Selected recent HERMES results

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Abstract. The first phase of HERMES data taking covers the years 1995 to 2000. Data were taken with longitudinally polarised $^3$He (1995), hydrogen (1996-1997) and deuterium (1998-2000) targets, but also with several other unpolarised targets ($H_2$, $D_2$, $^3$He, $^4$He, $N_2$, Ne and Kr). Some selected results from this data taking period are discussed: the spin-dependent structure function $g_1$ from deuterium, which has been measured with high accuracy down to $x = 0.0021$; quark and antiquark helicity distributions from semi-inclusive deep-inelastic scattering on hydrogen and deuterium, which indicate that the anti-quark distributions are consistent with zero and with each other and do not favour a substantial negative polarisation of the strange quark sea; and the first measurement of nuclear attenuation of identified fast charged and neutral pions, charged kaons, protons and antiprotons produced from nitrogen and krypton targets.


1 Introduction

HERMES is one of the four experiments at the HERA electron-proton collider at DESY. It uses the high current longitudinally polarised electron or positron beams of HERA with a beam energy $E$ of about 27.6 GeV together with polarised and unpolarised gas targets internal to the storage ring. Scattered electrons and particles produced in the deep-inelastic electron-nucleon interactions are detected and identified by an open geometry forward spectrometer with large momentum and solid angle acceptance [1]. HERMES is based on two special techniques: longitudinal electron polarisation in a high energy storage ring [2], which is achieved by a system of spin rotator magnets [3], and a storage cell target [4] where the nuclear-polarised atoms from a high intensity polarised source [5] are present as pure atomic species without dilution from unpolarised target material.

The primary scientific goal of HERMES was and still is the detailed investigation of the spin structure of the nucleon. But the physics reach of the experiment extends well beyond this specific aspect of hadronic physics and the experiment explores many details of hadron structure, hadron production and hadronic interactions with electromagnetic probes at centre-of-mass energies $\sqrt{s}$ of around 7 GeV.

The first phase of HERMES data taking covers the years 1995 to 2000. Data were taken with longitudinally polarised $^3$He (1995), hydrogen (1996-1997) and deuterium (1998-2000) targets, but also with several other unpolarised targets ($H_2$, $D_2$, $^3$He, $^4$He, $N_2$, Ne and Kr). These data yielded a lot of high precision results on inclusive and semi-inclusive polarised deep-inelastic scattering and have confirmed and extended our understanding of the contribution of quark spins to the spin of the nucleon. The results include: the measurement of the spin-dependent structure function $g_1$ for $^3$He, $H$ and $D$, the determination of the generalised Drell-Hearn-Gerasimov integral for proton, neutron and deuterium, the flavour decomposition of the quark helicity distributions from semi-inclusive polarised deep-inelastic scattering, a first indication of a positively polarised gluon distribution from a double-spin asymmetry in the production of pairs of hadrons with high transverse momenta, the observation of a double-spin asymmetry in the cross section for exclusive electro-production of vector mesons, an experimental indication for effects of transversity in the nucleon, azimuthal single-spin asymmetries in hard exclusive electro-production of real photons and pions which can be related to generalised parton distributions, the investigation of longitudinal spin-transfer in electro-production of $\Lambda$ hyperons in the current fragmentation region and the observation of a positive transverse polarisation of $\Lambda$ particles produced in quasi-real photo-production. A comprehensive review of these results on spin-asymmetries in deep-inelastic electron-nucleon scattering can be found in [4]. Additional results include: the determination of a flavour asymmetry in the light quark sea from charged pion production from unpolarised hydrogen and deuterium targets [8], multiplicity distributions in pion electro-production [9], cross sections and decay angular distributions for hard exclusive electro-production of vector mesons [10], the first observation of a coherence length effect on exclusive coherent and incoherent electro-production of $\rho^0$ mesons [11].
from nuclear targets and their $Q^2$ dependence [12][13], and the measurement of the attenuation of fast hadrons produced from nuclear targets [14][15]. Many more results from ongoing analyses based on data collected in this first phase of data taking will be published in the near future. In this paper only a few aspects are discussed: the spin-dependent structure function $g_1$ from deuterium, quark and antiquark helicity distributions from semi-inclusive deep-inelastic scattering on $D$ and $H$, and the attenuation of fast hadrons produced from nuclear targets.

The second phase of HERMES data taking will cover the years until the end of 2006. The physics program, which is summarised in the contribution by W.D. Nowak to this conference [16], will concentrate on measurements which is summarised in the contribution by W.D. Nowak to this conference [16].

The seven data points from SMC at even lower values of $x$ have been applied yet to these preliminary HERMES data. They have substantially smaller error bars and much smaller point to point fluctuations than those from the other experiments, and determine the $x$ dependence of this ratio now very well. This is especially evident in the range of very small $x$, but also at higher $x$ where the central values of various previous data sets scattered substantially. At $x$ below about 0.03 the asymmetry is compatible with zero, with a slight tendency to negative values. One can conclude from this behaviour that at these small $x$ values $\Delta d(x)$ and $\Delta u(x)$ have about the same magnitude, but opposite sign. If the asymmetry really gets negative then one can speculate that either the magnitude of the down-quark helicity distribution must get bigger than the up-quark helicity distribution or that the net sea-quark helicity distribution must be negative. At large $x$ the rise of the asymmetry with $x$ is much less steep than for the proton data [17][18][19], the limit at $x \to 1$ possibly being substantially smaller than unity.

The preliminary HERMES result from the 2000 data for $g_1^d(x)$ at the measured values of $Q^2$ is shown as a function of $x$ together with the corresponding data from E143, E155 and SMC in the $x$ range covered by the HERMES data.

2 The spin-dependent deuteron structure function $g_1^d(x, Q^2)$

In the years 1998 to 2000 data were taken at HERMES with the longitudinally polarised deuterium target. Altogether about 9 million DIS events were collected, corresponding to an integrated luminosity of about 80 pb$^{-1}$. The average beam polarisation was $|P_B|$ = 0.53 and the average target polarisation $|P_T|$ = 0.845. The kinematic range of the data is $0.0021 < x < 0.85$, $0.1 < y < 0.91$, $Q^2 > 0.1$ GeV$^2$ and $W^2 > 3.24$ GeV$^2$. Here $x = Q^2/2M\nu$ is the Bjorken variable, $-Q^2$ is the squared four-momentum transfer, $M$ is the nucleon mass, $\nu$ is the energy of the virtual photon, $y = \nu/E$, and $W$ is the invariant mass of the photon-nucleon system.

The preliminary HERMES result for the structure function ratio $g_1^d/F_1^d$ for the data from the year 2000 is shown in Fig. 1 together with the corresponding data from SMC [17], E143 [18] and E155 [19]. Here

$$g_1^d(x, Q^2) = \frac{1}{2}[g_1^u + g_1^d](x, Q^2) = \frac{1}{4} \sum_q e_q^2 \Delta q(x, Q^2)$$

$$= \frac{5}{36}[\Delta u + \Delta \bar{u} + \Delta d + \Delta \bar{d} + \Delta s + \Delta \bar{s}](x, Q^2)$$

$$- \frac{1}{12}[\Delta s + \Delta \bar{s}](x, Q^2)$$

is the spin-dependent structure function and $F_1^d$ the corresponding spin-independent structure function. $\Delta q(x, Q^2)$ is the quark helicity distribution for flavour $q$ and $e_q$ is the quark charge in units of the elementary charge. For each data point in $x$ the mean $Q^2$ is different for each experiment as can be seen from the lower panel of the figure. The seven data points from SMC at even lower values of $x$ down to $x \cong 10^{-4}$ are not shown here. No corrections for smearing effects, which will increase somewhat the error bars and influence the central values mainly at very low $x$, have been applied yet to these preliminary HERMES data. They have substantially smaller error bars and much smaller point to point fluctuations than those from the other experiments, and determine the $x$ dependence of this ratio now very well. This is especially evident in the range of very small $x$, but also at higher $x$ where the central values of various previous data sets scattered substantially. At $x$ below about 0.03 the asymmetry is compatible with zero, with a slight tendency to negative values. One can conclude from this behaviour that at these small $x$ values $\Delta d(x)$ and $\Delta u(x)$ have about the same magnitude, but opposite sign. If the asymmetry really gets negative then one can speculate that either the magnitude of the down-quark helicity distribution must get bigger than the up-quark helicity distribution or that the net sea-quark helicity distribution must be negative. At large $x$ the rise of the asymmetry with $x$ is much less steep than for the proton data [17][18][19], the limit at $x \to 1$ possibly being substantially smaller than unity.

The preliminary HERMES result from the 2000 data for $g_1^d(x)$ at the measured values of $Q^2$ is shown as a function of $x$ together with the corresponding data from SMC in Fig. 1. It is evident that with these new data also the $x$ dependence of $g_1^d$ is very well determined in the range $x > 2 \cdot 10^{-3}$. Below $x$ values of about $3 \cdot 10^{-2}$ it is compatible with zero with a slight tendency to negative values.