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

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Spin-azimuthal asymmetries in semi-inclusive pion production in polarized deep-inelastic scattering have been measured for the first time. A significant $sin\phi$ asymmetry amplitude of the order of 2% was observed in the cross section for positron scattering off a longitudinally polarized hydrogen target. This result can be interpreted as an effect of a T-odd fragmentation function.

1. INTRODUCTION

The intrinsic transverse momentum of quarks in the nucleon plays a crucial role in single-spin asymmetries in polarized hard processes[1–7]. These asymmetries are interpreted as the effects of "time-reversal-odd" (T-odd) distribution functions [6,7] and/or fragmentation functions [1,3], arising from nonperturbative hadronic initial and final state interactions. These T-odd functions have been invoked [4,7] to explain large asymmetries observed in $p + p^{\uparrow} \rightarrow \pi X$ [8]. In the case of leading hadrons produced in the current fragmentation region in semi-inclusive deep-inelastic scattering (SIDIS), the contributions of T-odd distribution functions (the so-called Sivers mechanism) is expected to be suppressed[7]. Hence a measured single-spin asymmetry can be due to hard scattering amplitudes of higher twist or due to the T-odd fragmentation functions (the so-called Collins mechanism). Recently terms of order $1/Q$ in the $sin\phi$ azimuthal asymmetry in SIDIS have been investigated [3,9], and the contributions to that asymmetry of both leading twist and twist-three terms have been identified. They combine to give an asymmetry in the HERMES kinematics that is estimated to be of the order of a few percent.

The kinematics of the process are illustrated in Fig. 1. The k and $k^{'}$ are the 4-momenta and E and $E^{'}$ the laboratory energies of the incoming and outgoing leptons, respectively. The transverse ($P_{\perp}$) momenta of the pion is defined with respect to the virtual photon direction in the initial γN center of mass frame and E_{π} is the pion laboratory energy and M the proton mass.

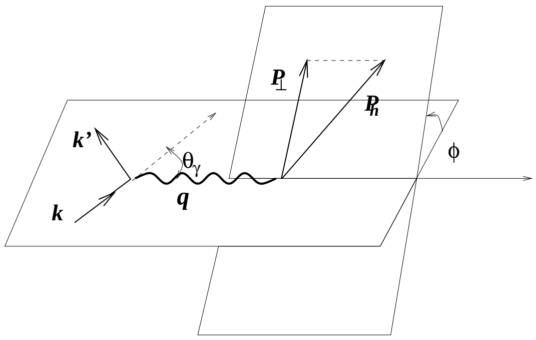

Figure 1. Kinematic planes for hadron production in semi-inclusive DIS.

2. DATA SELECTION AND RESULTS

The data were obtained during the 1996 and 1997 running periods of the HERMES experiment using a longitudinally polarized ^{1}H internal gas target [10] in the 27.5 GeV longitudinally polarized positron beam at DESY. A detailed description of the HERMES spectrometer is provided elsewhere [11]. The relevant quantities and cuts are summarized in the Table 1.

Measurements were performed with all combi-

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Table 1
The HERMES experiment

Target	hydrogen
Polarization	0.86 ± 0.05 (longitudinal)
Acceptance in θ_x	$-1.7 < \theta_x < 1.7$
Acceptance in θ_y	$0.4 < \lvert\theta_y\rvert < 1.4$
DIS cuts	$Q^2 = -(k - k')^2 > 1$
	$W^2 = 2M\nu + M^2 - Q^2 > 4$
	$y = (E - E')/E < 0.85$
Cuts on hadrons	$z = E_\pi/(E - E') > 0.2$
	$P_\perp > 0.05$
Identified π^+/π^-	$\sim 110k/80k$

nations of beam and target helicities, giving one the possibility of measuring single- and double-spin terms in the total cross section.

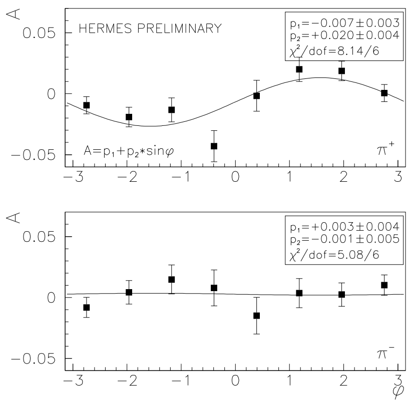

Figure 2. Spin-azimuthal asymmetry in the cross section for π^+ (top) and π^- (bottom). Error bars represent the statistical uncertainties. The curves are sinusoidal fits to the data.

The spin asymmetry in azimuthal distribution in the cross section is defined as

$$A(\phi) = \frac{N^+L^- - N^-L^+}{N^+L^-P^- + N^-L^+P^+}. \quad (1)$$

The $N^\pm$ are the numbers of DIS events, where the positron is accompanied by a pion for each target spin state corresponding to the polarization values $P^\pm$ and the dead-time corrected luminosities $L^\pm$, all averaged over the two beam helicities.

This asymmetry is shown as a function of the variable ϕ in Fig. 2. The π^+ asymmetry clearly shows a sinusoidal behavior while the π^- asymmetry is smaller and consistent with zero within the experimental errors. These findings are in agreement with expectations based on u-quark dominance in the valence region for the proton [1]. The negative pion asymmetries are expected to be diluted approximately by the ratio of squared charges of u and d quarks.

The average values for these asymmetry are $0.022 \pm 0.004(stat.) \pm 0.004(syst.)$ for the π^+ and $-0.001 \pm 0.005(stat.) \pm 0.004(syst.)$ for the π^-.

The quantities of interest, analyzing powers for target longitudinal polarization ($A^\pm_{OL}$), are evaluated as

$$A^\pm_{OL} = \frac{\int \sin\phi \, \frac{\mathrm{d}N^\pm}{\mathrm{d}\phi}}{P^\pm \int \frac{\mathrm{d}N^\pm}{\mathrm{d}\phi}}. \quad (2)$$

Integrations are performed over the spectrometer acceptance in ϕ, y, z.

The measured A_{OL} ($A_{OL} = A^+_{OL} - A^-_{OL}$), integrated over the transverse pion momentum $P_\perp$ is presented as a function of Bjorken variable x in Fig. 3, where it shows increasing behavior. This suggests that the sea contribution does not dominate the effect, in agreement with existing interpretation of single-spin asymmetries as being associated with valence quark contributions [4,7].

In Fig. 4, A_{OL} is plotted as a function of $P_\perp$, after integration over x, and also shows an increasing behavior with increasing $P_\perp$. This behavior can be understood by considering the dominant role of the intrinsic quark transverse momentum where $P_\perp$ remains below ~ 1 GeV [1,3].

The values of A^+_{OL} and A^-_{OL} for the two target helicities are consistent, indicating that significant instrumental asymmetries are absent. The main contributions to the systematic uncertainties are due to the uncertainty in the target polarization quoted above, and false asymmetries resulting from the spectrometer acceptance. The radiative corrections to the unpolarized cross sec-

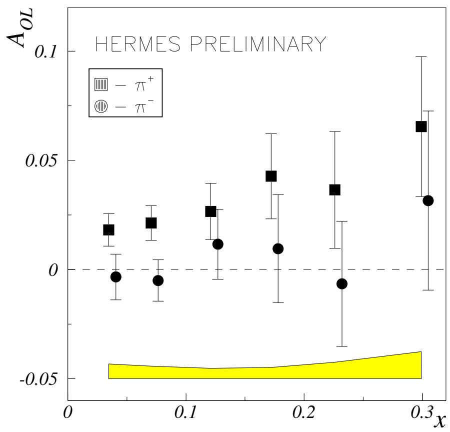

Figure 3. Target spin analyzing power in the $sin\phi$ moment (A_{OL}) as a function of Bjorken x, for π^+ (squares) and π^- (circles) . Error bars show the statistical uncertainties and the band represents the systematic uncertainties.

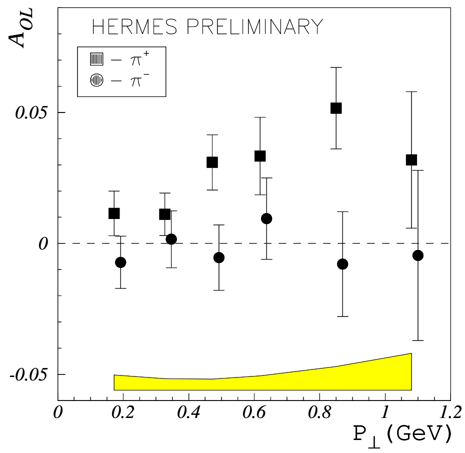

Figure 4. Target spin analyzing power in the $sin\phi$ moment as a function of transverse momentum, for π^+ (squares) and π^- (circles) . Error bars show the statistical uncertainties and the band represents the systematic uncertainties.

tion were evaluated and found to contribute less than 0.1% [12]. Moreover, those events that are included in the analysis have an average value of y around 0.5, where the radiative corrections are expected to be small and independent of the hadron charge.

3. CONCLUSIONS

Spin-azimuthal asymmetries of pions produced in deep-inelastic positron scattering on a longitudinally polarized hydrogen target and a polarized beam have been measured. A significant azimuthal asymmetry was observed for π^+-production with unpolarized positrons on a longitudinally polarized hydrogen target, while the one for π^--production was found to be consistent with zero within errors. 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. The appearance of this asymmetry can be interpreted as an effect of the T-odd fragmentation function.

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