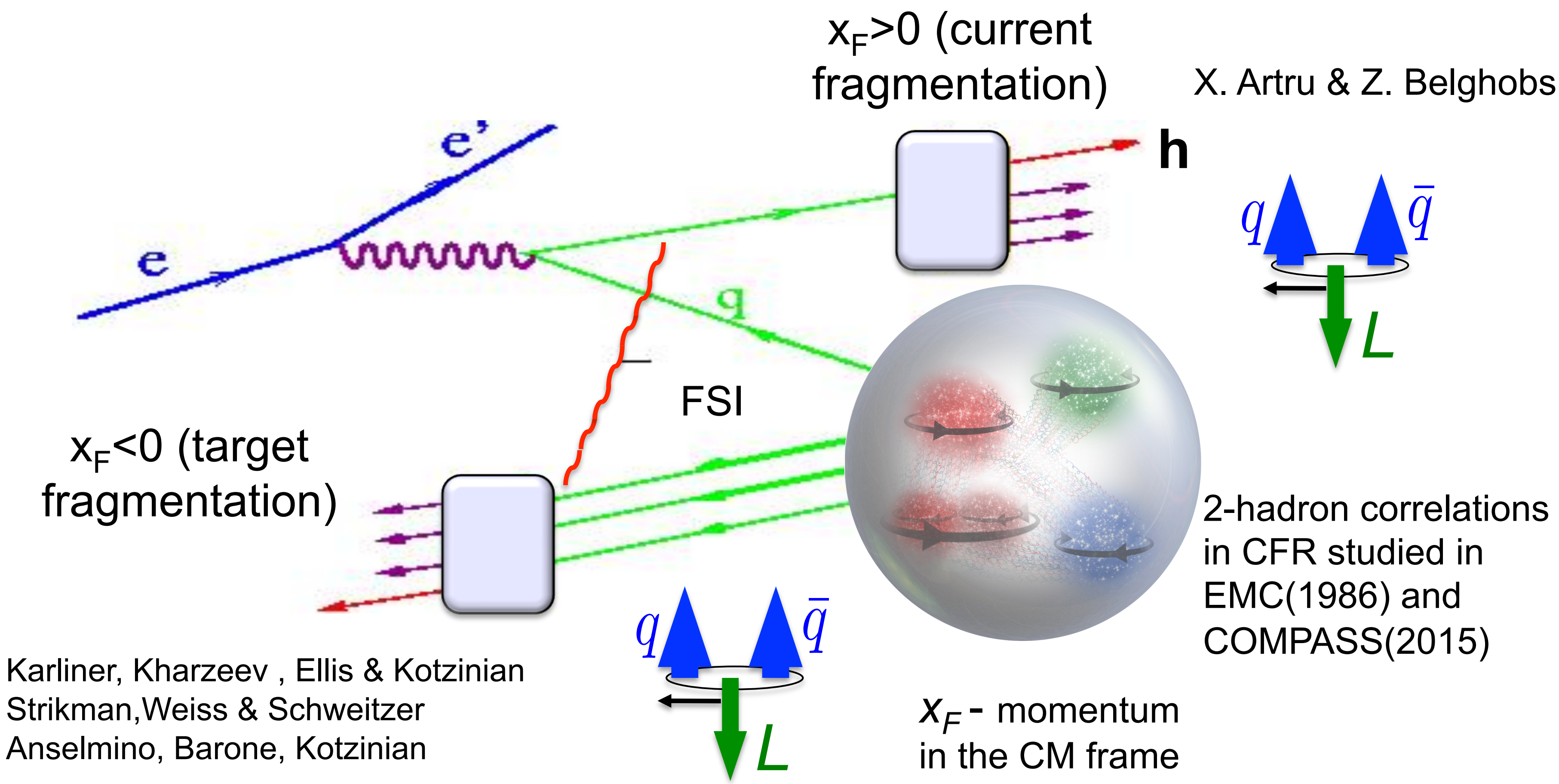
Correlation in current and target fragmentation regions

Harut Avakian* (JLab)

- Transverse Momentum in Hadron Production
- Non perturbative sea and k_T-distributions
- Accessing spin-orbit correlations in di-hadron production
- Back to back production of hadrons in SIDIS
- Summary

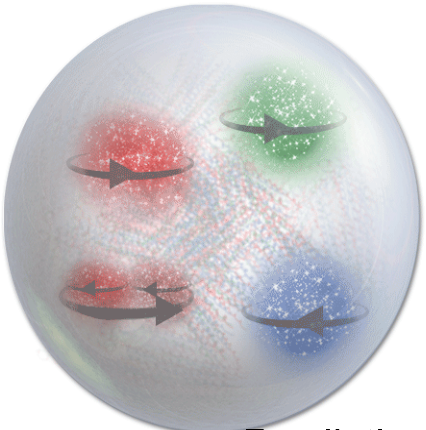
*) In collaboration with Kijun Park

Hadron production in hard scattering

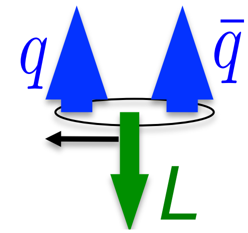


Correlations of the spin of the target or/and the momentum and the spin of quarks, combined with final state interactions define the azimuthal distributions of produced particles

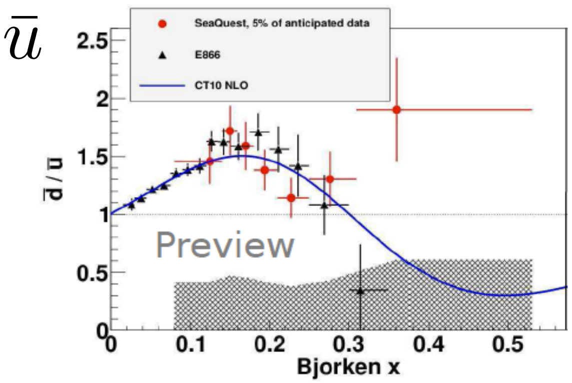
Features of partonic 3D non-perturbative distributions



Non-perturbative sea in nucleon is a key to understand the nucleon structure

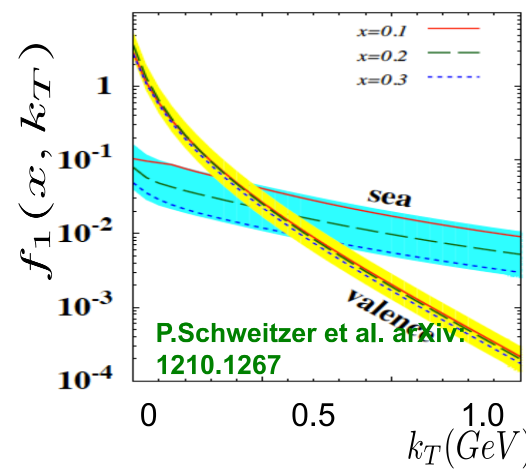


Large flavor asymmetry as evidence $\bar{d} > \bar{u}$



- Predictions from dynamical model of chiral symmetry breaking [Schweitzer, Strikman, Weiss JHEP 1301 (2013) 163]

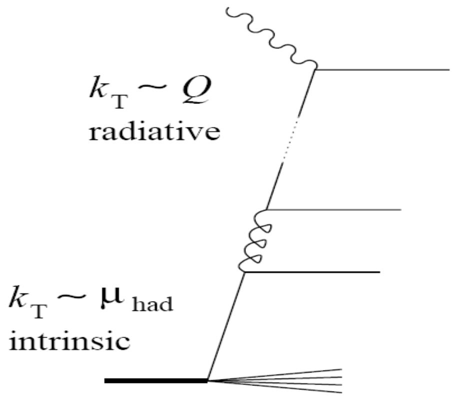
  -- k_T (sea) >> k_T (valence)
  -- short-range correlations between partons (small-size q-qbar pairs)
  -- directly observable in P_T-dependence of hadrons in SIDIS



- spin and momentum of struck quarks are correlated with remnant
- correlations of spins of q-q-bar with valence quark spin and transverse momentum will lead to observable effects

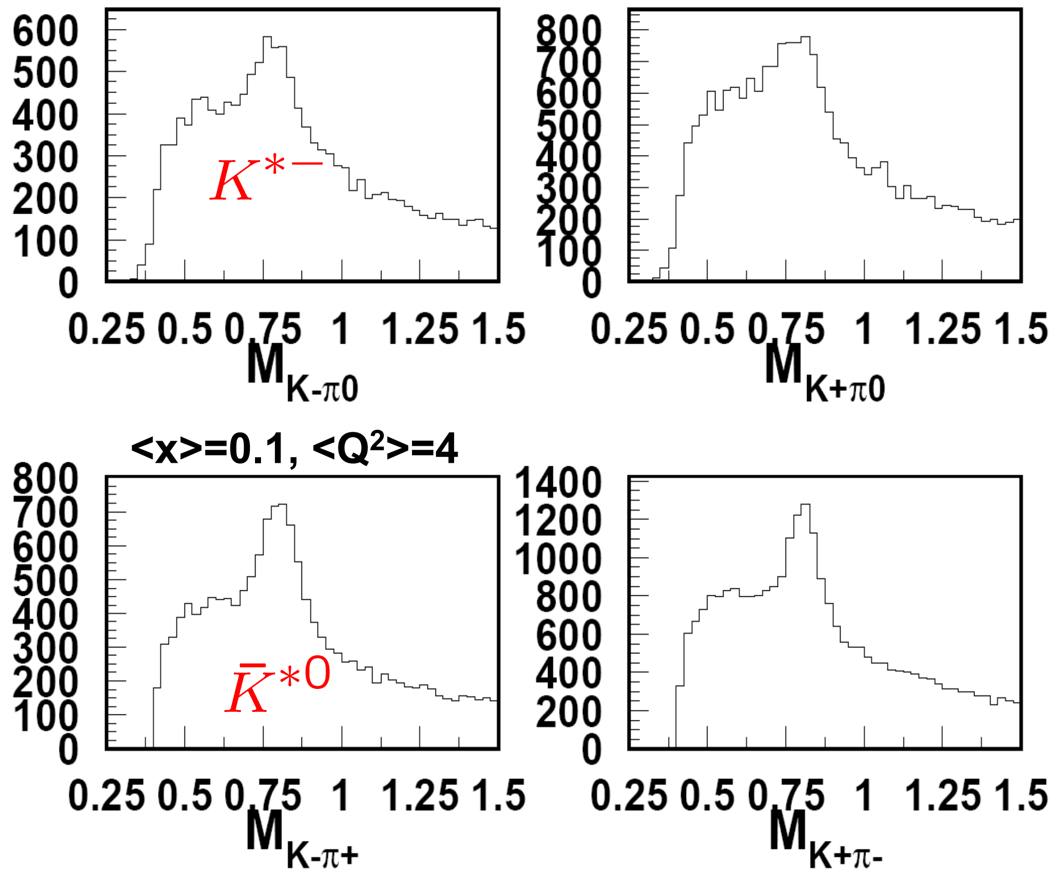
Intrinsic k_T: SIDIS observables

Schweitzer, Strikman, Weiss; in progress



- Aim: Observe intrinsic k_T of sea quarks due to QCD vacuum fluctuations
- Challenge: Separate intrinsic k_T from perturbatively generated k_T (DGLAP evolution)
- Idea: Isolate non-singlet sea through SIDIS cross section differences, e.g.

EIC 4x60 (Lumi 10^{33},cm^{-2}sec^{-1} , ~1 hour)

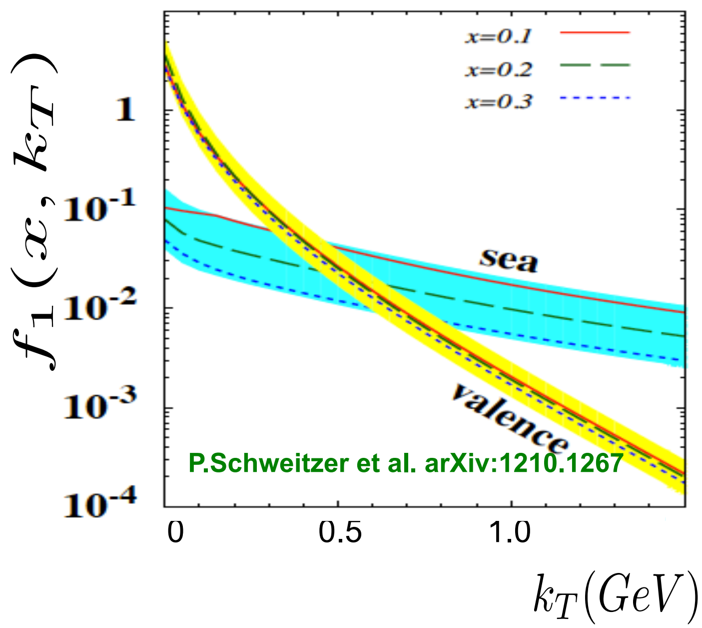


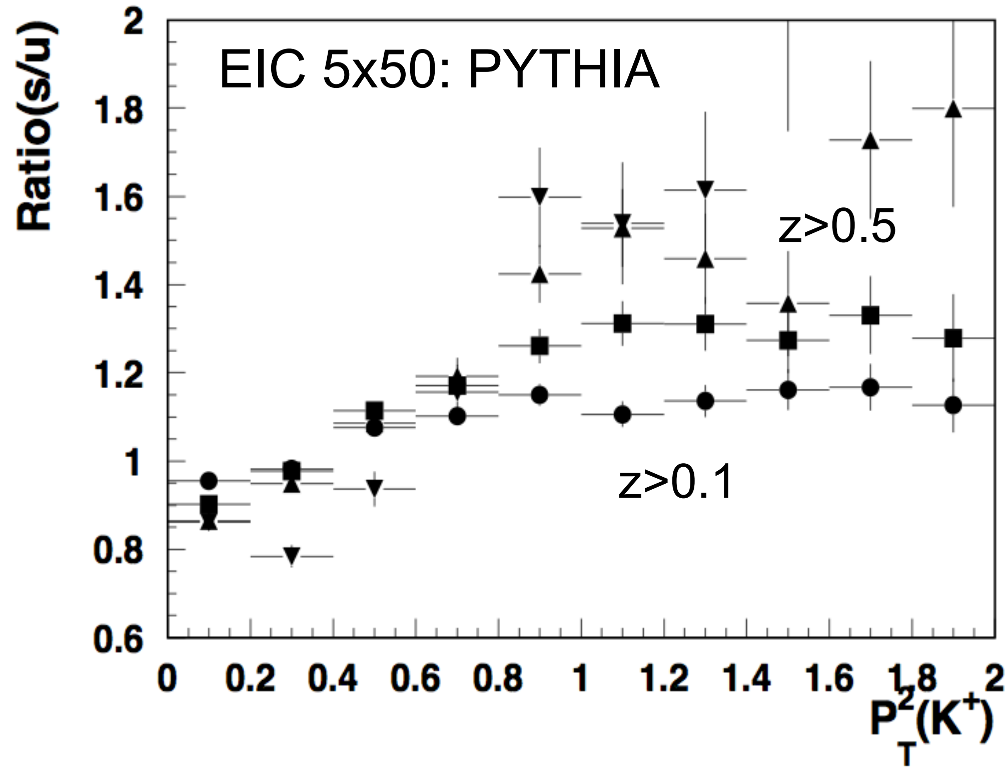
$$\begin{array}{ccc} & \overset{s\bar{u}}{} \quad\quad\quad \overset{s\bar{d}}{} & \\ d\sigma(K^{*-}) - d\sigma(\bar{K}^{*0}) & \sim & (\bar{u} - \bar{d}) * FF \\ d\sigma(\rho^{+}) - d\sigma(\rho^{-}) & \sim & (u_{val} - d_{val}) * FF \end{array}$$

σ(p) = 0.05 + 0.06*p [GeV] %

K*s can be studied with EIC

P_T-distributions of Kaons from s and u quarks



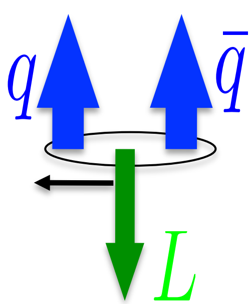


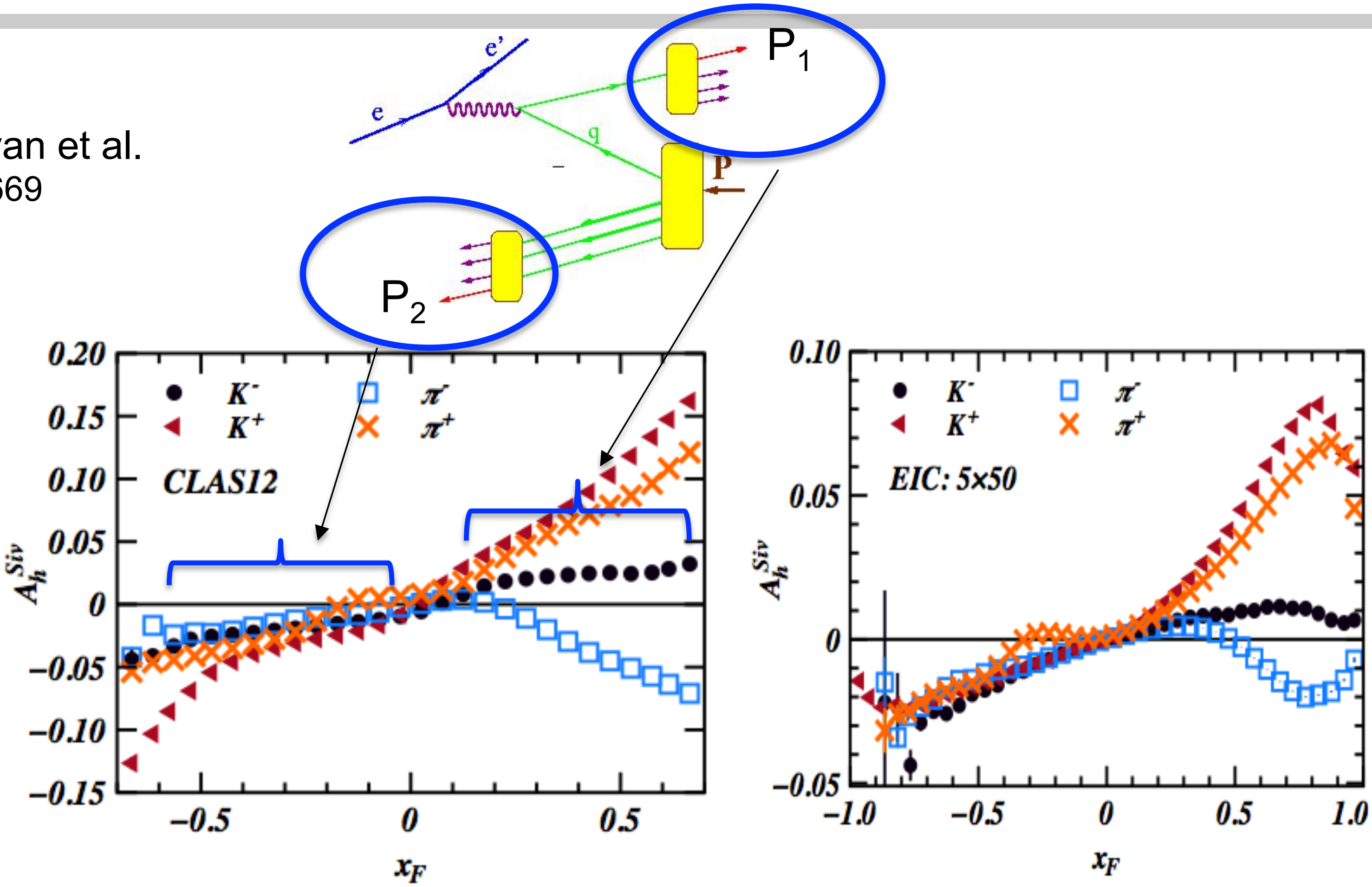
Increase the <k_T> in PYTHIA
(no orbital effects accounted)

- At relatively large x (x>0.01), where non perturbative sea start to dominate significant fraction of Kaons may come from s-quarks
- Additional control possible by detection of target fragments

Target fragmentation: Sivers effect

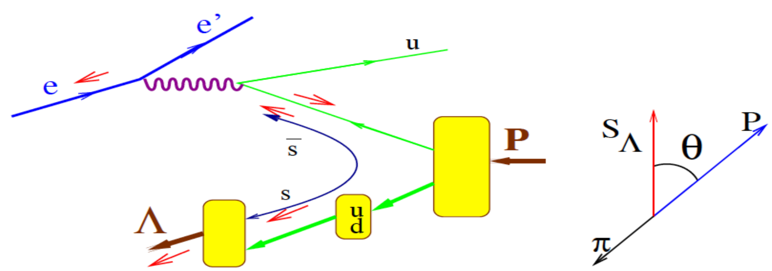
H. Matevosyan et al.
arXiv:1502.02669

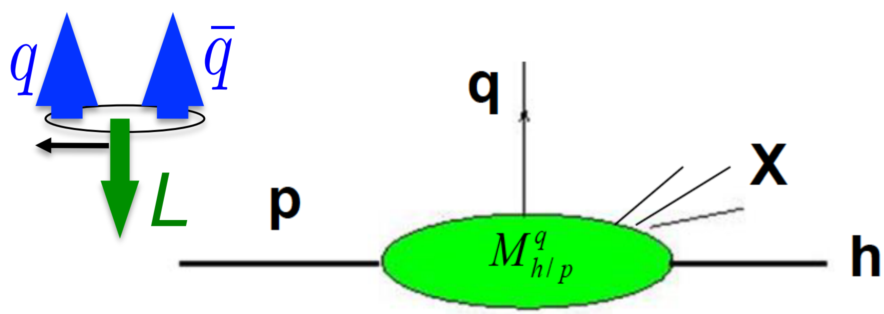




Wide coverage of CLAS12 and EIC will allow studies of kinematic dependences of the Sivers effect, both in current and target fragmentation regions

Target fragmentation region: Λ production





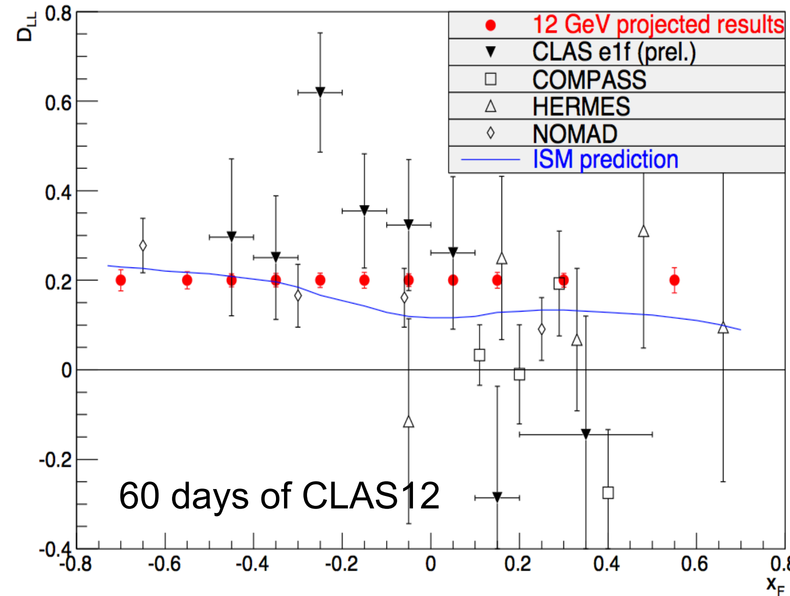
probability to produce the hadron h when a quark q is struck in a proton target

Measurements of fracture functions opens a new avenue in studies of the structure of the nucleon in general and correlations between current and target fragmentation in particular

$$A^{TFR}_{LUL} = hS_{\parallel} \frac{y\left(1-\frac{y}{2}\right)\sum_a e_a^2 \Delta M^L}{\left(1-y+\frac{y^2}{2}\right)\sum_a e_a^2 M}$$

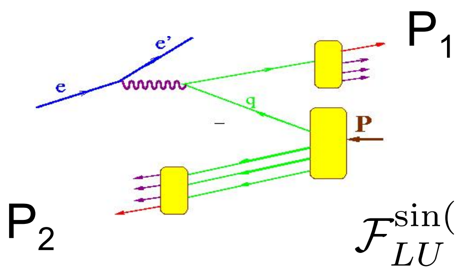
$$D^{LL} = \frac{\sum_a e_a^2 \Delta M^L}{\sum_a e_a^2 M}$$

polarization transfer coefficient



•Large acceptance of CLAS12 and EIC provide a unique possibility to study the nucleon structure in target fragmentation region
•First measurements already performed using the CLAS data at 6 GeV.

Back-to-back hadron (b2b) production in SIDIS

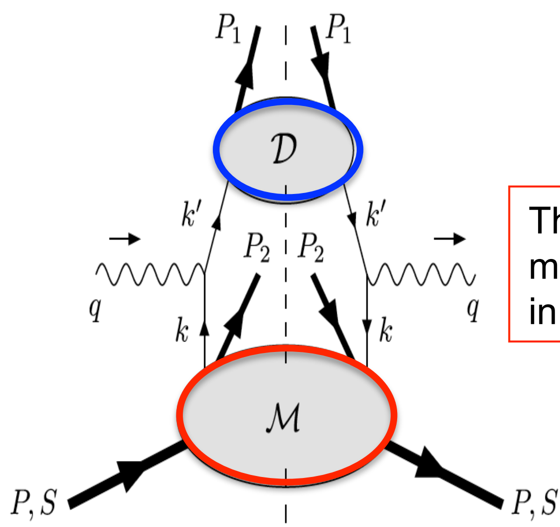


M. Anselmino, V. Barone and A. Kotzinian, Physics Letters B 713 (2012)

$$\mathcal{F}_{LU}^{\sin(\phi_1-\phi_2)} = \frac{|\vec{P}_{1\perp}\vec{P}_{2\perp}|}{m_N m_2}\mathcal{C}[w_5 M_L^{\perp h} D_1]$$

Leading Twist

	U	L	T
U	M	$M_L^{\perp,h}$	$M_T^h, M_T^\perp$
L	$\Delta M^{\perp,h}$	ΔM_L	$\Delta M_T^h, \Delta M_T^\perp$
T	$\Delta_T M_T^h, \Delta_T M_T^\perp$	$\Delta_T M_L^h$ $\Delta_T M_L^\perp$	$\Delta_T M_T, \Delta_T M_T^{hh}$ $\Delta_T M_T^{\perp\perp}, \Delta_T M_T^{\perp h}$



The beam–spin asymmetry appears, at leading twist and low transverse momenta, in the deep inelastic inclusive lepto-production of two hadrons, one in the target fragmentation region and one in the current fragmentation region.

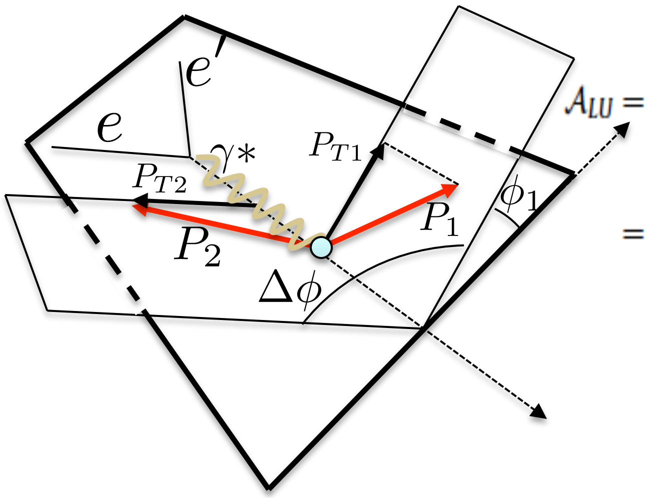
$$A_{LU} = -\frac{y\left(1-\frac{y}{2}\right)}{\left(1-y+\frac{y^2}{2}\right)}\frac{\mathcal{F}_{LU}^{\sin\Delta\phi}}{\mathcal{F}_{UU}}\sin\Delta\phi$$

Back-to-back hadron production in SIDIS would allow:
- study SSAs not accessible in SIDIS at leading twist
- measure fracture functions
- control the flavor content of the final state hadron in current fragmentation (detecting the target hadron)
- study entanglement in correlations in target vs current
- access quark short-range correlations and χSB (Schweitzer et al)
- ...

B2B hadron production in SIDIS: First measurements

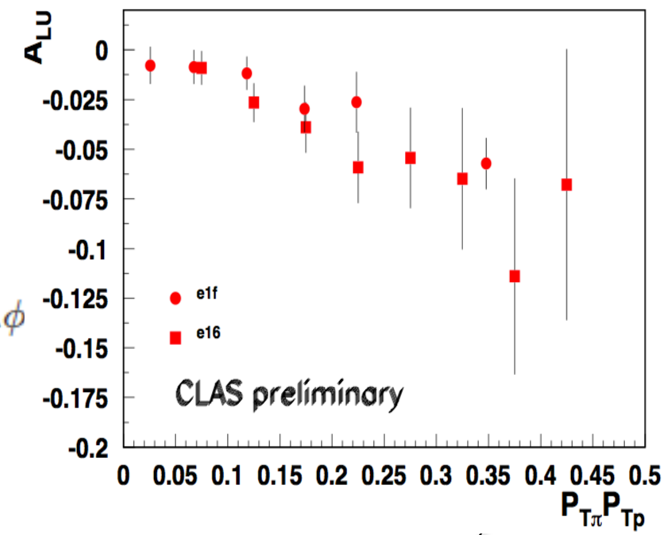
M. Anselmino, V. Barone and A. Kotzinian, Physics Letters B 713 (2012)

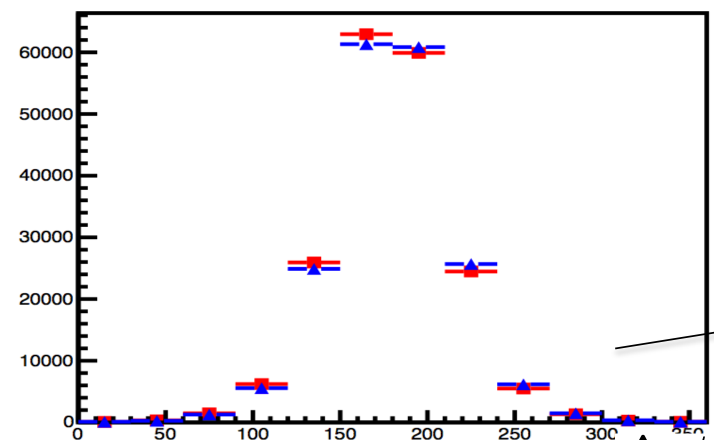
$$ep \rightarrow e' p \pi^+ X$$

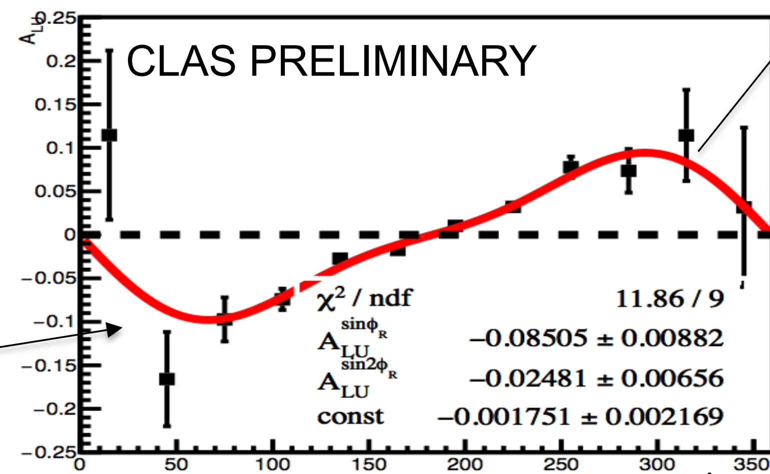


$$A_{LU} = -\frac{y(1-\frac{y}{2})}{(1-y+\frac{y^2}{2})} \frac{\mathcal{F}_{LU}^{\sin\Delta\phi}}{\mathcal{F}_{UU}} \sin\Delta\phi$$

$$= -\frac{|\boldsymbol{P}_{1\perp}||\boldsymbol{P}_{2\perp}|}{m_N m_2} \frac{y(1-\frac{y}{2})}{(1-y+\frac{y^2}{2})} \frac{\mathcal{C}[w_5 M_L^{\perp,h} D_1]}{\mathcal{C}[MD_1]} \sin\Delta\phi$$



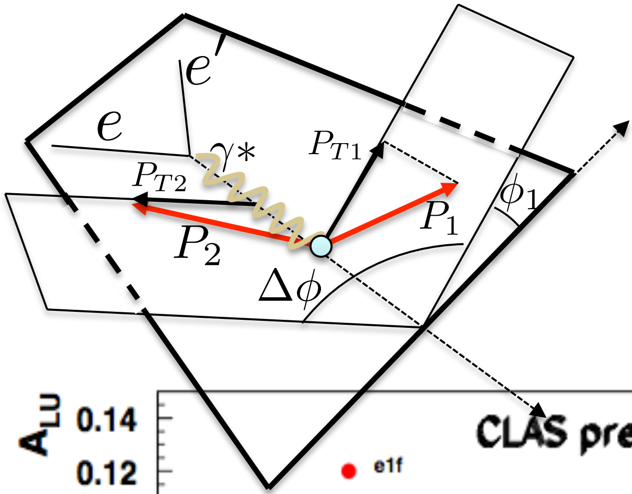


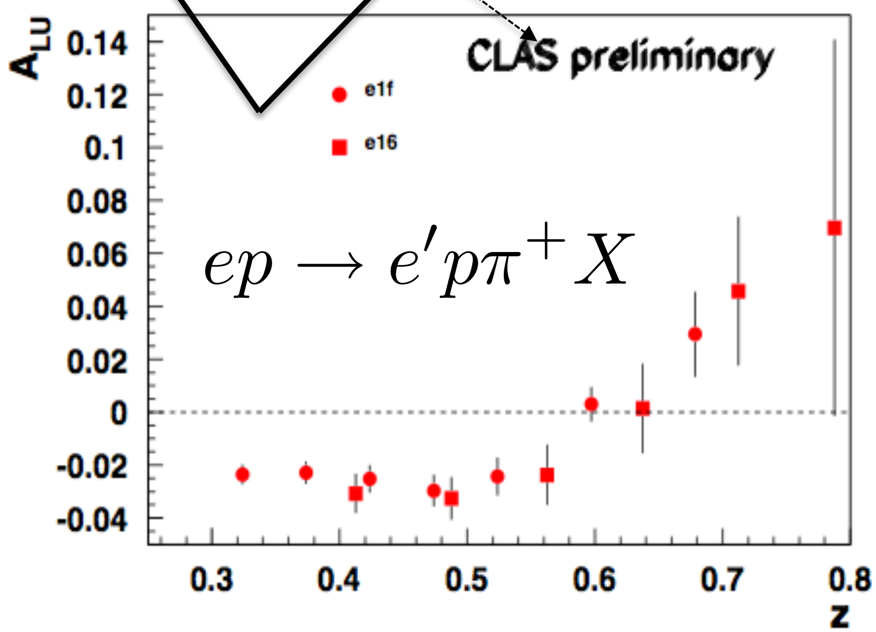


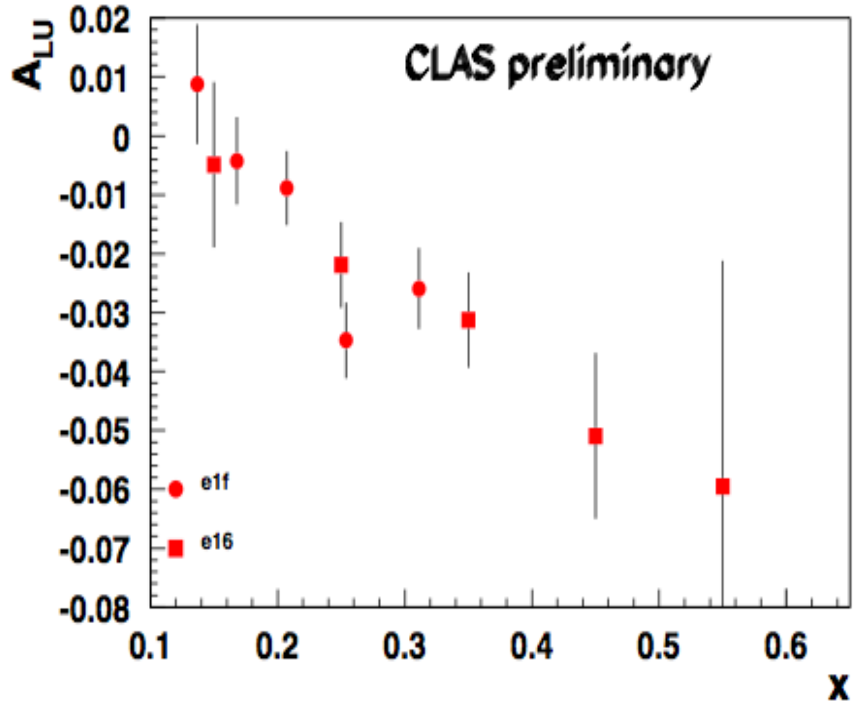
$\Delta\phi$ $\Delta\phi$

Significant asymmetries observed by CLAS at 6 GeV

A_{LU} comparing CLAS data sets e16 and e1f





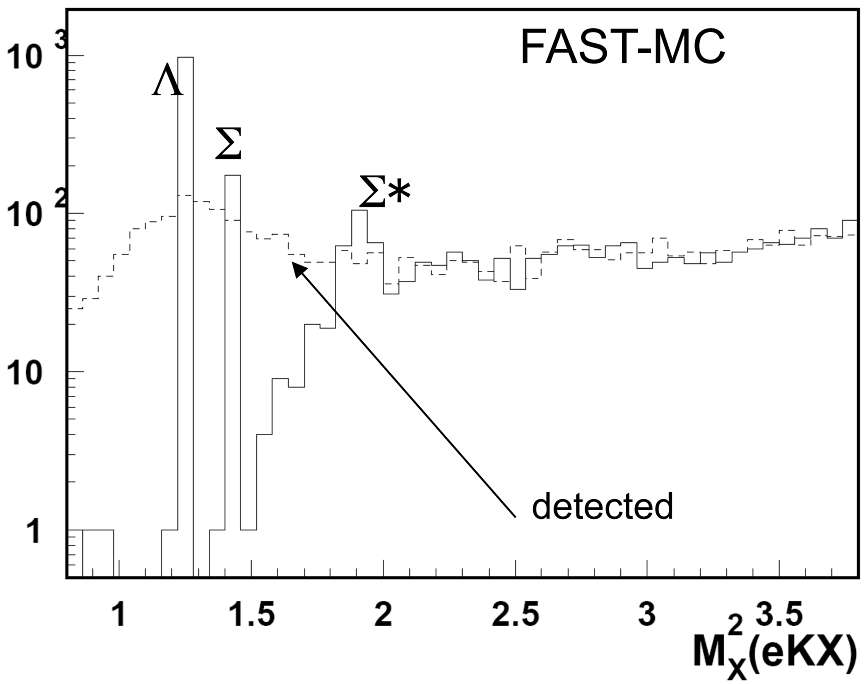


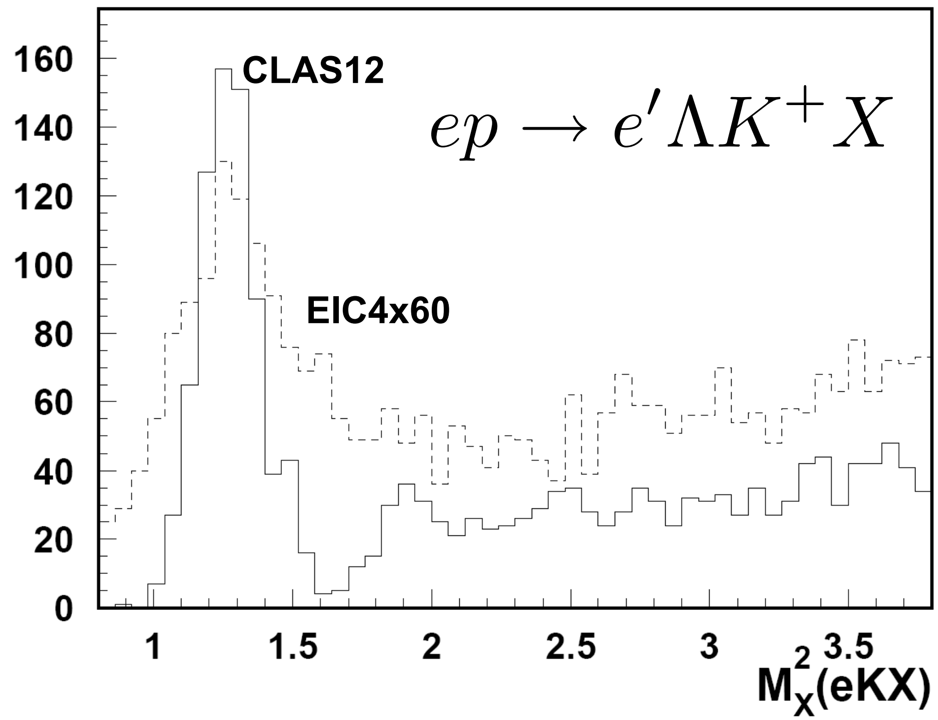
e1f: weaker field, lower Q^2 and x

e16: higher field, higher average Q^2

- Asymmetries may change the sign in the exclusive limit
- Asymmetries are large in the large x-region

Kaon production in SIDIS

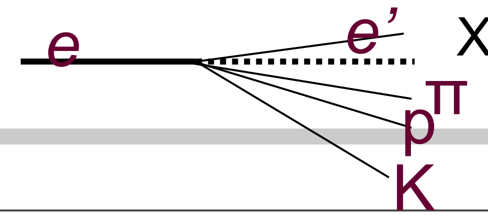


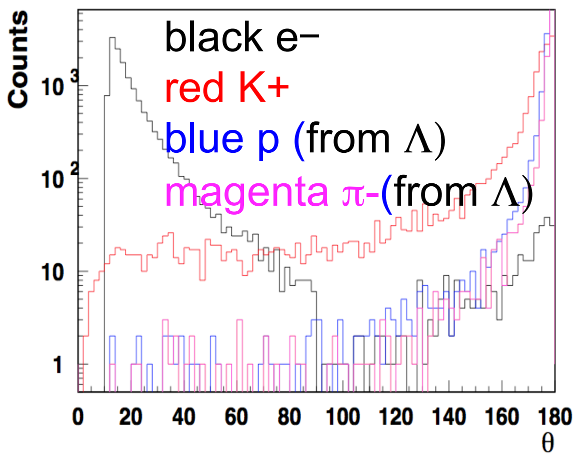


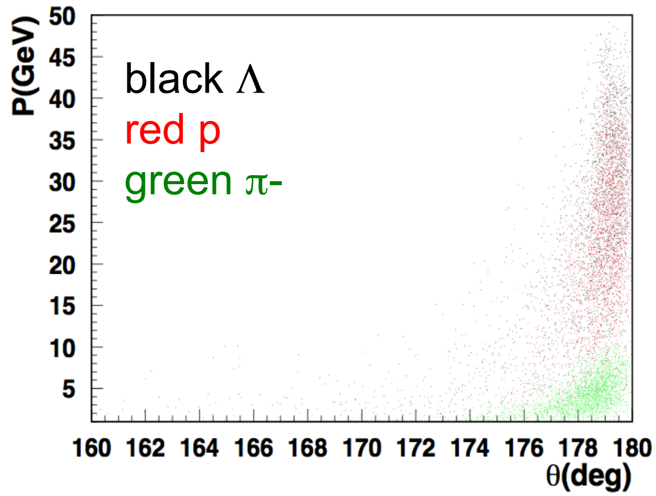
σ(p) = 0.05 + 0.06*p [GeV] %

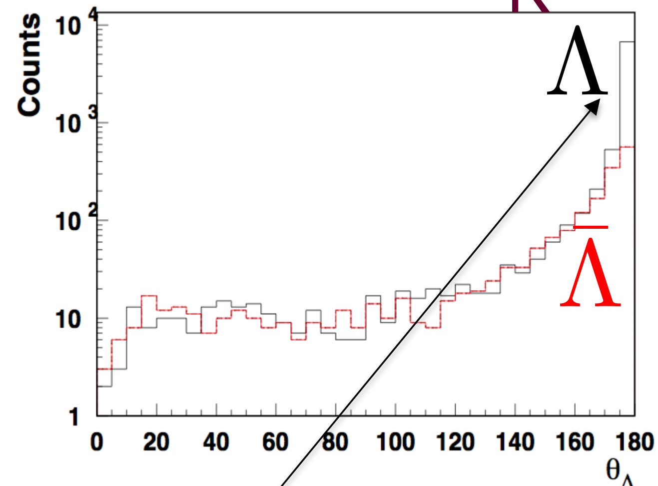
Identification using the missing mass may be possible

Lambda production in EIC (5x50 GeV)

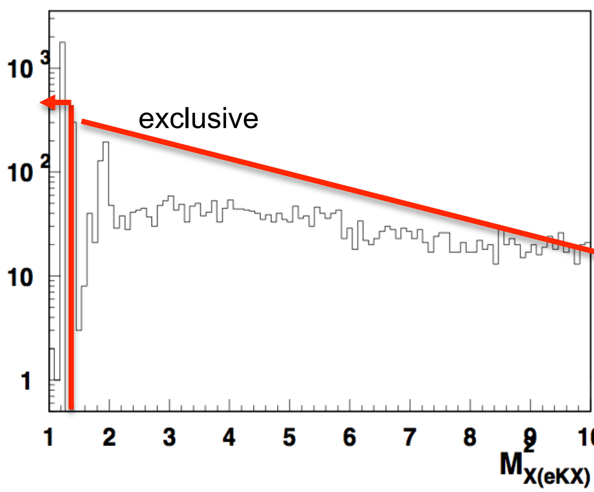


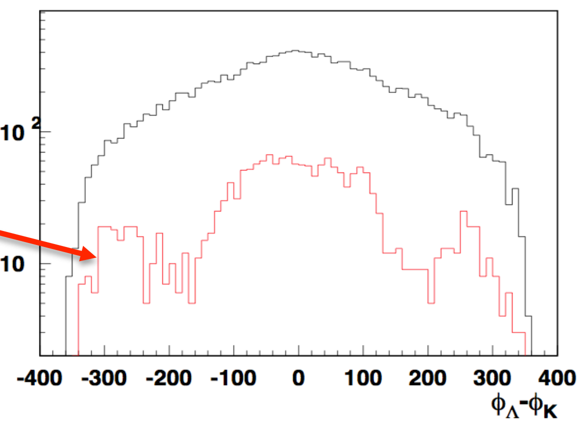


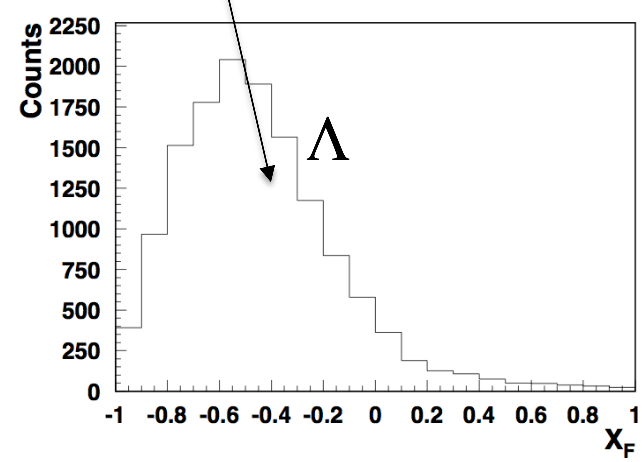




most of the Λs in the target fragment

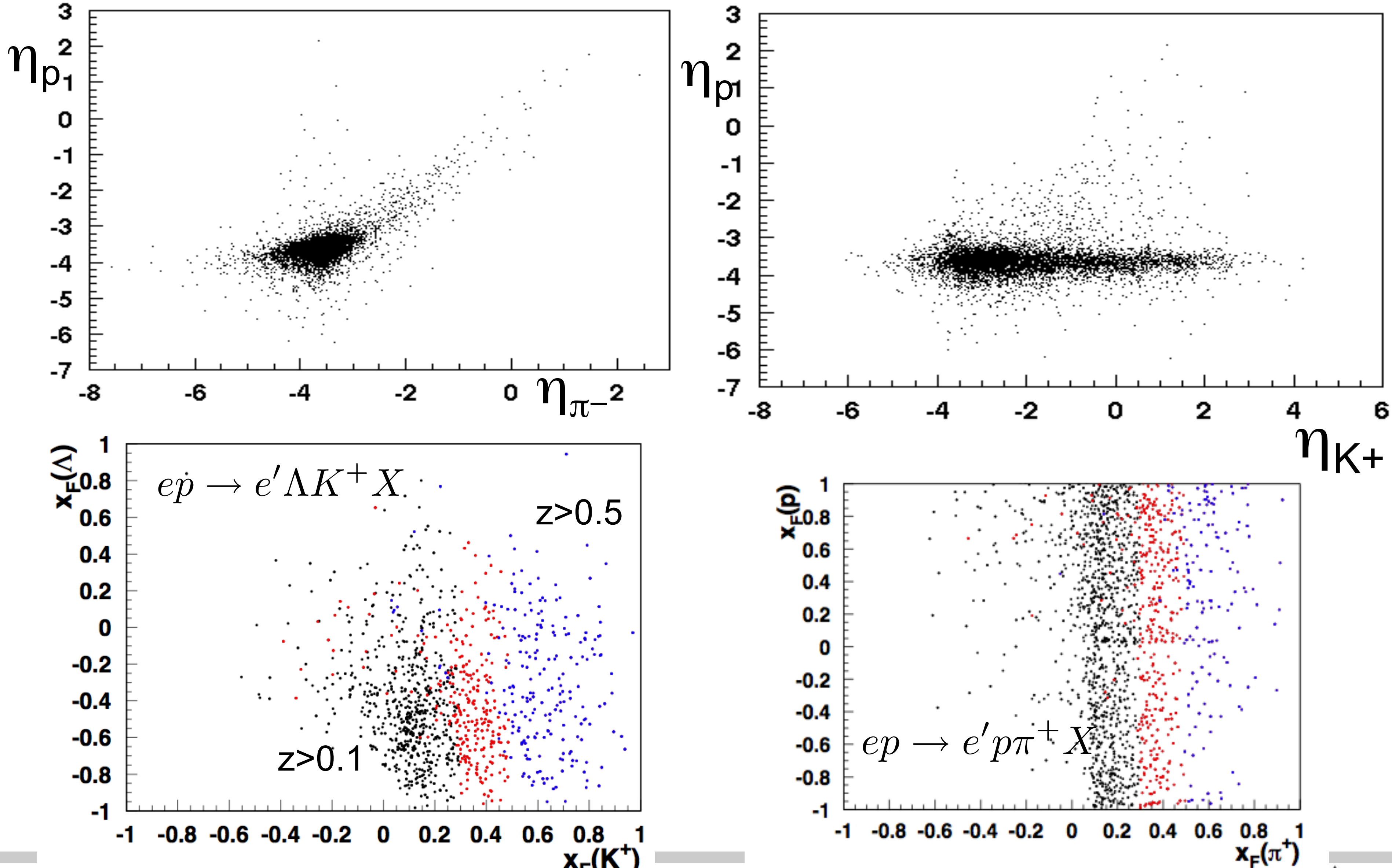






At forward angles Lambdas are mainly from target fragments

EIC 5x50 GeV: Kinematic distributions of Lambdas and Kaons



Summary

• Flavor and spin content changes with transverse momentum and z, opening new possibilities for multi-dimensional analysis

•Studies of the nucleon structure beyond the traditional current fragmentation, provides qualitatively new tool to study the nucleon structure.

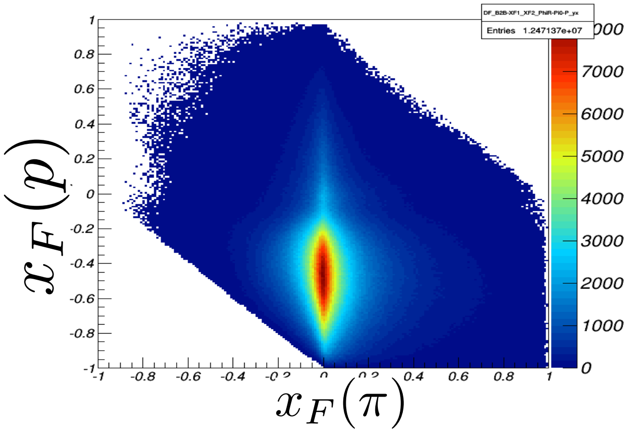
•SSA in b2b SIDIS have been studied at JLab for proton pion and Lambda kaon final states and very significant effects reported for the first time.

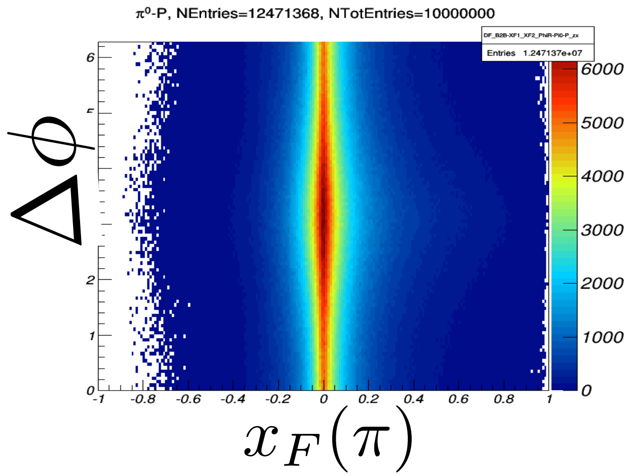
•Large acceptance of the EIC combined with clear separation of target and current fragmentation regions provide a unique possibility to study the nucleon structure in target fragmentation region and correlations of target and current fragmentation regions

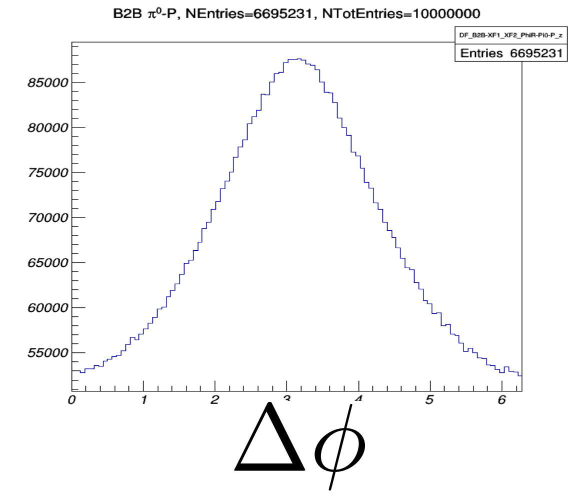
Support slides

b2b distributions: EIC 5x50 (proton-pion)

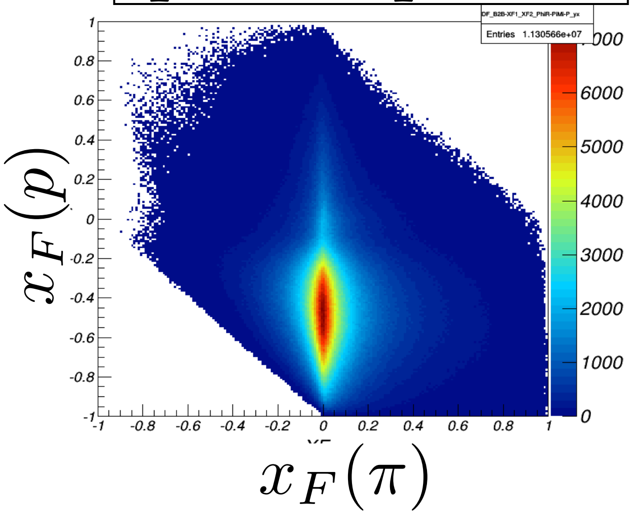
$\boxed{ep \rightarrow e' p \pi^0 X}$

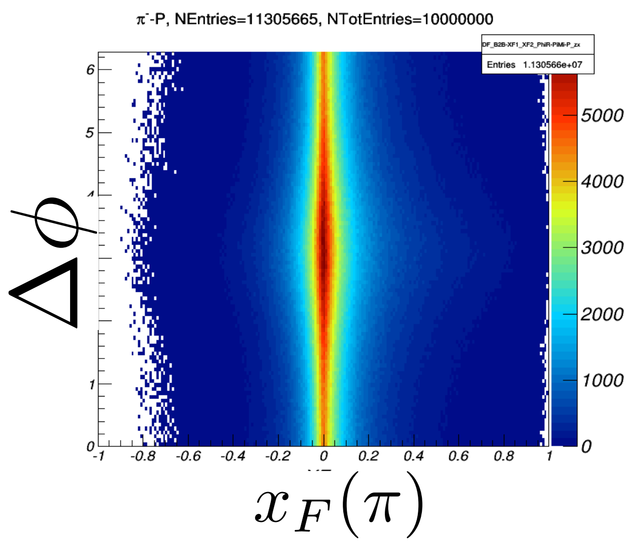


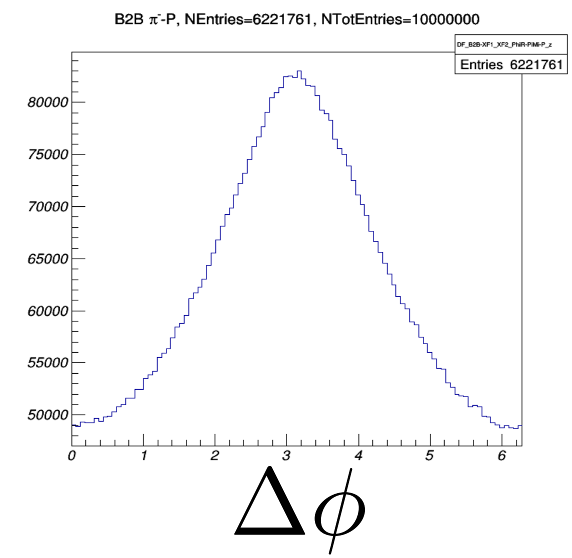


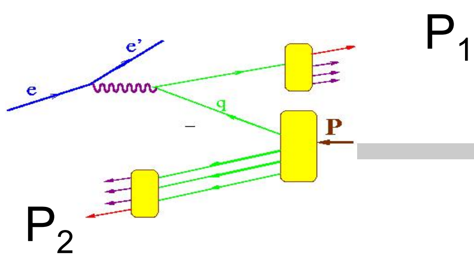


$\boxed{ep \rightarrow e' p \pi^+ X}$



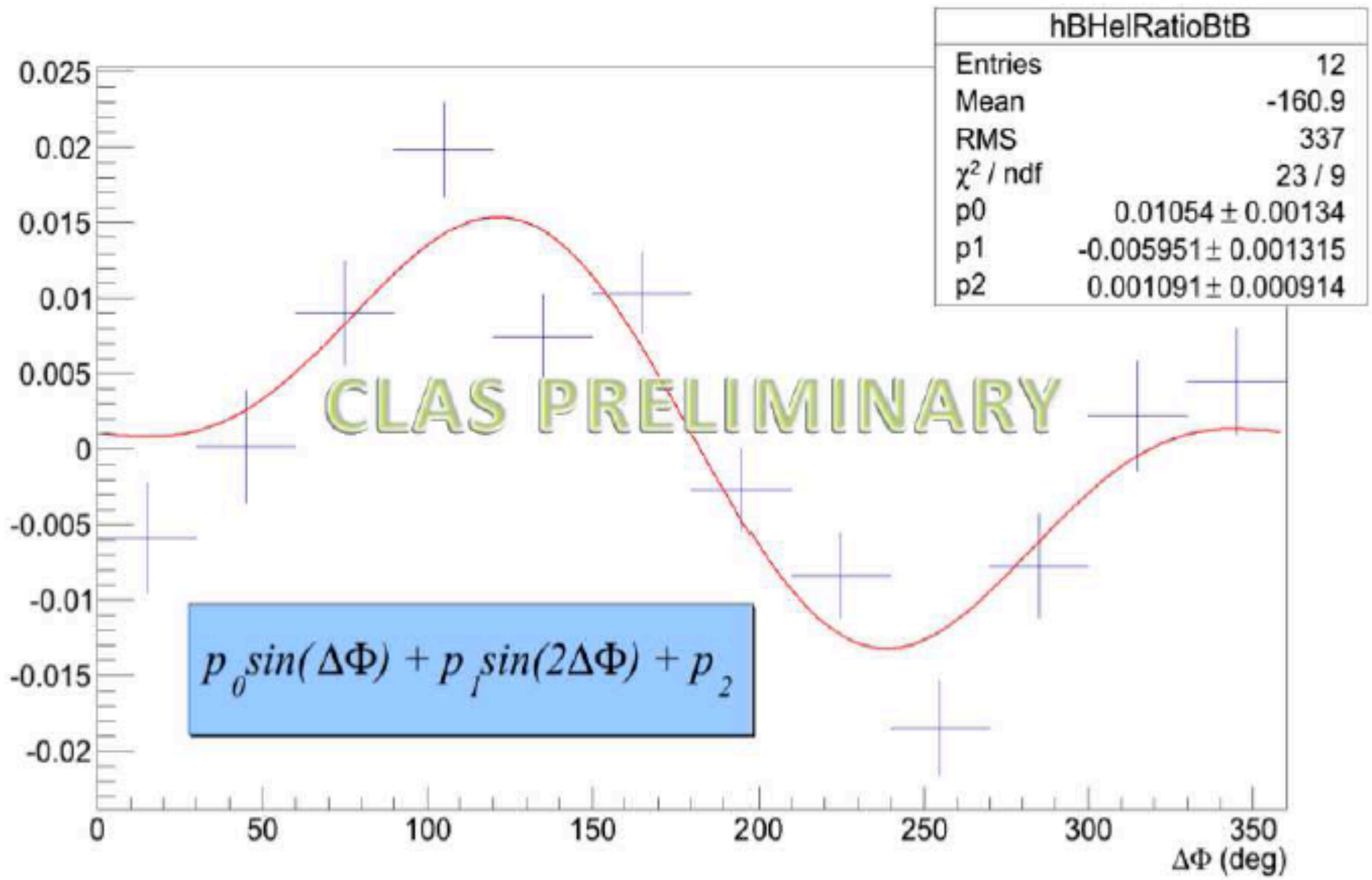






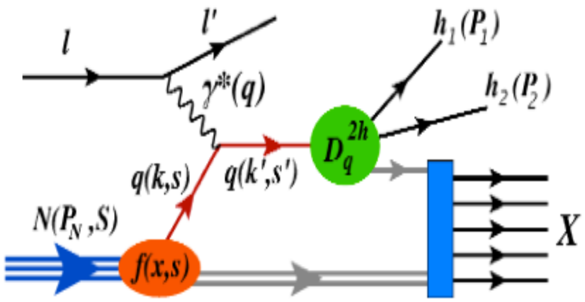
old studies

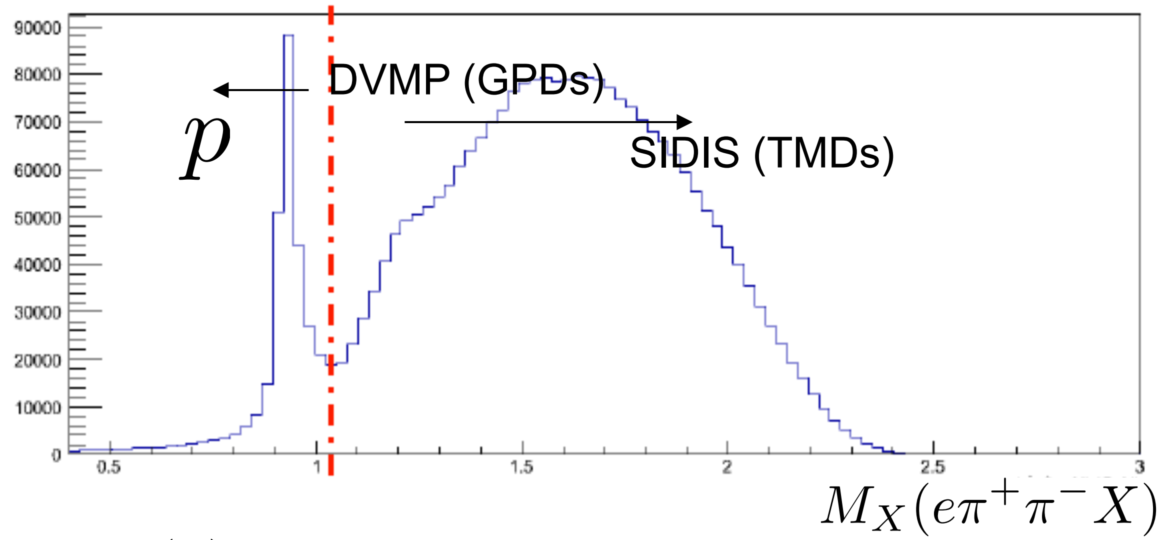
$$ep \to e'\pi^+\pi^- X$$



significantly higher dilutions reduces the effect

Dihadron asymmetries from CLAS

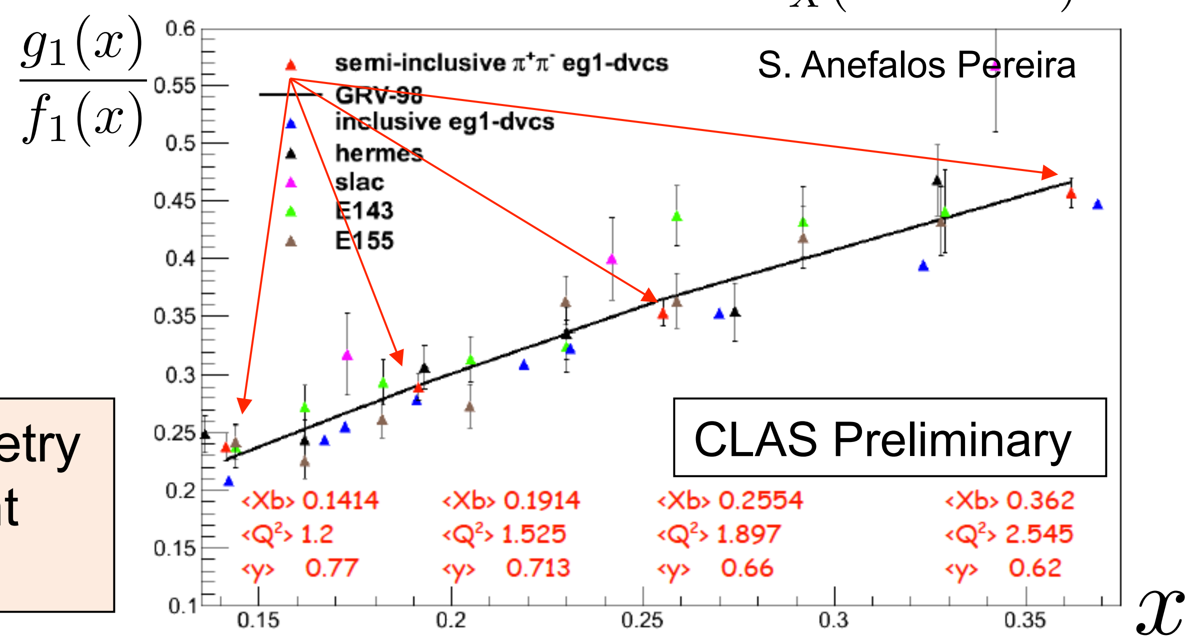




$$\frac{F_{LL}}{F_{UU}} \sim \frac{g_1(x)}{f_1(x)}$$

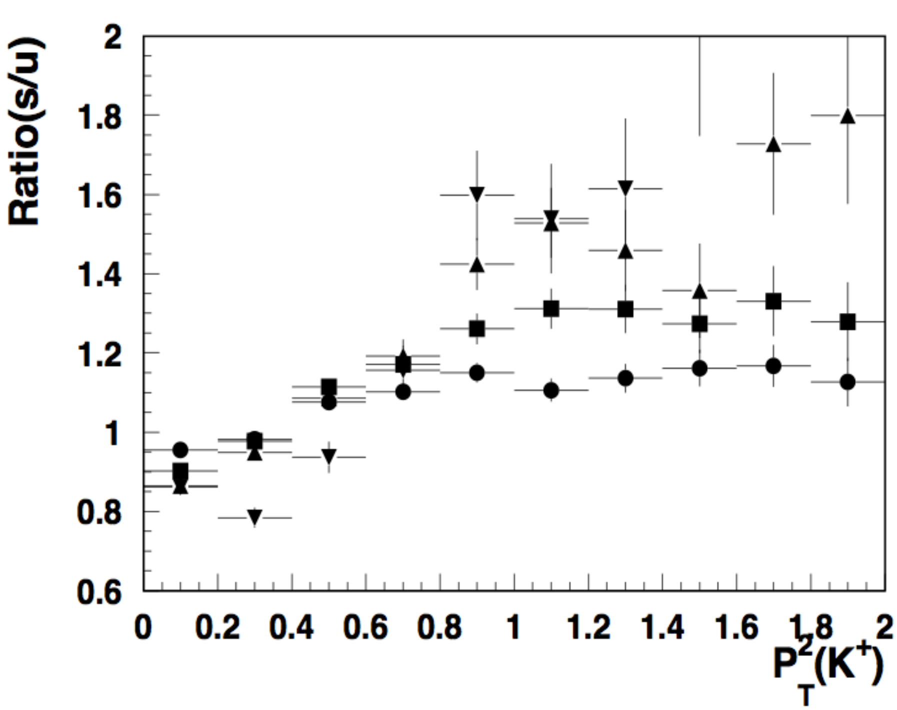
$$F_{UU,T} = x f_1^q(x)\, D_1^q\big(z, \cos\theta, M_h\big)$$
$$F_{LL} = x g_1^q(x)\, D_1^q\big(z, \cos\theta, M_h\big)$$

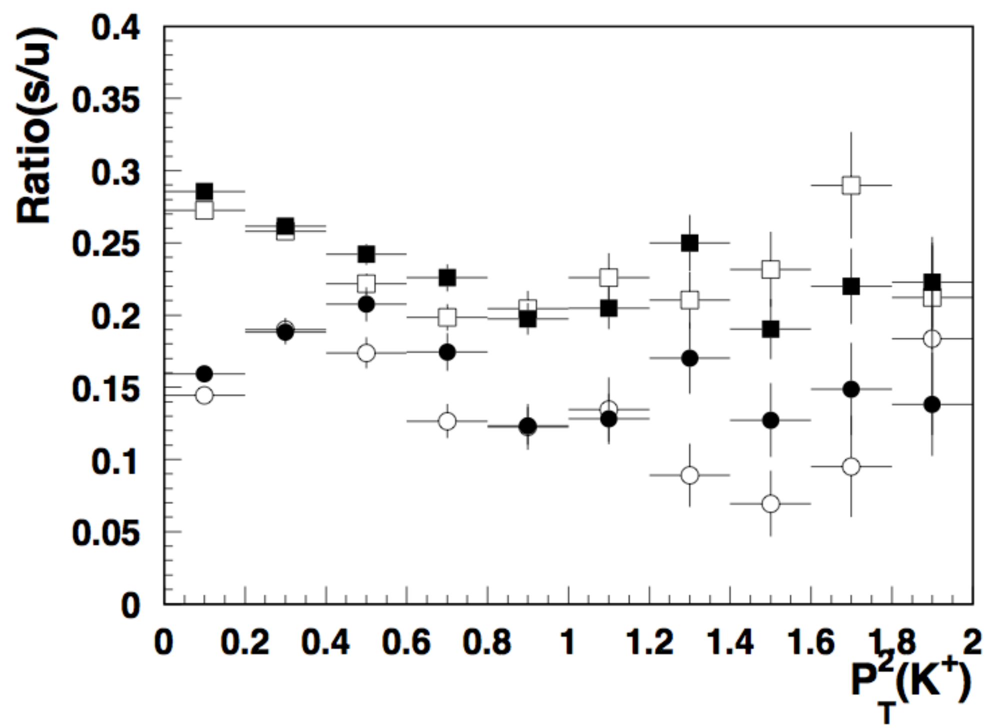
$$D_1^{u\to\pi+\pi-} \approx D_1^{d\to\pi+\pi-}$$



Dihadron double spin asymmetry measured at 6 GeV consistent with DIS

PT-distributions of Kaons from s and u quarks

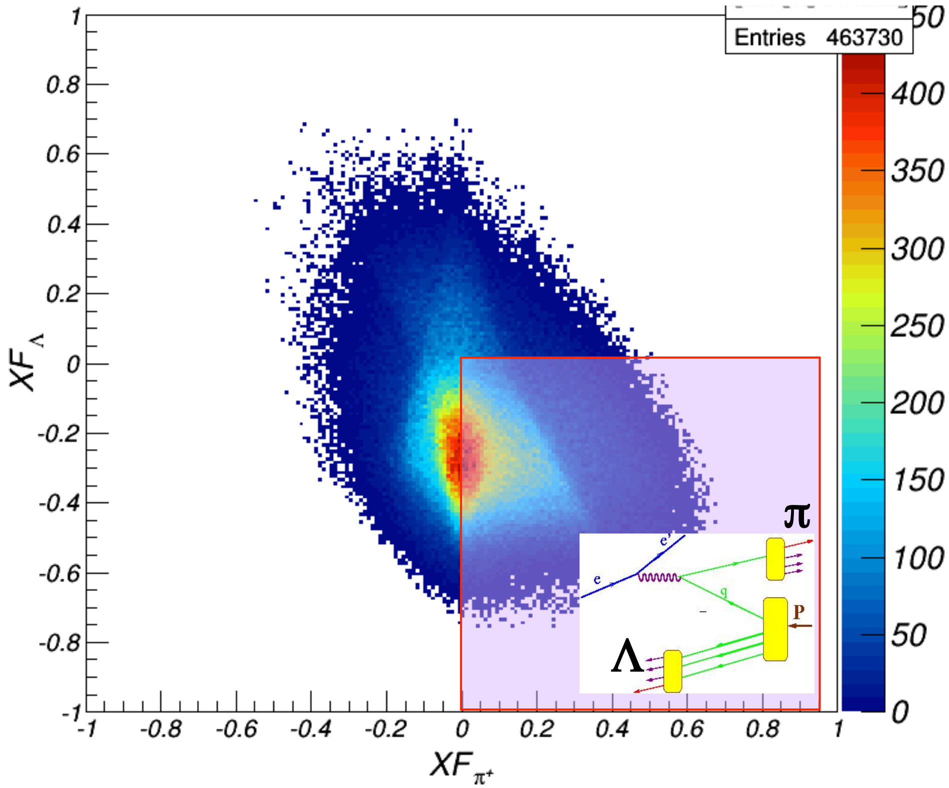


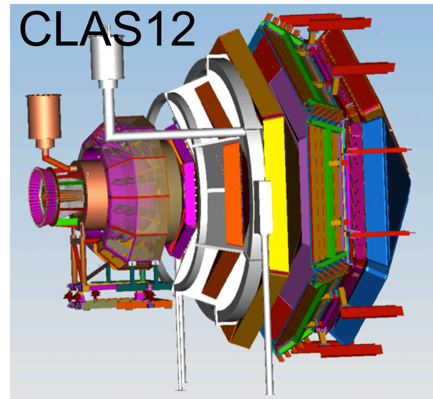


Dihadron production at JLAB12

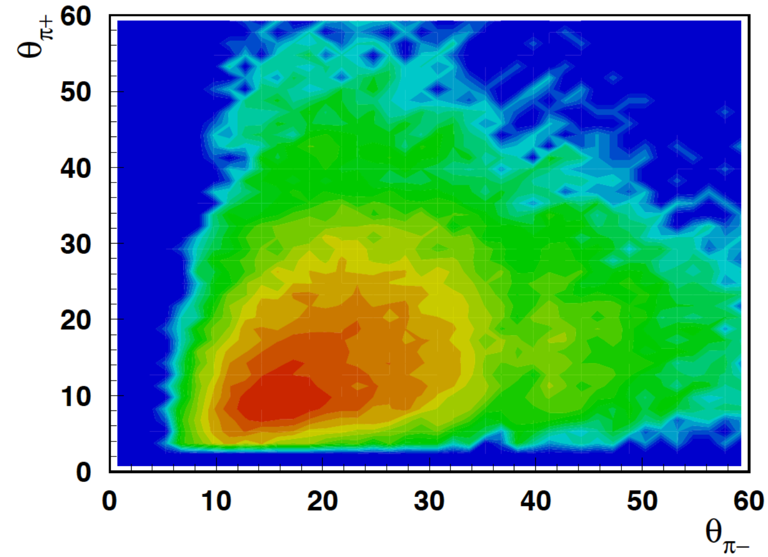
Use the clasDIS (LUND based) generator + FASTMC to study hh pairs

x_F - momentum in the CM frame





SoLID

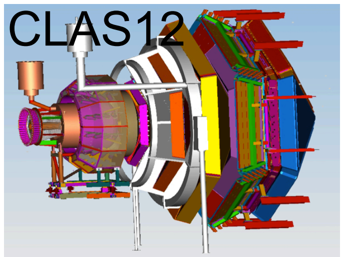


Dihadron sample defined by SIDIS cuts + $x_F>0$ (CFR) and $x_F<0$ (TFR) for both hadrons

Wide angular coverage is important

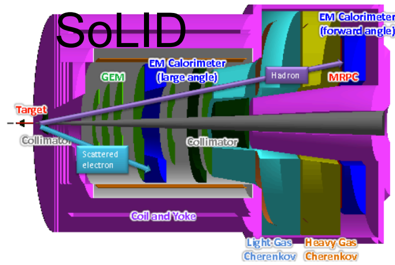
Accessing transversity in dihadron production at JLab

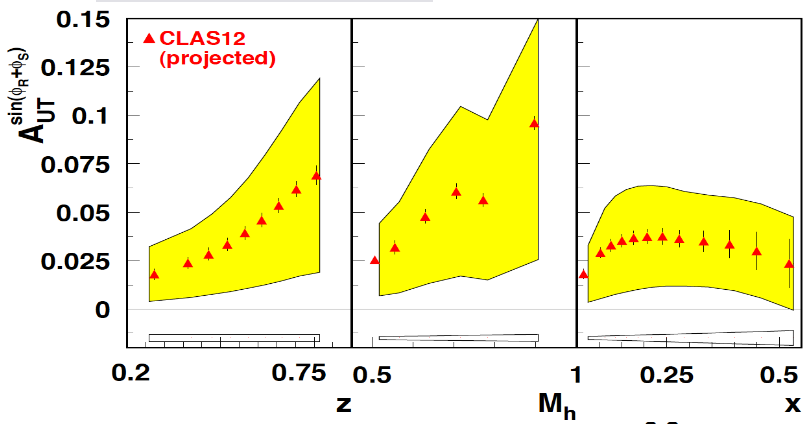
Measurements with polarized protons

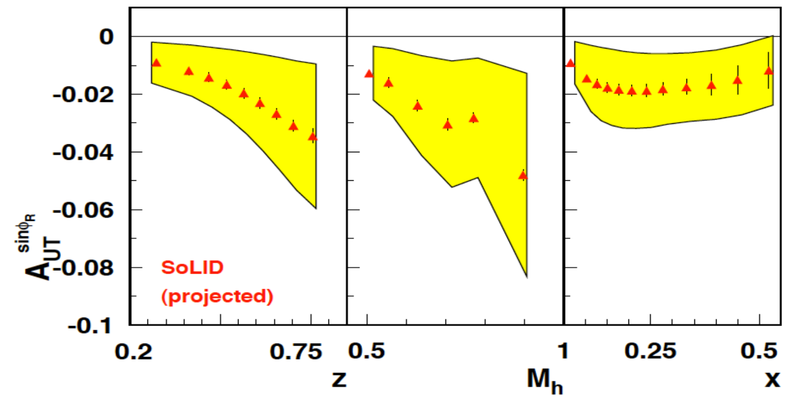


$$A_{UT}(\phi_R,\theta) = \frac{1}{fP_t}\frac{(N^+ - N^-)}{(N^+ + N^-)}$$

Measurements with polarized neutrons

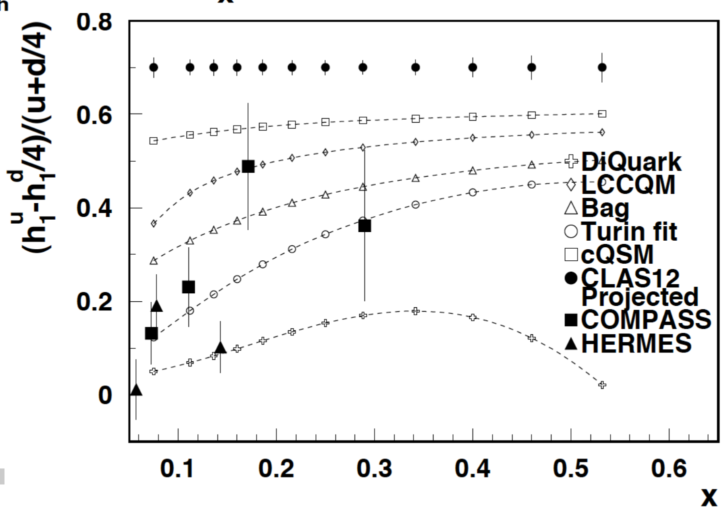






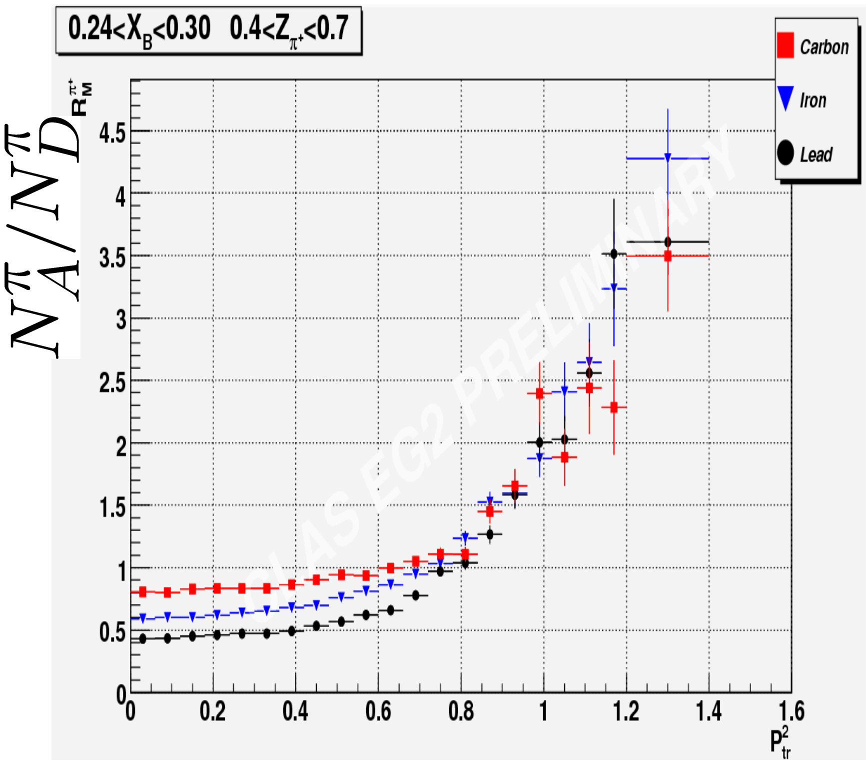
Bacchetta, Radici

$$\frac{H_{1,sp}^{\sphericalangle,u}(z,M_h)[4h_1^u - h_1^d(x)]}{D_1^u(4f_1^u + f_1^d)}$$



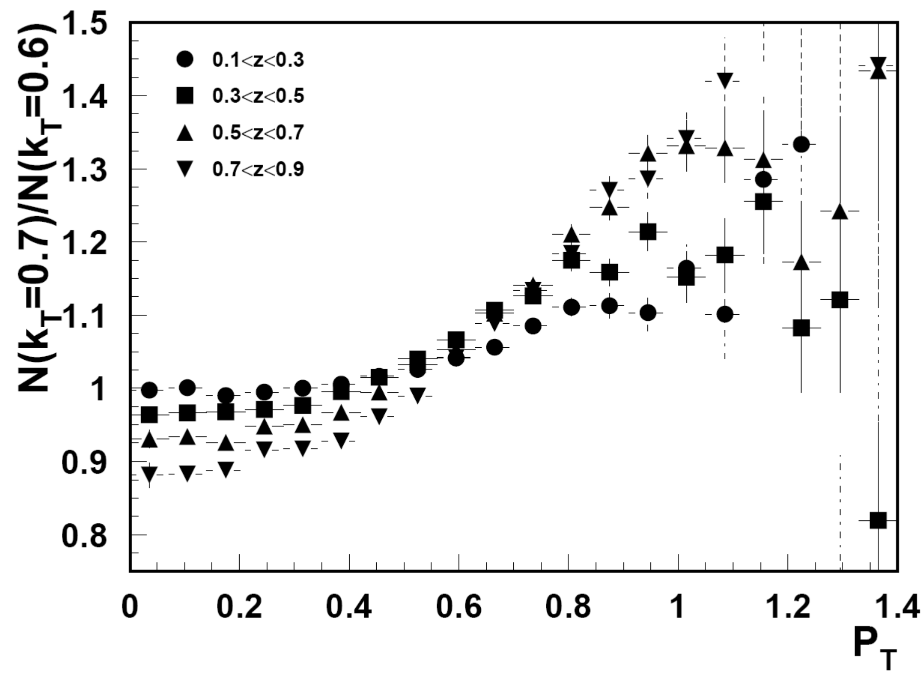
$$\frac{H_{1,sp}^{\sphericalangle,u}(z,M_{\pi\pi})\ \left(4h_1^d(x) - h_1^u(x)\right)}{D_1^u(z,M_{\pi\pi})\ \left(4f_1^d(x) + f_1^u(x)\right)}$$

Quark distributions at large k_T



bigger effect at large z

$P_T = p_\perp + z\,k_T$

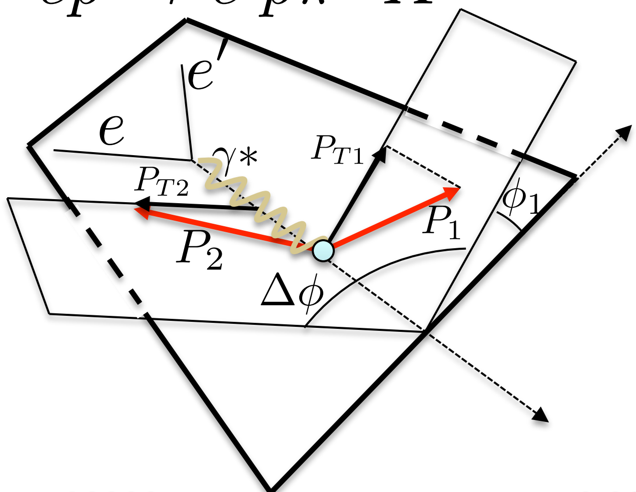


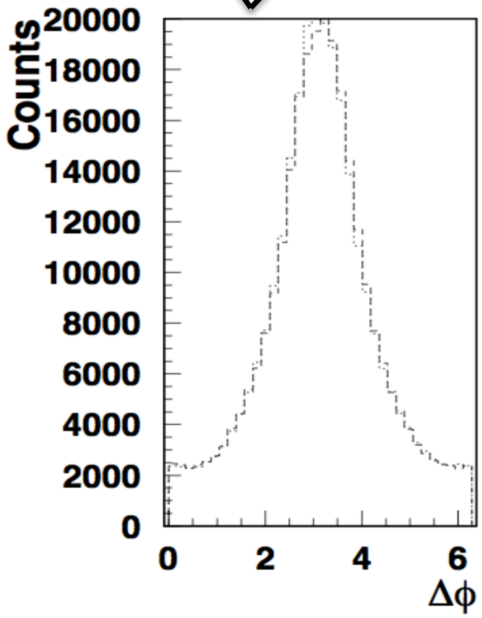
Higher probability to find a hadron at large P_T in nuclei

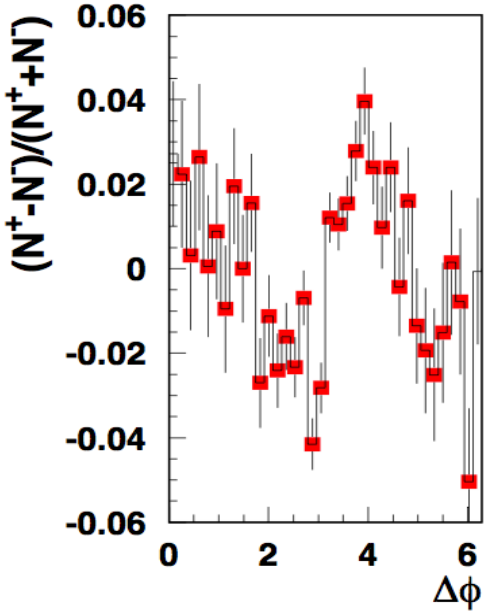
k_T-distributions may be wider in nuclei?

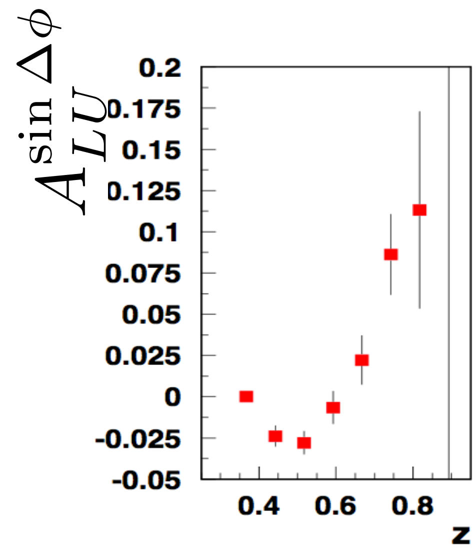
b2b SSAs

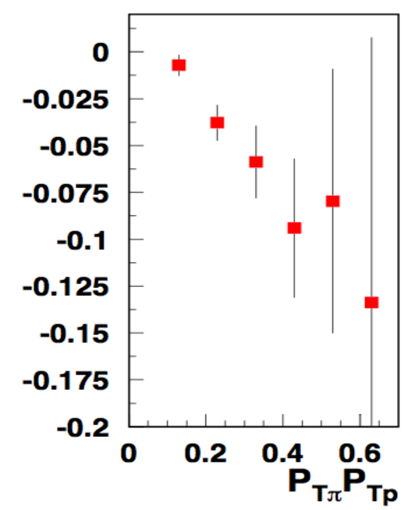
$ep \rightarrow e'p\pi^+X$

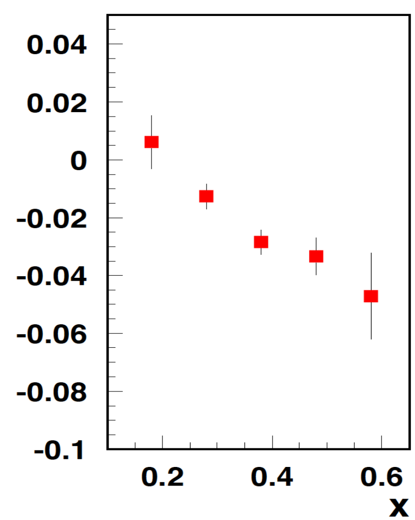


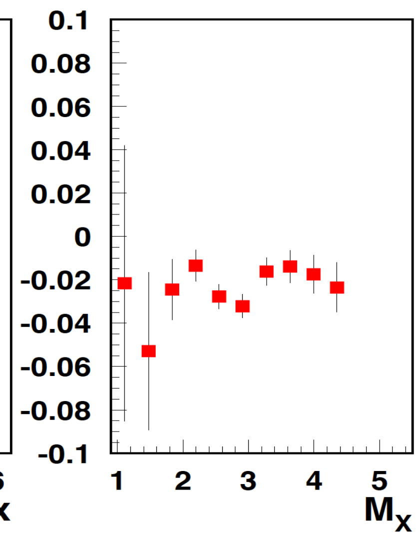








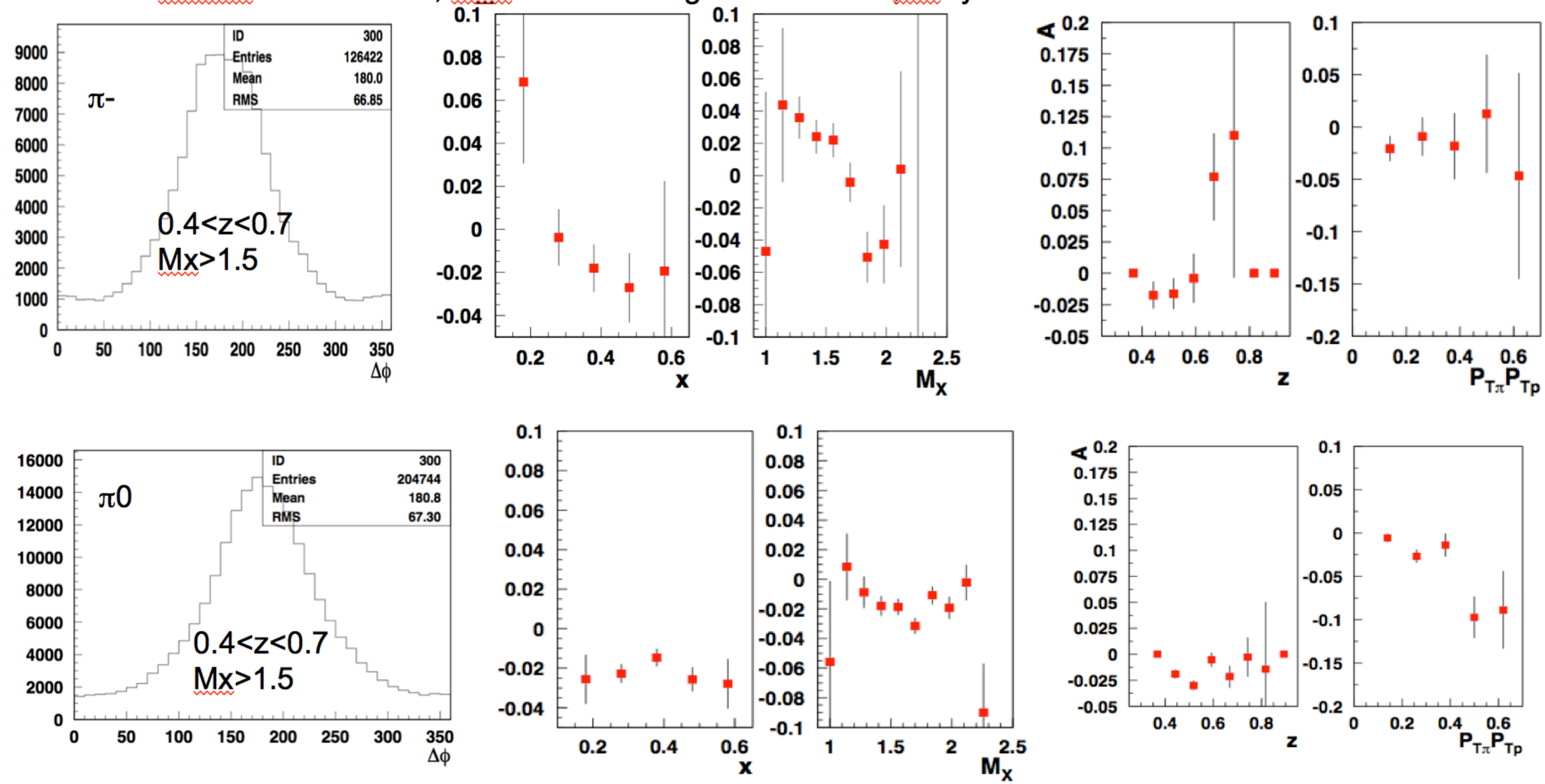




b2b SSAs

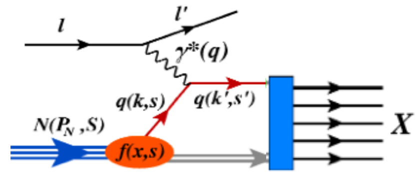
b2b SSA (ALU) for ep->e'pπX for e16 data set

with fiducial electron cuts, M_x is the missing mas of the e'\piX system.



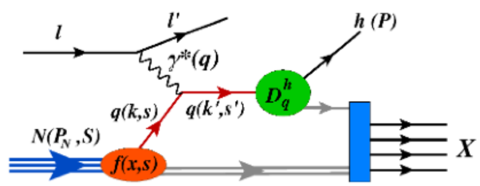
QCD: from testing to understanding

0h DIS



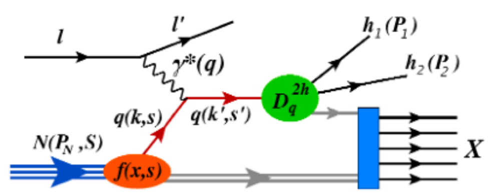
Testing stage:
pQCD predictions, observables in the kinematics where theory predictions are easier to get (higher energies, 1D picture, leading twist, current fragmentation, IMF)

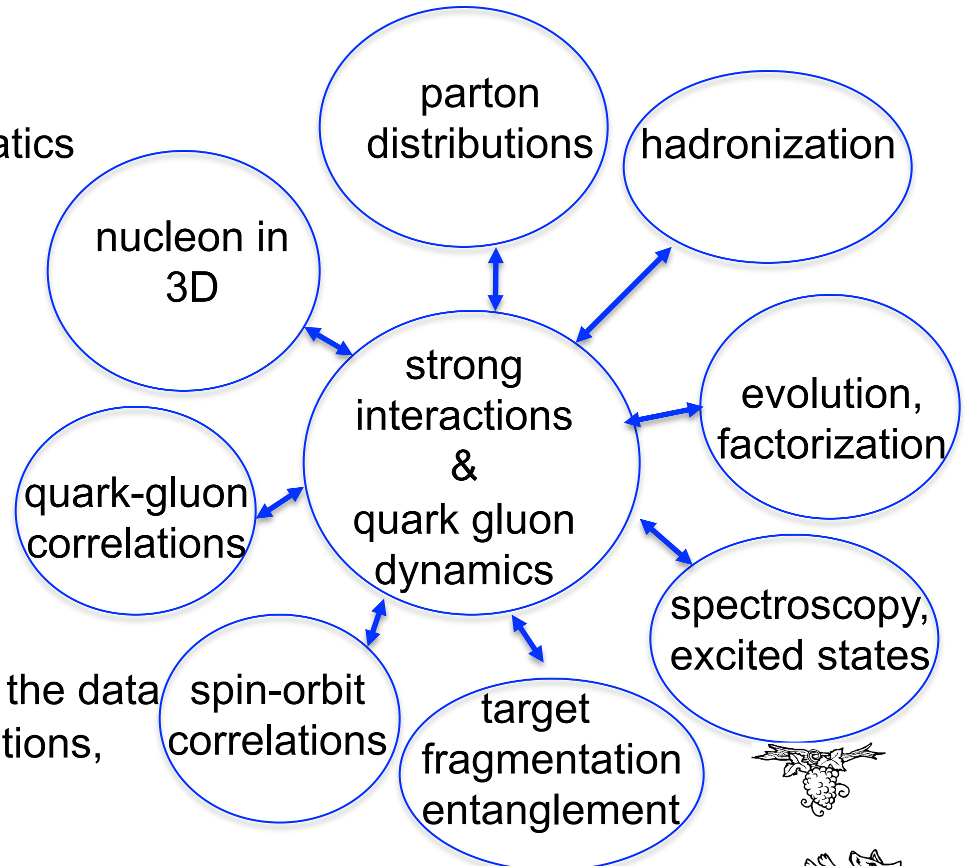
1h SIDIS/DVMP

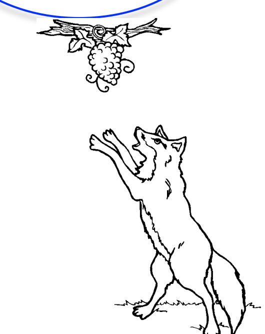


Understanding stage:
non-perturbative QCD, strong interactions, observables in the kinematics where most of the data is available (all energies, quark-gluon correlations, orbital motion)

2h SIDIS/DVMP

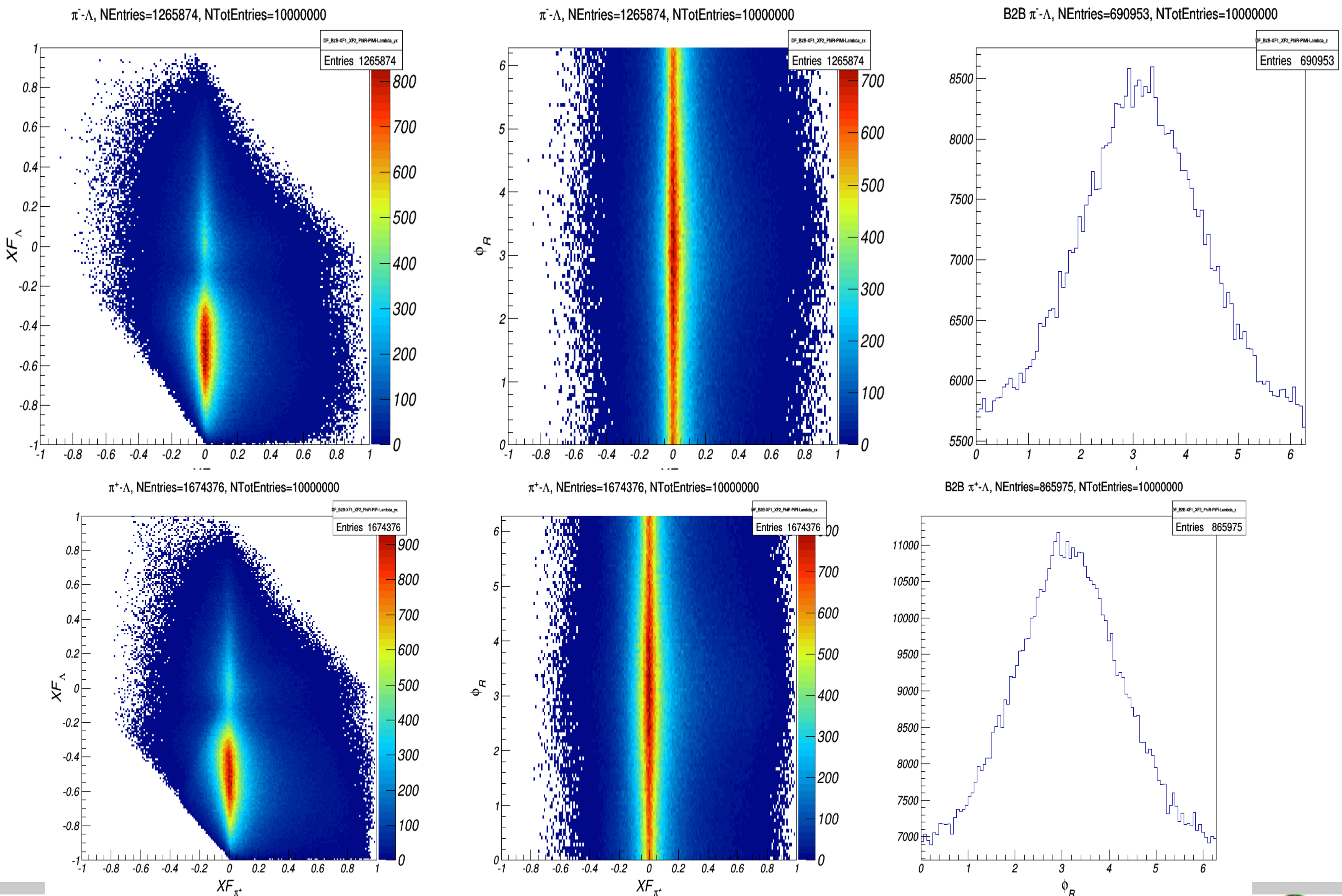




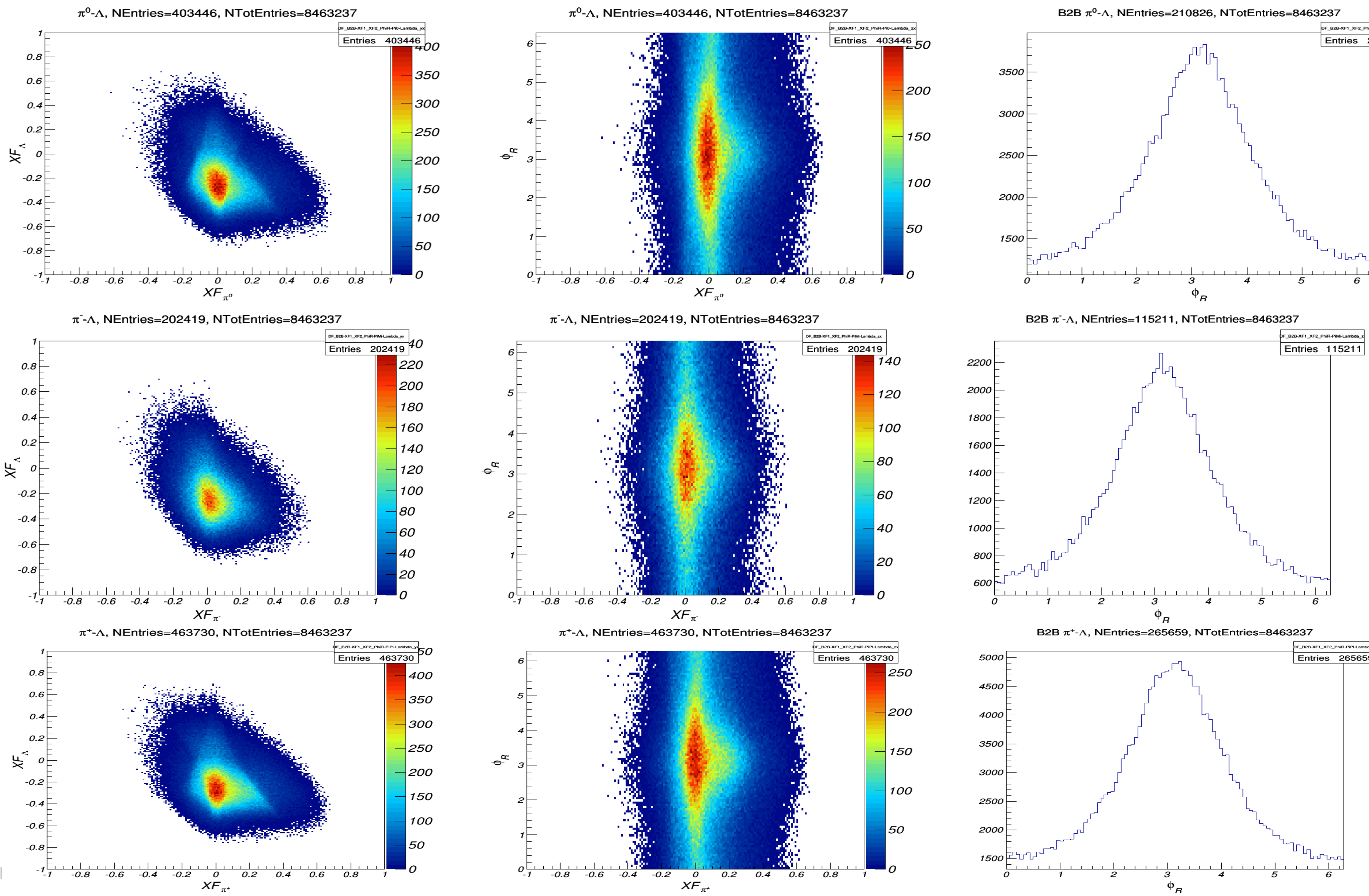


production in SIDIS provides access to correlations inaccessible in simple SIDIS (BEC,dihadron fragmentation , correlations of target and current regions, entanglement....)

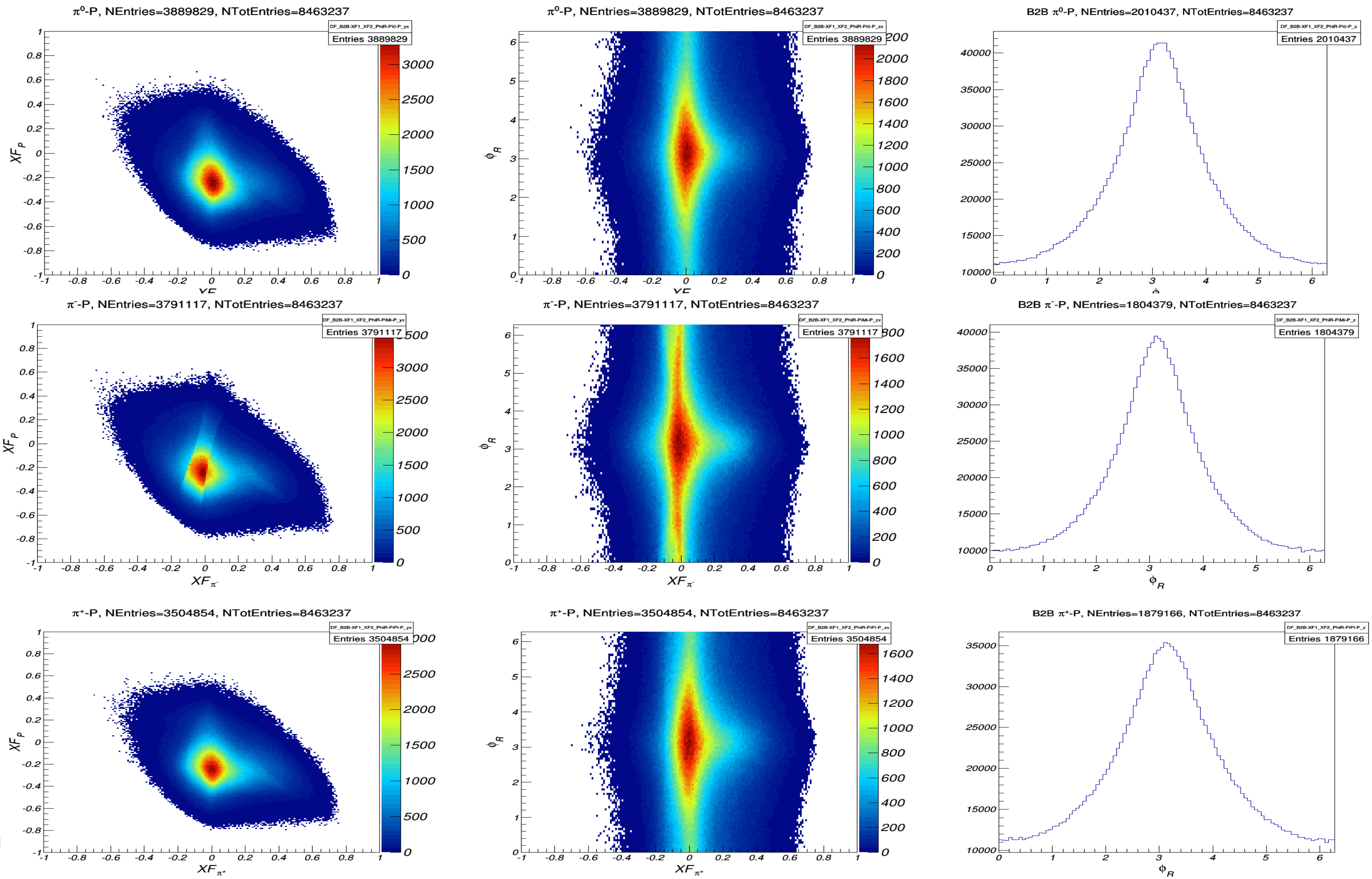
b2b distributions: EIC 5x50 (Lambda-pi)



b2b distributions: CLAS12(Lambda-pion)



b2b distributions: CLAS12 (proton-pion)



CLAS6 kinematics