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NEW RESULTS IN LEPTON-NUCLEON SPIN PHYSICS

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This review summarizes new experimental results in polarized lepton-nucleon scattering obtained since the last DIS conference.

1 Introduction

New information on the spin structure of the nucleon from polarized lepton-nucleon scattering has been obtained since the last DIS conference mainly by five experiments: HERMES at HERA/DESY, COMPASS and SMC at CERN, and the Hall A and CLAS experiments at JLAB. Before I discuss the new results let me briefly summarize the main features of these experiments.

HERMES uses the longitudinally polarized electron or positron beam of HERA ($E \approx 27.5$ GeV, beam current $I_{max} \approx 50$ mA, beam polarization $P_{B,max} \approx 0.6$) and either polarized pure atomic gas targets of hydrogen, deuterium ($P_T^{H,D} \approx 0.85$) and ^3He ($P_T \approx 0.5$) or high density unpolarized gas targets, internal to the electron storage ring. The luminosity covers a range from about $4 \cdot 10^{30}$ cm^{-2}s^{-1} for the polarized H target and a beam current of 10 mA and several 10^{33} cm^{-2}s^{-1} for unpolarized D_2. Scattered electrons/positrons and particles produced in deep-inelastic electron-nucleon interactions are detected and identified by an open-geometry forward spectrometer with large momentum and angular acceptance [1]. In the years 1995 to 2000 data were taken with longitudinal target polarization. Most of the deuteron data were collected in the year 2000, when HERA performed extremely well. A review of the results obtained with longitudinally polarized targets can be found in [2]. The second phase of data taking started in 2002 with a transversely polarized hydrogen target, the main goal being the determination of the experimentally still unexplored transversity distribution, the Collins fragmentation function and the Sivers distribution function. Despite the very slow start of HERA after the high-luminosity upgrade, about 0.75 Million DIS events could be collected in autumn/winter 2002/03. Preliminary results obtained from these data are discussed in section 5. Until this summer the statistics could be increased by more than a factor of 4. Since the last DIS conference HERMES published several results in nucleon spin physics covering subjects like: the evidence for quark hadron duality in the proton spin asymmetry A_1 [3], the Q^2 dependence of the generalized Gerasimov-Drell-Hearn integral [4], single-spin azimuthal asymmetries in semi-inclusive electro-production of pions and kaons on a longitudinally polarized deuterium target [5], double-spin asymmetries in the cross section of ρ^0 and ϕ production [6], and the flavor decomposition of sea quark helicity distributions in the nucleon [7]. Many additional results have been presented at this conference.

The COMPASS experiment [8] started data taking in summer 2002. It uses the CERN high-energy muon beam ($E_\mu \approx 160$ GeV, $P_B \approx -0.76$, intensity: $2.8 \cdot 10^8 \mu^+$/spill or $I_\mu \approx 10\ pA$) and a cryogenic polarized LiD target ($P_T^D \approx 0.5$). The average luminosity of this experiment is about $5 \cdot 10^{32}$ cm^{-2}s^{-1}. At present the SMC polarized target magnet is being used which limits the forward angular acceptance to a range $\Theta < 70$ mrad instead of 180 mrad for the foreseen COMPASS target magnet. Advanced technology is used for many detectors and the data acquisition system. In the years 2002/03 about 500 TByte of raw data have been collected (corresponding to about 10^{10} events with longitudinal and about $3 \cdot 10^9$ events with transverse target polarization) and event reconstruction requires a huge amount of computing power. The kinematical acceptance extends down to $Q^2_{min} \approx 5 \cdot 10^{-5}$ (GeV/c)^2 and $x_{min} \approx 4 \cdot 10^{-6}$. Only about 0.1% of the data is in the DIS regime $Q^2 > 1$ (GeV/c)^2 with $x > 3 \cdot 10^{-3}$. COMPASS has started to produce physics output and several preliminary results have been presented at this conference. I will mainly discuss the data relevant for the determination of the gluon polarization (section 4) and for the determination of transversity and the Collins fragmentation function (section 5). SMC published an extraction of the gluon polarization from the double-spin asymmetry for pairs of high-p_T hadrons [9].

JLAB provides an electron beam with high intensity and high polarization ($E < 5.7$ GeV, $I < 200$ μA, $P_B \approx 0.7$). The Hall A collaboration performed inclusive measurements on a longitudinally and transversely polarized high pressure ^3He gas target ($P_T \approx 0.35$). Luminosities of up to 10^{36} cm^{-2}s^{-1} have been used. The scattered electrons were detected in two high resolution spectrometers [10]. Although the beam energy is rather low the high luminosity allows to study DIS in a limited kinematic region. Very high precision data for longitudinal and transverse spin asymmetries allow to determine the spin-dependent neutron structure functions $g^n_{1,2}$ and the polarization of up- and down-quarks at large values of x [11,12,13]. The CEBAF Large Angle Spectrometer (CLAS) [14] is optimized for the detection of charged hadrons in the final state. The luminosity is limited to values below 10^{34} cm^{-2}s^{-1}. First measurements of g_1^p at low values of Q^2 [15] were performed with a polarized proton target. In the context of the subject of this review CLAS also published results on single-spin azimuthal asymmetries [16], which are of importance for the determination of Generalized Parton Distributions.

2 Spin-dependent structure functions and NLO-QCD analysis

There is very little addition experimental information on the measurement of the spin-dependent structure functions (SF) $g_{1,2}(x, Q^2)$ and their NLO-QCD analysis since the last two DIS conferences. For completeness the 2-year old compilation of the world data of $x \cdot g_1(x)$ for the proton, deuteron and neutron by Uta Stößlein [17] is shown in the left panel of Fig. 1.

The main features of the data are: very good agreement between the results of the different experiments, no significant Q^2-dependence of the structure function ratio g_1/F_1 within the experimental accuracies. The x-dependence of g_1 for the deuteron is now very well determined with the HERMES data, which have sub-

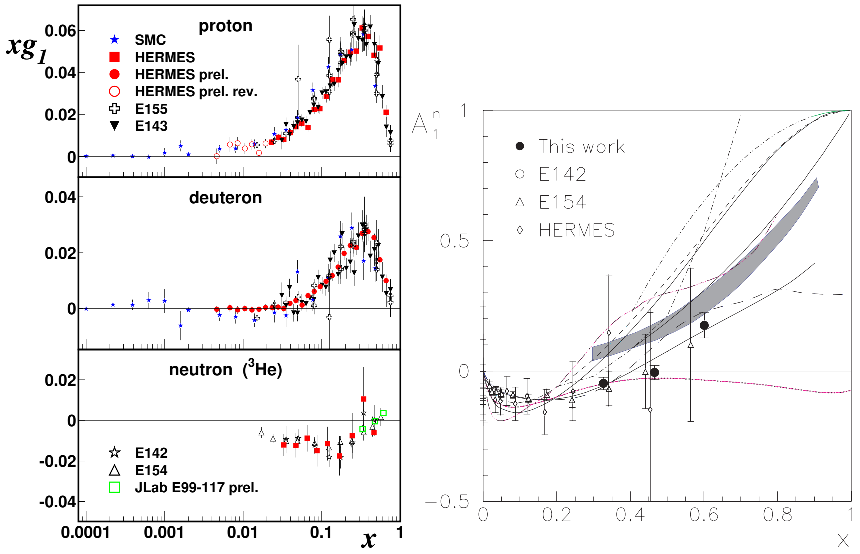

Figure 1. Compilation of recent data on the spin-dependent structure functions $xg_1(x, Q^2)$ for proton, deuteron and neutron (from ^{3}He) (left panel) and compilation of results for g_1^n from ^{3}He targets including the new results from the Hall A Collaboration at JLAB at large x together with several theoretical predictions (right panel).

stantially smaller statistical error bars and much smaller point to point fluctuations than those from the other experiments. HERMES developed a revised method for the unfolding of radiative corrections and experimental smearing effects, which leads to an error inflation at low and high values of x. Final results can be expected this autumn. First preliminary results on $A_1^d(x)$ have been presented by COMPASS. Due to the lower beam energy and the restricted angular acceptance the average $< Q^2 >$ of this data is about half as large as for the corresponding SMC data. This will be very useful for the determination of the Q^2 evolution of g_1^d.

Very precise information about the large-x behavior of $A_{1,2}^n$ and $g_{1,2}^n$ for the neutron has been obtained by the Hall A collaboration at JLAB [11,12]. Data were collected at the three x-points $< x >= 0.327; 0.466$ and 0.601 with $< Q^2 >$ values of $2.709; 3.516$ and 4.833 $(\mathrm{GeV/c})^2$. As shown in the right panel of Fig. 1 these data have improved the world data precision in this region by about an order of magnitude and provide valuable inputs to parameterizations of quark helicity distributions and nucleon models which differ substantially in the high-x regime. The collaboration also published results on the moments of the spin-dependent SFs (based on courageous extrapolations to $x = 1$ and $x = 0$) and conclude for instance that the Burkardt-Cottingham sum rule [18] is fulfilled for the neutron [13].

Several groups have performed NLO QCD-fits to the spin-dependent SFs (see e.g. the more recent papers [19,20,21]). To reduce the number of fit parameters a flavor symmetric sea-quark helicity distribution has been assumed and the first moments of the valence helicity distributions Δu_v and Δd_v have been constrained using the F and D constants experimentally determined from weak-decay of the members of the spin-$\frac{1}{2}$ baryon octet. The up-quark helicity distribution $\Delta u(x)$ seems to be rather well determined from the QCD fits as well in shape as in magnitude, while the fits give a much larger possible range for the down-quark helicity distribution $\Delta d(x)$. The sea-quark helicity distributions and especially $\Delta s(x)$ are essentially undetermined from these fits. The moments of the parton helicity distributions extracted from the various fits agree rather well. All authors obtain a negative small sea-polarization, a relatively small contribution of quark spins to the spin of the nucleon, $\Delta\Sigma \approx 0.25$, and a positive moment of the gluon helicity distribution. In the latter quantity the errors of the fits are large, $\Delta g(x)$ is essentially unconstrained by the present inclusive data on polarized DIS.

3 Quark helicity distributions

The quark helicity distributions can in principle be determined in polarized semi-inclusive deep-inelastic scattering (SIDIS) when in addition to the scattered lepton also a leading hadron is detected which provides a statistical tag on the struck quark flavor. Results of such analyses have been previously reported by SMC [22] (proton and deuteron targets) and by HERMES [23] (proton and ^{3}He targets). HERMES has now also published such results based in addition on the high statistics deuteron data with identified positive and negative pions and kaons. The results for the quark and anti-quark helicity distributions $x \cdot \Delta q(x)$ obtained from a LO analysis of these data [7] are shown in the left panel of Fig. 2 together with two LO-QCD fits [24,25] to previously published inclusive data.

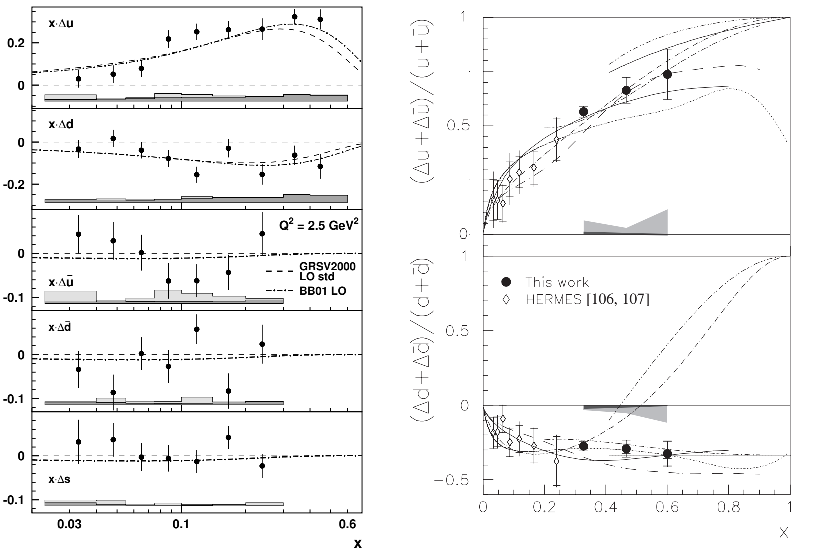

Figure 2. HERMES results for the quark helicity distributions from the 1996 - 2000 hydrogen and deuterium data as a function of x (left panel) and quark polarizations at large x determined by the Hall A experiment at JLAB from inclusive polarized ^{3}He data (right panel).

The helicity distributions $\Delta u(x)$ and $\Delta d(x)$ extracted from the HERMES data are consistent with previous results and with the LO-QCD fits. The sea-quark helicity distributions $\Delta\bar{u}(x)$, $\Delta\bar{d}(x)$ and $\Delta s(x)$, extracted separately from these data for the first time, are consistent with zero and with each other. The statistical error bars are, however, still substantially larger than the magnitude of the distributions obtained from the QCD fits. Within errors there is no indication for a substantial negative polarization of the strange sea that was deduced from the analysis of inclusive data assuming SU(3) symmetry. There is also no evidence in the data for a large flavor asymmetry in the light quark sea helicity distribution $\Delta\bar{u}(x) - \Delta\bar{d}(x)$. More high precision data from COMPASS and RHIC are urgently needed to better constrain the sea-quark helicity distributions.

In the right panel of Fig. 2 the quark polarizations $(\Delta u + \Delta\bar{u})/(u + \bar{u})$ and $(\Delta d + \Delta\bar{d})/(d + \bar{d})$ determined by the Hall A experiment at JLAB from their inclusive polarized ^{3}He data is shown [11,12]. These data are very important to constrain the high-x behavior of the quark helicity distributions of these flavors.

4 The gluon helicity distribution $\Delta g(x, Q^2)$

The apparent deficit in the contribution of quark spins to the nucleon spin can be explained by assuming a substantial gluon polarization $\Delta g/g$, but $\Delta g(x, Q^2)$ is essentially unconstrained by the present inclusive data. Even if additional more precise fixed target data will become available, as expected mainly from COMPASS, it is rather unlikely that such inclusive data will sufficiently constrain $\Delta g(x, Q^2)$. The reason is the very weak Q^2 dependence of the inclusive spin asymmetries and the relatively small range in Q^2 for each value of x.

Presently the most promising approach for studying Δg seems to be direct measurements via processes where the cross section is proportional to the gluon density. In lepton-nucleon scattering such a process is *photon-gluon fusion* (PGF) [26,27]. This process can be isolated either by studying reactions in which a charmed quark anti-quark pair is produced and the necessary hard scale is given by the mass of the c-quark, or alternatively by measuring a quark and an anti-quark jet at large transverse momenta p_T relative to the direction of the virtual photon [28,29]. At the relatively low center-of-mass energy of polarized fixed target experiments only few hadrons are produced and observed and therefore pairs of hadrons at large transverse momenta instead of di-jets have to be used to tag PGF [30]. Here p_T has to be at least of the order of 1 GeV/c to ensure the hard scale. The analyzing power for the PGF subprocess is negative. Hence, if a *negative* double spin asymmetry for pairs of correlated hadrons with high transverse momenta is measured on a polarized proton target one can safely conclude that $\Delta g/g$ is *positive*, since all other possible subprocesses contributing to the asymmetry have a positive analyzing power.

New results for the double-spin asymmetry (DSA) for the production of pairs of hadrons with high transverse momenta have recently been presented by SMC and COMPASS and preliminary results for the data collected with a longitudinally polarized deuterium target are available from HERMES.

HERMES results: Let me first recall the HERMES proton results on this subject which have already been published some time ago [31]. HERMES selected quasi-real photo-production events with at least two hadrons (of opposite charge) in the final state, which were required to have a momentum > 4.5 GeV/c and a transverse momentum $p_T > 0.5$ GeV/c relative to the positron beam direction. With the requirement $p_T^{h2}, p_T^{h2} > 1$ GeV/c an asymmetry $\mathbf{A}_{\|} = \mathbf{-0.28 \pm 0.12}(\text{stat.}) \pm \mathbf{0.02}(\text{sys.})$ was obtained. To relate the measured DSA to $\Delta g/g$ one has to understand precisely the relative contribution of various subprocesses to the hadron pair production cross section: photon-gluon fusion (PGF), the QCD Compton effect (QCDC), interaction via the hadronic structure of the photon (VMD), non-resonant hadronic 'anomalous' photon structure and finally usual hadron production in lowest order DIS (LP). From Monte-Carlo simulations in leading order it was concluded that only PGF and QCDC contribute significantly to the measured asymmetry with subprocess asymmetries $\hat{a}_{\text{PGF}} = -1$ for real photons and massless quarks and $\langle \hat{a}_{\text{QCDC}} \rangle \approx +0.5$ (averaged over the selected kinematics). The gluon polarization at the average kinematics of the experiment ($\langle Q^2 \rangle = 0.06$ (GeV/c)^2 and $\langle p_T^2 \rangle = 2.1$ (GeV/c)^2, $0.06 < x_g < 0.28$, $\langle x_g \rangle = 0.17$) deduced by HERMES was: $\langle \mathbf{\Delta g/g} \rangle = \mathbf{0.41 \pm 0.18\,(stat.) \pm 0.03\,(exp.sys)}$.

Preliminary HERMES results have been reported for the combined proton and deuterium data. For the whole data sample with $p_T^{h1} > 1.5$ GeV/c and $p_T^{h2} > 0.5$ GeV/c one obtains $\mathbf{A}_{\|} = \mathbf{-0.039 \pm 0.028}$. The significance increases with the cut on p_T^{h2} and for $p_T^{h2} > 1.0$ GeV/c the asymmetry reaches $\mathbf{A}_{\|} = \mathbf{-0.133 \pm 0.058}$ with a systematic error of 8.1 %. A new extraction of $\langle \Delta g/g \rangle$ based on all HERMES data is currently underway using improved simulations based on PYTHIA6.

SMC results: A similar analysis has been performed recently by the SMC collaboration [9]. The total data sample collected by the SMC experiment during the years 1993-1996 with a muon beam energy $E = 190$ GeV and longitudinally polarized hydrogen and deuterium target was used for this analysis. A sample of DIS events was selected by requiring the reconstructed beam muon and the scattered muon with $Q^2 > 1$ (GeV/c)^2 and at least two hadrons. Other kinematic requirements imposed on the data sample were: $0.4 < y > 0.9, x_F > 0.1$, and $z > 0.1$. Based on a Monte Carlo simulation it was found that the selection on $\sum p_T^2$ is optimal for enhancing the PGF sample. A minimal $p_T > 0.7$ GeV/c of each hadron and $\sum p_T^2 > 2.5$ (GeV/c)^2 has been chosen. Furthermore a classification procedure based on neural networks (NN) has been used, which according to the corresponding studies provides samples with a higher purity and better statistical precision than the method based on $\sum p_T^2$.

The measured DSA, for proton and deuteron, for all such events with $p_T^{h1,h2} > 0.7$ (GeV/c) and those after the additional selections $\sum p_T^2 > 2.5$ (GeV/c)^2 or 'NN response' > 0.26 is positive for all cases. It does not change significantly with the selection, the results for the proton and the deuteron are compatible within errors. For the 'NN response' the averaged partonic asymmetries for the different subprocesses, as determined by Monte-Carlo, are $\langle \hat{a} \rangle_{\text{LP}} = 0.8$, $\langle \hat{a} \rangle_{\text{QCDC}} = 0.6$, and $\langle \hat{a} \rangle_{\text{PGF}} = -0.49$, and the final proton sample consists of 38% LP, 29% QCDC and 33% PGF. The contributions of the different processes for the proton and the deuteron samples differ by less than 2%. With these numbers and averaging the results for proton and deuteron, SMC obtains with the NN classification a *negative* gluon polarization: $\mathbf{\Delta g/g = -0.20 \pm 0.28 \pm 0.10}$.

COMPASS results: The COMPASS analysis follows closely the procedure used by SMC with the selection criterion $\sum p_T^2 > 2.5$ (GeV/c)^2 and with identical cuts on the relevant kinematical variables. In this case, no cut on Q^2 has been applied, the Q^2 distribution spans a range $3 \cdot 10^{-3}$ to 10 (GeV/c)^2 with the maximum around 10^{-1} (GeV/c)^2. From the deuteron data taken in 2002 COMPASS obtains the preliminary result: $\mathbf{A_{\parallel}/D = -0.065 \pm 0.036(stat.) \pm 0.005(syst.)}$. The asymmetry is negative as for the corresponding HERMES data and agrees within errors with the HERMES result for the combined deuterium and hydrogen data with $p_T^{h2} > 0.5$. The error should be further reduced by a factor of about 2 with the statistics expected from the 2003/04 data. The extraction of $\Delta g/g$ from this result requires a detailed Monte-Carlo simulation, which is still under development.

Another possibility to tag photon-gluon fusion and to determine $\Delta g/g$ pursued by COMPASS is open charm production. D^0 events have been reconstructed by D^* tagging, i.e. by the additional detection of a soft pion, π_s, from the decay $D^{*+} \to D^0\pi_s^+ \to K^-\pi^+\pi_s^+$. A clean signal with about 200 events above a background of about the same magnitude has been observed. The number of reconstructed D^0 is at present not yet large enough for an accurate determination of $\Delta g/g$. It is, however, expected that with the about fourfold statistics from the years 2002-2004 and by improvements in the particle identification and track reconstruction the number of reconstructed D^0 will be substantially increased.

In this context one should also mention the recent results from the PHENIX collaboration at RHIC [32] on the double helicity asymmetry in inclusive mid-rapidity π^0 production in polarized pp collisions at $\sqrt{s} = 200$ GeV in a range of p_T between 1 and 5 GeV/c. At the kinematics of this experiment the reaction is dominated by gluon-gluon processes and the asymmetry is expected to be positive. The measured asymmetry is small, the average value is negative in contrast to the expectation. Within the errors the data are, however, consistent with a small gluon polarization as obtained for instance with the GRSV-std gluon distribution [24].

My main conclusions are at the moment: the new results indicate that $\Delta g/g$ might be rather small and much higher precision data from different processes are urgently needed to settle the question about shape and magnitude of $\Delta g(x)$.

5 Transversity, Collins and Sivers mechanism

A complete description of the partonic structure of the nucleon in leading twist requires in addition to the unpolarized quark distributions $q\left(x, Q^2\right)$ and the quark helicity distributions $\Delta q\left(x, Q^2\right)$ a third quark distribution, named transversity $\delta q\left(x, Q^2\right)$ [33]. The corresponding structure function is denoted as $h_1\left(x, Q^2\right)$. Physically, one may think of transversity $\delta q(x)$ as the distribution of quarks with spin parallel to the nucleon spin minus the distribution of quarks polarized anti-parallel to the nucleon spin for a transversely polarized nucleon, in analogy to the helicity distribution $\Delta q(x)$ for a longitudinally polarized nucleon. While $\delta q(x)$ and

$\Delta q(x)$ should be identical in the non-relativistic quark model, they are different for quarks moving relativistically since then rotations and boosts do not commute.

Transversity has thus far remained unmeasured because it is chiral-odd and hard interactions conserve chirality. Therefore transversity cannot be probed in inclusive DIS. Its measurement requires processes involving some additional chiral-odd structure like e. g. another transversity distribution in transversely polarized Drell-Yan production of lepton pairs, or a chiral-odd fragmentation function in SIDIS. One of the possibilities to study transversity [33,34] is via the azimuthal angular asymmetry in the distribution of hadrons produced in SIDIS. Such an asymmetry can arise if the transverse polarization of the struck quark influences the transverse momentum of the produced hadron and thereby its distribution in the azimuthal angle ϕ about the virtual photon direction relative to the lepton scattering plane. The corresponding chiral-odd fragmentation function $H_1^\perp$, which is also odd under naive time reversal, is known as the "Collins fragmentation function" [35,36]. It arises from the interference of two amplitudes with different imaginary parts, generating a nontrivial phase in the DIS amplitude [37,38,39].

Such an angular asymmetry could, however, also be produced by a different mechanism involving correlations between the transverse polarization of the target nucleon and the transverse momentum of quarks. The transverse quark momentum can survive both the photo-absorption and the fragmentation and can reappear in the transverse momentum of the produced hadron and thereby influence its azimuthal distribution relative to the direction of target polarization. The corresponding T-odd "Sivers distribution function" $f_{1T}^\perp$ [38,40,41] is so-far experimentally unexplored. One especially interesting aspect of this distribution function is the possible relation to orbital angular momenta of quarks [42].

Measurements with a transversely polarized target allow to distinguish between the Collins mechanism and the Sivers mechanism [43,44,45]. The Collins mechanism will cause a $\sin(\phi + \phi_S)$ moment proportional to $\delta q(x) \cdot H_1^\perp(z)$, while the Sivers mechanism will cause a $\sin(\phi - \phi_S)$ moment proportional to $f_{1T}^\perp(x) \cdot D(z)$. Here ϕ_S is the angle between the electron scattering plane and the target spin axis and $D(z)$ is the familiar unpolarized fragmentation function.

An azimuthal asymmetry can also arise in the case of a longitudinally polarized target due to a small transverse component $P_{\mathrm{T}}^\perp$ of the target polarization relative to the virtual photon direction: $P_{\mathrm{T}}^\perp = |P_T| \cdot \sin\theta_\gamma$. Here θ_γ is the virtual photon emission angle with $< \sin\theta_\gamma > \approx 0.16$ for the HERMES data. For a longitudinally polarized target the direction of $P_{\mathrm{T}}^\perp$ coincides with the scattering plane and therefore azimuthal asymmetries arising from the Collins and Sivers mechanisms have a common $\sin\phi$ behavior and they cannot be separated. Furthermore in this case the $\sin\phi$-weighted asymmetry is dominated by additional leading and higher twist terms [38].

HERMES has observed such an azimuthal asymmetry in semi-inclusive electroproduction of charged [46] and neutral [47] pions on a longitudinally polarized proton target and of pions and kaons from a polarized deuterium target [5]. As an example the measured analyzing powers $A_{\mathrm{UL}}^{\sin\phi}$ (the first subscript denotes the beam polarization, the second the target polarization with U unpolarized, L longitudinally and T transversely polarized) for π^+, π^-, π^0, and K^+ production are

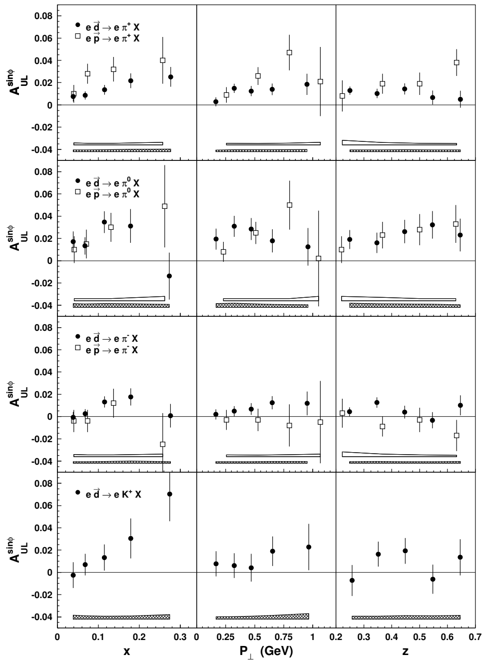

Figure 3. HERMES results for the analyzing powers $A_{\mathrm{UL}}^{\sin\phi} A_{UL}$ for π^+, π^-, π^0, and K^+ production.

shown in Fig. 3. The experimental data are well described by theoretical calculations which contain the transversity distributions calculated in the chiral quark soliton model (χQSM) [48], the quark-diquark model (QdQ) [49] or a perturbative QCD model (pQCD) [49] as an input.

Since 2002 HERMES has taken data with a transversely polarised proton target and COMPASS has taken some fraction of the data with a transversely polarised deuterium target. HERMES has evaluated the corresponding azimuthal asymmetry, $\bar{A}^h_{UT}(\phi, \phi_S)$, in two dimensions and extracted the Collins and Sivers virtual-photon asymmetries by a simultaneous fit to $\sin(\phi + \phi_S)$ and $\sin(\phi - \phi_S)$. Preliminary results for the "Collins moments" are shown in the left panel of Fig. 4 as a function of x and z. The measured asymmetries are small but different from zero providing evidence for the existence of both the transversity distribution and the Collins fragmentation function. The π^+ asymmetry is positive with an average value of $0.021 \pm 0.007(stat)$ and seems to be slightly rising with x and z. The π^- asymmetry has an average value of $-0.038 \pm 0.008(stat)$ and thereby higher magnitude than the π^+. The π^0 asymmetries have substantially larger error bars due to the lower π^0 reconstruction efficiency and seem to favour slightly negative values.

These results are quite unexpected. Assuming a similar behaviour for the transversity distributions as for the helicity distributions, $|\delta(u(x)| > |\delta(d(x)|$, and for the Collins function a similar behaviour as for the unpolarised fragmentation

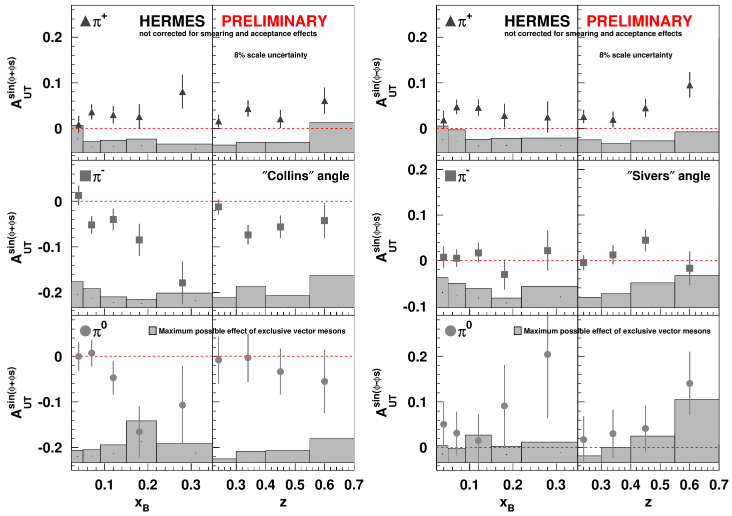

Figure 4. HERMES results for the "Collins moments" (left panel) and the "Sivers moments" (right panel) for pions obtained with a transversely polarised hydrogen target.

function, i.e. a suppression of the disfavoured fragmentation function, $H_{1,disfav}^{\perp}$, compared to the favoured one, $H_{1,fav}^{\perp}$, one would expect a much larger magnitude of the asymmetry for π^+ than for π^-. One possible explanation for the different behavior observed experimentally could be a substantial magnitude with opposite sign for the disfavoured Collins function $H_{1,disfav}^{\perp} \approx -H_{1,fav}^{\perp}$ [50].

COMPASS extracted the Collins asymmetry from the data taken in 2002 in an 1-dimensional analysis. In Fig. 5 preliminary results for the asymmetry for leading hadrons are shown as a function of x. The data are compatible with zero within errors. This might be partly due to the use of a deuterium target. An improvement in statistics by a factor of about four is expected from the full 2002-2004 data set. Note that the two collaborations used a definition of the angle ϕ which differs by π and therefore the sign of one of the data sets should be inverted for a direct comparison.

In the right panel of Fig. 4 the preliminary HERMES results for the "Sivers moments" are shown. The π^+ asymmetry is significantly positive with an average value of $0.017 \pm 0.004(stat)$, providing the first evidence for a T-odd parton distribution function appearing in leptoproduction. The π^- asymmetry is consistent with zero at $0.002 \pm 0.005(stat)$, while the error bars for the π^0 asymmetry are still to large for a definite conclusion. Since the π^+ asymmetry is dominated by u-quarks, its positive value with the definition of azimuthal angles used by HERMES implies a negative value for the Sivers function of this flavour. HERMES expects an improvement in statistics by about a factor of 8-10 until the end of data taking with the transversely polarised hydrogen target. The improved statistical accuracy should then allow to extract the Sivers functions for u- and d-quarks in a procedure similar to the one used for the extraction of the quark helicity distributions.

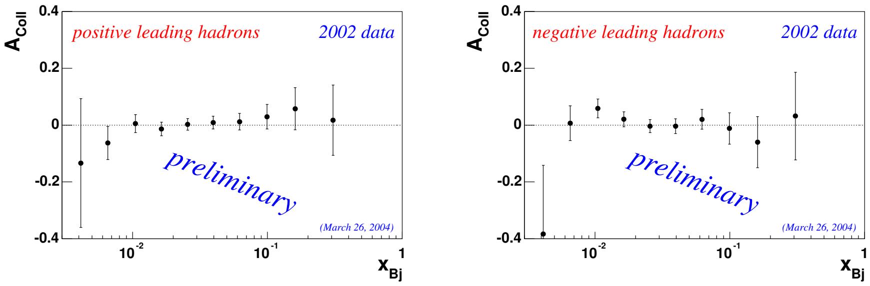

Figure 5. COMPASS results for the "Collins moments" of positive and negative hadrons obtained with a transversely polarised deuterium target.

6 Conclusions

During the last year exciting new information on the nucleon spin structure from polarized lepton-nucleon scattering has been obtained. The results from several experiments indicate that the gluon helicity distribution might be quite small. For the first time SIDIS results from transversely polarised targets have been presented providing evidence for the existence of the transversity distribution, the Collins fragmentation function and the Sivers distribution function. Many more interesting results can be expected in the near future.

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References

1. K. Ackerstaff et al. (HERMES), Nucl. Instr. Meth. A **417** (1998) 230-265.
2. K. Rith, Progr. Part. Nucl. Phys. **49** (2002) 245-324.
3. A. Airapetian et al. (HERMES), Phys. Rev. Lett. **90** (2003) 092002.
4. A. Airapetian et al. (HERMES), Eur. Phys. J. C **26** (2003) 527-538.
5. A. Airapetian et al. (HERMES), Phys. Lett. B **562** (2003) 182-192.
6. A. Airapetian et al. (HERMES), Eur. Phys. J. C **29** (2003) 171-179.
7. A. Airapetian et al. (HERMES), Phys. Rev. Lett. **92** (2004) 012005.
8. G.K. Mallot for the COMPASS collaboration, Nucl. Instr. Meth. A **518** (2004) 121-124.
9. B. Adeva et al. (SMC), Phys. Rev. D **70** (2004) 012002.
10. J. Alcorn et al., Nucl. Instr. Meth. A **522** (2004) 294-346.
11. X. Zheng et al. (JLAB-Hall A), Phys. Rev. Lett. **92** (2004) 012004.
12. X. Zheng et al. (JLAB-Hall A), nucl-ex/0405006, to appear in Phys. Rev. C.
13. M. Amarian et al. (JLAB-Hall A), Phys. Rev. Lett. **92** (2004) 022301.

14. B.A. Mecking et al. (CLAS), Nucl. Instr. Meth. A **503** (2003) 513-553.
15. R. Fatemi et al. (CLAS), Phys. Rev. Lett. **91** (2003) 222002.
16. H. Avakian et al. (CLAS), Phys. Rev. D **69** (2004) 112004.
17. U. Stößlein, Proceedings of DIS2002, Acta Phys. Pol. B **33** (2002) 2813-2834.
18. H. Burkardt and W.N. Cottingham, Ann. Phys. **55** (1970) 453-463.
19. J. Blümlein and H. Böttcher, Proceedings of DIS2002, Acta Phys. Pol. B **33** (2002) 3725-3730; J. Phys. G **29** (2003) 1959-1961.
20. E. Leader, A.V. Sidorov, D.B. Starnenov, Proceedings of DIS2002, Acta Phys. Pol. B **33** (2002) 3695-3700.
21. M. Hirai et al. (AAC), Phys. Rev. D **69** (2004) 054021.
22. B. Adeva et al. (SMC), Phys. Lett. B **420** (1998) 180-190.
23. K. Ackerstaff et al. (HERMES), Phys. Lett. B **464** (1999) 123-134.
24. M. Glück et al., Phys. Rev. D **63** (2001) 094005.
25. J. Blümlein and H. Böttcher, Nucl. Phys. B **636** (2002) 225-263.
26. V. Barger et al., Phys. Lett. B **91** (1980) 253-258.
27. J. Babcock et al., Phys. Rev. D **18** (1978) 162-181.
28. M. Fontannaz et al., Z. Phys. C **8** (1981) 349-351.
29. G. Sterman et al., Rev. Mod. Phys. **67** (1995) 157-248.
30. A. Bravar et al., Phys. Lett. B **421** (1998) 349-359.
31. A. Airapetian et al. (HERMES), Phys. Rev. Lett. **84** (2000) 2584-2588.
32. S.S. Adler et al.(PHENIX), hep-ex/0404027.
33. V. Barone and P.G. Ratcliffe, *Transverse Spin Physics*, World Scientific, 2003.
34. R. L. Jaffe, hep-ph/9710465.
35. J. Collins, Nucl. Phys. B **396** (1993) 161-182.
36. J. Collins et al., Nucl. Phys. B **420** (1994) 565-582.
37. A.M. Kotzinian and P. J. Mulders, Phys. Lett. B **406** (1997) 373-380.
38. P. J. Mulders and R. D. Tangerman, Nucl.Phys. B **461** (1996) 197-237; *erratum-ibid.* B **484** (1997)538-540.
39. D. Boer and P. J. Mulders, Phys. Rev. D **57** (1998) 5780-5786.
40. D. W. Sivers, Phys. Rev. D **41** (1990) 83-90.
41. D. W. Sivers, Phys. Rev. D **43** (1991) 261-263.
42. M. Burkardt, Phys. Rev. D **66** (2002) 114005, Phys. Rev. D **69** (2004) 074032.
43. M. Anselmino and F. Murgia, Phys. Lett. B **442** (1998) 470-478.
44. J, Collins, Phys. Lett. B **536** (2002) 43-48.
45. D. Boer et al., Nucl. Phys. B **667** (2003) 201-241.
46. A. Airapetian et al. (HERMES), Phys. Rev. Lett. **84** (2000) 4047-4051.
47. A. Airapetian et al. (HERMES), Phys. Rev. D **64** (2001) 097101.
48. A.V. Efremov, K. Goeke and P. Schweitzer, Eur. Phys. J. C **24** (2002) 407-412; Eur. Phys. J. C **32** (2003) 337-346.
49. B. Ma, I. Schmidt and J. Yang, Phys. Rev. D **66** (2002) 094001.
50. R. Seidl, PhD thesis, University of Erlangen-Nürnberg (June 2004), DESY-THESIS-2004-029.