Collins and Sivers asymmetries on the deuteron from the COMPASS data

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Abstract. COMPASS is a fixed target experiment presently running at CERN. In 2002, 2003, and 2004 it used a 160 GeV polarized muon beam coming from SPS and scattered off a ^{6}LiD (deuteron) target. The nucleons in the target can be polarized either longitudinally or transversely with respect to the muon beam and 20% of the running time has been devoted to transverse polarization. Hereby the final results for the Collins and the Sivers asymmetries calculated from the data taken in transverse polarization in 2002 are presented. In the forthcoming 2006 run, COMPASS plans to run with a NH_3 (proton) target. Projections for the statistical accuracy which will be ultimately achieved on both the proton and the deuteron asymmetries are also given.

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THE THEORETICAL FRAMEWORK

The cross-section for polarized deep inelastic scattering[1] of leptons off spin 1/2 hadrons can be expressed, at the leading twist, as a function of three independent quark distribution function: $q(x)$, $\Delta q(x)$ and $\Delta_T q(x)$. The latter is chiral-odd and can be measured in nucleon - (anti) nucleon hard scattering or in semi-inclusive deep inelastic scattering (SIDIS). In SIDIS $\Delta_T q(x)$ can be probed in combination with the Collins fragmentation function, $\Delta D_a^h(z, p_T^h)$, chiral-odd as well, via azimuthal single spin asymmetries (SSA) in the hadronic end-product[2]. A similar effect can arise from the dependence of the nucleon structure on the intrinsic quark transverse momentum k_T[3]; such an effect is described by the so called Sivers distribution function, $\Delta_0^T q(x, k_T)$.

Leptoproduction on transversely polarized nucleons is a favourable setting to disentangle the Collins and Sivers effects since they are function of linearly independent kinematic variables.

According to Collins, the fragmentation function of a quark of flavour a in a hadron h can be written as[4]:

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

where $\mathbf{p_T^h}$ is the final 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 hadron energy, E_l is the incoming lepton energy and $E_{l'}$ is the scattered lepton energy). The angle appearing in the fragmentation function, known as “Collins angle” and noted as Φ_C, is conveniently defined in the system where the z-axis is the virtual photon direction and the x-z plane is the muon scattering plane. 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. Since $\Phi'_s = \pi - \Phi_s$, with Φ_s the azimuthal angle of the transverse spin of the initial quark (nucleon), the relation $\Phi_C = \Phi_h + \Phi_s - \pi$ is also valid. The fragmentation function $\Delta D_a^h(z, p_T^h)$ couples to transverse spin distribution function $\Delta_T q(x)$ and gives rise to SSA (denoted as A_{Coll}) dependent on x, z and p_T^h kinematic variables.

Following the Sivers hypothesis, 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 written as [5]:

$$\mathrm{P}_{q/p^\uparrow}(x, \mathbf{k_T}) - \mathrm{P}_{q/p^\uparrow}(x, -\mathbf{k_T}) = \sin\Phi_S \, \Delta_0^T q(x, k_T^2)$$

where $\Phi_S = \Phi_k - \Phi_s$ is the azimuthal angle of the quark with respect to the nucleon transverse spin orientation. It has been demonstrated by theoretical arguments [6, 7], that SSA (denoted as A_{Siv}) coming from the coupling of the Sivers function with the un-polarised fragmentation function $D_a^h(z, p_T^h)$ can be observed at the leading twist from polarised Semi-Inclusive DIS.

PHYSICS RESULTS AND PERSPECTIVES

The COMPASS [8, 9] experiment makes use of a high energy (160 GeV), intense (10^8/spill), muon beam naturally polarised by the $\pi-$ decay mechanism. The polarized 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 polarized.

Hereby we discuss the analysis of the data collected in year 2002 with target polarization oriented transversely to the beam direction. This sample, about 200 pb^{-1} in integrated luminosity and divided in two separate periods, is about 20% of the total beam time. Within each period, after 4–5 days of data taking, a polarization reversal was performed by changing the RF frequencies in the two cells. The full description of the analysis and results can be found in [10].

Events were selected in which a primary vertex (with identified beam and scattered muon) was found in one of the two target cells with a least one outgoing hadron. A clean separation of muon and hadron samples was achieved by cuts on the amount of material traversed in the spectrometer. In addition, the kinematic cuts $Q^2 > 1(\mathrm{GeV}/c)^2$, $W > 5$ GeV/c^2 and $0.1 < y < 0.9$ were applied to the data to ensure a deep-inelastic sample above the region of the resonances and within the COMPASS trigger acceptance. The upper bound on y also serves to keep radiative corrections small. SSA have been looked for both the leading hadron in the event, and for all the hadrons.

In transverse polarisation, one can write the number of events as follows:

$$N(\Phi_{C/S}) = \alpha(\Phi_{C/S}) \cdot N_0 \left(1 + \varepsilon_{C/S} \sin\Phi_{C/S}\right),$$

where ε is the amplitude of the experimental asymmetry and α is a function containing the apparatus acceptance. The former amplitude can be expressed as a function of the

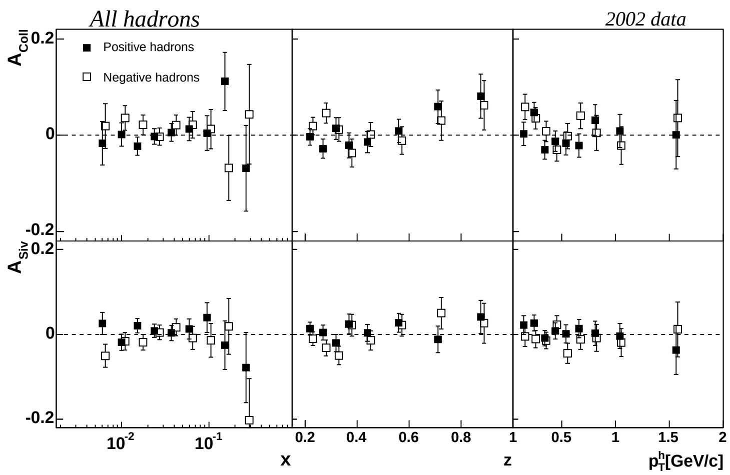

FIGURE 1. Collins and Sivers asymmetry for positive (full points) and negative (open points) hadrons as a function of x, z and p_T^h.

Collins and Sivers asymmetries through the expressions:

$$\varepsilon_C = A_{Coll} \cdot P_T \cdot f \cdot D_{NN} \qquad\qquad \varepsilon_S = A_{Siv} \cdot P_T \cdot f\,,$$

where P_T ($\simeq 0.45$) is the polarisation of the target, D_{NN} is the spin transfer coefficient, and f ($\simeq 0.40$) is the target dilution factor. To eliminate systematic effects due to acceptance, in each period the asymmetry ε_C (ε_S) is fitted separately for the two target cells from the event flux with the two target orientations using the expression:

$$\varepsilon_{C/S} \sin\Phi_{C/S} = \frac{N_h^{\uparrow}(\Phi_{C/S}) - R \cdot N_h^{\downarrow}(\Phi_{C/S} + \pi)}{N_h^{\uparrow}(\Phi_{C/S}) + R \cdot N_h^{\downarrow}(\Phi_{C/S} + \pi)}$$

where $R = N_{h,tot}^{\uparrow}/N_{h,tot}^{\downarrow}$ is the ratio of the total number of events in the two target polarisation orientations. The results of the asymmetries plotted against the kinematic variables x, z and p_T^h are shown in Fig. 1 for positive (full points) and negative (open points) hadrons. Similar results have been obtained selecting only the leading hadrons from the reactions.

Possible sources for systematic errors have been deeply investigated as described in [10]: the conclusion from those studies is that systematic errors affecting the measurements are smaller than the quoted statistical errors.

Within the accuracy of the measurements, both the Collins and Sivers asymmetries turned out to be small and compatible with zero, with a marginal indication of a Collins effect at large z for both positive and negative charges.

Concerning the Sivers asymmetries, a recent phenomenological work[11] has demonstrated that HERMES results for protons[12] and COMPASS results do not contradict each other.

In 2003 and 2004 COMPASS has been collecting data on a transversely polarized deuteron target with the same share with longitudinal configuration as for 2002. Due

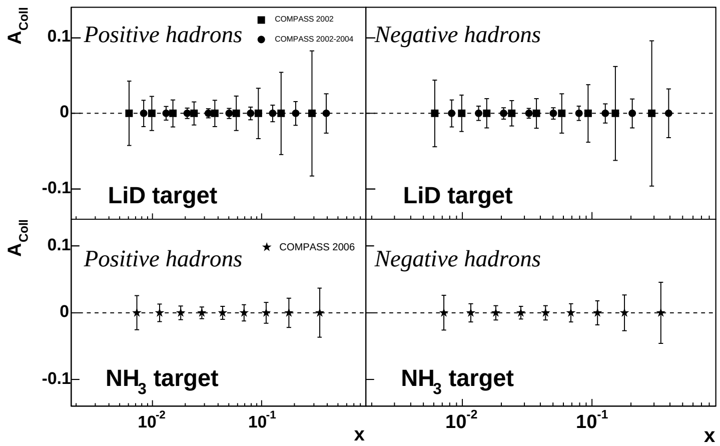

FIGURE 2. Estimation of statistical errors for A_{Coll} as a function of x for deuterium (top) and proton (bottom) targets and for positive (left) and negative hadrons (right).

to the major improvements done on the trigger system, and on the DAQ hardware and software, the total integrated lumonisity taken with a transversely polarized target now amounts to more than 2 nb^{-1}. After the 2005 stop of all the accelerators in CERN, the COMPASS collaboration plans to take data on a transversely polarized proton target (NH_3) in 2006. The statistical accuracy for the measurement of A_{Coll} on both the deuteron and proton targets is shown in figure 2 as a function of x. For the proton, it was assumed to have 30 days of data taking.

COMPASS has shown that A_{Coll} and A_{Siv}, if non vanishing, are tiny. The COMPASS proton data, available after the 2006 run, together with the new measurements of the Collins function recently shown by the BELLE [13] collaboration, will permit a flavor decomposition of $\Delta_T q(x)$ achieving an accurate look at the "transverse" spin structure of the nucleon.

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