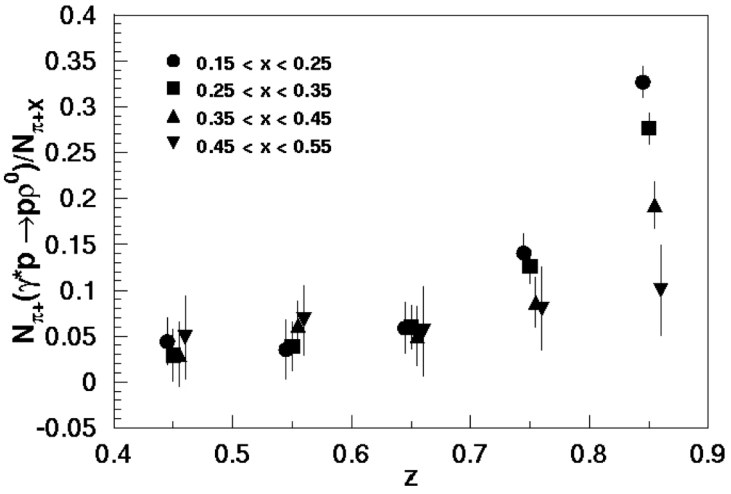
x=0.19,z=0.45,P_T=0.42 GeV



CLAS data consistent with HERMES (27.5 GeV)

Vector meson contributions vs dihadrons

1) Should we worry about pions/kaons coming from vector meson decays?
2) What about ρ+ and ρ-
3) What do we know about relevant observables for pions specifically coming from vector meson decays
4) What about SIDIS rhos (can we measure?)
5) What is radiative correction due to rho?
6) Vector meson as resonance in dihadron production?



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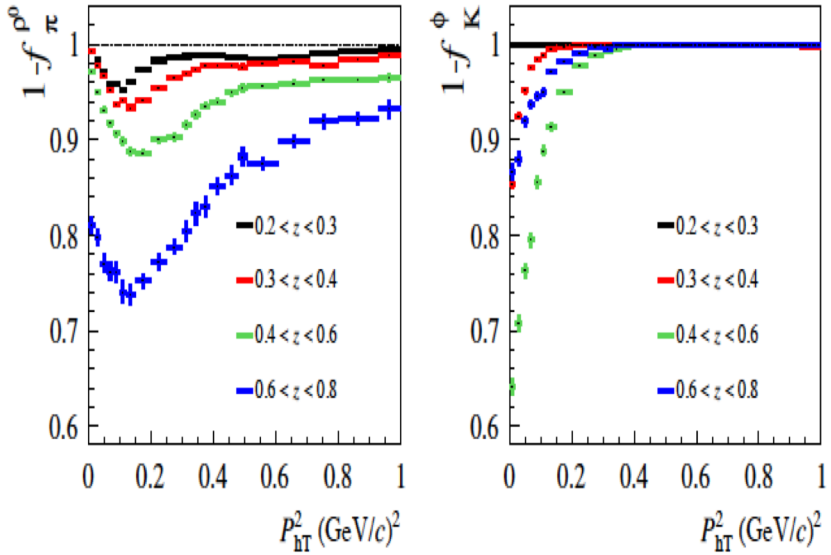
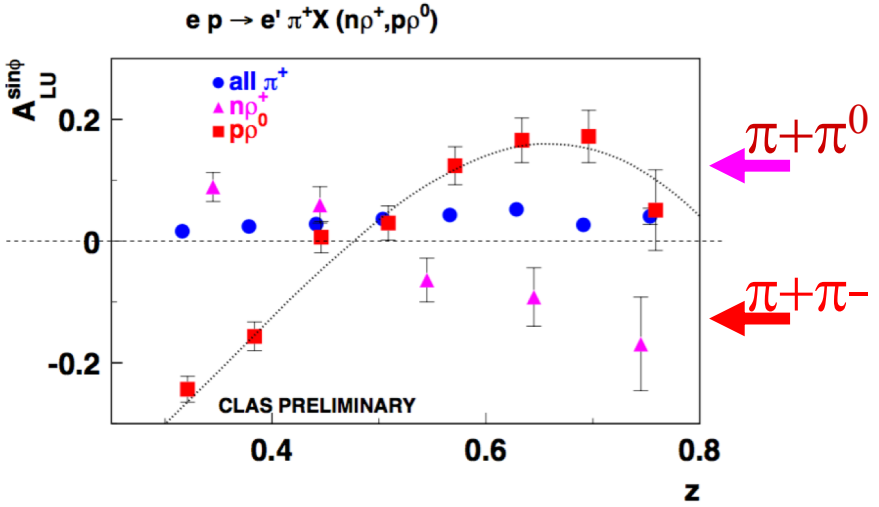
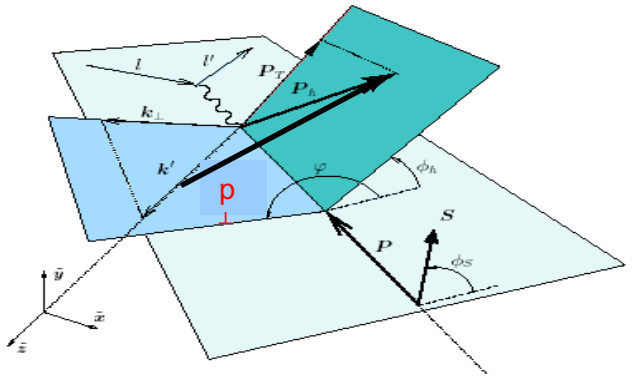




Reproduce SIDIS output with MC

SIDIS MC in 7D (10D)



$$\frac{d\sigma^{eN\to e'hX}_{\lambda\Lambda}}{dx dQ^2 dz dP^2_{hT} d\phi_h d\phi_l d\phi_s} = \sum_{l=1}^{L} SF_l$$

step-1 $x_i, Q^2_i z_i P^{i2}_{hT} \phi^i_h \phi^i_l \phi^i_s$

step-2 (for a given E_{beam},λ,Λ) P^{el}_i, P^h_i

step-3 (detected for a given Detector configuration)

$x_j, Q^2_j z_j P^2_{hT,j} \phi^j_h \phi^j_l \phi^j_s$

Theory

Provide a set of SF_l

For a given model/theory based on underlying non-perturbative input calculate SF_l

Output counts for a given energy and detector setup

Summary

- Understanding the Q^2-dependence of structure, distribution and fragmentation functions is critical for 3D description of the nucleon

•Separation of evolution of non-perturbative object, from background contributions including kinematic factors, higher twist contributions, exclusive processes..) will require multidimensional binning.

•Extraction procedures should have a mechanism for estimation of systematics due to different unaccounted contributions (target fragmentation, phase space limitations, higher twists, exclusive hadron and di-hadron, medium modifications…), could only be done with realistic, flexible MC with radiative effects

•Data from CLAS12 (bigger effects) combined with HERMES (cleaner target, wider Q2) and COMPASS (cleaner sample from target fragmentation) could be combined to study underlying systematics of spin-orbit correlations

Support slides

One TMD PDF: Solution to Evolution

Ex: Cutoff Prescription:

$$\mathbf{b}_*(\mathbf{b}_\mathrm{T}) \equiv \frac{\mathbf{b}_\mathrm{T}}{\sqrt{1+b_T^2/b_{\max}^2}}$$

$$\mu_b \equiv C_1/|\mathbf{b}_*(b_T)|$$

$$\tilde{F}_{f/P}(x,\mathbf{b}_\mathrm{T};Q,Q^2) = \sum_j \int_x^1 \frac{d\hat{x}}{\hat{x}} \tilde{C}_{f/j}(x/\hat{x},b_*;\mu_b^2,\mu_b,g(\mu_b)) f_{j/P}(\hat{x},\mu_b) \times$$

Collinear PDFs

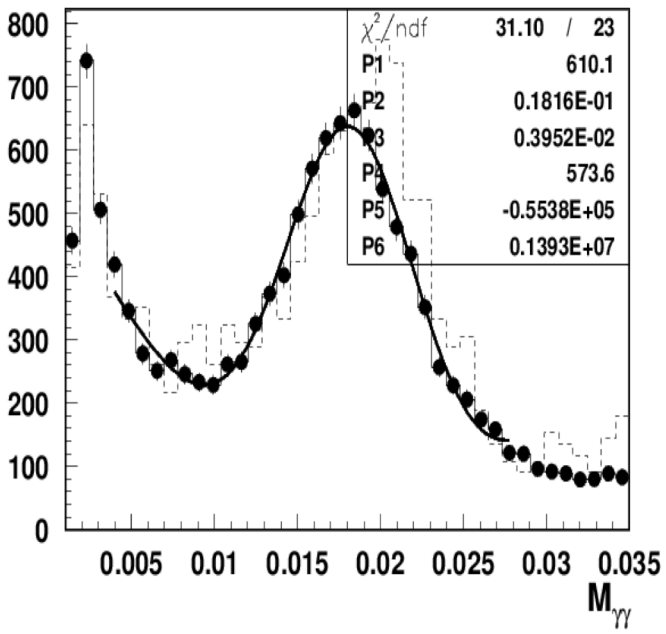
$$\times \exp\left\{ \ln\frac{Q}{\mu_b}\tilde{K}(b_*;\mu_b) + \int_{\mu_b}^{Q}\frac{d\mu'}{\mu'}\left[\gamma_F(g(\mu');1) - \ln\frac{Q}{\mu'}\gamma_K(g(\mu'))\right]\right\} \times$$

$$\times \exp\left\{ -g_{f/P}(x,b_T;b_{\max}) - g_K(b_T;b_{\max}) \ln\frac{Q}{Q_0} \right\}$$

Nonperturbative parts large b_-

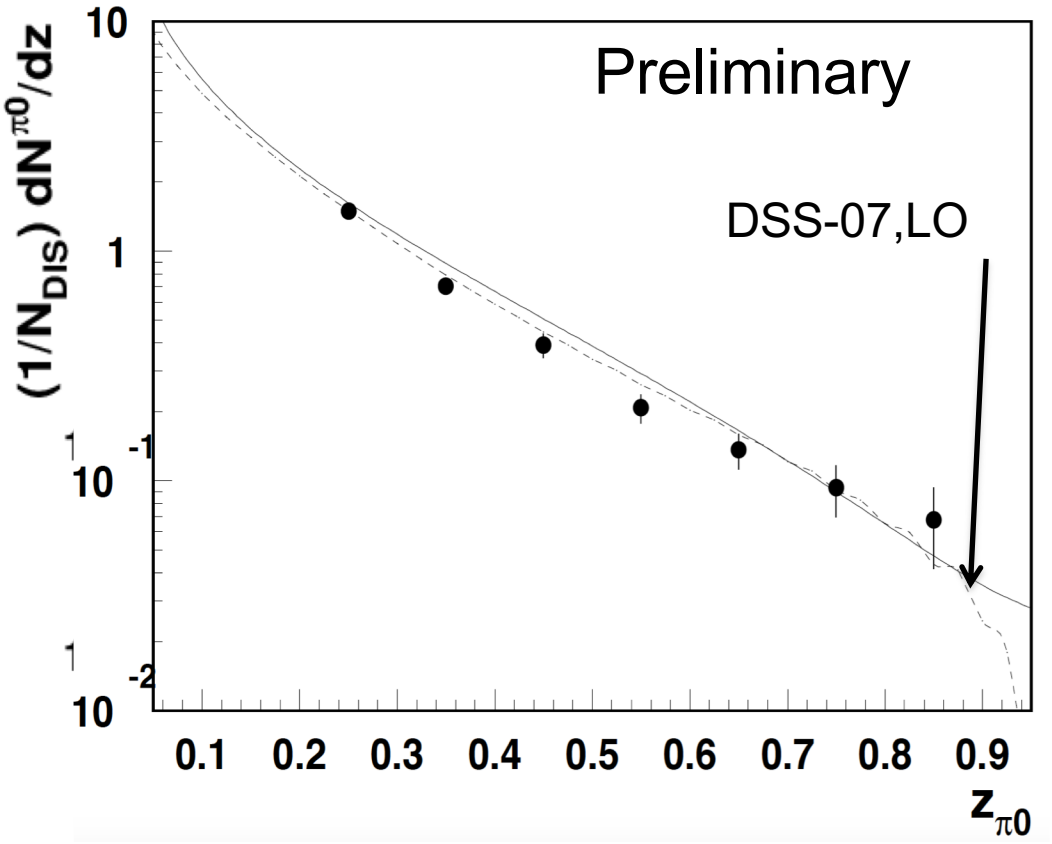
Evolution effects complex, integrated in bins of other kinematical variables for different structure functions may not cancel

clas12: e'π⁰X multiplicity



Efficiency fairly constant at z>0.25

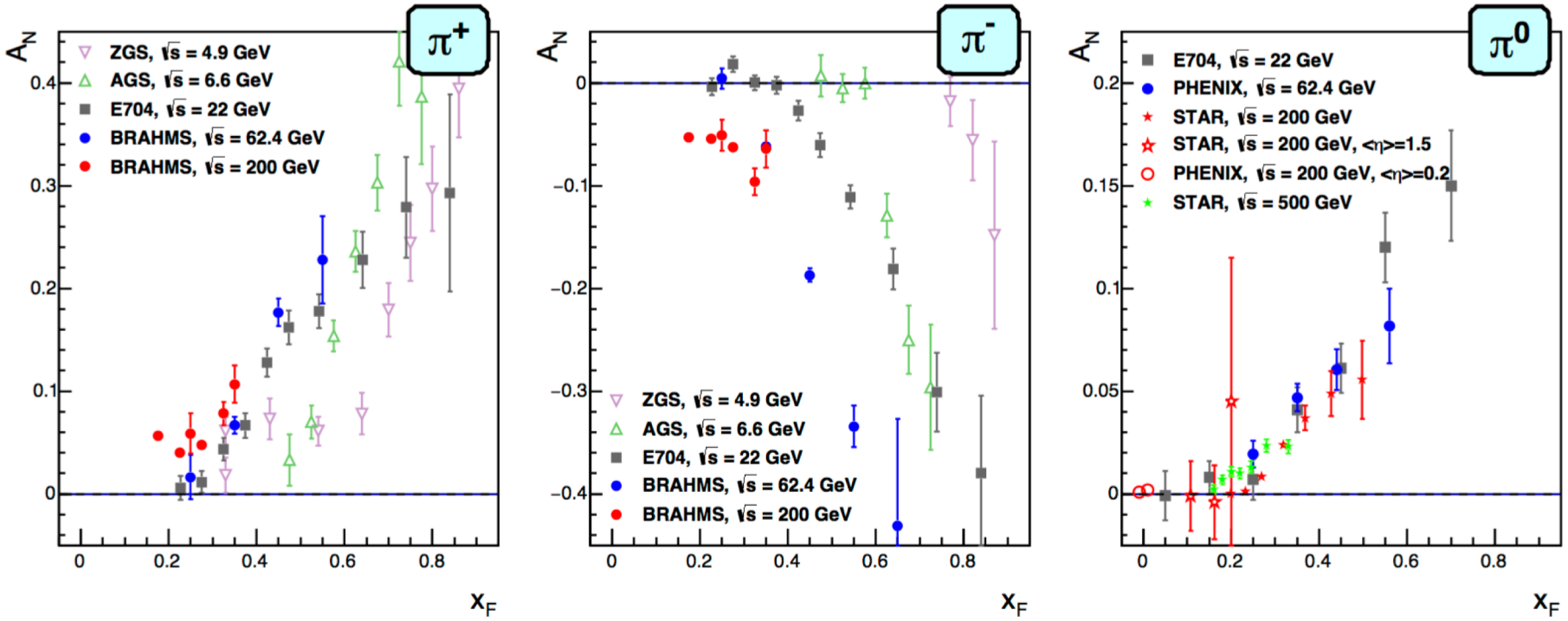
1% of CLAS12 spring run



- Ratio e'π⁰X/ e'X follows z-dependence of the fragmentation function
- Multiplicity consistent with HERMES,clas6,LO FFs
- Improve the fiducial cuts and estimate systematics due to various cuts

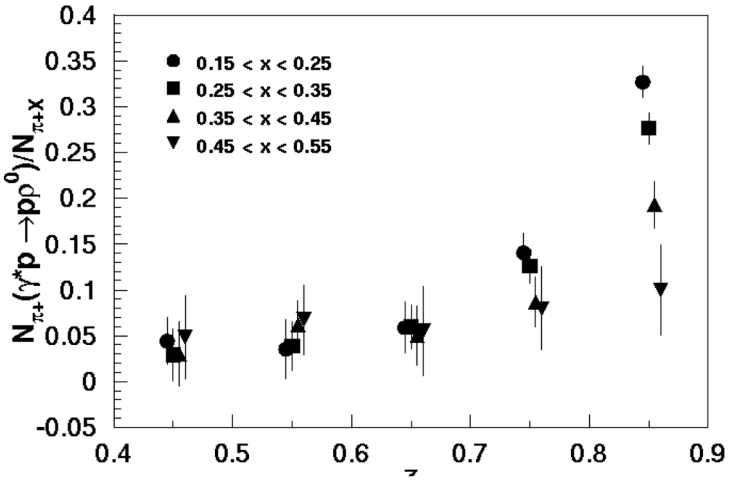
pi0s

https://arxiv.org/pdf/1512.05379.pdf

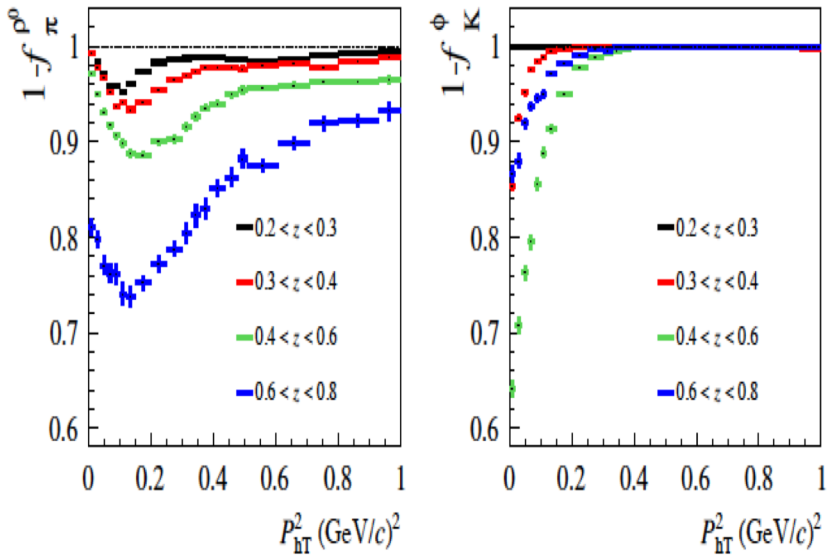


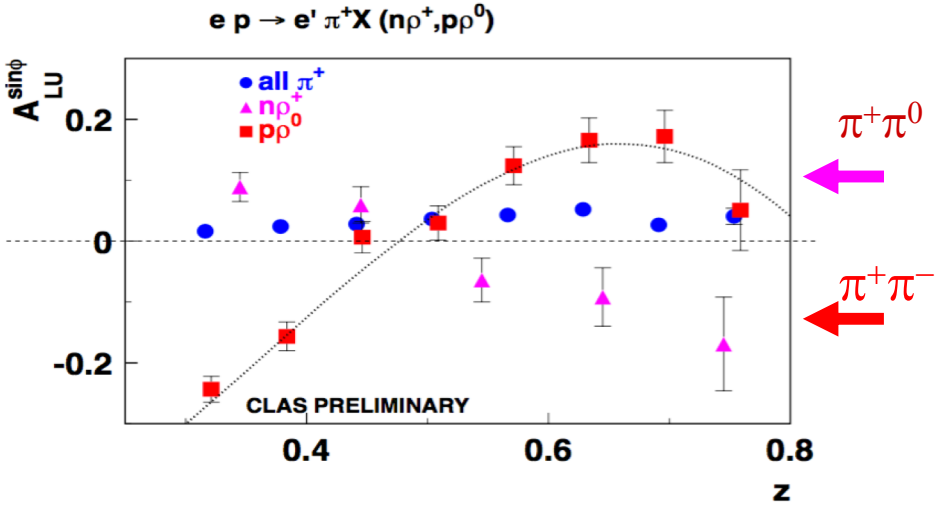
The role of vector mesons and dihadrons in SIDIS

1) Should we worry about pions/kaons coming from vector meson decays?
2) What about ρ+ and ρ-
3) What do we know about relevant observables for pions specifically coming from vector meson decays
4) What about SIDIS rhos (can we measure?)
5) What is radiative correction due to rho?
6) Vector meson as resonance in dihadron production?



COMPASS:1709.07374





Fraction of dihadrons should be significantly higher at EIC!