Spin Physics at HERMES

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Abstract. The HERMES experiment at DESY is a second generation experiment to study the spin structure of the nucleon by measuring not only inclusive but also semi-inclusive and exclusive processes in deep-inelastic lepton scattering. An overview of most recent results is given.

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INTRODUCTION

A major goal in the study of QCD in recent years has been the detailed investigation of the spin structure of the nucleon. The nucleon spin can be decomposed conceptually, into the spin of its constituents according to

$$\langle s_z^N \rangle = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \Delta L_z, \tag{1}$$

where the three terms are the contributions from quark and gluon spins and the total orbital angular momenta of the quarks and gluons, respectively. HERMES aims to obtain information on all these contributions by measuring inclusive and semi-inclusive deep-inelastic scattering processes as well as hard exclusive processes.
In the following sections, after a brief description of the experiment, are presented the final results for the polarised structure function g_1 of the proton and the deuteron from measurements with longitudinally polarised beams and targets and a precise determination of the flavour-singlet axial charge a_0. By also observing a produced hadron it has been possible to extract the helicity distributions of individual quark flavours in the nucleon. From the double spin asymmetries measured at high p_T for inclusively produced charged hadrons a new, precise value of $\Delta g/g$ has been extracted. New preliminary results from measurements of single-spin asymmetries for charged pions and kaons from deep-inelastic scattering off a transversely polarised target clearly show that the transversity distribution and the Sivers function are non-zero. The role of the quark orbital angular momentum is adressed by studying hard exclusive processes like Deeply-Virtual Compton Scattering (DVCS) which are interpreted in term of Generalised Parton Distributions (GPDs).
The results presented in this contribution are discussed in more detail elsewhere at this conference [1]. Further HERMES results have been discussed during this conference [2] too.

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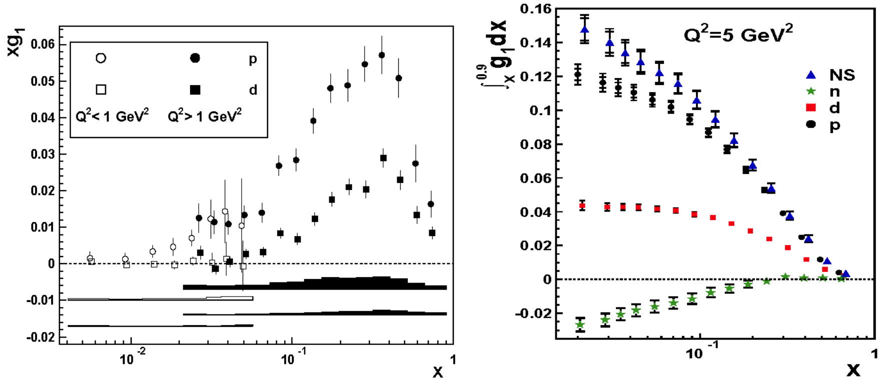

FIGURE 1. HERMES results for xg_1 vs x for the proton and the deuteron (left) and the integrals of $g_1^{p,d,n,NS}$ over the range $0.021 < x < 0.9$ as function of the low-x limit of integration.

The HERMES experiment has been taking data at the HERA accelerator in Hamburg, Germany since 1995. HERMES scatters longitudinally polarised electron and positron beams of 27.5 GeV from longitudinally or transversely polarised targets internal to the beam pipe. Featuring polarised beams and targets, and an open-geometry spectrometer with excellent particle identification, HERMES is well suited to study the spin-dependent inclusive and semi-inclusive DIS reactions. The PID capabilities of the experiment were significantly enhanced in 1998 when the threshold Cerenkov detector (used to identify pions above momenta of 4 GeV) was upgraded to a dual Ring Imaging system (RICH), which provides full separation between charged pions, kaons and protons over essentially the entire momentum range of the experiment.

INCLUSIVE SPIN ASYMMETRIES

The final HERMES result for the polarised structure function g_1 from all data taken with longitudinally polarised hydrogen and deuterium targets [3] is presented in Fig. 1, left panel. The statistical precision of the proton data is comparable to that of the hitherto most precise data from SLAC and CERN in the same x range, while the deuteron data provide the most precise determination of $g_1^d(x,Q^2)$, compared to previous measurements. The right panel of Fig. 1 shows the integrals of $g_1^{p,d,n,NS}$ over the range $0.021 < x < 0.9$, corresponding to the event selection $Q^2 > 1$ GeV^2, as function of the low-x limit of integration evaluated at $Q_0^2 = 5$ GeV^2. For $x < 0.04$, g_1^d becomes compatible with zero and its measured integral shows saturation. Based on the *assumed* saturation of the integral of g_1^d, the flavour-singlet axial charge has been determined in the $\overline{MS}$ scheme at $Q_0^2 = 5$ GeV^2 using only the g_1^d integral and the axial charge a_8 as inputs: $a_0 = 0.330 \pm 0.011(\text{theo.}) \pm 0.025(\text{exp.}) \pm 0.028(\text{evol.})$. In this factorisation scheme, the result can be interpreted as the contribution $\Delta\Sigma$ of quark spins to the spin of the nucleon. The data therefore suggest that the quark helicities contribute a substantial fraction to the nucleon helicity, but there is still need for a major contribution from gluons and/or

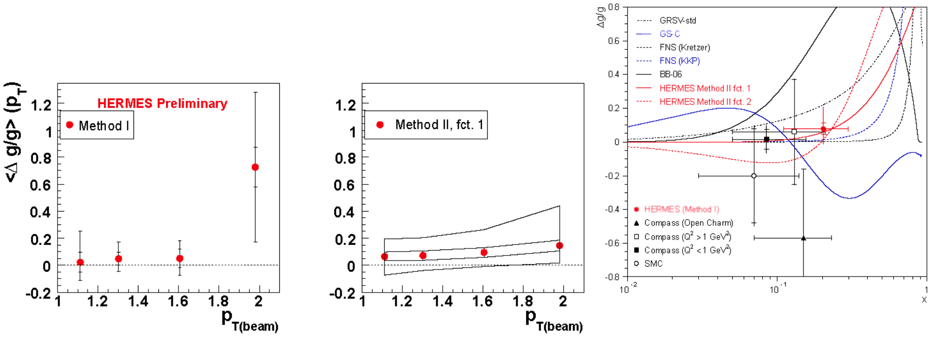

FIGURE 2. HERMES results for $\Delta g/g$ vs p_t (left) and compilation of world data on $\Delta g/g(x)$ (right). The curves represent two fit functions from Method II (see text) and results from several NLO-QCD fits.

orbital angular momenta of more than half of the sum of Eq. 1.

QUARK HELICITY DISTRIBUTIONS

Semi-inclusive deep-inelastic scattering is a powerful tool to determine the separate contributions $\Delta q_f(x)$ of the quarks and antiquarks of flavour f to the total spin of the nucleon. By means of the technique of flavour tagging, individual spin contributions can be determined directly from spin asymmetries of hadrons with the appropriate flavour content. The helicity distributions $\Delta u(x)$ and $\Delta d(x)$ extracted from the HERMES data [4] are consistent with LO-QCD fits. The sea quark helicity distributions $\Delta\bar{u}(x)$, $\Delta\bar{d}(x)$ and $\Delta s(x)$, extracted for the first time, are consistent with zero and with each other. A new result for a direct measure of the polarisation of the strange sea in the proton of much improved precision and free of systematic uncertainties in the fragmentation functions [5] shows no indication for a substantial negative polarisation of the strange sea that was deduced from the analysis of inclusive data assuming SU(3) symmetry.

THE GLUON HELICITY DISTRIBUTION $\Delta g(x, Q^2)$

A direct LO, model dependent extraction of $\Delta g/g$ has been performed by studying charged hadron production at large transverse momenta p_T relative to the direction of the virtual photon. The high statistic data sample of antitagged (vetoed by the beam particle) inclusive charged hadrons was used. To relate the measured longitudinal double-spin asymmetry to the gluon polarisation $\Delta g/g$, information on the relative contributions of the various subprocesses to the inclusive hadron production cross section, their asymmetries and variation with p_T has been obtained from detailed Monte Carlo simulation using Pythia 6.2 and parametrisations of the spin dependent parton distributions of the nucleon and the photon. This information is used to obtain the signal asymmtry which

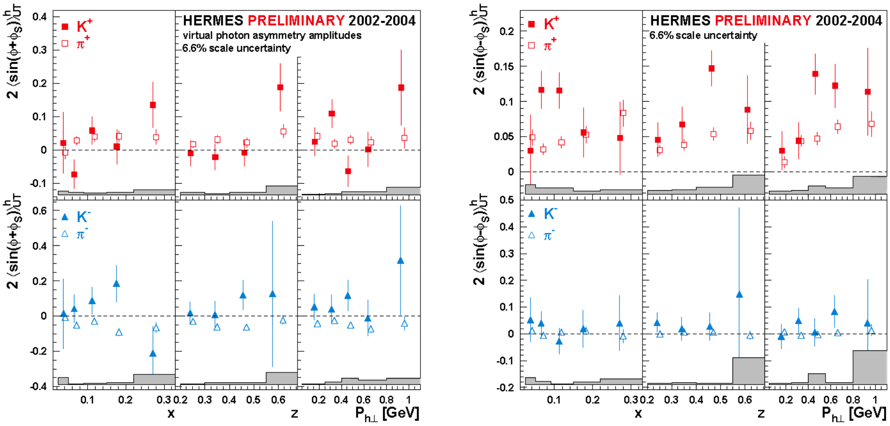

FIGURE 3. HERMES results for the *Collins* moments (left) and *Sivers* moments (right) of charged pions and kaons obtained with a transversely polarised target.

still contains a convolution of $\Delta g(x)/g(x)$ with the hard subprocess cross section. Two methods have been applied to extract the average $\langle \Delta g/g \rangle (p_T)$ from the signal asymmetry using different assumptions on the shape of $\Delta g(x)/g(x)$. Method I assumes that $\Delta g(x)/g(x)$ is constant in the measured x range while Method II employs a functional form for $\Delta g(x)/g(x)$. The results for $\langle \Delta g/g \rangle (p_T)$ obtained from the deuterium data on charged combined hadrons are shown in Fig. 2 for both Methods. Method II allows to determine the average x of the measurement, and by integrationg over $1.05 < p_T < 2.5$ GeV a value of $\Delta g/g = 0.071 \pm 0.034(\text{stat}) \pm 0.010(\text{sys-exp})\,^{+0.127}_{-0.105}(\text{sys-models})$ has been obtained at $\langle x \rangle = 0.22$ and $\langle \mu^2 \rangle = 1.35$ GeV^2. This result is shown in Fig. 2 (right panel) together with previous determiations of $\Delta g/g$ [6, 7] and are compared to several different parametrisations obtained from NLO-QCD fits [8, 9, 10, 11]. The data favour a very small Δg, or $\Delta g(x)$ has a node at x around 0.1.

TRANSVERSE SPIN EFFECTS

A complete description of the quark structure of the nucleon in leading twist requires in addition to the unpolarised distribution $q(x,Q^2)$ and the helicity distribution $\Delta q(x,Q^2)$ a third quark distribution, named transversity $\delta q(x,Q^2)$. Due to its chiral-odd nature, transversity cannot be measured in inclusive DIS but only in a process in which it is combined with another chiral-odd object. Using a transversely polarised nucleon target, the transversity enters the cross section combined with the chiral-odd fragmentation function (FF) $H_1^\perp$ known as *Collins* function. [12].
Azimuthal spin asymmetries can also be generated by the T-odd *Sivers* distribution $f_{1T}^\perp(x,k_T)$ [13] that appears in the cross section together with the unpolarised FF, D_q^h. The Sivers distribution describes a correlation between the transverse polarisation of the target nucleon and the $\vec{p}_T$ of the struck quark. Its existence requires non-zero orbital

angular momenta of quarks.
Measurements with a transversely polarised target allow to distinguish between the Collins and the Sivers meachanism. The characteristic signature of the Collins (Sivers) effect is a $sin(\phi + \phi_S)$ ($sin(\phi - \phi_S)$) modulation of the cross section in the distribution of the azimuthal angle ϕ of the pion around the virtual photon direction and relative to the lepton scattering plane, and ϕ_S, the angle between the scattering plane and the transverse spin component of the target nucleon. In the years 2002-2005 HERMES has taken data with a transversely polarised proton target. The azimuthal asymmetries are evaluated in two dimensions (ϕ and ϕ_S) and the amplitudes for the Collins and Sivers mechanism were extracted simultaneously. Preliminary results for charged pions and kaons, based on the data taken in the years 2002-2004 which correspond to about 30% of the total statistics and supersede the published result for charged pions [14], are shown in Fig. 3. The average Collins amplitude is positive for π^+ and negative for π^- with a magnitude for π^- comparable or larger than the one for π^+. One explanation could be a substantial magnitude for the disfavoured Collins fragmentation function with an opposite sign than the favoured one. These non-zero Collins asymmetries provide clear evidence for the existence of both the transversity distribtion and the Collins fragmentation function. The significant positive Sivers amplitudes for π^+ and K^+ provide the first evidence for a T-odd parton distribution function appearing in leptoproduction and imply a non-vanishing orbital angular momentum of the quarks inside the nucleon.

EXCLUSIVE PROCESSES AND QUARK ORBITAL MOMENTUM

An exciting new field is opened with measurements of hard exclusive production of mesons and real photons (Deeply Virtual Compton Scattering, DVCS). The parton correlation functions (known as Generalised Parton Distributions, GPDs) accessible in these processes are related to the total angular quark momentum contribution in the nucleon [15]. Thus, with prior knowledge of $\Delta\Sigma$ (Eq. 1) the orbital angular momentum of the quarks L^q may become accessible. Such studies appear to mark a major advance in unravelling the spin structure of the nucleon.

DVCS provides the theoretically cleanest access to GPDs. DVCS amplitudes can be determined through a measurement of the interference between the DVCS and Bethe-Heitler (BH) processes, in which the photon is radiated from a parton and from the lepton, respectively. Measuring the ϕ-dependence of a cross section asymmetry with respect to the charge (spin) of the lepton beam provides information about the real (imaginary) part of the DVCS amplitude. HERMES has already measured azimuthal asymmetries with respect to the beam helicity [16], to the target helicity [17] and w.r.t. the beam charge [18]. New results have been shown for the beam-spin asymmetry measured on nuclear targets [2].

A very exciting observable is the DVCS *transverse* target-spin asymmetry (TTSA) shown in Fig. 4 as obtained from the HERMES data accumulated in 2002-2004 using a transversely polarised hydrogen target. This asymmetry provides direct access to the total angular momentum $J_{u,d}$ within a certain GPD model [19] that parametrises the GPDs using J_u and J_d as free parameters. In this particular GPD model, the data favour a non-zero value of J_u in the order of about 0.4, assuming $J_d = 0$.

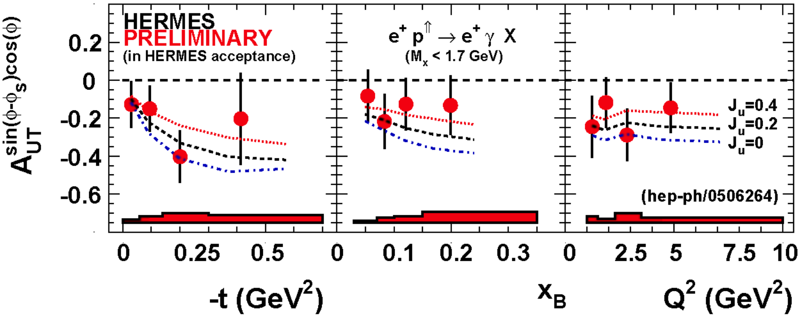

FIGURE 4. HERMES results for the transverse target-spin asymmetry compared to GPD model calculations (see text).

PROSPECTS OF HERMES SPIN PHYSICS

In spite of many years of experiments, a detailed decomposition of the spin of the nucleon remains elusive. More precise results from HERMES are expected soon from the full 2002-2005 data set taken with a transversely polarised hydrogen target. In February 2007 a recoil detector has been installed and HERMES emphasises measurements in the exciting new field of hard exclusive production of mesons and real photons with positron and electron beams.

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