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Effects of transversity in deep-inelastic scattering by polarized protons

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ABSTRACT

Single-spin asymmetries for pions and charged kaons are measured in semi-inclusive deep-inelastic scattering of positrons and electrons off a transversely nuclear-polarized hydrogen target. The dependence of the cross section on the azimuthal angles of the target polarization (ϕ_S) and the produced hadron (ϕ) is found to have a substantial $\sin(\phi + \phi_S)$ modulation for the production of π^+, π^- and K^+. This Fourier component can be interpreted in terms of non-zero transversity distribution functions and non-zero favored and disfavored Collins fragmentation functions with opposite sign. For π^0 and K^- production the amplitude of this Fourier component is consistent with zero.

Most of our knowledge about the internal structure of nucleons comes from deep-inelastic scattering (DIS) experiments. At the energies of current fixed-target experiments, the dominant process in DIS of charged leptons by nucleons is the exchange of a single space-like photon with a squared four-momentum $q^2 = -Q^2$, where Q^2 is much larger than the typical hadronic scale, usually set to be the squared mass M^2 of the nucleon. The cross section for this lepton scattering process can be decomposed in a model-independent way in terms of structure functions. Factorization theorems based on quantum chromodynamics (QCD) provide an interpretation of these structure functions in terms of parton distribution functions (PDFs), which ultimately reveal crucial aspects of the dynamics of confined quarks and gluons.

Polarized inclusive DIS on nucleons, $lN \to l'X$ (where X denotes the undetected final state), neglecting weak boson exchange can be described by four structure functions (see, e.g., Refs. [1,2]). They can be interpreted using collinear factorization theorems (see, e.g., Refs. [3,4] and references therein). Three of the structure functions contain contributions at leading order in an expansion in M/Q (twist expansion). These contributions include the leading-twist (twist-2) quark distribution functions $f_1^q(x)$ and $g_1^q(x)$ [2] (for simplicity, the dependence on Q^2 has been dropped). The variable x represents the fraction of the nucleon momentum carried by the parton in a frame where the nucleon moves infinitely fast in the direction opposite to the probe. The hard probe defines a specific direction (**q** in Fig. 1), usually denoted as longitudinal, and the transverse plane perpendicular to it. In a parton-model picture, $f_1^q(x)$ describes the number density of quarks of flavor q in a fast-moving nucleon without regard to their polarization. The PDF $g_1^q(x)$ describes the difference between the number densities of quarks with helicity equal or opposite to that of the nucleon if the nucleon is longitudinally polarized. The integrals over x of $f_1^q(x)$ and $g_1^q(x)$ are related to the vector and axial charge of the nucleon, respectively.

There is a third leading-twist PDF, the function $h_1^q(x)$,[7] called the transversity distribution (see Ref. [5] for a review on the subject). Its integral over x is related to the tensor charge of the nucleon [6]. It can be interpreted as the difference between the densities of quarks with transverse polarization parallel or antiparallel to the transverse polarization of the nucleon [7]. In contrast to $f_1^q(x)$ and $g_1^q(x)$, there exists no gluon analog of $h_1^q(x)$ in the case of spin-$\frac{1}{2}$ targets. Therefore, $h_1^q(x)$ cannot mix with gluons under QCD evolution.

The transversity distribution does not appear in any structure function in inclusive DIS because it is odd under inversion of the quark chirality. It must be combined with another chiral-odd non-perturbative partner to appear in a cross section for hard processes involving only QED or QCD, as such interactions preserve chirality. For this reason, in spite of decades of inclusive DIS studies, no experimental information on the transversity distribution was available until recently. In lepton–nucleon scattering, the transversity distribution can be accessed experimentally only in semi-inclusive DIS with a transversely polarized target, where it can appear in combination with, e.g., the chiral-odd Collins fragmentation function [8]. This Letter presents a measurement of the associated signal.

In semi-inclusive DIS, $lN \to l'hX$, where a hadron h is detected in the final state in coincidence with the scattered lepton, the cross section depends on, among other variables, the hadron transverse momentum and its azimuthal orientation with respect to the lepton scattering plane about the virtual-photon direction. If the target is polarized and the polarization of the final state is not measured, the semi-inclusive DIS cross section can be decomposed in terms of 18 semi-inclusive structure functions (see, e.g., Ref. [9]).

When the transverse momentum of the produced hadron is small compared to the hard scale Q, semi-inclusive DIS can be described using transverse-momentum-dependent factorization [10, 11]. The semi-inclusive structure functions can be interpreted in terms of convolutions involving transverse-momentum-dependent parton distribution and fragmentation functions [12]. The former encode information about the distribution of partons in a three-dimensional momentum space, and the latter describe the hadronization process in a three-dimensional momentum space.

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[7] In literature, the distribution functions $f_1^q(x)$, $g_1^q(x)$, and $h_1^q(x)$ are also denoted as $q(x)$, $\Delta q(x)$, and $\delta q(x)$ (or $\Delta_T q(x)$), respectively.