Azimuthal Single-Spin Asymmetries in Semi-Inclusive DIS from HERMES

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Physics Goals

- Understanding polarization effects in fragmentation process:

- Chiral-odd distribution functions and
  T-odd fragmentation functions.

The single-spin asymmetries (SSA) depend only on the polarization of the beam or target. They appear to be due to initial and/or final state interactions.

T-odd distribution and fragmentation functions are leading to SSA in polarized hard processes.

We look for a correlation between the (transverse or longitudinal) polarization of the target and the azimuthal distribution of the produced hadrons.

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SSA in Various Experiments

SSA (A_N) might originate in QCD from the distribution function (DF), fragmentation function (FF), elementary scattering process (ESP) and also from orbital motion & surface effect (OM & SE **by Boros & Co.**)

process	A_N originates from ... quark DF	ESP	quark FF	OM & SE
$l + p(\uparrow) \rightarrow l + \begin{pmatrix} \pi^{\pm} \\ K^{+} \end{pmatrix} + X$	$A_N \approx 0$	$A_N = 0$	$A_N \neq 0$	$A_N = 0$
$p + p(\uparrow) \rightarrow \pi^{\pm} + X$	$A_N \neq 0$	$A_N \approx 0$	$A_N \neq 0$	$A_N \neq 0$
$p + p(\uparrow) \rightarrow \begin{pmatrix} l\bar{l} \\ W^{\pm} \end{pmatrix} + X$ in the fragmentation region of $p(\uparrow)$	$A_N \neq 0$	$A_N \approx 0$	$A_N = 0$	$A_N \neq 0$
$Z^0 \rightarrow$ 2-jet Decays	$A_N = 0$	$A_N = 0$	$A_N \neq 0$	$A_N = 0$

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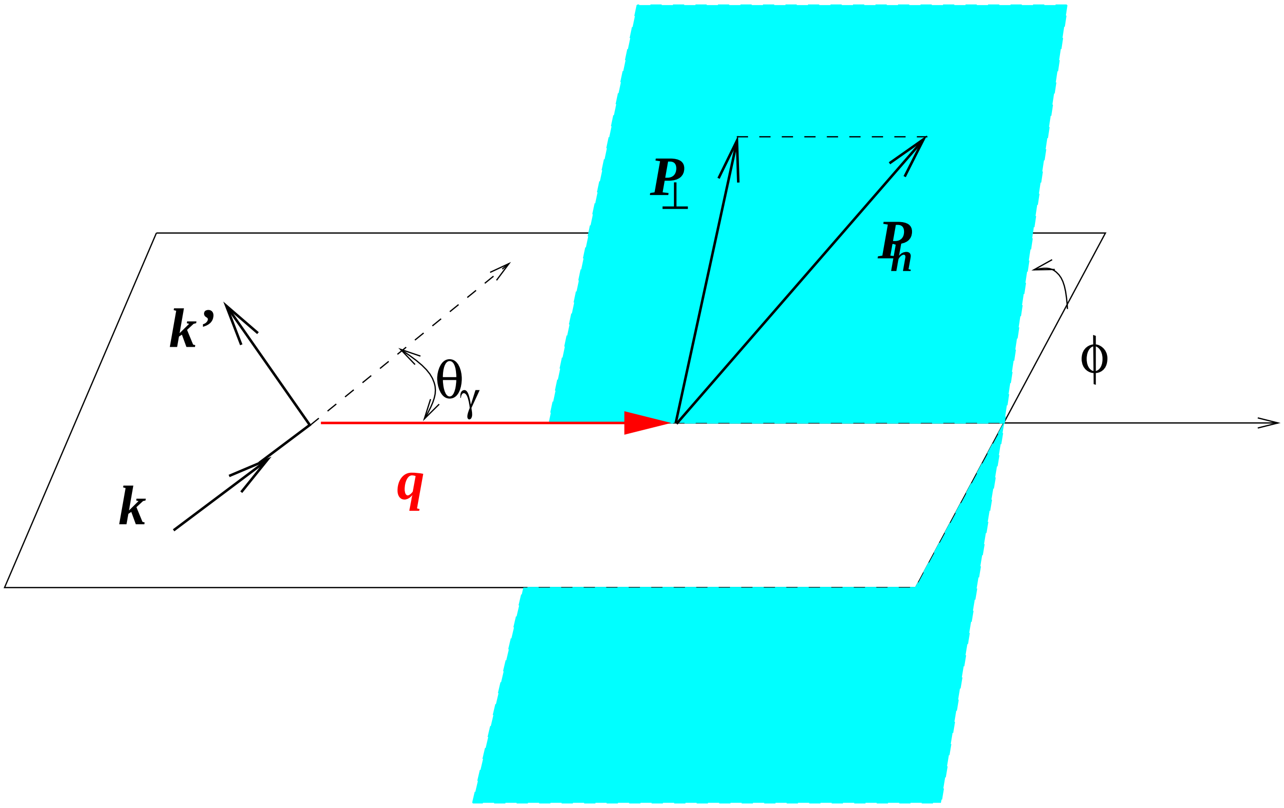
SIDIS Kinematics



Variables are defined as:

$x = Q^2/2P \cdot q$,

$y = P \cdot q/P \cdot k$,

$z = P \cdot P_h/P \cdot q$

$P_\perp$ (hadron transverse momentum)

ϕ (azimuthal angle).

$W^2 = 2M\nu + M^2 - Q^2$

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The Experiment

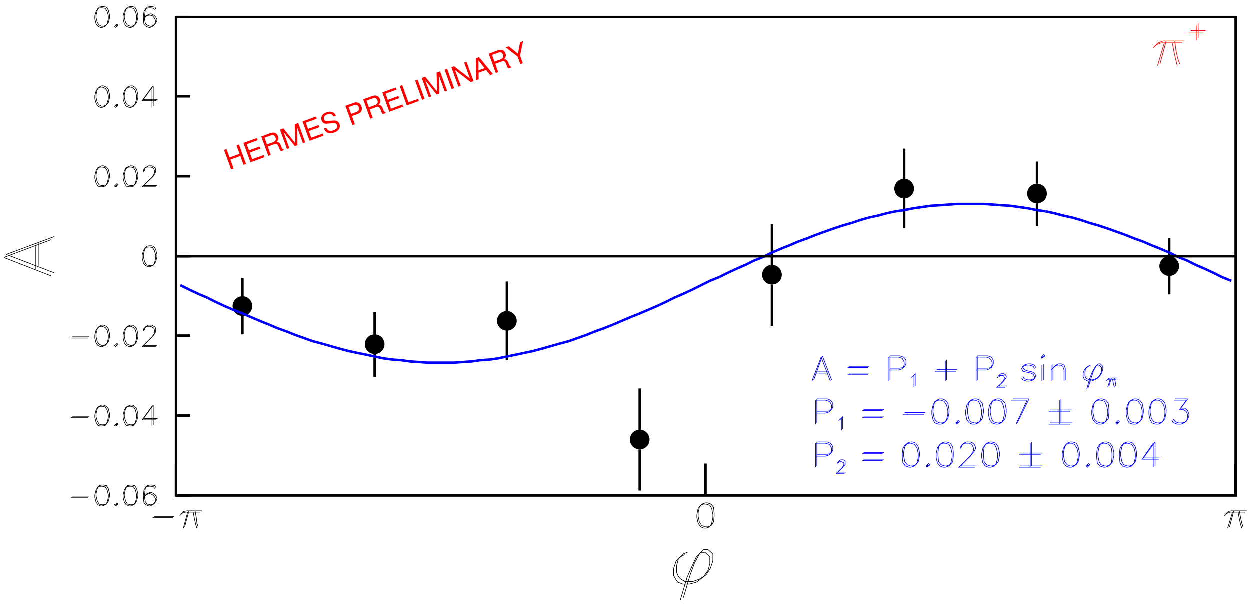
$$\vec{l} + \vec{p} \rightarrow l + \pi^{\pm} + X$$

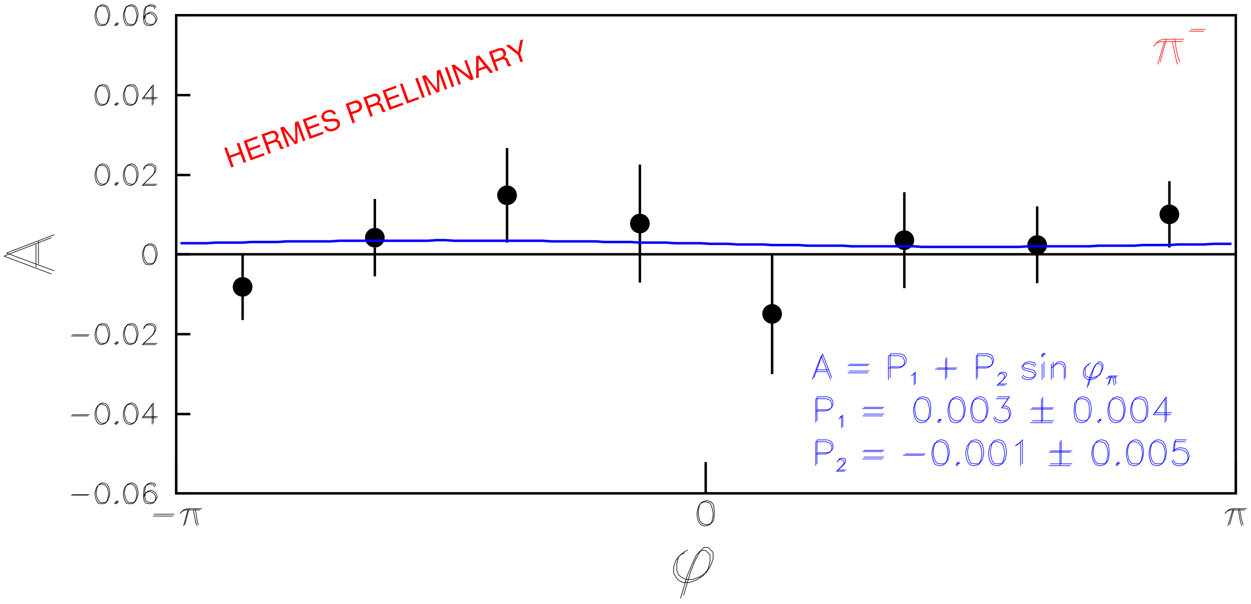
Beam energy Beam Polarization	27.56 0.55 ± 0.04 (longitudinal)
Target Target Polarization	hydrogen 0.86 ± 0.05 (longitudinal)
Acceptance in θ_x Acceptance in θ_y	$-1.7 < \theta_x < 1.7$ $0.4 < \lvert\theta_y\rvert < 1.4$
DIS cuts	$Q^2 > 1$ $W^2 > 4$ $y < 0.85$
Cuts on final hadrons	$z > 0.2$ $P_{\perp} > 0.05$
Number of identified π^+ Number of identified π^-	$\sim 110k$ $\sim 80k$

Spin-Azimuthal Asymmetries

$$A(\phi) = \frac{1}{P_H} \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)},$$

where $N^{\pm}(\phi)$ are numbers of pions in a ϕ bin for two target spin states, and P_H is the nucleon polarization.





Azimuthally weighted cross Sections

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

When the cross section is integrated over the final transverse momentum of hadrons the T-odd terms leading to single-spin asymmetries vanish.

Weighting the SIDIS cross section:

$$\langle W \rangle_{\underbrace{P_e P_H}_{O,L,T}} = \int d^2\mathbf{p}_\perp W(p_\perp, \phi_h) \frac{d\sigma_{P_e P_H}^{[\vec{e}\vec{H}\to e\vec{h}X]}}{dx\, dy\, dz\, d^2\mathbf{p}_\perp},$$

P_e,P_H = O(unpolarized) , L(longitudinally polarized) or T(transversely polarized)

P_e is the lepton polarization.

- $W(p_\perp, \phi_h) = \sin\phi$ in this analysis.

Extracting Analyzing Powers

Calculate azimuthally weighted moments of cross sections:

$$\mathcal{A}_{OL} = \frac{\int \sin\phi \, \frac{\mathrm{d}\sigma^+}{\mathrm{d}\phi}}{P_H^+ \int \frac{\mathrm{d}\sigma^+}{\mathrm{d}\phi}} - \frac{\int \sin\phi \, \frac{\mathrm{d}\sigma^-}{\mathrm{d}\phi}}{P_H^- \int \frac{\mathrm{d}\sigma^-}{\mathrm{d}\phi}},$$

$\sigma^\pm$: cross section.
$P_H^\pm$: target polarization.
$\pm$: sign of the target spin.

Integrations are over spectrometer acceptance in ϕ and/or y, z, $P_\perp$, x.

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Weighted cross sections

Longitudinally polarized target

- $W = \sin(2\phi)$ (Twist-2 terms)

  $\langle \sin(2\phi) \rangle_{OL} \propto \sum_{a,\bar{a}} e_a^2 \, h_{1L}^{\perp a}(x) \, H_1^{\perp a}(z),$

  $h_{1L}^{\perp}(x)$ describes the quark transverse polarization in a longitudinally polarized nucleon.

- $W = \sin(\phi)$ (Twist-3 terms)

  $\langle \sin(\phi) \rangle_{OL} \propto \sum_{a,\bar{a}} e_a^2 x h_L^a(x) H_1^{\perp a}(z) + \ldots$

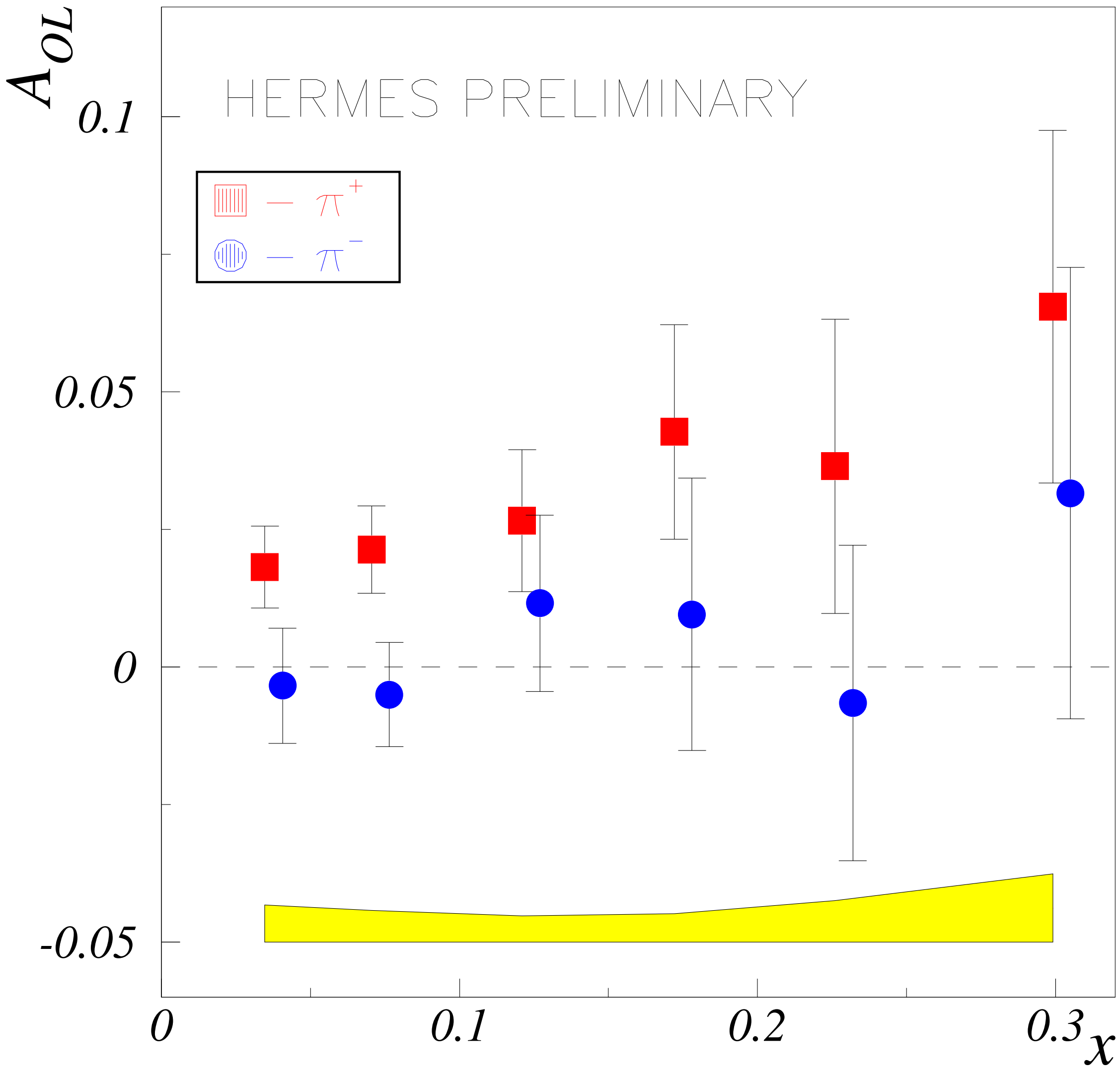
  $h_L(x)$ Twist-3 chiral-odd distribution function related to $h_1(x)$ and $h_{1L}^{\perp}(x)$.

  $h_L(x)$ like $g_T(x)$ has a twist-2 part:

  $h_L(x) = 2x \int_x^1 dy \frac{h_1(y)}{y^2}$

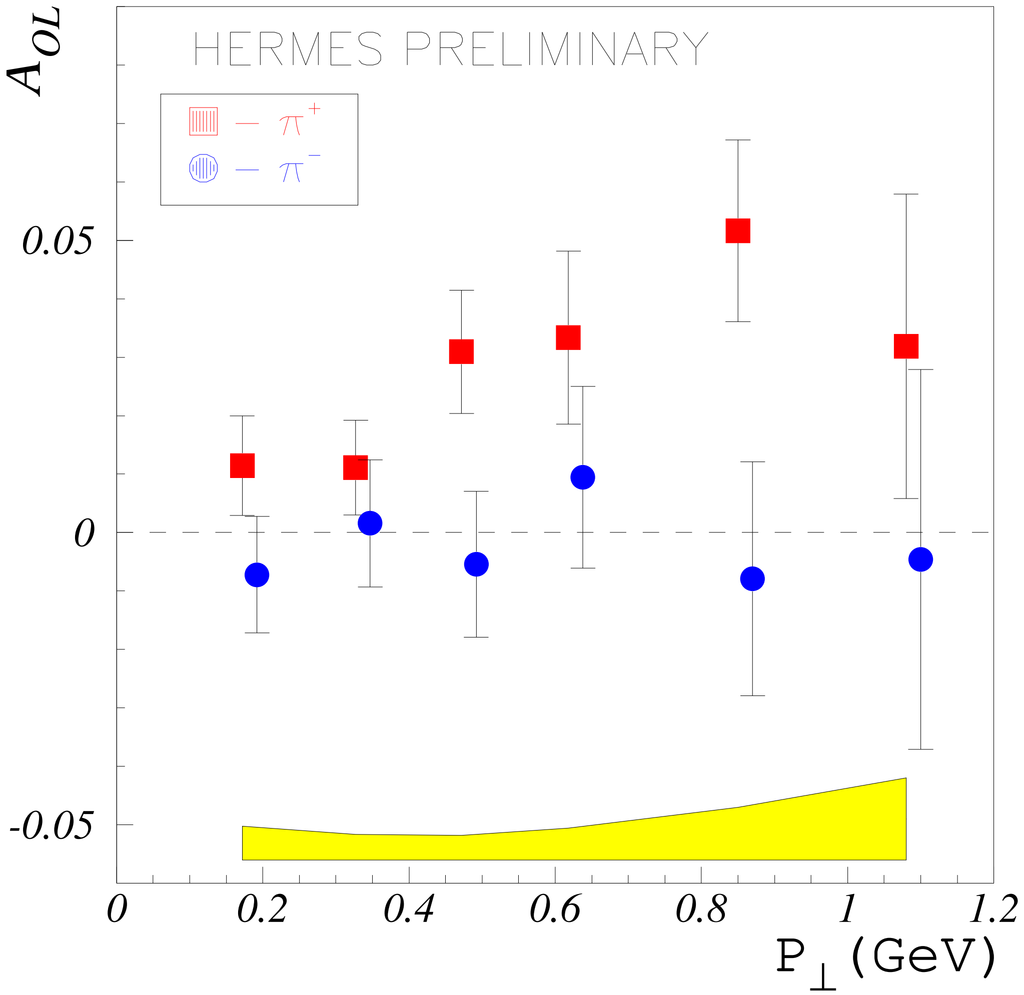
  $H_1^{\perp a}(z)$ is the T-odd "Collins " spin dependent fragmentation function.

SSA $\mathcal{A}_{OL}$: x dependence



Band on bottom of the plot represent the systematic uncertainties.

SSA $\mathcal{A}_{OL}$: $P_\perp$ dependence



Band represents the systematic error.

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Summary

- The spin-azimuthal asymmetries of pions produced in DIS of a positron beam on a longitudinally polarized hydrogen target have been measured for the first time.

- A significant azimuthal asymmetry was observed for π^+-production
$0.022 \pm 0.005(stat.) \pm 0.003(syst.)$,
while the one for π^--production was found to be consistent with zero within errors
$-0.002 \pm 0.006(stat.) \pm 0.003(syst.)$.

- The π^+ asymmetry is a single-(target) spin effect and shows x- and $p_\perp$-behaviors in agreement with naive expectations based on the Collins model for fragmentation.