Polarized Lepton–Nucleon Scattering at HERMES

James Stewart*
Desy Zeuthen, Platanenallee 6, D-15738 Zeuthen Germany
E-mail: James.Stewart@desy.de

on behalf of the HERMES Collaboration

ABSTRACT: New preliminary data on the structure function ratio g_1^d/F_1^d are shown. This ratio appears to be independent of Q^2 within the experimental uncertainties. The extraction of the polarized quark distribution functions Δq from semi–inclusive deep inelastic scattering is presented along with results on Deeply Virtual Compton Scattering (DVCS). The experimental program for the next running period is also briefly discussed.

1. Introduction

The HERMES experiment at DESY is built around a large acceptance fixed–target spectrometer [1] designed to study the spin structure of the nucleon using the Deep Inelastic Scattering (DIS) process. The combination of polarized/unpolarized internal gas targets with the polarized 27 GeV HERA lepton beam allows precision measurements of cross section asymmetries in inclusive and semi–inclusive deep inelastic scattering. Data were collected using longitudinally polarized ^{3}He, hydrogen, and deuterium with average polarizations of 0.46 ± 0.05, 0.88 ± 0.04, and 0.84 ± 0.03, respectively. The average polarization of the HERA beam, P_l, was 0.55. The momentum resolution of the spectrometer is $\delta p/p =$ 0.7 - 1.3 %. Information from a transition radiation detector, a preshower detector, and the relation between energy and momentum measured from the spectrometer and the electromagnetic calorimeter respectively, give a lepton identification efficiency of 98% with a hadron contamination of $\leq 1\%$. For the data taken since 1998 identification of pions, kaons, and protons is made possible by using a RICH detector.

As the instantaneous luminosity with an unpolarized target can be two orders of magnitude higher than with the polarized target, rare processes can be studied using the polarized beam and the unpolarized target. The data presented on DVCS is only one example of a large variety of results from HERMES using unpolarized targets.

*Speaker.

2. Inclusive and semi–inclusive deep inelastic scattering

At leading twist three parton distribution functions q_f, Δq_f, and δq_f (cf. sect. 4) are needed to fully describe the nucleon. In the quark parton model at leading order the unpolarized and polarized structure functions are $F_1(x) = 1/2\sum_f e_f^2 q_f(x)$ and $g_1(x) = 1/2\sum_f e_f^2 \Delta q_f(x)$, where $q_f(x)$ are the quark number density distribution functions and $\Delta q_f(x)$ are the quark helicity distribution functions. The structure function F_1 is independent of the polarization of the nucleon and can be measured in inclusive unpolarized DIS experiments. The polarized structure function g_1 can be determined from the double spin asymmetry $A_\parallel$ measured using a longitudinally polarized beam and target if F_1 is known. $A_\parallel$ is defined in Eq. 2.1 where $\sigma^{\rightrightarrows}(\sigma^{\rightleftarrows})$ is the scattering cross section when the target and beam spins are parallel(anti-parallel). $A_\parallel$ is related to the virtual–photon asymmetries A_1 and A_2 and also g_1 through the kinematic factors η and γ, and the photon depolarization factor D.

$$A_\parallel = \frac{\sigma^{\rightleftarrows} - \sigma^{\rightrightarrows}}{\sigma^{\rightleftarrows} + \sigma^{\rightrightarrows}} = D(A_1 + \eta A_2) \qquad and \qquad A_1 = \frac{g_1 - \gamma^2 g_2}{F_1} \tag{2.1}$$

The new HERMES measurement of g_1/F_1^d on the deuteron is shown in Fig. 1. In this preliminary analysis the first 1.1 million DIS events taken in 1998-2000 have been analyzed. The final data set contains a factor of 7 more data. As a simplification in this analysis A_2^d is set equal to γA_1^d which is equivalent to setting g_2 equal to zero; this assumption introduces an additional 3% systematic uncertainty. Within the experimental uncertainties g_1^d/F_1^d appears to be independent of Q^2. NLO fits to the g_1 world data set are presented elsewhere in this proceedings[2].

NLO analyses of the inclusively analyzed data have the limitation that only certain linear combinations of the polarized Parton Distribution Functions (PDFs) can be measured. In order to extract the polarized quark distributions directly additional information is needed. The large acceptance of the HERMES spectrometer and its good PID capability allows the collection of a large data set where an identified hadron is detected in coincidence with the scattered positron. As the quark content of the detected hadron is correlated with the quark struck in the DIS process, the double spin asymmetry in semi–inclusive hadron production can provide the necessary additional information to extract the individual polarized PDFs. Assuming factorization the semi–inclusive deep–inelastic scattering (SIDIS) cross section asymmetry A_1^h can be written in leading order as

$$A_1^h(x) = \frac{1 + R(x,Q^2)}{1+\gamma^2} \cdot \sum_f \underbrace{\frac{e_f^2 q_f(x) \int dz D_f^h(z)}{\sum_{f'} e_{f'}^2 q_f'(x) \int dz D_{f'}^h(z)}}_{P_f^h(x)} \frac{\Delta q_f(x)}{q_f(x)}. \tag{2.2}$$

In Eq. (2.2) $D_f^h(z)$ are the unpolarized fragmentation functions and $z = E_h/\nu$ is the fraction of the virtual photon's energy carried by the hadron h. The quantity denoted with the under–bracket in Eq. (2.2) consists of purely unpolarized quantities and is referred to as the hadron purity function $P_f^h(x)$. In analogy to the fragmentation functions it can

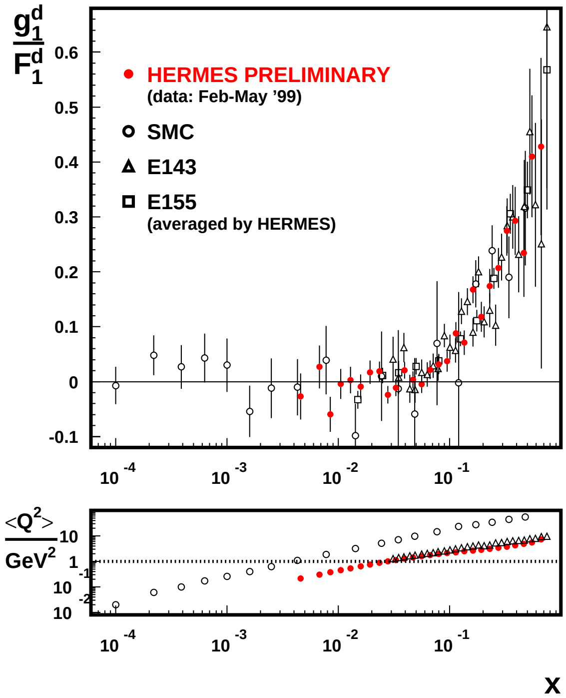

Figure 1: The structure function ratio g_1^d/F_1^d as a function of x. The lower panel shows the measured Q^2 for each data point.

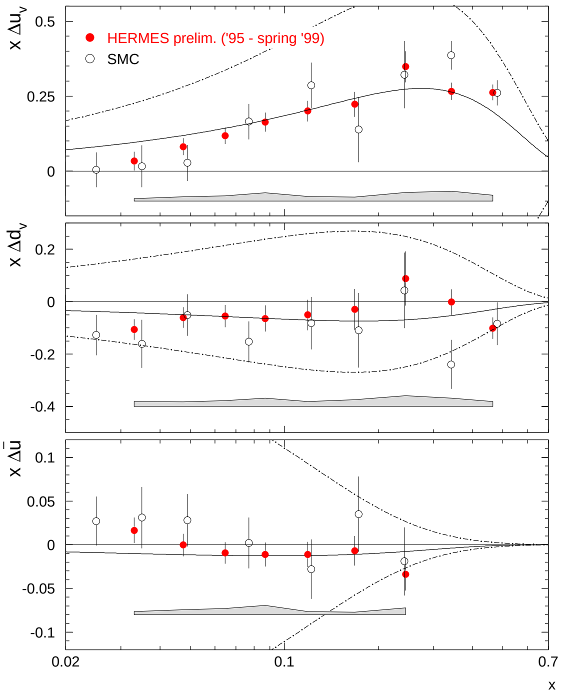

Figure 2: The polarized quark distribution functions as a function of x.

be interpreted as the probability that a quark q_f was struck if a hadron h was detected. The $P_f^h(x)$ are determined using the LUND string breaking model where the parameters were tuned to fit the hadron multiplicities measured at HERMES. The CTEQ4LQ parameterization of the unpolarized PDFs were used as input for the evaluation of $P_f^h(x)$. Eq. (2.2) is a linear equation relating the SIDIS asymmetry to the polarized quark PDFs. One such equation can be written for every hadron type detected and also for the inclusive asymmetry. Therefore the inclusive and semi–inclusive hadron asymmetries form a set of linear equations which can be solved for the individual polarized quark PDFs. Fig. 2 shows the results of the most recent HERMES analysis [3]. In this analysis the asymmetries for positively and negatively charged hadrons measured with polarized H, D, ^{3}He targets were used in addition to the inclusive data. At present only 1/7 of the collected deuterium data is included in the analysis. Due to limited statistics the sea polarization had to be assumed to be the same for all flavors. Once the analysis of the complete data set with the information from the RICH detector is finished it is expected to be possible to also extract the sea polarization.

3. Deeply Virtual Compton Scattering

Skewed Parton Distributions (SPDs) describe simultaneously different hard processes from inclusive to hard exclusive, i.e. they include parton distribution functions and form factors. Deeply Virtual Compton scattering (DVCS) is theoretically the cleanest channel to access the SPDs. However, as the final state of the DVCS process is identical to that of the Bethe–Heitler (BH) process, these two processes interfere. The beam helicity asymmetry in exclusive leptoproduction of real photons at leading twist can be written as [4]

$$d\sigma^{\uparrow} - d\sigma^{\downarrow} \sim sin(\phi) \quad Im\left[F_1\mathcal{H}_1 + \frac{x}{2-x}(F_1+F_2)\tilde{\mathcal{H}}_1 + \frac{t}{4M^2}F_2\mathcal{E}_1\right], \tag{3.1}$$

where F_1 and F_2 are the Dirac and Pauli form factors. The amplitudes $\mathcal{H}_1$, $\tilde{\mathcal{H}}_1$, and $\mathcal{E}_1$ are convolutions in t of the hard scattering parts with the SPD's. In Eq. 3.1, ϕ is the azimuthal angle between the lepton scattering plane and the photon production plane. The above given single spin asymmetry measured as a function of the azimuthal angle is $\mathrm{A_{LU}} = P_l^{-1}\left(N^+(\phi) - N^-(\phi)\right)/[N^+(\phi) + N^-(\phi)]$, where $N^{+/-}(\phi)$ is the normalized yield for the given beam helicity (+/-). The HERMES measurement of $\mathrm{A_{LU}}$ for events with only one positron and one photon detected in the spectrometer is shown in Fig. 3 for the exclusive missing mass region[5]. To account for the limited resolution of the spectrometer and smearing effects the exclusive missing mass region was chosen as $-1.5 < M_x < 1.7$ GeV which corresponds to -3σ below and $+1\sigma$ above the nucleon mass. The dependence of $\mathrm{A_{LU}}$ on the missing mass cut has been studied by plotting the sinϕ moment of $\mathrm{A_{LU}}$, $A_{LU}^{\sin\phi} = \frac{2}{N}\sum_{i=1}^{N}\frac{\sin\phi_i}{(P_l)_i}$ with $N = N^+ + N^-$, as a function of missing mass (Fig. 4). From this it is clear that smeared non–exclusive data for $\mathrm{M}_x > 2.5$ can only marginally dilute the measured exclusive asymmetry; this is included in the systematic error. The possible false asymmetry due to π^0 contamination where one photon was missed by the spectrometer was estimated to be less than 12.5% . Events where a Δ is produced are included in the exclusive data set. However, as the BH $\gamma^* p \to \gamma\Delta$ process is suppressed [6] and interference can only occur between processes with identical final states, the measured beam-spin asymmetry

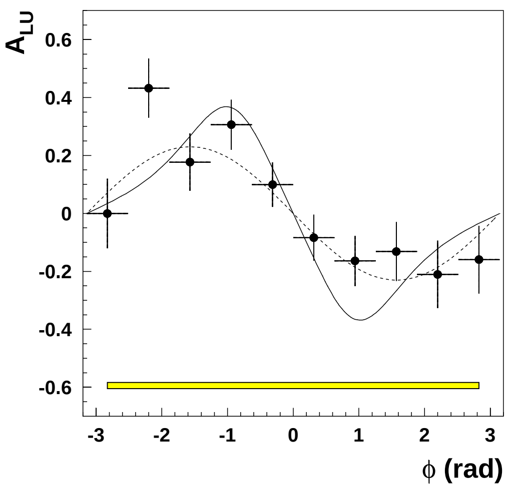

Figure 3: Azimuthal dependence of the single spin asymmetry A_{LU}. The dashed curve is a sinϕ fit with an amplitude of 0.23.

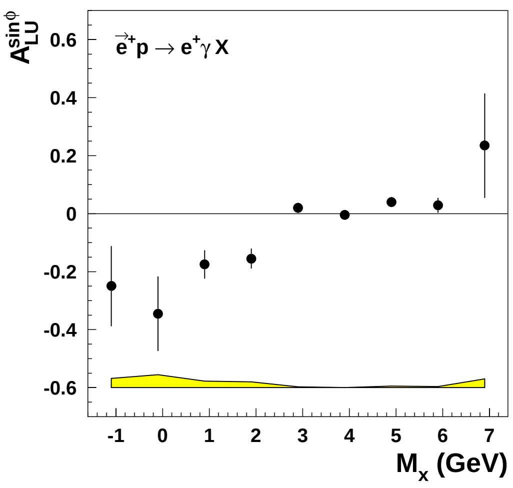

Figure 4: The sinϕ moment of the single spin asymmetry A_{LU} as a function of missing mass M_x.

can be compared to SPD based calculations. The result of a recent twist-3 calculation [7] is shown in Fig. 3 as a solid curve and agrees fairly well with the measured data.

4. Future plans

The transversity distribution functions δq_f are chiral odd and, because measured quantities must be chiral even, they cannot be accessed in an inclusive measurement. For this reason they remain the last unmeasured leading twist distribution functions. One possibility to access the δq_f is to measure the single spin asymmetry in inclusive pion production[8]. In this process the chiral odd Collins fragmentation function combines with δq_f to make a chiral even and therefore observable cross section. HERMES has measured the single spin asymmetry in semi–inclusive π^+, π^-, and π^0 production using a longitudinally polarized target[9]. The sinϕ moment of the asymmetry for π^+ and π^0 production is found to be 0.02. This measurement indicates that the Collins fragmentation function is not small. The asymmetry measured from a longitudinally polarized target is sensitive to the about 15% transverse component of the γ^* polarization, which means that for data taken with a transversely polarized target large asymmetries are expected. In 2002 – 2003 HERMES will take data with a transversely polarized hydrogen target in order to measure δq_f.

For the years 2004-2005 the collaboration is planning to upgrade the spectrometer with a new recoil detector to detect the recoil proton in exclusive processes. The detection of the recoil proton will enable the determination of exclusivity on an event–by–event basis for γ, π, and ρ electroproduction data. Information from the recoil detector will suppress contributions from Δ production. The recoil detector will also improve the t resolution. With the high statistics attainable using unpolarized targets and polarized $e^{+/-}$ beams, it will be possible to measure $\mathrm{A_{LU}}$ as a function of t.

Finally, HERMES is considering running for an additional year with a longitudinally polarized hydrogen target in order to improve the accuracy of the Δs measurement.

References

[1] K. Ackerstaff *et. al.* [HERMES Collaboration], *Nucl. Instrum. Meth.* **A417** (1998) 230

[2] A. Siderov These Proceedings

[3] T. Lindemann, Spin 2000 proceedings, edited by K. Hatanaka et. al., Osaka, Japan, AIP Conf. Proc. 570, 2001, p. 392

[4] A.V. Belitsky et al., *Nucl. Phys.* **B 593** (2001) 289

[5] A. Airapetian et al. [HERMES Collaboration], *Phys. Rev. Lett.* **87** (2001) 182001

[6] L.L. Frankfurt, M.V. Polyakov, and M. Strikman, Contribution to the Workshop "Jefferson Lab Physics and Instrumentation with 6-12 GeV Beams", Newport News, Va, June 15-18 1998, `hep-ph/9808449`

[7] N. Kievl, M. Polyakov, and M. Vanderhaegen, *Phys. Rev.* **D 63** (2001) 114014

[8] J.C. Collins, *Nucl. Phys.* **B 396** (1993) 161

[9] A. Airapetian *et. al.* [HERMES Collaboration], *Phys. Rev. Lett.* **84** (2000) 4047