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FLAVOR SEPARATED QUARK POLARIZATIONS AT HERMES

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Recent HERMES results are presented on the flavor decomposition of the sea quark helicity distributions in the nucleon from semi-inclusive deep inelastic scattering. For the first time, a five component decomposition of quark helicity distributions using flavor tagging has been performed. The helicity distributions of the *up* and *down* quarks confirm the results obtained from inclusive deep inelastic scattering, however, there is no evidence for either a negative strange quark polarization or for a flavor asymmetry in the light sea polarization.

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1. Introduction

Understanding how the spin of the nucleon is constructed from its elementary constituents has proven to be a significant challenge both theoretically and experimentally. In a simple constituent quark model, the spin of the nucleon can be decomposed as

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{\rm q} + L_{\rm G}\,, \tag{1}$$

where $\Delta\Sigma$ and ΔG are the intrinsic spins carried by the quarks and gluons, and $L_{\rm q}$ and $L_{\rm G}$ the orbital angular momenta of the quarks and gluons.

To obtain some feeling for the expected magnitudes of these various contributions to the nucleon polarization, one may turn to phenomenological models. In the constituent quark model, the nucleon is composed entirely of valence quarks. By imposing appropriate symmetry conditions on the nucleon wave function, one obtains the values $\Delta u = +4/3$ and $\Delta d = -1/3$ (which adds up the net quark polarization $\Delta\Sigma$ of 1). If one considers instead of constituent quarks the current quarks seen by dynamical QCD processes, relativistic effects have to be taken into account because of the light quark masses. Calculations performed in e.g. the relativistic bag model then suggest that $\Delta\Sigma \simeq 0.60 - 0.75$ [1]. The remainder of the nucleon spin is accounted for by the angular momentum of the moving quarks. To include sea quarks in the picture one may turn, for example, to meson cloud models where the nucleon is described as a bare, valence object which has a probability to emit pseudo-scalar mesons. It is through the emission of such mesons that the quark sea is generated. One calculation performed in this way [2] indicates that the sea quarks should carry a negative polarization, but that the anti-quarks in the sea are unpolarized: all anti-quarks in this picture are members of a spin-0 meson, and therefore carry no polarization. An alternative picture of the nucleon comes from the chiral-quark soliton model, where the nucleon appears as a chiral soliton in a pion mean field. A recent calculation of this type [3], performed in the large N_c limit, suggests that the $\bar{\mathrm{u}}$ and $\bar{\mathrm{d}}$ quarks do carry a significant polarization, but of opposite sign: $\Delta\bar{u} \simeq -\Delta\bar{d}$, and that $\Delta\bar{u} - \Delta\bar{d} > \bar{d} - \bar{u}$. Yet another picture of the nucleon comes from the statistical model, where the nucleon appears as a gas of massless partons. A calculation carried out in this model [4] suggests that the $\bar{\mathrm{u}}$ and $\bar{\mathrm{d}}$ quarks also carry a significant non-zero polarization, but that $\Delta\bar{u} - \Delta\bar{d} \sim \bar{d} - \bar{u}$.

This brief sample of phenomenological models makes it clear that spin structure experiments are probing very basic properties of the nucleon: The measurement of these quantities has the power to distinguish between different pictures of how the nucleon is constructed.

2. *Inclusive measurements*

The longitudinal spin structure function $g_1(x, Q^2)$ has been measured by a number of experiments using the scattering of polarized leptons from polarized targets [5]. In leading order QCD and the quark parton model, this structure function is given by the charge weighted sum over the polarized quark spin distributions Δq for flavor q: $g_1(x) = \frac{1}{2}\sum_q e_q^2 \Delta q(x)$. The notation $\Delta q(x)$ denotes the polarized counterpart of the familiar parton distribution functions (PDF): $\Delta q(x) \equiv q^+(x) - q^-(x)$. Here, x is the Bjorken scaling variable, and $q^+(q^-)$ indicates quarks whose spins are parallel (anti-parallel) to the spin of the nucleon. In the framework of next-to-leading order (NLO) QCD, the relationship between $g_1(x, Q^2)$ and the polarized PDF's is more complex, and includes a contribution from the gluon spin distribution ΔG.

Numerous spin-dependent NLO fits exist in the literature. One example is the global fit performed by the SMC collaboration [6]. The results indicate (using the AB factorization scheme) that the quark spins account for only a relatively small fraction of the total nucleon spin (of order 38%). Further, the strange sea would seem to have a slight negative polarization, of order −10%. The gluon polarization ΔG, by comparison, is only poorly constrained by the inclusive data, but there is some indication that it is positive. Since inclusive deep inelastic scattering (DIS) is sensitive only to the magnitude of the quark charge, DIS fails to distinguish quarks from anti-quarks, i.e. $\Delta q = \Delta(q + \bar{q})$. Therefore, no direct information about the sea quark polarizations is available from these inclusive measurements.

3. Quark polarizations from semi-inclusive measurements

To proceed further in our knowledge of the polarized parton distributions, experimenters have turned to *semi-inclusive* asymmetry measurements. In these measurements a hadron is detected in coincidence with the scattered lepton. Through the agency of the fragmentation functions $D_{\mathrm{h}}^{\mathrm{q}}$, a probabilistic relationship exists between the flavor of the struck quark q and the flavor content of the hadrons h generated in the final state. Although fragmentation functions have been extracted from mostly high energy $\mathrm{e^+e^-}$ collider data [7], their applicability at lower energies is supported by their agreement with fragmentation functions [8] for charged pions extracted from HERMES measurements of hadron multiplicities.

By measuring the double spin asymmetries A_1^{h} in the cross sections for leptoproduction of various types of hadrons, one can extract a complete flavor decomposition of the quark and anti-quark helicity distributions. In LO QCD, the photon-nucleon double spin asymmetry A_1^{h} is given by[1]

$$A_1^{\mathrm{h}}(x,z) = \frac{\sum_{\mathrm{q}} e_{\mathrm{q}}^2 \Delta q(x) D_{\mathrm{q}}^{\mathrm{h}}(z)}{\sum_{\mathrm{q}} e_{\mathrm{q}}^2 q(x) D_{\mathrm{q}}^{\mathrm{h}}(z)} \, \frac{(1+R(x))}{(1+\gamma^2)}. \tag{2}$$

The sum at the moderate beam energies of the HERMES experiment is over quark and anti-quark flavors $q = (\mathrm{u}, \bar{\mathrm{u}}, \mathrm{d}, \bar{\mathrm{d}}, \mathrm{s}, \bar{\mathrm{s}})$, and $z \equiv E_{\mathrm{h}}/\nu$ with ν and E_{h} being the energies of the virtual photon and the detected hadron. The factor involving $\gamma^2 = Q^2/\nu^2$ and R, the ratio of longitudinal to transverse virtual photon cross section, accounts for the longitudinal component included in most parameterizations of the unpolarized PDFs $q(x)$. Semi-inclusive asymmetries have been measured by HERMES in 1998–2000, where pions and kaons were identified from a deuterium target, as shown in Fig. 1.

Integrating Eq. (2) over z, the photon-nucleon asymmetry A_1^{h} can be rewritten as

$$A_1^{\mathrm{h}}(x) = \sum_{\mathrm{q}} P_{\mathrm{q}}^{\mathrm{h}}(x) \frac{\Delta q(x)}{q(x)} \, \frac{(1+R(x))}{(1+\gamma^2)}, \tag{3}$$

where $P_{\mathrm{q}}^{\mathrm{h}}(x)$ are the spin-independent purities

$$P^{\mathrm{h}}(x) \equiv \frac{e_{\mathrm{q}}^2 q(x) \int\limits_{\mathrm{min}}^{\mathrm{max}} D_{\mathrm{q}}^{\mathrm{h}}(z)\,\mathrm{d}z}{\sum_{\mathrm{q}'} e_{\mathrm{q}'}^2 q'(x) \int\limits_{\mathrm{min}}^{\mathrm{max}} D_{\mathrm{q}'}^{\mathrm{h}}(z)\,\mathrm{d}z} \,. \tag{4}$$

[1]For simplicity, we suppress here the weak logarithmic dependence of all functions on $-Q^2$, the squared four-momentum of the exchanged virtual photon.

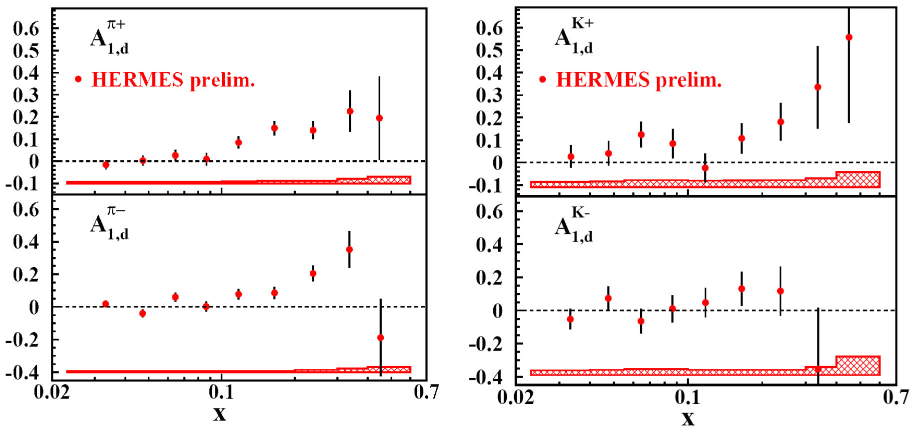

Fig. 1 . Virtual photoabsorption asymmetries A_1^{h} for semi-inclusive DIS on the deuterium target as a function of Bjorken x, for identified charged pions and kaons. The error bars are statistical, and the bands represent the systematic uncertainties.

Each purity function describes the conditional probability that the virtual photon hit a quark of flavor q when a hadron of type h was detected. In analogy with Eq. (4), the purities were extracted from a Monte Carlo simulation, using a model of the DIS process, the fragmentation process, and the detector.

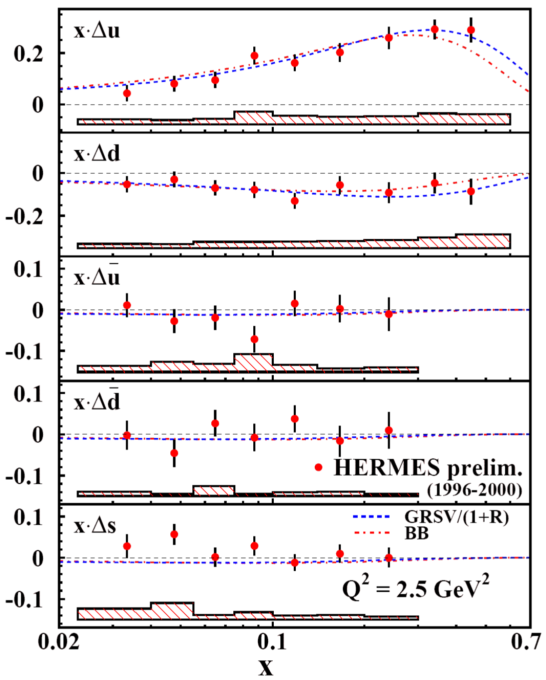

Fig. 2. Quark helicity distributions at $\langle Q^2 \rangle = 2.5\ \mathrm{GeV}^2$, as a function of Bjorken x, compared to two LO QCD fits to previously published inclusive data [9,10]. The error bars are statistical and the error bands represent the systematic uncertainties, which include the contributions from the uncertainties of the unpolarized quark densities, the fragmentation model, and the asymmetries.

With asymmetry data available for a variety of hadrons from both proton and "neutron" targets, the above system of equations (Eq. 3) becomes sufficiently constrained to be solved to extract the $\Delta q(x)$ for several flavors of q. In combination with identified pions from hydrogen in 1996–1997 and with inclusive data, they result in the first five-flavor extraction of quark polarizations from semi-inclusive data, as shown in Fig. 2. Sea quarks of all three flavors are treated independently, with the only assumption being $\Delta s(x)/s(x) \equiv \Delta\bar{s}(x)/\bar{s}(x)$.

The extracted distributions $\Delta u(x)$ and $\Delta d(x)$ are consistent with previous (semi-)inclusive results, but have much improved precision. The sea distributions, extracted separately for the first time, are consistent with zero and with each other. There is no indication of a negative polarization of the strange sea that appears in the analysis of only inclusive data, in which SU(3) flavor symmetry in the analysis of hyperon beta decay is assumed. In addition, there is, as shown in Fig. 3, no evidence for as large a positive flavor asymmetry $\Delta\bar{u}(x) - \Delta\bar{d}(x)$ in the light quark sea as was predicted by the theoretical calculations [3,4] discussed in Section 1. In fact, it appears that the simplest model, the meson cloud model, describes the data best.

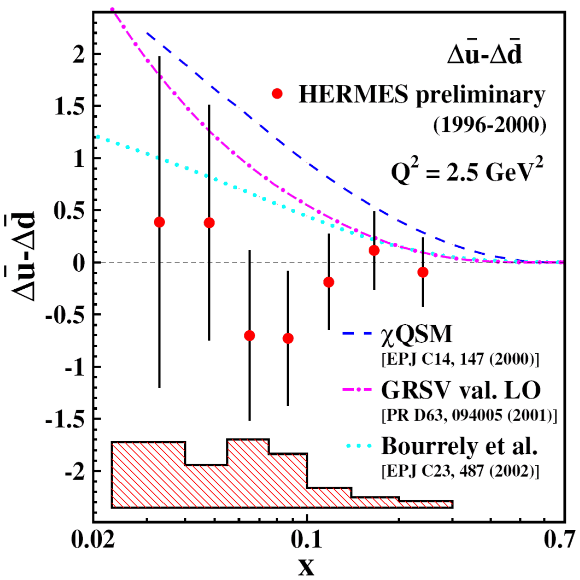

Fig. 3. The light quark sea flavor asymmetry $\Delta\bar{u} - \Delta\bar{d}$ in the helicity distributions, as a function of Bjorken x, at $\langle Q^2\rangle = 2.5$ GeV^2, compared to three theoretical predictions [4,9,11]. The error bars are statistical and the error bands represent the systematic uncertainties.

In conclusion, a purity based extraction from new semi-inclusive DIS data has produced for the first time a five-flavor separation of helicity distributions. There is no evidence for either a negative strange quark polarization or for a flavor asymmetry in the light sea polarization.

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OKUSNO RAZDVOJENE KVARKOVSKE POLARIZACIJE U HERMESU

Predstavljamo nedavne ishode mjerenja HERMES za okusno razdvajanje raspodjela heliciteta kvarkovskog mora u nukleonu zasnovane na polu-inkluzivnom duboko-neelastičnom raspršenju. Načinili smo prvo razdvajanje kvarkovskih raspodjela heliciteta na pet sastavnica primjenom označavanja okusa. Raspodjele heliciteta u i d kvarkova potvrđuju ishode mjerenja inkluzivnih duboko-neelastičnih raspršenja, međutim, ne nalazimo znakove niti za negativnu polarizaciju stranih kvarkova niti za asimetriju okusa u polarizaciji lakog mora.