COLLINS AND SIVERS ASYMMETRIES ON THE DEUTERON FROM COMPASS DATA

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COMPASS is a fixed polarised target experiment presently running at CERN. In 2002, 2003, and 2004 a 160 GeV/c polarised μ^+ beam was utilized coming from SPS and scattered off a ^{6}LiD (deuteron) target. The nucleons in the target can be polarised either longitudinally or transversely with respect to the μ^+ beam. Around 20% of the running time has been dedicated to transverse polarisation measurements on the deuteron target. The final results for the Collins and the Sivers asymmetries extracted from the 2002 data are presented. Error estimates are shown for the data taken in 2003 and 2004. The COMPASS collaboration plans a run with a NH_3 (proton) target in 2006. Estimated projections for the statistical accuracy on the proton are also given.

1. Introduction

The transversity distribution $\Delta_T q(x) = q(x)_\uparrow - q(x)_\downarrow$ supplies together with the unpolarised distribution functions $q(x)$ and the helicity distribution $\Delta q(x)$ a description of the quark structure of the nucleon at the twist-two (leading twist) level. The inclusive cross-section for deep inelastic scattering of longitudinally polarised leptons on polarised nucleons, at the leading twist, can be written as a function of $q(x)$, $\Delta q(x)$ and $\Delta_T q(x)$ [1]. $\Delta_T q(x)$ is chiral-odd and can be extracted from the Drell-Yan process in polarised nucleon-nucleon scattering or from semi-inclusive deep inelastic scattering (SIDIS) on a transversely polarised target, where a part of the hadronic system is detected in final state. In SIDIS the convolution of $\Delta_T q(x)$ with the chiral-odd Collins fragmentation function $\Delta D_q^h(z, p_T^h)$ is measured via azimuthal single spin asymmetries (SSA) [2]. Another mechanism of generating SSA was proposed by Sivers [3] which takes into account the dependence of the nucleon structure on the intrinsic quark transverse momentum k_T. This effect is described by Sivers distribution function, $\Delta_T^0 q(x, k_T)$. Collins and Sivers effects are functions of linearly independent kinematic variables and, therefore, decouple from each other in SIDIS on transversely polarised nucleons. In general, there are several methods to study transversity at COMPASS. These are the azimuthal distributions of single hadrons (discussed here), the azimuthal dependence of the plane containing hadron pairs [4] and the measurements of transverse polarisation of Λ hyperons [5].

2. Collins and Sivers angles

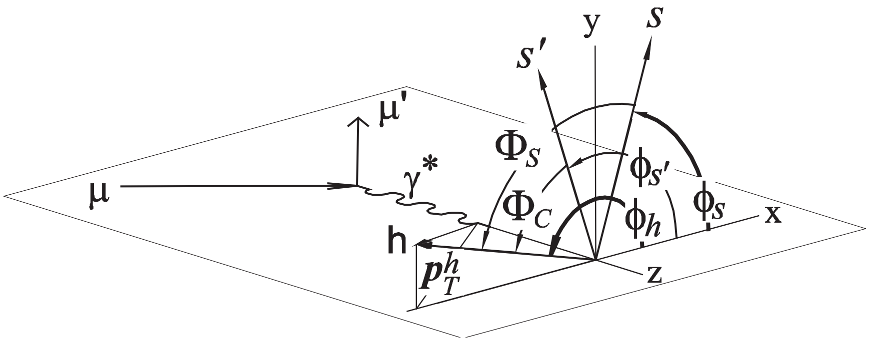

Figure 1. Definition of Collins and Sivers angles in COMPASS.

The Collins fragmentation function of a quark of flavour q in a hadron h can be written [6]

$$\Delta D_q^h(z, \mathbf{p_T^h}) = D_q^h(z, p_T^h) + \Delta D_q^h(z, p_T^h) \cdot \sin \Phi_C, \tag{1}$$

where $\mathbf{p_T^h}$ is the hadron transverse momentum with respect to the virtual photon direction and $z = E_h/(E_l - E_{l'})$ is the fraction of available energy carried by the hadron, E_h is the energy of the hadron, E_l is the energy of the incoming lepton and $E_{l'}$ is the energy of the scattered lepton. Φ_C is so-called Collins angle. The latter is usually defined in the system where the z-axis is the virtual photon direction and the x-z plane is the muon scattering plane, see Fig. 1. In this frame $\Phi_C = \phi_h - \phi_s'$, where ϕ_h is the hadron azimuthal angle, and ϕ_s' is the azimuthal angle of the transverse spin of the struck quark. QED calculations are used to show that the components of the quark spin in initial and final state are related [7] $\phi_s' = \pi - \phi_s$, therefore $\Phi_C = \phi_h + \phi_s - \pi$. The fragmentation function $\Delta D_q^h(z, p_T^h)$ couples to transverse spin distribution function $\Delta_T q(x)$ and generates a SSA, A_{Coll}, which depends on x, z and p_T^h.

According to Sivers the difference in the probability of finding an unpolarised quark of transverse momentum $\mathbf{k_T}$ and $\mathbf{-k_T}$ inside a polarised nucleon can be expressed in the following way [8]:

$$P_{q/p^{\uparrow}}(x, \mathbf{k_T}) - P_{q/p^{\uparrow}}(x, -\mathbf{k_T}) = \sin \Phi_S \cdot \Delta_0^T q(x, k_T^2), \qquad (2)$$

where $\Phi_S = \phi_h - \phi_s$ is the azimuthal angle of the quark with respect to the nucleon transverse spin orientation. The SSA A_{Siv} has a non-vanishing contribution at leading twist [9][10] due to coupling of the Sivers function to the unpolarised fragmentation function $D_q^h(z, p_T^h)$.

3. COMPASS experiment and data analysis

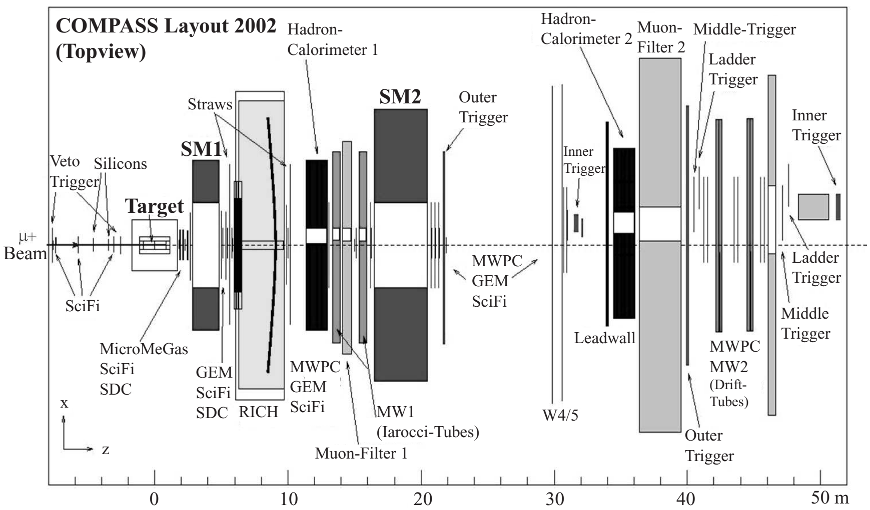

Figure 2. Schematic view of the COMPASS experiment .

COMPASS [11][12] is a fixed target experiment located in CERN. A 160 GeV μ^+ beam, naturally polarised by the π^+ decay, with an intensity of $2{\cdot}10^8$/spill is used, with a 4.8 s spill every 16.2 s. The layout of the COMPASS experiment is shown in Fig. 2. Main components of the COMPASS spectrometer are the polarised ^{6}LiD target and two spectrometer magnets: SM1 and SM2. The polarised target consists of two ^{6}LiD cells, each 60 cm long, located along the beam one after the other in two separate RF cavities. Data are taken simultaneously on the two target cells which are oppositely polarised. The polarisation is reversed once a week when operating in the transverse polarisation mode. SM1, the large-angle spectrometer magnet (up to 180 mrad), has an integrated field-strength of 1.0 Tm and enables the measurement of particles of lower momentum. SM2, the small-angle spectrometer magnet (up to 30 mrad), has an integrated field-strength of 4.4 Tm and measures particles with higher momenta. Both spectrometer stages are equipped with detectors for track reconstruction and particle identification.

20% of the total beam-time in 2002, 2003 and 2004 was devoted to the run with the transversely polarised deuteron target. The accumulated sample of 2002 data with transverse polarisation of the target comprises $6 \cdot 10^9$ events. The analysis discussed below refers to this sample. The sample was taken during two separate periods. In each period a polarisation was reversed after 4-5 days by changing the RF frequencies in two target cells.

To select semi-inclusive events, an incoming and scattered muon (primary vertex) plus at least one hadron from this vertex were required. Muon identification was performed with a muon filters, consisting of a large amount of material to pass. To ensure a DIS event, the kinematic cuts $Q^2 > 1$ (GeV/c)^2, $W > 5$ GeV/c^2 and 0.1< y <0.9 were applied to the data. The upper limit on y was applied to keep radiative corrections small. In addition the transverse momentum cut $p_T^h > 0.1$ GeV/c was applied to unambiguously calculate angles. Asymmetries have been extracted for the hadron with the highest energy (leading, $z > 0.25$) as well as for all detected hadrons with $z > 0.2$.

Collins and Sivers asymmetries were fitted separately. The number of events for each cell is given by

$$N(\Phi_{C/S}) = N_0 \cdot \alpha(\Phi_{C/S})(1 + \epsilon_{C/S} \sin \Phi_{C/S}), \tag{3}$$

where $\epsilon_{C/S}$ is the amplitude of the experimental asymmetry, α is a function which depends on the detector acceptance, and N_0 is product of the muon flux, the number of particles in the target and the spin averaged cross-section. The amplitude can be written as a function of the Collins and Sivers asymmetries:

$$\epsilon_C = A_{Coll} \cdot P_T \cdot f \cdot D_{NN} \qquad \epsilon_S = A_{Siv} \cdot P_T \cdot f, \tag{4}$$

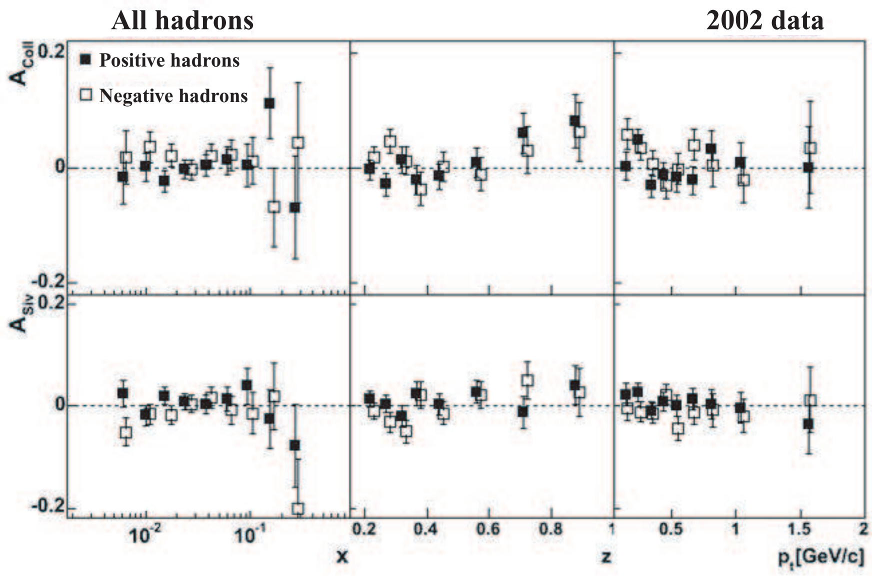

Figure 3. Collins (upper row) and Sivers (lower row) asymmetry for positive (filled squares) and negative (open squares) all hadrons as a function of x, z and p_T^h (left to right). Only statistical errors are shown.

where P_T (≈ 0.5) is the target polarisation, $D_{NN} = (1-y)/(1-y+y^2/2)$ is the transverse spin transfer coefficient (for Sivers $D_{NN} = 1$), and f (≈ 0.4) is the target dilution factor. The asymmetry $\epsilon_{C/S}$ is fitted separately for the two target cells with two opposite spin orientations:

$$\epsilon_{C/S} \sin \Phi_{C/S} = \frac{N_h^{\uparrow}(\Phi_{C/S}) - R \cdot N_h^{\downarrow}(\Phi_{C/S})}{N_h^{\uparrow}(\Phi_{C/S}) - R \cdot N_h^{\downarrow}(\Phi_{C/S})}. \tag{5}$$

$R = N_{h,tot}^{\uparrow}/N_{h,tot}^{\downarrow}$ is a normalisation factor and corresponds to the ratio of the total number of events with two target polarisation orientations. The obtained results for the asymmetries are plotted against the kinematic variables x, z and p_T^h (see Fig. 3 for all hadrons and for leading hadrons see Fig. 4) [13]. Only statistical errors are shown. Filled squares correspond to the positively charged hadrons and unfilled squares points correspond to the negatively charged hadrons.

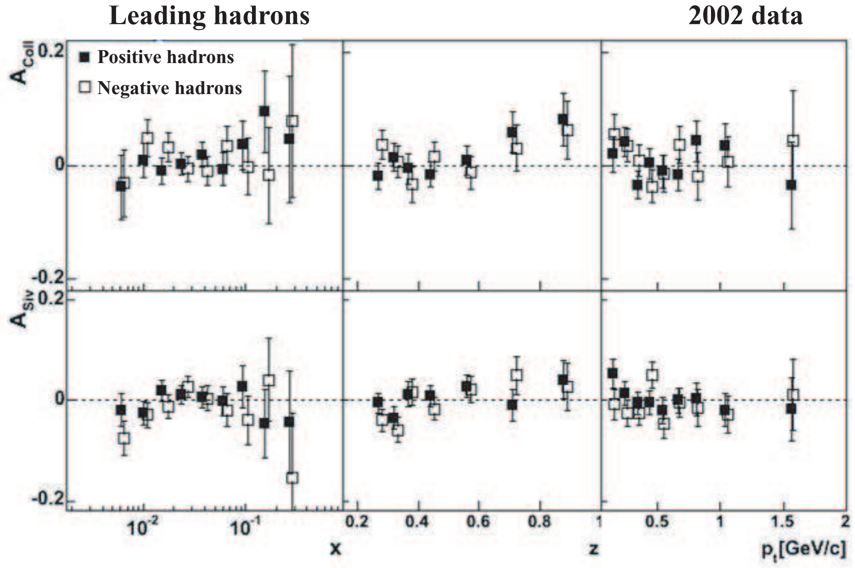

Figure 4. Collins (upper row) and Sivers (lower row) asymmetry for positive (filled squares) and negative (open squares) leading hadrons as a function of x, z and p_T^h (left to right). Only statistical errors are shown.

Possible sources for systematic errors have been thoroughly investigated and various tests were performed. It was concluded that systematic errors are smaller than the quoted statistical errors [13].

Extensive Monte Carlo (MC) studies were performed and a good agreement between MC and data has been achieved. MC investigations have shown that around 20% of correctly reconstructed leading hadrons are not pions but mainly kaons and protons.

4. Results and discussions

As we can see in Fig. 3 and 4 both the Collins and Sivers asymmetries are small and compatible with zero. This may hint to a cancellation between proton and neutron or the Collins mechanism is too small. However, if the Collins function $\Delta D_q^h(z, p_T^h)$ is not zero and as large as indicated from preliminary results by the BELLE [14][15] collaboration, then this is an evidence for the cancellation in the isoscalar target.

Recent phenomenological fits were performed on HERMES and COMPASS data [16][18] for Sivers asymmetries and for Collins asymmetries [19].

The compatibility of HERMES results [17] for protons and COMPASS results on the deuteron target was demonstrated.

In 2003 and 2004 COMPASS has collected data on a transversely polarised deuteron target. The estimated statistical errors for the Collins asymmetries from all 2002-2004 data are compared with the statistical errors of the published data in Fig. 5 (top plots). Apart from that, it is possible to separate π, K and p employing the information from RICH (Ring Imaging Čerenkov Detector) available for 2003 and 2004 data. The COMPASS collaboration plans to take data on a transversely polarised proton target (NH_3) in 2006. The statistical accuracy for the measurements of A_{Coll} on both the deuteron (2002-2004 data) and proton targets, assuming 30 days of data taking, is shown in Fig. 5 as a function of x. The current setup was implied.

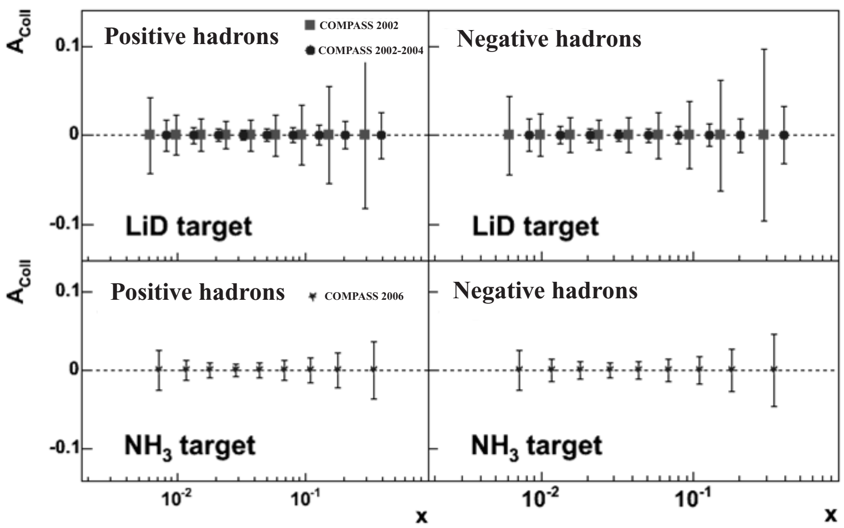

Figure 5. Estimate of the statistical errors for A_{Coll} as a function of x for deuterium (top) and proton (bottom) targets for positive (left) and negative hadrons (right).

COMPASS 2002 measurements have shown that A_{Coll} and A_{Siv} are small and almost vanishing. The COMPASS data on the proton target (NH_3) will be available after the 2006 run. These data with the new measurements of the Collins function reported by BELLE collaboration [14][15] will allow a flavour separation, giving a precise information about a transverse spin structure of the nucleon.

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