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Polarized quark distributions extracted from inclusive and semi-inclusive deeply inelastic scattering at HERMES

Patricia Liebing (on behalf of the HERMES collaboration)

DESY-Zeuthen, Platanenalle 6, D-15738 Zeuthen

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Abstract. The helicity structure of the nucleon can be revealed by the determination of the spin dependent structure function $g_1(x,Q^2)$. This has been done by the HERMES experiment with high precision by measuring double spin asymmetries in inclusive deep inelastic scattering of longitudinally polarized positrons on longitudinally polarized protons or deuterons. Furthermore, semi-inclusive asymmetries of hadrons, pions and kaons were extracted and used to perform a five component separation of the helicity distributions of u, $\bar{u}$, d, $\bar{d}$ and s quarks in a LO QCD analysis. In general, the results agree well with phenomenological fits to inclusive data. While these fits predict a negative strange quark polarization, the HERMES result suggests a zero or slightly positive value. A possible breaking of the flavor symmetry of the polarized light sea $\Delta\bar{u} - \Delta\bar{d}$ was also investigated and found to be consistent with zero within the experimental precision.

1 Introduction

The HERMES experiment at DESY uses the 27.5 GeV polarized positron (or electron) beam at the HERA accelerator and a pure polarized gaseous target (hydrogen or deuterium) to perform precision measurements of the inclusive spin-dependent structure function $g_1(x)$ and of the quark polarizations $\Delta q(x)/q(x)$. With the large forward acceptance of the spectrometer and its excellent particle identification [1] it is possible to measure inclusive reactions in deep inelastic scattering (DIS), where only the scattered lepton is detected, as well as semi-inclusive DIS (SIDIS) events, where hadrons are detected in coincidence with the lepton. For the hydrogen data set, pions could be identified using the information from a threshold Cherenkov counter. For the deuterium data a Ring-Imaging Cherenkov (RICH) detector provided the possibility to identify pions and kaons [2].

The kinematic quantities measured in inclusive DIS are the negative squared momentum transfer $Q^2 \equiv -q^2 = -(k-k')^2$ and the energy transfer $\nu = E-E'$ to the virtual photon, and the Bjorken scaling variable $x = Q^2/(2M\nu)$ which all can be derived from the four-momenta of the incoming and outgoing lepton, $k = (E, \overrightarrow{k})$ and $k' = (E', \overrightarrow{k}')$ and of the target nucleon with $P = (M, \overrightarrow{0})$. The squared invariant mass of the final hadronic system is $W^2 = (P+q)^2$. From the lepton-nucleon double-spin asymmetry $A_\parallel$ defined as the relative difference of cross sections with beam and target helicities antiparallel and parallel, the virtual photon asymmetry A_1 can be determined. A_1 in turn can be related to the structure function g_1:

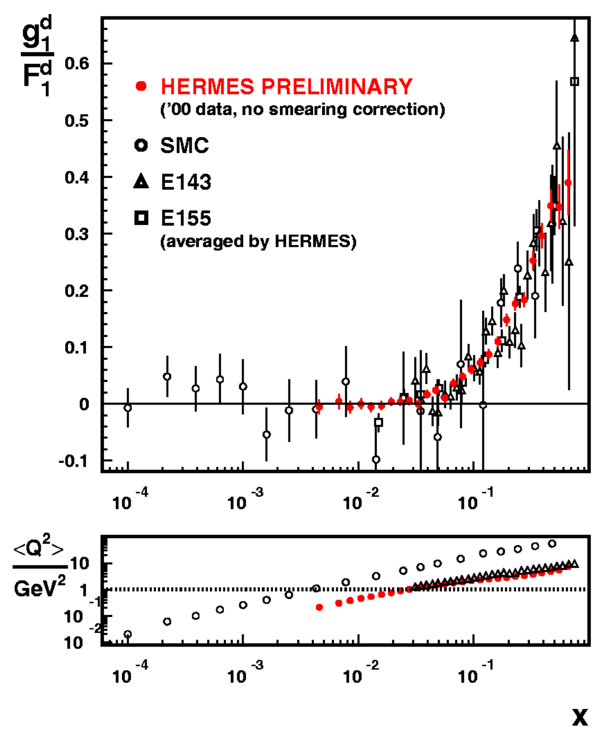

Fig. 1. The inclusive asymmetry g_1^d/F_1 extracted from the HERMES 2000 data on deuterium. A comparison to results from SMC [6] and SLAC experiments [7,8] is also shown. The *lower panel* shows the average Q^2 for each *data point*

$$A_1(x,Q^2) \simeq \frac{A_\parallel(x,Q^2)}{D(1+\eta\gamma)} \simeq \frac{g_1(x,Q^2)}{F_1(x,Q^2)}, \qquad (1)$$

where D is the photon depolarization factor, and η, γ are (small) kinematic factors. In LO QCD, g_1 can be interpreted as the charge weighted sum of polarized quark distributions:

$$g_1(x,Q^2) = \frac{1}{2}\sum_q e_q^2 \left(\Delta q(x,Q^2) + \Delta\bar{q}(x,Q^2)\right), \quad (2)$$

where the polarized quark densities Δq are defined as the difference $q^+ - q^-$ between densities of quarks with positive and negative helicity with respect to that of the nucleon. The unpolarized quark densities are given by $q \equiv q^+ + q^-$. In SIDIS additionally the fractional energy of the detected hadron $z = E_h/\nu$ and its relative longitudinal momentum with respect to the virtual photon direction in the hadronic center of mass frame $x_F \simeq 2p_L/W$ are determined. The semi-inclusive virtual photon asymmetry for a hadron of type h is in LO QCD:

$$A_1^h(x,Q^2) \sim \frac{\sum_q e_q^2 \Delta q(x,Q^2) \int_{z_{min}}^{z_{max}} dz D_q^h(z,Q^2)}{\sum_q' e_q'^2 q'(x,Q^2) \int_{z_{min}}^{z_{max}} dz D_{q'}^h(z,Q^2)} \quad (3)$$

with the fragmentation function D_q^h denoting the probability that a quark of flavor q fragments into a final state hadron h carrying the energy fraction z. Introducing the spin-independent purities

$$P_q^h(x) = \frac{e_q^2\, q(x) \int_{z_{min}}^{z_{max}} dz\, D_q^h(z)}{\sum_q e_q^2\, q(x) \int_{z_{min}}^{z_{max}} dz\, D_q^h(z)}, \quad (4)$$

equation (3) can be rewritten:

$$A_1^h(x) \sim \sum_q P_q^h(x) \frac{\Delta q(x)}{q(x)}, \quad (5)$$

where all quantities have been integrated in each x-bin over the available range in Q^2 . The purities P_q^h describe the probability that the hadron h originates from an event where a quark of flavor q was struck. They were extracted using Monte Carlo simulations to account for the limited acceptance of the spectrometer. For the unpolarized quark distributions in (4) the CTEQ5L parametrization [3] was used, for the fragmentation functions the parameters of the LUND string fragmentation model implemented in JETSET [4] were tuned to fit the hadron multiplicities measured at HERMES [5].

2 Inclusive and semi-inclusive asymmetries

Figure 1 shows the inclusive asymmetry A_1^d measured on the deuteron as a function of x in the range $Q^2 > 0.1$ GeV^2, $W^2 > 3.24$ GeV^2 and $y = \nu/E < 0.91$. Good consistency between the preliminary HERMES data on g_1/F_1 with an earlier measurement of SMC [6] is observed despite the fact that the average Q^2 of SMC is about a factor of ten larger than that of HERMES, as can be seen from the lower panel of the figure.

Figure 2 shows the semi-inclusive asymmetries for pions and kaons on the deuteron, within a momentum range of $4 < p_h < 13.8$ GeV. The SIDIS asymmetries are measured at $Q^2 > 1$ GeV^2, $W^2 > 10$ GeV^2 and $y < 0.85$, with the hadron required to have $0.2 < z < 0.8$ and $x_F > 0.1$. The lower z cut and the cut on x_F effectively suppress hadrons from the target fragmentation region, while the upper z cut reduces contributions from exclusive events to the semi-inclusive sample.

Except for negative kaons, whose asymmetry is consistent with zero, all asymmetries are positive and rising with x. Since a negative kaon constitutes a sea-only object ($\bar{u}s$) it is more sensitive to sea quarks than the other hadrons which all contain valence quarks of the nucleon.

Equation (5) can be generalized for a set of measured asymmetries combined into a vector $\overrightarrow{A}$:

$$\overrightarrow{A} \sim P\overrightarrow{Q}, \quad (6)$$

where P is now a matrix of purities and $\overrightarrow{Q}$ is the vector of quark polarizations to be determined. For the recent analysis [10], $\overrightarrow{Q} = (\Delta u/u, \Delta d/d, \Delta\bar{u}/\bar{u}, \Delta\bar{d}/\bar{d}, \Delta s/s, \Delta\bar{s}/\bar{s} \equiv 0)$. The vector $\overrightarrow{A}$ contains the semi-inclusive asymmetries of both proton and deuteron targets as well as the inclusive asymmetries within the same kinematic range. From the solution vector $\overrightarrow{Q}$ obtained by minimization methods, the quark helicity distributions $\Delta q(x)$ can be derived by multiplying each of the quark polarizations with the corresponding unpolarized PDF at fixed $Q^2 = 2.5$ GeV^2. The polarizations are assumed to be Q^2 independent.

Figure 3 shows the results of this procedure for the x-weighted distributions $x\Delta q(x)$.

Note that in contrast to the LO QCD fits to inclusive data [11,12] overlaid in Fig. 3, in the HERMES analysis no assumptions were made on the symmetry of the sea flavors, except $\Delta\bar{s}/\bar{s} \equiv 0$. The systematic error bands include uncertainties due to the fragmentation parameters used for the purities in addition to the experimental error of the asymmetries. For $x > 0.3$, the polarization of the sea flavors was fixed at zero, the small uncertainties for the non-sea flavors arising from this as well as from setting $\Delta\bar{s}/\bar{s} \equiv 0$ were also included in their systematic error.

The helicity density of the u quark is found to be positive and large at $x > 0.1$, while that of the d quark is negative and rather flat in x. The helicity densities of the light sea quarks are compatible with zero. Contrary to the small negative strange sea polarization resulting from QCD fits to inclusive data, the strange quark helicity appears slightly positive. However, within the uncertainties there is no disagreement with the QCD fits.

Figure 4 shows the result for the difference of the helicity distributions $\Delta\bar{u} - \Delta\bar{d}$. No breaking of the flavor symmetry in the light sea as expected from some phenomenological models (see for instance [13]), could be observed at the present level of experimental accuracy.

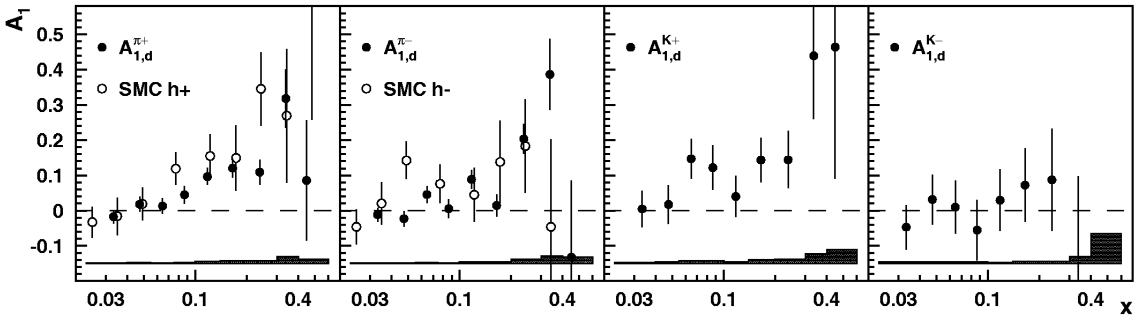

Fig. 2. HERMES results on the semi-inclusive asymmetries on deuterium for identified charged pions (compared to all charged hadrons from SMC [9] in th x-range of HERMES), and for identified charged kaons. The *error bands* represent the systematic uncertainties

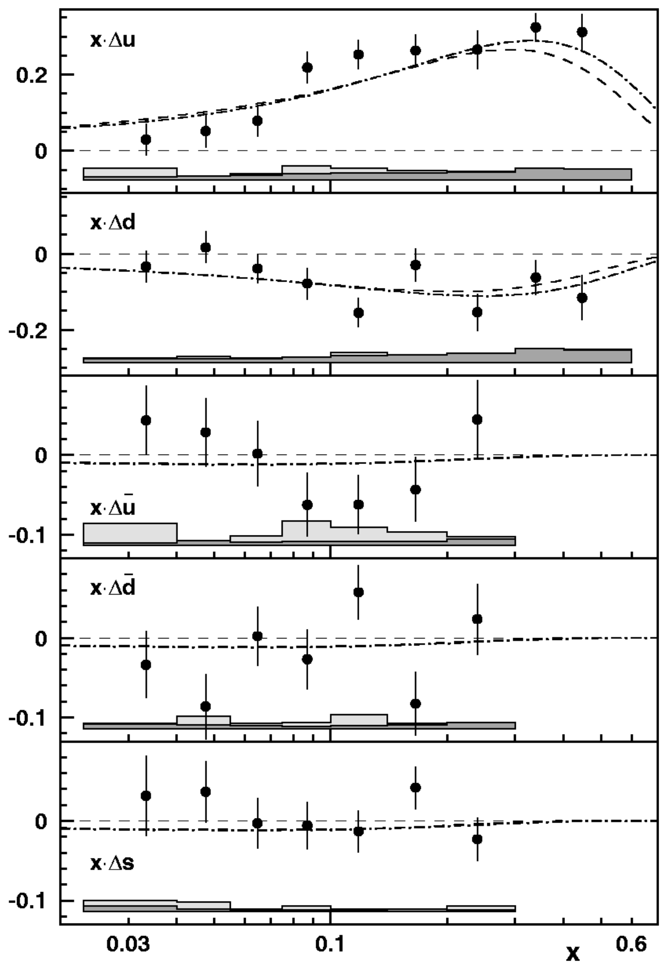

Fig. 3. The x-weighted polarized parton distributions $x\Delta q(x)$, extracted from HERMES semi-inclusive asymmetries on polarized hydrogen and deuterium targets. The data are shown at fixed $Q^2 = 2.5$ GeV^2. The *curves* show results from LO QCD fits to previously published inclusive data from [11] (*dashed, 'standard scenario'*) and [12] (*dot-dashed, 'scenario 1'*). The *light shaded error band* shows the systematic uncertainties arising from uncertainties of the fragmentation model, the *dark shaded area* shows the ones due to the uncertainties of the experimental asymmetries

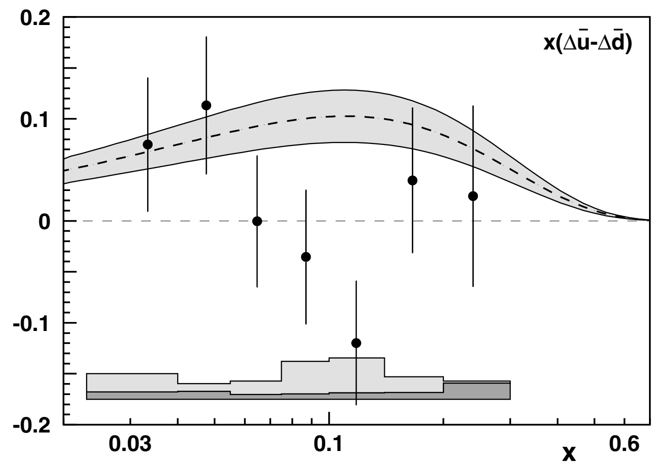

Fig. 4. The x-weighted difference of the *light sea* helicity densities $x(\Delta\bar{u}-\Delta\bar{d})$ at $Q^2 = 2.5$ GeV^2 as a function of x, compared to a theoretical prediction from [13] (*dashed curve* with *theoretical error band*). The *systematic error bands* have the same meaning as in Fig. 3

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