MEASUREMENT OF THE STRANGE QUARK HELICITY DISTRIBUTION FROM SEMI-INCLUSIVE DIS ON THE DEUTERON

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An isoscalar extraction of Δs from deep-inelastic scattering of longitudinally polarized positrons on longitudinally polarized deuterons is presented. The isoscalar extraction method allows measurement of the strange fragmentation functions directly from the multiplicities of charged kaons observed in the same data, leading to a significant reduction of the uncertainty on the measurement of the strange sea polarisation. Previously published HERMES results that favour a strange quark polarisation consistent with zero are confirmed with enhanced accuracy.

1. Introduction

The contributions to the nucleon's spin $\langle s_z^N \rangle$ can be written in a formalistic way as $\langle s_z^N \rangle = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_z^q + \Delta G + L_z^G$, where $\Delta\Sigma$ is the helicity contributed by the spins of the quarks, ΔG is the helicity carried by the spins of the gluons while L_z^q and L_z^G are the contributions from orbital angular momenta of quarks and gluons. The total quark helicity $\Delta\Sigma$ is defined as the sum of the helicity distributions of up, down and strange quarks and antiquarks, $\Delta\Sigma \equiv \Delta u + \Delta\overline{u} + \Delta d + \Delta\overline{d} + \Delta s + \Delta\overline{s}$. Especially the helicity of the strange quarks is of interest as it allows to extract information about the sea polarization in the nucleon due to the fact that strange quarks are – contrary to up and down quarks – pure sea objects.

2. Isoscalar measurement of $\Delta s + \Delta\overline{s}$

The analysis presented in this articles is a reanalysis of previously published HERMES data [1]. The original result that the strange sea polarisation is compatible with zero is confirmed with significantly improved accuracy.

The isoscalar extraction method is sensitive to the total strange quark helicity $\Delta S \equiv \Delta s + \Delta \overline{s}$. Due to the fact that strange quarks carry no isospin, the strange sea distributions in proton and neutron are identical. For an isoscalar target like the deuteron the fragmentation process in DIS can be described with isospin symmetric fragmentation. This allows one to obtain the fragmentation functions needed in this analysis directly from the multiplicities of charged kaons in the same data set. The only symmetry assumptions used for the analysis described here are isospin symmetry between proton and neutron and charge-conjugation invariance in the fragmentation process.

Input for this analysis are the inclusive asymmetry $A_{1,d}(x, Q^2)$ and the semi-inclusive asymmetry for the production of charged kaons, irrespective of their sign, $A_{1,d}^{K^\pm}(x, Q^2, z)$. Here, x is the Bjorken scale variable, $-Q^2$ is the squared four-momentum of the exchanged virtual photon and $z \equiv E_h/\nu$, where ν is the energy of the virtual photon and E_h is the energy of the final state hadron in the target rest frame.

The semi-inclusive virtual photo-absorption cross section for kaon production in leading order can be written as

$$\sigma^K(x, z) \propto \sum_q e_q^2\, q(x)\, D_q^K(z), \tag{1}$$

where the sum runs over the quark and anti-quark flavours $q = u + \overline{u} + d + \overline{d} + s + \overline{s}$ and $D_q^K(z)$ is the fragmentation function which gives the number density that a quark of flavour q will fragment into a kaon. Therefore, the double-spin asymmetry is given by:

$$A_1^K(x, z) = \frac{\sigma_{1/2}^K - \sigma_{3/2}^K}{\sigma_{1/2}^K + \sigma_{3/2}^K} = \frac{\sum_q e_q^2\, \Delta q(x)\, D_q^K(z)}{\sum_q e_q^2\, q(x)\, D_q^K(z)}. \tag{2}$$

In this measurement the excellent PID performance due to the HERMES RICH detector allows one to select a clean sample of positively identified kaons. Using purities the asymmetry can be expressed as

$$A_1^{K^\pm}(x, z) = \sum_q \mathcal{P}_q^{K^\pm}(x, z) \frac{\Delta q(x)}{q(x)}, \tag{3}$$

where the purities

$$\mathcal{P}_q^{K^\pm}(x, z) = \frac{e_q^2\, q(x)\, D_q^{K^\pm}(z)}{\sum_{q'} e_{q'}^2\, q'(x)\, D_{q'}^{K^\pm}(z)} \tag{4}$$

give the probability, that the virtual photon struck a quark of flavour q in the nucleon when a $K^\pm$ is detected in the final state. This leads to a simple linear relationship between the two measured asymmetries and the total non-strange quark distribution $Q(x) \equiv u(x) + \overline{u}(x) + d(x) + \overline{d}(x)$ and the total strange quark distribution $S(x) \equiv s(x) + \overline{s}(x)$:

$$\begin{pmatrix} A_{1,d}(x) \\ \\ A_{1,d}^{K^\pm}(x) \end{pmatrix} \propto \begin{pmatrix} \mathcal{P}_Q(x) & \mathcal{P}_S(x) \\ \\ \mathcal{P}_Q^{K^\pm}(x) & \mathcal{P}_S^{K^\pm}(x) \end{pmatrix} \begin{pmatrix} \Delta Q(x)/Q(x) \\ \\ \Delta S(x)/S(x) \end{pmatrix}. \tag{5}$$

The purities in this system of equations can be expressed in terms of PDFs and fragmentation functions:

$$\mathcal{P}_Q(x) = \frac{5\,Q(x)}{5\,Q(x) + 2\,S(x)}, \qquad \mathcal{P}_S(x) = \frac{2\,S(x)}{5\,Q(x) + 2\,S(x)}, \tag{6}$$

$$\mathcal{P}_Q^{K^\pm}(x) = \frac{Q(x)\int \mathcal{D}_{\text{non-strange}}^{K^\pm}(z)\ \mathrm{d}z}{Q(x)\int \mathcal{D}_{\text{non-strange}}^{K^\pm}(z)\ \mathrm{d}z + S(x)\int \mathcal{D}_{\text{strange}}^{K^\pm}(z)\ \mathrm{d}z}, \tag{7}$$

$$\mathcal{P}_S^{K^\pm}(x) = \frac{S(x)\int \mathcal{D}_{\text{strange}}^{K^\pm}(z)\ \mathrm{d}z}{Q(x)\int \mathcal{D}_{\text{non-strange}}^{K^\pm}(z)\ \mathrm{d}z + S(x)\int \mathcal{D}_{\text{strange}}^{K^\pm}(z)\ \mathrm{d}z} \tag{8}$$

with the integrated fragmentation functions

$$\int \mathcal{D}_{\text{non-strange}}^{K^\pm}(z)\ \mathrm{d}z \equiv 4\int D_{\mathrm{u}}^{K^\pm}(z)\ \mathrm{d}z + \int D_{\mathrm{d}}^{K^\pm}(z)\ \mathrm{d}z \tag{9}$$

and

$$\int \mathcal{D}_{\text{strange}}^{K^\pm}(z)\ \mathrm{d}z \equiv 2\int D_{\mathrm{s}}^{K^\pm}(z)\ \mathrm{d}z. \tag{10}$$

In these expressions $D_{\mathrm{u}}^{K^\pm}(z)$, $D_{\mathrm{d}}^{K^\pm}(z)$ and $D_{\mathrm{s}}^{K^\pm}(z)$ are the usual fragmentation functions as e.g. measured in e^+/e^- collider experiments.

The integrals of $\int \mathcal{D}_{\text{non-strange}}^{K^\pm}(z)\ \mathrm{d}z$ and $\int \mathcal{D}_{\text{strange}}^{K^\pm}(z)\ \mathrm{d}z$ can be obtained from unpolarized SIDIS data taken at HERMES kinematics, assuming only charge conjugation invariance in the fragmentation process: $D_u^{K^\pm} = D_{\overline{u}}^{K^\mp}$, $D_d^{K^\pm} = D_{\overline{d}}^{K^\mp}$, $D_s^{K^\pm} = D_{\overline{s}}^{K^\mp}$. The strange and non-strange fragmentation functions are then extracted by fitting the measured x dependence of the ratio of multiplicities for charged kaons,

$$\frac{\mathrm{d}N^{K^\pm}(x)/\mathrm{d}x}{\mathrm{d}N^{\mathrm{DIS}}(x)/\mathrm{d}x} = \frac{Q(x)\int \mathcal{D}_{\text{non-strange}}^{K^\pm}(z)\ \mathrm{d}z + S(x)\int \mathcal{D}_{\text{strange}}^{K^\pm}(z)\ \mathrm{d}z}{5\,Q(x) + 2\,S(x)}. \tag{11}$$

3. Results

The obtained values are $\int \mathcal{D}^{K^\pm}_{\rm non-strange}(z)\ {\rm d}z = 0.38 \pm 0.021 \pm 0.01$ and $\int \mathcal{D}^{K^\pm}_{\rm strange}(z)\ {\rm d}z = 1.84 \pm 0.27 \pm 0.11$. Compared to an analysis based on e^+/e^- collider data the uncertainties are much smaller due to the fact that it is no longer necessary to take an external strangeness suppression factor for $s\bar{s}$ production into account which is poorly known at HERMES kinematics [2],[3]. This significantly improves the accuracy of the extracted value for ΔS compared to the previously published result [1].

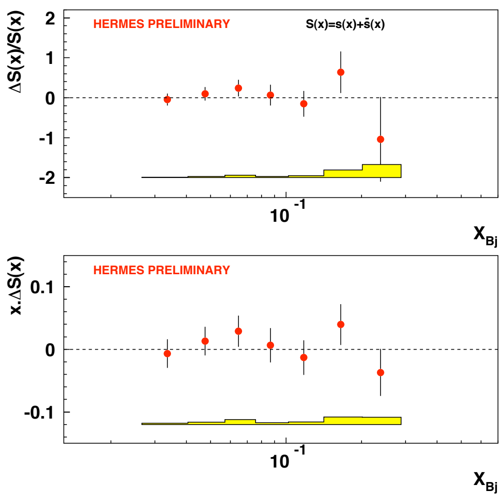

Figure 1. Strange and non-strange quark polarization in the kinematic region $0.02 < x < 1$ extracted from HERMES SIDIS deuteron data with an isoscalar method.

Figure 1 shows the non-strange and strange quark polarizations extracted with the isoscalar approach described in this article. The integrals in the kinematic range $0.02 < x < 1$ are $\int_{0.02}^{1} \Delta Q\ {\rm d}x = 0.286 \pm 0.026 \pm 0.011$ and $\int_{0.02}^{1} \Delta S\ {\rm d}x = 0.006 \pm 0.029 \pm 0.007$ respectively. Both values are in excellent agreement with previous published values. The HERMES measurement clearly favours a strange sea polarization compatible with zero.

References

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