Transversity

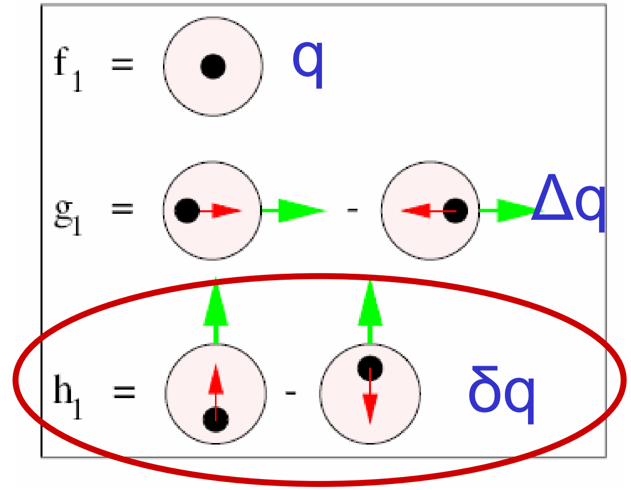
--status & opportunities with Hall C upgrade--

Lingyan Zhu

University of Illinois at Urbana-Champaign

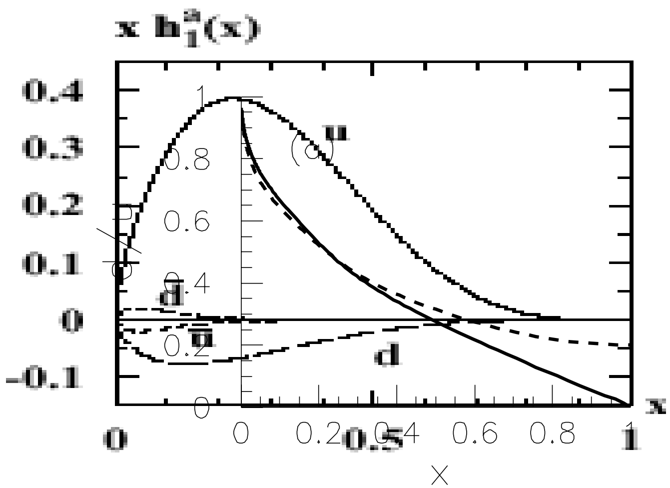
Hall C Summer Workshop, Aug. 25, 2006

Transversity

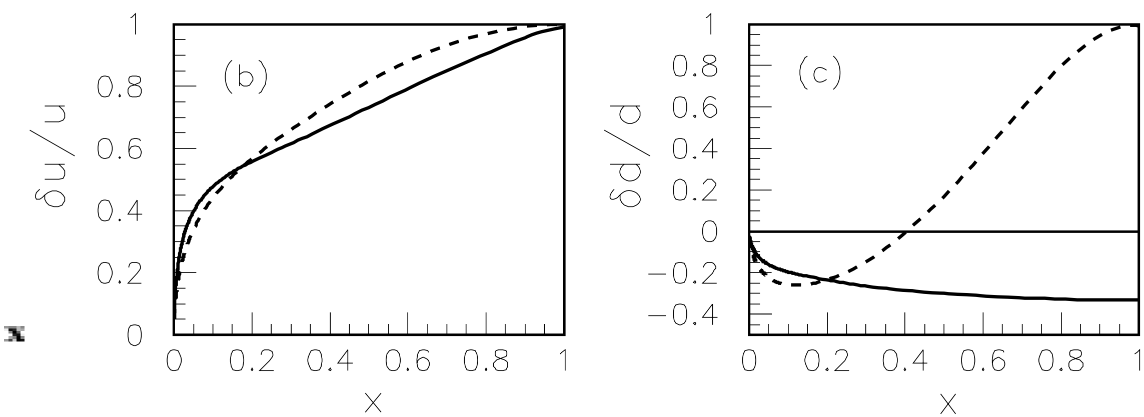


- $\delta q(x) = \Delta q(x)$ for non-relativistic quarks
- δq and gluons do not mix
  → Q^2-evolution for δq and Δq are different
- Chiral-odd → not accessible in inclusive DIS

Chiral-quark soliton model



Quark – diquark model (solid) & pQCD-based model (dashed)



P. Schweitzer *et al*,

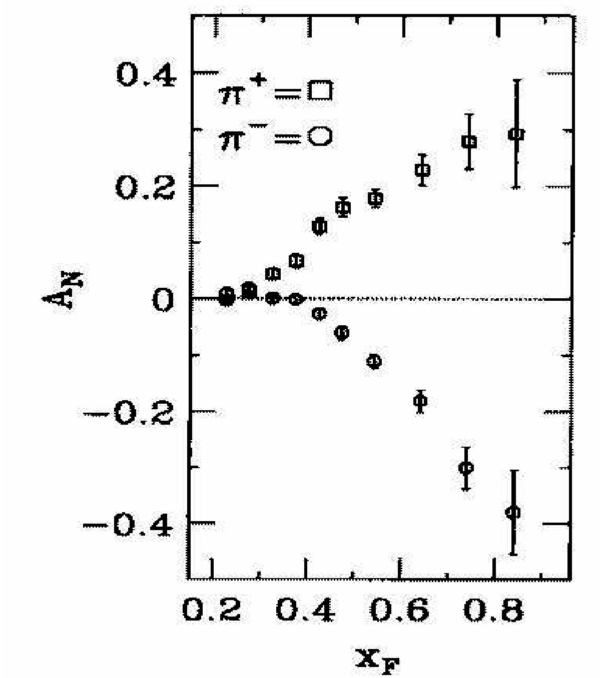
Phys.Rev. D64 (2001) 034013

B.Q. Ma, I. Schmidt and J. J. Yang,

Phys.Rev. D65 (2002) 034010

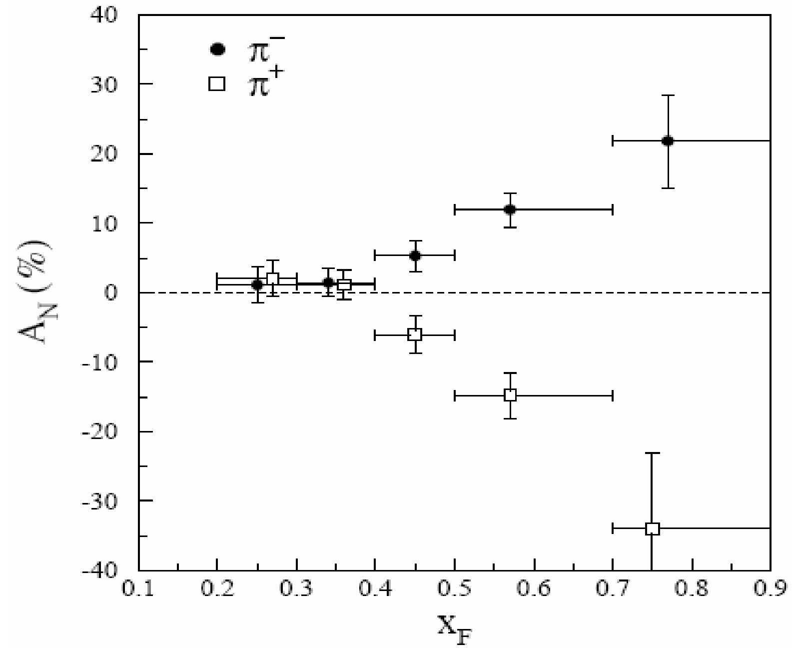
$$p^{\uparrow} p \to \pi X$$

FNAL E704: Phys.Lett. B264 (1991) 462.

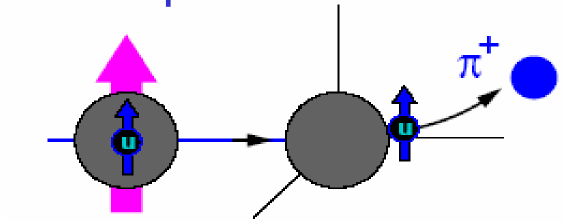


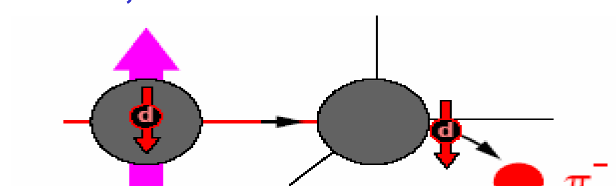
$$\bar{p}^{\uparrow} p \to \pi X$$

E704: Phys.Rev.Lett. 77 (1996) 2626.



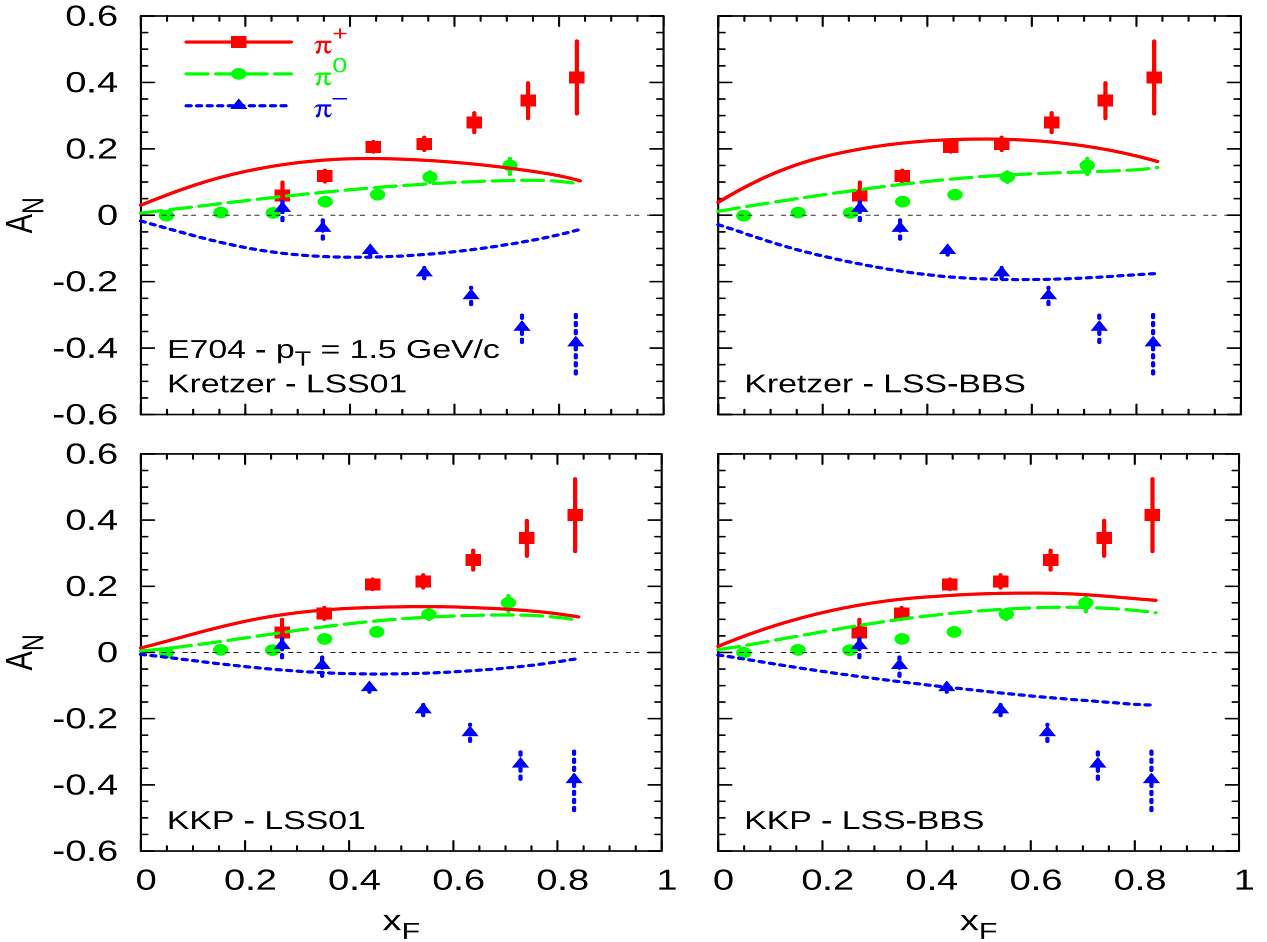
One possible explanation: transversity $\delta u > 0$, $\delta d < 0$





Suppression of the Collins mechanism

M.Anselmino *et al*, Phys.Rev. D71 (2005) 014002 [hep-ph/0408356]

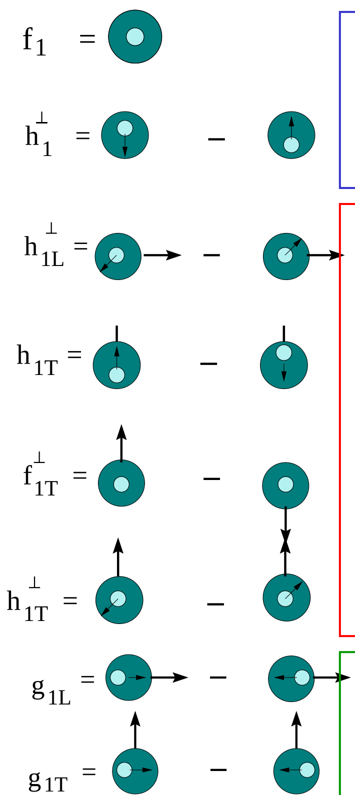


Sivers effect is not suppressed by the intrinsic partonic motion.

All Eight Quark Distributions Are Probed in Semi-Inclusive DIS

D. Boer, R. Jakob, and P.J. Mulders, NPB564, 471 (2000) [hep-ph/9907504].

$$\left[\frac{d\sigma(lH \to l'hX)}{d\Omega dx dz d^2 q_T}\right]_{UU} = \frac{\alpha^2 x z^2 s}{Q^4} \sum_{q,\bar{q}}$$



Unpolarized

$$\Big\{(1-y+y^2/2)e_q^2 \mathcal{F}[f_1 D_1]$$

$$+ \ (1-y)e_q^2 \cos(2\phi)\mathcal{F}\left[\left(2\hat{h}\cdot p_T \hat{h}\cdot k_T - p_T \cdot k_T\right)\frac{h_1^{\perp} H_1^{\perp}}{M_1 M_2}\right]$$

Polarized target

$$- \ |S_L|(1-y)e_q^2 \sin(2\phi)\mathcal{F}\left[\left(2\,\hat{h}\cdot p_T\ \hat{h}\cdot k_T \ - \ p_T\cdot k_T\right)\frac{h_{1L}^{\perp} H_1^{\perp}}{M M_h}\right]$$

$$- \ |S_T|(1-y)e_q^2 \sin(\phi+\phi_S)\mathcal{F}\left[\hat{h}\cdot k_T \frac{h_1 H_1^{\perp}}{M_h}\right]$$

Transversity/Collins

$$+ \ |S_T|(1-y+y^2/2)e_q^2 \sin(\phi-\phi_S)\mathcal{F}\left[\hat{h}\cdot p_T \frac{f_{1T}^{\perp} D_1}{M}\right]$$

Sivers

$$- \ |S_T|(1-y)e_q^2 \sin(3\phi-\phi_S)\mathcal{F}\left[\left(4\,(\hat{h}\cdot p_T)^2\,\hat{h}\cdot k_T - 2\,\hat{h}\cdot p_T\ p_T\cdot k_T \ - \ p_T^2\,\hat{h}\cdot k_T\right)\frac{h_{1T}^{\perp} H_1^{\perp}}{2M^2 M_h}\right]$$

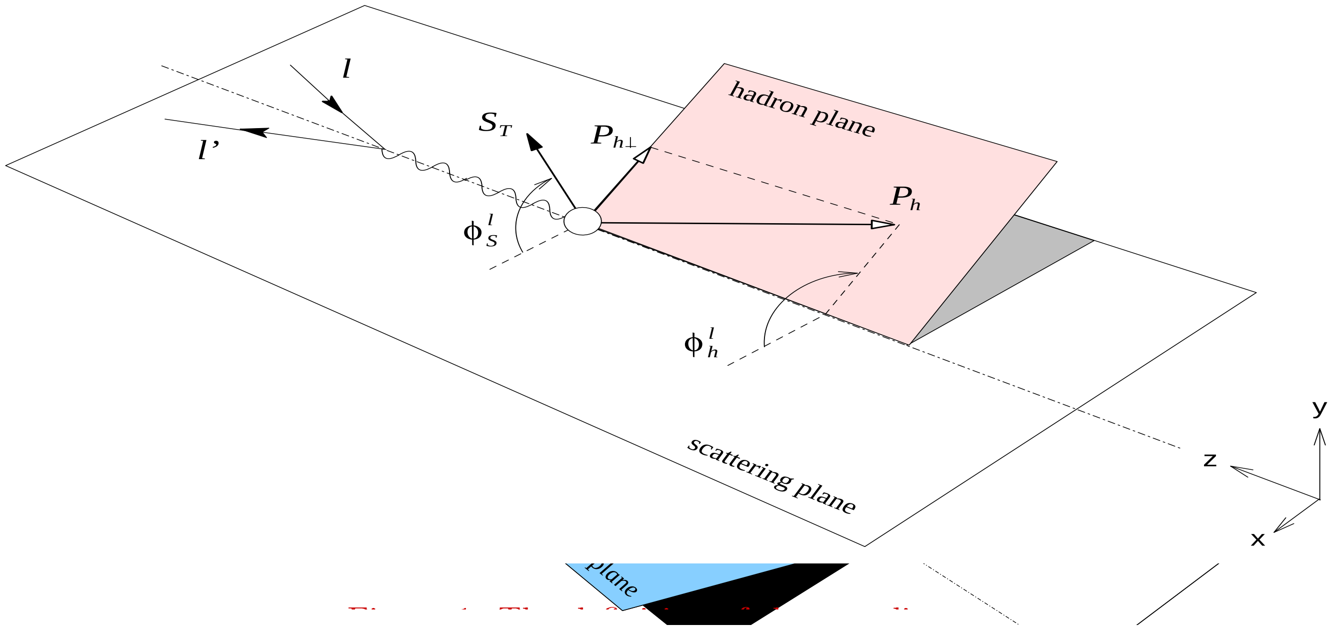
Polarized beam and target

$$+ \ \lambda_e |S_L| y(1-y/2)e_q^2 \mathcal{F}[g_1 D_1]$$

$$+ \ \lambda_e |S_T| y(1-y/2)e_q^2 \cos(\phi-\phi_S)\mathcal{F}\left[\hat{h}\cdot p_T \frac{g_{1T} D_1}{M}\right]\Big\}$$

S_L and S_T: Target Polarizations; λe: Beam Polarization

Target Single-Spin Asymmetry in SIDIS



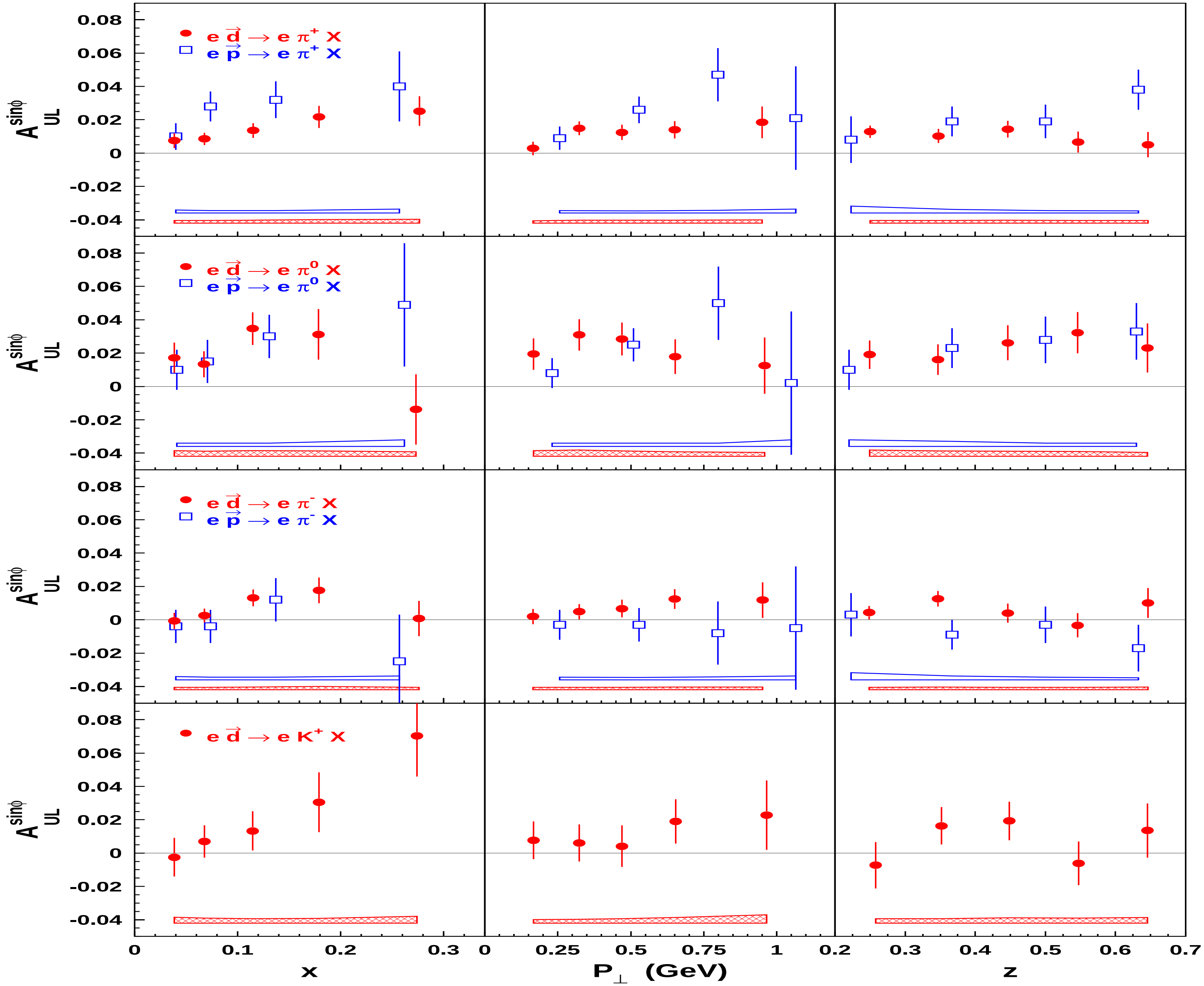
$$
\begin{aligned}
A_{UT}^{uw,gauss} &\propto A(<p_T>,<k_T>)|S_T|(1-y)\sin(\phi_h+\phi_S)\sum e_q^2 h_1^q H_{1q}^{\perp h(1/2)} \quad \text{Collins term} \\
&+ B(<p_T>,<k_T>)|S_T|(1-y+y^2/2)\sin(\phi_h-\phi_S)\sum e_q^2 f_{1T}^{\perp q} D_{1q}^{h(1/2)}
\end{aligned}
$$

Sivers term

p_T /k_T: Intrinsic transverse momentum of quark/fragmentation

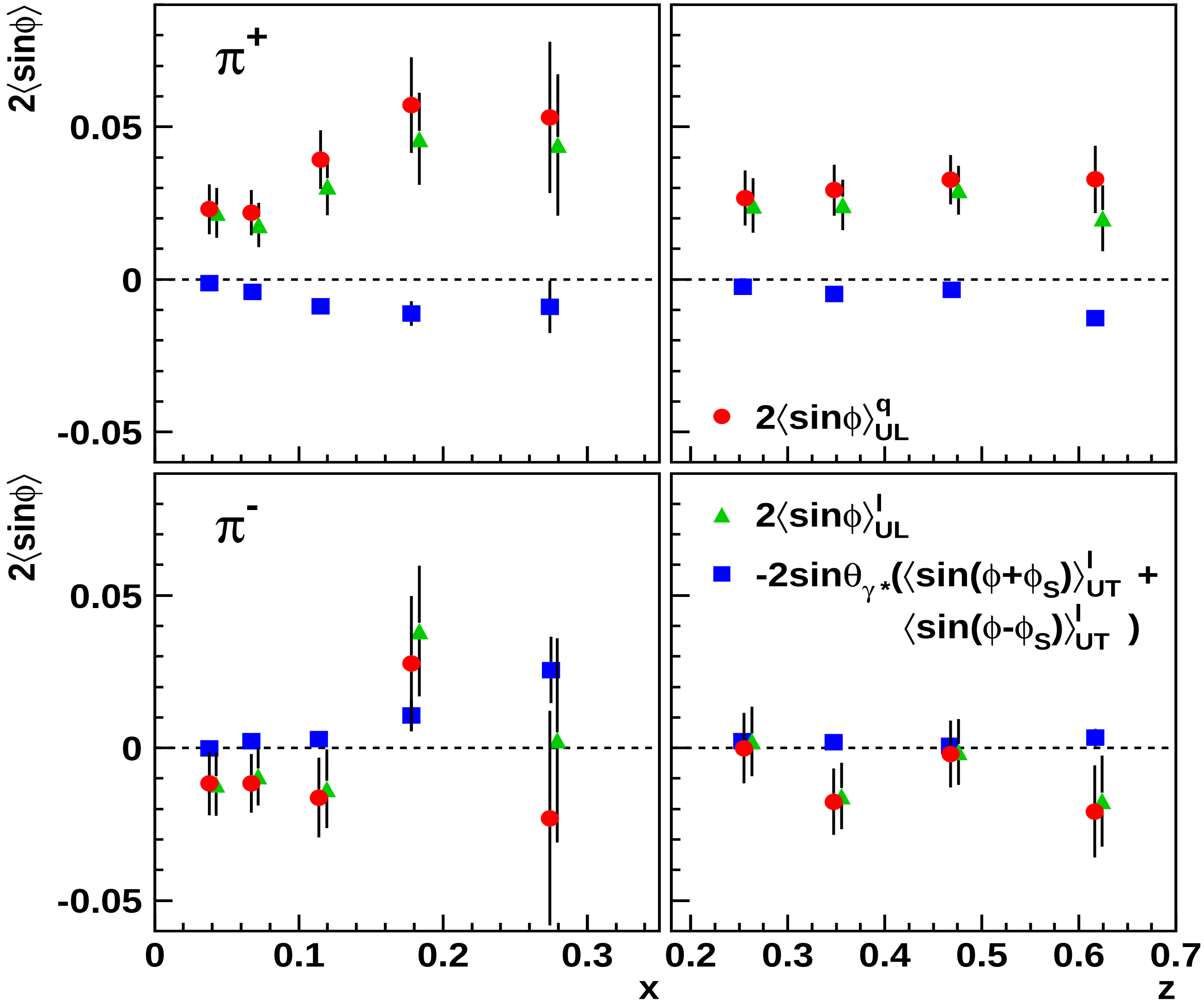
The angles are defined relative to the virtual photon direction.

$A_{UL}^{\sin\phi}$ from HERMES



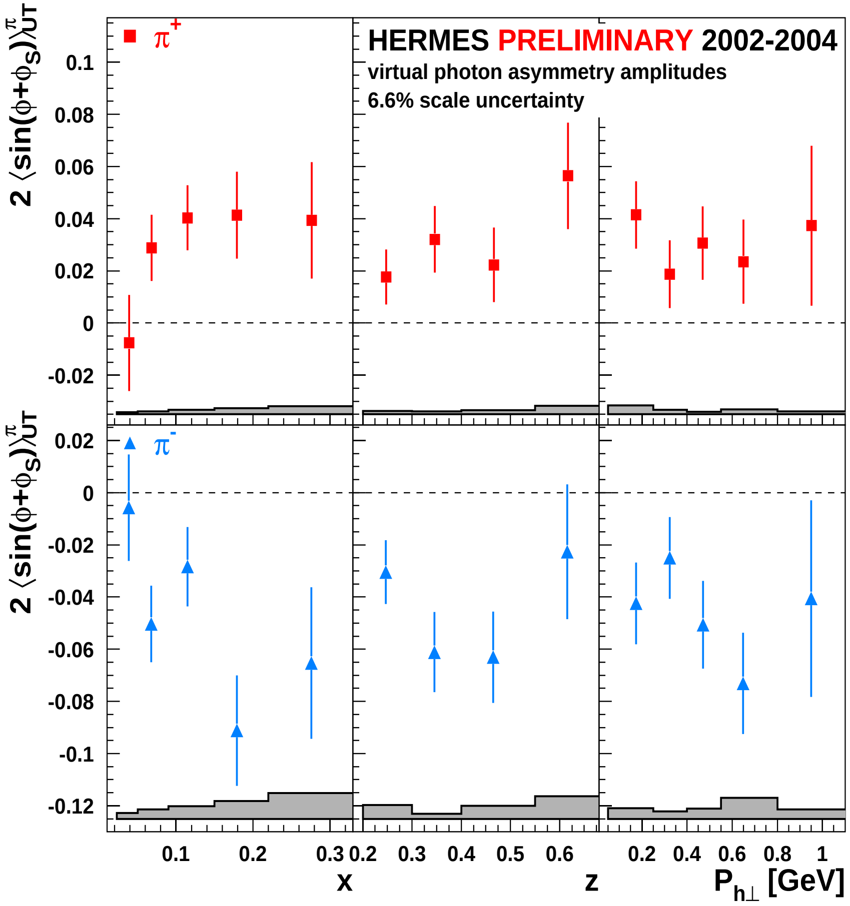
$A_{UL}^{\sin\phi}$ from HERMES

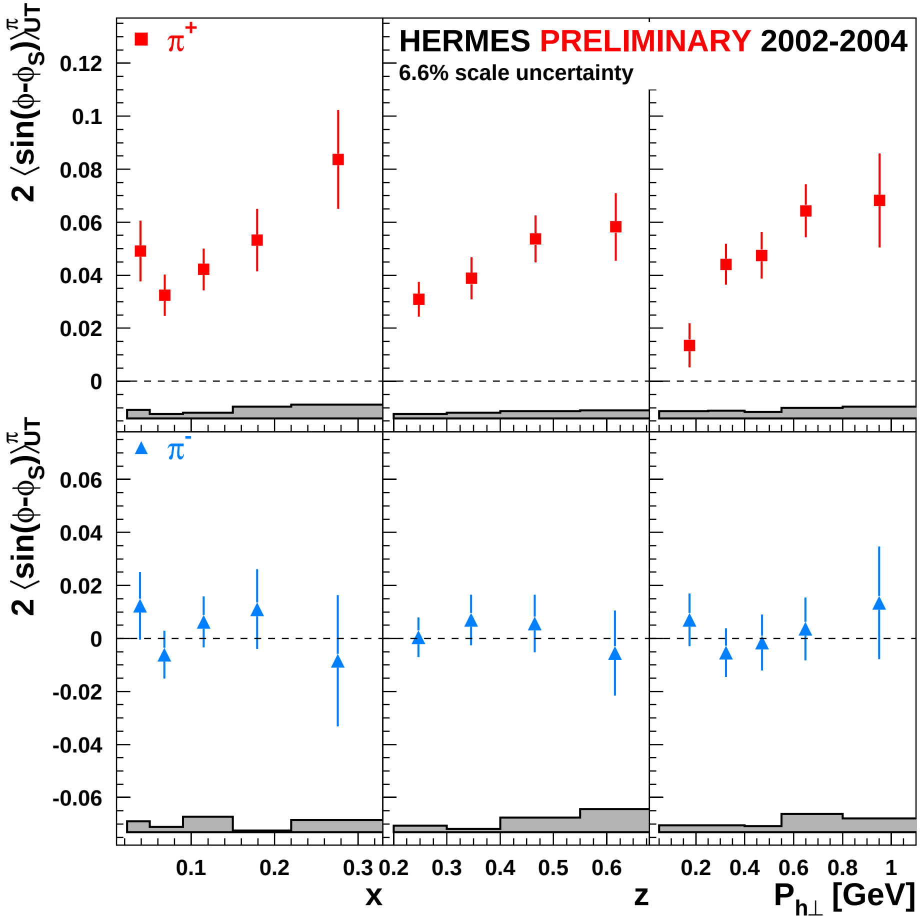
turned out to be dominated by high twist effect



HERMES data: Collins and Sivers Moments

$2 < \sin\phi_{Collins} >^{\pi}_{UT}$ $2 < \sin\phi_{Sivers} >^{\pi}_{UT}$

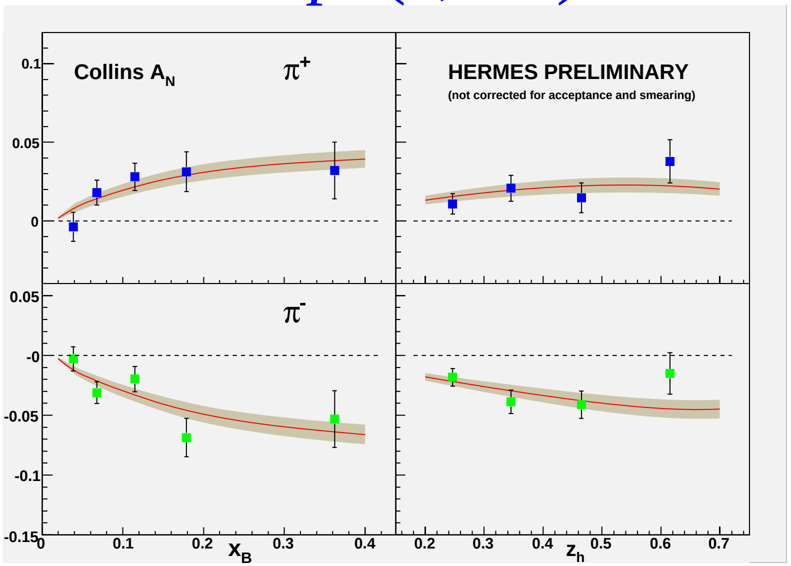




Extraction of Collins functions from HERMES data

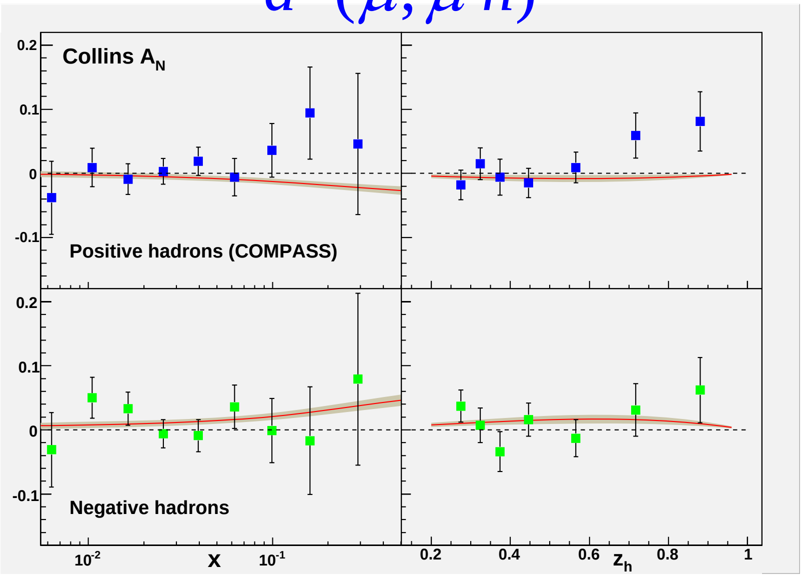
Fits to the Hermes data

$p^{\uparrow}(e, e'\pi)$



"Prediction" of the Compass data

$d^{\uparrow}(\mu, \mu' h)$



Assuming $H_1^{\perp, fav}(z) = C_{fav} z(1-z) D_1^{fav}(z); \quad H_1^{\perp, unfav}(z) = C_{unfav} z(1-z) D_1^{fav}(z)$

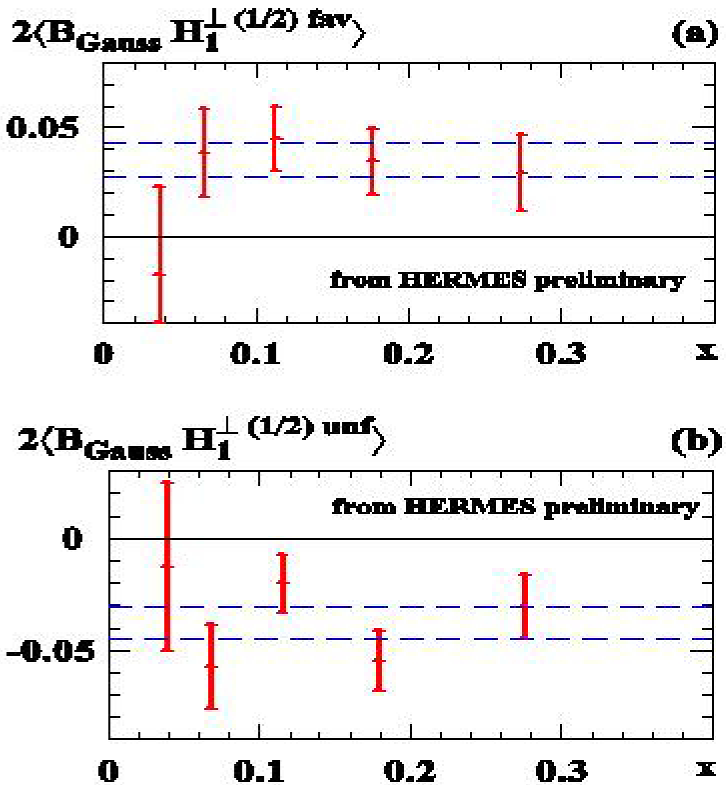
$$C_{fav} = -0.29 \pm 0.04, \quad C_{unfav} = 0.33 \pm 0.04$$

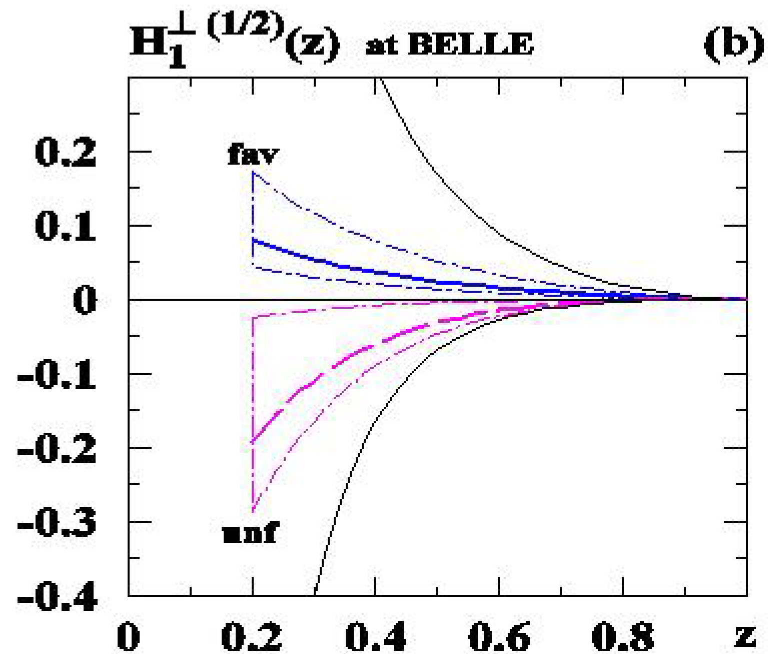
W. Vogelsang & F. Yuan, Phys.Rev.D72(2005)054028 [hep-ph/0507266]

$$H_1^{\perp, unfavored} / H_1^{\perp, favored} \approx -1$$

Favored/Unfavored Collins fragmentation functions

$$ep^{\uparrow} \rightarrow e'\pi X \qquad\qquad e^+e^- \rightarrow h_1 h_2 X$$





Efremov, Goeke, and Schweitzer, Phys.Rev. D73 (2006) 094025

SIDIS and e^+e^- data are consistent within uncertainties.

Collins Asymmetry in Pion SIDIS

$$H^{+} \equiv H_{u}^{\pi^{+}} = H_{\bar{u}}^{\pi^{-}} = H_{\bar{d}}^{\pi^{+}} = H_{d}^{\pi^{-}}$$

$$H^{-} \equiv H_{\bar{u}}^{\pi^{+}} = H_{u}^{\pi^{-}} = H_{d}^{\pi^{+}} = H_{\bar{d}}^{\pi^{-}}$$

$$H_{s}^{\pi} \equiv H_{s}^{\pi^{+}} = H_{s}^{\pi^{-}} = H_{\bar{s}}^{\pi^{+}} = H_{\bar{s}}^{\pi^{-}}$$

$H = H_1^{\perp(1/2)}$

for unweighted Collins moments

$$A_p^{\pi^+} \propto \frac{(4\delta u + \delta\bar{d})H^{+} + (\delta d + 4\delta\bar{u})H^{-} + (\delta s + \delta\bar{s})H_s^{\pi}}{(4u + \bar{d})D^{+} + (d + 4\bar{u})D^{-} + (s + \bar{s})D_s^{\pi}}$$

$$A_p^{\pi^-} \propto \frac{(4\delta u + \delta\bar{d})H^{-} + (\delta d + 4\delta\bar{u})H^{+} + (\delta s + \delta\bar{s})H_s^{\pi}}{(4u + \bar{d})D^{-} + (d + 4\bar{u})D^{+} + (s + \bar{s})D_s^{\pi}}$$

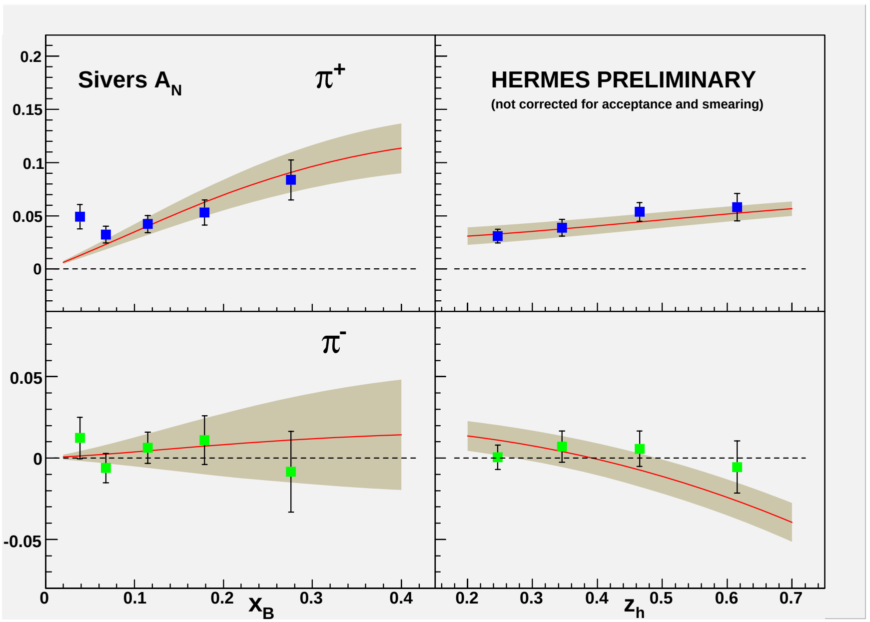
$$A_n^{\pi^+} \propto \frac{(4\delta d + \delta\bar{u})H^{+} + (\delta u + 4\delta\bar{d})H^{-} + (\delta s + \delta\bar{s})H_s^{\pi}}{(4d + \bar{u})D^{+} + (u + 4\bar{d})D^{-} + (s + \bar{s})D_s^{\pi}}$$

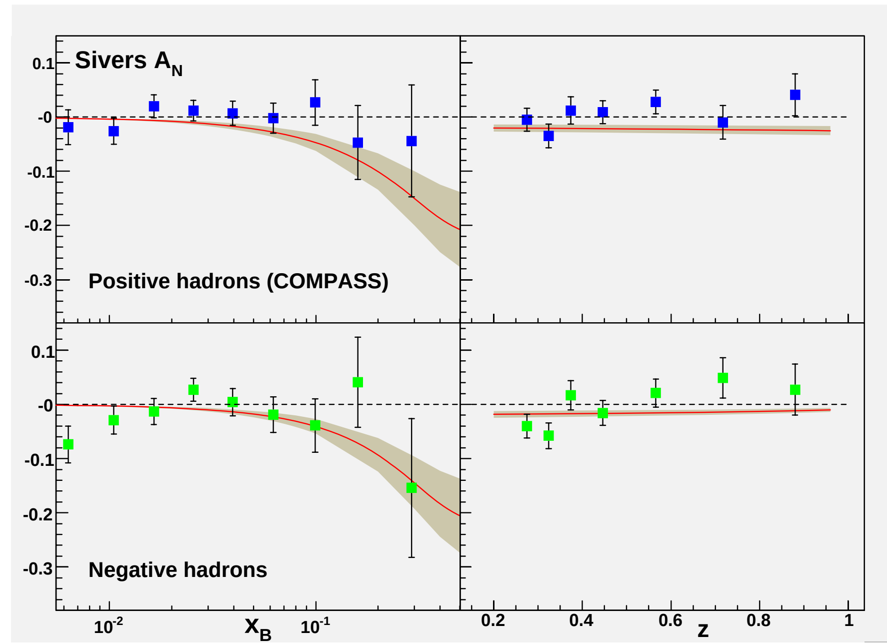
$$A_n^{\pi^-} \propto \frac{(4\delta d + \delta\bar{u})H^{-} + (\delta u + 4\delta\bar{d})H^{+} + (\delta s + \delta\bar{s})H_s^{\pi}}{(4d + \bar{u})D^{-} + (u + 4\bar{d})D^{+} + (s + \bar{s})D_s^{\pi}}$$

$$\frac{H^{-}}{H^{+}} = \frac{A_p^{\pi^-}}{A_p^{\pi^+}} \cdot \frac{D^{-}}{D^{+}} \approx -1 \text{ with u quark dominance}$$

Extraction of Sivers function from HERMES data

Fits to the Hermes data | "Prediction" of the Compass data





Assuming $f_{1T}^{\perp,u}(x) = S_u\, x(1-x)\, u(x); \quad f_{1T}^{\perp,d}(x) = S_d\, x(1-x)\, u(x)$

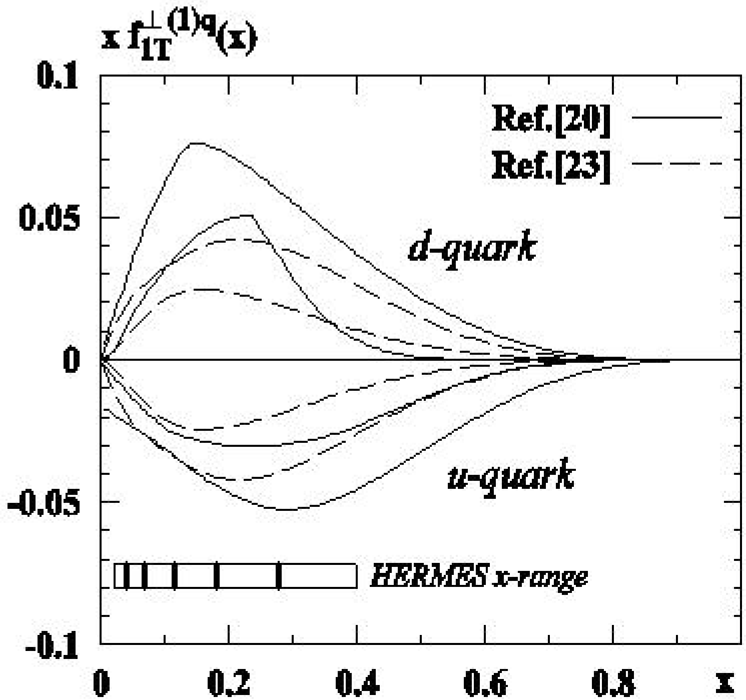
$S_u = -0.81 \pm 0.07, \quad S_d = 1.86 \pm 0.28$

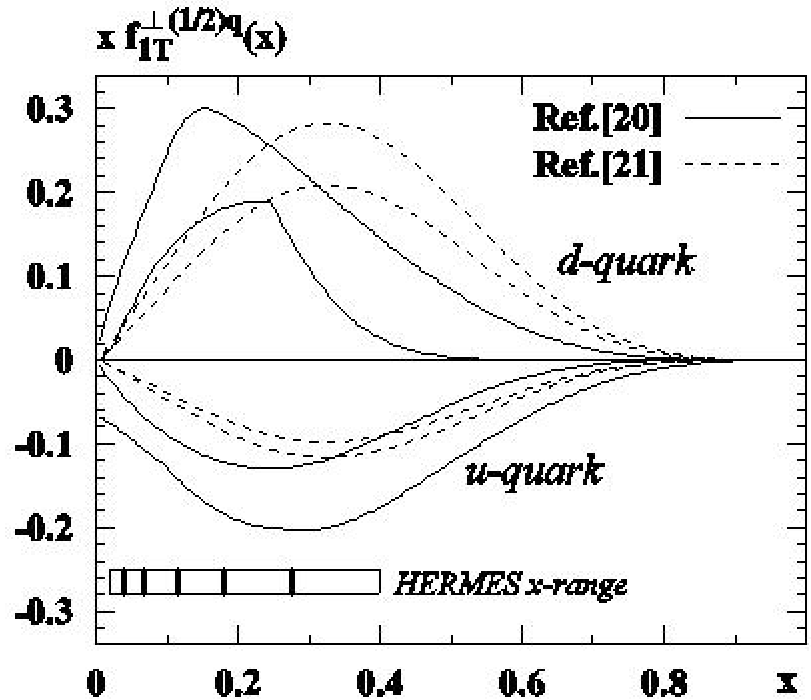
Vogelsang and Yuan, Phys.Rev.D72(2005)054028 [hep-ph/0507266]

Striking flavor dependence of the Sivers function

Comparing extractions of Sivers functions

M.Anselmino *et al*, hep-ph/0511017





Ref.[20] M.Anselmino *et al*, Phys.Rev.D72(2005)094007[hep-ph/0507181]
Ref.[21] W.Vogelsang & F.Yuan, Phys.Rev.D72(2005)054028[hep-ph/0507266]
Ref.[23] J.C.Collins *et al*, hep-ph/0510342

Satisfactory qualitative agreement between different models

Sivers Asymmetry in Pion SIDIS

$$A_p^{\pi^+} \propto \frac{(4f_{1T}^{\perp,u} + f_{1T}^{\perp,\bar{d}})D^+ + (f_{1T}^{\perp,d} + 4f_{1T}^{\perp,\bar{u}})D^- + (f_{1T}^{\perp,s} + f_{1T}^{\perp,\bar{s}})D_s^{\pi}}{(4u+\bar{d})D^+ + (d+4\bar{u})D^- + (s+\bar{s})D_s^{\pi}}$$

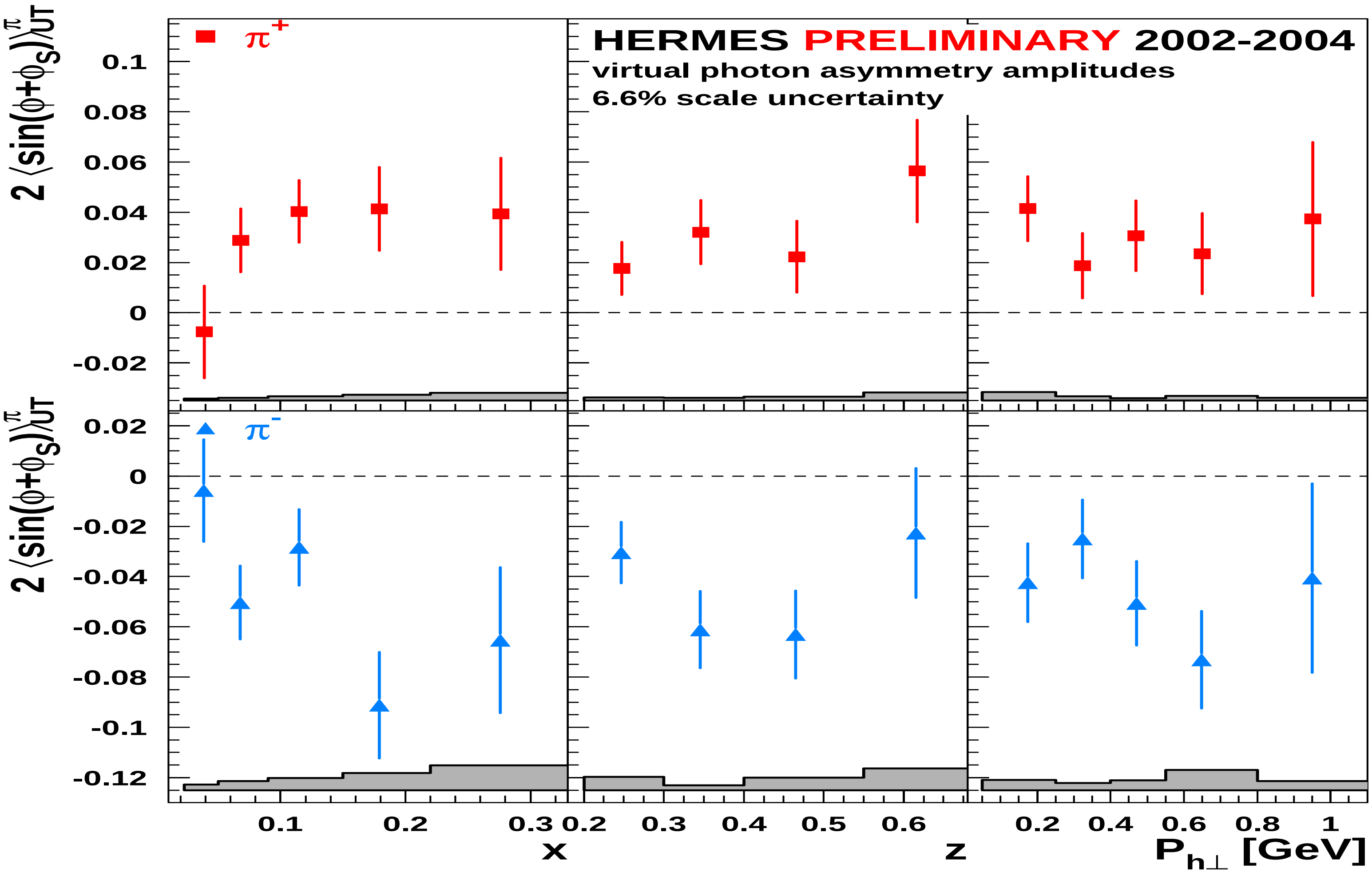
$$A_p^{\pi^-} \propto \frac{(4f_{1T}^{\perp,u} + f_{1T}^{\perp,\bar{d}})D^- + (f_{1T}^{\perp,d} + 4f_{1T}^{\perp,\bar{u}})D^+ + (f_{1T}^{\perp,s} + f_{1T}^{\perp,\bar{s}})D_s^{\pi}}{(4u+\bar{d})D^- + (d+4\bar{u})D^+ + (s+\bar{s})D_s^{\pi}}$$

$$A_n^{\pi^+} \propto \frac{(4f_{1T}^{\perp,d} + f_{1T}^{\perp,\bar{u}})D^+ + (f_{1T}^{\perp,u} + 4f_{1T}^{\perp,\bar{d}})D^- + (f_{1T}^{\perp,s} + f_{1T}^{\perp,\bar{s}})D_s^{\pi}}{(4d+\bar{u})D^+ + (u+4\bar{d})D^- + (s+\bar{s})D_s^{\pi}}$$

$$A_n^{\pi^-} \propto \frac{(4f_{1T}^{\perp,d} + f_{1T}^{\perp,\bar{u}})D^- + (f_{1T}^{\perp,u} + 4f_{1T}^{\perp,\bar{d}})D^+ + (f_{1T}^{\perp,s} + f_{1T}^{\perp,\bar{s}})D_s^{\pi}}{(4d+\bar{u})D^- + (u+4\bar{d})D^+ + (s+\bar{s})D_s^{\pi}}$$

$$A_p^{\pi^-} \approx 0 \Rightarrow \frac{f_{1T}^{\perp,u}}{f_{1T}^{\perp,d}} \approx -\frac{D^+}{4D^-} \approx -2$$

Collins $P_{h\perp}$ dependence



$$A_p^{\pi^\pm} \propto P_{h\perp}?$$

Current Status

- Proton data show very large transverse asymmetry, which initiated the excitement on transversity. But more likely, it was due to Sivers effect instead of Collins effect involving transversity.

- HERMES longitudinal data being described very well by various of models turned out to be dominated by high-twist effect.

- HERMES transverse data show some surprising features, for example in Collins H^-/H^+, Sivers $f_{1T}{}^u/f_{1T}{}^d$, and P_{hT} dependence. The current constraint on the transversity is pretty loose, and the x, z and P_T distributions are coupled together.

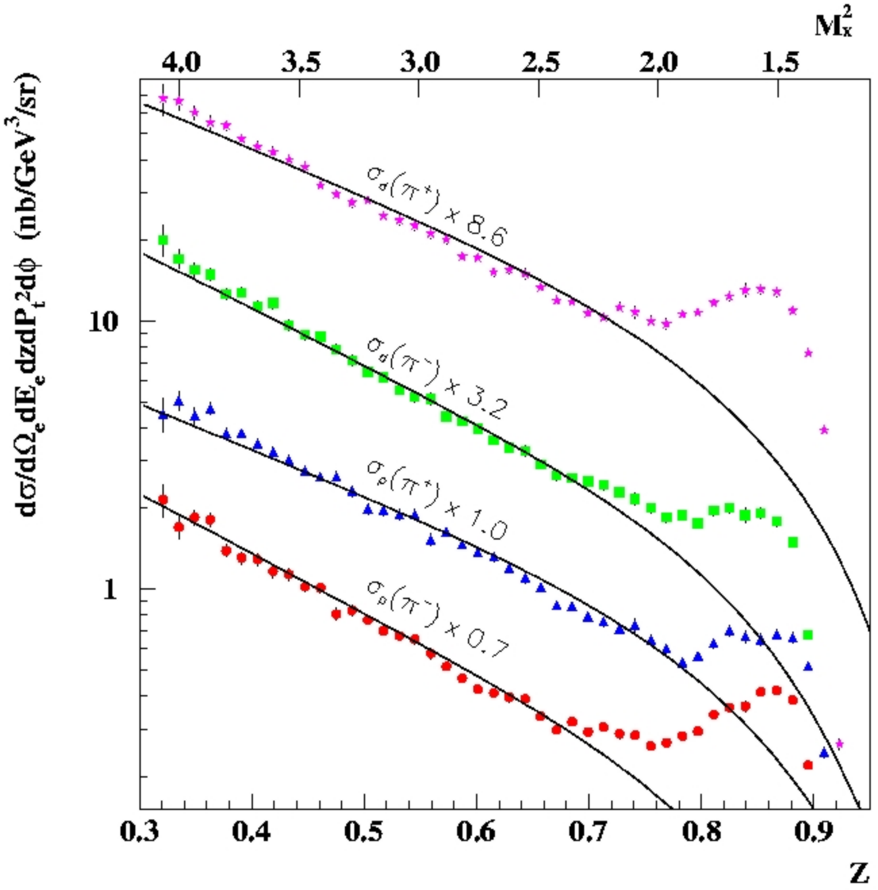
- More data especially with controlled kinematics are essential for cross check, multi-dimension binning, transversity extraction, ...

The way of learning is a way of correcting.

Is SIDIS applicable at JLab?

Preliminary results from Hall-C E00-108

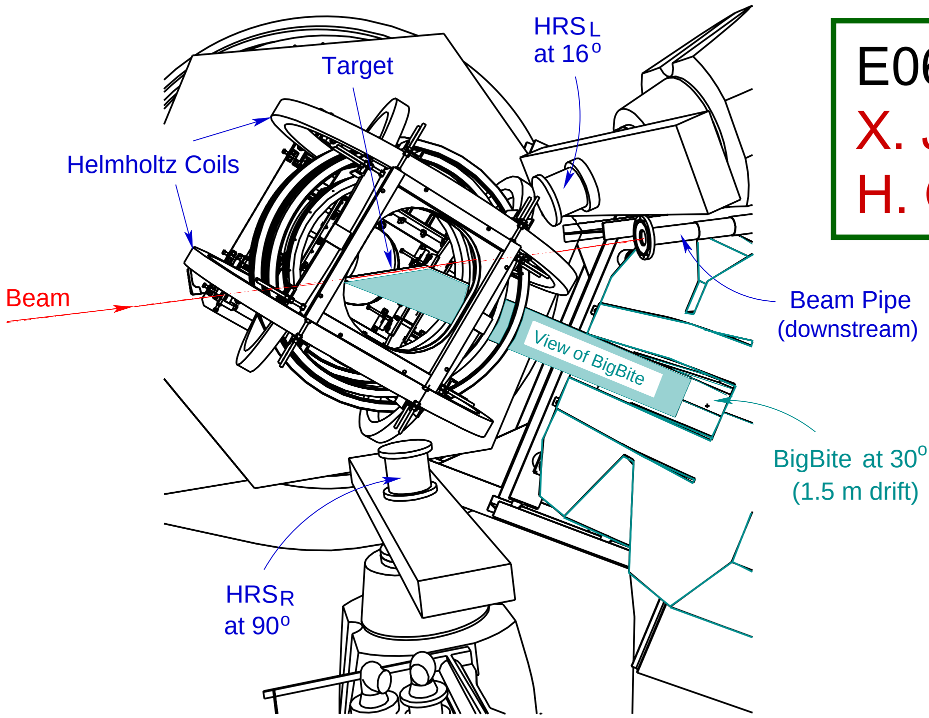
$p(e,e'\pi^{\pm})$ and $d(e,e'\pi^{\pm})$ at $x = 0.3$



E=5.75 GeV

Data beyond Δ region are well described by LO SIDIS ansatz.

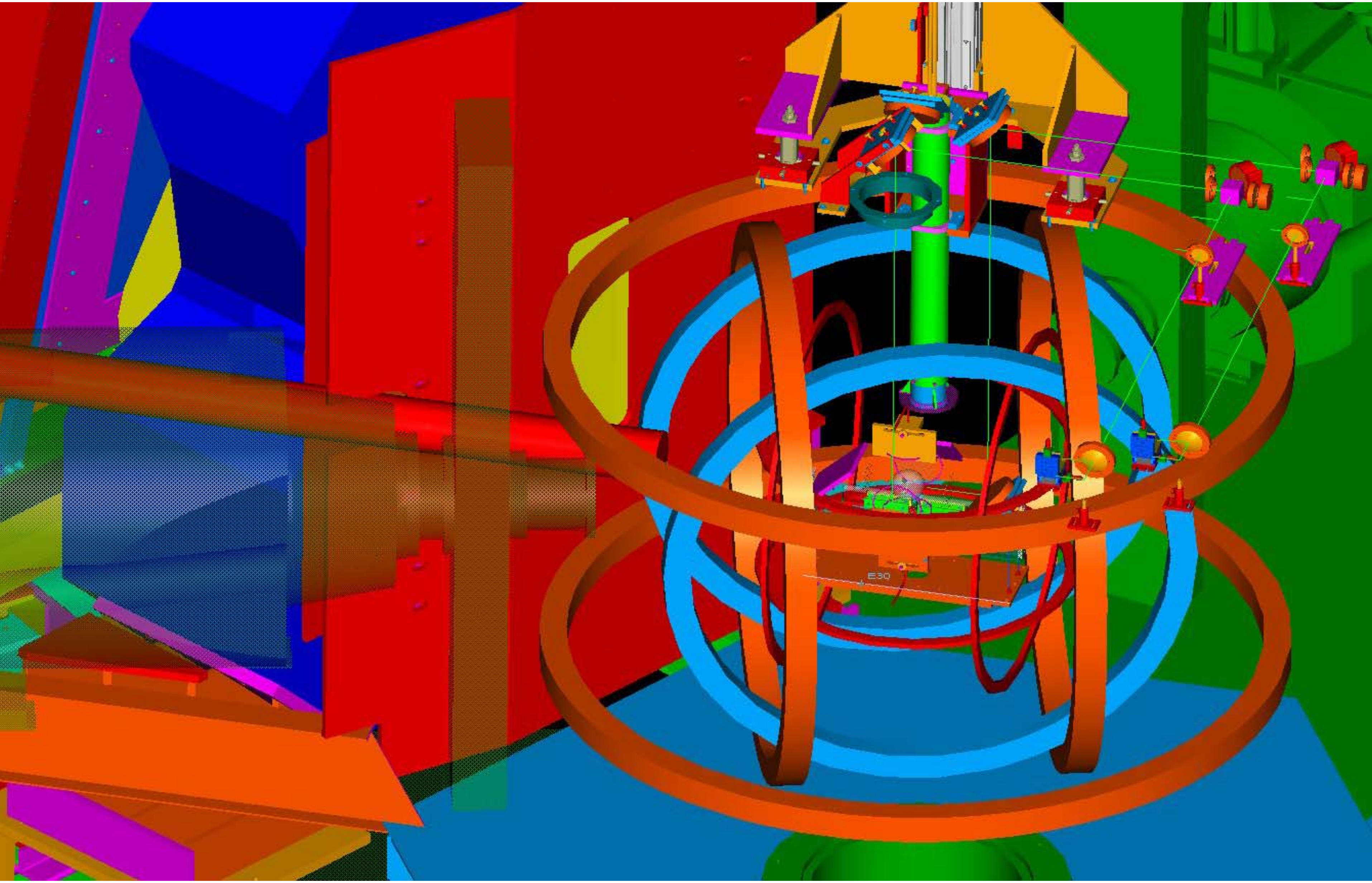
$^3He^{\uparrow}(e,e'\pi^{+/-})x$ at Hall-A



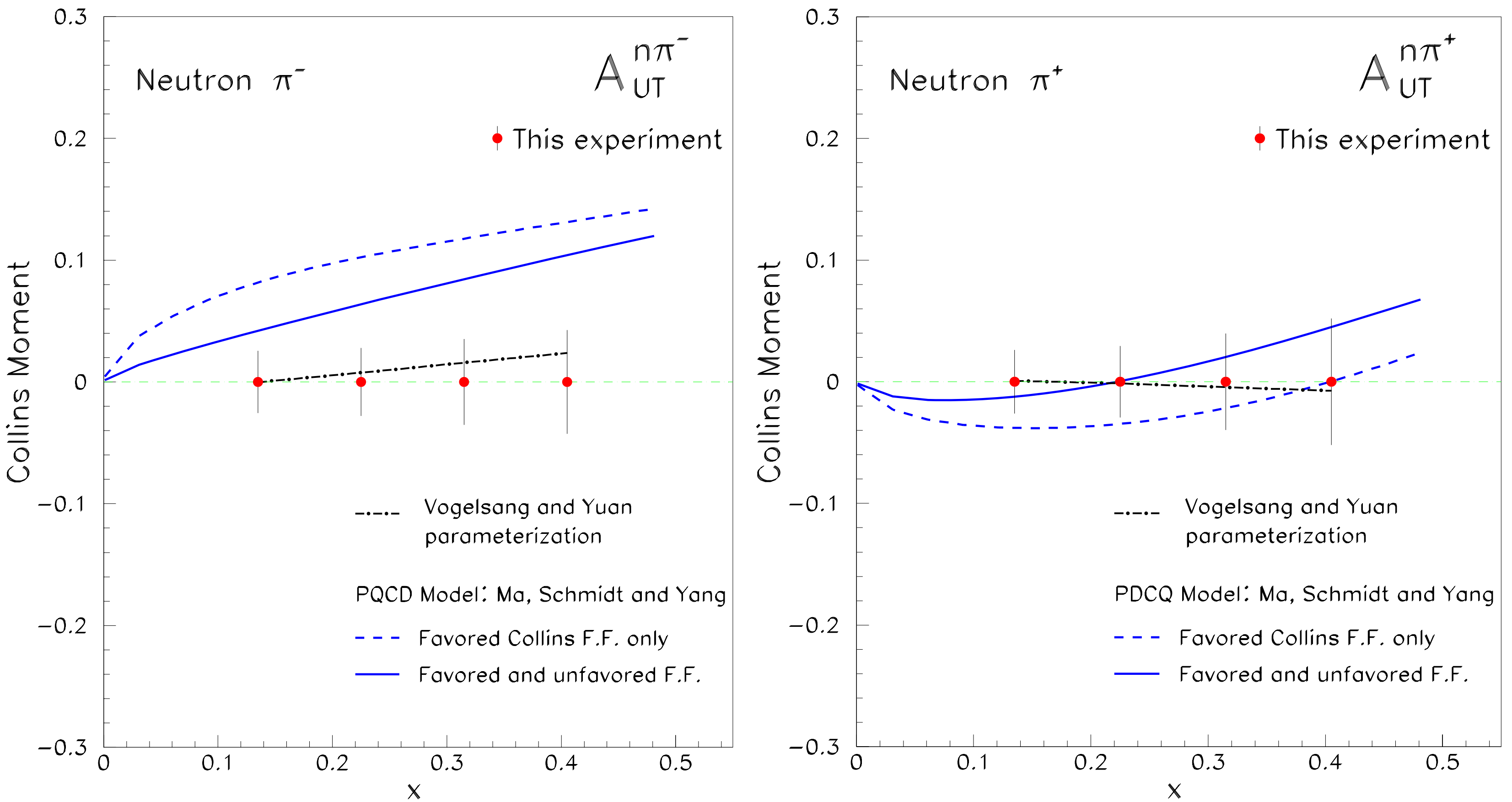
E06-010/06-011 Spokespersons:
X. Jiang, J.P. Chen, E. Cisbani, H. Gao, J.C. Peng

- **Beam**
  - **6 GeV, 15 µA e^- beam**
- **Target**
  - **Optically pumped Rb-K spin-exchange ^3He target, 50 mg/cm^2, ~42% polarization, transversely polarized with tunable direction**
- **Electron detection**
  - **BigBite spectrometer, Solid angle = 60 msr, $\theta_{Lab} = 30^0$**
- **Charged pion detection**
  - **HRS spectrometer, $\theta_{Lab} = -16^0$**

Polarized ^{3}He target with vertical coils



Predictions of Collins asymmetry on neutron

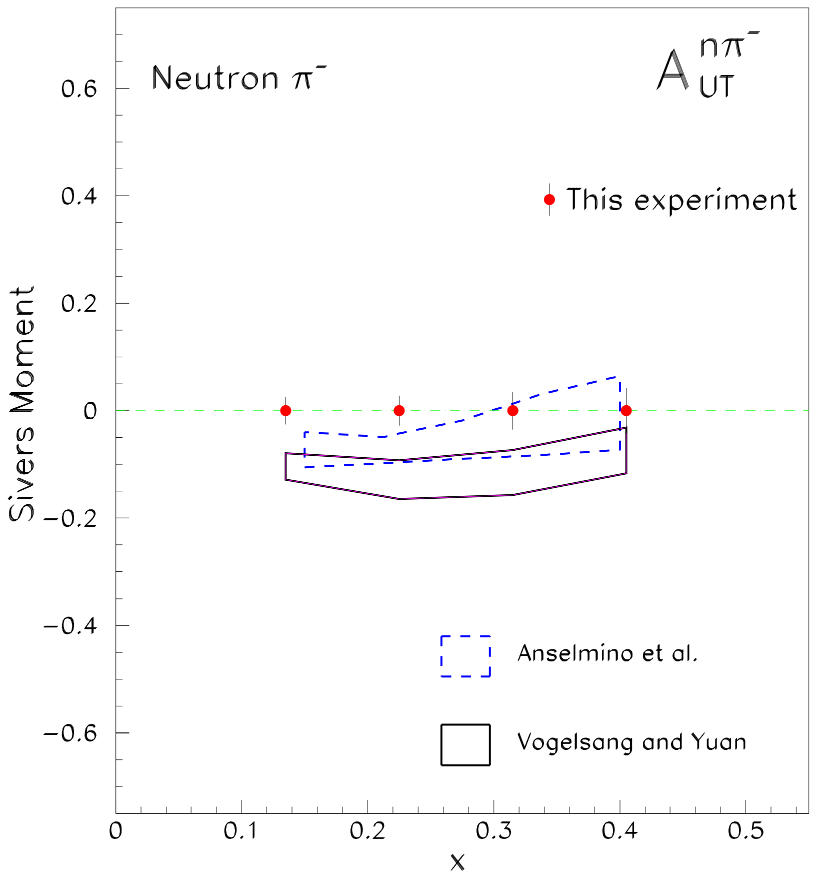


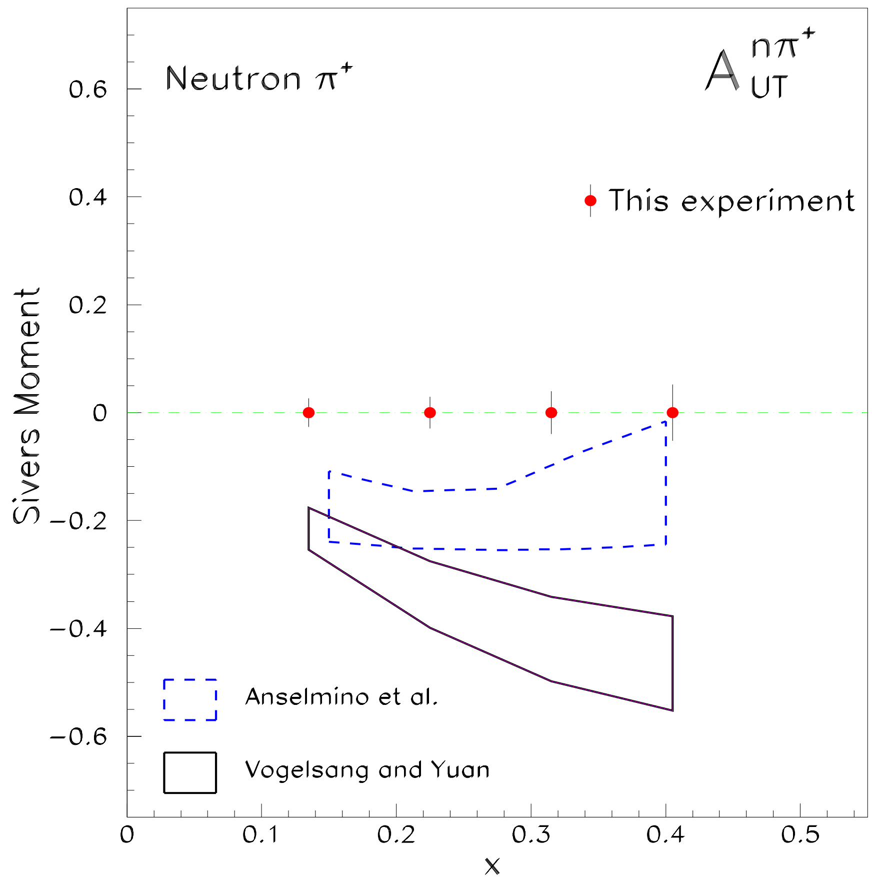
π-

π+

The errors with approved beam time will be 33% higher.

Predictions of Sivers asymmetry on neutron



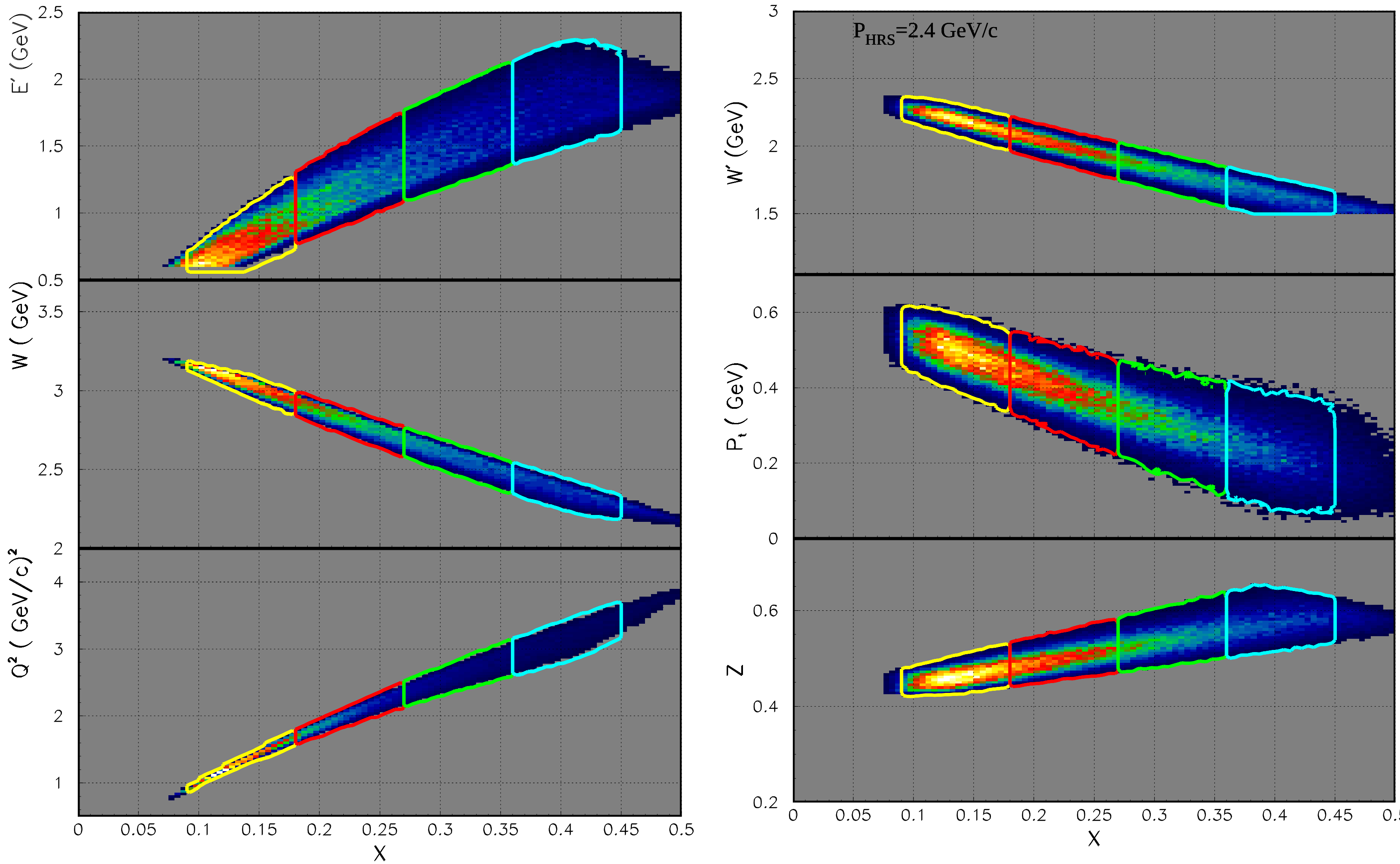


π-

π+

The errors with approved beam time will be 33% higher.

Kinematic Coverage at 6 GeV

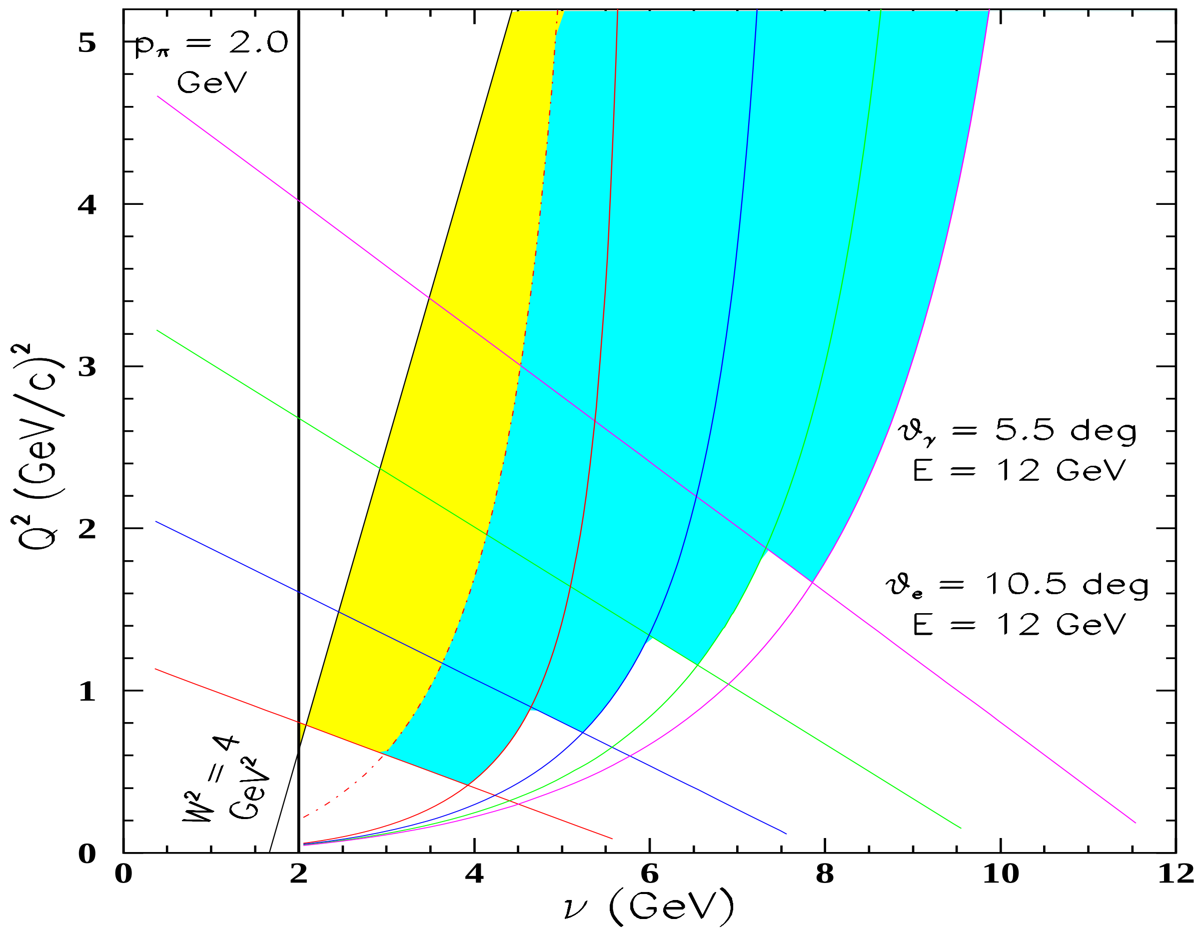


$\langle x \rangle$=0.135,0.225,0.315,0.405 $\langle z \rangle$=0.473,0.515,0.558,0.601

X is strongly correlated with Q^2

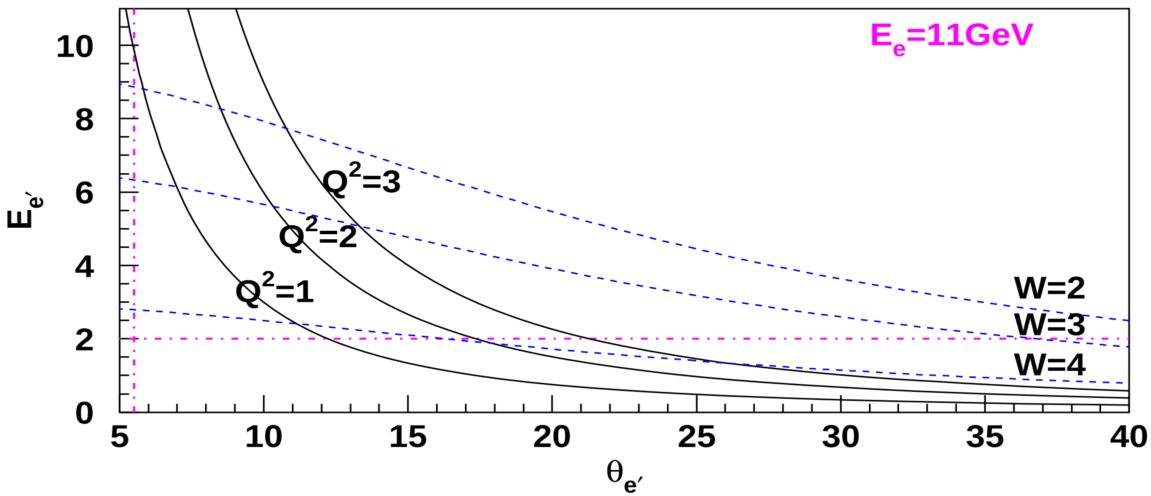
Kinematic Coverage w HMS(e)+SHMS(h)

Hall C CDR (2002): R. Ent and C.E. Keppel

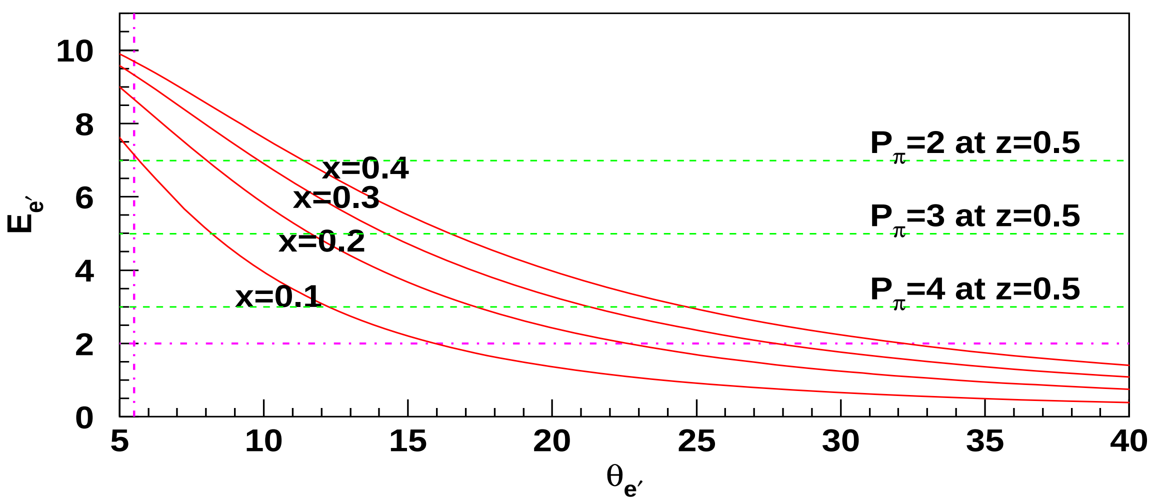


Higher beam energy with JLab upgrade offer larger phase space.

Kinematical Coverage w SHMS(e)+HMS(h)



$$Q^2 = 4E_eE_{e'}\sin^2(\theta_{e'}/2)$$
$$W = \sqrt{M^2 + 2M(E_e - E_{e'}) - Q^2}$$



$$x = \frac{Q^2}{2M(E_e - E_{e'})}$$
$$z = \frac{E_\pi}{E_e - E_{e'}}$$

Larger $\theta_{e'}$, $E_{e'}$ ➔ larger x, Q^2; smaller W, W', θ_q, σ

Kinem. Ex: x-dependence at fixed Q

E=11GeV

E' (GeV)	θ_e (deg)	x	W (GeV)	Q^2 (GeV^2)	y	θ_q (deg)	P_π (GeV)	θ_π (deg)	z	$\|P_T\|$ (GeV)	W' (GeV)
4.80	12.5	$0.22^{-0.04}_{+0.10}$	3.16	2.50	0.56	-9.34	3.10	-13.1	0.50	0.20	2.31
6.20	11.0	$0.28^{-0.06}_{+0.19}$	2.72	2.51	0.44	-13.54	2.40	-18.4	0.50	0.20	2.00
7.50	10.0	$0.38^{-0.10}_{+0.50}$	2.22	2.51	0.32	-19.82	1.74	-13.1	0.50	0.20	1.65

Due to δP

- SHMS(e) + HMS(h)

- Same central Q^2, z, P_T

- $\Phi_{Sivers} > \pm 47^o$; $\Phi_{Collins} > \pm 58^o$

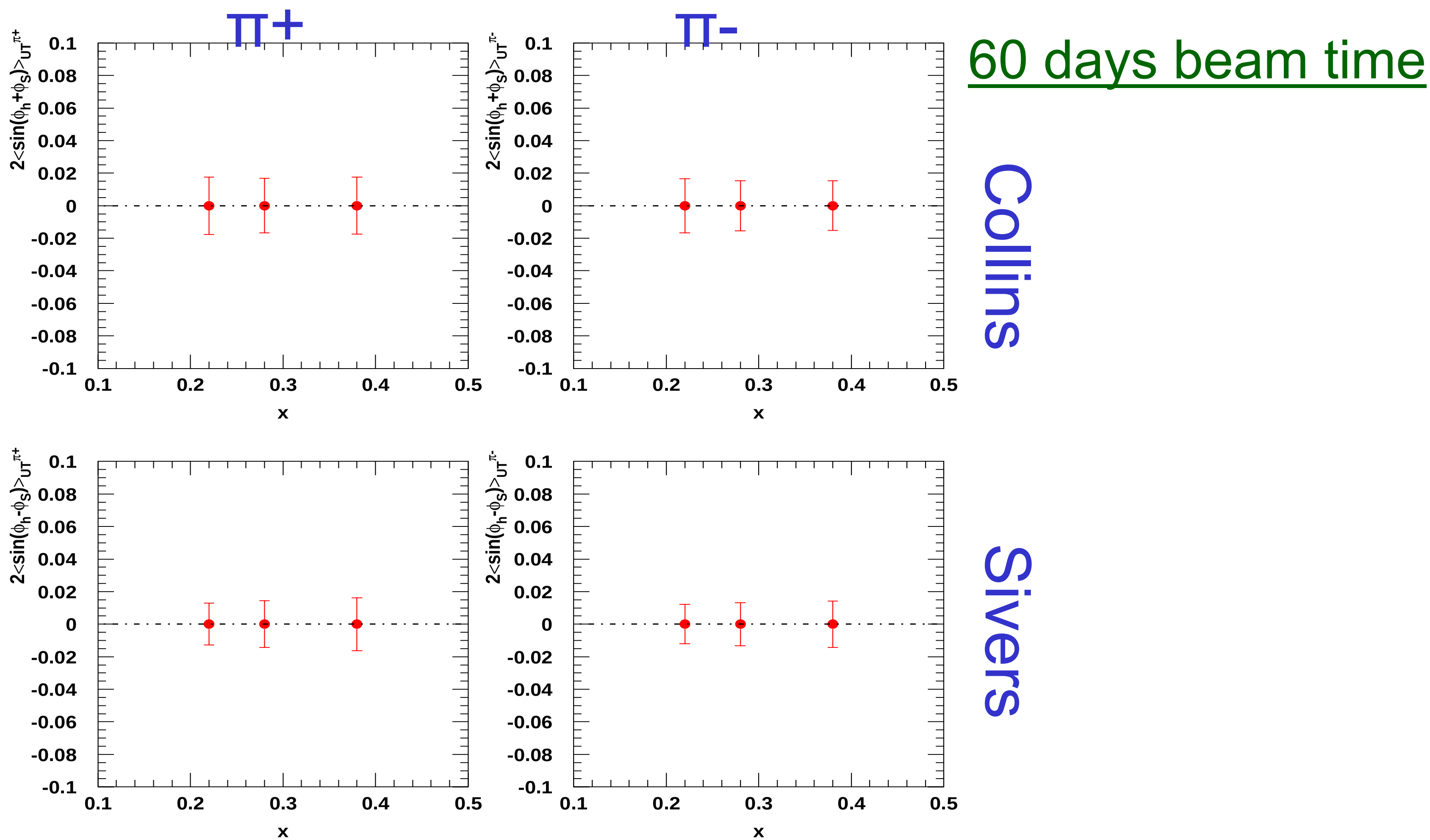
--Full Sivers/Collins angle coverage with two target polarization direction

$$\phi_s \approx \frac{\pm 0.050}{\sin(\theta_e - \theta_q)}$$

$$\phi_{Sivers} \equiv \phi_h - \phi_s \approx \arcsin\frac{\pm 0.085 P_h}{P_\perp}$$

$$\phi_{Collins} \equiv \phi_h + \phi_s$$

Projected Results of Collins/Sivers Moments



- Statistical uncertainty for He raw asymmetry: ~0.1%
- Statistical uncertainty for neutron moments: ~2%

Systematic Uncertainties for SSA

- Statistical uncertainty for He raw asymmetry: ~0.1%

$$A_{meas} = \frac{N^+ - N^-}{N^+ + N^-}$$

- Spin-correlated luminosity: 0.1% in A ➔ 0.2% in x

$$A_{true} = \frac{N^+ - N^- \cdot (1+x)}{N^+ + N^- \cdot (1+x)}, \ \delta_x A \sim 0.5|x|$$

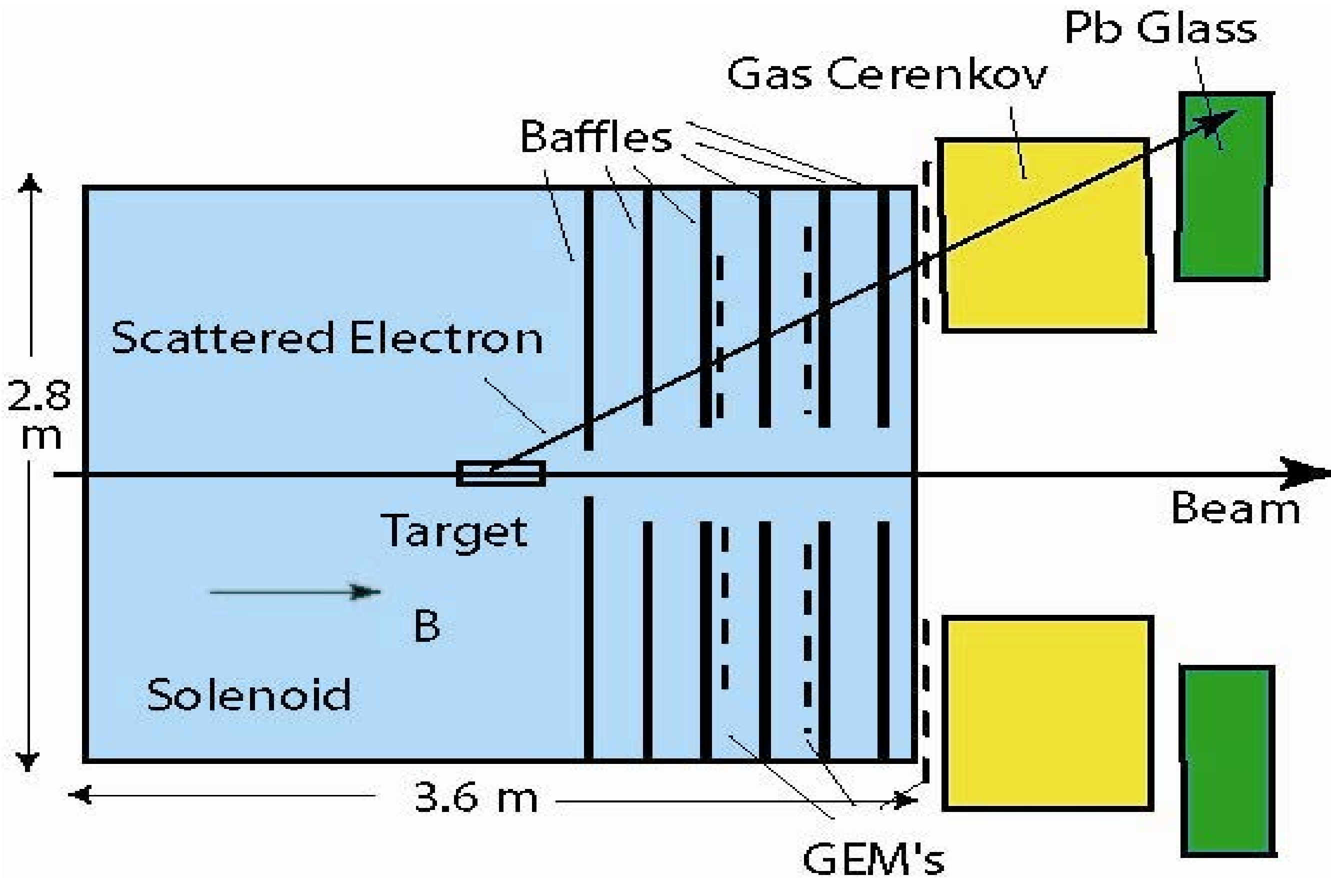
- Target polarization: 3% in y, 0.1% in A ➔ A<3.4%

$$A_{true} = (1+y) \cdot \frac{N^+ - N^-}{N^+ + N^-}, \ \delta_y A = |y| A$$

Solenoid Option with 11 GeV beam

From J.P. Chen's talk at USTC in China, Aug. 2006

BaBar Solenoid?



- Acceptance 10-30 times HMS+SHMS
- PID: Gas Cherekov + Shower Counter

•Challenge: polarized ^{3}He target inside the solenoid

Summary

- HERMES transverse data show some surprising features, for example in Collins H^-/H^+, Sivers f_{1T}^u/f_{1T}^d, and P_{hT} dependence. The current constraint on the transversity is pretty loose, and the x, z and P_T distributions are coupled together.
- More data especially with controlled kinematics are essential for cross check, multi-dimension binning and transversity extraction, …

- The A-rated Hall A transversity experiment with polarized ^3He target will measure the pion(kaon) SIDIS target single-spin asymmetry on neutron with 6 GeV beam.
- JLab upgrade provides much larger phase space for SIDIS with higher beam energy. A few 12 GeV SIDIS experiments has been proposed, ex cos2Φ measurement in Hall B, dbar/ubar and R measurement in Hall C using unpolarized target.
- Hall C with HMS/SHMS and especially ^3He target can contribute to the transversity program by studying target single-spin asymmetry of SIDIS at controlled kinematics, for example at fixed Q^2, x, z, and small P_T, complementary to Hall B's single-spin asymmetry program.
- The Hall A solenoid option with high luminosity and large acceptance sounds attracting.