Frascati Physics Series Vol. XXXVI (2004), pp. 433–438
DAΦNE 2004: Physics at meson factories – Frascati, June 7-11, 2004
Selected Contribution in Plenary Session

FLAVOR DECOMPOSITION OF THE NUCLEON'S SPIN AT HERMES

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Abstract

Since 1995, the HERMES collaboration has measured inclusive and semi-inclusive double-spin asymmetries on polarized ^{3}He, hydrogen and deuterium targets in the kinematic range $0.023 < x < 0.6$ and 1 GeV$^2 < Q^2 <$ 10 GeV^2. With the installation of a ring imaging Čerenkov detector in 1998, the asymmetries of charged pions and kaons could be determined for the first time. Using the measured asymmetries, the polarized quark densities are extracted for all flavors separately in a leading order QCD analysis. This includes a determination of the difference of the *u-sea* and *d-sea* quark distributions as well as the first measurement of the strange *sea* polarization.

*On behalf of the HERMES collaboration

1 Introduction

Since the discovery of deep inelastic scattering (DIS) in the late 1960s at SLAC [1], the technique has proven to be one of the most fruitful methods for studying the partonic structure of the nucleon. DIS interactions occur when a highly virtual photon interacts electro-magnetically with a nucleon so violently that it breaks up the nucleon. When this occurs the interaction can be approximated as the photon interacting with an individual constituent quark. Polarized DIS, in particular, allows one to study the partonic spin structure of the target. The first polarized DIS measurements, made by the EMC collaboration [2], showed that only a small fraction of the total spin of the proton comes from the quarks. Experiments that followed at SMC, E143, E142, etc. [3] found the contribution to be $20\% - 30\%$ rather than the $\simeq 60\%$ that is expected from relativistic quark model calculations [4]. This interesting puzzle was dubbed the "spin crisis" and has launched many experimental and theoretical efforts to understand how the spin and orbital momentum of the partons (quarks and gluons) sum to yield the spin of the proton.

In DIS the measured kinematic quantities are the momenta of the beam lepton $k = (k^0, \vec{k})$, the scattered lepton $k' = (k'^0, \vec{k'})$, and, in the case of semi-inclusive (SI) DIS, the measured hadron $p' = (p'^0, \vec{p'})$ (see fig. 1). In the lab frame, the four momentum of the target nucleon collapses to $p = (M, \vec{0})$ for a fixed target. The common kinematic quantities used to characterize SIDIS interactions are: $Q^2 = -(k - k')^2$, the negative four momentum transfer of the virtual photon; $W^2 = M^2 + M\nu - Q^2$, the invariant mass of the final state; $x = Q^2/(2M\nu)$, the Bjorken scaling variable, where $\nu = (k^0 - k'^0)$; and $z = p'^0/\nu$, the fraction of the photon energy carried by the measured hadron.

In the SIDIS case, the measured hadron provides a *flavor tag*, thereby conveying some information about the flavor of the struck quark to the experimenter. The HERMES experiment uses the polarized 27.5 GeV positron (or electron) beam of the HERA accelerator and pure polarized gaseous targets of hydrogen and deuterium to measure inclusive and SI lepton-nucleon double spin asymmetries ($A_{\|}$, $A_{\|}^h$). The lepton-nucleon asymmetry is defined as the relative difference, in scattering cross section, for the beam and target helicity being aligned and anti-aligned. This can be related to the photon-quark

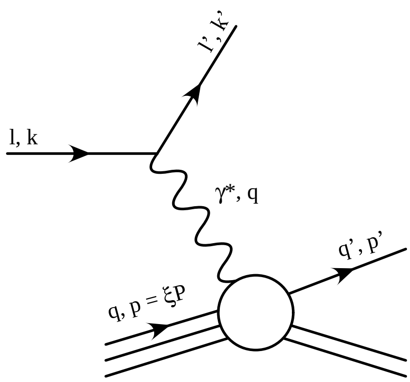

Figure 1: *Schematic depiction of DIS. In this process the virtual photon ($\gamma*$) breaks apart the nucleon and probes the interior quark structure.*

asymmetry and the structure function g_1 as follows:

$$A_1(x, Q^2) \simeq \frac{A_{\parallel}}{D(1+\eta\gamma)} \overset{g_2=0}{\simeq} \frac{g_1}{F_1} \tag{1}$$

where D represents the depolarization at the photon lepton vertex and η, γ are (small) kinematic factors. In the parton model of DIS the structure functions of the polarized (unpolarized) cross sections can, in LO QCD, be represented by a charge-weighted sum of the polarized (unpolarized) parton distribution functions (PDFs):

$$g_1 = \frac{1}{2}\Sigma_q e_q^2 \Delta q(x, Q^2) \quad (\ F_1 = \frac{1}{2}\Sigma_q e_q^2 q(x, Q^2) \ ) \tag{2}$$

where the sum runs over all quark and anti-quark flavors and the polarized (unpolarized) PDFs are given by the difference (sum) $\Delta q = q^+ - q^-$ ($q = q^+ + q^-$) between the density of quarks with spin along the direction of the nucleon spin and those with opposite helicity. In the SIDIS case the asymmetry can be written as:

$$A_1^h \sim \frac{\Sigma_q e_q^2 \Delta q(x, Q^2) \int_{z_{min}}^{z_{max}} D_q^h(z, Q^2)}{\Sigma_{q'} e_{q'}^2 \Delta q'(x, Q^2) \int_{z_{min}}^{z_{max}} D_{q'}^h(z, Q^2)} = \Sigma_q P_q^h(x) \frac{\Delta q(x)}{q(x)} \tag{3}$$

where $D_q^h(z)$ is the fragmentation function which parameterizes our ignorance of the dynamics involved in re-hadronization of the struck quark. It gives us the probability that when a quark q, is struck it will end up in a hadron of type h with fractional energy z. Additionally, the last equality sign has introduced the notion of a purity $P_q^h(x)$, which represents the probability that a measured hadron h came from a struck quark of flavor q. The suppression of the Q^2

dependence in this expression is the result of integrating each quantity over the available range of Q^2 in any x bin. In the HERMES analysis, these purities are calculated using a JETSET [5] based monte-carlo simulation, which is tuned to reproduce unpolarized data [6]. The only inputs to the simulation are unpolarized parton distribution functions from inclusive fits and the Lund string model of fragmentation. For the hydrogen data set, only pions could be identified with a threshold Čerenkov detector, but with the addition of a ring imaging Čerenkov detector in 1998, both pions and kaons could be identified for the deuterium target.

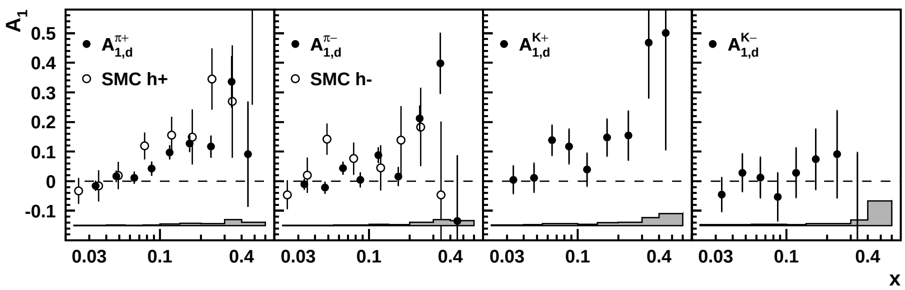

Figure 2: *HERMES results for SI pion and kaon double-spin asymmetries (A_1^h) on the deuteron. The positive and negative hadron asymmetries from the SMC measurement are also shown. The error band (bar) represents the systematic (statistical) uncertainty.*

2 Inclusive and Semi-Inclusive Asymmetries

The published HERMES data [7] on semi-inclusive asymmetries for the proton (not shown here) and the deuteron (fig. 2) targets is based on 1.8 and 6.5 million DIS respectively. In order to increase the probability that a measured final state hadron originated from a DIS event, the kinematic cuts $Q^2 > 1.0$ GeV^2 and $W^2 > 10$ GeV^2 are made. Semi-inclusive hadrons were selected by requiring $0.2 < z < 0.8$ and $x_F \simeq 2p'_L/W > 0.1$, where p'_L is the fraction of the hadron's momentum that lies along the virtual photon direction in the photon-nucleon center-of-mass frame. Setting a lower bound on z and x_F suppresses hadrons from the target region, while the upper limit on z eliminates exclusive events.

The quark polarizations are extracted by combining the inclusive and semi-inclusive asymmetries from both targets to over-constrain a multidimensional χ^2 calculation (eq. 4) which arises from eq. 1.

$$\chi^2 = (\vec{A} - \mathbf{P}\vec{Q})^T \nu_A^{-1} (\vec{A} - \mathbf{P}\vec{Q}) \tag{4}$$

where the vector of PDFs is given by:

$$\vec{Q} = (\vec{q}_1, \vec{q}_2, ...\vec{q}_9) \quad \vec{q}_i = (\frac{\Delta u(x_i)}{u(x_i)}, \frac{\Delta d(x_i)}{d(x_i)}, \frac{\Delta \bar{u}(x_i)}{\bar{u}(x_i)}, \frac{\Delta \bar{d}(x_i)}{\bar{d}(x_i)}, \frac{\Delta s(x_i)}{s(x_i)}) \tag{5}$$

In eq. 4 the χ^2 is calculated for nine x bins and every asymmetry simultaneously, which leads to 45 free parameters for the minimization. Six out of 45 free parameters are lost by fixing the sea distributions to zero for $x > 0.3$. In contrast to LO QCD fits to inclusive data, this technique does not assume a symmetric sea, except for $\Delta s = \Delta \bar{s}$.

The x-weighted polarized parton distributions are shown in fig. 3. For this figure, the ratios $\Delta q/q$ were multiplied by the CTEQ5L unpolarized PDFs at a common $Q^2 = 2.5$ GeV^2 in order to isolate the polarized PDFs. The u distribution is positive and large above $x = 0.1$, while the d polarization is smaller and negative over the entire x range. All of the sea distributions are compatible with zero, which is particularly interesting in the strange sector where a small negative polarization is found from inclusive LO QCD fits.

In addition to the standard extraction, an attempt was made to extract the polarized light sea asymmetry which is predicted by the chiral quark soliton model and may be expected in light of its unpolarized counterpart. The result is shown in fig. 3 as compared to the theoretical prediction. Unfortunately, the uncertainty in the result does not prove the existence or lack of a polarized light sea asymmetry.

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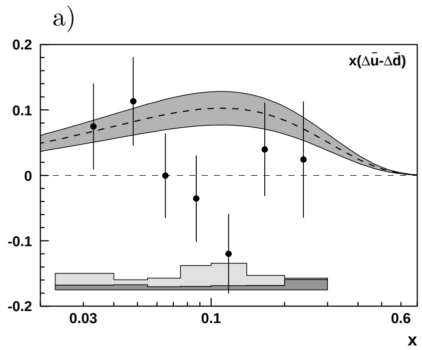

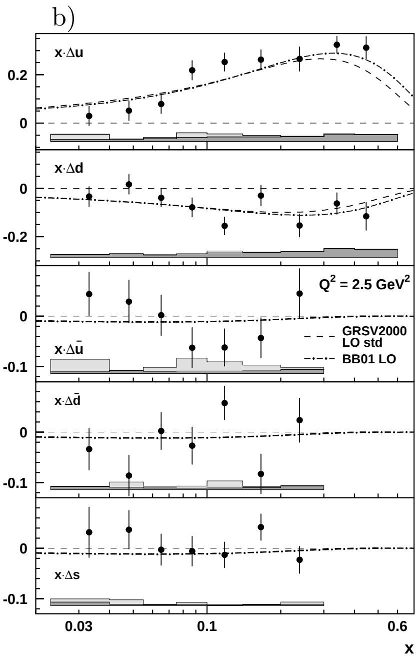

Figure 3: *a) Light sea asymmetry result from a second extraction where the $\Delta u(x)/u(x)$ parameter is replaced with $(\Delta u(x) - \Delta u(x))/(u(x) - d(x))$. The result is compared to a prediction from the chiral quark soliton model [8] (dashed curve with theoretical error bands). b) The x-weighted polarized PDFs $x\Delta q(x)$ extracted from the HERMES inclusive and semi-inclusive asymmetries on polarized hydrogen and deuterium targets at a common $Q^2 = 2.5\ GeV^2$. The curves represent LO QCD fits to inclusive data from [9] (dashed) and [10] (dot-dashed).The light error bands represent the systematic error arising from uncertainties in the fragmentation model and the dark band represents experimental uncertainties.*