FLAVOR DECOMPOSITION OF THE QUARK HELICITY DISTRIBUTIONS IN THE NUCLEON FROM SEMI-INCLUSIVE DEEP-INELASTIC SCATTERING

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Five quark helicity distributions including those for three sea quark flavors were extracted from new SIDIS data on a deuterium target as well as previously published hydrogen target data. These distributions are consistent with zero for all three sea flavors. A recently predicted flavor asymmetry in the polarization of the light quark sea appears to be disfavored by the data.

1. Introduction

Previous next-to-leading order extractions of the quark helicity distributions, made from inclusive deep inelastic scattering (DIS) measurements (SMC, E143, E155, HERMES), suffer from an inability to separate contributions of individual quark flavors without assuming SU(3) flavor symmetry and using data from hyperon \( \beta \) decay. An alternative leading order approach has been conducted at HERMES\(^1\)\(^2\). By utilizing semi-inclusive DIS to measure \( A_1^q \), where final state hadrons are measured in conjunction with the scattered lepton, the struck quark can be flavor-tagged and the individual quark contributions to \( A_1 \) can be unraveled.

2. Method

In leading order QCD, the longitudinal double-spin asymmetry can be written as follows:

\[
A_1(x, Q^2) = \frac{\sum_q e_q^2 \Delta q(x, Q^2)}{\sum_q e_q^2 q(x, Q^2)}. \tag{1}
\]
By measuring a hadron $h$ in conjunction with the scattered lepton, one can rewrite the preceding formula,

$$A_h^1(x, Q^2, z) = \sum_q e_q^2 \Delta g(x, Q^2) D_h^q(z, Q^2) \sum_q e_q^2 q(x, Q^2) D_h^q(z, Q^2) = \sum_q \rho_h^q(x, Q^2, z) \Delta g(x, Q^2) q(x, Q^2),$$

(2)

where $D_h^q$ are fragmentation functions, and $\rho_h^q(x, Q^2, z)$ is the purity matrix which describes the likelihood that a hadron $h$ is produced from a struck quark of flavor $q$. This unpolarized purity matrix was generated through a LEPTO-based Monte Carlo simulation using CTEQ5L for unpolarized parton distribution functions and JETSET for fragmentation. The input parameters of the JETSET, Lund-string fragmentation model were tuned to unpolarized DIS data from HERMES. The systematic uncertainty contribution from the tune was estimated by computing a purity matrix at a tune that poorly describes the semi-inclusive yields observed at HERMES kinematics.

In terms of measured asymmetries and computed purities, one can express (2) as the matrix equation, $\vec{A}_1(x) = N(x) \vec{P}(x) \vec{Q}(x)$, where the nuclear mixing matrix $N$ takes into account the probabilities of interacting with different nucleons in the deuteron. The vector $\vec{A}(x)$ includes the inclusive and semi-inclusive asymmetries for each hadron species measured. The numbers of inclusive and semi-inclusive events included in this analysis are presented in Table 1. Finally, $\vec{Q}(x) = \left( \Delta u(x), \Delta d(x), \Delta \bar{u}(x), \Delta \bar{d}(x) \right)$ is the vector of unknown quark helicity distributions. The expression, $\chi^2 = \left( \vec{A}_1 - N \vec{P} \vec{Q} \right)^T \nu^{-1}_A \left( \vec{A}_1 - N \vec{P} \vec{Q} \right)$,

<table>
<thead>
<tr>
<th>Target</th>
<th>DIS Events</th>
<th>$\pi^+$</th>
<th>$\pi^+$</th>
<th>$K^+$</th>
<th>$K^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>$1.7 \times 10^6$</td>
<td>$1.17 \times 10^4$</td>
<td>$8.2 \times 10^3$</td>
<td>$3.85 \times 10^3$</td>
<td>$7.6 \times 10^3$</td>
</tr>
<tr>
<td>D</td>
<td>$6.7 \times 10^6$</td>
<td>$4.91 \times 10^3$</td>
<td>$3.85 \times 10^3$</td>
<td>$7.6 \times 10^3$</td>
<td>$3.3 \times 10^3$</td>
</tr>
</tbody>
</table>

is numerically minimized to solve for $\Delta q(x)$. The matrix $\nu_A$ is a statistical covariance matrix describing the correlations between bins. It is produced with a rigorous model-independent unfolding procedure in which Monte Carlo is used to compute the migration of events between kinematic bins resulting from acceptance and QED radiative smearing. Because this method assumes no functional form for the underlying physics, there is an apparent inflation of error bars which reflects the uncertainty contributions from all.
possible kinematic correlations. When incorporated into models and world fits (i.e. when a functional form is assumed) and the correlation matrix is taken into account, the uncertainties will become significantly smaller.

The configuration of the HERA beam and HERMES target were changed from year to year. Beam and target species and average polarizations are given in Table 2.

Table 2. Beam and target configuration by year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Beam and % Polarization</th>
<th>Target and % Polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>$e^+$ 52.8 H 78.8</td>
<td>H 85.0</td>
</tr>
<tr>
<td>1997</td>
<td>$e^+$ 53.1 H 85.0</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>$e^−$ 52.1 D 81.7</td>
<td>D 81.7</td>
</tr>
<tr>
<td>1999</td>
<td>$e^+$ 53.3 D 81.0</td>
<td>D 84.5</td>
</tr>
<tr>
<td>2000</td>
<td>$e^+$ 53.3 D 90.5</td>
<td></td>
</tr>
</tbody>
</table>

3. Results

The results of the 5-flavor $\Delta q(x)$ extraction are presented in Fig.1a. The sea quark distributions are all set to zero for $x > 0.3$ as they are poorly constrained by limited statistics in this range. $\Delta \bar{s}(x) \equiv 0$ for similar reasons. As expected, the results show that $\Delta \bar{u}(x)$ is positive and $\Delta \bar{d}(x)$ is negative, and that both reach their greatest magnitude in the valence quark range. The sea quark distributions are all consistent with zero. With respect to the zero polarization hypothesis, $\chi^2/NDF = 7.4/7$, 11.2/7, and 4.3/7 for the extracted $\bar{u}(x)$, $\bar{d}(x)$, and $s(x)$ respectively. The statistical precision is insufficient to distinguish the symmetric sea hypothesis from the GRVS 2000 LO or BB01 LO parameterizations. Unlike the large asymmetry that has been observed for the unpolarized distributions $\bar{u}(x)$ and $\bar{d}(x)$, no evidence for a light sea polarization was found (Fig.1b). Chiral quark soliton calculations predict a large positive $\Delta \bar{u}(x) - \Delta \bar{d}(x)$. Meson cloud models predict a small negative $\Delta \bar{u}(x) - \Delta \bar{d}(x)$. The symmetric sea hypothesis produced $\chi^2/NDF = 7.7/7$, the meson cloud model, $\chi^2/NDF = 8.1/7$, and the Chiral Quark Soliton Model, $\chi^2/NDF = 17.6/7$, when compared to the extracted distributions.

An alternative analysis was also performed to extract $\Delta s(x) + \Delta \bar{s}(x)$. Because the strange quark helicity density $\Delta s(x) + \Delta \bar{s}(x)$ has no isospin, it can be extracted from the isoscalar deuteron alone. A simple purity matrix can be computed using kaon fragmentation functions from $e^+e^-$collider data describing specifically the likelihood of strange quark fragmentation
The HERMES collaboration has performed the first ever independent 5-flavor $\Delta q(x)$ extraction. This semi-inclusive leading order approach takes advantage of the open geometry and excellent particle identification of HERMES to flavor-tag events and make possible such an extraction using a purity method. This measurement provides a first glimpse of antiquark polarization, which show no evidence of the pronounced flavor asymmetry between $\bar{u}$ and $\bar{d}$ observed in the unpolarized sector.

References
2. A. Airapetian et al. (HERMES), Phys. Rev. D (in press)