Transverse single-spin asymmetries in inclusive hadron electroproduction at HERMES

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Abstract. Single-spin asymmetries were investigated in inclusive electroproduction of charged pions and kaons from a transversely polarized hydrogen 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 with significantly different p_T dependence for different bins in x_F.

1. Introduction

Transverse single-spin asymmetries A_N for inclusive hadron production with transversely polarized proton beams or targets, $p^{\uparrow(\downarrow)} + p \longrightarrow h + X$, have been studied since more than 30 years. Up to date, such left-right asymmetries A_N have been observed over a large kinematic range with center-of-mass energies from $\sqrt{s} = 4.9$ GeV up to 200 GeV. They were found to be positive for π^+, π^0, η, K^+, K^-, and anti-protons, negative for π^- and neutrons, and compatible with zero for protons. In all non-zero cases, A_N increases in magnitude with increasing p_T and $x_F = 2p_L/\sqrt{s}$, where p_T (p_L) is the transverse (longitudinal) momentum of the produced hadron with respect to the direction of the incident proton. A review of experimental results can be found, e.g., in Refs. [1, 2] together with a discussion on the current theoretical work. Originally it was expected from QCD that at high center-of-mass energies and transverse momenta the cross sections should have very little spin dependence and that transverse asymmetries should be suppressed by $\alpha_s m_q/M$, where α_s is the strong coupling constant and m_q (M) is the quark (nucleon) mass. Recent theoretical attempts to explain the experimental results include two approaches. One is based on unintegrated, transverse-momentum dependent distribution and fragmentation functions, in particular the quark transversity distribution and the Collins fragmentation function [3, 4], or the Sivers effect [5] which originally has been invented to explain the observed large single-spin asymmetries. The other approach links collinear parton dynamics to higher-twist quark-gluon correlations [6, 7, 8]. Both approaches succeed to reproduce the existing measurements of A_N to a very good extent, and have been shown to be related to and consistent with each other [9].

As discussed in Refs. [7, 10], the measurement of transverse target single-spin asymmetries in inclusive hadron electroproduction, $e\ p^{\uparrow} \rightarrow h\ X$, at high transverse hadron momenta might be more easy to interpret. The HERMES experiment has performed first measurements of this kind. Preliminary results for charged pions and kaons are presented in this contribution.

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2. Experiment

The data were collected with the HERMES spectrometer [11] at the HERA e-p accelerator facility. The 27.6 GeV lepton (electron or positron) beam was scattered off a nuclear-polarized gaseous hydrogen target internal to the lepton ring. The direction of the target-spin vector was transverse to the beam direction. It was reversed in both "upward" (↑) and "downward" (↓) directions at 1-3 minute time intervals to minimize systematic effects. Both the nuclear polarization P and the atomic fraction inside the target cell were continuously measured [12]. The beam was longitudinally polarized, but a helicity-balanced data sample was used to obtain an effectively unpolarized beam. Events were selected with at least one charged-hadron track. The scattered lepton was not requested for this analysis and therefore the data sample is dominated by events from quasi-real photoproduction ($Q^2 \approx 0$ GeV^2, where $-Q^2$ is the four-momentum squared of the virtual photon). Hadrons were identified using a dual-radiator ring-imaging Cherenkov (RICH) detector, and distinguished from leptons by using a transition-radiation detector, a scintillator pre-shower counter, the RICH detector, and an electromagnetic calorimeter, resulting in a hadron-lepton misidentification of less than 2% in the hadron momentum range 2 GeV $< p <$ 15 GeV. The total statistics collected amount to about 120 million (8 million) pion (kaon) tracks.

The differential yield for a given target spin direction can be expressed as

$$\frac{d^3N^{\uparrow(\downarrow)}}{dx_F\ dp_T\ d\phi} = d^3\sigma_{UU}\left[L^{\uparrow(\downarrow)} + (-)L_P^{\uparrow(\downarrow)}\ A_{UT}^{\sin\phi}(x_F, p_T)\sin\phi\right]\ \Omega(x_F, p_T, \phi). \tag{1}$$

Here, ϕ is the azimuthal angle about the beam direction between the hadron production plane and the "upwards" target spin direction, and σ_{UU} denotes the unpolarized cross section, $x_F \simeq 2p_L/\sqrt{s}$ is the Feynman variable with $\sqrt{s}$ being the lepton-nucleon center-of-mass energy and p_L (p_T) is the longitudinal (transverse) momentum of the hadron with respect to the lepton beam direction. Also, $L^{\uparrow(\downarrow)}$ is the total luminosity in the ↑ (↓) polarization state, $L_P^{\uparrow(\downarrow)}$ is the luminosity weighted by the magnitude P of the target polarization, and Ω is the detector acceptance efficiency. The average beam polarization was about 0.76 (0.71) for the data taking periods with a positron (electron) beam. The $\sin\phi$ azimuthal dependence follows directly from the form $\vec{S}\cdot(\vec{k}\times\vec{p})$ of the spin-dependent part of the cross section (see, e.g., Ref. [10]), and $A_{UT}^{\sin\phi}$ refers to its amplitude, with $\vec{S}$ being the target spin, and $\vec{k}$, $\vec{p}$ the momenta of the incident lepton and the produced hadron, respectively.

The asymmetry was calculated as

$$A_{UT}(x_F, p_T, \phi) = \frac{N^{\uparrow}/L_P^{\uparrow} - N^{\downarrow}/L_P^{\downarrow}}{N^{\uparrow}/L^{\uparrow} + N^{\downarrow}/L^{\downarrow}} \ \simeq A_{UT}^{\sin\phi}\sin\phi\ , \tag{2}$$

where $N^{\uparrow(\downarrow)}$ are the number of events measured in bins of x_F, p_T, and ϕ. Due to the rapid reversal of the target-spin direction, the acceptance function Ω cancels in each (x_F, p_T, ϕ) kinematic bin, if the bin size or the asymmetry is small. Experimentally, the $A_{UT}^{\sin\phi}$ amplitudes were extracted performing a maximum-likelihood fit to the asymmetry alternately binned in p_T and x_F, and unbinned in ϕ. For a detector with full 2π-coverage in ϕ, the $\sin\phi$ amplitude and the left-right asymmetry A_N are related by $A_N = -2A_{UT}^{\sin\phi}/\pi$.

3. Results

Preliminary results for the $A_{UT}^{\sin\phi}$ amplitudes for charged pions and kaons are shown as a function of p_T in the left panel of Fig. 1 and as a function of x_F in the right panel of the figure. The error bars indicate the statistical uncertainties of the measurement. The amplitudes vanish, as expected, for small p_T. For positive pions and kaons they increase with p_T up to $p_T \simeq 0.8$ GeV and seem to decrease again for larger p_T. This p_T dependences resembles very much the

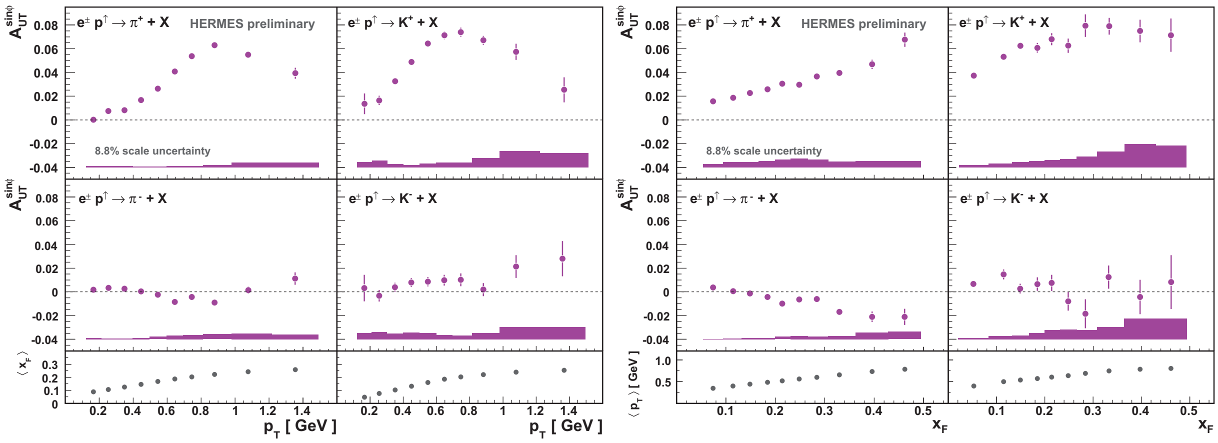

Figure 1. Preliminary HERMES results for $A_{UT}^{\sin\phi}$ amplitudes for charged pions and kaons as a function of p_T (left) and x_F (right).

one observed for the Sivers asymmetry in semi-inclusive deep-inelastic scattering [13] but not that of the Collins asymmetry [14], in agreement with the prediction in Ref. [10], where it is assumed that the inclusive assymmetry is mainly caused by the Sivers effect. For π^- and K^-, the asymmetry amplitudes oscillate around zero, with slightly positive values at high p_T. Similar to the Sivers asymmetry, the K^+ asymmetry is slightly larger than the π^+ asymmetry. The asymmetries for K^+ and K^- are very different in contrast to the results in pp scattering, where they are rather similar [2]. For π^+ and K^+, the amplitudes increase smoothly with x_F up to values of about 0.1. For π^-, the (negative) asymmetry increases in magnitude up to values of about 0.04. It is essentially zero for K^-. Systematic uncertainties are shown in Fig. 1 as bands. They include contributions due to corrections for misalignment of the detector, beam position and slope at the interaction point and bending of the beam and the produced hadron in the transverse holding field of the target magnet. They 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 with a functional form that described all measured asymmetries. For each measured point the systematic uncertainty was obtained as the maximum value of either the statistical uncertainty of the Monte Carlo sample or the difference between the input asymmetry and the extracted one. An overall 8.8% scale uncertainty stems from the uncertainty of the target polarization.

The variables x_F and p_T are strongly correlated through the HERMES acceptance as can be seen in the bottom panels of Fig. 1. To separate the kinematical dependences a two-dimensional extraction of the asymmetries was performed binning simultaneously in x_F and p_T. Preliminary results for the extracted asymmetry amplitudes are shown in Fig. 2 as a function of p_T for three different bins in x_F. Total uncertainties are shown, obtained by combining statistical and systematic uncertainties in quadrature, with the inner error bars representing statistical uncertainties only. For π^+ and K^+, the p_T dependence is very similar in all three x_F bins. For negative pions, however, the asymmetry is negative in the highest x_F bin ($0.20 < x_F < 1.00$), oscillates around zero in the middle x_F bin and is slightly positive in the lowest x_F bin. For K^-, the amplitudes are consistent with zero for high x_F and slightly positive at low x_F.

A thorough interpretation of these interesting results is rather challenging due to the relatively small range in p_T covered by the data. The predictions in Ref. [10] are made for pions only and for p_T values of 1.5 GeV and 2.5 GeV, i.e., above the range covered by these preliminary data. So far, no theoretical calculations for kaons are available. The final results of these measurements will be presented with an extended p_T range up to 2 GeV and for four bins in x_F.

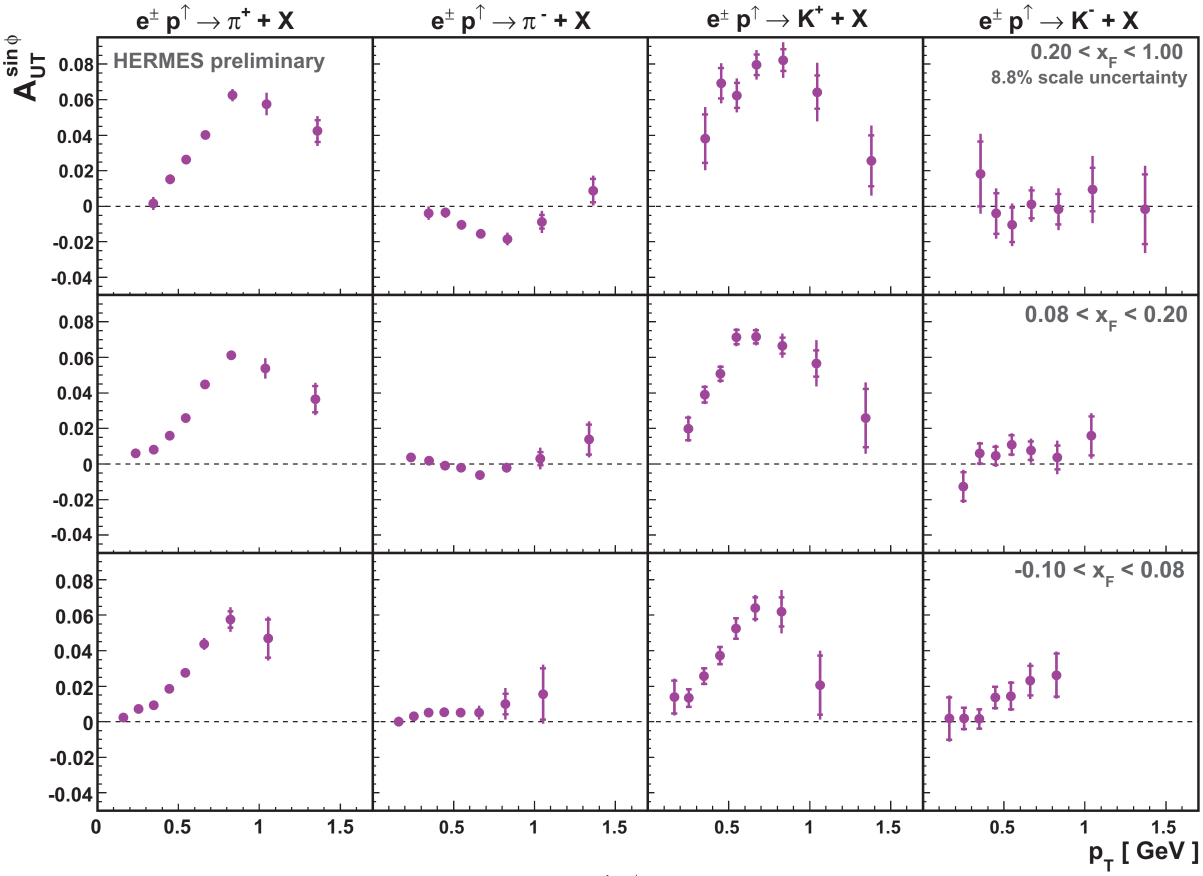

Figure 2. Preliminary HERMES results for $A_{UT}^{\sin\phi}$ amplitudes for charged pions and kaons as a function of p_T for three different bins of x_F.

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