BNL Single-Spin Asymmetry Workshop, June 2005.

# Plans of Transverse Target SSA Measurements in SIDIS at Jefferson Lab Hall A and Hall C

Xiaodong Jiang (Rutgers University), June $2^{nd}$, 2005.

With a relatively high luminosity available for fixed target experiments at Jefferson Lab's Hall A and Hall C, transversely polarized target single-spin asymmetry measurements in SIDIS reactions will become a reality in the next few years. These experiments include:

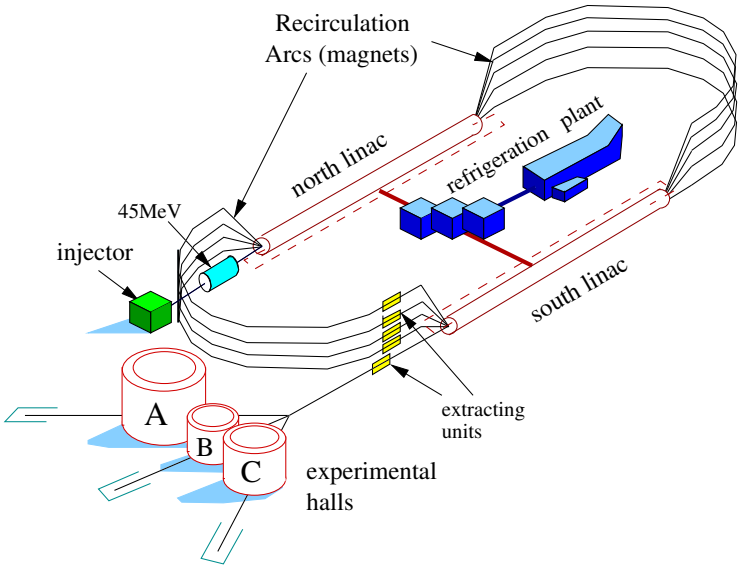
- Neutron SSA measurements at Hall A on a transversely polarized $^3$He target in $n^{\uparrow}(e, e'\pi^{\pm})$ reactions.
- Proton SSA measurements at Hall C in $p^{\uparrow}(e, e'\pi^{\pm})$ reactions.
- Proton SSA measurements at Hall C in $p^{\uparrow}(e, e'\pi^{0})$ reaction.

A few points of discussion:

- Transversity can be determined without ever measuring Collins fragmentation functions.
- Target single-spin asymmetry measurements require the lepton beam to be unpolarized. COMPASS transverse deuteron data is a mixture of double-spin and target single-spin asymmetries.
- Double-spin asymmetry $A_{LT}$, and the transverse-momentum dependent distribution function $g_{1T}$, is the easiest leading-twist TMD parton distribution functions to measure at Jefferson Lab.

# Thomas Jefferson National Accelerator Facility

Newport News, Virginia.




6 GeV polarized electron beam ($P_e = 85\%$, $I = 120\ \mu$A).

Continuous beam to three experiment halls for fixed target experiment.

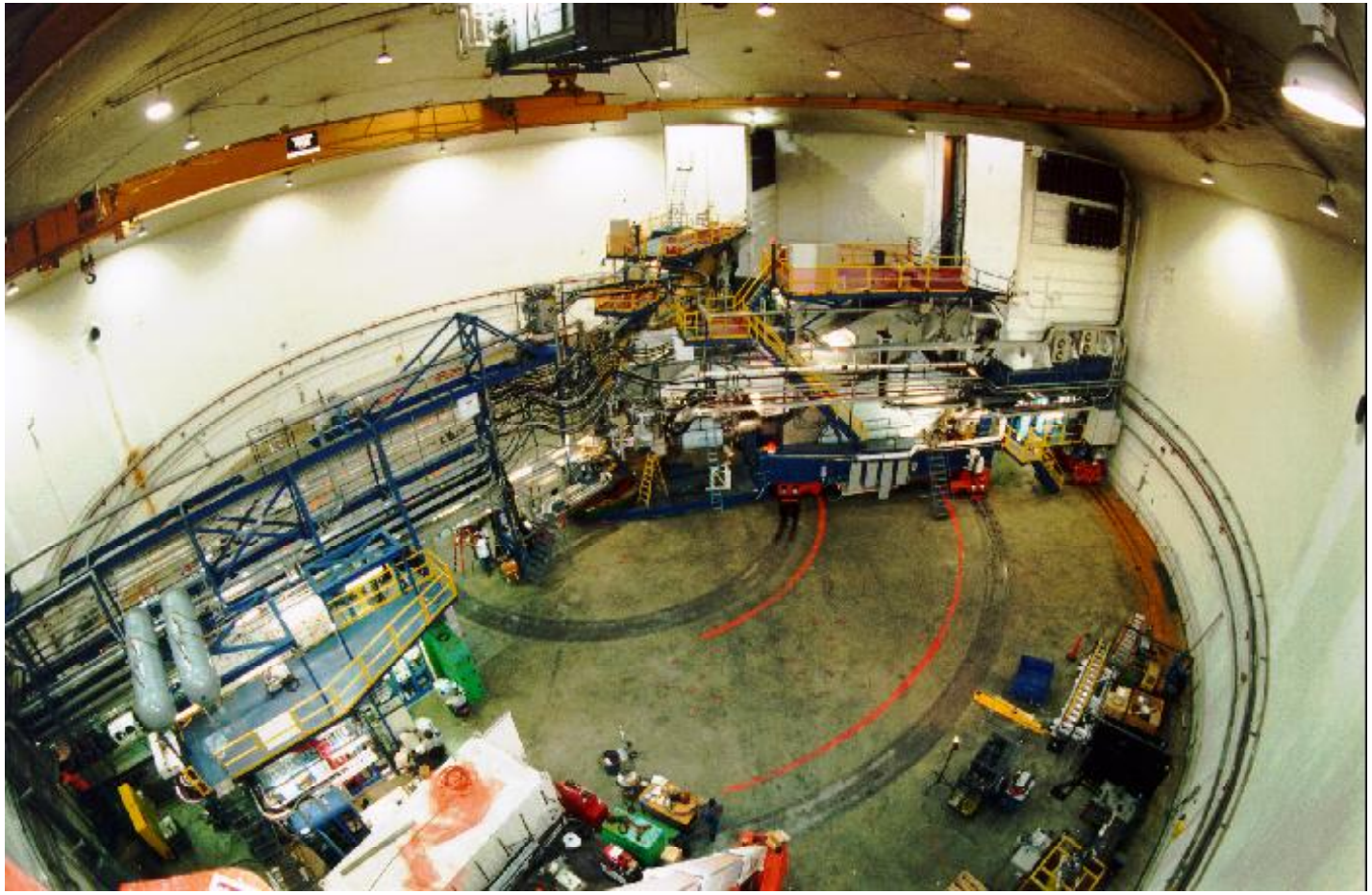
Electron beam helicity is randomly flipped at a rate of 30 Hz.

Hall A: two high resolution magnetic spectrometers.

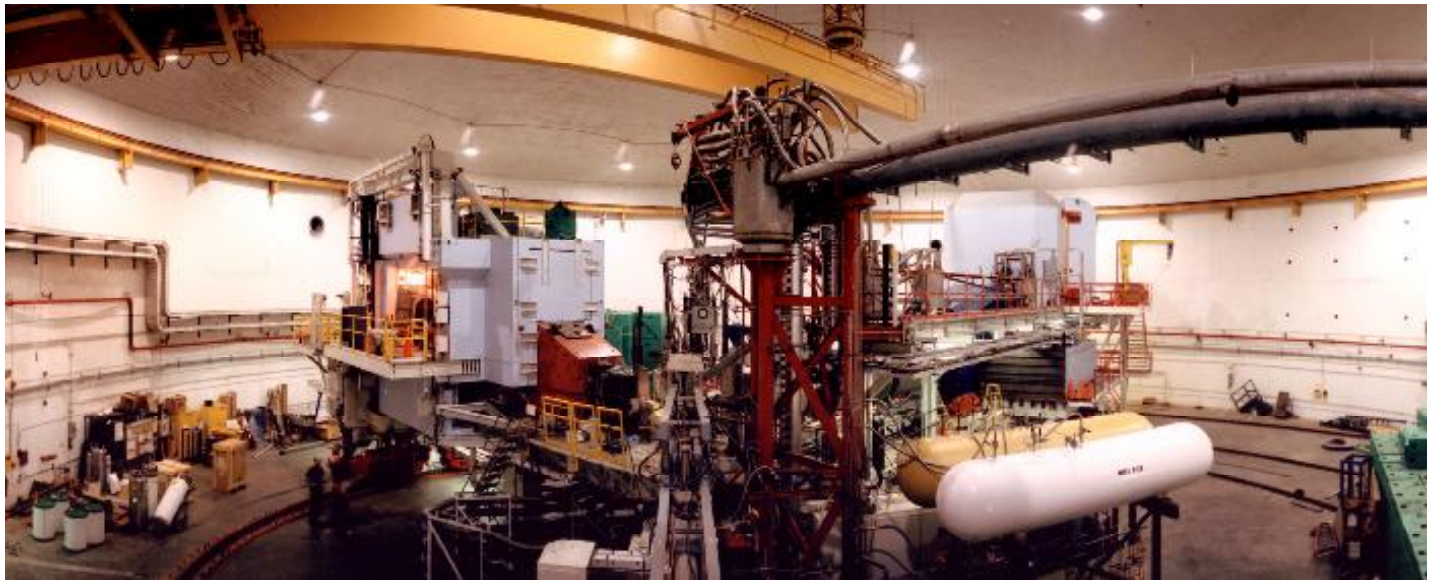
Hall B: a large acceptance spectrometer.

Hall C: two magnetic spectrometers.

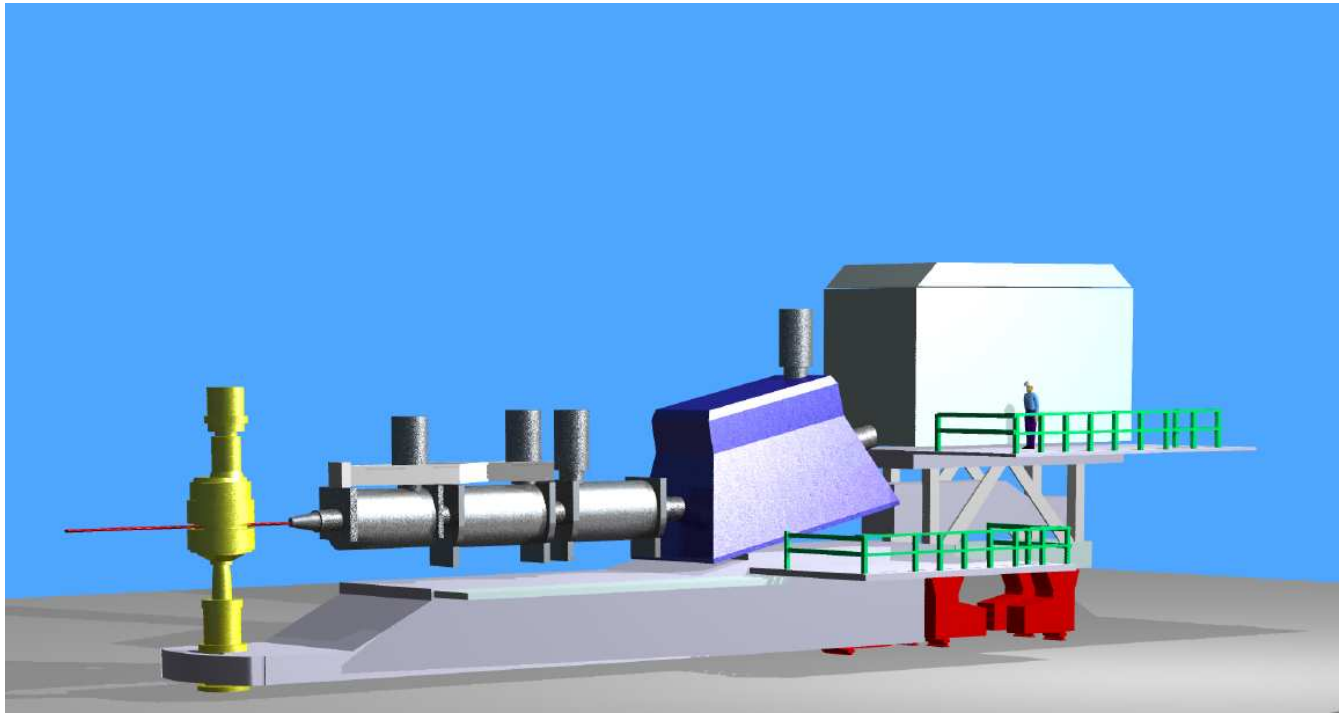
# Hall A: Two High Resolution Magnetic Spectrometers



# Hall C: Two Magnetic Spectrometers



# One Example: Hall C HMS Spectrometer



# High Luminosity for SIDIS at Jefferson Lab

Polarized proton in Hall C ($NH_3$): $\mathcal{L}_{\vec{p}} = 0.85 \times 10^{35}$ cm$^{-2}$s$^{-1}$.

(HERMES:$\mathcal{L}_{\vec{p}} = 1.3 \times 10^{31}$ cm$^{-2}$s$^{-1}$).

Polarized $^3$He in Hall A : $\mathcal{L}_{\vec{He}} = 1.0 \times 10^{36}$ cm$^{-2}$s$^{-1}$.

(HERMES:$\mathcal{L}_{\vec{He}} = 6.2 \times 10^{31}$ cm$^{-2}$s$^{-1}$).

Typical scattering angle is 30$^\circ$ for SIDIS at JLab (compare with $0^\circ - 10^\circ$ at HERMES).

Access $0.12 < x < 0.42$ with $\langle Q^2 \rangle$=2.2 GeV$^2$ with $W > 2.3$ GeV.

## Accessing Transversity $h_1^q(x)$ through SIDIS

Transversity distribution $h_1^q$ is chiral–odd, not accessible through inclusive DIS.

➡ Accessible in SIDIS $N^{\uparrow}(e, e'h)$ through chiral–odd quark fragmentation function $H_1^{\perp}$ J.C. Collins, NPB 396, 161(1993).

$$A_{UT}^{h,Collins}(x, z, P_{h\perp}^2) \propto \frac{\sum_q e_q^2 \cdot h_1^q(x) \otimes H_{1q}^{\perp h}(z, P_{h\perp}^2)}{\sum_q e_q^2 \cdot f_1^q(x) \otimes D_{1q}^h(z, P_{h\perp}^2)}.$$

# Neutron Transversity: Jefferson Lab Experiment E03-004

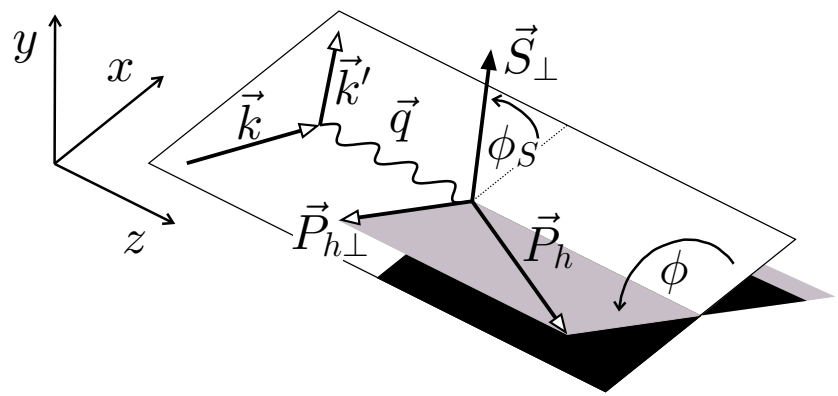
Spokespersons: J.-P. Chen (JLab), X. Jiang (Rutgers), J.-C. Peng (UIUC)

Argonne, CalState-LA, Duke, E. Kentucky, FIU, UIUC, JLab, Kentucky, Maryland, UMass,

MIT, ODU, Rutgers, Temple, UVa, W&M, USTC-China, CIAE-China, Glasgow-UK, INFN-Italy,

U. Ljubljana-Slovenia, St. Mary's-Canada, Tel Aviv-Israel, St. Petersburg-Russia.

$$A_{UT}(\phi_h^l, \phi_S^l) = \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow}$$



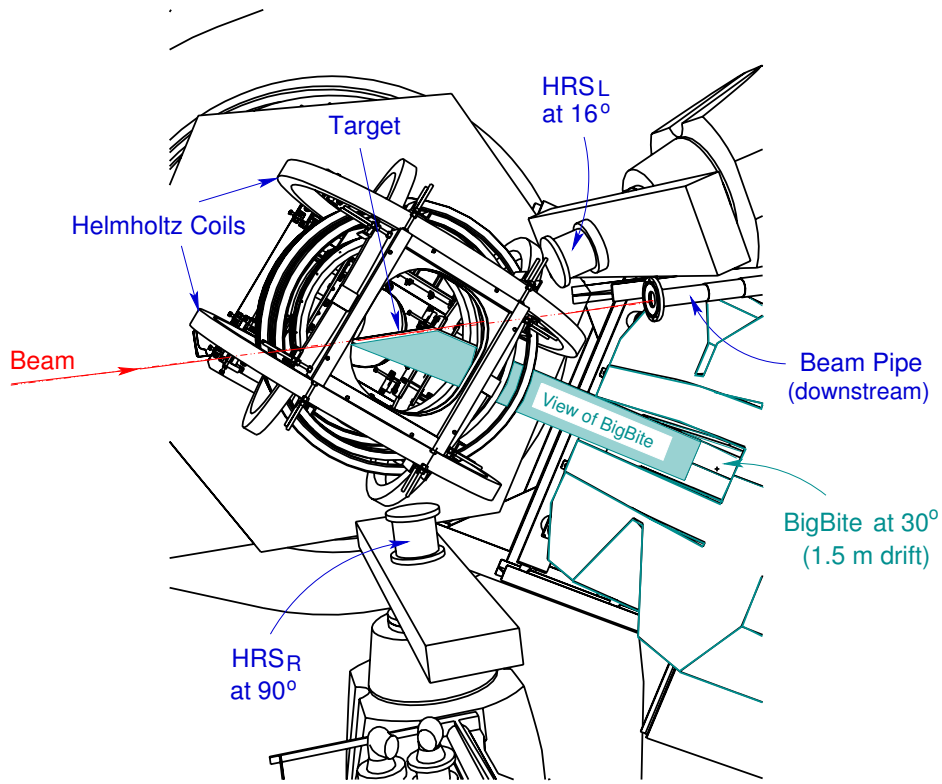

$$\begin{aligned}\sigma_{UT} \quad &\propto \quad S_T(1-y)\frac{P_{h\perp}}{zM_h}\,\sin(\phi_h^\ell + \phi_S^\ell)\cdot\sum e_q^2\, h_1^q(x)\otimes H_{1q}^{\perp h}(z, P_{h\perp}^2) \\ &+ \quad S_T(1-y+\frac{y^2}{2})\frac{P_{h\perp}}{zM_N}\,\sin(\phi_h^\ell - \phi_S^\ell)\cdot\sum e_q^2\, f_{1T}^{\perp q}(x)\otimes D_{1q}^h(z_h, P_{h\perp}^2)\end{aligned}$$

- Collins angle: $\phi_C = \phi_h^l + \phi_S^l$, ➡ target spin rotation $\approx$ out-of-plane detection.

- Need to cover a range of $\phi_h^\ell$ and $\phi_S^\ell$.

One experiment only covers a range of $(x, z, P_{h\perp})$.

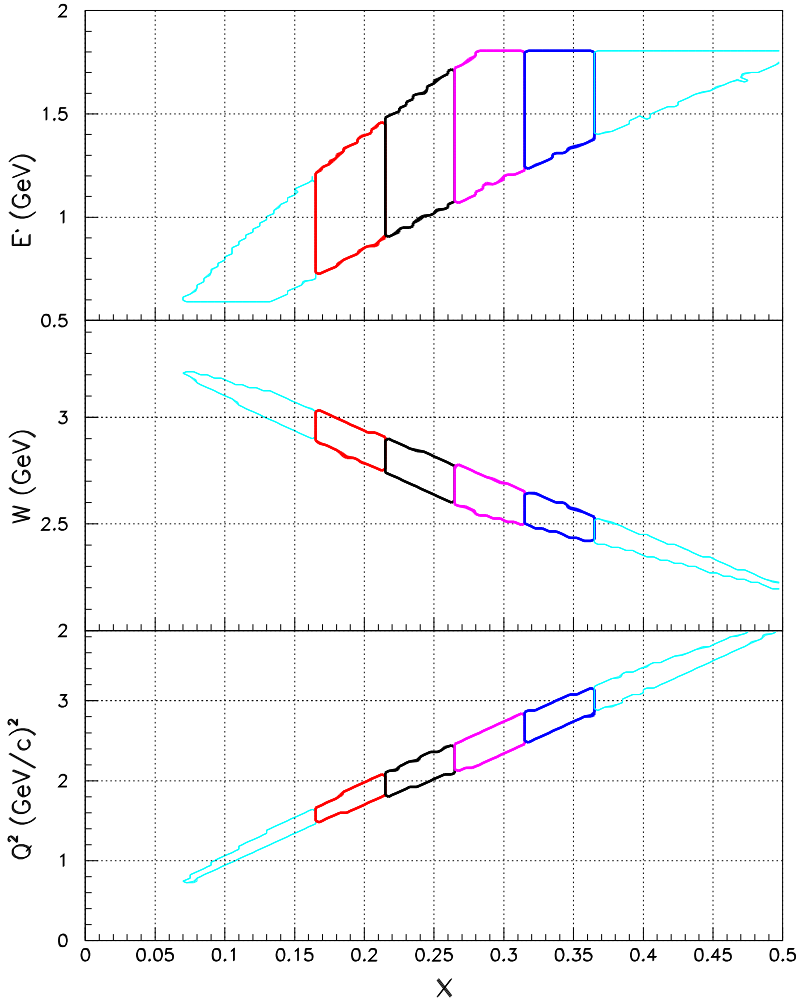
# JLab E03-004: $n^{\uparrow}(e, e'\pi^-)X$ with a 6 GeV Beam




- A magnetic spectrometer BigBite as $e$-arm: at $30°$.
- One existing high resolution spectrometer as $h$-arm: at $16°$, $p_h = 2.4$ GeV/c.
- Hall A polarized $^3$He$^{\uparrow}$ target. Rotate $\phi_S$ to cover $\phi_{Collins}$ and $\phi_{Sivers}$.

# E03-004 Kinematic Coverage

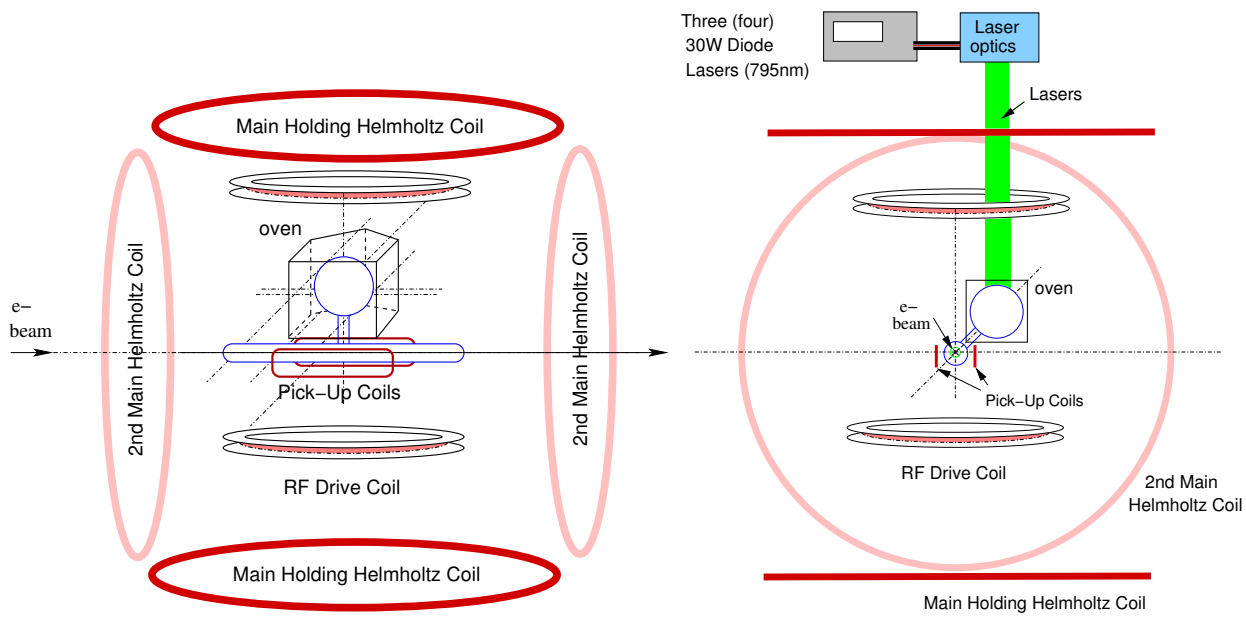
$x$: 0.19–0.34, $Q^2$: 1.8–2.7 GeV$^2$, $W$: 2.5–2.9 GeV.



# The Hall A Polarized $^3$He Target

40 cm long 10 atm pressure, $P_T \approx 42\%$, I=15 $\mu$ A, $\Rightarrow \mathcal{L}(^3He) = 10^{36} cm^{-2} s^{-1}$.

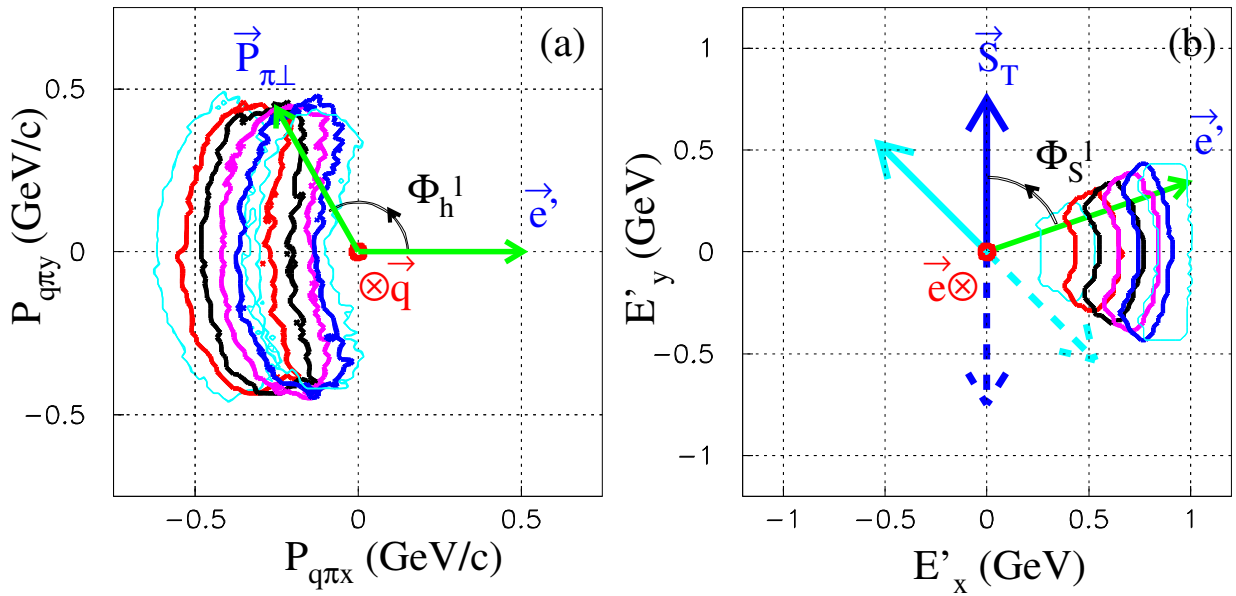
Used successfully in many experiments with in-plane polarization.




Be able to rotate the target spin in any direction.

# Collins angle: $\phi_C = \phi_h^l + \phi_S^l$

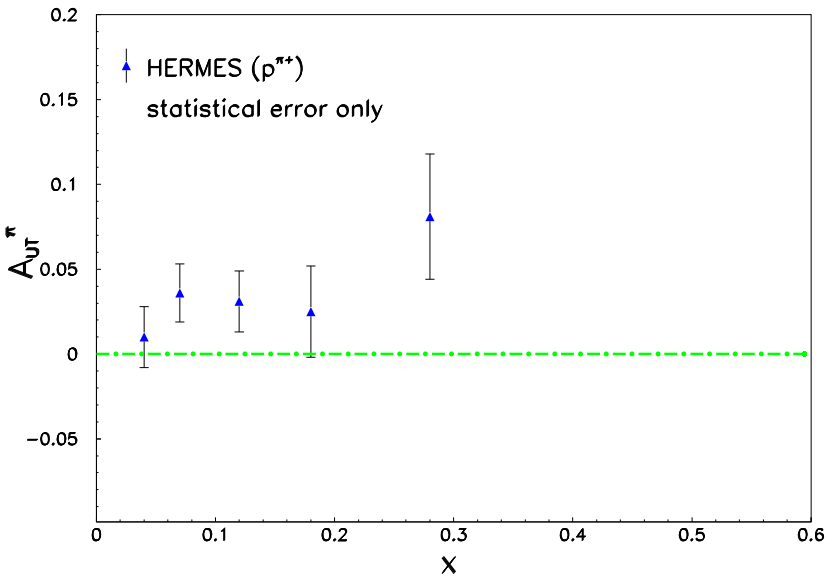
View along $\vec{q}$: $\Delta\phi_h^l \approx 126^\circ$ along $\vec{e}$: $\Delta\phi_S^l \approx 54^\circ$.

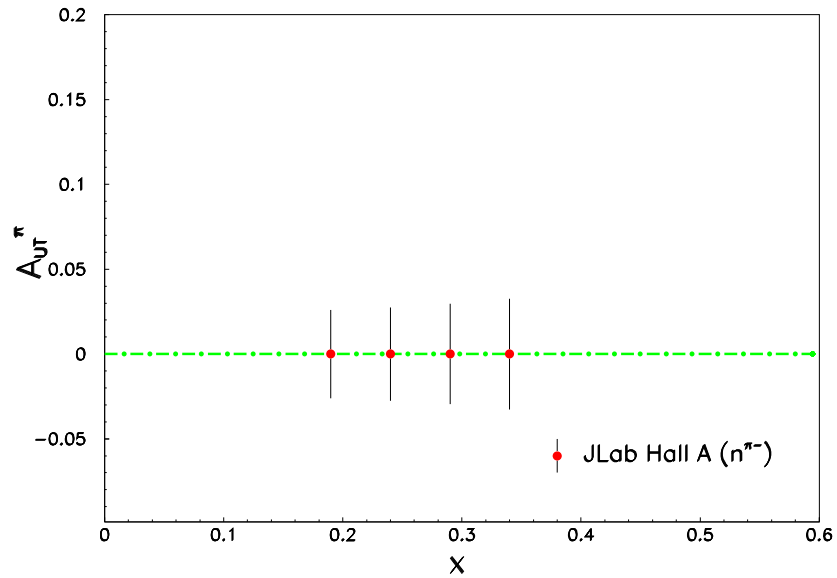



- two target spin: $\Delta\phi_C \approx 126^\circ + 54^\circ \times 2 \approx 234^\circ$.
- one target spin: $\Delta\phi_C \approx 126^\circ + 54^\circ \approx 180^\circ$.

$$A_{UT}(\phi_h^l, \phi_S^l) = \frac{N(\phi_h^l, \phi_S^l) - \frac{\mathcal{L}^\uparrow}{\mathcal{L}^\downarrow} N(\phi_h^l, \phi_S^l + \pi)}{N(\phi_h^l, \phi_S^l) + \frac{\mathcal{L}^\uparrow}{\mathcal{L}^\downarrow} N(\phi_h^l, \phi_S^l + \pi)}$$

# The Projected Statistical Uncertainties on Collins $A_{UT}^{\pi^-}(n)$




Notice that:

$$A_{UT}^{\pi^+}(p) \propto 4h_1^u \cdot H_1^{\perp +} + h_1^d \cdot H_1^{\perp -}$$

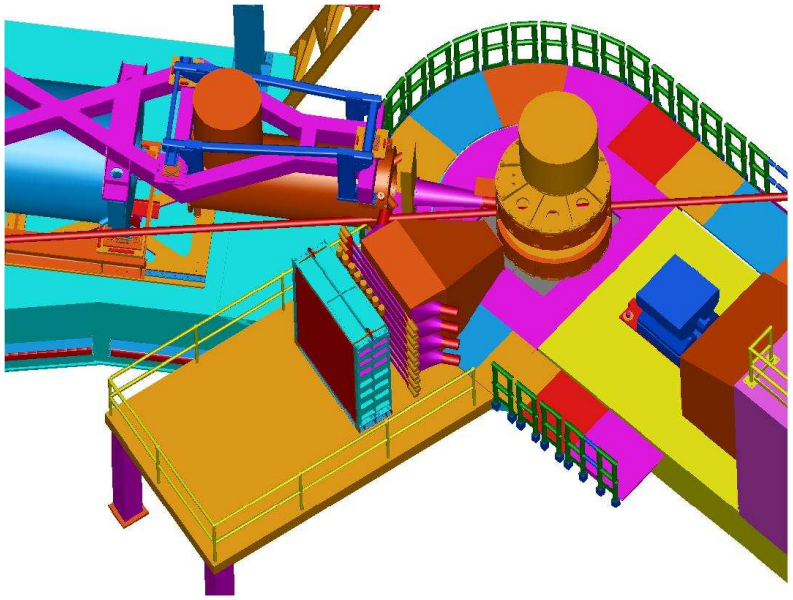
$$A_{UT}^{\pi^-}(n) \propto 4h_1^d \cdot H_1^{\perp -} + h_1^u \cdot H_1^{\perp +}$$

$A_{UT}^{\pi^+}(p)$: $h_1^u$ dominates.

$A_{UT}^{\pi^-}(n)$: both $h_1^u$ and $h_1^d$ contribute.

# A Letter-of-Intent to Measure SSA in $p^{\uparrow}(e, e'h)X$

A LOI has been submitted to Jefferson Lab PAC25 (LOI04-003).



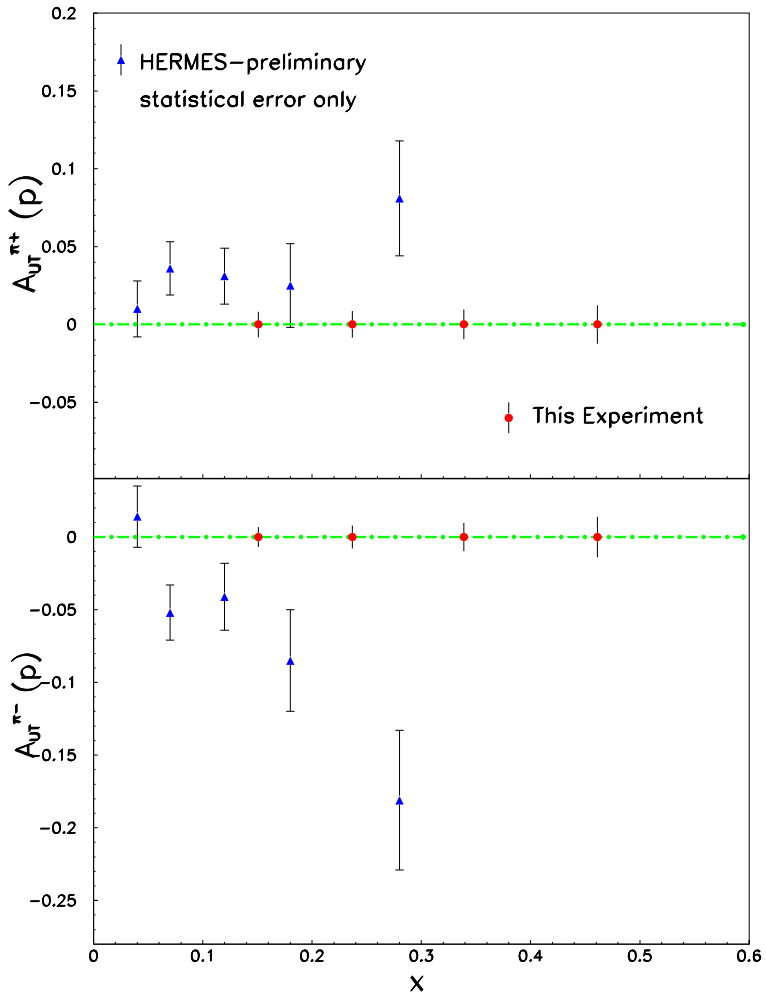
A Hall C experiment with 6 GeV beam.

A large calorimeter array as $e$-arm, $\Delta\Omega_e = 300$ msr.

Existing spectrometer HMS as $h$-arm.

Run for 45 days.

# The Expected Statistical Uncertainties $p^{\uparrow}(e, e'h)X$




$E_0$=6 GeV, run for 45 days total. For both $\pi^+$ and $\pi^-$ production.

# Can be Easily Extended to $p^{\uparrow}(e, e'\pi^0)X$ Channel

Need to build another large calorimeter array for $\pi^0$ detection to replace the HMS spectrometer as the hadron-arm.

Need a strong dipole magnet down-stream of the polarized target to bend the 6 GeV electron beam away to reduce beam related background.

A document of experiment proposal is in progress, to be submitted to Jefferson Lab PAC.

## Determine transversity without ever measuring $H_{1q}^{h\perp}$ ?

Assuming SU(2) symmetry and charge conjugation invariance (neglecting sea quark contribution):

$$A_{UT}^{\pi^+}(p) \propto 4h_1^u \cdot H_1^{\perp +} + h_1^d \cdot H_1^{\perp -}$$

$$A_{UT}^{\pi^-}(p) \propto 4h_1^u \cdot H_1^{\perp -} + h_1^d \cdot H_1^{\perp +}$$

$$A_{UT}^{\pi^+}(n) \propto 4h_1^d \cdot H_1^{\perp +} + h_1^u \cdot H_1^{\perp -}$$

$$A_{UT}^{\pi^-}(n) \propto 4h_1^d \cdot H_1^{\perp -} + h_1^u \cdot H_1^{\perp +}$$

Four independent measurements to constrain four unknown quantities.

Plus $\pi^0$ measurements to serve as consistency checks:

$$A_{UT}^{\pi^0}(p) \propto (4h_1^u + h_1^d) \cdot (H_1^{\perp +} + H_1^{\perp -})/2$$

$$A_{UT}^{\pi^0}(n) \propto (4h_1^d + h_1^u) \cdot (H_1^{\perp +} + H_1^{\perp -})/2$$

## Better yet:

If we take the sum of $\pi^+ + \pi^-$:

$$A_{UT}^{\pi^+ + \pi^-}(p) \propto (4h_1^u + h_1^d) \cdot (H_1^{\perp +} + H_1^{\perp -})$$

$$A_{UT}^{\pi^+ + \pi^-}(n) \propto (4h_1^d + h_1^u) \cdot (H_1^{\perp +} + H_1^{\perp -})$$

$$\frac{A_{UT}^{\pi^+ + \pi^-}(p)}{A_{UT}^{\pi^+ + \pi^-}(n)} = \frac{4 + h_1^d/h_1^u}{4h_1^d/h_1^u + 1}$$

## But, what if $H_1^{\perp +} \approx -H_1^{\perp -}$ ?

We can take the difference $\pi^+ - \pi^-$:

$$A_{UT}^{\pi^+ - \pi^-}(p) \propto (4h_1^u - h_1^d) \cdot (H_1^{\perp +} - H_1^{\perp -})$$

$$A_{UT}^{\pi^+ - \pi^-}(n) \propto (4h_1^d - h_1^u) \cdot (H_1^{\perp +} - H_1^{\perp -})$$

$$\frac{A_{UT}^{\pi^+ - \pi^-}(p)}{A_{UT}^{\pi^+ - \pi^-}(n)} = \frac{4 - h_1^d/h_1^u}{4h_1^d/h_1^u - 1}$$

# Summary

After the HERMES transverse target data collection ends, transverse target SSA physics will be continued at Jefferson Lab for 6 GeV now and 12 GeV in the future. This includes:

- Neutron transversity measurement in $n^{\uparrow}(e, e'\pi^{-})$. Approved for 24 days of beam in Hall A, waiting for the beam time schedule.
- Neutron transversity in $n^{\uparrow}(e, e'\pi^{+})$ (a new Hall A proposal).
- Proton transverse SSA in $p^{\uparrow}(e, e'\pi^{\pm})$ (LOI in Hall C), pending on target magnet design.
- To be expanded to $p^{\uparrow}(e, e'\pi^{0})$ (Hall C).

When these measurements finish:

- Asymmetry and relative cross section from many channels will be available at the same kinematics.
- Data can be combined to form ratios.

# Comments on Transverse Target SSA in SIDIS

- Target SSA ($A_{UT}$) requires a lepton beam that is not polarized.
- When a polarized lepton beam is used in target SSA measurements, beam helicity ($\lambda_e$) flip is needed and proper acceptance average and weighting should be taken to eliminate possible contamination from double-spin asymmetries. $\sigma_T = \sigma_{LT} + \sigma_{UT}$.
- Double-spin asymmetries will not automatically drop out of the angular moments since "a real experiment" never has infinite and uniform acceptance coverage.

$$
\begin{aligned}
\sigma_T \quad \propto \quad & \lambda_e S_T y(1-\frac{y}{2}) \cdot \frac{P_{h\perp}}{zM_h} \cos(\phi_h^\ell - \phi_S^\ell) \cdot \sum e_q^2 \, g_{1T}^q(x) \otimes D_{1q}^{\perp h}(z, P_{h\perp}^2) \\
+ \quad & S_T(1-y) \cdot \frac{P_{h\perp}}{zM_h} \sin(\phi_h^\ell + \phi_S^\ell) \cdot \sum e_q^2 \, h_1^q(x) \otimes H_{1q}^{\perp h}(z, P_{h\perp}^2) \\
+ \quad & S_T(1-y+\frac{y^2}{2}) \frac{P_{h\perp}}{zM_N} \sin(\phi_h^\ell - \phi_S^\ell) \cdot \sum e_q^2 \, f_{1T}^{\perp q}(x) \otimes D_{1q}^{h}(z_h, P_{h\perp}^2)
\end{aligned}
$$

# COMPASS Transverse Deuteron Data

- COMPASS muon beam was naturally polarized in one direction from pion decay, with $P_b = 76\%$.
- Muon beam helicity was never flipped. Only the target spin (two target cells) was flipped.
- In principle, double-spin terms contribute to the measured asymmetries since $\sigma_T = \sigma_{LT} + \sigma_{UT}$.
- When angular moments are taken, double-spin contamination terms depend on the "acceptance weighted average".

# A Few Comments on $g_{1T}$

A leading-twist $k_T$ dependent distribution:

- Never been measured before. No clue on its size. $g_{1T} \equiv 0$ if quark angular momentum $L_q = 0$.
- Linked through Lorentz invarience: $g_2(x) = -\frac{d}{dx} g_{1T}(x)$ ???
- Some calculations expect a large asymmetry (Yuan, Gamberg).
- Positivity limit link $g_{1T}$ with $f_{1T}^{\perp}$.
- One expects $g_{1T}^u / g_{1T}^d$ behave like $g_1^u / g_1^d$ ?

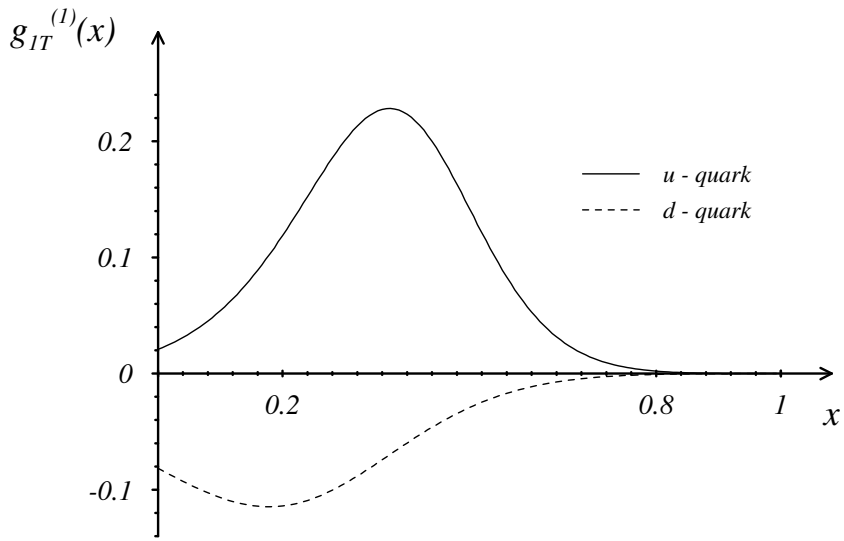
On the experiment side:

- One of the easiest SIDIS observable to measure at Jefferson Lab.
- HERMES should already have data on $A_{LT}^h(p)$.

Will we have suprises on $g_{1T}$ ? What're our expectations on $g_{1T}$ to start with ?

# The Combined $A_{LT}^h$ Asymmetries to Extract $g_{1T}^q$

Leading twist quark transverse momentum dependent distribution, originated from the real part of the interference between $L = 0$ and $L = 1$ wave function. Double-spin asymmetries $A_{LT}^h$ with $\cos(\phi_h - \phi_S)$ dependence.




Bag model calculation, Jacob, Mulders and Rodrigues, NPA 1997.

At the leading order:

$$A_{LT}^{\pi^+ + \pi^-}(p) = \frac{4g_{1T}^u + g_{1T}^d}{4u + d}$$

$$A_{LT}^{\pi^+ + \pi^-}(n) = \frac{g_{1T}^u + 4g_{1T}^d}{u + 4d}$$

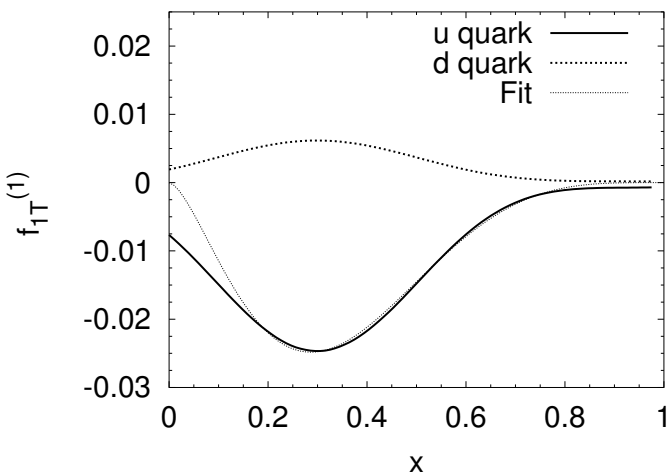
$$A_{LT}^{\pi^+ - \pi^-}(p) = \frac{4g_{1T}^u - g_{1T}^d}{4u - d}$$

$$A_{LT}^{\pi^+ - \pi^-}(n) = \frac{g_{1T}^u - 4g_{1T}^d}{u - 4d}$$

Double-spin asymmetries $A_{LT}^h$ from JLab experiments.

# The Combined $A_{UT}^{h}$ to Extract Sivers Function $f_{1T}^{\perp q}$

Leading twist quark transverse momentum dependent distribution, originated from the imaginary part of the interference between $L = 0$ and $L = 1$ wave function.




Bag model calculation, F. Yuan, hep-ph/0308157

At the leading order:

$$\left(A_{UT}^{\pi^+ + \pi^-}\right)_{Sivers}(p) = \frac{4f_{1T}^{\perp u} + f_{1T}^{\perp d}}{4u + d}$$

$$\left(A_{UT}^{\pi^+ + \pi^-}\right)_{Sivers}(n) = \frac{f_{1T}^{\perp u} + 4f_{1T}^{\perp d}}{u + 4d}$$

$$\left(A_{UT}^{\pi^+ - \pi^-}\right)_{Sivers}(p) = \frac{4f_{1T}^{\perp u} - f_{1T}^{\perp d}}{4u - d}$$

$$\left(A_{UT}^{\pi^+ - \pi^-}\right)_{Sivers}(n) = \frac{f_{1T}^{\perp u} - 4f_{1T}^{\perp d}}{u - 4d}$$