# Single-Spin Azimuthal Asymmetries in Semi-Inclusive Electro-Production of Pions at HERMES

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**Abstract.** Single-spin azimuthal asymmetries in semi-inclusive pion production in longitudinally polarized deep-inelastic scattering have been measured for the first time in the HERMES experiment. A significant target-spin asymmetry amplitude of the order of 2% was observed both for $\pi^+$ and $\pi^0$. The $\pi^-$ asymmetry is consistent with zero. The corresponding analyzing power in the $sin\phi$ moment has been determined as a function of $x$ and $P_\perp$. These results can be interpreted as an effect of a chiral-odd spin distribution function in combination with the T-odd fragmentation function that is sensitive to the transverse polarization of the fragmenting quark.

## INTRODUCTION

At leading order QCD the description of the nucleon involves three sets of Distribution Functions (DF). Two of them, the unpolarized DFs, $f_1^q$, related to the parton momentum distributions, and the polarized DFs, $g_1^q$, which represent the distribution of quark helicities in a longitudinally polarized nucleons, are well known. The third set of DFs, $h_1^q$, called transversity, remains hiterto unmeasured; it is the distribution of transverse quark spin in a transversely polarized nucleon with respect to its (infinite) momentum [1,2]. The function $h_1^q$ is *chiral-odd* and, since the strong and the electromagnetic interactions conserve chirality, is not directly observable in inclusive lepton-nucleon scattering experiments. It can be measured through spin asymmetries containing two chiral-odd functions: in Drell-Yan with two DFs and in semi-inclusive DIS with a DF and a fragmentation function (FF). The latter, called Collins fragmentation function ($H_1^\perp$), describes how the probability of producing a hadron depends on its direction with respect to the direction of the transverse polarization of the struck quark. It has a time-reversal-odd structure (T-odd) resulting from the final-state interactions in the fragmentation process, rather than from any fundamental violation of time-reversal invariance [3]. An observable single-spin dependence is predicted to appear in the dependence of the cross section on the azimuthal angle $\phi_c$ between the spin axis of a *transversely* polarized target

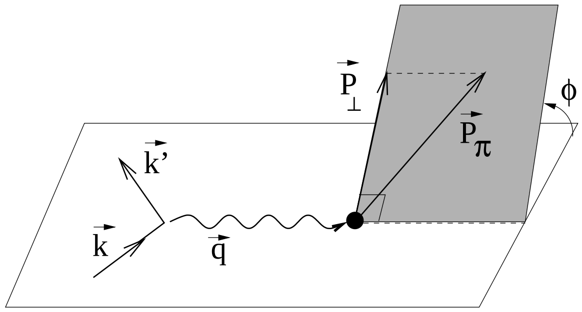


**FIGURE 1.** Kinematic planes and definition of the Collins angle for hadron production in semi-inclusive DIS of leptons off a nucleon.

and the plane spanned by the momenta of the virtual photon and the pion. This angle is known as the Collins angle [4].

Recently HERMES has measured semi-inclusive pion production from a *longitudinally* polarized proton target [5]; in this case the Collins angle becomes the azimuthal angle $\phi$ of the pion around the virtual photon direction, with respect to the lepton scattering plane, see Fig.1.

## KINEMATICS AND DATA SELECTION

The kinematics of the process is illustrated in Fig.1. Here $k$ and $k'$ are the 4-momentum and $E$ and $E'$ the energies of the incoming and outgoing leptons, $P_\pi$ is the 4-momenta of the produced pion, $\vec{q}$ is the 4-momentum transfer with $q^2 = -Q^2$, $W^2 = 2M\nu + M^2 - Q^2$ is the invariant mass of the photon-proton system and $x = Q^2/2M\nu$ is the Bjorken variable. $E_\pi$ is the pion energy, $M$ is the proton mass and $z = E_\pi/\nu$ is the pion fractional energy referred to the photon.

The data were taken during the 1996 and 1997 running periods of the HERMES experiment using a longitudinally polarized $^1$H internal gas target in the 27.5 GeV longitudinally polarized positron beam of the HERA ring at DESY. A detailed description of the HERMES spectrometer can be found in [6].

The kinematical requirements on the scattered positron used in this analysis are $1 < Q^2 < 15$ GeV$^2$, $W > 2$ GeV, $0.023 < x < 0.4$ and $y = \frac{\nu}{E} < 0.85$. Charged pions were identified in the energy range $4.5 < E_{\pi^\pm} < 13.5$ GeV. The neutral pions were reconstructed by the two decay photons collected by the electromagnetic calorimeter after imposing the cuts on the single cluster energy $E_\gamma > 1.0$ GeV and on the invariant mass range $0.100 < M_{\gamma\gamma} < 0.170$ GeV, respectively.

Acceptance effects were minimized and exclusive pion production was suppressed by imposing the requirement $0.2 < z < 0.7$. The limit $P_\perp > 50$ MeV, where $P_\perp$ is defined with respect to the virtual-photon direction, was applied to a pion to allow an accurate measurement of the angle $\phi$.

Measurements were performed with all combinations of beam and target helicities, opening the possibility of evaluating single- and double-spin terms in the cross

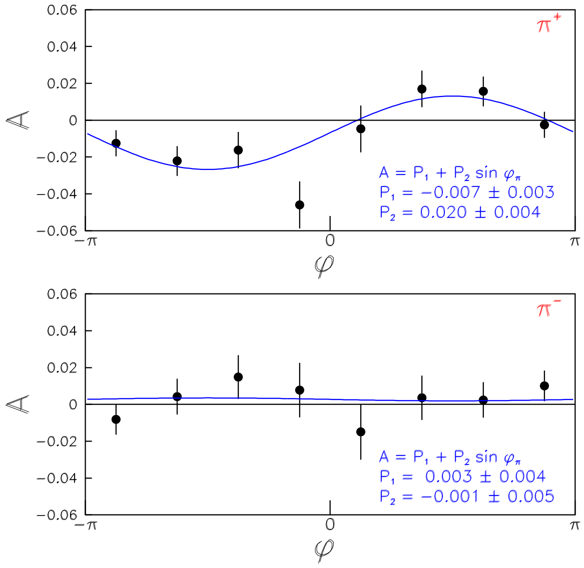


**FIGURE 2.** Spin-azimuthal asymmetry in the cross section for $\pi^+$ (top) and $\pi^-$ (bottom). Error bars represent the statistical uncertainties. The curves are sinusoidal fits to the data.

section. The average hydrogen target polarization in the 1996 and 1997 HERMES running periods was 0.86 with a fractional uncertainty of 5%.

## RESULTS

The $\phi$ dependence of the single target-spin asymmetry in the cross section is defined as:

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

Here $N$ is the number of DIS events where the positron is accompanied by a pion, corresponding to the polarization values $P$ and the dead-time corrected luminosities $L$, all averaged over the two beam helicities. The $\rightarrow$ and $\leftarrow$ symbols refer to the two target spin states.

The asymmetry (1) is shown as a function of the variable $\phi$ in Fig.2 for both $\pi^+$ and $\pi^-$. The $\pi^+$ asymmetry clearly shows a sinusoidal behavior while the $\pi^-$ asymmetry is consistent with zero within the experimental errors. These findings are in agreement with the expectation based on the $u$-quark dominance in the valence region for the proton [4,7,8]. The average values of these asymmetries are $0.022 \pm 0.005(stat) \pm 0.003(syst)$ for the $\pi^+$ and $-0.002 \pm 0.006(stat) \pm 0.004(syst)$ for the $\pi^-$.

The various contributions to the $\phi$ dependent spin asymmetry are isolated by extracting moments of the cross section weighted by corresponding $\phi$ dependent functions $W$. This can be done by calculating the analyzing powers for the case of unpolarized beam and longitudinally polarized target. It can be written as:

$$A_{UL}^{W} = \frac{\frac{L^{\rightarrow}}{L_P^{\rightarrow}} \sum_{i=1}^{N^{\rightarrow}} W(\phi_i) - \frac{L^{\leftarrow}}{L_P^{\leftarrow}} \sum_{i=1}^{N^{\leftarrow}} W(\phi_i)}{\frac{1}{2}[N^{\rightarrow} + N^{\leftarrow}]}.$$

Hera $L_P$ corresponds to the dead-time corrected luminosity, averaged with the magnitude of the target polarization. The weighting functions $W(\phi) = sin\phi$ and $W(\phi) = sin2\phi$ are expected to provide sensitivity to the Collins fragmentation function discussed above. Analyzing powers were extracted by integrating over the spectrometer acceptance in the kinematic variables $y$ and $z$. Corrections were applied for the effects of the spectrometer acceptance, based on a Monte Carlo simulation.

The single target-spin related term $A_{UL}^{sin2\phi}$ was found to be consistent with zero within errors both for $\pi^+$ and $\pi^-$. The average values are $-0.002 \pm 0.005(stat) \pm 0.010(syst)$ for the $\pi^+$ and $-0.005 \pm 0.006(stat) \pm 0.005(syst)$ for the $\pi^-$ respectively.

The term $A_{UL}^{sin\phi}$, integrated over the transverse pion momentum $P_\perp$ is presented as a function of Bjorken-$x$ in Fig.3 (left) for both neutral and charged pions. The $\pi^-$ behavior is compatible with zero and not shown in this figure. The fact that the dependence for $\pi^0$ and $\pi^+$ are very similar, is explained by $u$-quark dominance and, at the same time, indicates strong suppression of the Collins fragmentation functions associated to the other quarks (unfavored). $A_{UL}^{sin\phi}$ for $\pi^+$ and $\pi^0$ rises almost linearly from $x \simeq 0.05$ to $x \simeq 0.3$. This suggests that the sea contribution does not dominate the effect, in agreement with an existing interpretation of the single-spin asymmetry as being associated with valence quark contributions [9].

In Fig.3 (right) the analyzing power $A_{UL}^{sin\phi}$ is plotted as a function of $P_\perp$ of the detected pion, after integration over $x$. For $\pi^+$ and $\pi^0$ it shows an increasing behavior with increasing $P_\perp$ as long as $P_\perp$ remains below the typical hadronic mass of 1 GeV. This behavior can be understood by considering the dominant role of the intrinsic quark transverse momentum $k_\perp$ [10].

In all situations discussed above, the main contributions to the systematic uncertainties are coming from the uncertainty in the target polarization (5%) and from false asymmetries resulting from the spectrometer acceptance.

## CONCLUSIONS

Single-spin azimuthal asymmetries have been measured for the first time in the production of pions in deep-inelastic scattering using a longitudinally polarized hydrogen target. The analyzing power involving the $sin\phi$ moment shows a sizeable asymmetry for $\pi^+$ and is consistent with zero for $\pi^-$ within errors. The preliminary $\pi^0$ data are close to the $\pi^+$ ones. These effects measured as a function of $x$ and $P_\perp$ are in qualitative agreement with the theoretical predictions based on the Collins model of fragmentation. The appearance of these asymmetries can be interpreted

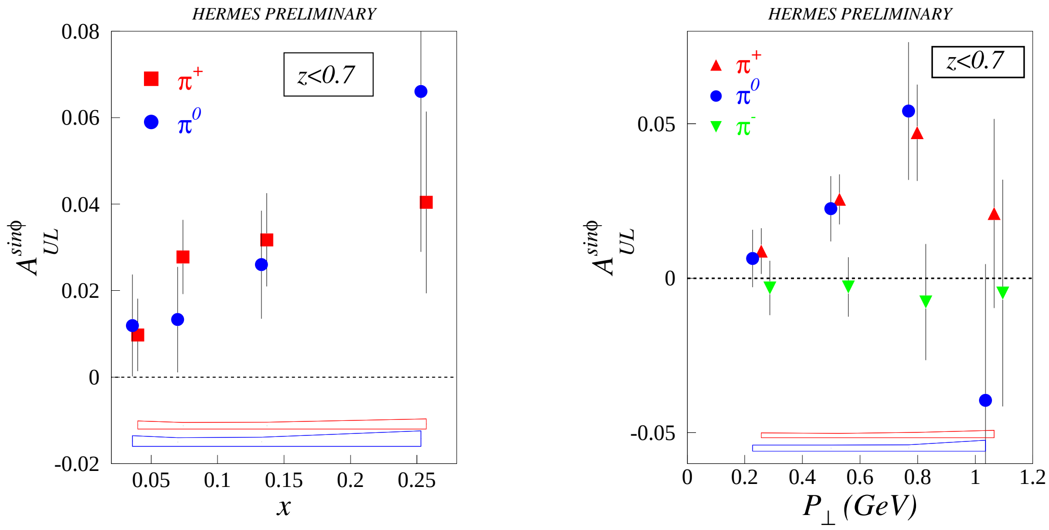


**FIGURE 3.** Target spin analyzing power in the $sin\phi$ moment as a function of Bjorken-$x$ (left) and as a function of $P_\perp$ of the detected pion (right). Error bars show the statistical uncertainties and the bands represent the systematic uncertainties. The $\pi^0$ data are preliminary, the $\pi^\pm$ data have been published in Ref. [5].

as an effect of chiral-odd distribution functions coupled with a T-odd fragmentation function [11]. This offers a mean to measure the transversity distribution using a transversely polarized target in a simple way, e.g. as suggested in Ref. [12].

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