Beam Single Spin Asymmetry in Pion Electroproduction

Semi-Inclusive Reactions Workshop
Jefferson Lab, 18-21 May, 2005

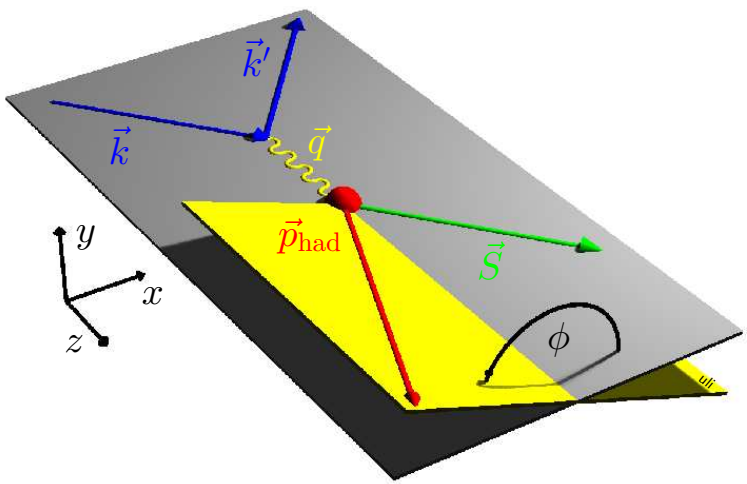
Eduard Avetisyan

eduard.avetisyan@desy.de

(Yerevan Physics Institute / INFN Frascati)

Semi Inclusive DIS:

$\vec{e}p \to e'hX$



$$
\begin{aligned}
Q^2 &= 4EE'\sin^2(\tfrac{\theta}{2}) \\
\nu &= E - E' \\
x &= \frac{Q^2}{2m\nu} \\
y &= \frac{\nu}{E} \\
z &= \frac{E_h}{\nu} \\
\sin\phi &= \frac{[\vec{k}_1\times\vec{k}_2]\cdot\vec{P}_\perp}{|\vec{k}_1\times\vec{k}_2||\vec{P}_\perp|}
\end{aligned}
$$

$$
\begin{aligned}
\sigma(\phi) &= A_0 + A_1\sin\phi + B_1\cos\phi + A_2\sin 2\phi + B_2\cos 2\phi\ldots \\
\frac{\mathrm{d}^3\sigma_{UU}}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}\phi} &= \frac{1}{2}\left(\frac{\mathrm{d}^3\sigma^+}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}\phi} + \frac{\mathrm{d}^3\sigma^-}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}\phi}\right) \\
\frac{2}{P}\,\frac{\mathrm{d}^3\sigma_{LU}}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}\phi} &= \frac{1}{P^+}\,\frac{\mathrm{d}^3\sigma^+}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}\phi} - \frac{1}{P^-}\,\frac{\mathrm{d}^3\sigma^-}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}\phi}
\end{aligned}
$$

DFs and FFs:

Factorization $\Rightarrow$ $\sigma^{eN\to ehX} = \sum f^{N\to q} \otimes \sigma^{eq\to eq} \otimes D^{q\to h}$

$\Downarrow$ **Distribution** $\qquad$ $\Downarrow$ **Fragmentation**

$\sigma_{unpol} \equiv \sigma_{UU} \propto (1-y+y^2/2)\sum_{a,\bar{a}} e_a^2 x f_1^a(x) D_1^a(z)$ **KNOWN!**

$\sigma_{pol} = \{\sigma_{UL}, \sigma_{LL}, \sigma_{UT}, \sigma_{LU}, \sigma_{LT}\}$

Beam Target polarization

$$\sigma_{UL} \propto S_L \sin\phi\,(2-y)\sqrt{1-y}\frac{M}{Q}\sum_{a,\bar{a}} e_a^2 x^2 h_L^a(x) H_1^{\perp a}(z) + \ldots$$

$$\sigma_{UT} \propto S_T (1-y)\sin(\phi+\phi_s)\sum_{a,\bar{a}} e_a^2 x h_1^a(x) H_1^{\perp a}(z) + \ldots$$

$$\sigma_{LU} \propto \lambda_e \sin\phi\, y\sqrt{1-y}\frac{M}{Q}\sum_{a,\bar{a}} e_a^2 x^2 \left[e^a(x) H_1^{\perp a}(z) + h_1^{\perp a}(x) E^a(z)\right]$$

DFs and FFs:

Factorization $\Rightarrow$ $\sigma^{eN\to ehX} = \sum f^{N\to q} \otimes \sigma^{eq\to eq} \otimes D^{q\to h}$

$\Downarrow$ **Distribution** $\qquad$ $\Downarrow$ **Fragmentation**

$\sigma_{unpol} \equiv \sigma_{UU} \propto (1 - y + y^2/2) \sum_{a,\bar{a}} e_a^2 x f_1^a(x) D_1^a(z)$ **KNOWN!**

$\sigma_{pol} = \{\sigma_{UL}, \sigma_{LL}, \sigma_{UT}, \sigma_{LU}, \sigma_{LT}\}$

Beam Target polarization

$$\sigma_{UL} \propto S_L \sin\phi\,(2-y)\sqrt{1-y}\frac{M}{Q}\sum_{a,\bar{a}} e_a^2 x^2 h_L^a(x) H_1^{\perp a}(z) + \ldots$$

$$\sigma_{UT} \propto S_T (1-y)\sin(\phi+\phi_s)\sum_{a,\bar{a}} e_a^2 x h_1^a(x) H_1^{\perp a}(z) + \ldots$$

$$\boxed{\sigma_{LU} \propto \lambda_e \sin\phi\, y\sqrt{1-y}\frac{M}{Q}\sum_{a,\bar{a}} e_a^2 x^2 \left[e^a(x) H_1^{\perp a}(z) + h_1^{\perp a}(x) E^a(z)\right]}$$

Asymmetries:

$$A_{LU} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{d\sigma_{LU}}{d\sigma_{UU}}$$

$$A_{LU} \propto \frac{e(x)H_1^\perp(z) + h_1^\perp(x)E(z)}{f_1(x)D_1(z)}$$

	Distribution	Fragmentation
Twist-2	$h_1^\perp$	$H_1^\perp$
Twist-3	e	E

Asymmetries:

$$A_{LU} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{d\sigma_{LU}}{d\sigma_{UU}}$$

$$A_{LU} \propto \frac{e(x)H_1^\perp(z) + h_1^\perp(x)E(z)}{f_1(x)D_1(z)}$$

	Distribution	Fragmentation
Twist-2	$h_1^\perp$	$H_1^\perp$
Twist-3	e	E

ADDITIONAL TERMS in the X-section!

$$\sigma_{LU} \propto \lambda_e \sin\phi\, y\sqrt{1-y}\frac{M}{Q}\sum_{a,\bar{a}} e_a^2 x^2 \Big[xz e^a(x)H_1^{\perp a}(z) + h_1^{\perp a}(x)E^a(z) +$$

$$+\frac{M_h}{M} f_1^a(x)G^{\perp a}(z) - xz\frac{M}{M_h} g^{\perp a}(x)D_1^a(z) -$$

$$-\frac{m}{M} z f_1^a(x)H_1^{\perp a}(z) - \frac{m}{M_h} z h_1^{\perp a}(x)D_1^a(z)\Big]$$

Asymmetries:

$$A_{LU} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{d\sigma_{LU}}{d\sigma_{UU}}$$

$$A_{LU} \propto \frac{e(x)H_1^\perp(z) + h_1^\perp(x)E(z)}{f_1(x)D_1(z)}$$

	Distribution	Fragmentation
Twist-2	$h_1^\perp$	$H_1^\perp$
Twist-3	e	E

ADDITIONAL TERMS in the X-section!

$$\sigma_{LU} \propto \lambda_e \sin\phi\, y\sqrt{1-y}\frac{M}{Q}\sum_{a,\bar{a}} e_a^2 x^2 \left[xz e^a(x)H_1^{\perp a}(z) + h_1^{\perp a}(x)E^a(z) + \right.$$

$$+\frac{M_h}{M} f_1^a(x)G^{\perp a}(z) - xz\frac{M}{M_h} g^{\perp a}(x)D_1^a(z) -$$

$$\left. -\frac{m}{M} z f_1^a(x)H_1^{\perp a}(z) - \frac{m}{M_h} z h_1^{\perp a}(x)D_1^a(z)\right]$$

Asymmetries:

$$A_{LU} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{d\sigma_{LU}}{d\sigma_{UU}}$$

$$A_{LU} \propto \frac{e(x)H_1^\perp(z) + h_1^\perp(x)E(z)}{f_1(x)D_1(z)}$$

	Distribution	Fragmentation
Twist-2	$h_1^\perp$	$H_1^\perp$
Twist-3	e	E

ADDITIONAL TERMS in the X-section!

$$\sigma_{LU} \propto \lambda_e \sin\phi\, y\sqrt{1-y}\frac{M}{Q}\sum_{a,\bar{a}} e_a^2 x^2 \left[xz e^a(x) H_1^{\perp a}(z) + h_1^{\perp a}(x) E^a(z) + \right.$$

$$A_{UL} \qquad + \frac{M_h}{M} f_1^a(x) G^{\perp a}(z) - xz\frac{M}{M_h} g^{\perp a}(x) D_1^a(z) -$$

$$\left. - \frac{m}{M} z f_1^a(x) H_1^{\perp a}(z) - \frac{m}{M_h} z h_1^{\perp a}(x) D_1^a(z) \right]$$

Asymmetries:

$$A_{LU} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{d\sigma_{LU}}{d\sigma_{UU}}$$

$$A_{LU} \propto \frac{e(x)H_1^\perp(z) + h_1^\perp(x)E(z)}{f_1(x)D_1(z)}$$

	Distribution	Fragmentation
Twist-2	$h_1^\perp$	$H_1^\perp$
Twist-3	e	E

ADDITIONAL TERMS in the X-section!

$$\sigma_{LU} \propto \lambda_e \sin\phi\, y\sqrt{1-y}\frac{M}{Q}\sum_{a,\bar{a}} e_a^2 x^2 \left[xze^a(x)H_1^{\perp a}(z) + h_1^{\perp a}(x)E^a(z) + \right.$$

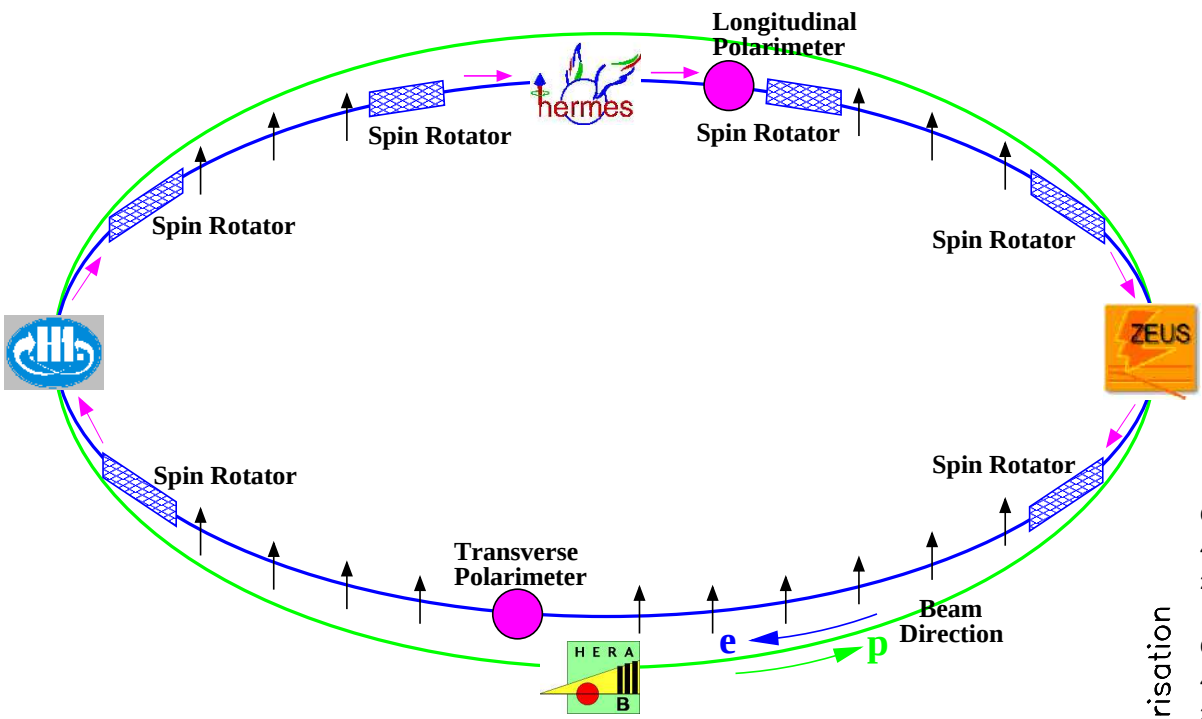
$$+\frac{M_h}{M} f_1^a(x)G^{\perp a}(z) - xz\frac{M}{M_h} g^{\perp a}(x)D_1^a(z) -$$

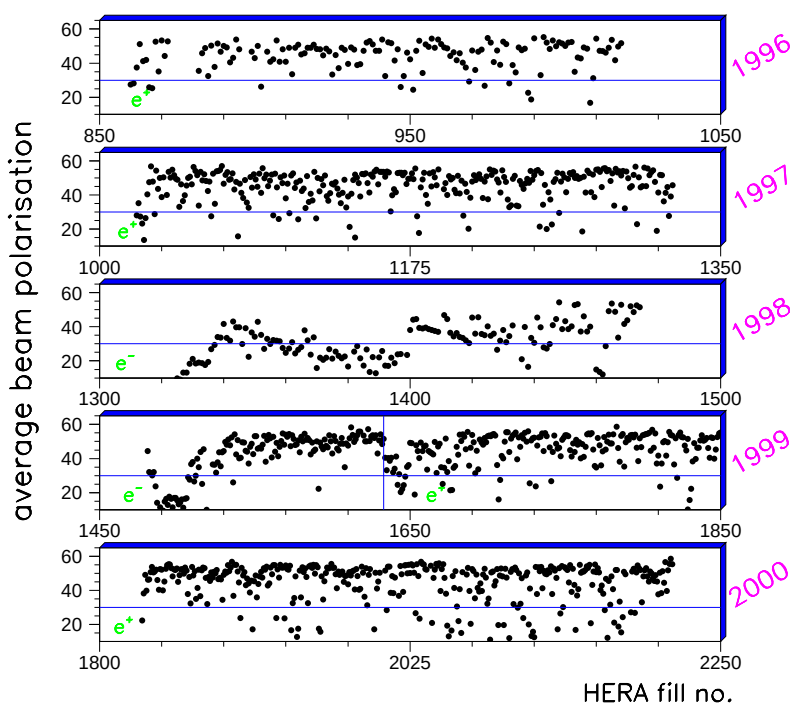
$$\left. -\frac{m}{M} z f_1^a(x)H_1^{\perp a}(z) - \frac{m}{M_h} z h_1^{\perp a}(x)D_1^a(z)\right]$$

A_{UL}

A_{LU}^{jet}

HERA setup:



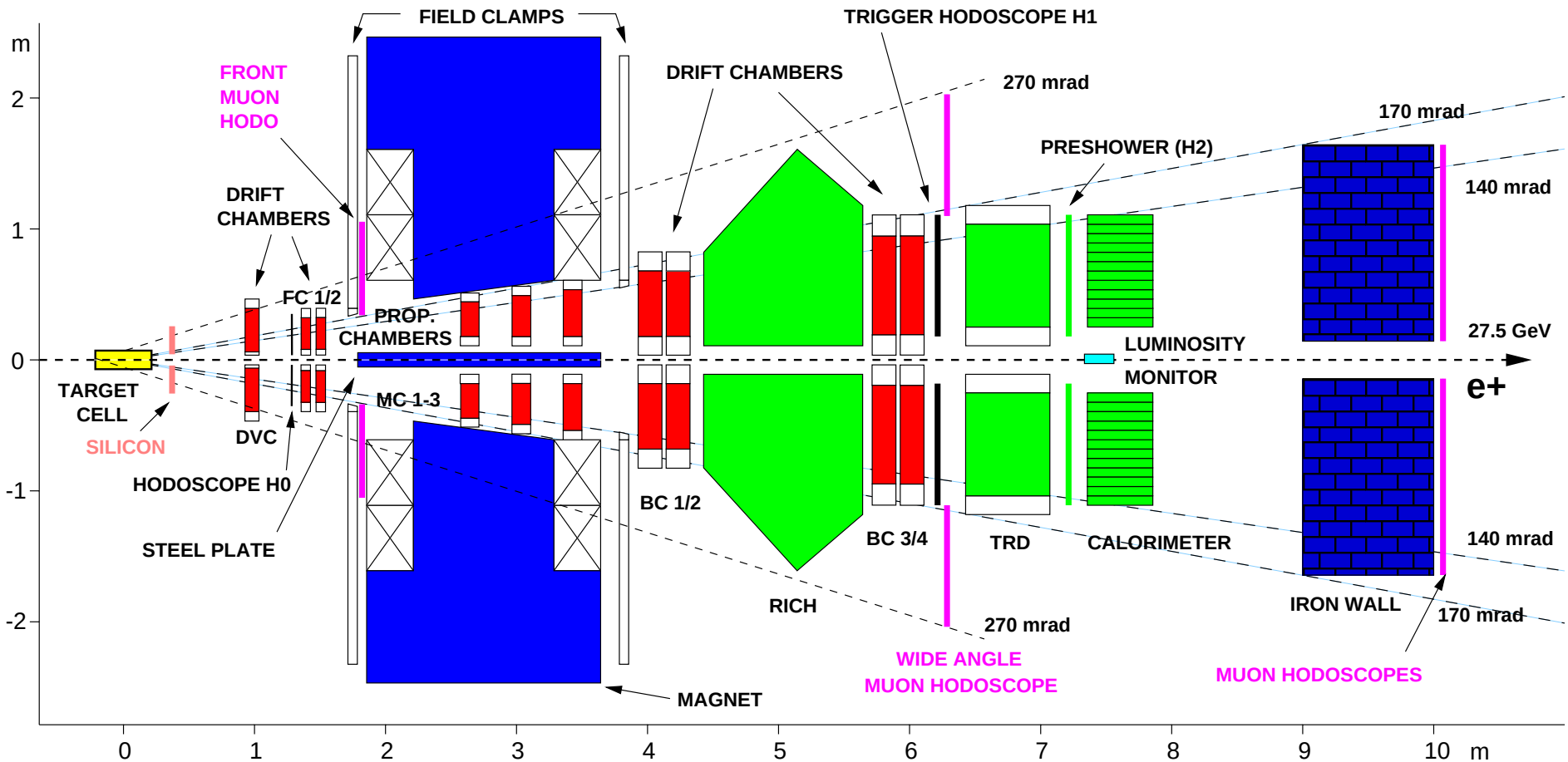


HERA-e beam self-polarized due to emission of synchrotron radiation

$\Rightarrow$ **Sokolov-Ternov effect**

$< \mathbf{P_{beam}} > \simeq \mathbf{55\%}$

HERMES Spectrometer:

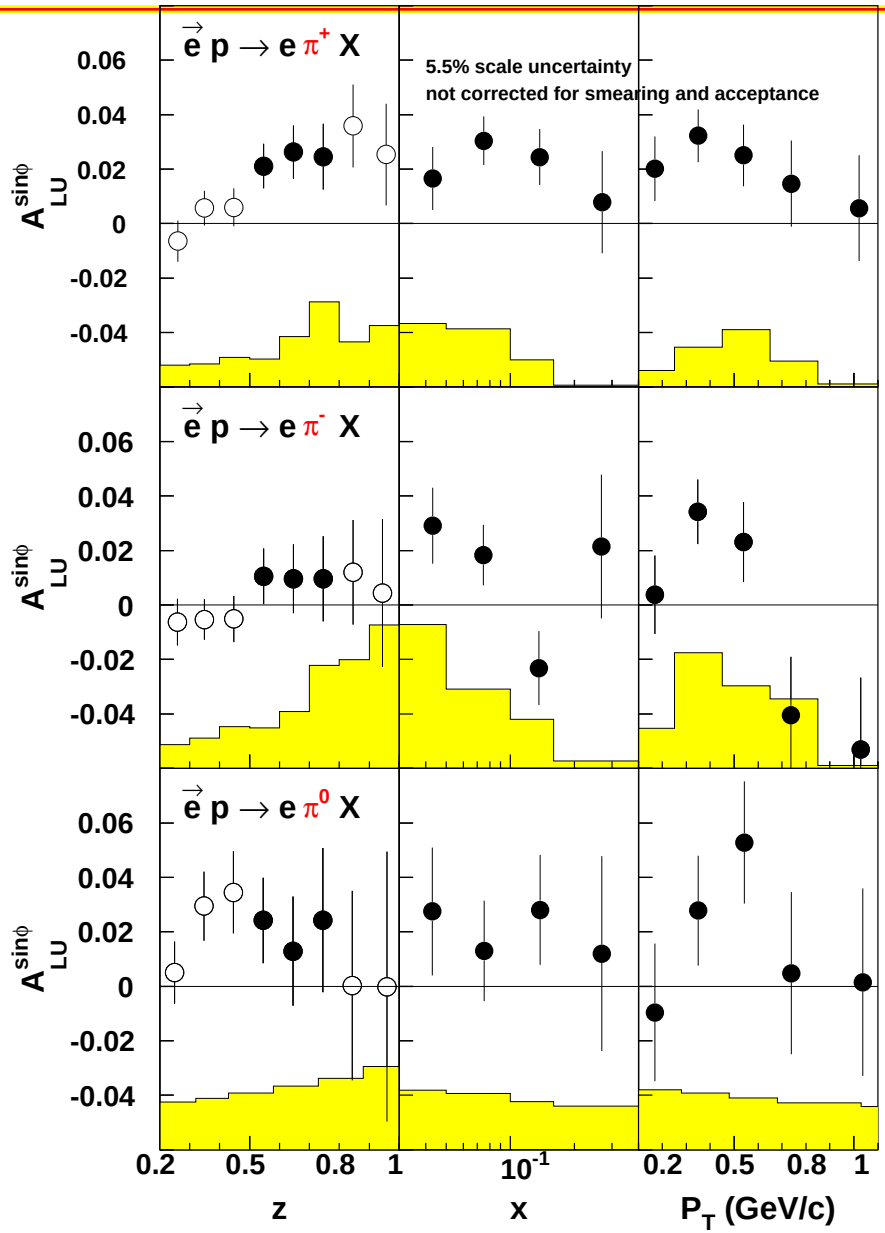


$$\mathbf{e + p \rightarrow e'X} \quad \Longleftrightarrow \quad \mathbf{e + p \rightarrow e'hX}$$

Beam SSA at HERMES

Asymmetry extraction:

$$A_{LU}^{\pm} = \frac{1}{P^{\pm} N^{\pm}} \sum_{i=1}^{N^{\pm}} \sin\phi$$



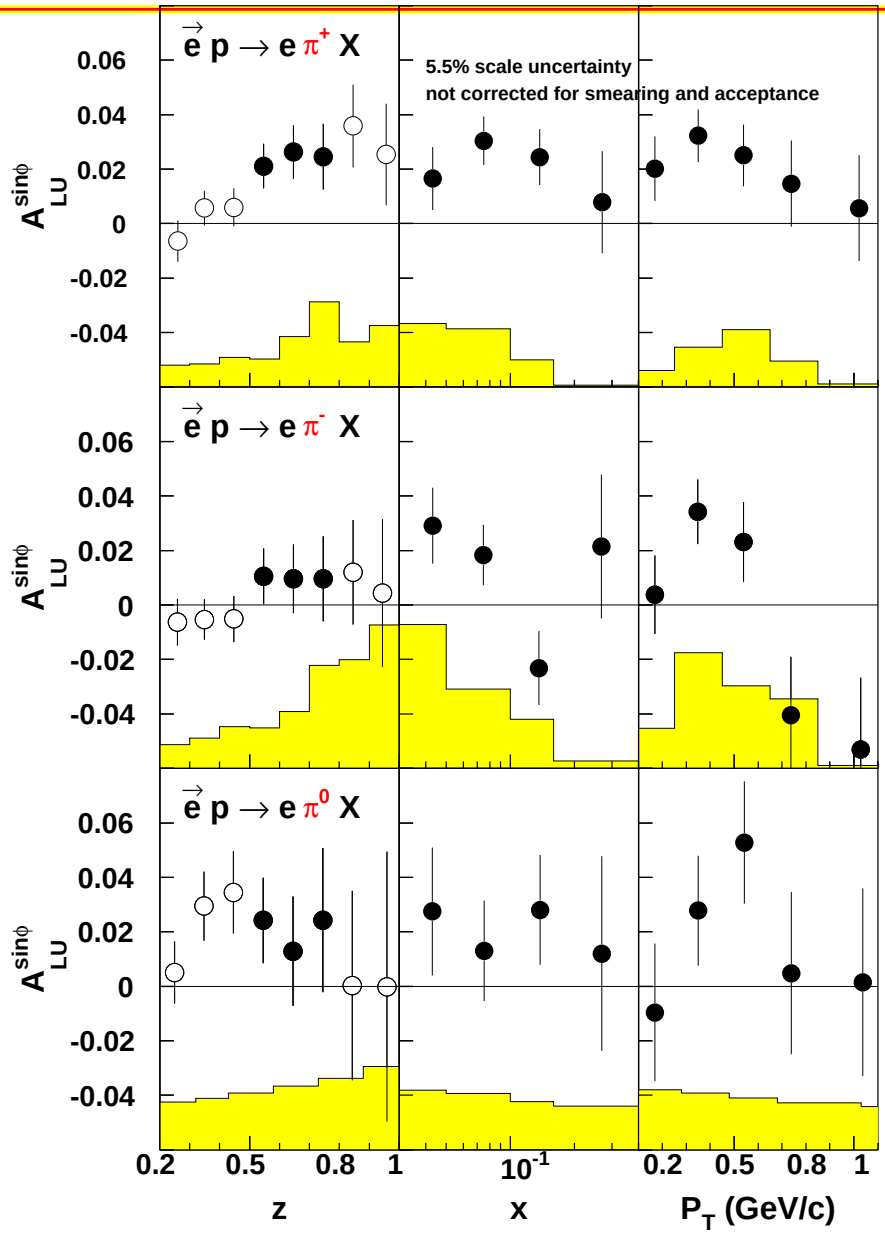
Beam SSA at HERMES

Asymmetry extraction:

$$A_{LU}^{\pm} = \frac{1}{P^{\pm} N^{\pm}} \sum_{i=1}^{N^{\pm}} \sin\phi$$

Fit method:

$$A(\phi) = \frac{N^{+}L^{-} - N^{-}L^{+}}{N^{+}L^{-}P^{-} + N^{-}L^{+}P^{+}}$$

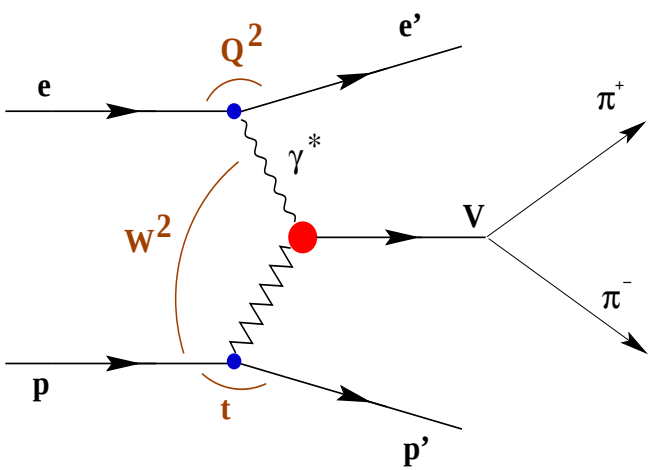


Beam SSA at HERMES

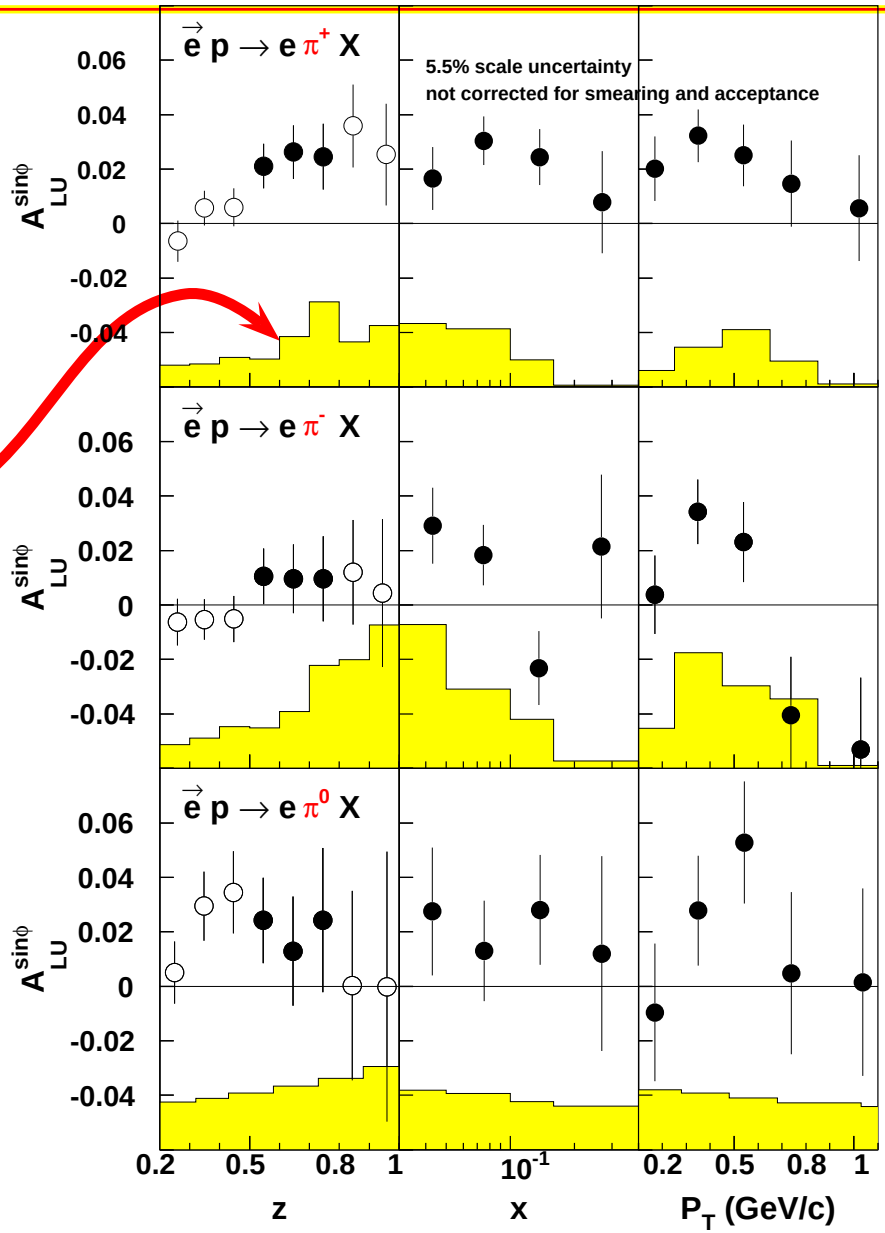
Asymmetry extraction:

$$A_{LU}^{\pm} = \frac{1}{P^{\pm} N^{\pm}} \sum_{i=1}^{N^{\pm}} \sin\phi$$

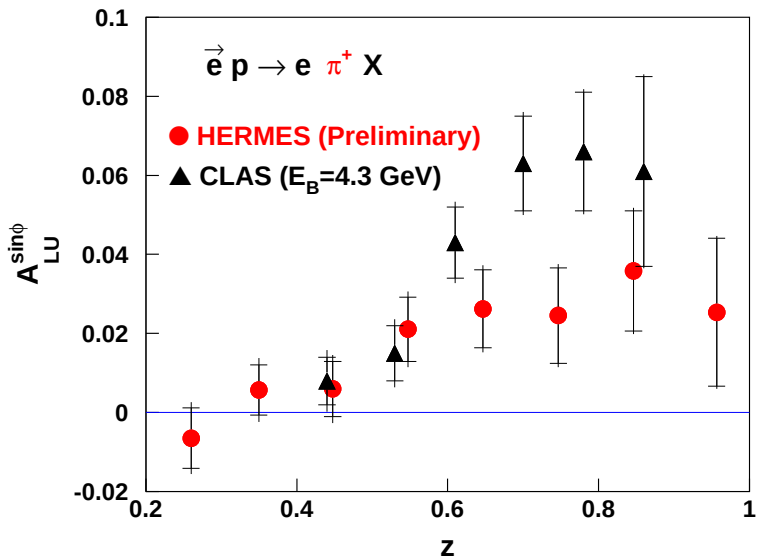
Interpretive error from VM

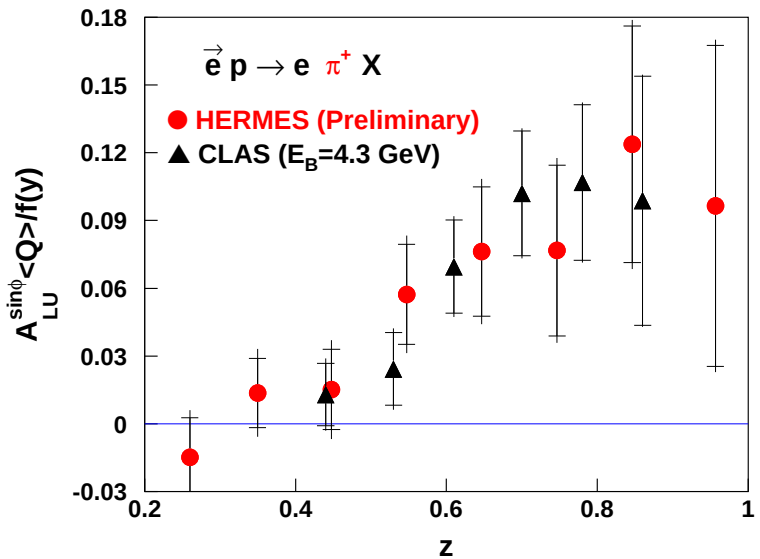


estimated from Monte-Carlo.



Comparison with CLAS:



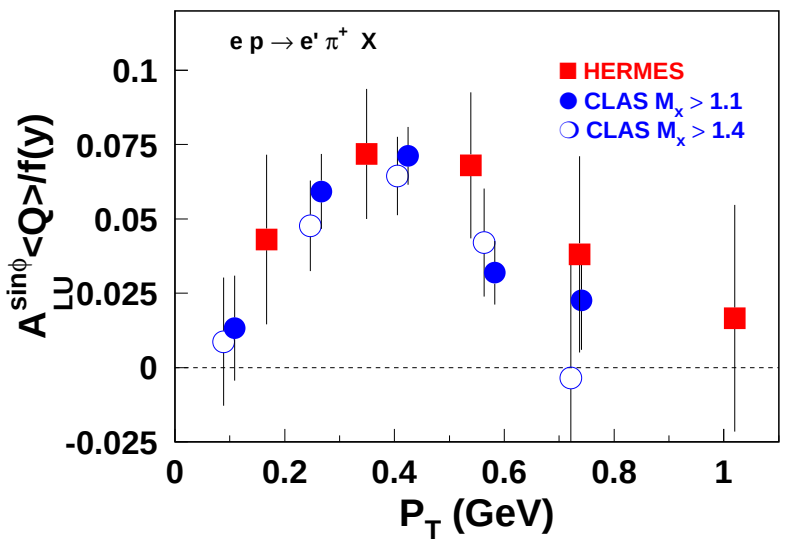


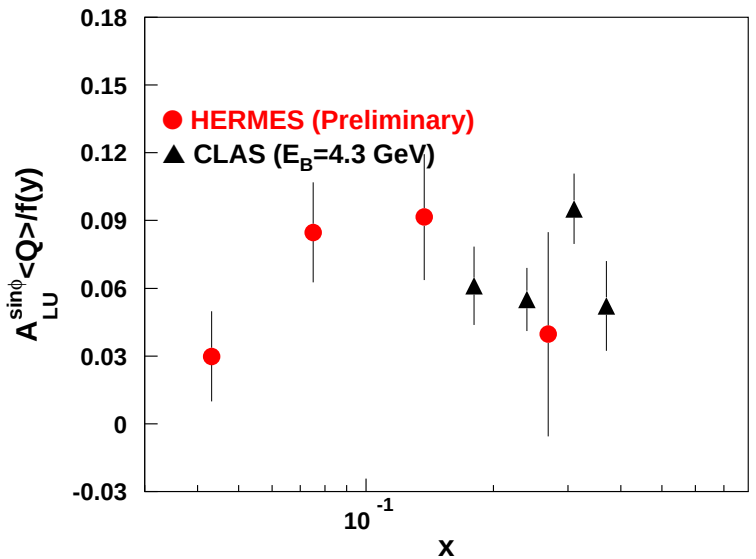
In leading order (neglecting σ_L/σ_T):

$$f(y) = \frac{\sqrt{2(1-y)}}{1-y+y^2/2}$$

Strong kinematic suppression factor in HERMES ($0.7 \to 0.35$ at higher z) roughly constant $(f(y) \simeq 0.7)$ in CLAS.

Comparison with CLAS(cont.):



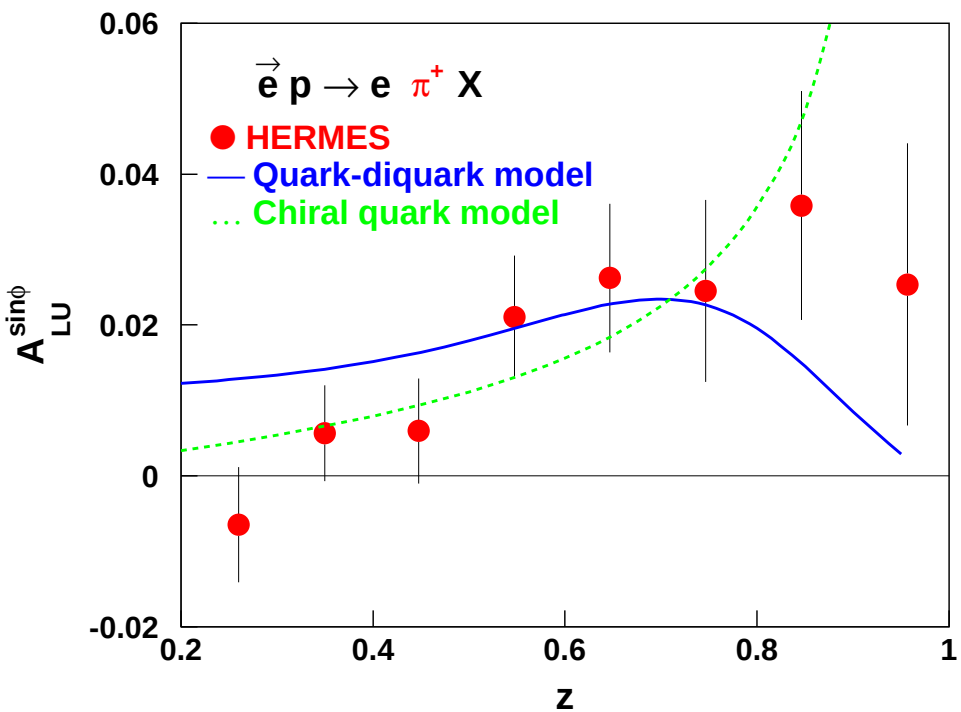


In leading order (neglecting σ_L/σ_T):

$$f(y) = \frac{\sqrt{2(1-y)}}{1-y+y^2/2}$$

Strong kinematic suppression factor in HERMES ($0.7 \rightarrow 0.35$ at higher z) roughly constant ($f(y) \simeq 0.7$) in CLAS.

Comparison with Theory:



Average kinematics:

$< P_T >= 0.45 GeV$

$< Q^2 >= 2.4 GeV^2$

L.Gamberg, D.Hwang, K.Oganessyan, Phys. Lett. B584 (2004) 276, (hep-ph/0311221)

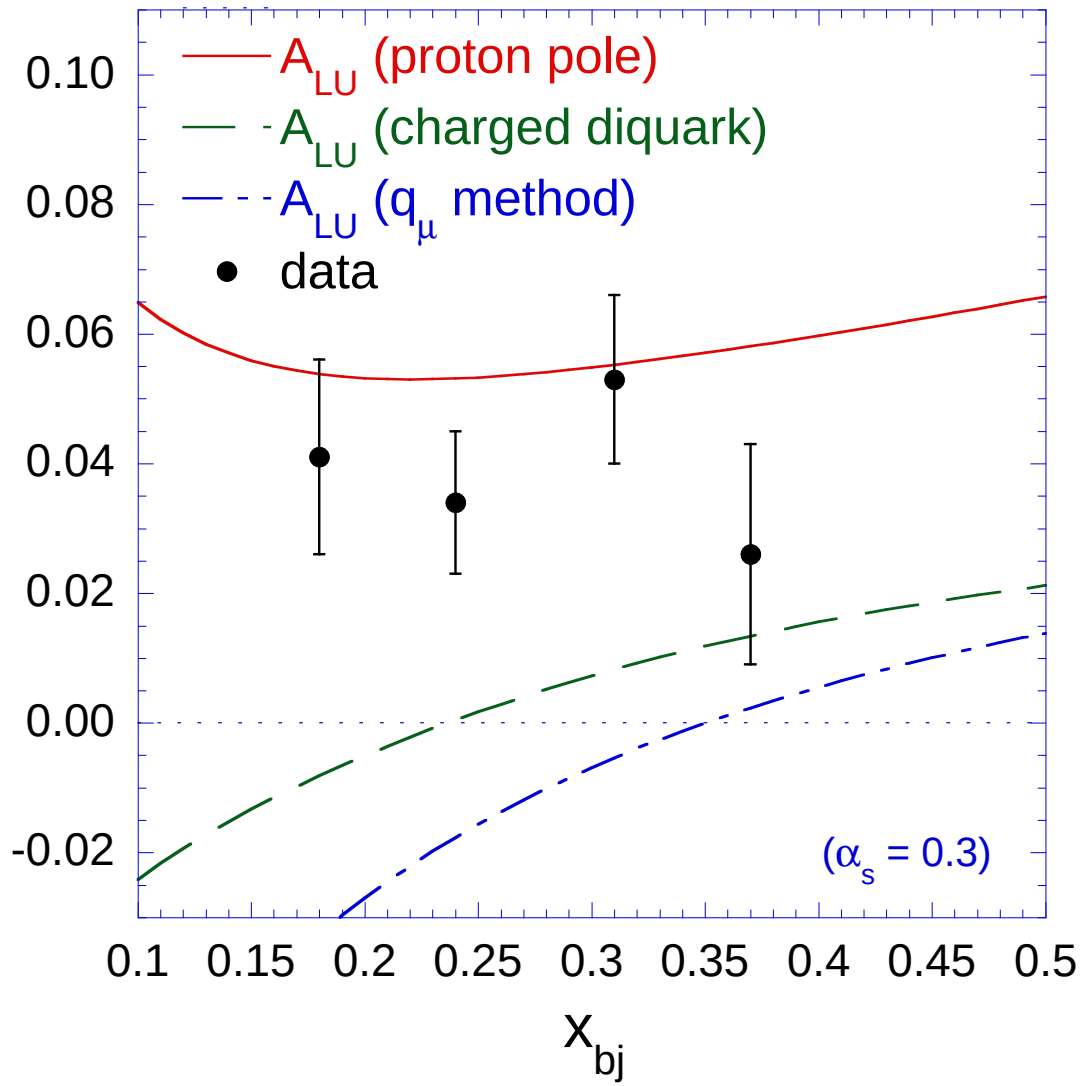
Quark-diquark spectator model, $e(x)H_1^{\perp}(z)$ dominant;

F.Yuan, Phys.Lett. B589 (2004) 28-34, (hep-ph/0310279)

Chiral quark model, $h_1^{\perp}(x)E(z)$ contribution only.

Comparison with Theory (CLAS):

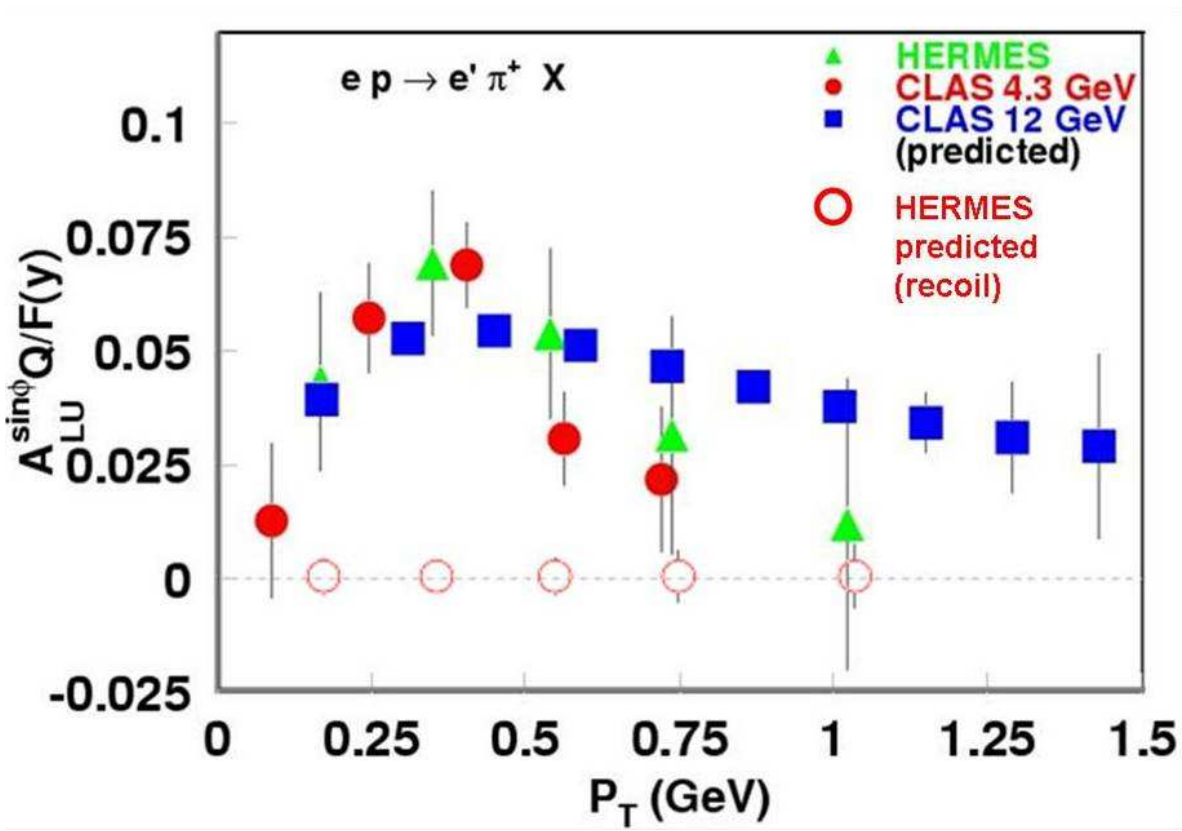
Beam Spin Asymmetry, E_{beam} = 4.25 GeV



A.Afanasev, C.Carlson, hep-ph/0308163 (to be published soon)

Future:

CLAS 12GeV upgrade $\Longleftrightarrow$ HERMES Recoil upgrade



Conclusions and Outlook:

- First measurement of Beam SSA for all pions
- Independent source of information about $H_1^{\perp}$ Collins function
- Possibility to access a set of new DFs and FFs
- Agreement with CLAS measurement of BSA for π^+ (after kinematic range corrections)
- Agreement with some theoretical model calculation

Still to come:

- HERA run II with >3M of DIS on hydrogen
- HERMES with Recoil - high lumi data + better separation of exclusive channels
- CLAS 12GeV upgrade - wider kinematic range, more statistics

Backup slides

The asymmetry of ρ^0 decay products (from data) and their contamination in the pion sample: