Transversity and Target Lab

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Polarized He3 Collaboration at JLab

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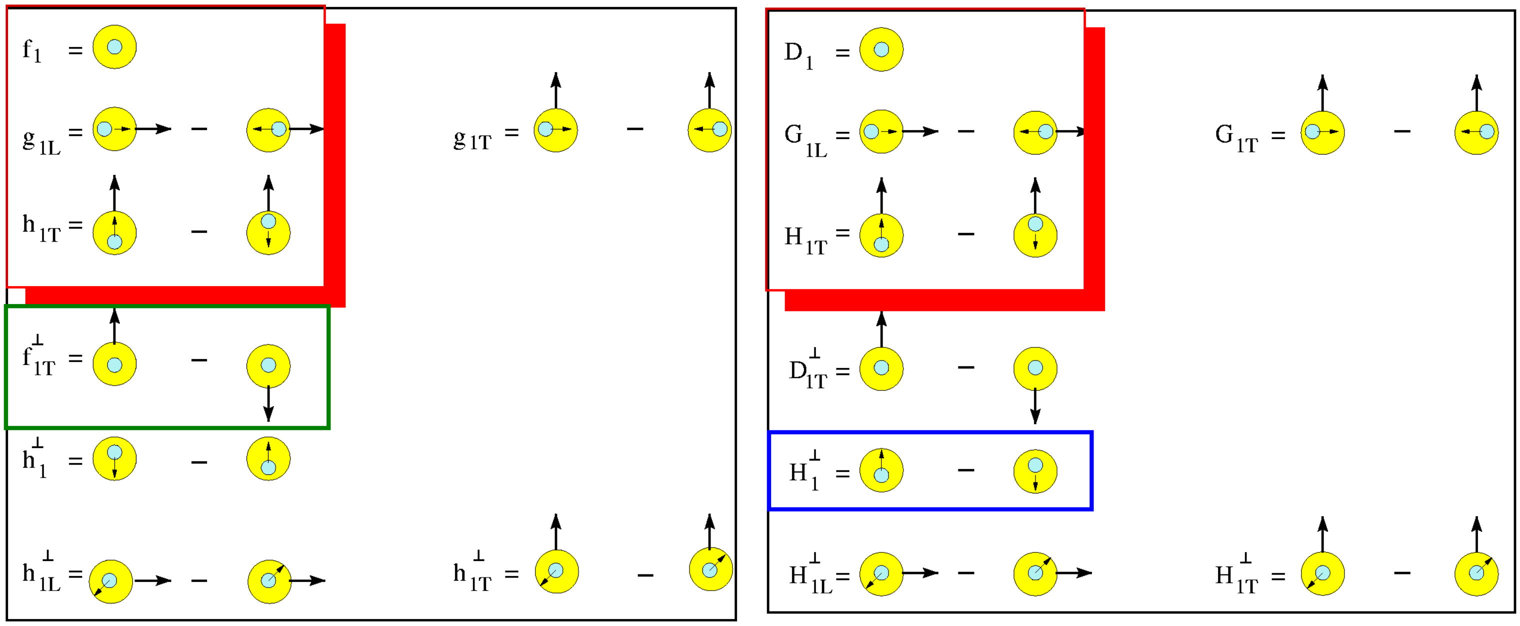
† Transversity Experiment †

† Requirements on the Target †

† Target Lab †

Parton Distribution and Fragmentation Functions

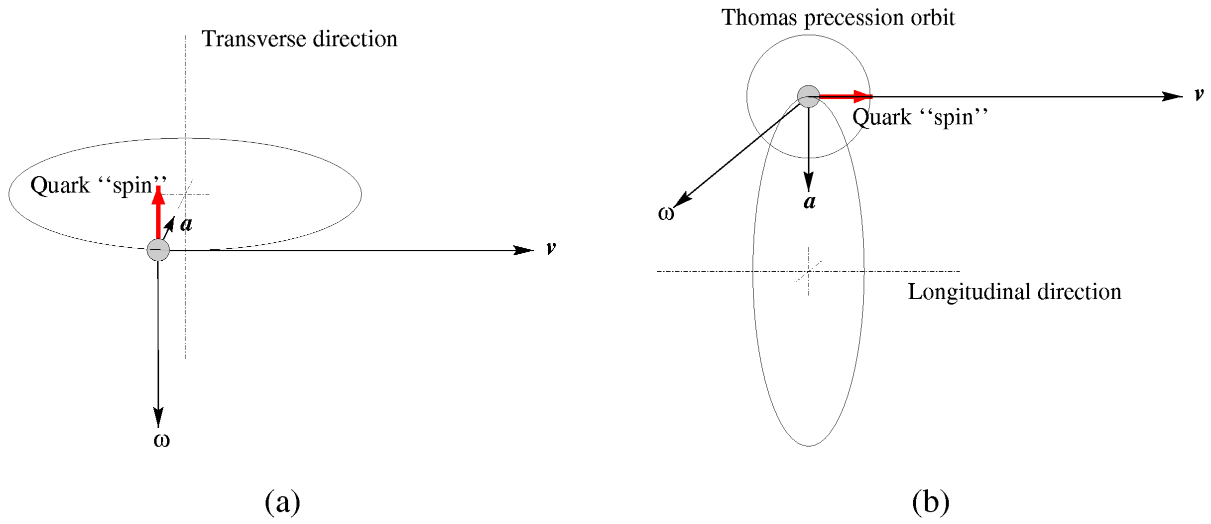
$$\sigma^{eH\to ehX} = \sum_q f^{H\to q} \otimes \sigma^{eq\to eq} \otimes D^{q\to h}$$



- survive $k_\perp$ integration
- Sivers distribution function
- Collins fragmentation function

Characteristics of Transversity

- $h_1(x) = g_1(x)$ at non-relativistic limit.
- do not mix with gluons $\rightarrow$ different Q^2 evolution from $g_1(x)$.
- Chiral odd $\rightarrow$ not accessible in inclusive DIS.
- $h_1(x) \leq (f_1(x) + g_1(x))/2.0 \rightarrow$ Soffer Bound



Thomas precession effect ($\omega_T = \frac{\nu \times /\alpha}{2c^2}$)
on transversity (a) and helicity (b)

Scattering Matrix & Soffer Bound

- In the helicity bases, transversity does not describe the square of a probability amplitude, but rather the interferences between two amplitudes.

$$\left\{ \begin{array}{cccc} f_1(x)+g_1(x) & 0 & 0 & 2h_1(x) \\ 0 & f_1(x)-g_1(x) & 0 & 0 \\ 0 & 0 & f_1(x)-g_1(x) & 0 \\ 2h_1(x) & 0 & 0 & f_1(x)+g_1(x) \end{array} \right\}$$

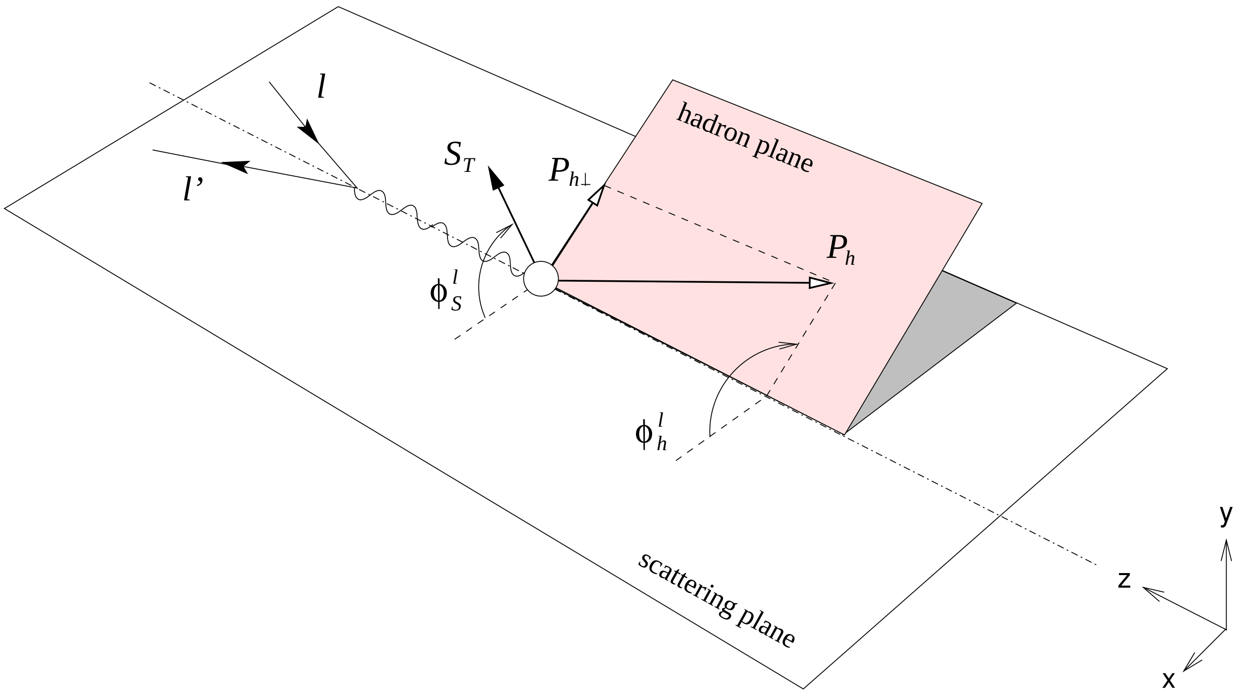
- Since the matrix must be positive semidefinite, one can obtain Soffer bound.

$$\begin{array}{rcl} f_1(x) & \geq & 0 \\ |g_1(x)| & \leq & f_1(x) \\ h_1(x) & \leq & (f_1(x)+g_1(x))/2.0 \end{array}$$

- In the transverse bases, transversity recovers a probability interpretation.

$$\left\{ \begin{array}{cccc} f_1(x)+h_1(x) & 0 & 0 & g_1(x)+h_1(x) \\ 0 & f_1(x)-h_1(x) & g_1(x)-h_1(x) & 0 \\ 0 & g_1(x)-h_1(x) & f_1(x)-h_1(x) & 0 \\ g_1(x)+h_1(x) & 0 & 0 & f_1(x)+h_1(x) \end{array} \right\}$$

Coordinate Definitions



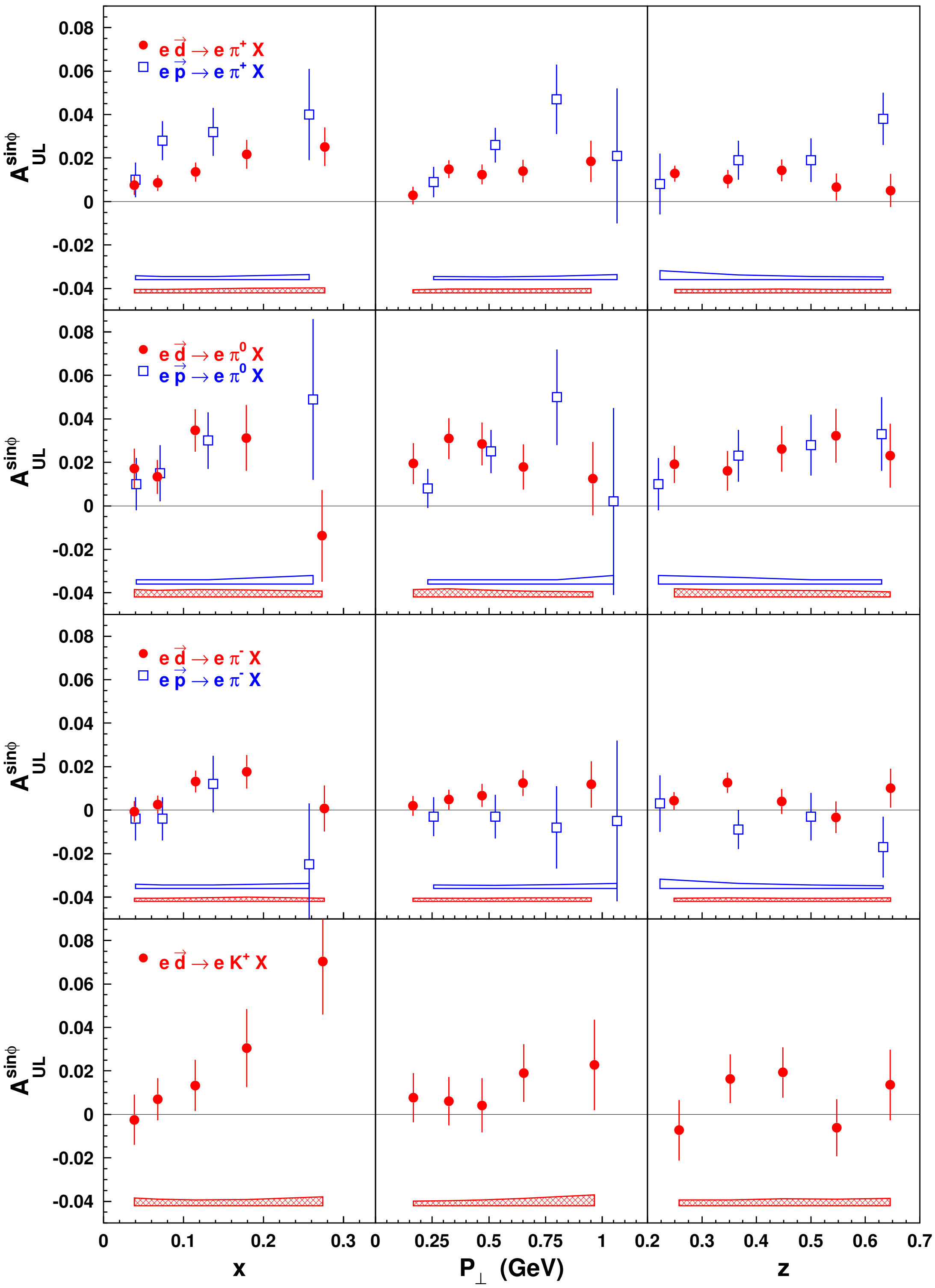
Attention: All the angles are defined relative to the photon direction! Not the beam direction.

For transverse single target spin asymmetry, the relevant terms are:

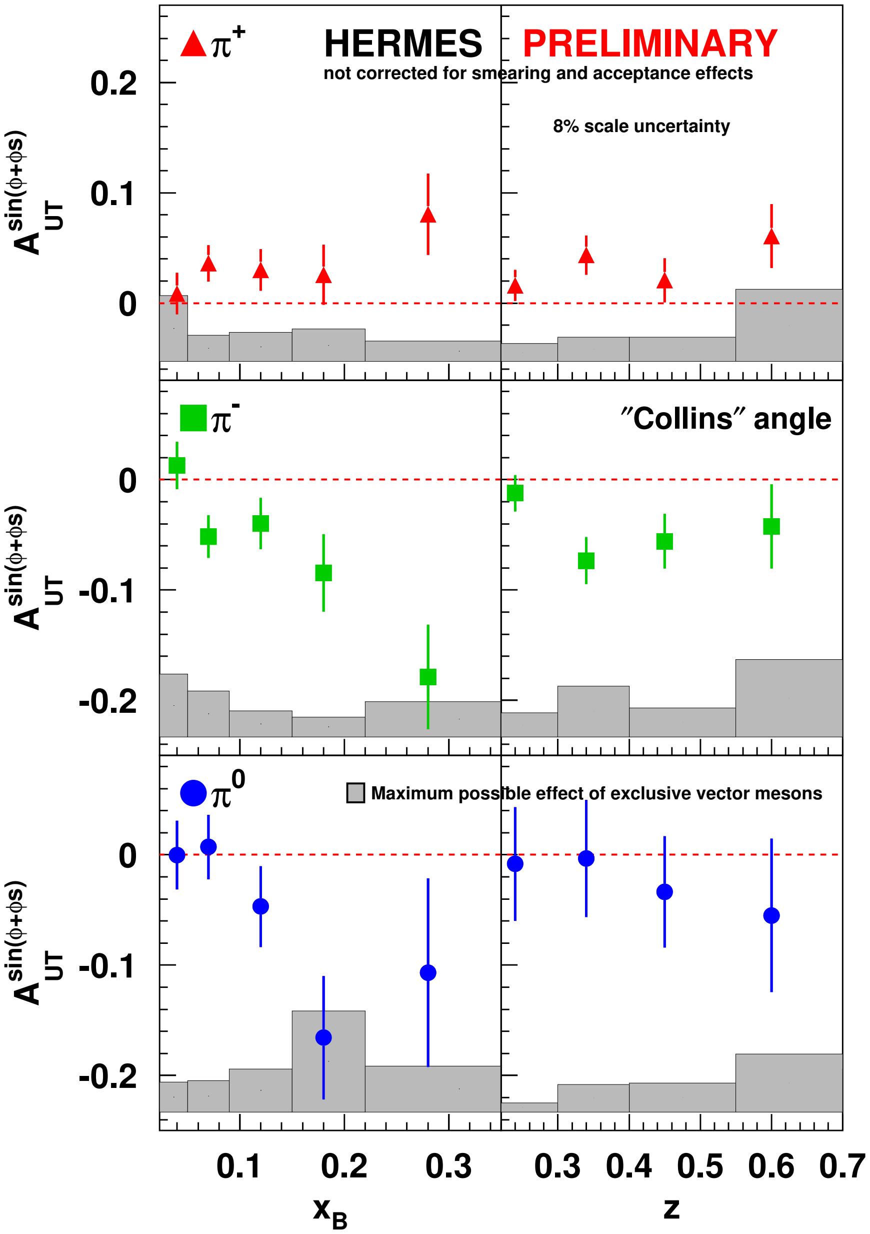
$$
\begin{aligned}
d^6\sigma^{LO} &= \frac{d\sigma}{dx\,dy\,d\phi^l\,dz\,d^2\mathbf{P}_{h\perp}} \sim \frac{4\pi\alpha^2 sx}{Q^4} \\
\times & \left\{ [1+(1-y)^2] \sum_{q,\bar{q}} e_q^2 f_1^q(x) D_1^q(z, \mathbf{P}_{h\perp}^2) \right. \\
+ & \quad |\mathbf{S}_T|(1-y)\frac{P_{h\perp}}{zM_h}\sin(\phi_h^l+\phi_S^l)\sum_{q,\bar{q}} e_q^2 h_1^q(x) H_1^{\perp q} \\
+ & \left. \quad |\mathbf{S}_T|(1-y+y^2/2)\frac{P_{h\perp}}{zM_N}\sin(\phi_h^l-\phi_S^l)\sum_{q,\bar{q}} e_q^2 f_{1T}^{\perp(1)q}(x) D_1^{\perp q} \right\}
\end{aligned}
$$

- from which the Collins ($\propto \sin(\phi_h^l+\phi_S^l)$) and Sivers ($\propto \sin(\phi_h^l-\phi_S^l)$) asymmetry can be formed.
- For longitudinal (in-plane polarization) target, $\phi_S^l = 0°, 180°$ Collins and Sivers asymmetry can not be separated. They both $\propto \sin\phi_h^l$.
- For E03-004,$\phi_S^l = \pm 90°, 135°, -45°$, $\phi_h^l = 180°$; $\Delta\phi_S^l = \pm 27°$, $\Delta\phi_h^l = 53° \sim 73°$.

HERMES Long. Results

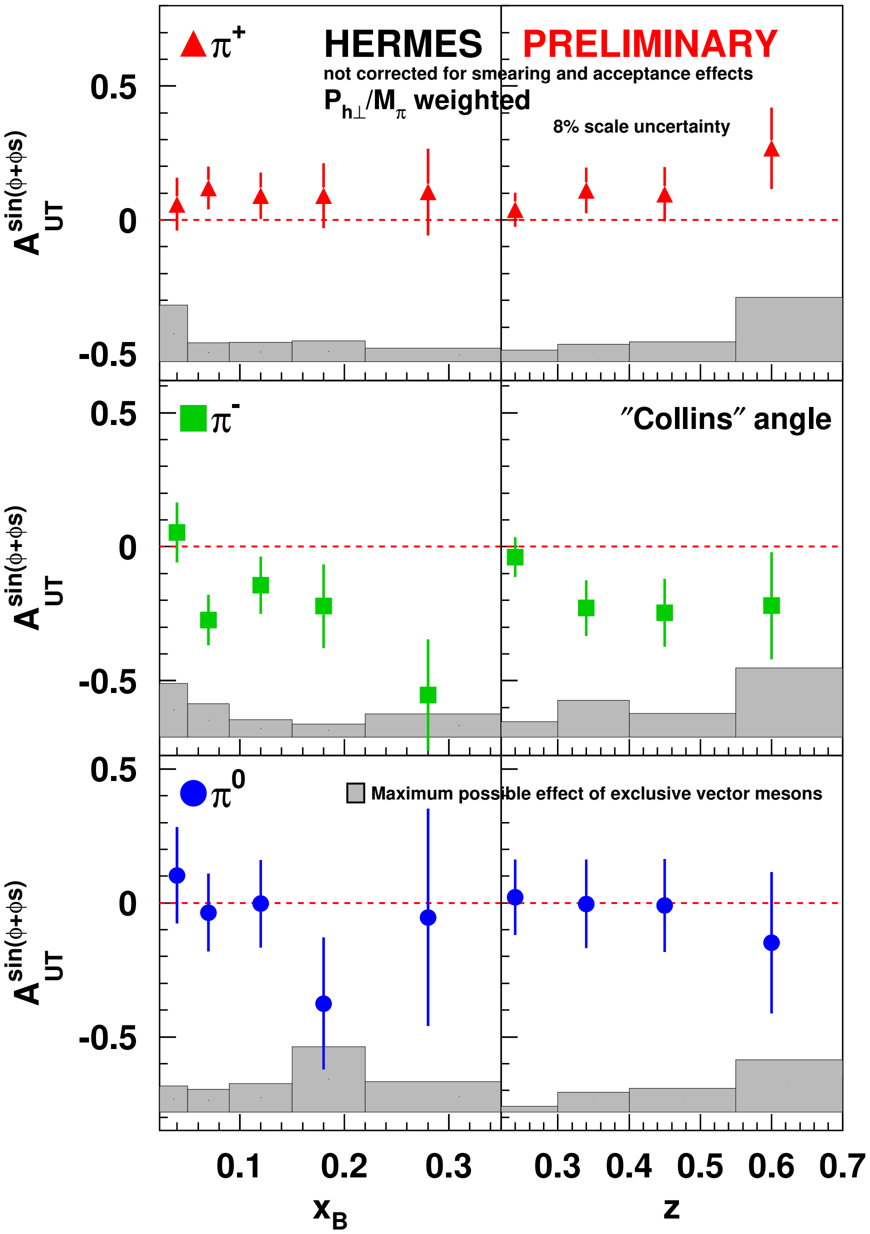


HERMES Tran. Data: Collins Moments

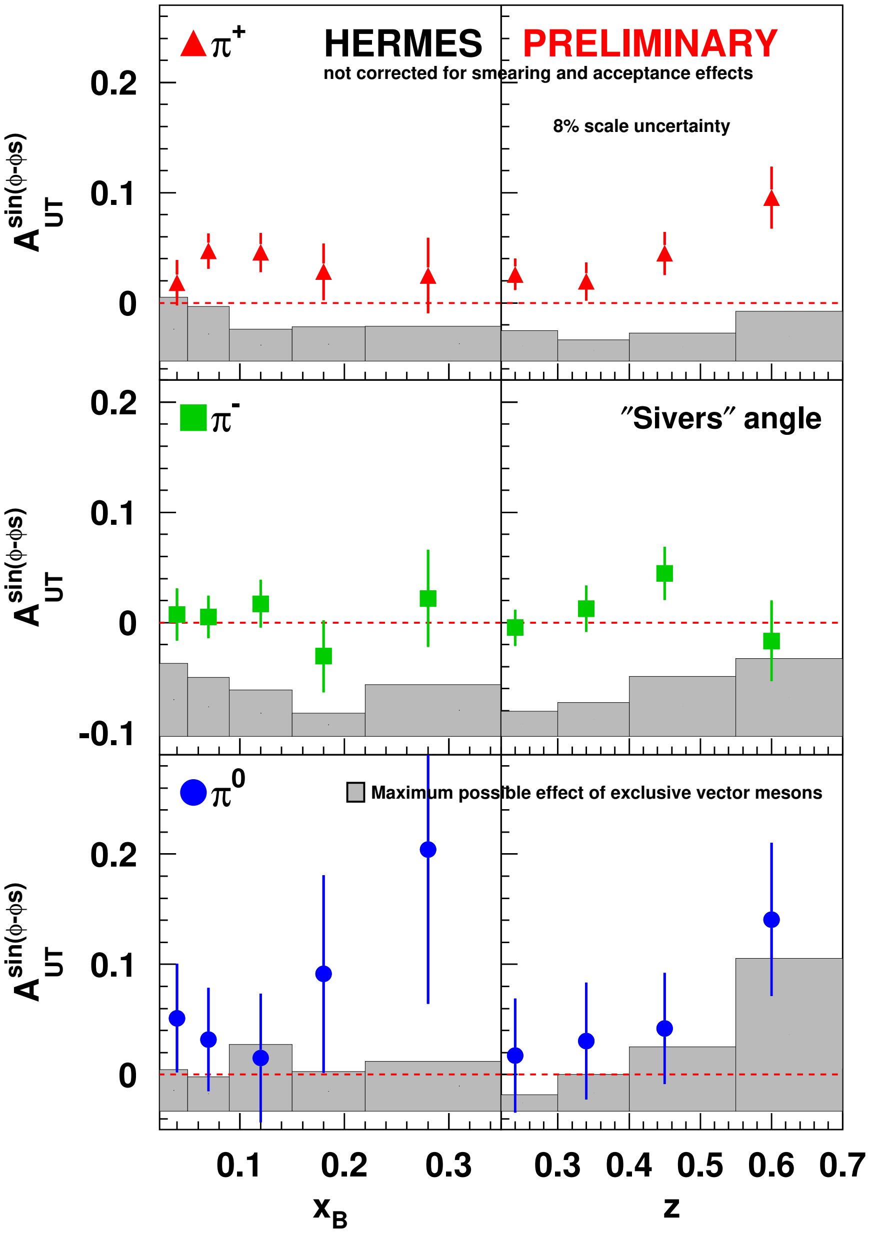


- Large Collins asymmetries for π^0 and π^-
- Disfavored Collins fragmentation function of opposite sign and similar magnitude to favored function

HERMES Tran. Data: Weighted Collins Moments



HERMES Tran. Data: Sivers Moments



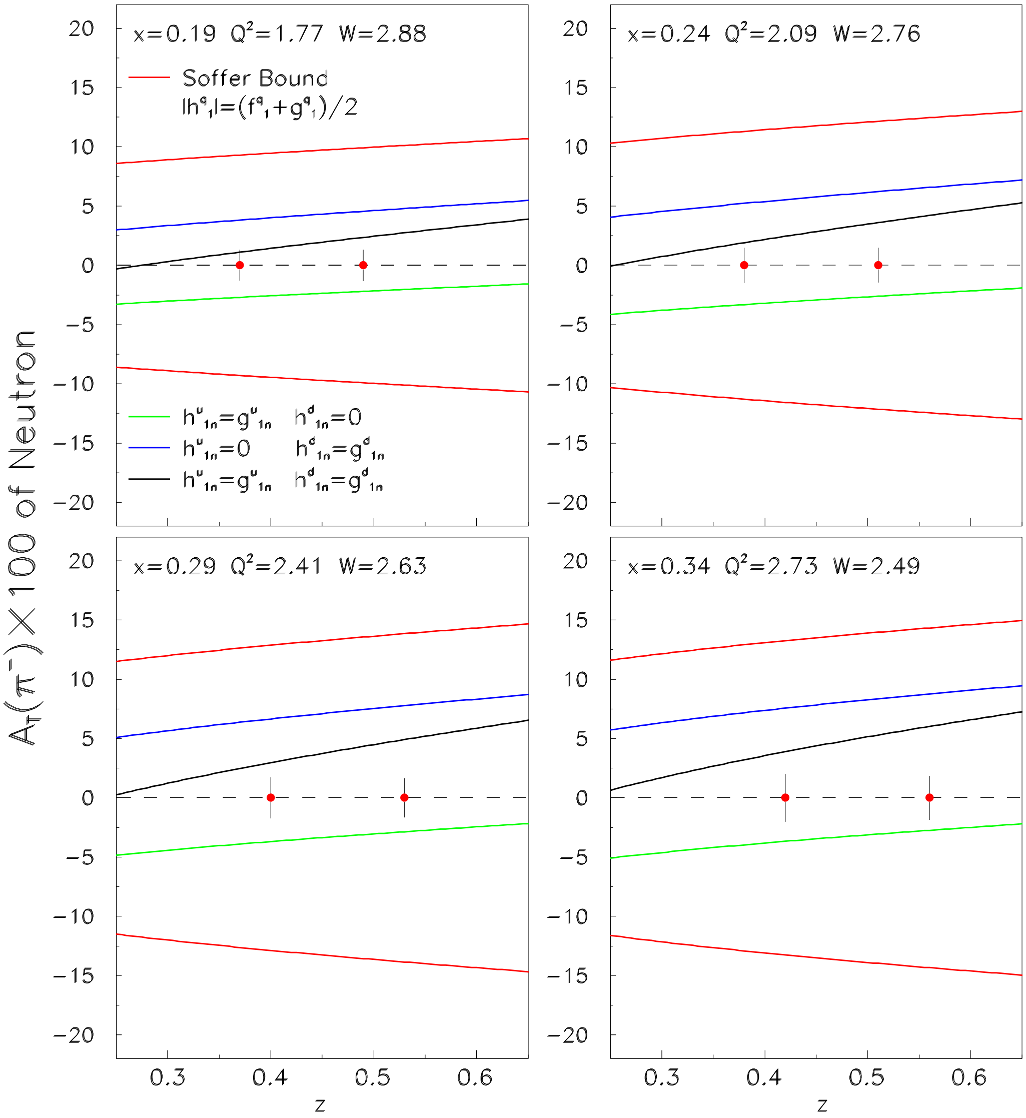
- Fist observation of non-zero Sivers effect.

Kinematics

E′ GeV	θ_e deg.	$\langle x \rangle$	W GeV	Q^2 GeV^2	θ_q deg.	$Rate_{(e,e')}$ Hz	p_π GeV/c	z	$P_\perp$ GeV/c	W' GeV
1.10	30.0	0.19	2.88	1.77	6.22	185	$\theta_{HRS} = 16.0°$			
							1.80	0.37	0.31	2.29
							2.40	0.49	0.41	2.07
1.30	30.0	0.24	2.76	2.09	7.60	151	$\theta_{HRS} = 16.0°$			
							1.80	0.38	0.26	2.19
							2.40	0.51	0.35	1.97
1.50	30.0	0.29	2.63	2.41	9.06	121	$\theta_{HRS} = 16.0°$			
							1.80	0.40	0.22	2.08
							2.40	0.53	0.29	1.86
1.70	30.0	0.34	2.49	2.73	10.63	96	$\theta_{HRS} = 16.0°$			
							1.80	0.42	0.17	1.96
							2.40	0.56	0.22	1.75

Note: PAC suggested that the measurement be undertaken at larger value of z, namely $z \simeq 0.5$ and 0.6.

Predictions

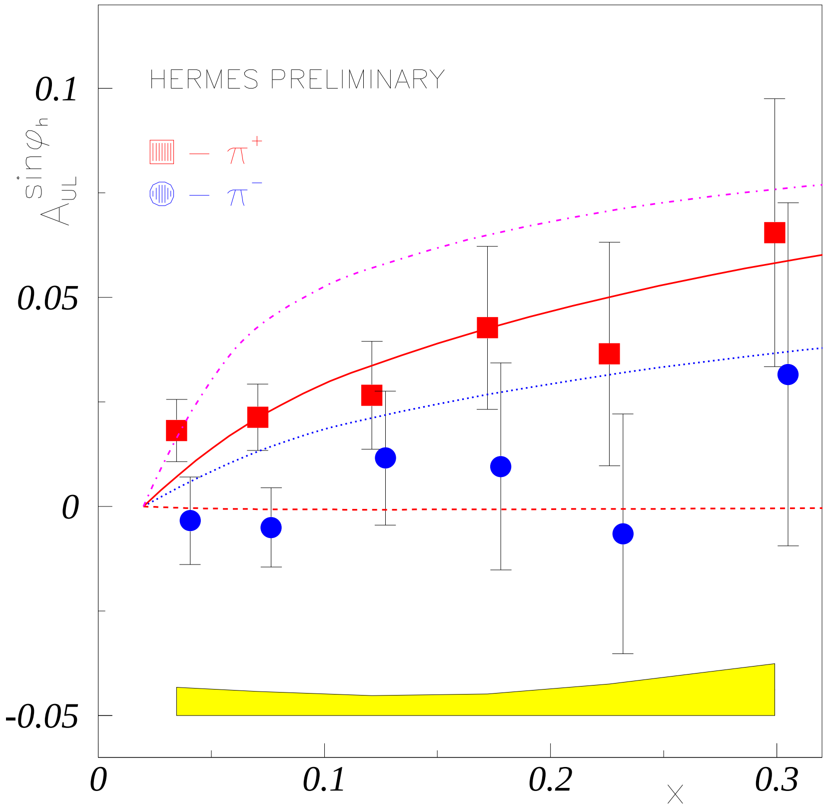


$$A_T(x,z,\mathbf{P}_{h\perp}^2) = \frac{1-y}{1-y+y^2/2}\left(\frac{P_{h\perp}}{zM_h}\right)\frac{\sum_{q,\bar{q}} e_q^2 h_1^q(x) H_1^{\perp q}(z,\mathbf{P}_{h\perp}^2)}{\sum_{q,\bar{q}} e_q^2 f_1^q(x) D_1^q(z,\mathbf{P}_{h\perp}^2)}$$

$H_1^{\perp q}(z,\mathbf{P}_{h\perp}^2)$ can be fitted from HERMES data with the suggested function by Collins:

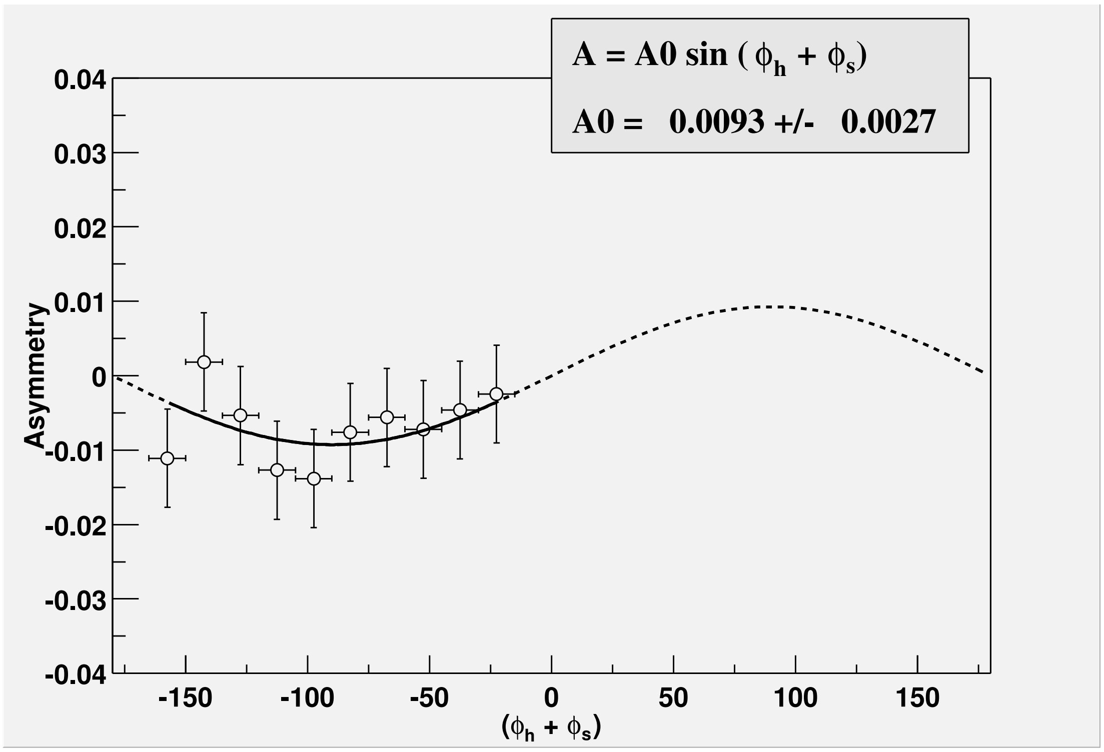
$$A_C \equiv \frac{|\mathbf{k}_\perp| H_1^{\perp q}(z,\mathbf{P}_{h\perp}^2)}{M_h D_1^q(z,\mathbf{P}_{h\perp}^2)} = \frac{M_C|\mathbf{k}_\perp|}{M_C^2+\mathbf{k}_\perp^2}$$

Modeling HERMES Long. Results



- $A_{UL}^{\sin\phi_h} \approx \frac{2M_h}{\langle P_{h\perp}\rangle} \langle \frac{|P_{h\perp}|}{M_h} \sin\phi_h \rangle$
- solid (π^+) and dashed (π^-): $h_1 = g_1$, $M_c = 0.7$ GeV.
- dotted (π^+): $h_1 = g_1$, $M_c = 0.3$ GeV.
- dot-dashed (π^+): $h_1 = (f_1 + g_1)/2$, $M_c = 0.7$ GeV.
- Gaussian distribution of D_1^q with $\langle z^2 k_T^2 \rangle = b^2 = 0.5^2$ GeV^2, suggested by DIS muon data.

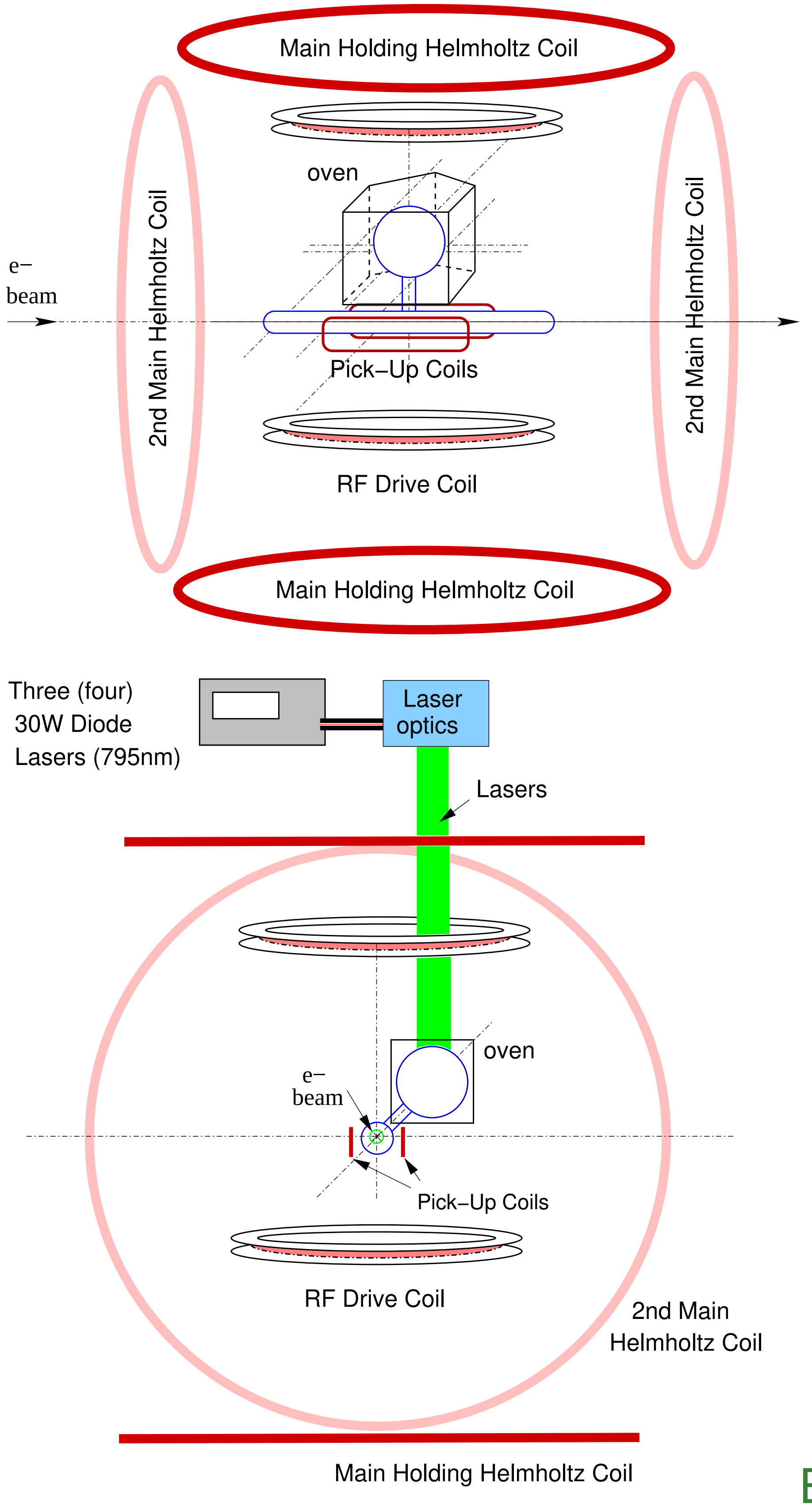
Projections



$A_T(^3He)$ at z=0.56,x=0.34 from the assumption of Collins effect dominance and $h^u_{1n} = 0$,$h^d_{1n} = g^d_{1n}$ (d-quark dominance and non-relativistic limit).

Transversity Requirements on the Target

- Normal requirements:
  - high polarization, long lifetime, ...
  - new types of cell are welcome.
- Transversely polarized Target: $\phi_S^l = \pm 90^\circ$
  - Another set of coils for vertical holding field. Do we have to disassemble the current target to add the coils?
  - Nothing in the way of the vertical laser beam. We may rotate the target cell by 45 degree and open an hole close to the target ladder.
  - The closing tip on top of the target cell should be shifted away from the laser beam.
  - Another set of RF coil? Or just rotate field to measure polarization?



Side View

Beam View

- Target spin flip: as fast and frequently as possible to minimize systematic errors
  - FM spin flip.
  - The polarization of laser beam should change correspondingly.
- Other polarization direction: $\phi_S^l = \pm 135^\circ, -45^\circ$ at the $\mathrm{P_{HRS}}$=1.8 GeV/c
  - Additional optical path(s).
  - Horizontal target rotation for different q direction? Will this affect the BigBite acceptance?More optical paths?
- Compatible with BigBite.
  - Magnetic Field interference. The field of BigBite dipole, located at 30° and 1.5 meters away from the target, can be up to $|\vec{B}| = 1.2$ T . Are correction coils, similar to what were used for Septum, good enough?
  - Target fully open for the BigBite acceptance?
- ...

Things Done at the Target Lab

Basically restored the target system at the target lab in the EEL building with Patricia, Vince, Kathy, Ameya under the supervision of JP.

- Laser alignment:

  three longitudinal laser beams are pointing at the pumping cell.

- Laser output power measurement:

  four of the five available lasers (coherent#2 to #5) were checked. The maximum power is 30, 25, 25, 24 Watts respectively.

- Laser temperature adjustment:

  the temperatures of three lasers (#2,#4,#5) were adjusted to 17.1, 8.6 and 13.4 degree so that the absorption happens around the middle of the spectrum.

- EPR system restoration.

- RTD repair:

  five RTDs were attached to the target and are measuring the temperature at the pumping cell and target cell.

- Lifetime measurement on 25 cm cell QueenMary and AFP loss analysis

  with different time intervals (1.5, 3, 6 hours) and different field direction (0,180 degree).

- Spin-up measurement on 25 cm cell QueenMary

  with different laser powers (with one, two, three lasers on).

- NMR-EPR cross-calibration and water calibration.

$\longrightarrow$Please listen to Ameya's talk for details.

Things to Do at the Target Lab

Basically to improve the target system and get ready for Gen, Transversity and other future he3 experiments:

- NMR FM sweep.
- FM spin flip.
- Water calibration.
- Cell density and wall thickness measurements.
- Tests on new cells:

  hybrid cell, different geometry shape
- Tests on new components:

  laser, optical fiber
- ...