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Measurement of the polarized parton distribution functions at HERMES

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Abstract. The HERMES experiment at DESY has measured the inclusive and semi-inclusive double-spin asymmetries of polarized positrons scattering from polarized hydrogen and deuterium targets in the kinematic range of Bjørken-x $0.023 < x < 0.06$ and $1\,\mathrm{GeV}^2 < Q^2 < 10\,\mathrm{GeV}^2$. A RICH detector was installed for the deuterium running period and by providing the identification of charged pions and kaons has enabled the first measurement of charged kaon asymmetries. Based on the measured proton and deuterium asymmetries the polarized quark distributions have been extracted in leading-order pQCD.

PACS. 13.60.Hb Total and inclusive cross-sections (including deep-inelastic processes) – 13.88.+e Polarization in interactions and scattering

1 Introduction

The study of the nucleon spin structure has attracted great interest since the EMC experiment [1] reported that only a small fraction of the proton's spin is carried by the quarks' spins. Several experiments have been carried out since which have confirmed this result [2]. The HERMES experiment [3] was designed to perform precise measurements of the polarized parton distribution functions (PDFs). It utilizes the 27.6 GeV polarized electron or positron beam of the HERA accelerator in combination with a polarized internal gaseous target. With its large forward acceptance, the spectrometer is well suited to measure inclusive reactions where only the scattered positron is detected as well as semi-inclusive processes where a hadron is detected in coincidence. The study of semi-inclusive channels is particularly important as the identity of fast hadrons from the fragmentation process is correlated with the flavor of the struck quark. This "flavor-tagging" correlation can be used to determine the polarized PDFs for each quark flavor.

2 Formalism of the analysis

Assuming factorization of the hard-scattering process and the fragmentation process, the photo-absorption spin asymmetry A_1^h for the production of a hadron of type h can be written in LO QCD as

$$A_1^h(x,z,Q^2) = C_R \cdot \frac{\sum_f e_f^2 \Delta q_f(x,Q^2) D_f^h(z,Q^2)}{\sum_{f'} e_{f'}^2 q_{f'}(x,Q^2) D_{f'}^h(z,Q^2)} . \quad (1)$$

Here, $C_R = (1 + R(x,Q^2))/(1+\gamma^2)$, where $\gamma^2 = Q^2/\nu^2$ and $R = \sigma_\mathrm{L}/\sigma_\mathrm{T}$ is the ratio of the longitudinal (σ_L) and transverse (σ_T) virtual-photon absorption cross-sections. The symbol e_f denotes the charge of the quark with flavor f. The fragmentation functions $D_f^h(z,Q^2)$ give the probability that a struck quark of flavor f will fragment into a hadron h; $z = E_h/\nu$ is the fraction of the virtual photon's energy carried by the hadron. The data are analyzed for $0.2 < z < 0.8$ and $x_\mathrm{F} > 0.1$, therefore the fragmentation functions are evaluated over this range as well. These selection criteria were chosen to enhance the contribution of hadrons from the current fragmentation region. The upper cut $z < 0.8$ eliminates exclusive events from the sample. In eq. (1), $q_f(x,Q^2)$ and $\Delta q_f(x,Q^2)$ are the unpolarized and polarized parton distribution functions where $\Delta q_f(x,Q^2) \equiv q^+(x,Q^2) - q^-(x,Q^2)$ and $q^{+(-)}$ is the number density of quarks with spin parallel (antiparallel) to the nucleon's spin.

As seen in eq. (1), a measured semi-inclusive asymmetry is related to a linear combination of all polarized PDFs. The set of all inclusive and semi-inclusive asymmetries measured on both polarized proton and deuterium targets form a set of linear equations which can be solved for the quark polarizations. After integrating over the Q^2 and z ranges for each x-bin, the set of asymmetries can

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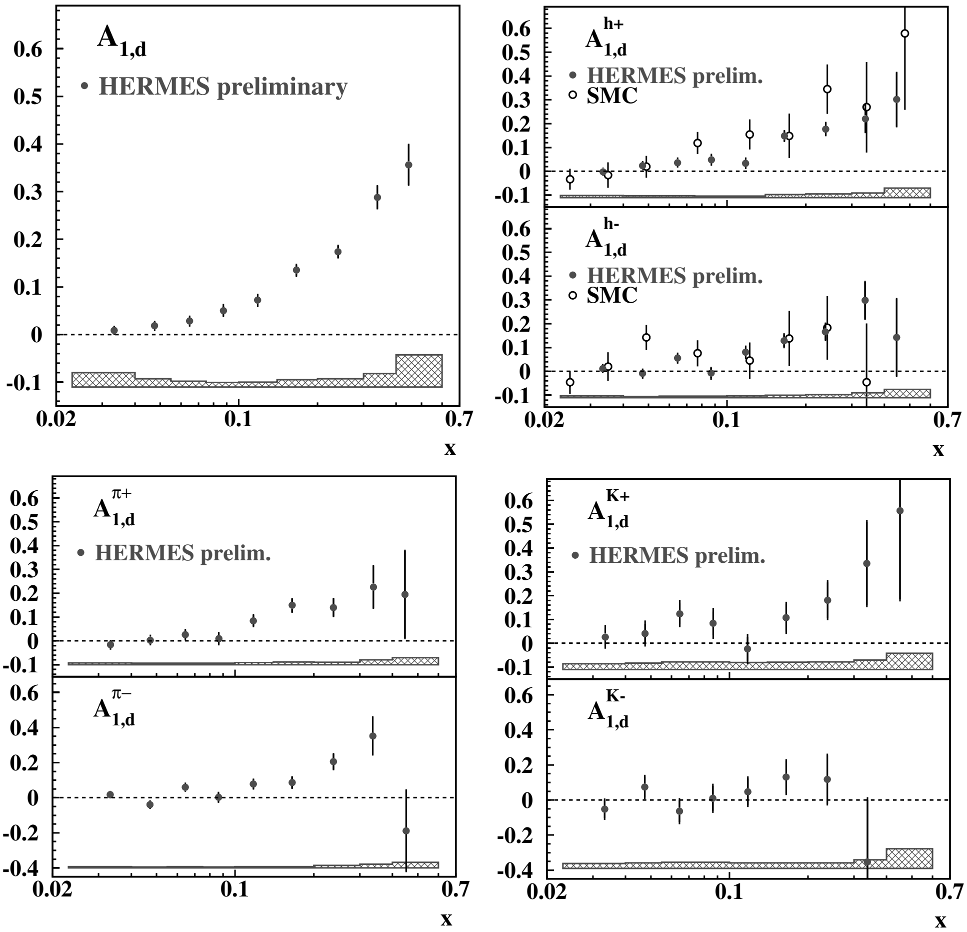

Fig. 1. Preliminary HERMES results on inclusive and semi-inclusive DIS asymmetries $A_{1,d}(x)$ as defined in eq. (1), here d denotes the polarized deuterium target. The shaded bands are the systematic uncertainties for the HERMES data.

be rewritten in matrix form as

$$\boldsymbol{A}(x) = C_R \cdot \boldsymbol{\mathcal{P}Q}(x). \qquad (2)$$

The vectors $\boldsymbol{A}(x)$ and $\boldsymbol{Q}(x)$ contain the measured asymmetries and the polarizations $\Delta q/q$ of the different quark flavors to be extracted.

The elements of the purity matrix $\boldsymbol{\mathcal{P}}$ depend solely on unpolarized quantities and can be written as follows:

$$P_f^h(x) \equiv \frac{e_f^2 q_f(x) \int_{0.2}^{0.8} \mathrm{d}z D_f^h(z)}{\sum_{f'} e_{f'}^2 q_{f'}(x) \int_{0.2}^{0.8} \mathrm{d}z D_f^h(z)}. \qquad (3)$$

The purity $P_f^h(x)$ describes the probability that a hadron h originates from an event where a quark of flavor f was struck. It depends on the fragmentation functions and the unpolarized PDFs. It also contains the influence from the limited acceptance of the spectrometer. The fragmentation was modeled in the LUND string model implemented in the JETSET 7.4 [4] package. In order to obtain a reliable model of the fragmentation at HERMES energies, the string breaking parameters have been tuned to reproduce the measured hadron multiplicities at HERMES. The systematic uncertainties associated with the fragmentation were estimated by repeating the analysis with an alternative fit to the measured multiplicities and with the default LUND parameter setting valid for the PETRA e^+e^- collider. The resulting variations in the quark polarizations were added in quadrature to the other sources of the systematic error. The CTEQ5LO parameterizations from ref. [5] were used for the unpolarized PDFs in this analysis.

3 Experimental results

The preliminary data presented here are based on 6.5 (1.8) million DIS events taken on a deuterium (hydrogen) target in the kinematic range $Q^2 > 1\,\mathrm{GeV}^2$ and $W^2 > 10\,\mathrm{GeV}^2$. The average Q^2 of the data sample was $2.5\,\mathrm{GeV}^2$. The HERMES dual radiator RICH was installed in 1998 at the start of the deuterium data taking period. It made possible the identification of pions, kaons, and protons over the momentum range $2 < p < 15\,\mathrm{GeV}$. A Monte Carlo simulation was used to correct the asymmetries for kinematic smearing in the variable x due to instrumental resolution and QED radiative effects. Figure 1 shows the new HERMES measurements of the inclusive and of the semi-inclusive $\pi^{+/-}$ and $\mathrm{K}^{+/-}$ asymmetries. This first measurement of

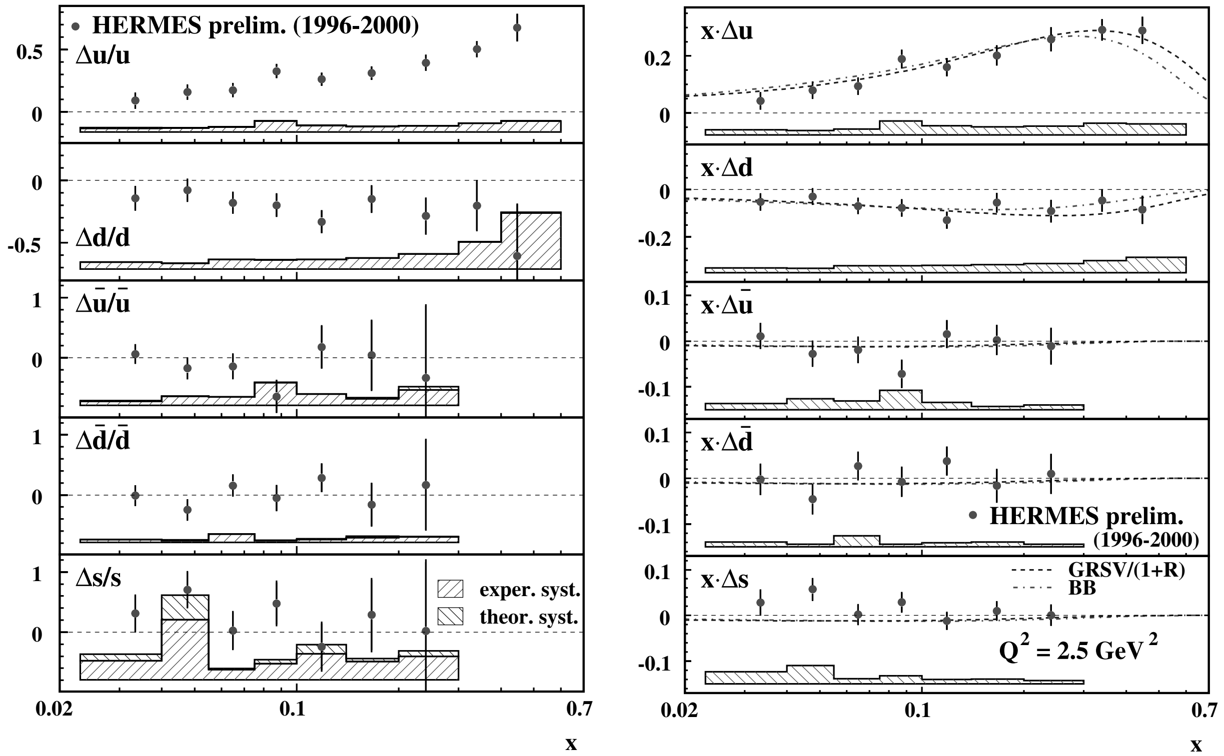

Fig. 2. HERMES preliminary results on the polarizations of the u, $\bar{u}$, d, $\bar{d}$, and $s+\bar{s}$ quark flavors *versus* x (left panel). The right panel shows the results on the corresponding polarized quark distributions at a common scale of $Q^2 = 2.5\,\mathrm{GeV}^2$. The dashed and dot-dashed lines are parameterizations from refs. [6,7]. The errors are statistical, while the shaded bands indicate the systematic uncertainties of the results. The contribution labeled "theor. syst." in the left panel gives the uncertainty due to the use of two different unpolarized parton densities [5,8].

the semi-inclusive kaon asymmetries is based on a sample of 86 (35) thousand identified $\mathrm{K}^{+(-)}$. Also shown in fig. 1 are the semi-inclusive hadron asymmetries for comparison with the previous results from SMC [9].

A new refined analysis is also available for the earlier inclusive and semi-inclusive asymmetries for charged hadrons and pions produced from a hydrogen target (1996-1997 data taking) [10]. Pion identification was accomplished for particles in the momentum range $4.5 < p < 13.5\,\mathrm{GeV}$ using a gas threshold Čerenkov counter. No kaon identification was possible. For this analysis the effects due to smearing, resolution, and QCD effects were treated in the same way as for the deuterium data. Compared to the previous HERMES publication of these results [11], a new analysis of the target data has been performed yielding updated values for the target polarization: $P_z = 0.75 \pm 0.06$ for 1996 and $P_z = 0.85 \pm 0.05$ for 1997.

Using the asymmetries in fig. 1 and the re-analyzed proton asymmetries, eq. (2) has been solved using a least-squares minimization technique for the vector of quark polarizations $\boldsymbol{Q}(x)$. In this analysis the light quark sea is fit independently and the only remaining assumption is that the strange sea is symmetric; therefore $\boldsymbol{Q}(x) = (\frac{\Delta u}{u}, \frac{\Delta d}{d}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta \bar{d}}{\bar{d}}, \frac{\Delta s}{s} = \frac{\Delta \bar{s}}{\bar{s}})$. In the fit procedure the polarization of all sea quark flavors was set to zero for $x > 0.3$ to avoid large uncertainties from correlations between the elements of $\boldsymbol{Q}(x)$. Figure 2 shows the obtained quark polarizations as well as the polarized quark momentum distributions. The polarized quark distributions Δu and Δd are consistent with earlier inclusive analyses [7,8]. Within their total uncertainties, all extracted sea quark polarizations are zero; no asymmetry between the $\Delta\bar{u}$ and $\Delta\bar{d}$ flavors is observed, and the polarized strange quark distributions favor slightly positive values in contrast to fits to inclusive data [7,8].

4 Conclusions

HERMES has measured with high precision a large set of double-spin asymmetries in the inclusive and semi-inclusive cross-sections. For the first time the semi-inclusive charged kaon asymmetries have been measured on a deuterium target. Based on a LO QCD analysis, Δu, $\Delta\bar{u}$, Δd, $\Delta\bar{d}$, and $\Delta s + \Delta\bar{s}$ have been extracted as a function of x in the range $0.023 < x < 0.6$. Within the accuracy of this first measurement, the flavor symmetry of the light quark see is compatible with the $SU(2)_f$ assumption and the strange sea polarization is consistent with zero.

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