Extracting Quark Distribution and Fragmentation Functions from Transverse Single-Spin Asymmetries

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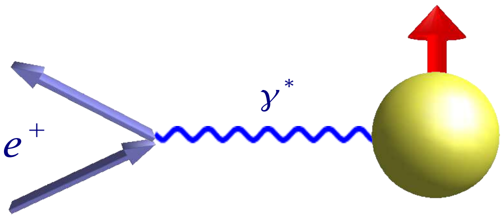
東工大理

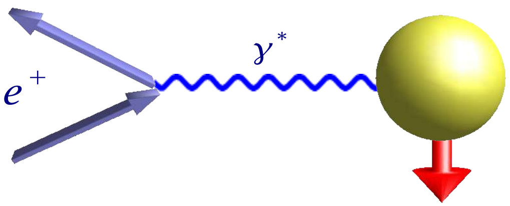
- Single-spin asymmetry
- Interpretation of measured asymmetries
  - Collins asymmetry
  - Sivers asymmetry
- Conclusion

Single Target-spin Asymmetry



$d\sigma^{\uparrow}$

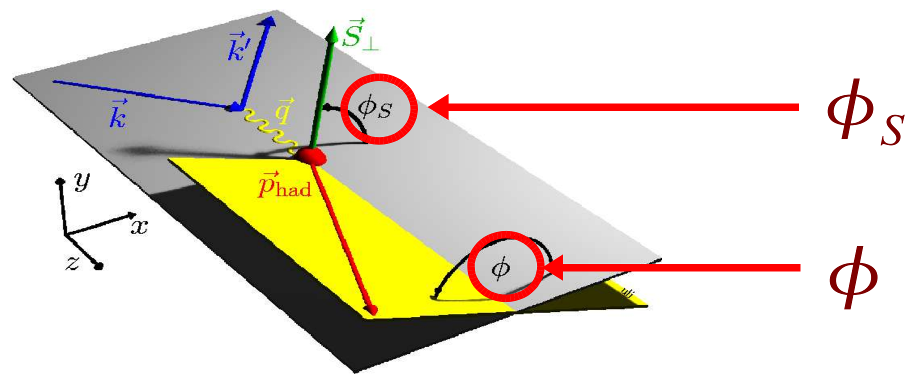
Unpolarized **T**ransversely polarized



$d\sigma^{\downarrow}$

$$A_{UT} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

$d\sigma^{\uparrow,\downarrow}$ π production cross-section



$$A_{UT} = A_{UT}^{Collins} \sin(\phi + \phi_S) + A_{UT}^{Sivers} \sin(\phi - \phi_S)$$

1. Collins Asymmetry

$$A_{UT} = \boxed{A_{UT}^{Collins}} \sin(\phi + \phi_S) + A_{UT}^{Sivers} \sin(\phi - \phi_S)$$

Collins Asymmetry

$$A_{UT} \equiv A_{UT}^{Collins} \sin(\phi + \phi_S) + A_{UT}^{Sivers} \sin(\phi - \phi_S)$$

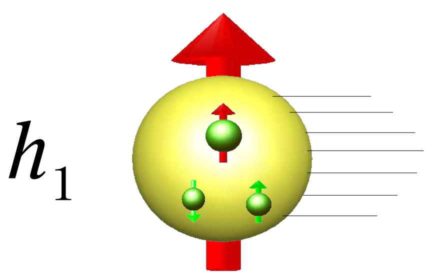
Collins asymmetry

$$A_{UT}^{Collins} \propto h_1(x)\ H_1^{\perp}(z)$$

Transversity (Polarized PDF) h_1

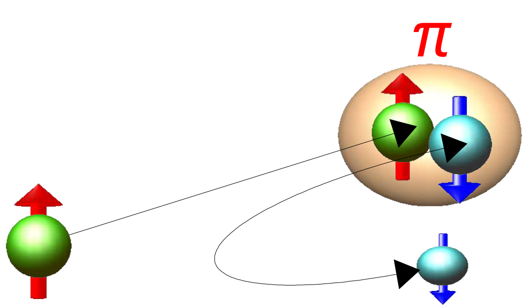
Collins FF (Polarized FF) $H_1^{\perp}$

h_1 describes transverse quark polarization in the transversely polarized nucleon.



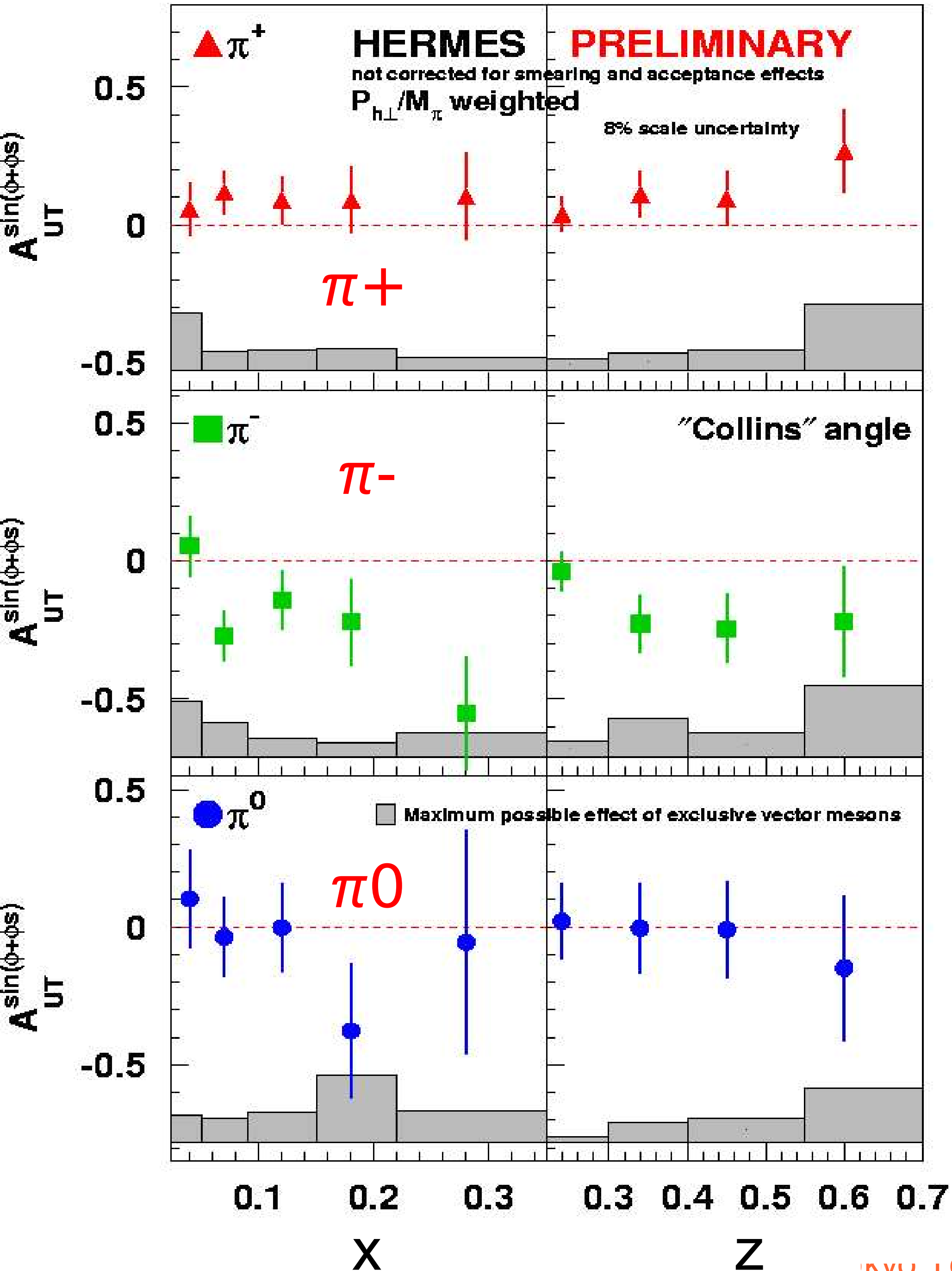
Provides information about relativistic nature of the nucleon.

$H_1^{\perp}$ describes fragmentation of pol. quark into unpol hadron.



Collins effects generates single-spin azimuthal asymmetry.

Measured Collins Asymmetries



$$A_{UT}^{Collins} \propto h_1(x)\ H_1^{\perp}(z)$$

Averaged Asymmetries

(0.023 < x < 0.4, 0.2 < z < 0.7)

$$\langle A_{UT}^{Collins}(\pi^+)\rangle > 0$$

$$\langle A_{UT}^{Collins}(\pi^-)\rangle < 0$$

$$\langle A_{UT}^{Collins}(\pi^0)\rangle \sim 0$$

Interpretation of Collins Results

Collins asymmetries have two unknown components. — well-known unpol. quantities

$$A_{UT}^{Collins} \approx \frac{\sum_q e_q^2 \, h_1^q(x) \, H_1^{\perp}(z)}{\sum_q e_q^2 \, q(x) \, D(z)}$$

- Define favored (ex. u→π+) and disfavored (ex. u→π-) FF

$$H^{fav} \equiv H_1^{u\rightarrow\pi^+} = H_1^{d\rightarrow\pi^-} = \ldots \qquad H^{dis} \equiv H_1^{u\rightarrow\pi^-} = H_1^{d\rightarrow\pi^+} = \ldots$$

- π+, π- and π0 asymmetries;

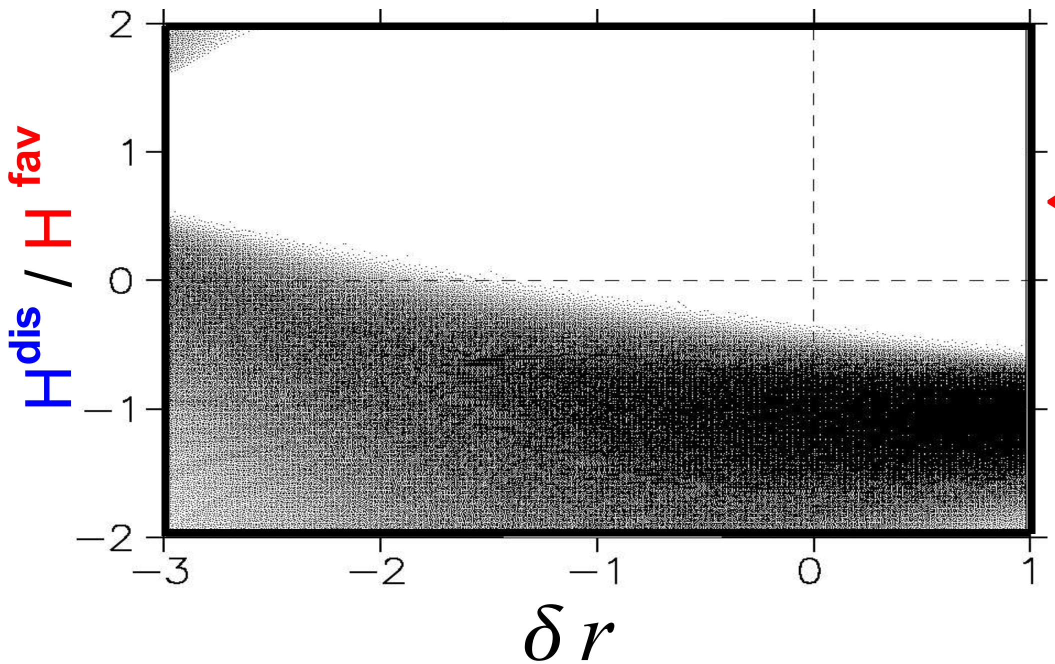
$$A^{\pi^+} = \frac{(4h_1^u + h_1^{\bar{d}})\, H^{fav} + (h_1^d + 4h_1^{\bar{u}})\, H^{dis}}{(4u + \bar{d})\, D^{fav} + (4\bar{u} + d)\, D^{dis}},$$

$$A^{\pi^-} = \frac{(4h_1^u + h_1^{\bar{d}})\, H^{dis} + (h_1^d + 4h_1^{\bar{u}})\, H^{fav}}{(d + 4\bar{u})\, D^{dis} + (4u + \bar{d})\, D^{fav}}, \qquad A^{\pi^0} = \frac{\cdots\cdot}{\cdots\cdot}$$

Interpretation of Collins Results

$$\frac{A^{\pi^-}}{A^{\pi^+}} \equiv \frac{4\,\tilde{H} + \delta r}{4\,\tilde{D} + r} \qquad \frac{A^{\pi^0}}{A^{\pi^+}} \equiv \frac{(4+\delta r)(1+\tilde{H})}{(4+r)(1+\tilde{D})}$$

Solution space populated according to statistical error



Likelihood distribution in solution space of

$$\tilde{H} \equiv \frac{H^{dis}}{H^{fav}}$$

$$\delta r \equiv \frac{h_1^d + 4\,h_1^{\bar{u}}}{h_1^u + (1/4)\,h_1^{\bar{d}}}$$

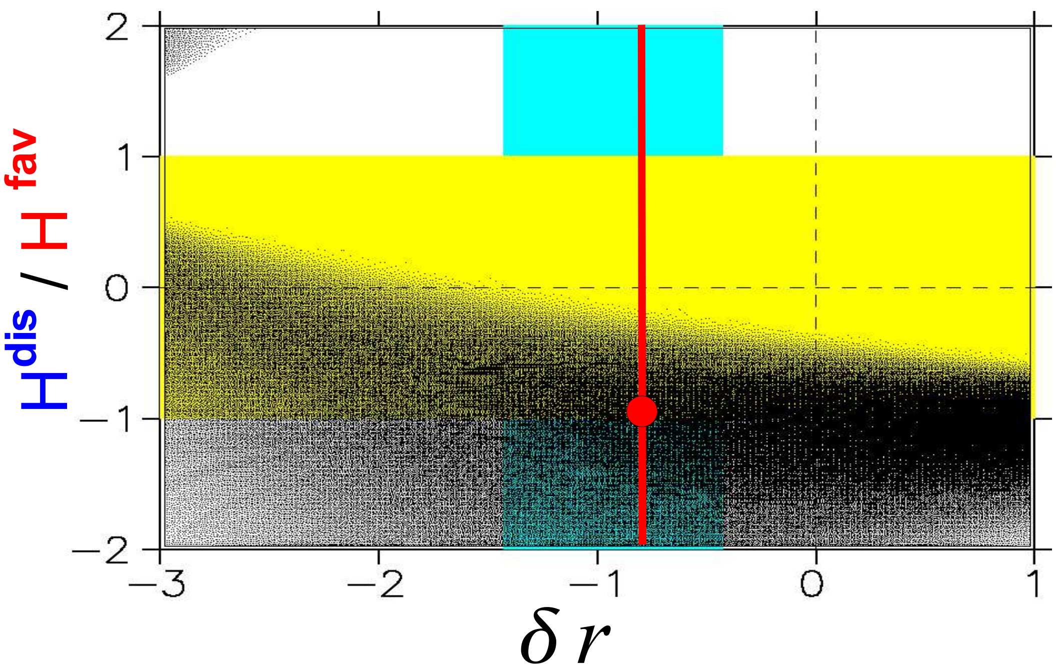
Well-known objects

$$\tilde{D} \equiv \frac{D^{dis}}{D^{fav}} \qquad r \equiv \frac{d + 4\,\bar{u}}{u + (1/4)\,\bar{d}}$$

Interpretation of Collins Results

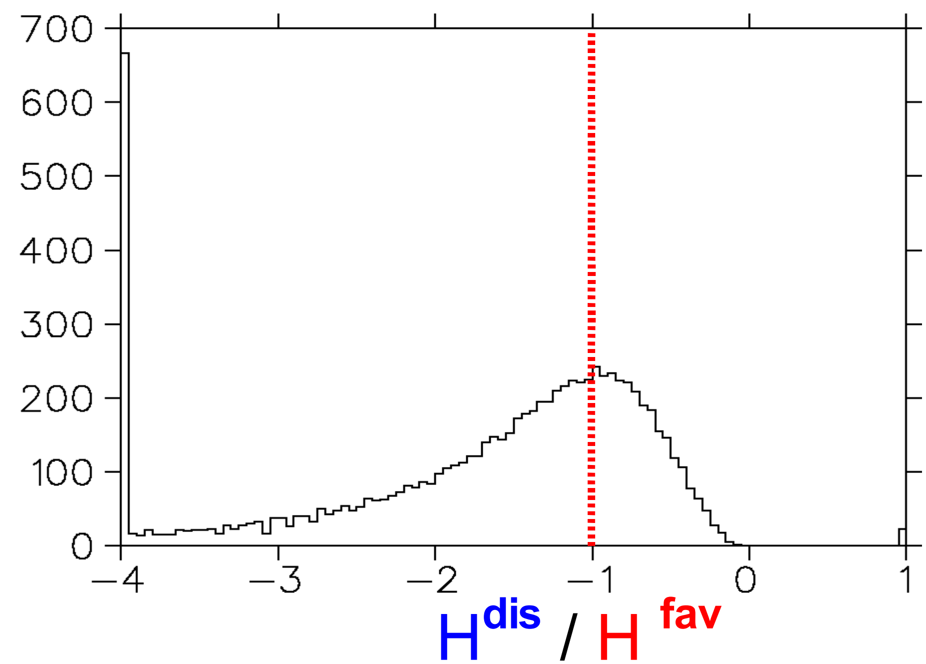
$$\frac{A^{\pi^-}}{A^{\pi^+}} \equiv \frac{4\tilde{H} + \delta r}{4\tilde{D} + r} \qquad \frac{A^{\pi^0}}{A^{\pi^+}} \equiv \frac{(4+\delta r)(1+\tilde{H})}{(4+r)(1+\tilde{D})}$$

- Chiral Quark Soliton Model (CQSM) [1]
- String Model [2]



[1] M. Wakamatsu et al., Phys. Rev. D60, 034020
[2] X. Artru, hep-ph/9310323

H^{dis} / H^{fav} solution at CQSM value
δr = - 0.93 (Q^2=2.5 GeV^2)



Collins FF has opposite sign for favored and disfavored
(neglecting VM contamination)

2. Sivers Asymmetry

$$A_{UT} = A_{UT}^{Collins} \sin(\phi + \phi_S) + A_{UT}^{Sivers} \sin(\phi - \phi_S)$$

Sivers Asymmetry

$$A_{UT} \equiv A_{UT}^{Collins} \sin(\phi+\phi_S) + A_{UT}^{Sivers} \sin(\phi-\phi_S)$$

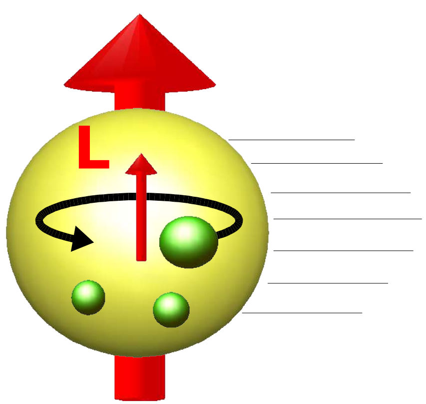
Sivers asymmetry

$$A_{UT}^{Sivers} \propto f_{1T}^{\perp}(x)\, D_1(z)$$

Unpol. FF

Sivers function

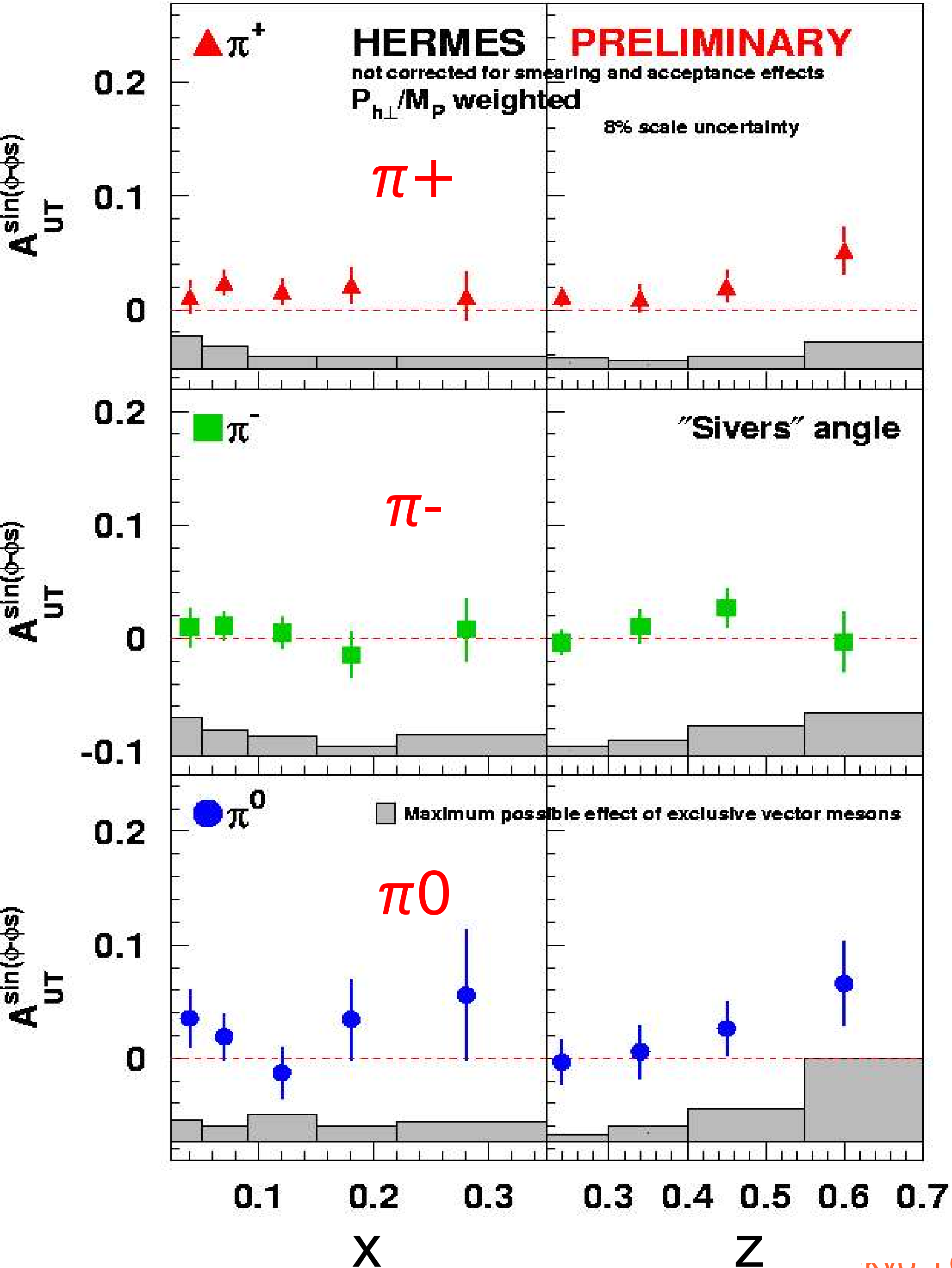
The Sivers function describes unpolarized quark in the transversely polarized nucleon.



$$f_{1T}^{\perp}(x)$$

Non-zero Sivers function requires quark orbital angular momentum.

Measured Sivers Asymmetries



$$A_{UT}^{Sivers} \propto f_{1T}^{\perp}(x)\; D_1(z)$$

Averaged Asymmetries

(0.023 < x < 0.4, 0.2 < z < 0.7)

$$\langle A_{UT}^{Sivers}(\pi^+)\rangle > \mathbf{0}$$

3σ away from zero.

$$\langle A_{UT}^{Sivers}(\pi^-)\rangle \sim \mathbf{0}$$

$$\langle A_{UT}^{Sivers}(\pi^0)\rangle \sim \mathbf{0}$$

Interpretation Sivers Results

$$A_{UT}^{Sivers} \approx \frac{\sum_q e_q^2 \, f_{1T}^{\perp}(x) \, D(z)}{\sum_q e_q^2 \, q(x) \; D(z)}$$

Only one unknown

well-known
unpol. objects

Combine π+ and π- asymmetries

$$C_1 A^{\pi^+} + C_2 A^{\pi^-} = f_{1T}^{\perp u} + (1/4) f_{1T}^{\perp \bar{d}}$$

$$C_3 A^{\pi^+} + C_4 A^{\pi^-} = f_{1T}^{\perp d} + 4 \; f_{1T}^{\perp \bar{u}}$$

Experimental results indicate;

$$f_{1T}^{\perp}(u) + \frac{1}{4} f_{1T}^{\perp}(\bar{d}) > 0$$

$$f_{1T}^{\perp}(d) + 4 f_{1T}^{\perp}(\bar{u}) < 0$$

- Non-zero Sivers function.
- Sivers function of u-quark has positive sign.
- Quark angular momentum could contribute to the nucleon spin.

Conclusion

- Single-spin asymmetry have been measured using 27.6 GeV positron beam and transversely polarized hydrogen target at the HERMES experiment.

- Collins asymmetry;

$$\langle A_{UT}^{Collins}(\pi^{+})\rangle > 0$$

$$\langle A_{UT}^{Collins}(\pi^{-})\rangle < 0$$

  - Favored and disfavored Collis FF have opposite sign.

- Sivers asymmetry;

$$\langle A_{UT}^{Sivers}(\pi^{+})\rangle > 0$$

  - First observation of non-zero Sivers effect.
  - Sivers function for u-quark is positive.

- More data are coming soon (about factor 4 by end of 2004).