Measurement of Parton Distributions of Strange Quarks in the Nucleon from Charged-Kaon Production in Deep-Inelastic Scattering on the Deuteron

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The momentum and helicity density distributions of the strange quark sea in the nucleon are obtained in leading order from charged-kaon production in deep-inelastic scattering on the deuteron. The distributions are extracted from spin-averaged $K^\pm$ multiplicities, and from $K^0$ and inclusive double-spin asymmetries for scattering of polarized positrons by a polarized deuteron target. The shape of the momentum distribution is softer than that of the average of the $\bar{u}$ and $\bar{d}$ quarks. In the region of measurement $0.02 < x < 0.6$ and $Q^2 > 1.0$ GeV$^2$, the helicity distribution is zero within experimental uncertainties.

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Parton distribution functions (PDFs) form the basis for the description of the flavor structure of the nucleon. The spin-averaged parton distribution functions $q(x)$ of quarks and antiquarks of flavors $q = (u, d, s)$ describe the quark momentum contributions, where $x$ is the dimensionless Bjorken scaling variable representing the momentum fraction of the target carried by the parton in a frame where the target has “infinite” longitudinal momentum. They are sums of the number densities of the quarks $q_\pm(x) [q_\pm(x)]$ with the same [opposite] helicity as that of the nucleon. The differences, or helicity distributions, $\Delta q(x) = q_\pm(x) - q_\mp(x)$ describe the flavor dependent contributions of the quark spins to the spin of the nucleon. The features of the parton distributions reflect the QCD dynamics of the constituents. Because strange quarks are objects which reflect directly proper-

In the absence of significant experimental constraints, current global QCD fits of PDFs \cite{13,14} assume the strange quark and antiquark momentum distributions $s(x)$ and $\bar{s}(x)$ to be given by $s(x) = \bar{s}(x) = r |\vec{p}(x) + \vec{d}(x)|/2$ with $r \approx 1/2$ at some low factorization scale. Measurements of neutrino and antineutrino production of dimuons \cite{9,10,11,12,13,14,15} provide useful but limited information \cite{16} on the normalization and shape of the distribution $s(x) + \bar{s}(x)$. In these experiments, extraction of the strange quark distributions requires knowledge of the charm quark mass, the charm hadron semileptonic branching ratio, and the “Peterson fragmentation parameter” \cite{17} that describes the kinematic dependence of the charm fragmentation function. These quantities together with the strange parton distributions themselves are fitted simultaneously in the extraction procedure. Much of the information on properties of the helicity distribution of strange quarks is based on the analysis of inclusive DIS and hyperon decay under the assumption of SU(3) symmetry among the structures of the octet baryons. In these inclusive experiments \cite{18} the first moment of the helicity distribution for strange quarks is one of the principal results. The most precise recent value is $-0.103 \pm 0.007 (\text{exp.}) \pm 0.013 (\text{theor.}) \pm 0.008 (\text{evol.})$ in LO \cite{19}. A full 5-flavor decomposition using HERMES semi-inclusive DIS data on proton and deuteron targets, although not sensitive to $\Delta s(x)$, yielded $\Delta s = 0.028 \pm 0.033 \pm 0.009$ for the first partial moment of the strange quark helicity density in the measured range $0.23 < x < 0.3$. A separate “isoscalar” extraction of $\Delta s + \Delta \bar{s}$ from DIS data on the deuteron alone gave $\Delta s + \Delta \bar{s} = 0.129 \pm 0.042 \pm 0.129$ in the measured range where the large systematic uncertainty reflected lack of knowledge of kaon fragmentation functions.

This letter reports a new isoscalar extraction of $s(x) + \bar{s}(x)$ and $\Delta(s(x) + \bar{s}(x))$ based on the same HERMES data obtained from polarized DIS on a deuteron target. The measurement reported here is complementary to the neutrino results, and is the first extraction of $s(x) + \bar{s}(x)$ in charged lepton DIS. Because strange quarks carry no isospin, the strange seas in the proton and neutron can be assumed to be identical. In the deuteron, an isoscalar target, the fragmentation process in DIS can be described by fragmentation functions that have no isospin dependence. Aside from isospin symmetry between proton and neutron, the only symmetry assumed is charge-conjugation invariance in fragmentation. For the isoscalar deuteron in Leading Order (LO), the inclusive unpolarized (U) electron scattering cross section in terms of the parton distributions $Q(x) \equiv u(x) + \bar{u}(x) + d(x) + \bar{d}(x)$ and $S(x) \equiv s(x) + \bar{s}(x)$ takes the form

$$\frac{d^2N_{\text{DIS}}(x)}{dx \, dQ^2} = \mathcal{K}_U(x, Q^2) \left[ 5Q(x) + 2S(x) \right] ,$$

(1)

where $\mathcal{K}_U(x, Q^2)$ is a kinematic factor containing the hard scattering cross section. The weak logarithmic dependence of the PDFs on $-Q^2$, the squared four-momentum of the exchanged virtual photon, has been suppressed for simplicity. Applying the same LO formalism to the semi-inclusive cross section for charged kaon production, irrespective of charge, hereafter designated as $K$ gives

$$\frac{d^2N_K(x)}{dx \, dQ^2} = \mathcal{K}_U(x, Q^2) \times \left[ Q(x) \int D_Q^K(z) dz + S(x) \int D_S^K(z) dz \right] ,$$

(2)

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where \( z = E_h/\nu \) with \( \nu \) and \( E_h \) the energies of the virtual photon and of the detected hadron in the target rest frame, \( D_Q^K(z) = 4D^K_{u}(z)+D^K_{d}(z) \) and \( D_Q^S(z) = 2D^K_{s}(z) \).

The fragmentation function \( D^K_q(z) \) describing the number density of charged kaons from a struck quark of flavor \( q \) is integrated over the measured range of \( z \). Combining Eqs. (1,2) and neglecting the term \( 2S(x) \) compared to \( 5Q(x) \), it follows immediately that

\[
S(x) \int D^S_Q(z) dz \approx Q(x) \left[ 5 \frac{d^2N^K(x)}{d^2N^{DIS}(x)} - \int D^K_Q(z) dz \right].
\]

Eq. (3) is the basis for the extraction of the quantity \( S(x) \int D^S_Q(z) dz \).

The data were recorded with a longitudinally nuclear-polarized deuteron gas target internal to the \( E = 27.6 \) GeV HERA positron storage ring at DESY. The self-induced beam polarization was measured continuously with Compton backscattering of circularly polarized laser beams [21, 22]. The open-ended target cell was fed by an atomic-beam source based on Stern-Gerlach separation with hyperfine transitions. The nuclear polarization of the atoms was flipped at 90 s time intervals, while both this polarization and the atomic fraction inside the target cell were continuously measured [23]. The average value of the deuteron polarization was 0.845 with a fractional systematic uncertainty of 3.5%.

Scattered beam leptons and coincident hadrons were detected by the HERMES spectrometer [24]. Leptons were identified with an efficiency exceeding 98% and a hadron contamination of less than 1% using an electromagnetic calorimeter, a transition-radiation detector, a preshower scintillation counter and a ring-imaging Čerenkov (RICH) detector [25]. The dual-radiator RICH was also used to identify charged kaons. Events were selected subject to the kinematic requirements \( Q^2 > 1 \text{GeV}^2, W^2 > 10 \text{GeV}^2 \) and \( y < 0.85 \), where \( W \) is the invariant mass of the photon-nucleon system, and \( y = \nu/E \). Coincident hadrons were accepted if \( 0.2 < z < 0.8 \) and \( x_F \approx 2p_L/W > 0.1 \), where \( p_L \) is the longitudinal momentum of the hadron with respect to the virtual photon direction in the photon-nucleon center of mass frame.

The charged kaon multiplicity was extracted by summing over the kaon yields for the two beam-target polarization states. An event weighting procedure was used to correct for RICH kaon identification inefficiencies. The effects of QED radiation, instrumental resolution, and acceptance were simulated [26, 27, 28], and corrections were applied to the data for each polarization state using a technique that unfolds kinematic migration of events [19]. The results are presented in Fig. 1. The trends in the data were not reproduced (see dotted curve in Fig. 1) by fitting the points using the CTEQ6L [29] strange quark PDFs in Eqs. 11 and 2 with \( \int D^S_Q(z) dz \) and \( \int D^K_Q(z) dz \) as free parameters. In view of the paucity of reliable data on \( S(x) \), it was assumed instead that it is unknown, and the analysis was carried out extracting the product \( S(x) \int D^S_Q(z) dz \) in LO. For \( x > 0.15 \) the multiplicity is constant at a value of about 0.080, implying that \( S(x)/Q(x) \) is constant. For this analysis \( S(x) \) is assumed to be negligible at large \( x \) from which it follows that \( S(x) = 0 \) for \( x > 0.15 \) and that \( S(x) < 0.02 \) and \( 0.010 \), in excellent agreement with the value 0.435 ± 0.044 obtained for \( Q^2 = 2.5 \text{GeV}^2 \) from the most recent global analysis of fragmentation functions [30]. The value 0.398 was then used in Eq. 10 together with values of \( Q(x) \) from CTEQ6L and the measured multiplicities to obtain the product \( S(x) \int D^S_Q(z) dz \) shown in Fig. 2. A small iterative correction was made to account for the neglect of the 2S(x) term in Eq. 1.

![FIG. 1: The multiplicity corrected to 4π of charged kaons in semi-inclusive DIS from a deuterium target, as a function of Bjorken x. The continuous curve is calculated from the curve in Fig. 1 using Eq. 3. The dashed(dash-dotted) curve is the nonstrange(strange) quark contribution to the multiplicity for this fit. The dotted curve is the best fit to \( \int D^S_Q(z) dz \) using CTEQ6L PDFs. The error bars are statistical. The band represents the systematic uncertainties. The values of \( \langle Q^2 \rangle \) for each bin are shown in the lower panel.](image1.png)

![FIG. 2: The strange fragmentation product \( S(x,Q^2) \int D^S_Q(z) dz \) obtained from the measured HERMES multiplicity for charged kaons at the \( Q^2 \) for each bin. The curve is a least squares fit of the form \( x^{-0.863}e^{-x/0.0487}(1-x) \). The band represents systematic uncertainties.](image2.png)
The result for the product together with a fit of the form $x^{-a_1} e^{-x/a_2} (1 - x)$ is shown in Fig. 2 and leads to the continuous curve in Fig. 3.

The improved fit (continuous curve in Fig. 3) to the multiplicity is an indicator that the actual distribution of $S(x)$ is substantially different from the average of those of the nonstrange antiquarks. To explore this point, the HERMES result for $S(x) \int D_S^z(z) dz$ has been evolved to $Q^2 = 2.5$ GeV$^2$. The $Q^2$ evolution factors were taken from CTEQ6L and the fragmentation function compilation given in [30]. Consideration of corrections to the evolution due to higher twist contributions is not necessary, since higher twist effects are expected to be significant [31] only for larger values of $x$ where the extracted distribution of $xS(x)$ vanishes. The distribution of $xS(x)$ was obtained from $S(x) \int D_S^z(z) dz$ by dividing by $\int D_S^z(z) dz = 1.27 \pm 0.13$, the value at $Q^2 = 2.5$ GeV$^2$ given in [30]. The results are presented in Fig. 3. The normalization of the HERMES points is determined by the value of $\int D_S^z(z) dz$ assumed. However, whatever the normalization, the shape of $xS(x)$ implied by the HERMES data is incompatible with $xS(x)$ from CTEQ6L as well as the assumption of an average of an isoscalar nonstrange sea. The absence of strength above $x \approx 0.1$ is clearly discrepant with CTEQ6L, while deviations from the CTEQ6L prediction at low $x$ could be, in part, a manifestation of higher order processes.

In the isoscalar extraction of the helicity distribution $\Delta S(x) = \Delta u(x) + \Delta \bar{u}(x)$, only the double-spin asymmetry $A_{K\parallel}^{\parallel}(x, Q^2)$ for all charged kaons, irrespective of charge, and the inclusive asymmetry $A_{K\parallel}^{\parallel}(x, Q^2)$ are used. In LO, the inclusive and the charged kaon double-spin(LL) asymmetries are determined by the relations

$$A_{K\parallel}^{\parallel}(x, Q^2) \frac{d^2N_{DIS}(x)}{dx dQ^2} = \mathcal{K}_{LL}(x, Q^2) [5\Delta Q(x) + 2\Delta S(x)] ,$$

where $\mathcal{K}_{LL}$ is a kinematic factor, and

$$A_{K\parallel}^{\parallel}(x, Q^2) \frac{d^2N_K(x)}{dx dQ^2} = \mathcal{K}_{LL}(x, Q^2) \left[ \Delta Q(x) \int D_Q^z(z) dz + \Delta S(x) \int D_S^z(z) dz \right] .$$

Eqs. (4) permit the simultaneous extraction of the helicity distribution $\Delta Q(x) = \Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x)$ and the strange helicity distribution $\Delta S(x) = \Delta s(x) + \Delta \bar{s}(x)$. The nonstrange integrated fragmentation function needed for a LO extraction of $\Delta S(x)$ was extracted from the multiplicity analysis of the same data.

The semi-inclusive asymmetries $A_{K\parallel}^{\parallel}$ were derived from the kaon spectra measured for each target polarization. The target polarization was corrected for the D-wave admixture in the deuteron wave function by applying the correction term $(1 - 1.5\omega_D)$ where $\omega = 0.05 \pm 0.01$ [32]. The corrected asymmetries are shown in Fig. 4. The inclusive asymmetries $A_{K\parallel}^{\parallel}$ were corrected for effects of QED radiation and instrumental smearing with the same procedures described above for the spin dependent kaon multiplicities. Contributions to the systematic uncertainties in the asymmetries include those from the beam and target polarizations, and the neglect of the transverse structure function $g_2(x)$ in an analysis based on Eqs. (4,5). The value of $\int D_S^z(z) dz = 1.27 \pm 0.13$ was used to extract $\Delta S(x)$. The results are presented in Fig. 4. The strange helicity distribution also agrees well with the less precise results of [20], and for $A_{K\parallel}^{\parallel}$ from those of RICH kaon identification.

The quark helicity distributions were extracted from the measured spin asymmetries $A_{K\parallel}^{\parallel}(x, Q^2)$ and $A_{K\parallel}^{\parallel}(x, Q^2)$ in an analysis based on Eqs. (4,5). The value of $\int D_S^z(z) dz = 1.27 \pm 0.13$ was used to extract $\Delta S(x)$. The results are presented in Fig. 4. The strange helicity distribution also agrees well with the less precise results of [20], and is consistent with zero over the measured range.

The first moments of the helicity densities in the measured region are presented in Tab. 2. The result for $\Delta Q$ over the measured range is consistent with the value $0.381 \pm 0.010$ (stat.) $\pm 0.027$ (sys.) for the full moment previously extracted from HERMES $g_1,d$ data [19]. The value of $\Delta S$ measured here is not in serious disagreement with $-0.0435 \pm 0.010$ (stat.) $\pm 0.004$ (sys.) ex-
TABLE I: First moments of various helicity distributions in decays under the assumption of SU(3) symmetry. The partial moment of the nonstrange fragmentation function of Leader et al. [51] from their analysis of world data.

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[1] H. L. Lai et al., Eur. Phys. J. C 12, 375 (2000).
[2] A. D. Martin et al., Eur. Phys. J. C 23, 73 (2002).
[3] F. Olness et al., Eur. Phys. J. C 40, 145 (1998).
[4] G. P. Zeller et al. (NuTeV), Phys. Rev. Lett. 88, 091802 (2002).
[5] S. Ketzer et al., Phys. Rev. D 69, 114005 (2004).
[6] R. S. Thorne et al. (2007), hep-ph/0706.0456.
[7] H. Abramowicz et al. (CDHS), Z. Phys. C15, 19 (1982).
[8] S. A. Rabinowitz et al. (CCFR), Phys. Rev. Lett. 70, 134 (1993).
[9] A. O. Bazarko et al. (CCFR), Z. Phys. C65, 189 (1995).
[10] P. Vilain et al. (CHARM), Eur. Phys. J. C11, 19 (1999).
[11] P. Astier et al. (NOMAD), Phys. Lett. B486, 35 (2000).
[12] M. Tzanov et al. (NuTeV), Phys. Rev. D 74, 012008 (2006).
[13] G. Berbier et al. (BEBC), Z. Phys. C29, 15 (1985).
[14] N. Ushida et al. (ES31), Phys. Lett. B121, 292 (1983).
[15] A. Kayis-Topalsu et al. (CHORUS), Phys. Lett. B626, 24 (2005).
[16] H. L. Lai et al., J. High Energy Phys. 4, 89 (2007).
[17] C. Peterson et al., Phys. Rev. D D27, 105 (1983).
[18] J. Ashman et al. (EMC), Phys. Lett. B206, 364 (1988).
[19] A. Airapetian et al. (HERMES), Phys. Rev. D 75, 012007 (2007).
[20] A. Airapetian et al. (HERMES), Phys. Rev. D 71, 012003 (2005).
[21] D. P. Barber et al., Nucl. Inst. & Meth. A 338, 166 (1994).
[22] M. Beckmann et al., Nucl. Inst. & Meth. A 479, 334 (2002).
[23] A. Airapetian et al., Nucl. Inst. & Meth. A 540, 68 (2005).
[24] K. Ackerstaff et al. (HERMES), Nucl. Inst. & Meth. A 417, 230 (1998).
[25] N. Akopov et al., Nucl. Inst. & Meth. A 479, 511 (2002).
[26] L. Mankiewicz et al., Comp. Phys. Comm. 71, 305 (1992).
[27] I. Akushevich et al. (1998), hep-ph/9906408.
[28] T. Sjöstrand et al., Comp. Phys. Comm. 135, 238 (2001).
[29] J. Pumplin et al., J. High Energy Phys. 7, 12 (2002).
[30] D. de Florian et al., Phys. Rev. D 75, 114010 (2007).
[31] A. D. Martin et al., Phys.Lett. B443, 301 (1998).
[32] R. Machleidt et al., Phys. Rep. 149, 1 (1987).
[33] P. L. Anthony et al. (E155), Phys. Lett. B553, 18 (2003).
[34] P. Ratcliffe, Czech J. Phys. 54, B11 (2004).
[35] J. Lichtenstadt and H. J. Lipkin, Phys. Lett. B353, 119 (1995).
[36] E. Leader et al., Phys. Lett. B488, 283 (2000).
[37] O. Schröder et al., Phys. Lett. B439, 398 (1998).
[38] E. Leader et al., Phys. Rev. D 73, 034023 (2006).