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Transverse target single-spin asymmetry A_{UT} of inclusive hadron electroproduction at HERMES

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- On behalf of the HERMES collaboration -

Single-spin asymmetries were investigated in the inclusive electroproduction of charged pions and kaons, from a transversely polarized proton target at the HERMES experiment. In the kinematic range $p_T < 3.0$ GeV and $-0.01 < x_F < 1$, positive asymmetries were measured for positive hadrons, while for negative hadrons they were found to be of smaller magnitude and significantly dependent on x_F.

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1. Introduction

The measurement and investigation of single-spin asymmetries (SSAs) in hadron-hadron and lepton-hadron interactions has been one of the tools to study the spin structure of the nucleon. Even when most effort has been lately focused on semi-inclusive deep-inelastic scattering (SIDIS), several inclusive measurements have been performed over the last three decades. Non-zero left-right asymmetries A_N were observed in inclusive hadron production at moderate transverse momentum 0.5 GeV $< p_T <$ 2 GeV, of transversely polarized proton beams on unpolarized proton targets $p^{\uparrow} p \to hX$ at center-of-mass energies 4.9 GeV $< \sqrt{s} <$ 200 GeV. The asymmetry A_N was found to be positive for π^+, π^0, K^+, K^-, and antiprotons, negative for π^- and compatible with zero for protons. In all non-zero cases, A_N increased in magnitude with increasing $Feynman-x$ ($x_F \simeq 2p_L/\sqrt{s}$, with p_L the longitudinal momentum of the hadron with respect to the direction of the incident polarized proton) reaching up to 20%-40% for pions produced at large values of x_F.

Two approaches have been proposed to accommodate the observed SSAs. One [1] is based on the use of transverse momentum dependent, distribution and fragmentations functions (TMDs), where the production mechanism seems to be dominated by the Sivers effect [2], originally invented as a possible explanation to the observed A_N. The other [3] links collinear parton dynamics to higher-twist quark-gluon correlations. Both approaches have been shown to be related and consistent with each other. See [4] for a review of the experimental results and theoretical models.

In recent years, it has been suggested [5] to investigate the process in inclusive electroproduction of hadrons from a transversely polarized proton target, $l p^{\uparrow} \to hX$, where only a hadron is detected in the final state, the final lepton remaining not observed. This would allow a test of the validity of the TMD factorization, essential for our understanding of the large SSAs measured in the single inclusive production of large p_T hadrons in proton-proton collisions, for processes with only one large scale (p_T). The data shown here represent the first measurement of such single-spin asymmetries.

2. Results

The data were collected with the HERMES spectrometer [6], located at the HERA accelerator at DESY, Hamburg. The 27.6 GeV positron or electron beam was scattered off the transversely nuclear polarized gaseous hydrogen target internal to the beam pipe. The direction of the target spin vector was reversed in both "upward" and "downward" directions at 1-3 minute time intervals to minimize systematic effects, while both the nuclear polarization and the atomic fraction inside the target cell were continuously measured [7]. The beam was longitudinally polarized, but a helicity-balanced data sample was used to obtain an effectively unpolarized beam.

Events were selected consisting on single charged-hadron tracks $ep \to hX$, with h being either a pion or a kaon. Hadrons were identified using a dual-radiator ring-imaging Cherenkov detector, resulting in a misidentification of less than 2% in the momentum range $[2, 15]$ GeV. The total collected statistics accounted for about 120 million pion tracks, and 8 million kaon tracks. As the scattered beam lepton was not detected, the following hadron variables were used: p_T, the transverse momentum of the hadron with respect to the lepton beam direction; $x_F \simeq 2p_L/\sqrt{s}$, with

p_L being the longitudinal momentum of the hadron; ϕ, the azimuthal angle between the hadron production plane and the "upwards" target spin direction.

The asymmetry was calculated as

$$A_{UT}(p_T, x_F, \phi) = \frac{\dfrac{N^\uparrow}{L_P^\uparrow} - \dfrac{N^\downarrow}{L_P^\downarrow}}{\dfrac{N^\uparrow}{L^\uparrow} + \dfrac{N^\downarrow}{L^\downarrow}}\,, \tag{2.1}$$

where $N^{\uparrow(\downarrow)}$ are the number of events measured in bins of p_T, x_F and ϕ; $L^{\uparrow(\downarrow)}$ is the total luminosity in the $\uparrow$ ($\downarrow$) polarization state, and $L_P^{\uparrow(\downarrow)} = \int L^{\uparrow(\downarrow)}(t)\ P(t)\ \mathrm{d}t$ is the integrated luminosity weighted by the magnitude P of the target polarization. The differential yield for a given target spin direction ($\uparrow$ upwards or $\downarrow$ downwards) can be expressed as

$$\begin{aligned} &\frac{\mathrm{d}^3 N^{\uparrow(\downarrow)}}{\mathrm{d}p_T\ \mathrm{d}x_F\ \mathrm{d}\phi} = \\ &\left[L^{\uparrow(\downarrow)}\ \mathrm{d}^3\sigma_{UU} + (-)L_P^{\uparrow(\downarrow)}\ \mathrm{d}^3\sigma_{UT}\right]\ \Omega(p_T, x_F, \phi) \\ &= \mathrm{d}^3\sigma_{UU}\left[L^{\uparrow(\downarrow)} + (-)\right. \\ &\left. L_P^{\uparrow(\downarrow)}\ A_{UT}^{\sin\phi}(p_T, x_F)\sin\phi\right]\ \Omega(p_T, x_F, \phi). \end{aligned} \tag{2.2}$$

Here, σ_{UU} is the unpolarized cross section, and Ω is the detector acceptance efficiency. The $\sin\phi$ azimuthal dependence derivates from the geometrical relation between the momentum of the incoming lepton, the target spin direction, and the hadron production plane; $A_{UT}^{\sin\phi}$ refers to its amplitude.

The $A_{UT}^{\sin\phi}$ amplitudes were extracted with a binned χ^2 fit of the functional form $p_1 \sin\phi + p_2$ to the measured asymmetry. Note that the relation between the $\sin\phi$ amplitude $A_{UT}^{\sin\phi}$ and the left-right asymmetry A_N can be easily obtained, in the case of a detector with full 2π-coverage in ϕ, as

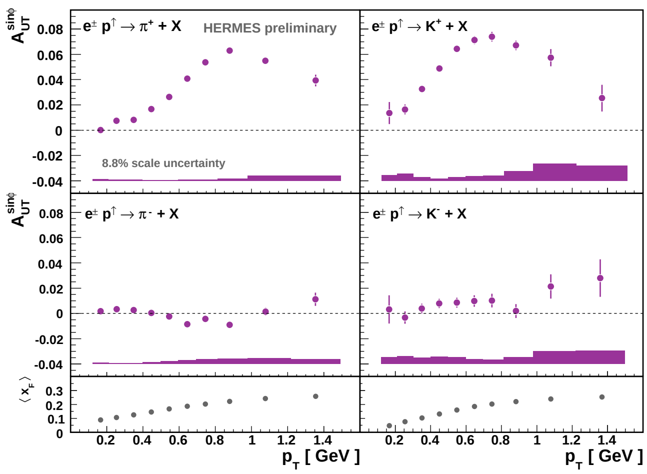

Figure 1: $A_{UT}^{\sin\phi}$ amplitudes for charged pions and kaons *vs* p_T.

$$A_N = \frac{\int_0^\pi d\phi\ \sigma_{UT}\sin\phi}{\int_0^\pi d\phi\ \sigma_{UU}} = \frac{2}{\pi}\cdot A_{UT}^{\sin\phi}. \tag{2.3}$$

The $A_{UT}^{\sin\phi}$ amplitudes are shown *vs.* p_T in Fig. 1. The asymmetries are clearly positive for positive hadrons, increasing with p_T until reaching values of about 7% for $p_T \simeq 0.9$ GeV, then decreasing in magnitude down to values of 2-4% for the highest p_T bin. For negative hadrons, the asymmetries are much smaller, oscillating around zero, with slightly positive values at high p_T. In

Fig. 2, the measured $A_{UT}^{\sin\phi}$ amplitudes for positive hadrons increase with x_F up to values of 7-8%. For negative pions, the asymmetry increases in magnitude up to about 2% for the last x_F bin, while it is essentially zero for the negative kaons.

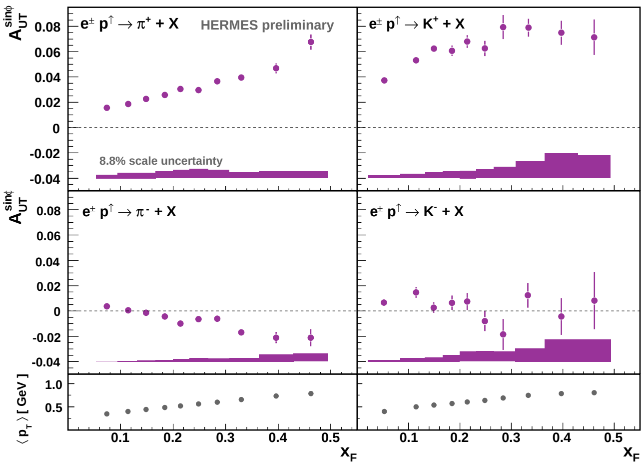

Figure 2: $A_{UT}^{\sin\phi}$ amplitudes for charged pions and kaons *vs.* x_F.

In both cases, the systematic uncertainties are shown as error bands. These were determined from a high statistics Monte Carlo sample obtained from a simulation containing a full description of the detector, where an artificial spin-dependent azimuthal asymmetry was implemented. A model of the asymmetries was extracted performing a maximum-likelihood fit over the entire data sample, where the functional form of the fit was chosen to be a 10-parameters Taylor expansion in p_T and x_F to third order. The $A_{UT}^{\sin\phi}$ amplitudes were then calculated from the spin-dependent Monte Carlo sample in the same way as done for data. The systematic uncertainties were taken as the biggest, on every kinematic bin, of either (i) the statistical error of the Monte Carlo asymmetries, or (ii) the deviation between the model funtion used as input and the reconstructed asymmetries. The smaller asymmetries measured for negative hadrons can be understood given the $u-$quark dominance in the used proton target.

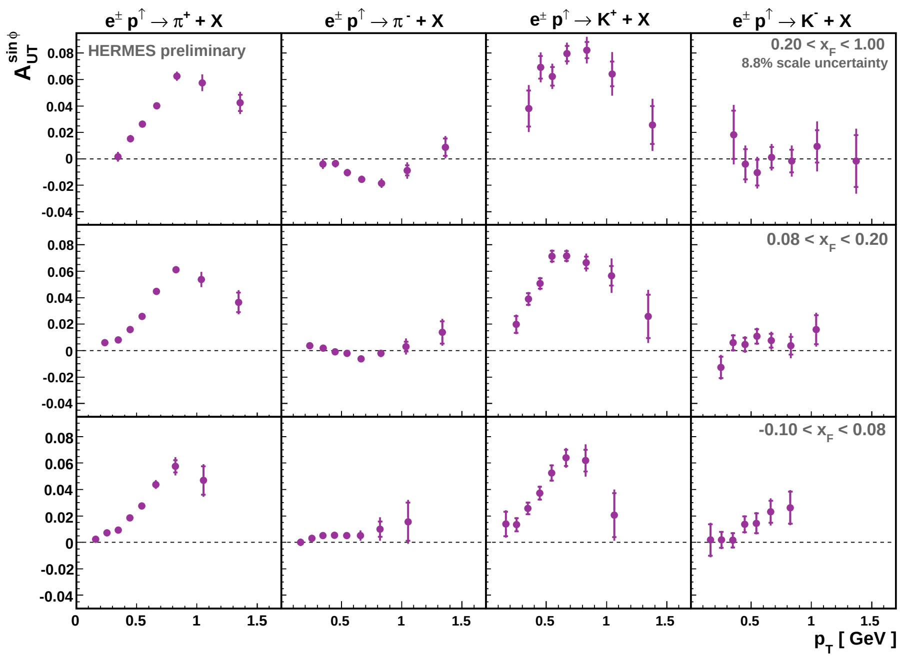

Figure 3: $A_{UT}^{\sin\phi}$ amplitudes *vs.* p_T for different bins of x_F, *top:* $0.2 < x_F < 1.0$, *middle:* $0.08 < x_F < 0.2$, *bottom:* $-0.1 < x_F > 0.08$.

The variables x_F and p_T are correlated as can be seen from the bottom panels of both figures where they are shown at the average bin kinematics. Fig. 3 shows the $A_{UT}^{\sin\phi}$ amplitudes extracted *vs.* p_T, for three different bins of x_F. Total error bars are shown, obtained by combining statistical and systematic uncertainties in quadrature. The most interesting feature is resembled in the case of the negative hadrons. For the lowest x_F bin, the asymmetries for π^- are clearly positive, going to zero for the medium x_F bin, and reaching negative values for most p_T bins at high x_F. A similar trend is observed for the K^- as well.

The measured asymmetries are in good agreement with the theoretical predictions in Ref. [5]. The p_T dependence is very similar to the HERMES results [8] for the Sivers asymmetry measured in semi-inclusive deep-inelastic scattering.

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