Flavour Decomposition of the Polarised Quark Distributions from Semi-Inclusive Data

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Spin asymmetries of the semi-inclusive cross section for the production of charged hadrons have been measured in deep-inelastic scattering of polarised leptons from polarised nuclei by the SMC experiment in the kinematic range $0.003 < x < 0.7$ and $1\ \mathrm{GeV}^2 < Q^2 < 56\ \mathrm{GeV}^2$ and by the HERMES experiment in the kinematic range $0.023 < x < 0.6$ and $1\ \mathrm{GeV}^2 < Q^2 < 10\ \mathrm{GeV}^2$. Recent results from HERMES on the extraction of polarised quark distributions from the measured spin asymmetries were presented at this conference for the first time. Polarised quark distributions were extracted as a function of x for up $(u+\bar{u})$ and down $(d+\bar{d})$ flavours, and for valence and sea quarks. The up quark polarisation is positive and the down quark polarisation is negative in the measured range. The polarisation of the sea is compatible with zero. The moments of the polarised quark distributions are presented. All HERMES results are preliminary.

Semi-inclusive polarised deep inelastic scattering allows one to measure the polarised quark distributions $\Delta q(x,Q^2) = q^{\uparrow}(x,Q^2) - q^{\downarrow}(x,Q^2)$ for each quark flavour $q = u,\bar{u},d,\bar{d},s,\bar{s}$. Here, $q^{\uparrow(\downarrow)}(x,Q^2)$ is the quark distribution with spin parallel (anti-parallel) to the nucleon spin, x is the Bjorken scaling variable, and $-Q^2$ is the squared four-momentum of the exchanged virtual photon. Provided factorisation of the scattering and the fragmentation process holds, the cross section for the production of a particular hadron h can be written in leading order (LO) QCD

$$\sigma^h(x,Q^2,z) \propto \sum_q e_q^2\ q(x,Q^2)\ D_q^h(z,Q^2)\,. \qquad (1)$$

In Eq. (1) e_q denotes the quark charge in units of the elementary charge e, $q(x,Q^2)$ are the unpolarised quark distributions, and $D_q^h(z,Q^2)$ are the fragmentation functions which are defined as the probability that a struck quark q fragments into a hadron h with fractional energy $z = E_h/\nu$, where E_h is the energy of the hadron and ν is the energy of the virtual photon. The asymmetry of the spin-dependent virtual photon nucleon absorption cross sections is defined as

$$A_1^{(h)} = \frac{\sigma_{1/2}^{(h)} - \sigma_{3/2}^{(h)}}{\sigma_{1/2}^{(h)} + \sigma_{3/2}^{(h)}}\,, \qquad (2)$$

where the index 1/2 (3/2) refers to the anti-parallel (parallel) orientation of the nucleon and photon spins. In LO QCD, A_1^h is related to the polarised and unpolarised quark distributions and fragmentation functions by

$$A_1^h(x,Q^2) = C_R\ \frac{\sum_q e_q^2\ \Delta q(x,Q^2)\ D_q^h(Q^2)}{\sum_q e_q^2\ q(x,Q^2)\ D_q^h(Q^2)}\,, \qquad (3)$$

where $D_q^h(Q^2) = \int_{0.2}^1 D_q^h(z,Q^2)dz$ and C_R is a correction factor accounting for the longitudinal component of the photon nucleon absorption cross section that is included in the experimentally determined parameterisations of $q(x,Q^2)$ but not in $\Delta q(x,Q^2)$ (see [1]). The region from 0.2 to 1, over which z is integrated, is determined by cuts on the hadron kinematics to select hadrons from the fragmentation of the struck quark. The inclusive asymmetry can be similarly expressed by $A_1(x,Q^2) = C_R\ \sum_q e_q^2\ \Delta q(x,Q^2)/\sum_q e_q^2\ q(x,Q^2)$. In Eq. (3) it has been assumed that the spin structure function g_2 vanishes, which is consistent with recent SLAC measurements.

Semi-inclusive polarised DIS experiments have been performed by SMC at CERN and by HERMES at DESY. The SMC experiment [2] uses a longitudinally polarised muon beam with energies of 100 GeV or 190 GeV incident on two target cells filled with butanol, deuterated butanol, or ammonia. The two cells are longitudinally polarised in opposite directions by dynamic nuclear polarisation. Hadron separation from leptons is achieved by a calorimeter which consists of an electro magnetic and a hadronic part. The HERMES experiment [3] utilises a 27.5 GeV beam of longitudinally polarised positrons incident on polarised pure atomic gas targets internal to the HERA storage ring. In 1995 an optically pumped polarised ^{3}He target was used. In 1996/97 the experiment was performed with an atomic beam source of polarised hydrogen. Particle identification is accomplished using a lead-glass calorimeter, a preshower counter, six transition radiation detector modules, and a N_2/C_4F_{10} threshold gas Čerenkov counter.

The measured inclusive and semi-inclusive asymmetries $A_1^{(h)}$ on proton and deuteron targets as measured by SMC are published in [4], and the HERMES asymmetries for proton and ^{3}He targets can be found in [5]. The proton asymmetries of both experiments are in agreement. The statistical error of the charged hadron asymmetries on the proton has been significantly reduced by the addition of the HERMES data from 1997.

Given the fragmentation functions and the unpolarised quark distributions, Eq. (3) together with the corresponding expression for the inclusive asymmetry A_1 can be used to extract the polarised quark distributions $\Delta q(x, Q^2)$ from a set of measured inclusive and semi-inclusive asymmetries. The equations can be written in matrix form

$$\vec{A}(x) = \mathcal{P}(x) \cdot \vec{Q}(x) \,, \tag{4}$$

where the vector $\vec{A}(x)$ contains as elements the measured inclusive and semi-inclusive charged hadron asymmetries on the proton and ^{3}He (HERMES) or on the proton and deuteron (SMC). The vector $\vec{Q}(x)$ contains the quark and anti-quark polarisations for each quark flavour and the matrix $\mathcal{P}(x)$ depends on the unpolarised quark distributions q, the fragmentation functions D_q^h and the correction term C_R. At HERMES the fragmentation functions have been determined from the LUND string fragmentation model as implemented in the JETSET-7.4 code [6] combined with a detailed model of the detector. For the unpolarised quark distributions a parameterisation of [7] was used. The free parameters of the LUND fragmentation model were tuned to fit the measured hadron multiplicities. In case of SMC, the fragmentation functions were taken from the EMC measurements.

Eq. (4) can be solved for $\vec{Q}(x)$ by minimising

$$\chi^2 = \left(\vec{A} - \mathcal{P} \cdot \vec{Q}\right)^{\mathrm{T}} \mathcal{V}_{\vec{A}}^{-1} \left(\vec{A} - \mathcal{P} \cdot \vec{Q}\right) \,, \tag{5}$$

where $\mathcal{V}_{\vec{A}}$ is the covariance matrix of the asymmetry vector $\vec{A}$. In the fit procedure constraints were imposed on the sea polarisation to improve statistical significance. HERMES assumed that the polarisation $\Delta q_s(x)/q_s(x)$ of sea quarks is independent of flavour, i.e.

$$\frac{\Delta u_s}{u_s} = \frac{\Delta d_s}{d_s} = \frac{\Delta s}{s} = \frac{\Delta \bar{u}}{\bar{u}} = \frac{\Delta \bar{d}}{\bar{d}} = \frac{\Delta \bar{s}}{\bar{s}} \tag{6}$$

for all values of x. The flavour decomposition was obtained by solving Eq. (4) for the vector

$$\vec{Q} = \left(\frac{\Delta u + \Delta \bar{u}}{u + \bar{u}}, \frac{\Delta d + \Delta \bar{d}}{d + \bar{d}}, \frac{\Delta s + \Delta \bar{s}}{s + \bar{s}}\right) \,, \tag{7}$$

where according to Eq. (6) the polarisations of the strange quarks and of the total sea are assumed to be equal: $(\Delta s(x) + \Delta \bar{s}(x))/(s(x) + \bar{s}(x)) = \Delta q_s(x)/q_s(x)$. For $x > 0.3$ the statistical error of the extracted sea polarisation $\Delta q_s/q_s$ is larger than the positivity limit $|\Delta q_s/q_s| \leq C_R^{-1}$. Therefore, in the region $x > 0.3$, the sea polarisation was set to zero and the corresponding effect on the results for the non-sea polarisations was included in their systematic uncertainties.

Fig. 1 shows the HERMES results for the quark polarisations obtained from data taken from 1995 to 1997. The up quark polarisation is positive and the down quark polarisation is negative over the measured range of x. Their absolute values increase with increasing values of x and remain different from zero within the full range of the measurement. The sea polarisation is compatible with zero over the measured x-range. For the up and down quarks, the systematic uncertainties are dominated by those of the beam and

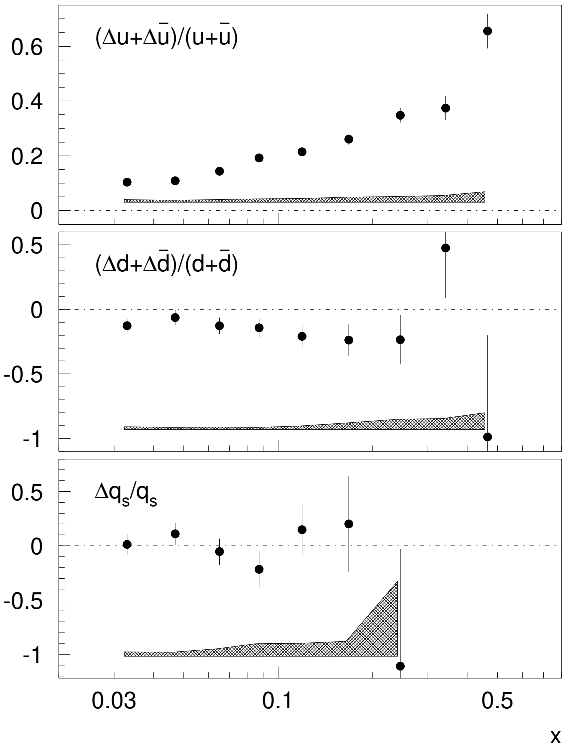

Figure 1. The flavour decomposition $(\Delta u(x) + \Delta\bar{u}(x))/\ (u(x) + \bar{u}(x))$, $(\Delta d(x) + \Delta\bar{d}(x))/(d(x) + \bar{d}(x))$ and $\Delta q_s(x)/q_s(x)$ of the quark polarisation as a function of x, derived from the HERMES inclusive and semi-inclusive asymmetries. The sea polarisation is assumed to be flavour independent in this analysis. The error bars shown are statistical, and the bands indicate the systematic uncertainties.

target polarisation measurements and of the ratio $R = \sigma_L/\sigma_T$ of the longitudinal to transverse photon absorption cross sections. For the sea quarks the systematic uncertainty is dominated by the uncertainty in the fragmentation functions which was determined by comparing the results obtained from different fragmentation models and from varying the fragmentation parameters in the Monte Carlo code.

Polarised quark distributions $\Delta q(x)$ were determined by HERMES by multiplying the quark polarisations $\Delta q(x)/q(x)$ with the unpolarised quark distributions from [7] at $Q^2 = 2.5$ GeV^2. It was assumed that the polarisation is independent of Q^2 within the Q^2-range of the measurement. This assumption is justified by the weak Q^2-dependence predicted by QCD and by the experimental result that there is no significant Q^2-dependence observed in the inclusive asymmetries (see e.g. [8]). Fig. 2 compares the polarised valence quark distributions $x\Delta u_v(x)$ and $x\Delta d_v(x)$ (derived from the relation $\Delta q_v(x) = (\Delta q(x) + \Delta\bar{q}(x)) - 2\Delta\bar{q}(x))$ and the sea distribution $x\Delta\bar{u}(x)$ as measured by HERMES with the results from SMC [4]. The SMC results from Ref. [4] were obtained at $Q^2 = 10$ GeV^2. The results shown in Fig. 2 were extrapolated to $Q^2 = 2.5$ GeV^2 by assuming a Q^2-independent polarisation. The positivity limit and a parameterisation [10] derived from inclusive spin asymmetries are included in Fig. 2. The parameterisation and the SMC results are consistent with the HERMES results.

The SMC results were derived under the assumption that

$$\Delta u_s = \Delta d_s = \Delta s = \Delta\bar{u} = \Delta\bar{d} = \Delta\bar{s}\,. \qquad (8)$$

The uncertainty of the HERMES result arising from the symmetry assumption on the sea polarisation was estimated by comparing the results produced by Eqs. (6) and (8), respectively. The fitted quark polarisations change by typically less than 0.01 when Eq. (6) is replaced by Eq. (8).

The first and second moments of the polarised quark distributions have been extracted. To allow for a direct comparison of the HERMES and SMC integrals over the measured x-range, the SMC values have been extrapolated to $Q^2 = 2.5$ GeV^2 and integrated over the HERMES x-range of $0.023 < x < 0.6$. The results of both experiments are found to be in agreement. Significant deviations from theory are observed between the second moment $\int_0^1 x\Delta u_v(x)\ dx = 0.124 \pm 0.009(stat.) \pm 0.014(syst.)$ at $Q^2 = 2.5$ GeV^2 as measured by HERMES from the prediction 0.198 ± 0.008 at $Q^2 = 4$ GeV^2 of a quenched lattice QCD calculation [11], while the SMC result of $0.155 \pm 0.017 \pm 0.010$ at $Q^2 = 10$ GeV^2 [4] still agrees with the lattice prediction of 0.189 ± 0.008 [11] at the same scale. For the second moment $\int_0^1 x\Delta d_v(x)\ dx$ the results are $-0.022 \pm 0.024 \pm 0.024$ at $Q^2 = 2.5$ GeV^2 (HERMES) and $-0.056 \pm 0.026 \pm 0.011$

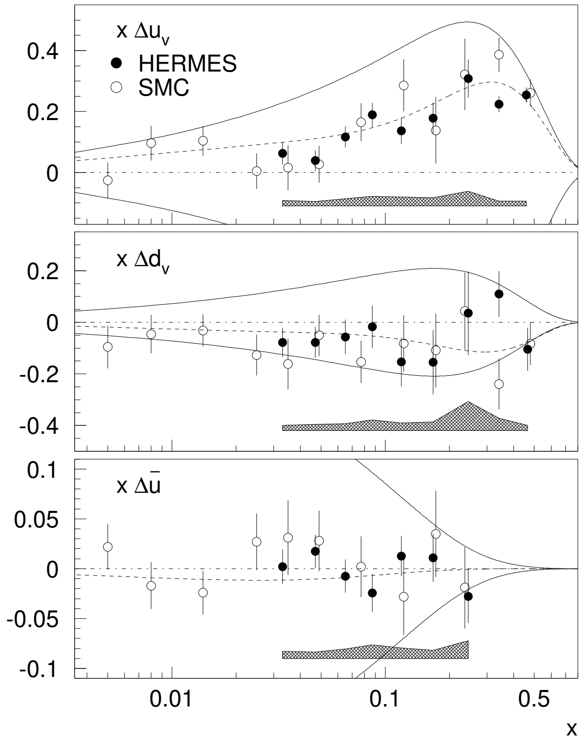

Figure 2. The polarised quark distributions from HERMES at $Q^2 = 2.5$ GeV^2 separately for the valence quarks $x\Delta u_v(x)$, $x\Delta d_v(x)$ and the sea quarks $x\Delta\bar{u}(x)$. The error bars shown are statistical, and the bands indicate the systematic uncertainties. The distributions are compared to results from SMC, extrapolated to $Q^2 = 2.5$ GeV^2. The error bars of the SMC result correspond to its total uncertainty. The solid lines indicate the positivity limit and the dashed lines are the parameterisation from [10] (Gluon A, LO).

at $Q^2 = 10$ GeV^2 (SMC) [4] in agreement with the lattice prediction from Ref. [11].

From the HERMES measurement the spin carried by up, down, and strange quarks is found to be $\Delta u + \Delta\bar{u} = 0.56 \pm 0.02 \pm 0.03$, $\Delta d + \Delta\bar{d} = -0.25 \pm 0.06 \pm 0.05$, and $\Delta s + \Delta\bar{s} = -0.02 \pm 0.03 \pm 0.04$ at $Q^2 = 2.5$ GeV^2. The strange quark contribution is found to be close to zero in this semi-inclusive analysis whereas it is significantly negative in the SU$(3)_f$ analysis of inclusive data [9]. Neither result is a direct measurement of $\Delta s + \Delta\bar{s}$ but depends on the assumption of SU$(3)_f$ symmetry for the inclusive case and on the sea symmetry condition (Eq. (6)) for the semi-inclusive case. For the singlet combination the HERMES data yield $\Delta q_0 = \int_0^1 [\Delta u(x) + \Delta\bar{u}(x) + \Delta d(x) + \Delta\bar{d}(x) + \Delta s(x) + \Delta\bar{s}(x)]dx = 0.28 \pm 0.04 \pm 0.09$. The triplet contribution $\Delta q_3 = \int_0^1 [\Delta u(x) + \Delta\bar{u}(x) - \Delta d(x) - \Delta\bar{d}(x)]dx = 0.83 \pm 0.07 \pm 0.06$ is in agreement with the value of $|g_A/g_V| \times C_{\mathrm{QCD}} = 1.01 \pm 0.05$ predicted by the Bjorken sum rule for $Q^2 = 2.5$ GeV^2. The octet combination $\Delta q_8 = \int_0^1 [\Delta u(x) + \Delta\bar{u}(x) + \Delta d(x) + \Delta\bar{d}(x) - 2(\Delta s(x) + \Delta\bar{s}(x))]dx$ can be related to the hyperon decay constants F and D according to $\Delta q_8 = (3F - D) \times C_{\mathrm{QCD}} = 0.46 \pm 0.03$. The semi-inclusive result $\Delta q_8 = 0.32 \pm 0.09 \pm 0.10$ agrees with the prediction. For the low-x extrapolation of the HERMES data a Regge-behaviour was assumed. The large theoretical uncertainties of the low-x extrapolation are not included in the quoted systematic errors.

Since 1998 the HERMES experiment has been taking data on a polarised deuteron target and has been equipped with a dual radiator RICH. The RICH provides hadron identification over the full momentum range and thus enables the measurement of semi-inclusive kaon and pion spin asymmetries. The 1998/99 data are expected to provide a first direct measurement of the light and strange sea polarisations.

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