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BEAM-SPIN AZIMUTHAL ASYMMETRIES IN PION ELECTROPRODUCTION AT HERMES

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We present the measurement of Single Beam-Spin Azimuthal Asymmetries in pion electroproduction off hydrogen in semi-inclusive deep inelastic scattering (SIDIS). The measurement was made using the HERMES spectrometer with an internal gas target and the polarized 27.6 GeV electron(positron) beam of HERA using the data taken during the years 1996-2000. The $\sin\phi$ modulation of the azimuthal asymmetry was measured for semi-inclusive π^+, π^- and π^0. The dependence of the asymmetry on the Bjorken x, pion relative (z) and transverse (P_T) momentum is presented. Results are compared to theoretical model calculation.

1 Introduction

Single-spin asymmetries (SSA) in SIDIS are known as a powerful tool for probing the spin structure of the nucleon. They give access to transverse momentum dependent (TMD) [1,2,3] parton distribution and naive time-reversal-odd (T-odd) fragmentation functions with prominent examples like the transversity distribution h_1 [4], Sivers $f_{1T}^{\perp}$ [5] and Collins $H_1^{\perp}$ [6] functions. Significant SSA were observed with longitudinally polarized target [7], transversely polarized target [8] and longitudinally polarized beam [9]. Beam-spin asymmetries (BSA) receive contributions from different combinations of twist-2 and twist-3 [10,11,12,13] TMD functions and in particular may provide access to the Collins function, which is important for the ongoing transversity measurements at HERMES and COMPASS. In this contribution we report measurements of beam SSA for π^+, π^- and π^0 using the HERMES detector at HERA.

2 The Semi-Inclusive Deep Inelastic Scattering Cross Section

Assuming that factorization holds in quark scattering and fragmentation processes the SIDIS cross section can be given as a convolution of a distribution function $f^{H\to q}$ (DF), an elementary hard scattering process cross section, and a fragmentation function $D^{q\to h}$ (FF),

$$\sigma^{eH\to ehX} = f^{H\to q} \otimes \sigma^{eq\to eq} \otimes D^{q\to h} \tag{1}$$

$$Q^2 = 4EE' \sin^2(\frac{\theta}{2})$$
$$\nu = E - E'$$
$$x = \frac{Q^2}{2m\nu}$$
$$y = \frac{\nu}{E} = \frac{p \cdot q}{p \cdot k}$$
$$z = \frac{E_h}{\nu}$$
$$\phi = \frac{\vec{q} \times \vec{k} \cdot \vec{P}_h}{|\vec{q} \times \vec{k} \cdot \vec{P}_h|} \cos^{-1} \frac{\vec{q} \times \vec{k} \cdot \vec{q} \times \vec{P}_h}{|\vec{q} \times \vec{k}| \cdot |\vec{q} \times \vec{P}_h|}$$

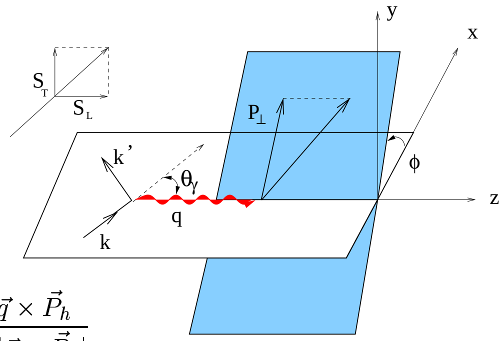

Figure 1. Definitions of kinematic planes and variables

The cross section in the polarized beam case can be written as [13]:

$$\frac{d\sigma_{LU}}{dxdydzd\phi} = \lambda_e \sin\phi \, y \sqrt{1-y} \frac{M}{Q} \sum_{a,\bar{a}} \mathbf{e_a^2} x^2 \tag{2}$$
$$\Big[xze^a(x) H_1^{\perp a}(z) + h_1^{\perp a}(x) E^a(z) + \frac{M_h}{M} f_1^a(x) G^{\perp a}(z) -$$
$$- xz \frac{M}{M_h} g^{\perp a}(x) D_1^a(z) - \frac{m}{M} z f_1^a(x) H_1^{\perp a}(z) - \frac{m}{M_h} z h_1^{\perp a}(x) D_1^a(z) \Big]$$

where λ_e is the beam polarization, m, M and M_h are the quark,nucleon and hadron masses, Q is the hard scale and the azimuthal angle ϕ is defined as the angle between the lepton scattering and hadron production planes (see Fig.1). The "L" and "U" indices stand for longitudinally polarized beam and unpolarized target, respectively. The sum is made over all quark flavors. The $f(x)$ and $D(z)$ are the corresponding distribution and fragmentation functions, respectively. (The complete tree-level description up to twist three for various processes can be found in [10]).

3 The Beam-Spin Asymmetry Measurement

The analyzing power for the beam-spin asymmetry can be extracted as corresponding moment of the event distributions for the two beam helicity states:

$$A_{LU}^{sin\phi} = \frac{1}{|P_B|} \frac{\sum_{i=1}^{N^\uparrow} sin\phi_i - \sum_{i=1}^{N^\downarrow} sin\phi_i}{\frac{1}{2}(N^\uparrow + N^\downarrow)} \tag{3}$$

where $\uparrow$ / $\downarrow$ denotes positive/negative helicity of the beam, $N^{\uparrow/\downarrow}$ is the number of selected events with a detected hadron for each beam spin state and $|P_B| \simeq 0.533 \pm 0.029$ is the mean absolute beam polarization measured by the two HERA polarimeters [14]. The scattered electrons/positrons (jointly referred to as positrons) and associated hadrons were detected by the HERMES spectrometer [15]. The separation between positrons and hadrons was accomplished by the

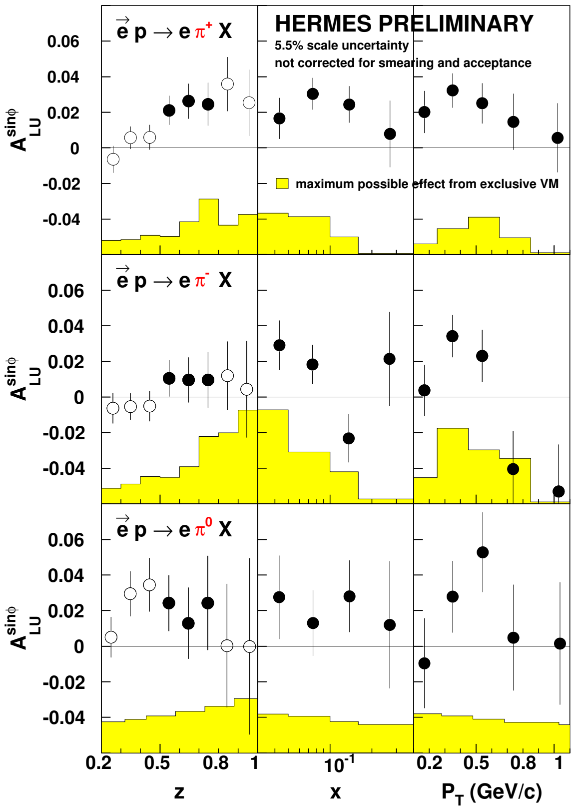

Figure 2. Dependence of beam SSA on z, x_B and P_T for pions. The measurement of the x_B and P_T dependences is made for $0.5 < z < 0.8$ range (indicated by full circles on the left column). Error bars represent the statistical uncertainty and the shaded bands represents an upper limit for a possible uncertainty from exclusive vector meson decay product contribution in the semi-inclusive pion sample. An additional 5.5% scale uncertainty is due to the beam polarization measurement.

use of a set of particle identification detectors: a transition radiation detector, a preshower, a threshold Čerenkov detector (replaced by a RICH detector [16] since 1998) and an electromagnetic calorimeter. The average identification efficiency exceeded 98% with a hadron contamination in the positron sample below 1%. The scattered positron was required to satisfy a set of cuts, namely $1 < Q^2 < 15$ GeV^2, $0.023 < x < 0.4$, $W^2 > 4$ GeV^2, $y < 0.85$. For identification of charged pions the Čerenkov and RICH detectors were used during the corresponding data taking periods. To assure reliable identification of pions ($> 95\%$) in both detectors the momentum range of $4.5 < p < 13.5$ GeV was chosen.

Neutral pions were identified requiring two trackless neutral clusters in the electromagnetic calorimeter with energies above a threshold of 1 GeV. By the reconstruction of the invariant mass of two photons $M_{\gamma\gamma}$, a clear peak around the π^0

mass is observed with a resolution of about 0.012 GeV. Neutral pions have been selected requiring $0.11 < M_{\gamma\gamma} < 0.16$ GeV . The asymmetry of the combinatorial background has been measured outside the mass window of the π^0 peak and a background subtraction has been applied to account for this.

The analyzing powers $A_{LU}^{\sin\phi}$ as a function of z, x and P_T (transverse momentum w.r.t. virtual photon direction) are shown in Fig.2. To reduce the contamination of the events from the target fragmentation region and contributions from exclusive processes a range of $0.5 < z < 0.8$ was chosen in the measurements of the x and P_T dependences (full circles in Fig.2). The measured $A_{LU}^{\sin\phi}$ asymmetry of π^+ is positive in the order of 2% and has a clear rise with increasing z, while the x and P_T dependences show a hint of a falloff in the lowest and highest bins. This measurement extends a former CLAS measurement of $A_{LU}^{\sin\phi}$ at JLAB [9] to lower x and higher Q^2 regions. The z and P_T dependences from both HERMES and CLAS measurements are in agreement within statistical accuracy after accounting for differences in the kinematics. The π^+ asymmetry is in agreement with a quark-diquark model based prediction that considers $e(x)H_1^{\perp}(z)$ and $h_1^{\perp}(x)E(z)$ terms [11]. Other theoretical models [12,18] calculating different components of Eq.2 are also in qualitative agreement with our measurement. The asymmetries measured for the first time on π^- and π^0 are positive, but compatible with zero within the present statistical uncertainties.

The semi-inclusive pion production ($ep \to e'\pi X$) with an underlying mechanism of quark fragmentation is diluted by exclusive vector meson production which can contribute significantly in certain kinematic ranges. Their contribution in the semi-inclusive pion sample has been investigated using a Pythia Monte-Carlo tuned for HERMES kinematics [17]. To estimate the possible contribution to the asymmetry, the $A_{LU}^{\sin\phi}$ has been measured for the decay products of ρ^0 mesons (which dominate the contamination). Due to lack of statistics that procedure was not used for ω and charged ρ mesons. For the latter cases a maximum possible asymmetry was assumed, constrained by only basic principles (positivity limits, kinematic suppression factor and asymmetry transfer coefficients). The resulting interpretive uncertainty is indicated by the shaded band in Fig.2.

In conclusion, we presented the beam induced single spin azimuthal asymmetry measured in the production of single pions in semi-inclusive DIS. The measured $A_{LU}^{\sin\phi}$ of π^+ is positive in the order of 2% and has a clear rise with increasing z, while the x and P_T dependences exhibit a hint of a falloff in the lowest and highest bins.

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