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Measurement of the polarized structure functions g_1, b_1 and the polarized quark distributions Δq at HERMES

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Final HERMES results on the proton, deuteron and neutron structure function g_1 are presented in the kinematic range $0.002 < x < 0.9$ and $0.1 < Q^2 < 20$ GeV^2. In the same kinematic range, the first measurements of the tensor asymmetry A_{zz} and the tensor structure function b_1 of the deuteron are shown.

Double-spin asymmetries of semi-inclusive cross sections for the production of identified pions and kaons have been measured in deep-inelastic scattering of polarized positrons on a polarized deuterium target at HERMES. Five helicity distributions including those for three sea quark flavors were extracted from these data together with re-analyzed previous data for identified pions from a hydrogen target.

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1. Introduction

Inclusive deep-inelastic scattering (DIS) of charged leptons from the deuteron, a spin-1 object, is described by eight structure functions, twice as many as required to describe DIS from a spin-$1/2$ nucleon [1]. The three leading-twist structure functions relevant to this discussion can be written within the Quark-Parton Model as [1]:

Nucleon:	$F_1 = \frac{1}{2}\sum_q e_q^2\,[q_\uparrow^{\frac{1}{2}} + q_\uparrow^{-\frac{1}{2}}]$ $g_1 = \frac{1}{2}\sum_q e_q^2\,[q_\uparrow^{\frac{1}{2}} - q_\downarrow^{\frac{1}{2}}]$ $b_1 = --$	Deuteron:	$F_1 = \frac{1}{3}\sum_q e_q^2\,[q_\uparrow^1 + q_\uparrow^{-1} + q_\uparrow^0]$ $g_1 = \frac{1}{2}\sum_q e_q^2\,[q_\uparrow^1 - q_\downarrow^1]$ $b_1 = \frac{1}{2}\sum_q e_q^2\left[2q_\uparrow^0 - (q_\uparrow^1 + q_\uparrow^{-1})\right]$

where $q_\uparrow^m$ ($q_\downarrow^m$) is the number density of quarks with spin up (down) along the z axis in a hadron or nucleus with helicity m moving with infinite momentum along the z axis. Reflection symmetry implies that $q_\uparrow^m = q_\downarrow^{-m}$. The sums run over quark flavors q with a charge e_q. Both structure functions and quark number densities depend on the Bjørken variable x which is the fraction of the nucleon momentum carried by the struck quark in the infinite-momentum frame, and $-Q^2$, the square of the four-momentum transfer by the virtual photon. F_1 describes the quark distributions averaged over the target spin states. g_1 describes the imbalance in the distribution of quarks with the same ($q_\uparrow^m$) or opposite ($q_\downarrow^m$) helicity with respect to that of the parent hadron. The tensor structure function b_1 does not exist for spin-$1/2$ targets. It describes the difference in the quark distributions between the helicity-0 $q^0 = (q_\uparrow^0 + q_\downarrow^0) = 2q_\uparrow^0$ and the averaged non-zero helicity $q^1 = (q_\uparrow^1 + q_\downarrow^1) = (q_\uparrow^1 + q_\uparrow^{-1})$

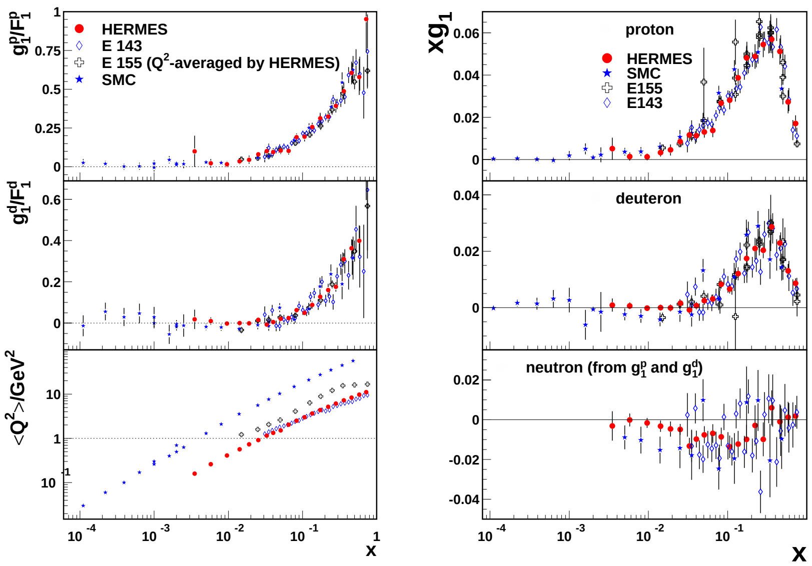

Figure 1: HERMES g_1/F_1 and xg_1 data in comparison to SLAC and CERN data for the proton (top panels) and the deuteron (middle panels) and xg_1 for the neutron from p and d data (right bottom panel) at the measured Q^2 (left bottom). Error bars show the quadratic sum of statistical and systematic uncertainties.

states of the deuteron. The tensor structure function b_1^{d} vanishes in the absence of nuclear effects, i.e. if the deuteron simply consists of a proton and neutron in a relative *S*-state [1].

Until recently, all of the information on the flavor decomposition of quark helicity distributions in the nucleon ($\Delta q = q_{\uparrow}^{\frac{1}{2}} - q_{\downarrow}^{\frac{1}{2}}$) resulted from analyses of inclusive data under the assumption of SU(3) symmetry. In order to improve the sensitivity to flavor dependencies, the HERMES experiment uses semi-inclusive deep-inelastic scattering to determine the separate contributions $\Delta q = q_{\uparrow}^{\frac{1}{2}} - q_{\downarrow}^{\frac{1}{2}}$ of the quarks and antiquarks of flavor q to the total spin of the nucleon.

The HERMES experiment [2] makes use of the 27.5 GeV positron beam of the HERA storage ring at DESY. A gaseous target containing longitudinally polarized hydrogen or deuterium was used to measure $g_1(x)$ and $\Delta q(x)$, while a tensor-polarized deuterium target was used for the measurement of b_1.

2. Measurement of g_1 and b_1

The spin structure function $g_1(x, Q^2)$ for the proton and the deuteron is determined from the ratio g_1/F_1 which is approximately equal to the virtual photon asymmetry A_1 measured via the longitudinal cross section asymmetry $A_{\|}$. For analysis details, see e.g. [3]. For the neutron, g_1^{n} is extracted as a linear combination of g_1^{p} and g_1^{d}.

The measured asymmetries have been corrected for detector smearing and QED radiative effects to obtain the Born asymmetries [4, 5]. These corrections have been applied using an unfolding algorithm that keeps track of the kinematic migration of events and does not require an analytic fit on the data. The final Born asymmetries depend only on the measured data, on the detector model, on the known unpolarized cross sections and on the model for background processes. Figure 1 shows the unfolded g_1/F_1 and xg_1 HERMES results and a compilation of world data on g_1/F_1 and xg_1 [6, 7, 8].

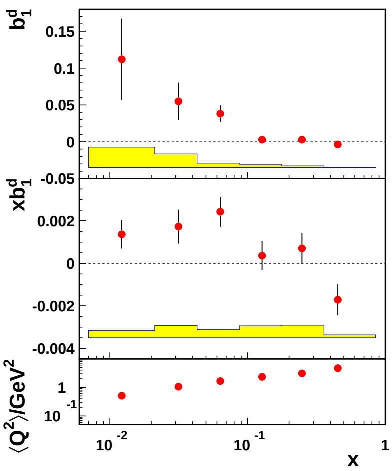

Figure 2: The HERMES tensor structure function b_1^{d}, $x \cdot b_1^{\mathrm{d}}$ and the average Q^2 of the measurements. The error bars are statistical only, the shaded bands show the estimated systematic uncertainties.

The HERMES proton data have a statistical precision comparable to the hitherto most precise data from SLAC in the same kinematic range. Very good agreement is seen between all experiments and no significant Q^2 dependence can be observed. The HERMES deuteron measurement is the presently most precise determination of the spin-dependent structure function $g_1^d(x, Q^2)$ of the deuteron. The HERMES and COMPASS results for $x < 0.03$ are both consistent with zero. The presently most precise determination of the spin-dependent structure function g_1^n of the neutron is obtained by combining the HERMES high precision deuteron and proton data.

The tensor structure function $b_1(x, Q^2)$ is obtained from the ratio b_1/F_1, measured via A_{zz} [9] which compares the helicity-0 state of the deuteron with its averaged non-zero states. In Fig. 2, b_1 is displayed as measured for the first time by HERMES; A_{zz} is only of the order of 1%, implying that the quadrupole contribution to the measurement of g_1 is negligible.

3. Measurement of the quark helicity distributions

By means of the technique of flavor tagging, individual spin contributions Δq for a flavor of type q can be determined from spin asymmetries of hadrons with the appropriate flavor content. HERMES has measured semi-inclusive pion and kaon asymmetries, of both proton and deuteron targets as well as the inclusive asymmetries. These measured asymmetries have been corrected for detector smearing and QED radiative effects to obtain the Born asymmetries which give then access to the polarized quark distributions [4, 5]. Fig. 3 shows the results of this procedure for the x-weighted distributions $x\Delta q(x)$. Note that in contrast to earlier experimental analyses [10] and the LO QCD fi ts to inclusive data [11, 12] overlaid in Fig. 3, the HERMES semi-inclusive analysis needs no assumptions on the symmetry properties of the sea flavors. The helicity density of the u quark is found to be positive and large at $x > 0.1$, while that of the d quark is negative and smaller. The helicity densities of the light sea quarks are compatible with zero. Contrary to the small negative strange sea polarization resulting from QCD fi ts to inclusive data, the strange quark helicity appears slightly positive. However, within the uncertainties there is no disagreement with the QCD fi ts.

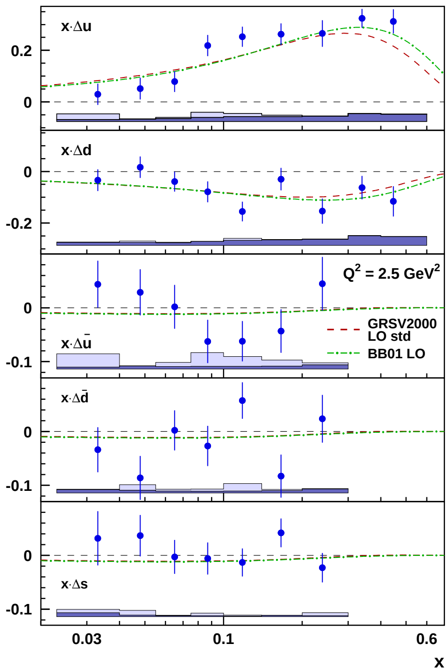

Figure 3: The x-weighted polarized parton distributions. The data are shown at fixed $Q^2 = 2.5$ GeV^2. The curves show results from LO QCD fits to previously published inclusive data from [11] (GRSV 2000, dashed) and [12] (Blümlein-Böttcher, dot-dashed). The light (dark) shaded error bands show the systematic uncertainties from model dependencies (apparative effects).

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