Recent HERMES results from inclusive and semi-inclusive hadron production with a transversely polarised target

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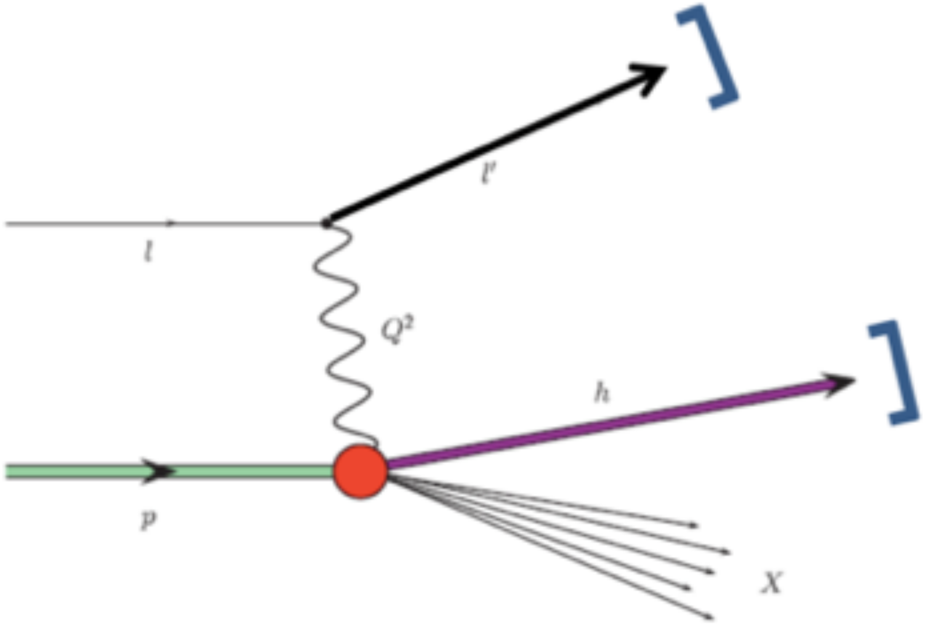
Transversity 2014, Chia, Sardinia
09-13 June, 2014

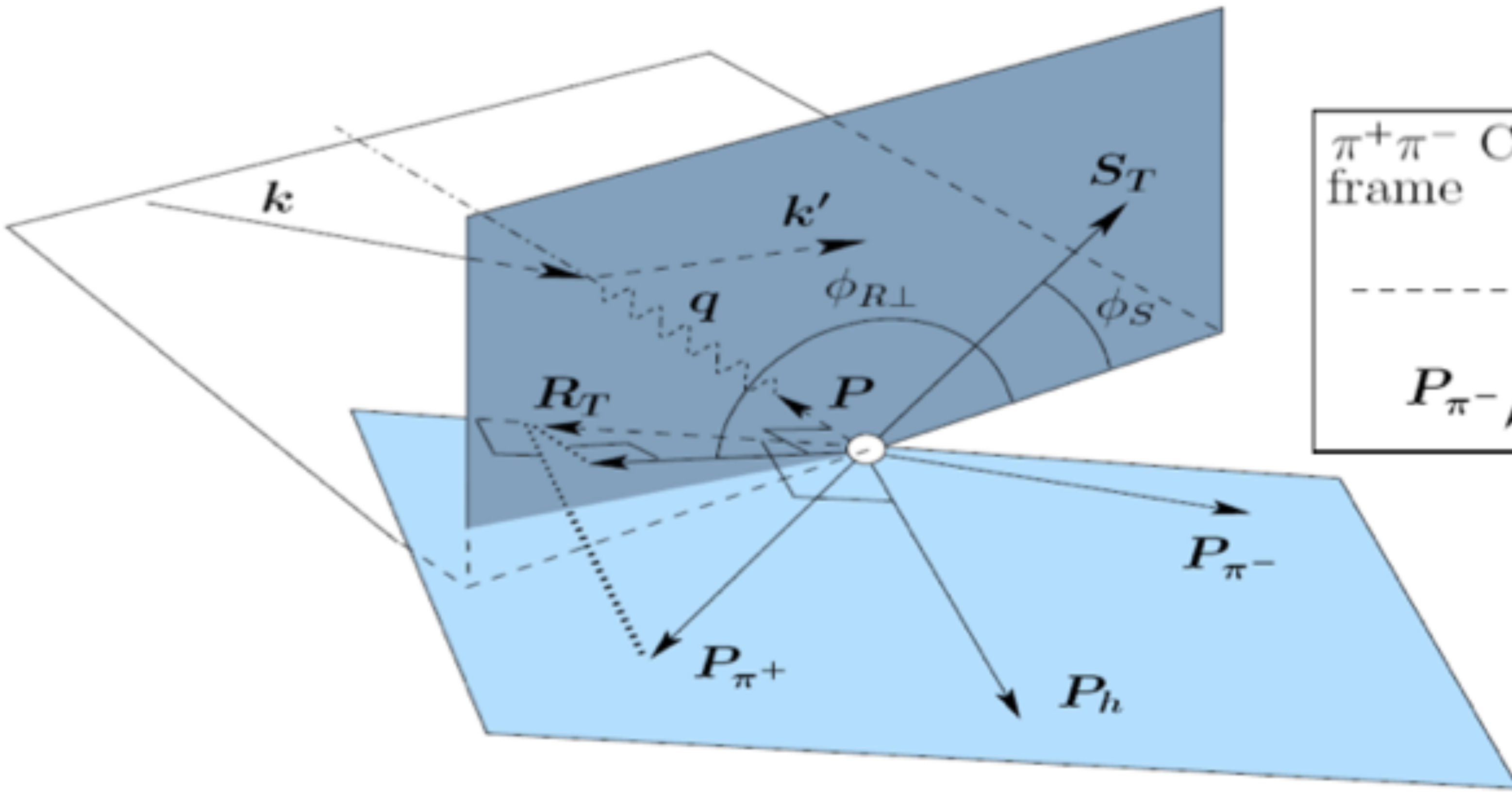
Outline

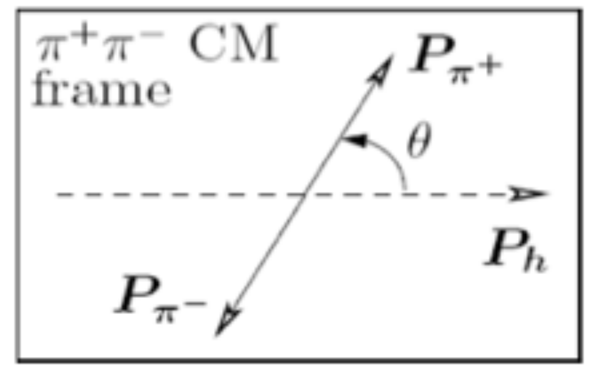
- Dihadron ($\pi\pi$ and KK) production in TMD semi-inclusive DIS on a transversely polarized proton target
- Transverse target single-spin asymmetry in inclusive electroproduction of charged pions and kaons
- Transverse polarization of Λ hyperons from quasi-real photoproduction on nuclei

Dihadron production in semi-inclusive DIS



Dihadron production





$$\vec{R} = \frac{1}{2}(\vec{P}_1 - \vec{P}_2)$$

$$\vec{P}_h = \vec{P}_1 + \vec{P}_2$$

$$\vec{R}_T = \vec{R} - \frac{\vec{R}.\vec{P}_h}{|\vec{P}_h|^2}\vec{P}_h$$

$$\phi_R = signum[(\vec{n} \times \vec{R}_T).\vec{P}_h] \arccos \frac{\vec{n}.\vec{R}_T}{|\vec{n}||\vec{R}_T|},$$

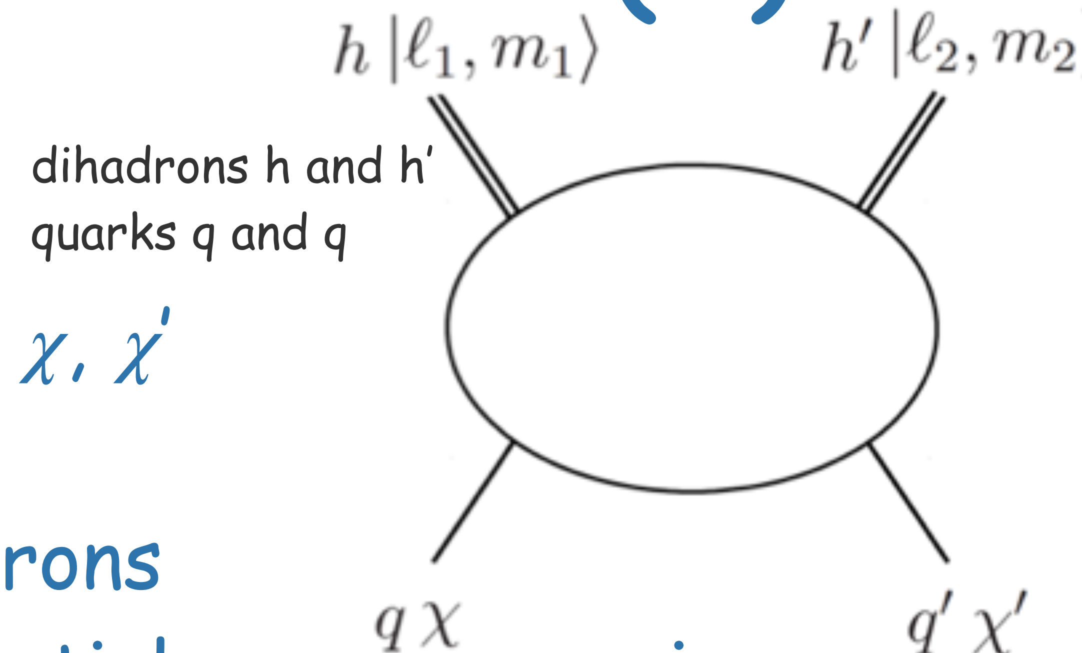
with $\vec{n} \perp \vec{P}_h$ and $(\vec{P}_h \times \vec{n}).(\vec{q} \times \vec{k}) > 0$

$x, y, z, P_{h\perp}$

ϕ_h, ϕ_R

dihadron mass M_{hh}

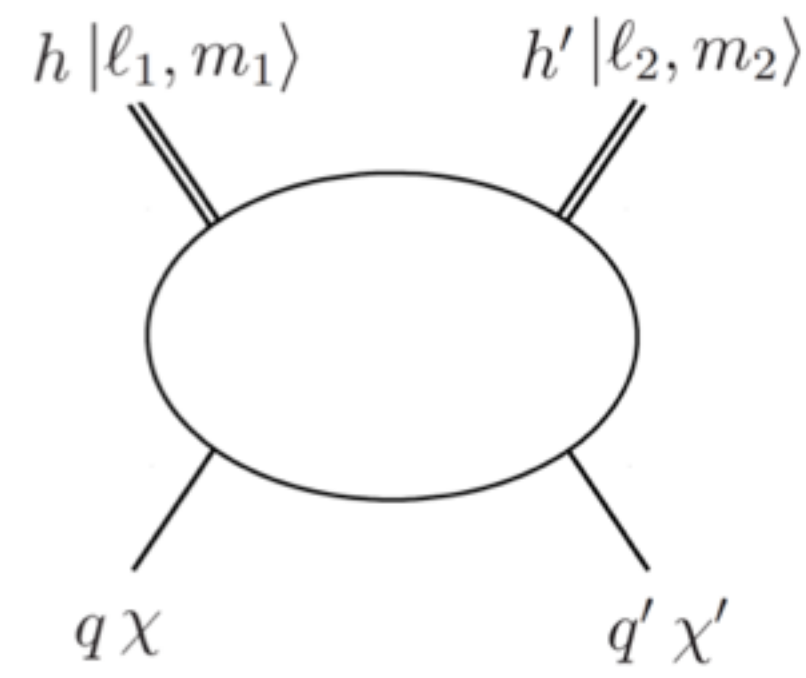
New convention for (di)hadron fragmentation functions (*)



- new convention for FFs:
  - FFs entirely defined by quark spin χ, χ'
  - final-state polarisation of (di-)hadrons $|l_1, m_1>, |l_2, m_2>$ contained in partial-wave expansion
- exactly 2 FFs:
  - unpolarised FF D_1 with χ=χ'
  - polarised (Collins) FF $H_1^\perp$ with $\chi \neq \chi$

(*) S. Gliske, "Transverse target moments of dihadron production in semi-inclusive DIS at HERMES", PhD thesis, University of Michigan, 2011.

Partial-wave expansion



- direct sum base $|l, m>$ rather than direct product base $|l_1, m_1>, |l_2, m_2$

$$
\begin{aligned}
\frac{1}{2}\otimes\frac{1}{2}\otimes\frac{1}{2}\otimes\frac{1}{2} &= \left(\frac{1}{2}\otimes\frac{1}{2}\right)\otimes\left(\frac{1}{2}\otimes\frac{1}{2}\right) \\
&= (1\oplus 0)\otimes(1\oplus 0)\,, \\
&= 2\oplus \underline{1\oplus 1\oplus 1}\oplus \underline{0\oplus 0}.
\end{aligned}
$$

experimentally $2 \oplus 1 \oplus 0$

- partial wave

$$
D_1 = \sum_{\ell=1}^{\infty}\sum_{m=-\ell}^{\ell} P_{\ell,m}(\cos\vartheta)e^{im(\phi_R-\phi_k)}D_1^{|\ell,m\rangle}(z, M_h, |\boldsymbol{k}_T|),
$$

$$
H_1^{\perp} = \sum_{\ell=1}^{\infty}\sum_{m=-\ell}^{\ell} P_{\ell,m}(\cos\vartheta)e^{im(\phi_R-\phi_k)}H_1^{\perp|\ell,m\rangle}(z, M_h, |\boldsymbol{k}_T|)
$$

Cross section

$$
\begin{aligned}
d\sigma_{UT} = \; & \frac{\alpha^2 M_h P_{h\perp}}{2\pi x y Q^2}\left(1+\frac{\gamma^2}{2x}\right)|\boldsymbol{S}_\perp| \\
& \times \sum_{\ell=0}^{2}\sum_{m=-\ell}^{\ell}\Bigg\{ A(x,y)\Big[P_{\ell,m}\sin((m+1)\phi_h - m\phi_R - \phi_S)) \\
& \qquad \times \left(F_{UT,T}^{P_{\ell,m}\sin((m+1)\phi_h - m\phi_R - \phi_S)} + \epsilon F_{UT,L}^{P_{\ell,m}\sin((m+1)\phi_h - m\phi_R - \phi_S)}\right)\Big] \\
& \quad + B(x,y)\Big[P_{\ell,m}\sin((1-m)\phi_h + m\phi_R + \phi_S)F_{UT}^{P_{\ell,m}\sin((1-m)\phi_h + m\phi_R + \phi_S)} \\
& \qquad + P_{\ell,m}\sin((3-m)\phi_h + m\phi_R - \phi_S)F_{UT}^{P_{\ell,m}\sin((3-m)\phi_h + m\phi_R - \phi_S)}\Big] \\
& \quad + V(x,y)\Big[P_{\ell,m}\sin(-m\phi_h + m\phi_R + \phi_S)F_{UT}^{P_{\ell,m}\sin(-m\phi_h + m\phi_R + \phi_S)} \\
& \qquad + P_{\ell,m}\sin((2-m)\phi_h + m\phi_R - \phi_S)F_{UT}^{P_{\ell,m}\sin((2-m)\phi_h + m\phi_R - \phi_S)}\Big]\Bigg\}.
\end{aligned}
$$

and analogously for $d\sigma_{UU}, d\sigma_{UL}, d\sigma_{LU}, d\sigma_{LL}, d\sigma_{LT}$

Structure functions

at leading twist

$$F_{UT,L}^{P_{\ell,m}\sin((m+1)\phi_h-m\phi_R-\phi_S)} = 0$$

$$F_{UT,T}^{P_{\ell,m}\sin((m+1)\phi_h-m\phi_R-\phi_S)} = -\mathcal{I}\left[\frac{|\boldsymbol{p}_T|}{M}\cos\left((m+1)\phi_h-\phi_p-m\phi_k\right) \times \left(f_{1T}^{\perp}D_1^{|\ell,m\rangle +} + \mathrm{signum}[m]g_{1T}D_1^{|\ell,m\rangle -}\right)\right],$$

"Sivers"

$$F_{UT}^{P_{\ell,m}\sin((1-m)\phi_h+m\phi_R+\phi_S)} = -\mathcal{I}\left[\frac{|\boldsymbol{k}_T|}{M_h}\cos\left((m-1)\phi_h-\phi_p-m\phi_k\right)\, h_1 H_1^{\perp|\ell,m\rangle}\right],$$

"Collins"

$$F_{UT}^{P_{\ell,m}\sin((3-m)\phi_h+m\phi_R-\phi_S)} = \mathcal{I}\left[\frac{|\boldsymbol{p}_T|^2|\boldsymbol{k}_T|}{M^2M_h}\cos\left((m-3)\phi_h+2\phi_p-(m-1)\phi_k\right) \times h_{1T}^{\perp}H_1^{\perp|\ell,m\rangle}\right].$$

"pretzelocity"

usual IFF related to $H_1^{\perp|1,1>}$

$\vec{p}_T, \phi_p$ struck quark
$\vec{k}_T, \phi_k$ fragmenting quark

Results

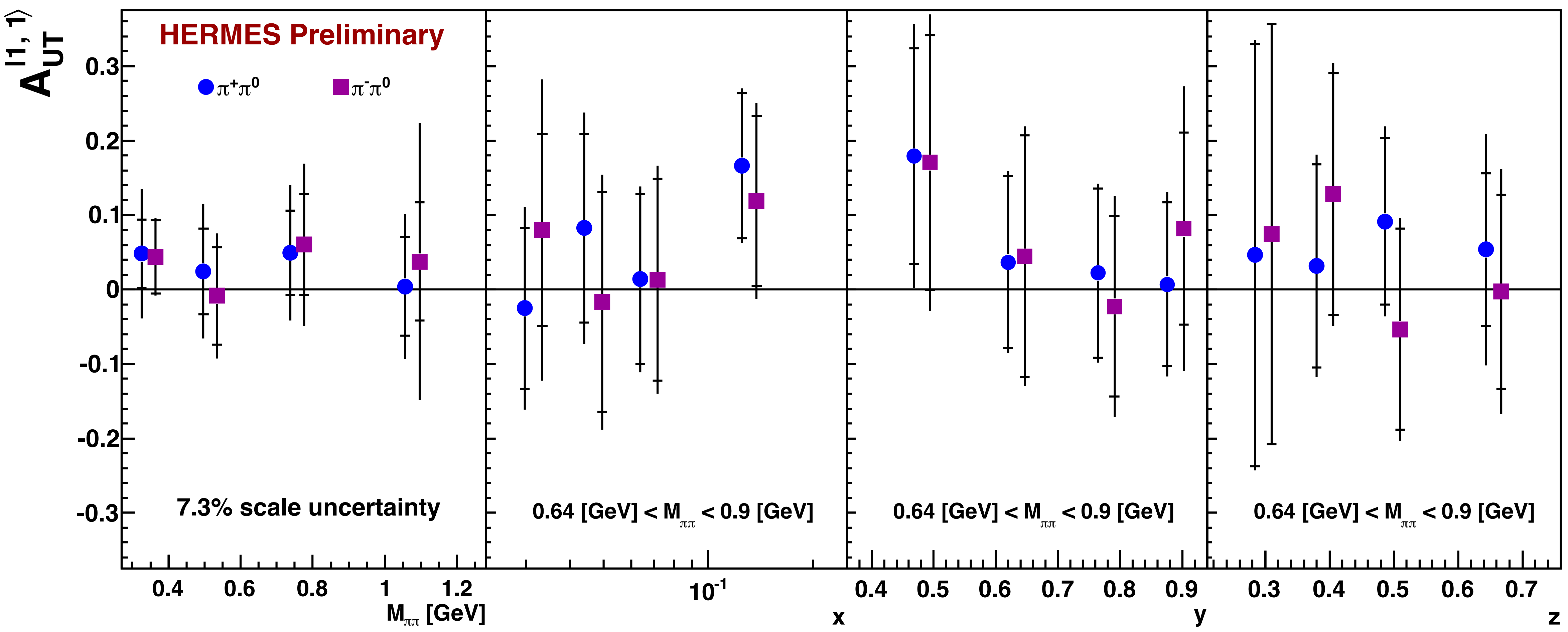
- Collins moments for

  $\pi^+\pi^-, \pi^+\pi^0, \pi^-\pi^0$
- Collins and Sivers moments for

  K^+K^- in ϕ resonance region
- Collins, Sivers and pretzelocity for $|0,0>$ moments for

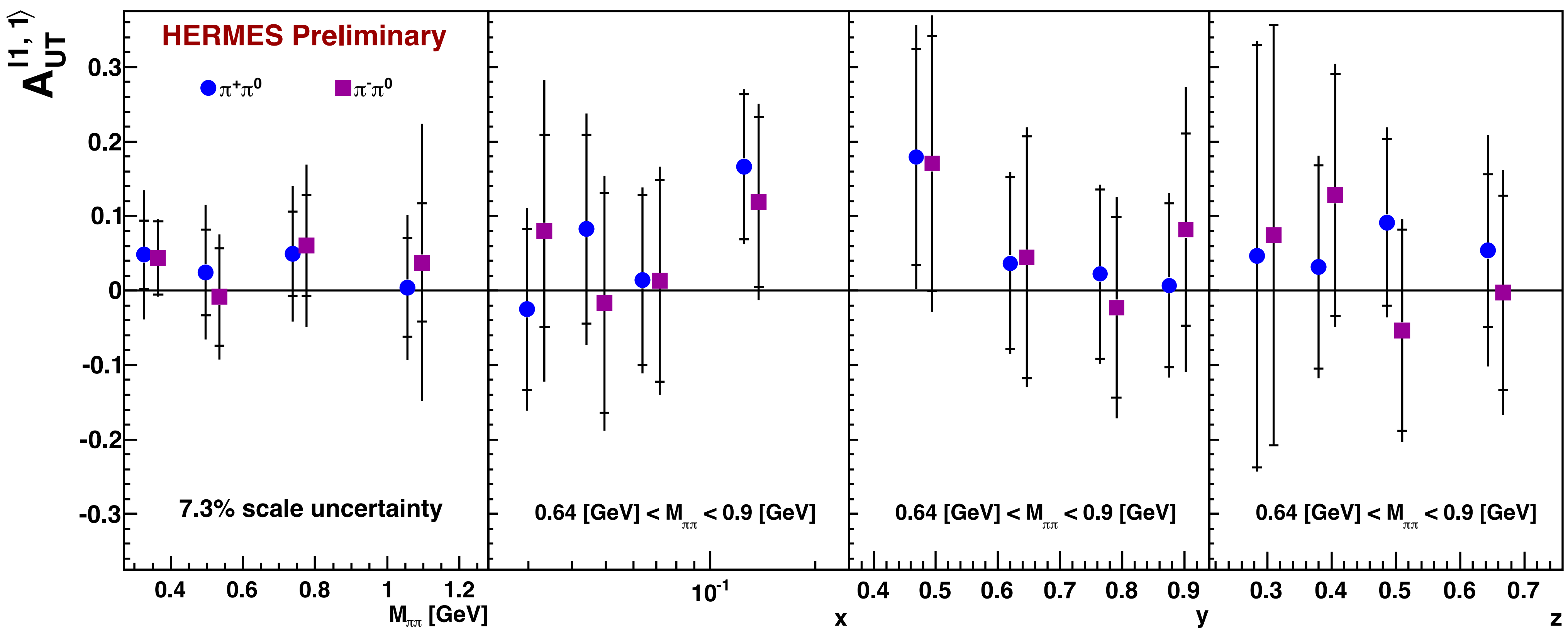
  K^+K^- outside ϕ resonance region since $l > 0, m > 0$ are zero (as expected)

$|1,1>$ Collins moments for $\pi\pi$

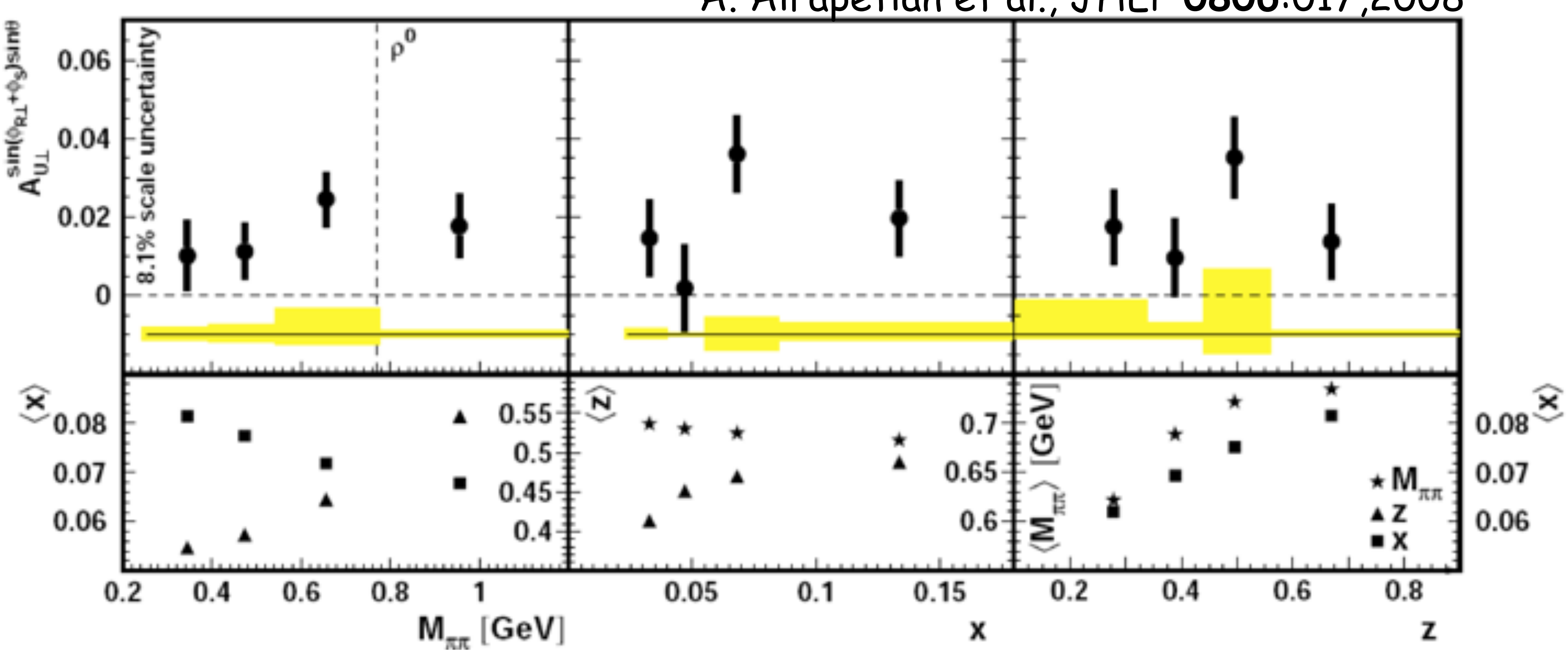


allows collinear access to transversity

$|1,1>$ Collins moments for $\pi\pi$

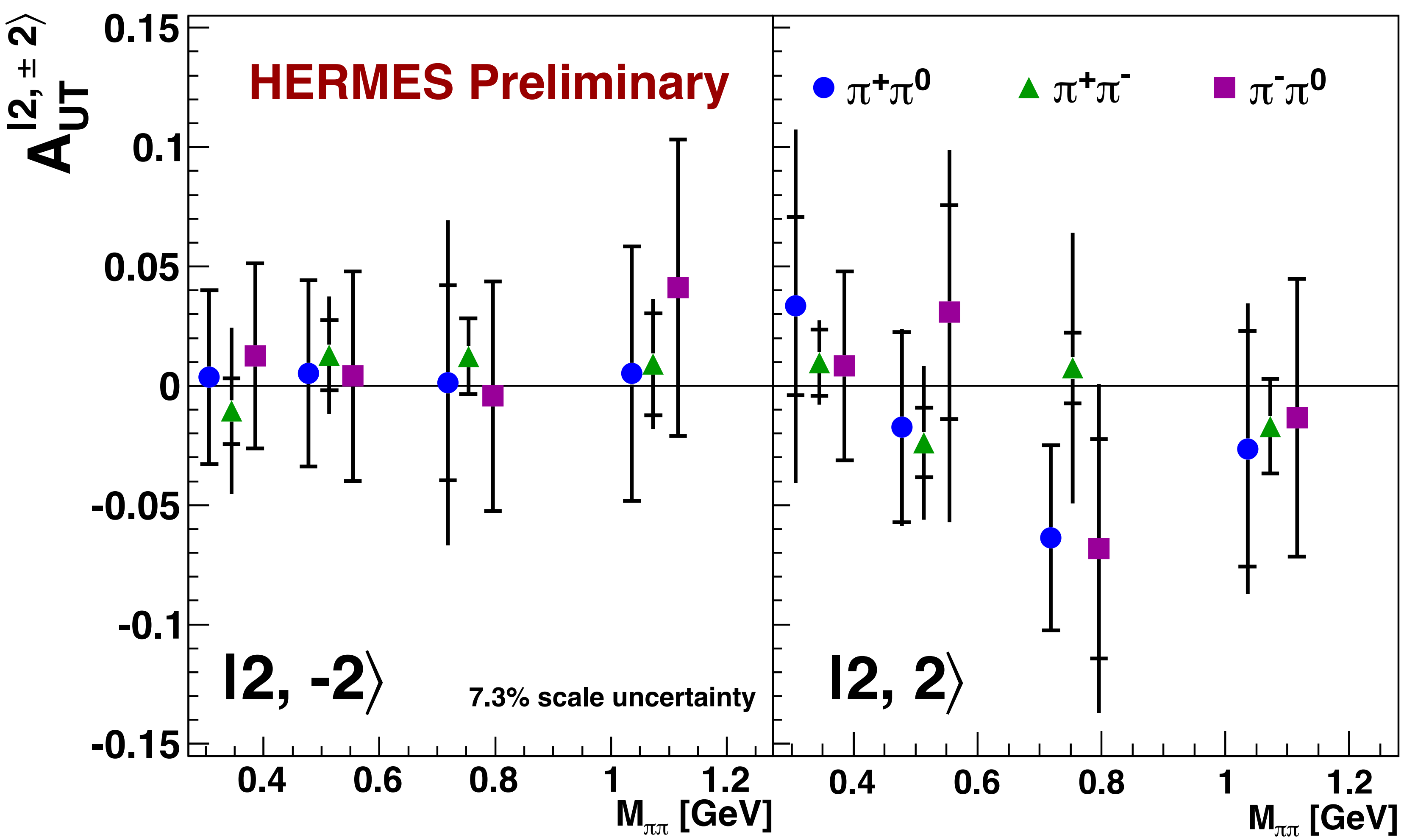


A. Airapetian et al., JHEP **0806**:017,2008



$|2, \pm 2>$ Collins moments for $\pi\pi$

$$|2, \pm 2> = |1, \pm 1> |1 \pm 1>$$



$|2, -2>$

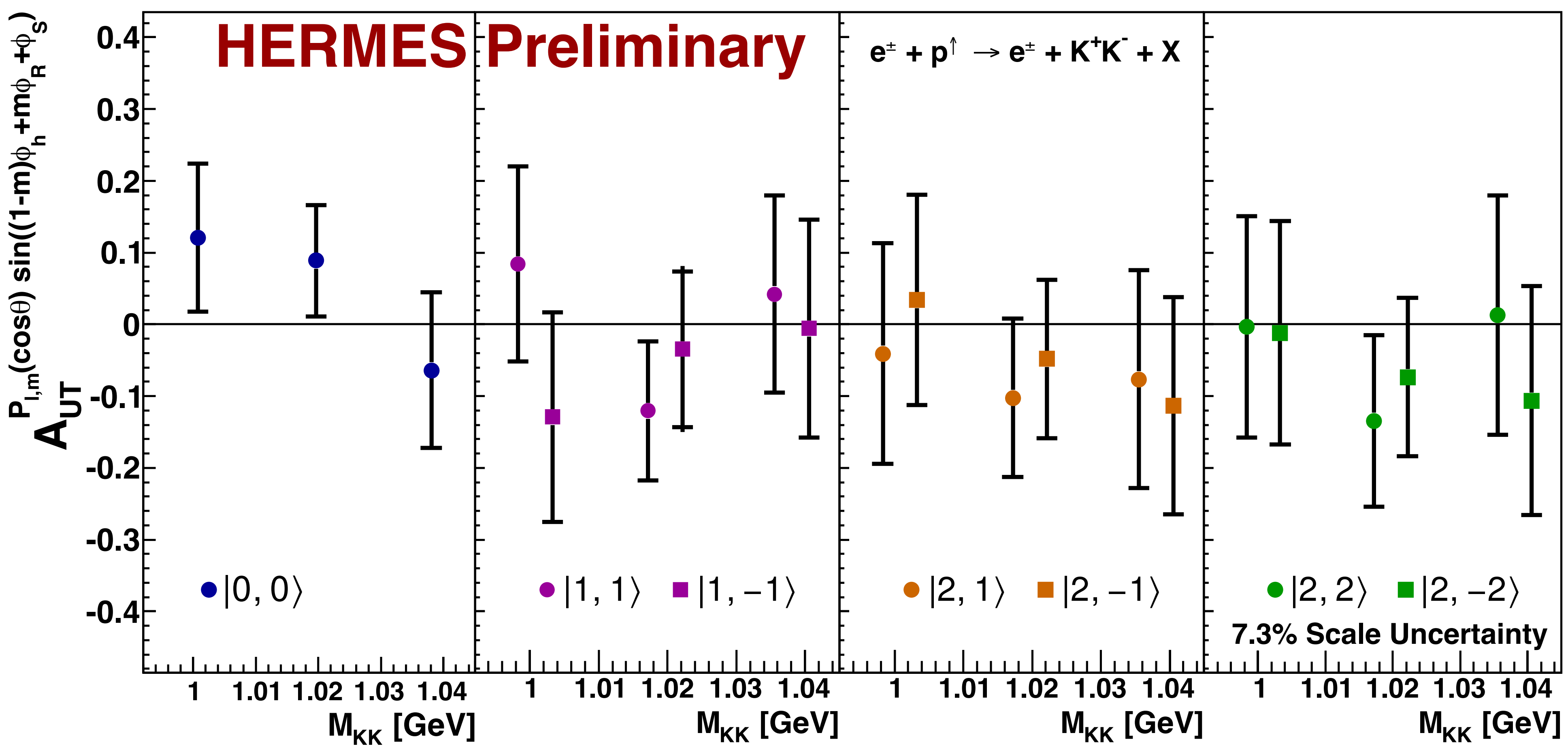
consistent with zero

$|2, +2>$

- no signal outside resonance region
- hint of negative signal for $\pi^\pm\pi^0$ in $\rho^\pm$ region
- no signal in ρ^0 region

Collins moments for K^+K^- in ϕ resonance region

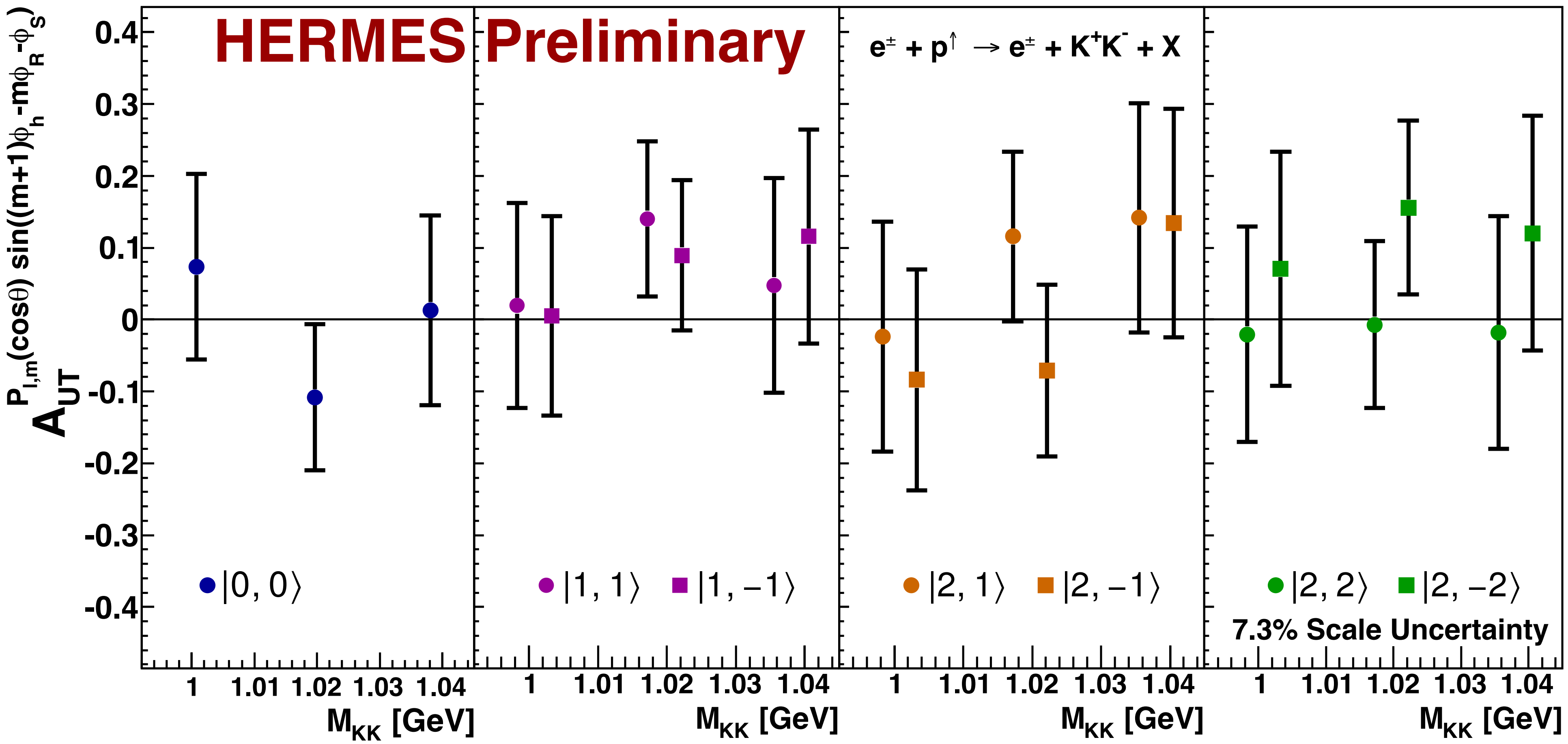
sensitive to transversity s-quark distribution



no indication for different signal in and outside ϕ-resonance region

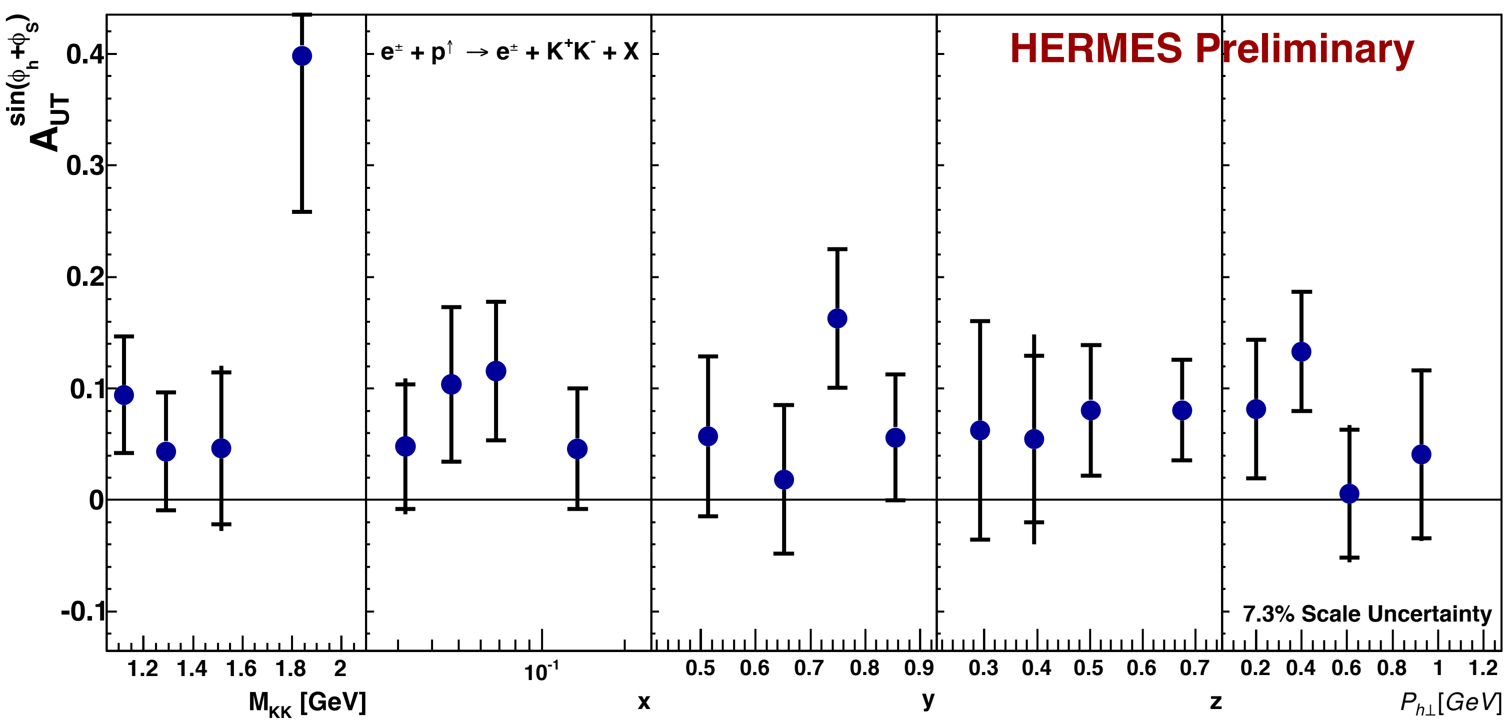
Sivers moments for K^+K^- in ϕ resonance region

sensitive to Sivers s-quark distribution

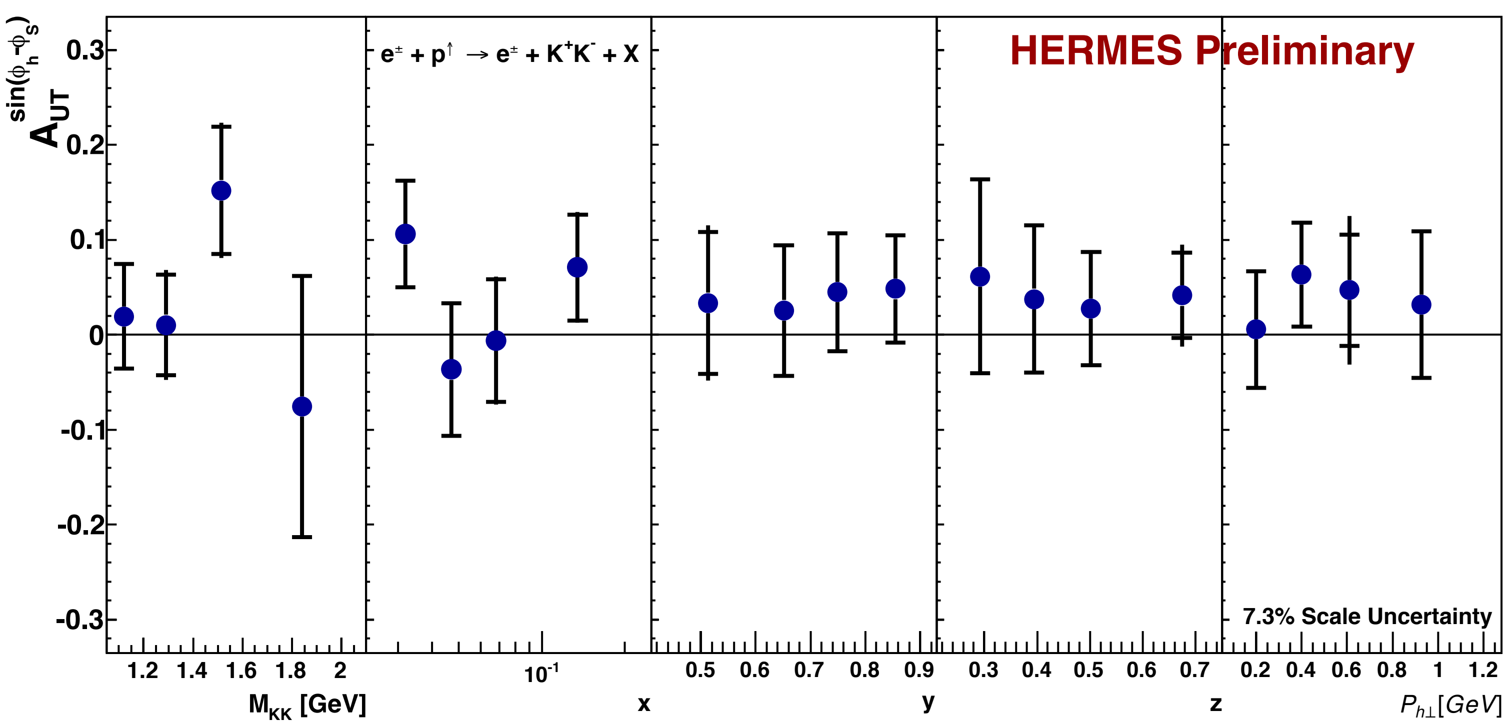


no indication for different signal in and outside ϕ-resonance region

Moments for K^+K^- outside ϕ resonance region @ leading twist

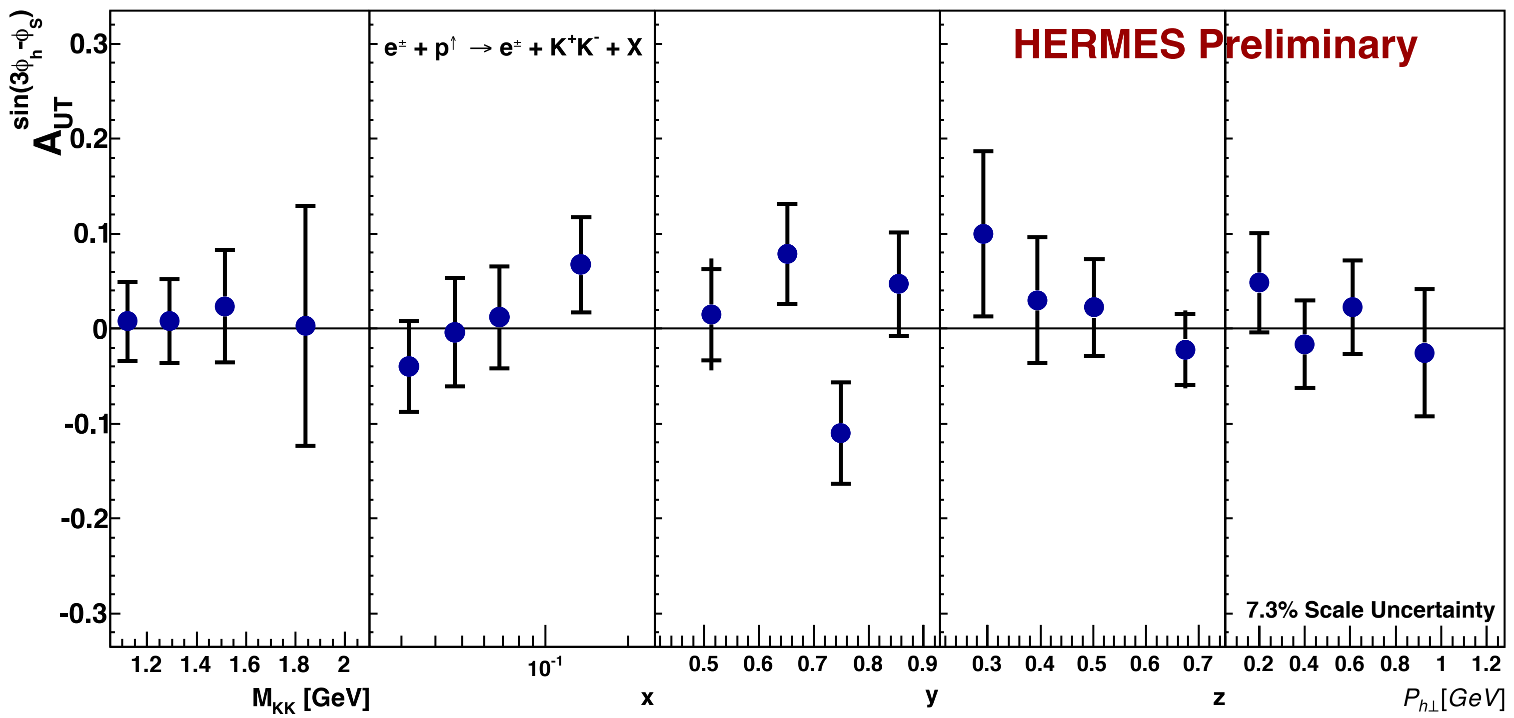


- consistent with small positive value



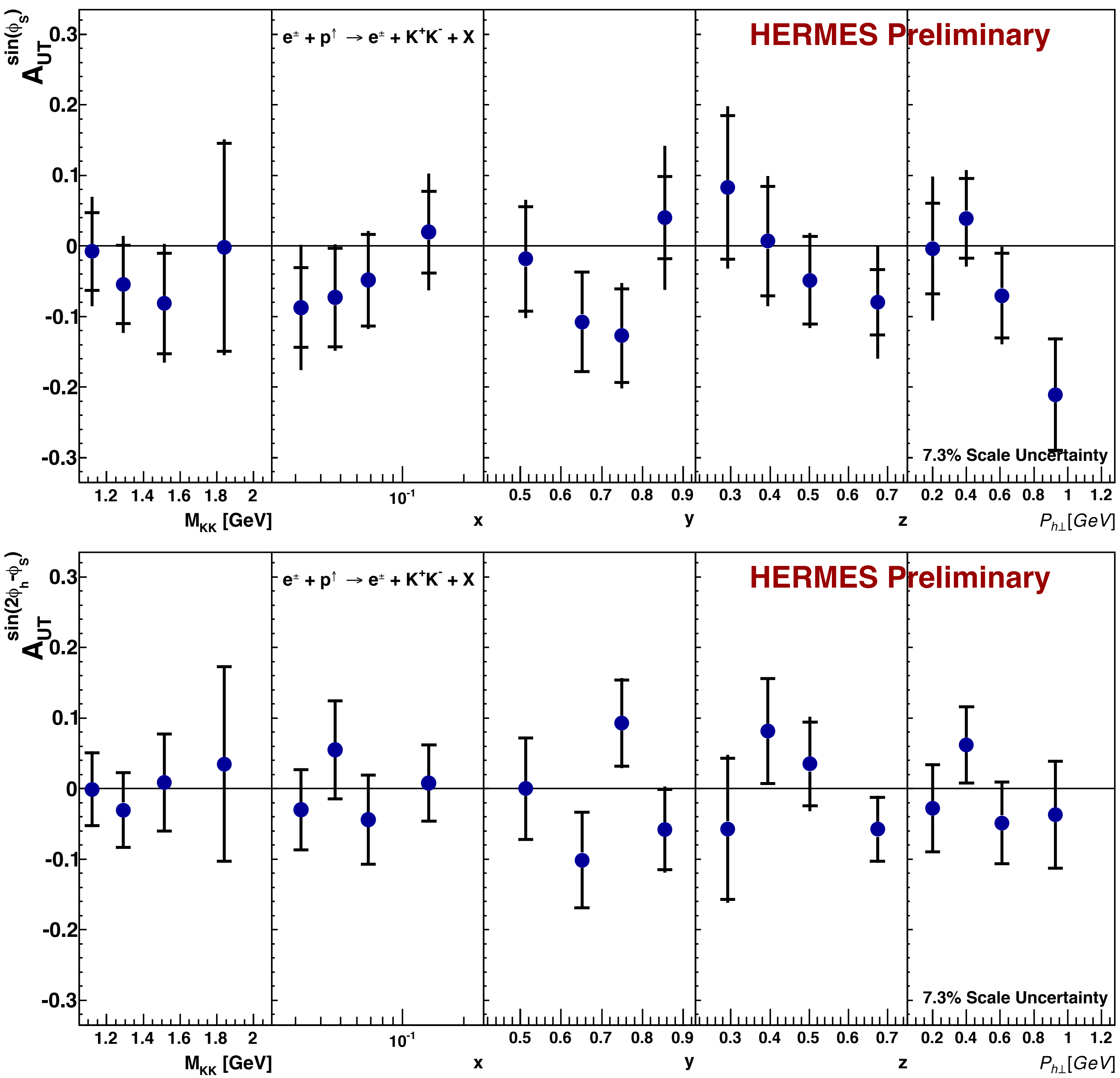
- consistent with small positive value

Moments for K^+K^- outside ϕ resonance region @ leading twist



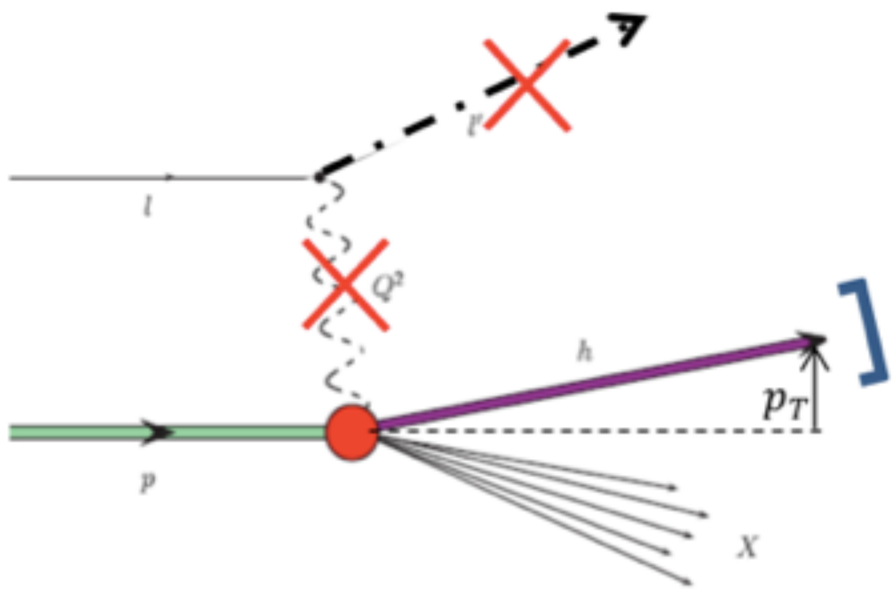
- consistent with zero

Moments for K^+K^- outside ϕ resonance region @ sub-leading twist



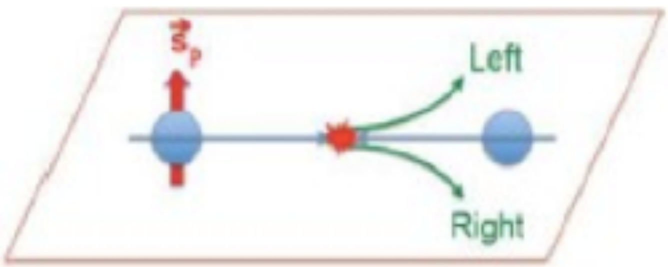
- consistent with zero

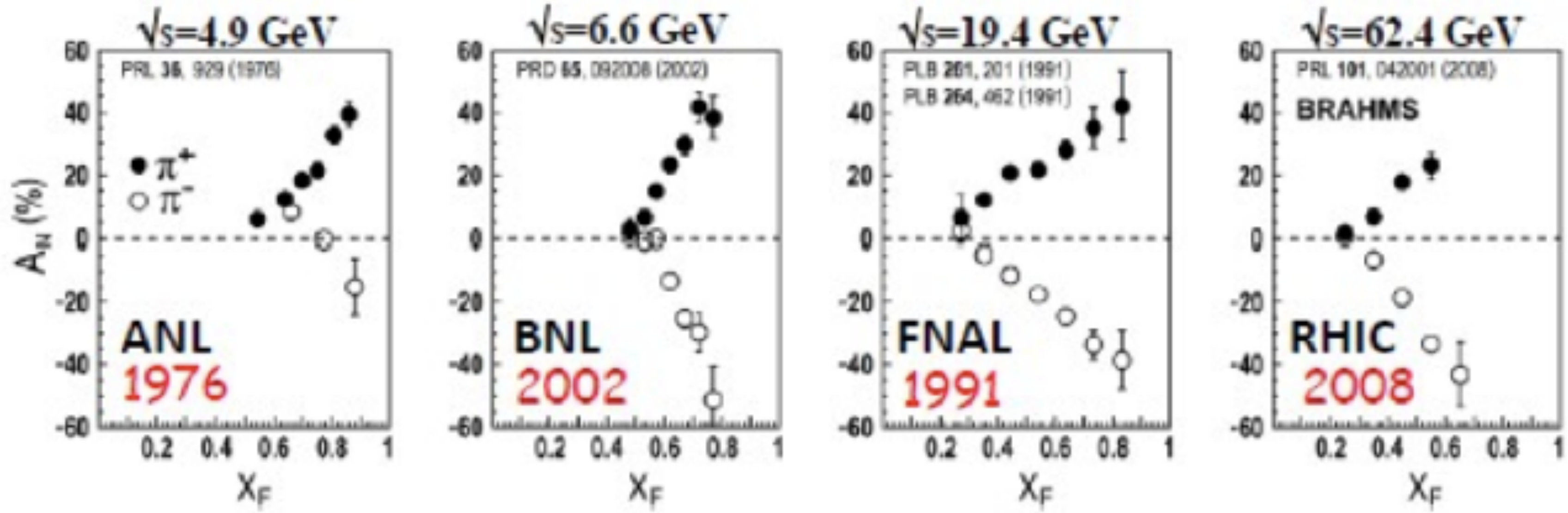
A_{UT} inclusive



Transverse target single-spin asymmetry in inclusive electroproduction of pions and kaons

- various polarized pp scattering experiments consistently observe since 35 years large A_N asymmetries, with $\sqrt{s}$ from 5 to 200 GeV





- not interpretable in leading-twist based on collinear factorisation

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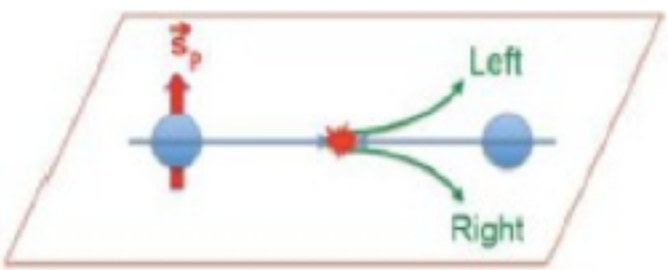
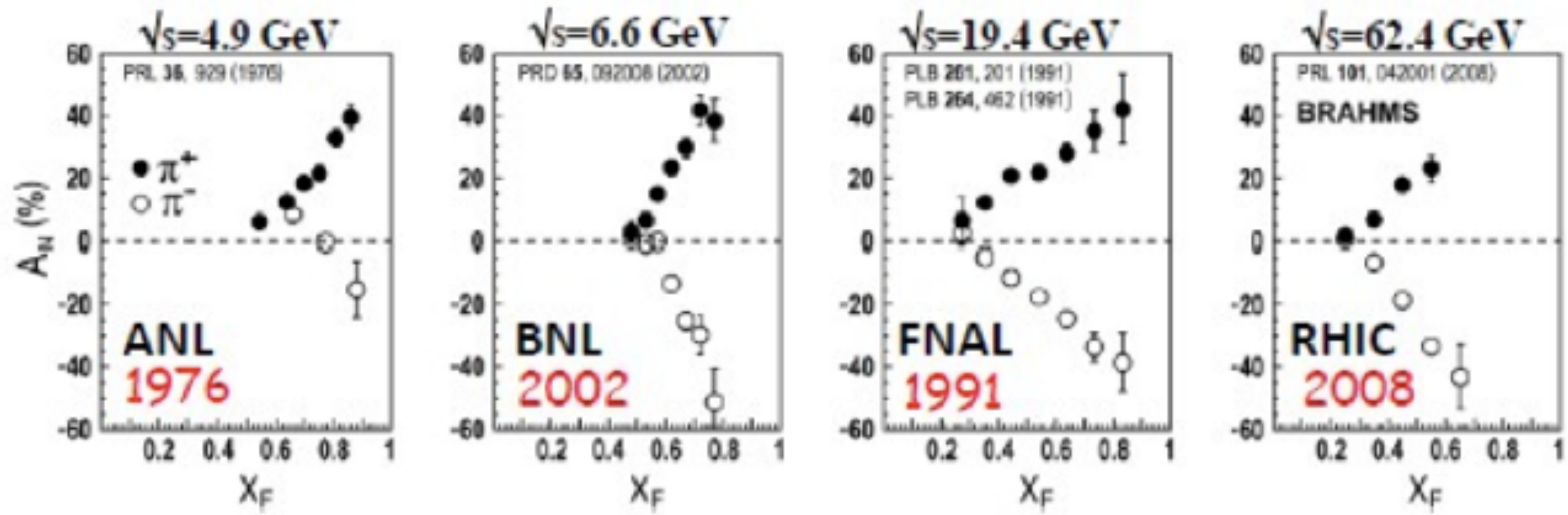
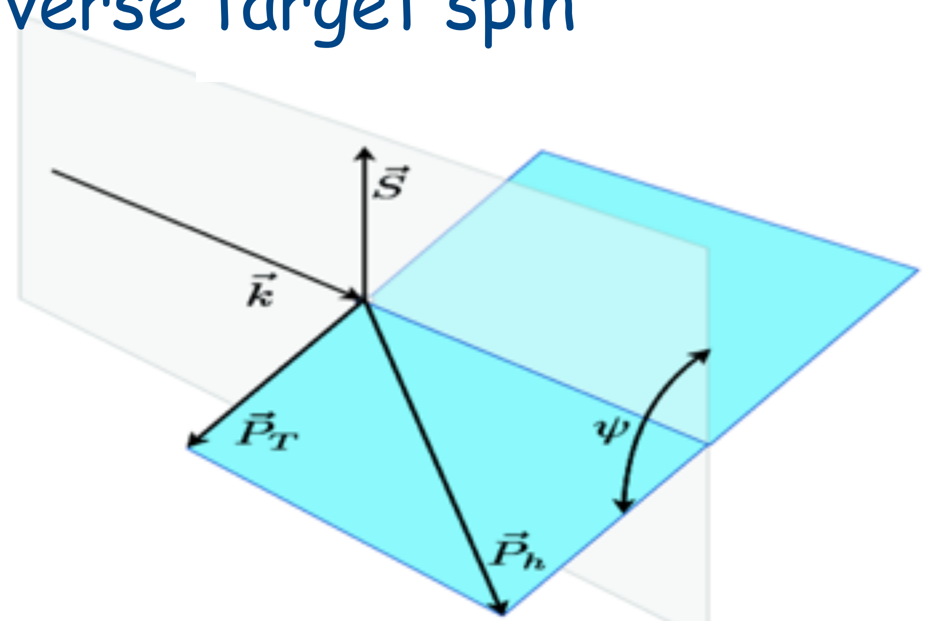




- not interpretable in leading-twist based on collinear factorisation
- HERMES measurement of inclusive transverse target spin asymmetry $A_{UT}^{\sin(\psi)}$:

$$d\sigma = d\sigma_{UU}[1 + s_\perp A_{UT}^{\sin(\psi)} \sin(\psi)]$$

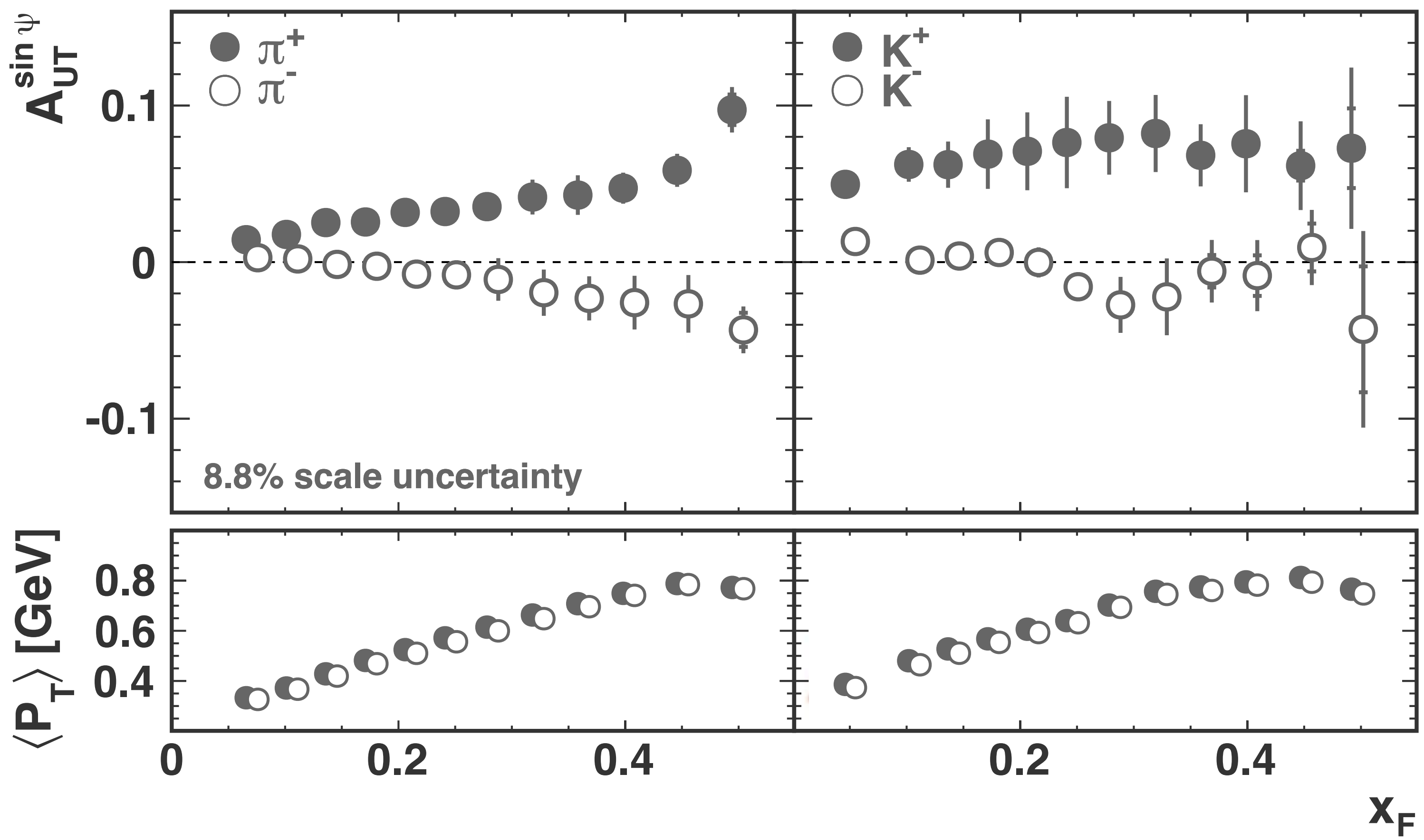
- $A_{UT}^{\sin(\psi)} = \frac{\pi}{2} A_N$
  - @ HERMES
    $\sin(\psi) \sim \sin(\phi - \phi_S)$



Results: x_F dependence

$x_F = 2P_L/\sqrt{s}$

A. Airapetian et al, Phys. Lett. B **728** (2014) 183-190



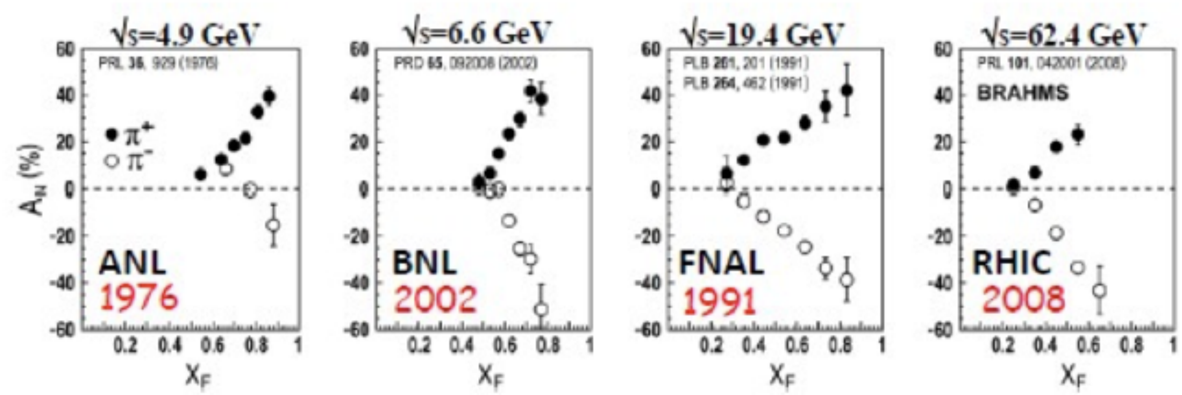
π^+

- positive, increase linearly with x_F

π^-

- negative, decrease linearly with x_F

x_F behavior of pions similar to what observed in hadron-hadron collisions



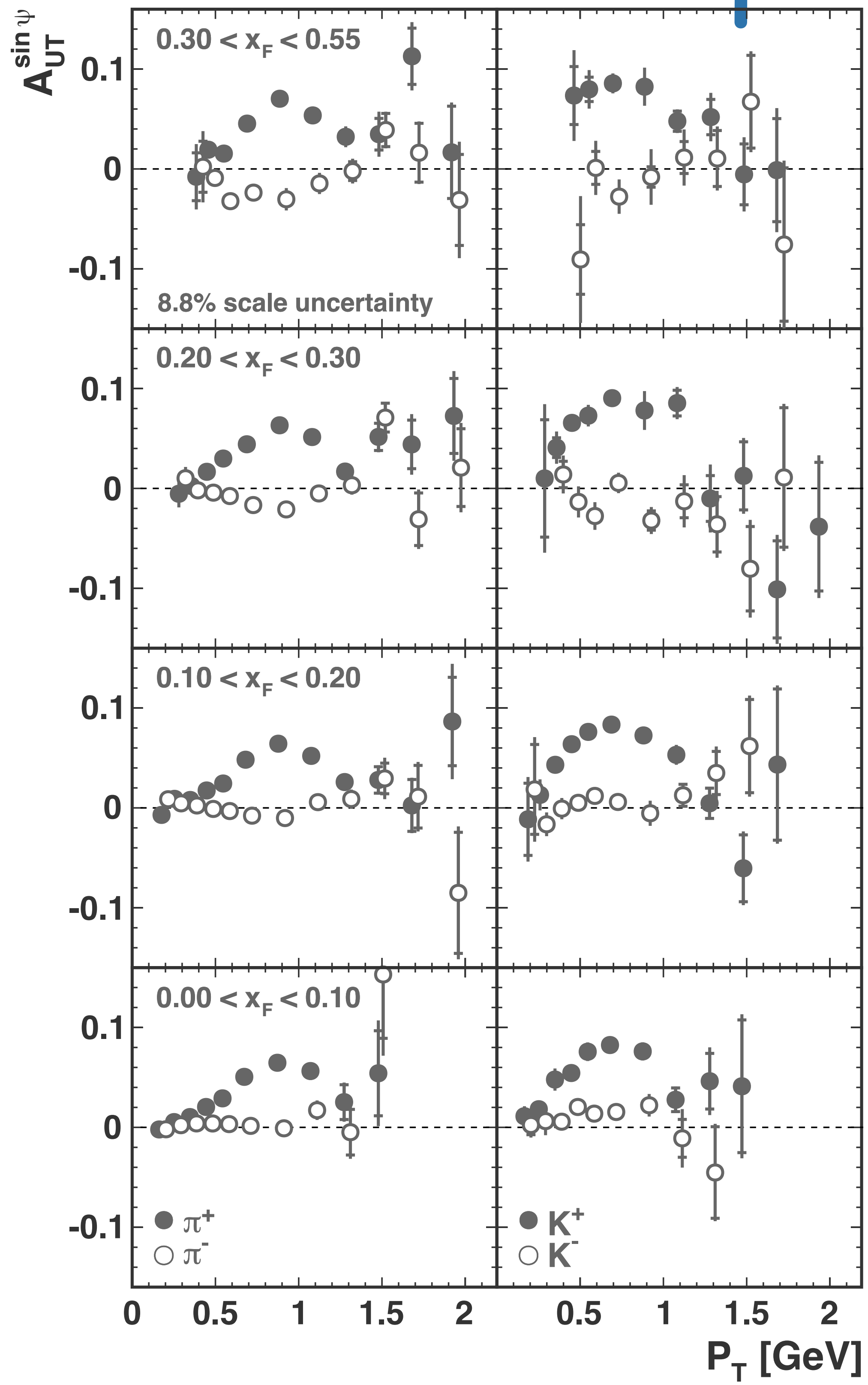
K^+

- positive, ~constant with x_F

K^-

- compatible with zero, with small variations over x_F

Results: disentangle x_F and P_T dependence



π^+

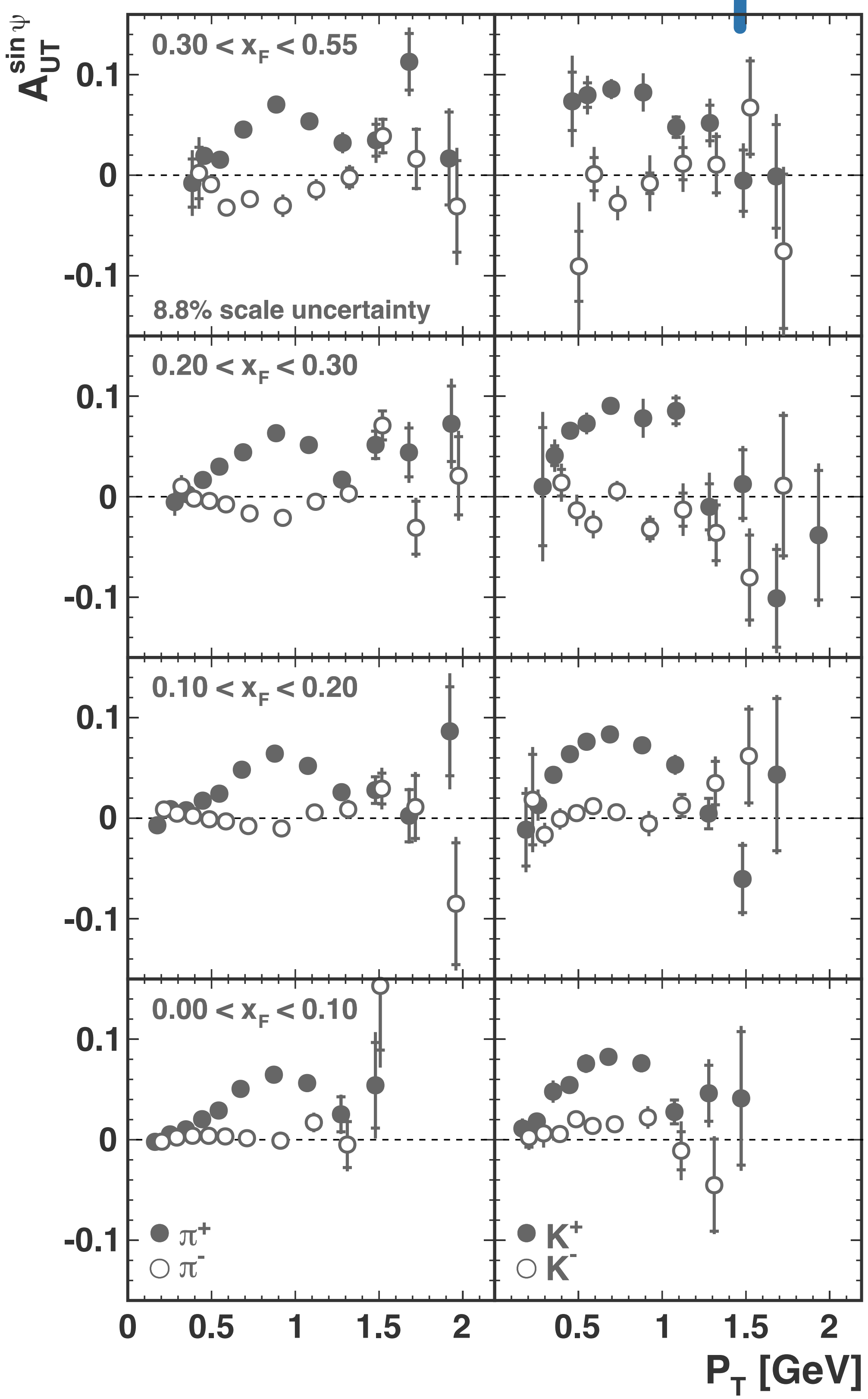
- increase with P_T up to $P_T \approx$ 0.8 GeV
- P_T dependence independent of x_F

→ x_F increase from P_T dependence

π^-

- small amplitudes,
  varyingly positive and negative with P_T
- decrease with increasing x_F

Results: disentangle x_F and P_T dependence



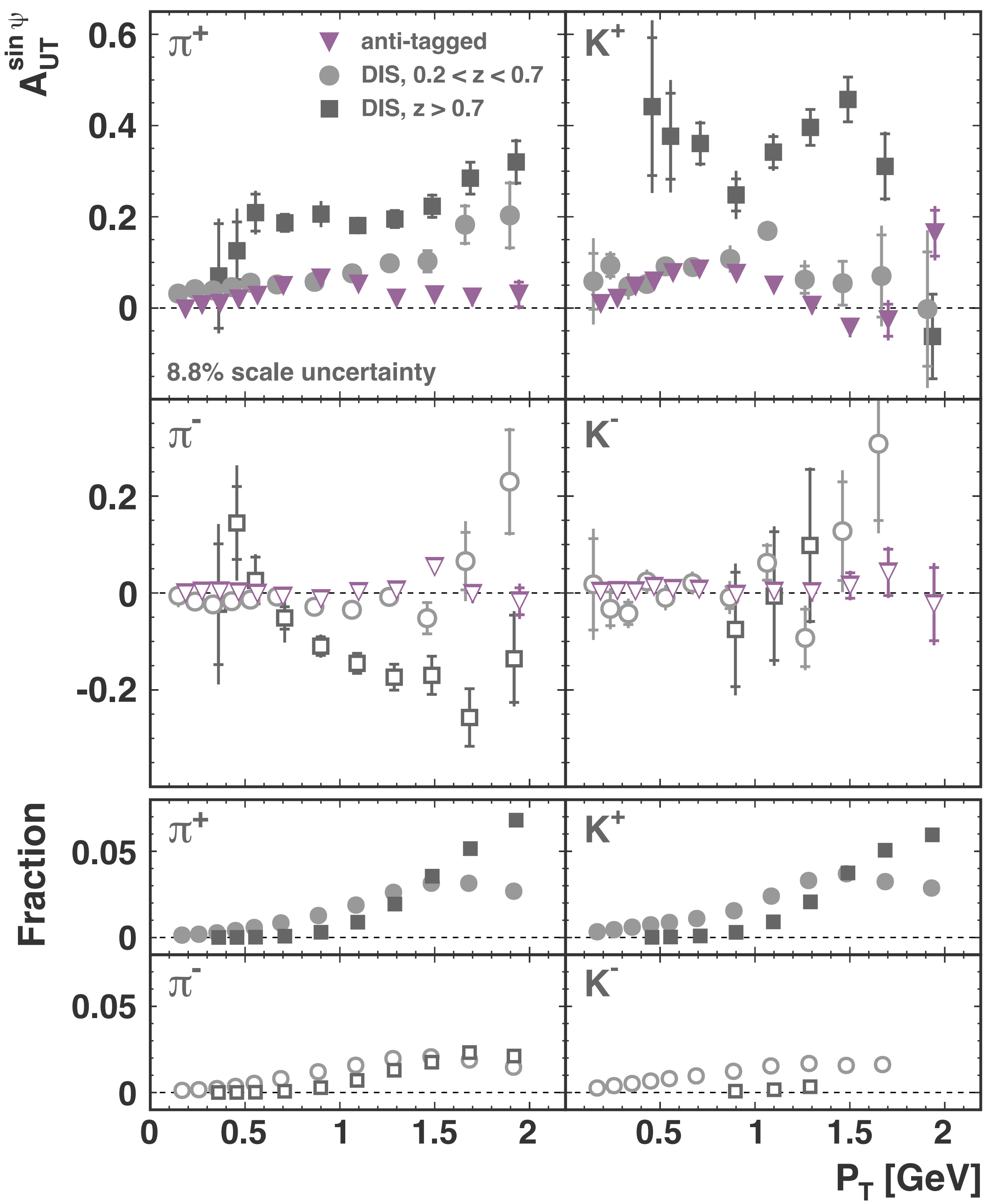
K^+

- increase with P_T up to $P_T \approx$ 0.8 GeV
- increase with increasing x_F

K^-

- small amplitudes
- decrease with increasing x_F

Contribution of various sub-samples

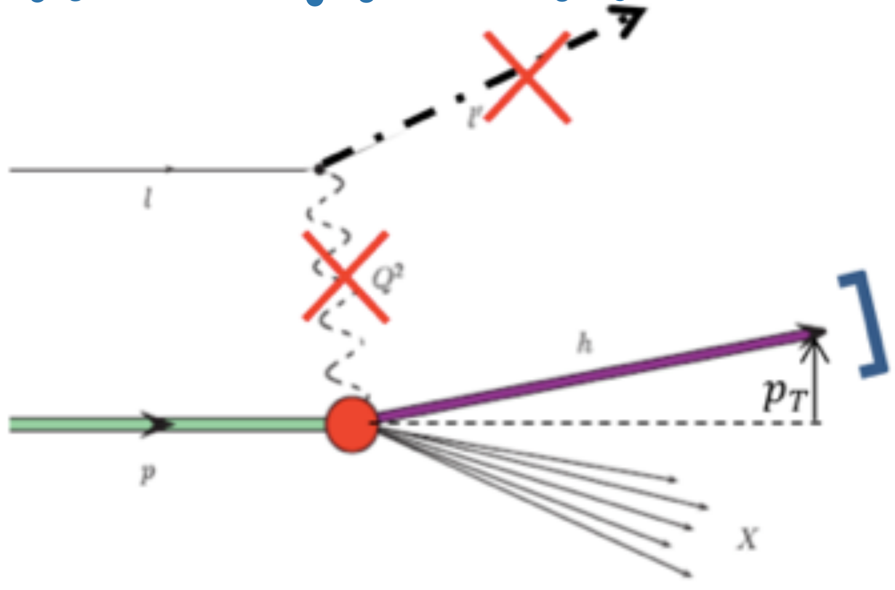


3 sub samples:

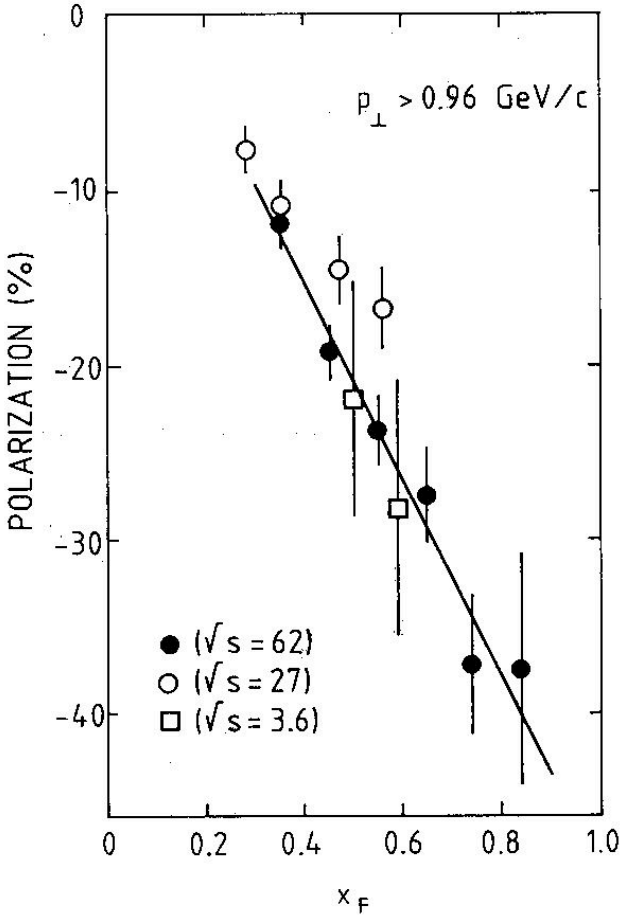
- anti-tagged: no $e^\pm$ detected (mostly $Q^2 \approx 0$)
- DIS with 0.2<z<0.7
- DIS with z>0.7

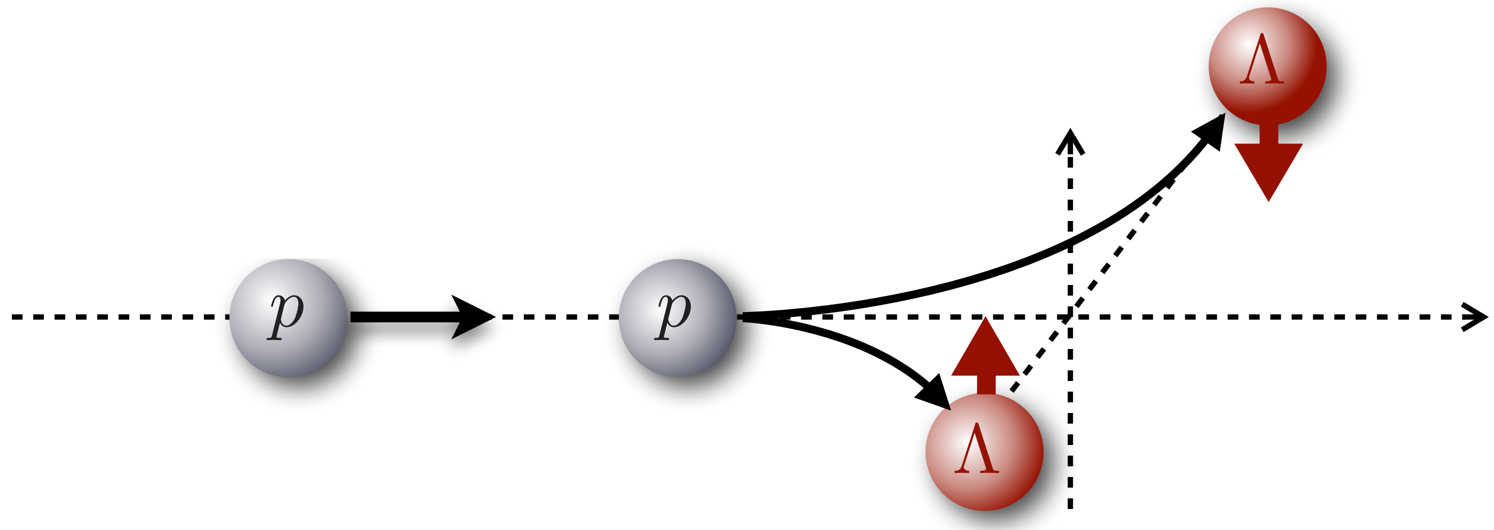
- anti-tagged results ~ overall results, majority of statistics
- 0.2<z<0.7 results: similar to Sivers amplitudes
- z>0.7 results: large asymmetries

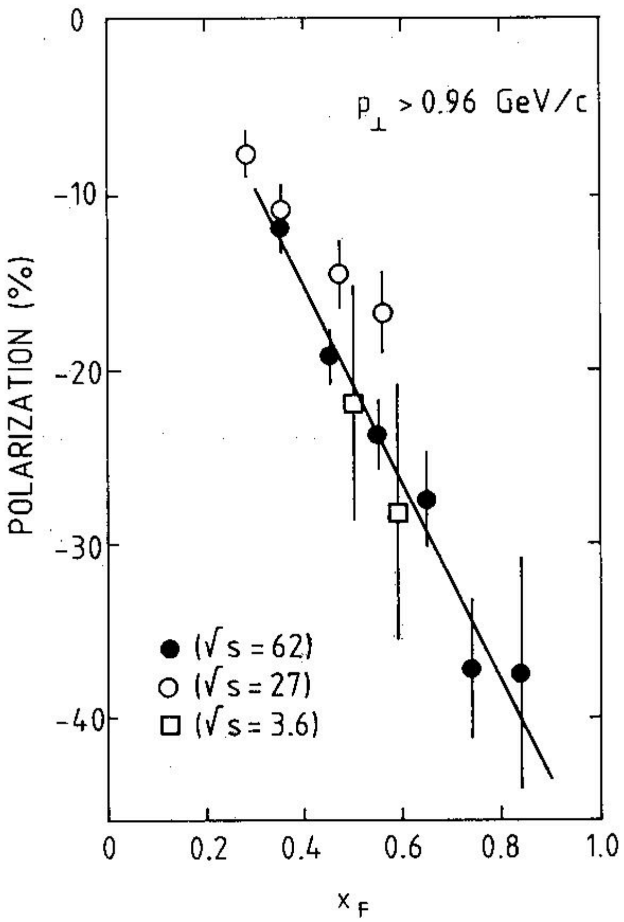
Transverse Λ polarization in inclusive measurement



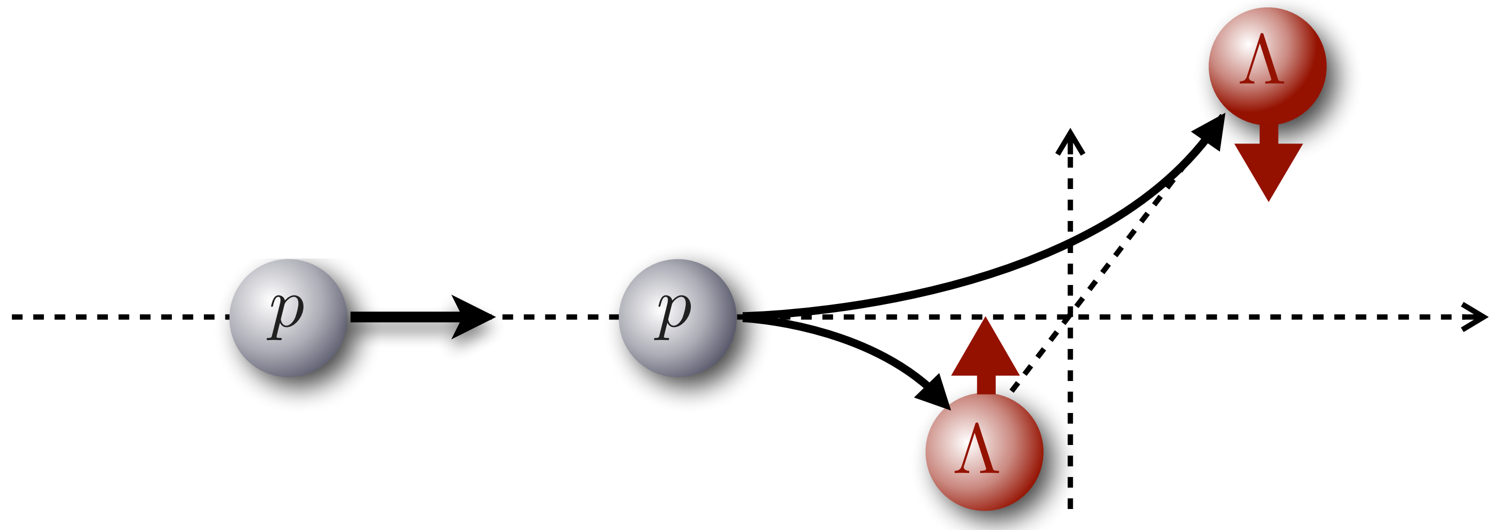
$pp \to \Lambda^{\uparrow} X$





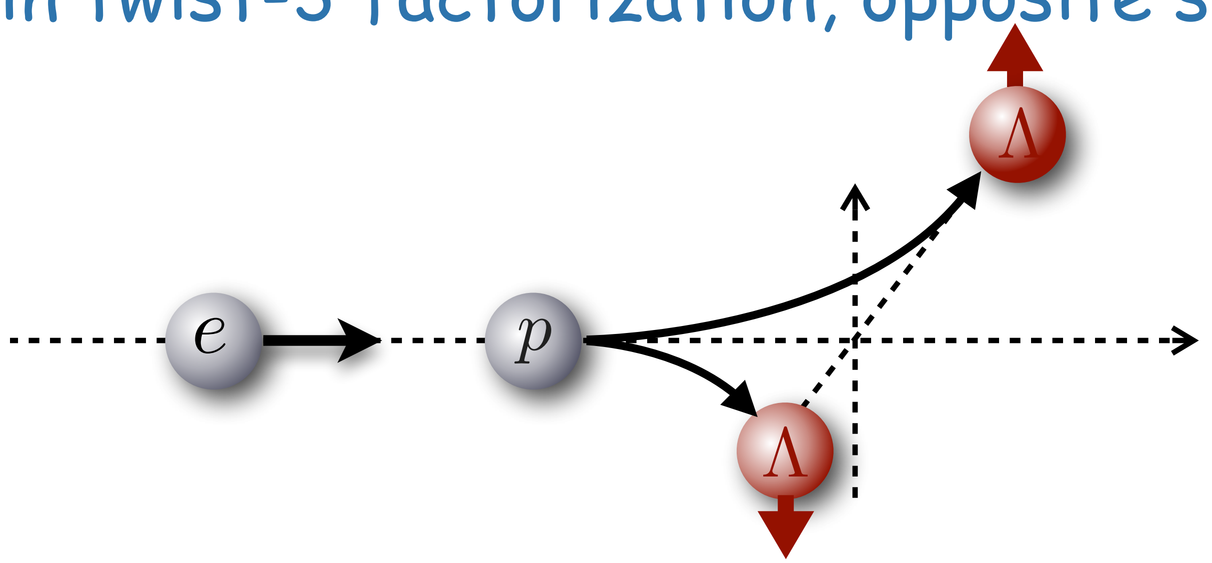


$pp \to \Lambda^\uparrow X$

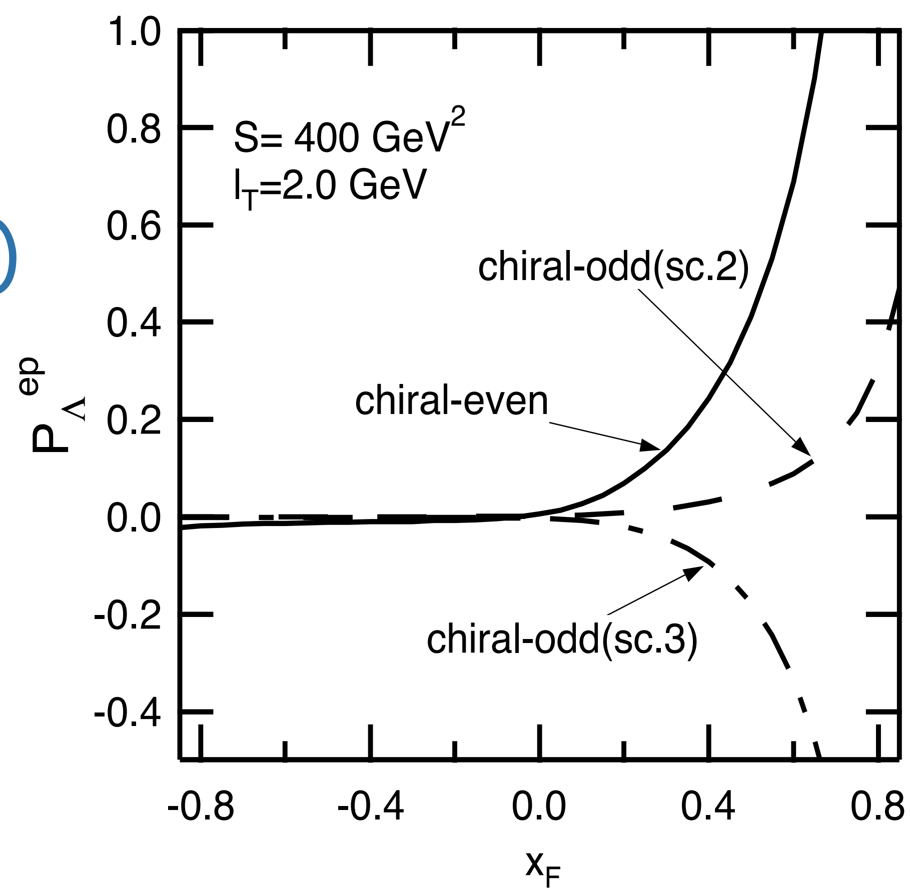


$ep \overset{?}{\to} \Lambda^\uparrow X$

- in SIDIS (large Q^2) proportional to polarizing FF $D_{1T}^\perp$ (naive T-odd, chiral even)
- in twist-3 factorization, opposite sign to pp



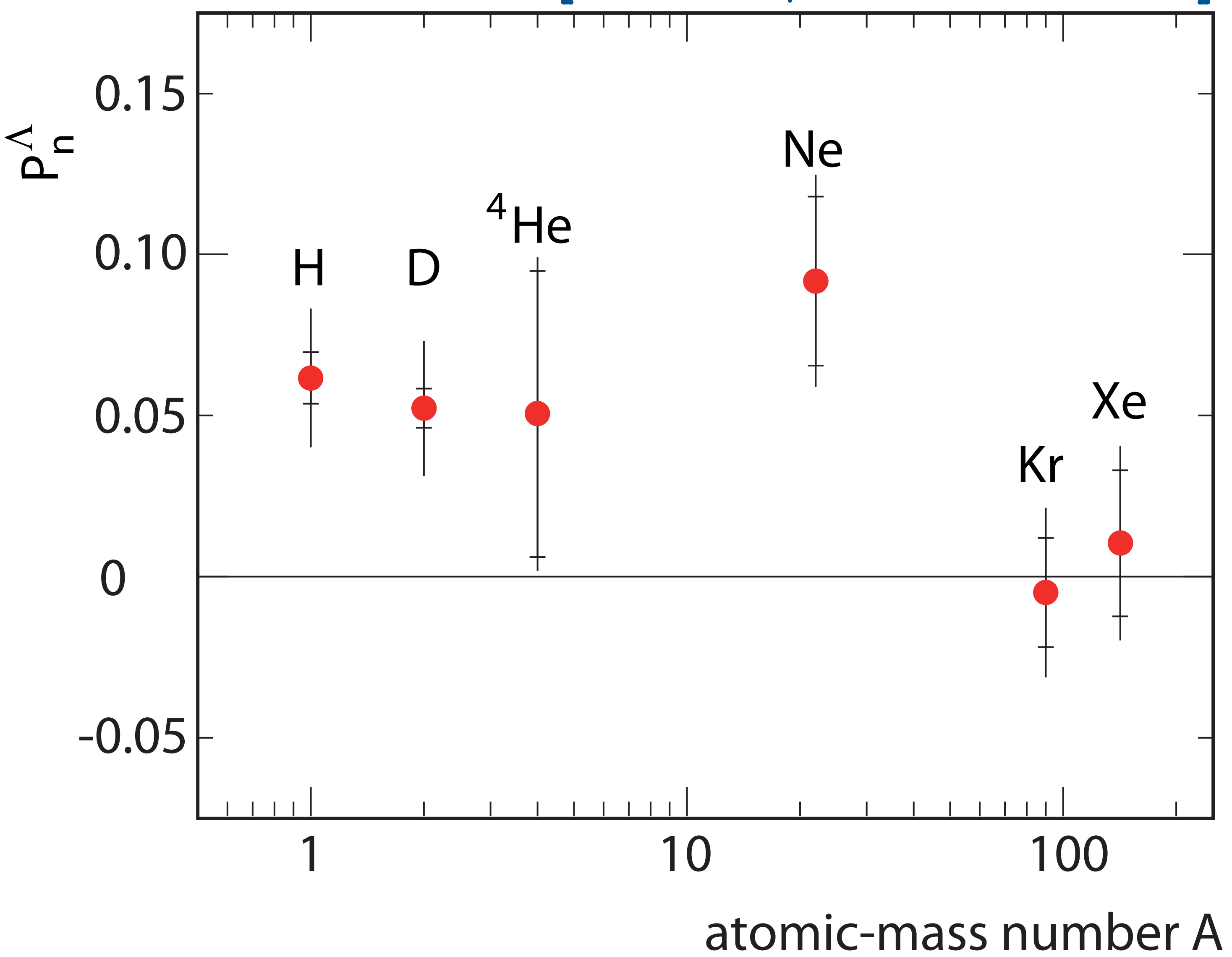
$ep \to \Lambda^\uparrow X$



[Y. Koike, hep-ph/0210434]

the other inclusive SSA

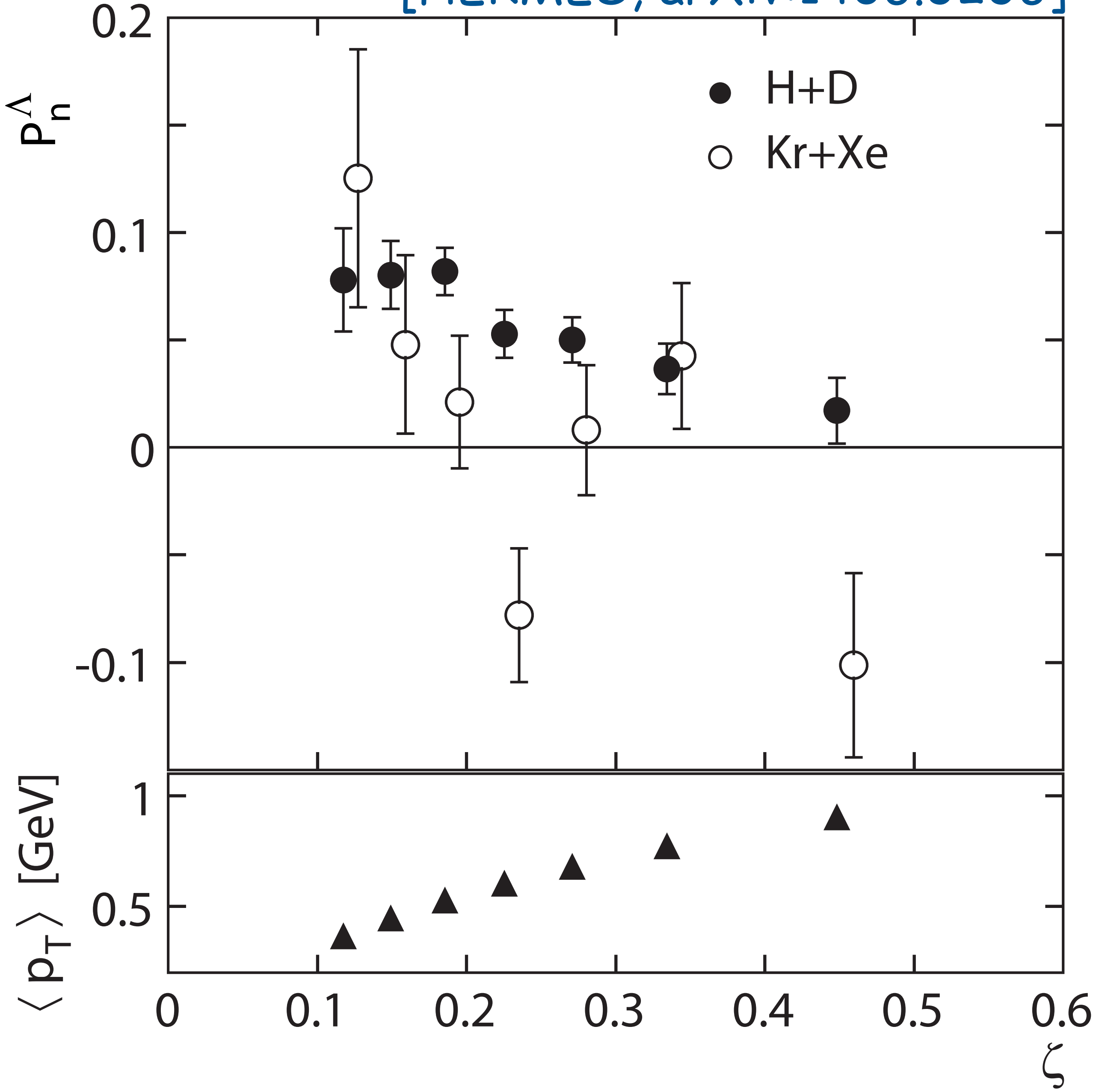
[HERMES, arXiv:1406.3236]

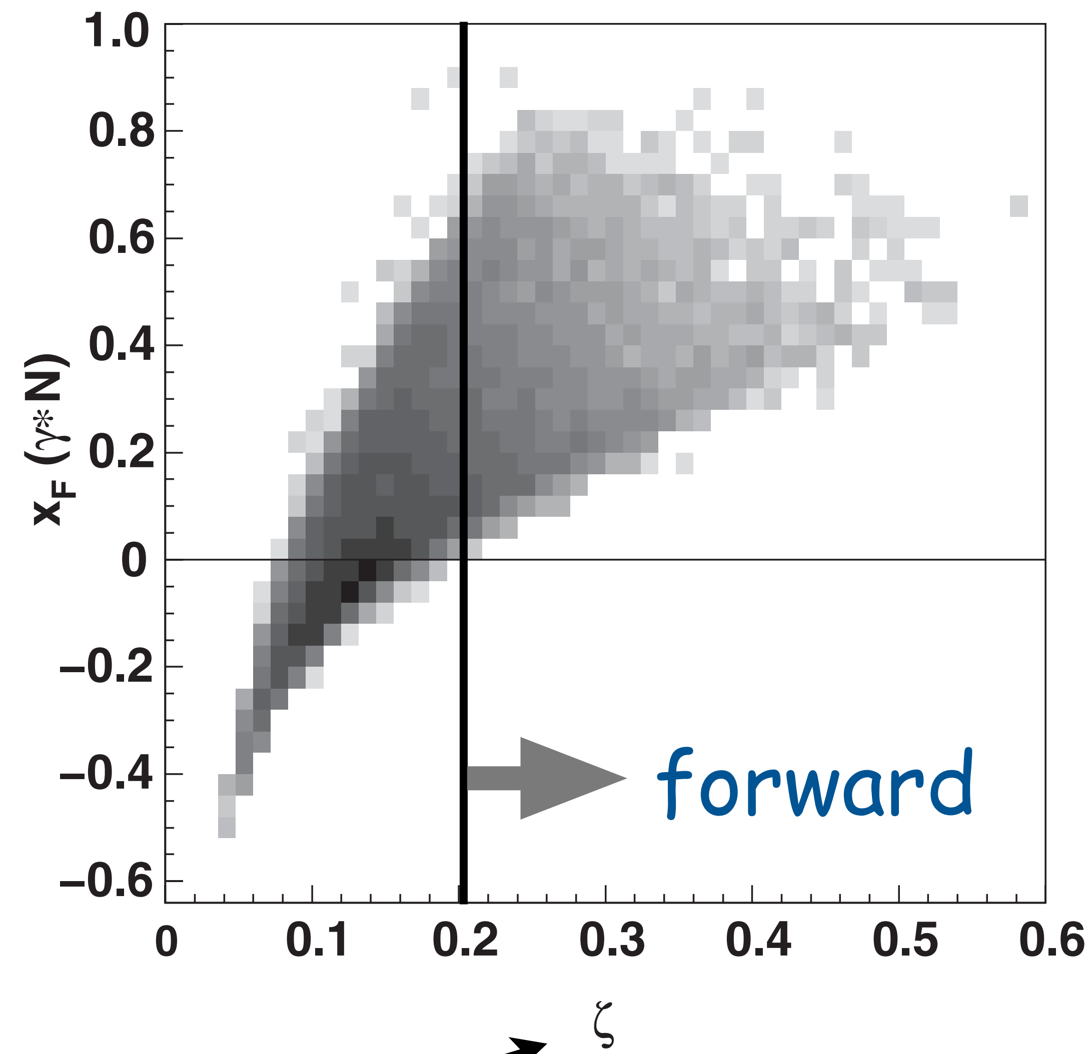


- clearly positive for light target nuclei
- consistent with zero for heavy targets

the other inclusive SSA

[HERMES, arXiv:1406.3236]



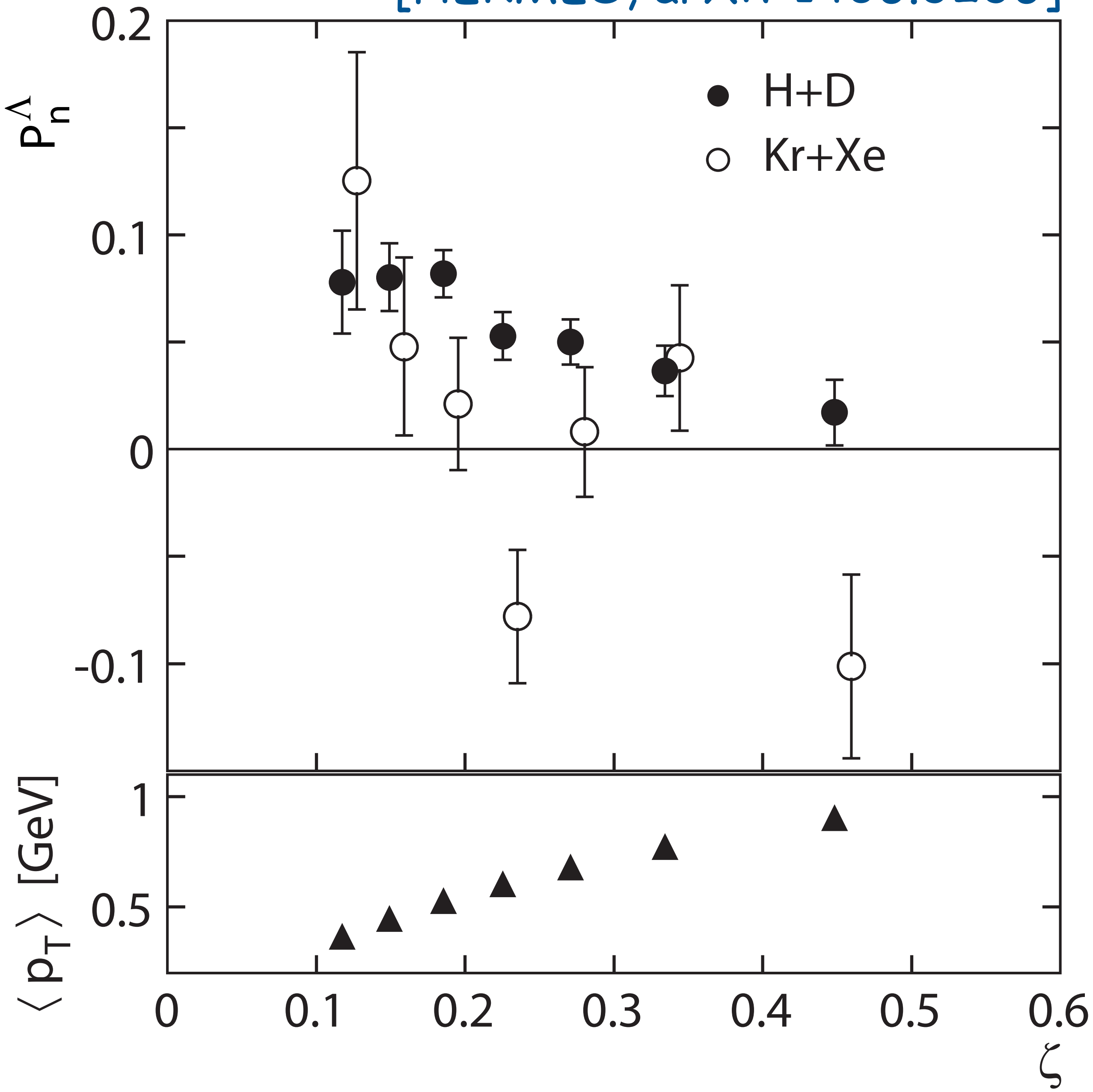


$$\zeta \equiv (E_\Lambda + p_{z\Lambda})/(E_e + p_e)$$

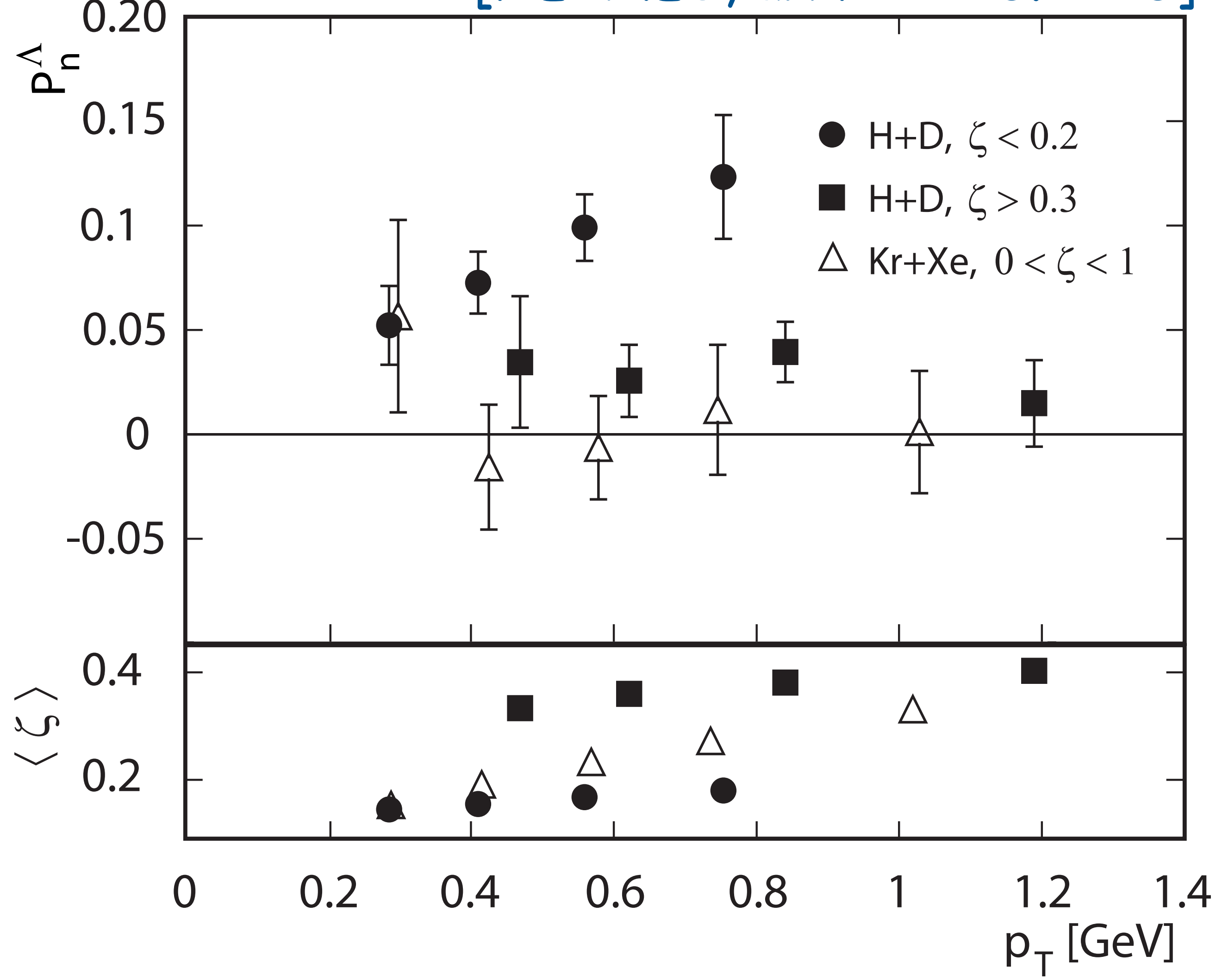
- larger in backward direction w.r.t. incoming lepton
- consistent with x_F dependence of twist-3 calculation (opposite sign conventions for x_F !)

the other inclusive SSA

[HERMES, arXiv:1406.3236]



[HERMES, arXiv:1406.3236]



- larger in backward direction w.r.t. incoming lepton
- distinct p_T dependences in forward and backward directions: rising with p_T in backward direction as in pp

Summary

- SIDIS dihadron moments (in new partial wave expansion) provide potentially rich information on various distribution and fragmentation functions
- inclusive A_{UT} provides information that can contribute to understanding of A_N in pp data
- inclusive production of Λ in ep can provide complementary information to pp data on the mechanism to generate Λ polarization