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LATEST HERMES RESULTS ON TRANSVERSE SPIN IN HADRON STRUCTURE AND FORMATION

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Abstract

Preliminary experimental results from measurements of single-spin asymmetries for single pions and kaons, and for pion pairs in deep-inelastic scattering (DIS) with transverse target polarization are presented. These results provide sensitivity to the transverse polarization and orbital angular momentum of quarks in the nucleon.

1 Introduction

At leading twist, neglecting the transverse momentum, the longitudinal momentum and spin of the quarks in the nucleon are described by three parton distribution functions (PDFs): the well-known momentum distribution, the known helicity distribution, and the up-to-now poorly known transversity distribution. These quantities depend only on the Bjorken variable x and on the scale Q^2. In the helicity basis, transversity is related to the quark-nucleon forward scattering amplitude involving helicity flip of both nucleon and quark. Being chiral-odd, transversity can be investigated only in observables that involve an additional chiral-odd quantity, e.g., in single-spin cross section asymmetries (SSA) in semi-inclusive DIS electroproduction (SIDIS) of single hadrons or hadron pairs on transversely polarized hadrons. Including the transverse momentum of quarks additional PDFs appear. A prominent example is the Sivers function [2] which requires a non-zero quark orbital angular momentum for its existence.

In 2002-05 the HERMES collaboration [1] took data using a gaseous transversely polarized hydrogen target (with an average polarization of $\approx 74\%$) internal to the 27.6 GeV HERA positron or electron beam. The HERMES dual-radiator ring-imaging Čerenkov detector allowed full $\pi^{\pm}$, $K^{\pm}$ and p identification for particle momenta between 2 and 15 GeV.

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2 SSA in single-hadron production

In semi-inclusive electroproduction of hadrons on a transversely polarized nucleon target with an unpolarized lepton beam a single-spin asymmetry A_{UT} in the azimuthal angles around the virtual-photon direction can arise. These angles, measured with respect to the lepton scattering plane, are the azimuthal angle ϕ of detected hadrons and the azimuthal angle ϕ_S of the target transverse polarization direction. The Collins and the Sivers mechanisms [2] have been identified as potential sources of the asymmetry. In the Collins mechanism, the asymmetry arises from the correlation between the transverse polarization of the fragmenting struck quark and the transverse momentum $P_{h\perp}$ of the produced hadron. In the Sivers mechanism, the asymmetry results from an intrinsic transverse momentum asymmetry of the quarks in the target nucleon. A non-zero Sivers function would require a non-zero orbital angular momentum of quarks in the nucleon [2].

In the measured SSA, transversity appears convoluted with the Collins function with the angular modulation $\sin(\phi + \phi_S)$, while the Sivers function appears with the $\sin(\phi - \phi_S)$ modulation. The Collins $2\langle\sin(\phi + \phi_S\rangle^h_{UT}$ and Sivers $2\langle\sin(\phi - \phi_S\rangle^h_{UT}$ azimuthal amplitudes are extracted simultaneously through a fit of the measured cross section asymmetry:

$$\begin{aligned} A^h_{UT}(\phi,\phi_S) &= \frac{\sigma_h^{\Uparrow}(\phi,\phi_S) - \sigma_h^{\Downarrow}(\phi,\phi_S)}{\sigma_h^{\Uparrow}(\phi,\phi_S) + \sigma_h^{\Downarrow}(\phi,\phi_S)} \\ &= 2\langle\sin(\phi + \phi_S\rangle^h_{UT}\sin(\phi+\phi_S) + 2\langle\sin(\phi - \phi_S\rangle^h_{UT}\sin(\phi-\phi_S), \end{aligned} \tag{1}$$

where h represents the detected hadron, and the symbol $\Uparrow$ ($\Downarrow$) is the target spin state. The dependence on x, the fractional hadron energy z, and on $P_{h\perp}$ of the extracted Collins and Sivers amplitudes is shown in Fig. 1 for charged pions and kaons. Compared to the previous publication [1], these results are based on nearly five times more statistics.

The Collins amplitudes are found positive for π^+ and negative for π^-. Assuming u-quark dominance, the large negative π^- amplitude on the proton is rather interesting, suggesting a substantial disfavoured Collins function with a sign opposite to that of the favoured Collins function. For charged kaons no significantly non-zero Collins amplitude is found. The extracted non-zero Collins amplitude for pions implies a non-zero transversity distribution and a non-vanishing Collins function. Recently, using the previously published HERMES data [1] in combination with data from COMPASS and BELLE, the first ever model-dependent extraction of the transversity distributions for *up* and *down* quarks has been performed [3].

The Sivers amplitudes are found to be significantly positive for both π^+ and K^+, implying a non-zero orbital angular momentum for quarks in the

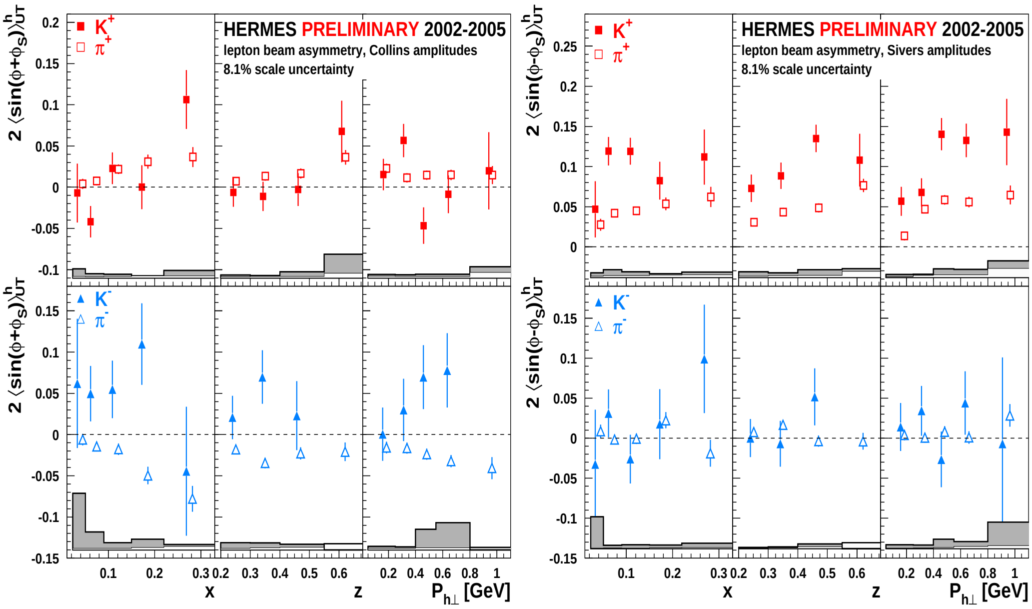

Figure 1: Kinematic dependencies of the extracted Collins (left panels) and Sivers (right panels) amplitudes for single charged pions and kaons on transversely polarized hydrogen target. Systematic uncertainties are shown by shaded bands.

nucleon. The large amplitude for K^+ suggest an important role of sea quarks. For negative pions and kaons the Sivers amplitude is consistent with zero.

3 Transversity in pion-pair production

An independent experimental constraint on transversity could be provided by analysing the SSA in semi-inclusive electroproduction of $\pi^+\pi^-$ pairs on a transversely polarized target [4]. The underlying mechanism is the transfer of the transverse spin of the fragmenting quark to the relative orbital angular momentum of the produced hadron pair. Consequently, this mechanism does not require transverse momentum of the pair. In this process transversity appears with the up-to-now unknown dihadron fragmentation function describing the interference between pion pairs in S- and P-wave.

The amplitude that involves transversity and the above mentioned interference fragmentation function, extracted in the HERMES kinematics, is shown in Fig. 2 versus the invariant mass of the pion pair $M_{\pi\pi}$. The presented data were accumulated during the 2002-04 running period using the positron beam and the transversely polarized hydrogen target. The signal is non-zero in the whole analyzed kinematics implying, for the first time, a non-zero two-pion interference fragmentation function sensitive to transverse

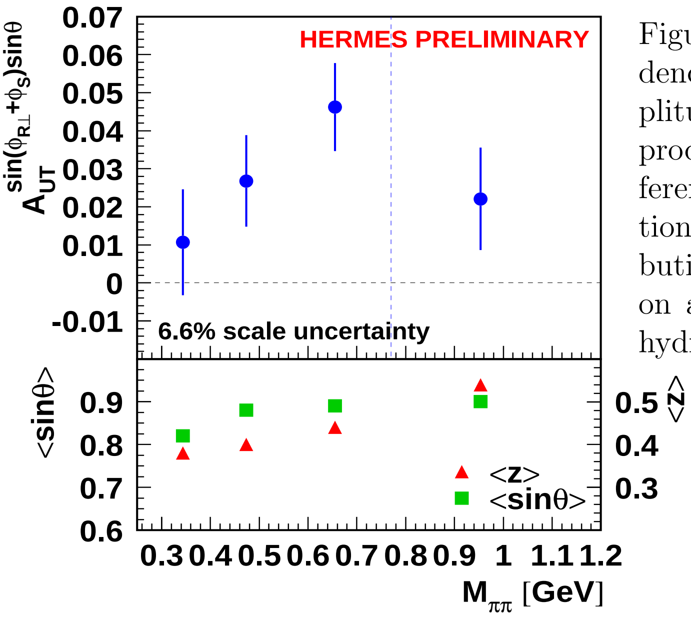

Figure 2: The dependence on $M_{\pi\pi}$ of the amplitude that involves the product of dihadron interference fragmentation function and transversity distribution for SIDIS $\pi^+\pi^-$ pairs on a transversely polarized hydrogen target.

quark polarization in the target nucleon. Furthermore, it is positive in the entire range of $M_{\pi\pi}$, not supporting a predicted sign change of the amplitude around the ρ^0 meson mass. The BELLE collaboration can extract dihadron fragmentation functions from their e^+e^- data. Such results could be combined with the present HERMES dihadron data to extract transversity in the proton, using a channel that is independent from the single-hadron channel. The analysis including the twice larger statistics of 2005 electron data is ongoing, possibly providing a significant constraint on two-pion formation models [4].

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