Transverse spin effects at COMPASS

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Abstract. The COMPASS experiment at the CERN SPS has a broad physics program focused on the nucleon spin structure and on hadron spectroscopy, using both muon and hadron beams. One of the main objectives for the spin program with the muon beam is the measurement of transverse spin effects in semi inclusive deep inelastic scattering. A longitudinally polarized 160 GeV/c muon beam is impinging on a transversely polarized target: from 2002 to 2004 a ^{6}LiD (deuteron) target has been used, while during 2007 data taking a NH_3 (proton) target was put in place. All measured transverse asymmetries on deuteron have been found to be small, and compatible with zero, within the few percent statistical errors. These results, which are currently used as input for global fits, can be interpreted as cancellation between u and d quark contribution in the deuteron. The first results for the Collins and Sivers asymmetries for charged hadrons from the 2007 proton COMPASS data are also presented and discussed.

Keywords: Semi-Inclusive Deep Inelastic Scattering, Collins asymmetry, Sivers asymmetry, Transversely polarized target, COMPASS
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INTRODUCTION

To fully describe the nucleon structure at leading order, three parton distribution functions (PDF) are needed: the well known momentum distribution function $q(x)$, the relatively well known helicity distribution $\Delta q(x)$ and finally the transversity distribution function $\Delta_T q(x)$ that gives the probability of finding a quark with spin parallel (or anti-parallel) to nucleon spin in a transversely polarized nucleon. Due to its chirally-odd nature, the transversity PDF can be measured only coupled with another chirally-odd quantity. For this reason transversity can not be measured in inclusive DIS experiments, but it is accessible in semi-inclusive DIS scattering. In COMPASS [1] the channels used to access transversity are single hadron production, hadron pair production and polarization of the Λ hyperons, addressed both on proton and on deuteron data.
From 2002 to 2007 COMPASS took data with a longitudinally polarized 160 GeV/c muon bin impinging on a polarized target. During 2002-2004 data was taken with a 2-cells ^{6}LiD target (dilution factor $f \sim 0.38$ and polarization $P_T \sim 50\%$), while during 2007, a three cells polarized NH_3 target (dilution factor $f \sim 0.14$ and $P_T \sim 90\%$) was used.

COLLINS AND SIVERS ASYMMETRIES

According to Collins [2], the fragmentation function of a polarized quark into an unpolarized hadron shows an azimuthal modulation with respect to the plane defined by the quark momentum and the quark spin. This gives rise to a distribution of the produced hadrons $N_h(\Phi_C) = N_h^0\,[1 + P_T\, D_{NN}\, A_{Collins}\sin(\Phi_C)]$, where $D_{NN} = \frac{(1-y)}{(1-y+y^2/2)}$ is the spin transfer coefficient from the photon to the struck quark. The angle Φ_C, known as the Collins angle, 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 $\Phi_C = \phi_h - \phi_{s'} = \phi_h + \phi_s - \pi$, where ϕ_h is the azimuthal angle of the produced hadron, ϕ_s the azimuthal angle of the transverse spin of the initial nucleon and $\phi_{s'} = \phi_s - \pi$ is the azimuthal angle of the stuck quark spin. The Collins asymmetry $A_{Collins}$ is the convolution of transversity PDF and the Collins fragmentation function:

$$A_{Collins} = \frac{\sum_q e_q^2\, \Delta_T q(x)\, \Delta_T^0 D_q^h(z, p_T^h)}{\sum_q e_q^2 q D_q^h(z, p_T^h)}, \tag{1}$$

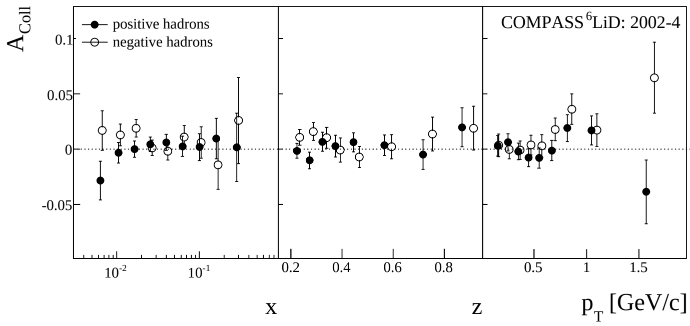
where $z = E_h/(E_l - E_l')$ is the fraction of available energy carried by the hadron and p_T^h is the hadron transverse momentum. Comparing the number of produced hadrons with two opposite polarizations, the amplitude of the modulation gives access to the Collins asymmetry.

When the quark transverse momentum k_T is taken into account, the SIDIS hadron production cross section [3] contains several independent target transverse spin dependent asymmetries. Among them the Sivers asymmetry is related to the Sivers transverse momentum dependent (TMD) PDF [4] that measures the coupling of the intrinsic transverse momentum of the unpolarized quarks to the spin in a transversely polarized nucleon. In SIDIS the azimuthal modulation of inclusively produced hadrons is $N_h(\Phi_S) = N_h^0\,[1 + P_T\, A_{Sivers}\sin(\Phi_S)]$, where the Sivers angle Φ_S, defined in the same reference system as the Collins angle, is $\Phi_S = \phi_h - \phi_s$. The Sivers asymmetry A_{Sivers} is given by the convolution of the unpolarized fragmentation function with the Sivers PDF $\Delta_T^0 q(x, \vec{k}_T)$

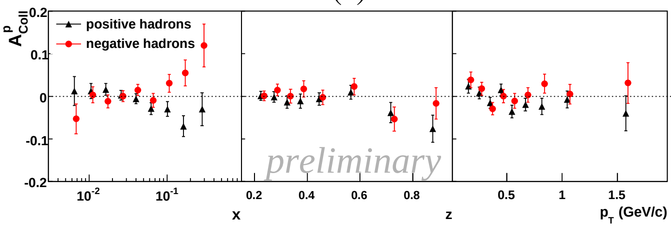
$$A_{Sivers} = \frac{\sum_q e_q^2\, \Delta_T^0 q(x, \vec{k}_T)\, D_q^h(z)}{\sum_q e_q^2 q(x) D_q^h(z)}. \tag{2}$$

RESULTS

The events coming from a primary vertex in the DIS region are selected, requiring the photon virtuality Q^2 to be above 1 GeV/c, the fractional energy of the virtual photon between 0.1 and 0.9 and the invariant mass of the hadronic state above 5 GeV/c^2. Moreover only hadrons with $p_T > 0.1$ (for a good definition of the hadron azimuthal angle) and $z > 0.2$ (in order to be in the current fragmentation region) are accepted. The final statistics after all cuts is, on deuteron, 8.5 M positive hadrons and 7.0 M negative hadrons. The results on proton are determined from only a fraction of $\sim 20\%$ of total collected data, corresponding to 5.7 M positive and 4.5 M negative hadrons.



(a)



(b)

FIGURE 1. **(a)** Collins asymmetries as a function of x, z, p_T^h on deuteron, for positive hadrons (closed circles) and negative hadrons (open circles). **(b)** Collins asymmetries as a function of x, z, p_T^h on proton, for positive hadrons (triangles) and negative hadrons (circles)

Collins asymmetries. The Collins asymmetries on unidentified hadrons on deuteron data [5, 6] are shown in figure 1.(a) as a function of x, z, p_T^h. The asymmetries are small, compatible with zero within the statistical accuracy. This is also the case for the identified pions and kaons asymmetries [7], and is in agreement with the results of the two-hadrons asymmetries and the Lambda polarization analysis on deuteron. In figure 1.(b) the new Collins asymmetries are shown for unidentified hadrons on proton data. The asymmetries are compatible with zero up to $x = 0.05$, while for greater values of x the signal increases up to 10%, with opposite sign and almost the same size for positive and negative hadrons. These results are in agreement with predictions based on global fits[8] of the HERMES, COMPASS deuteron and BELLE results.

Sivers asymmetries. The Sivers asymmetries for unidentified charged hadrons on deuteron data [5, 6] are shown in figure 2.(a). The asymmetries are compatible with zero within the statistical accuracy. The same result can be obtained for charged pions and kaons [7]. Naïvely, this result has been interpreted as the cancellation of the u and d quark contributions in an isoscalar target.
In figure 2.(b) the Sivers asymmetries are shown for charged hadrons on proton data, as a function of x, z, p_T^h: all the asymmetries are compatible with zero within the statistical error both for positive and negative hadrons. This is a very interesting result at variance with the HERMES results for positive and negative pions, and with the predictions of models [9, 10] which well reproduce those data, and need further theoretical investigation as well as more precise data.

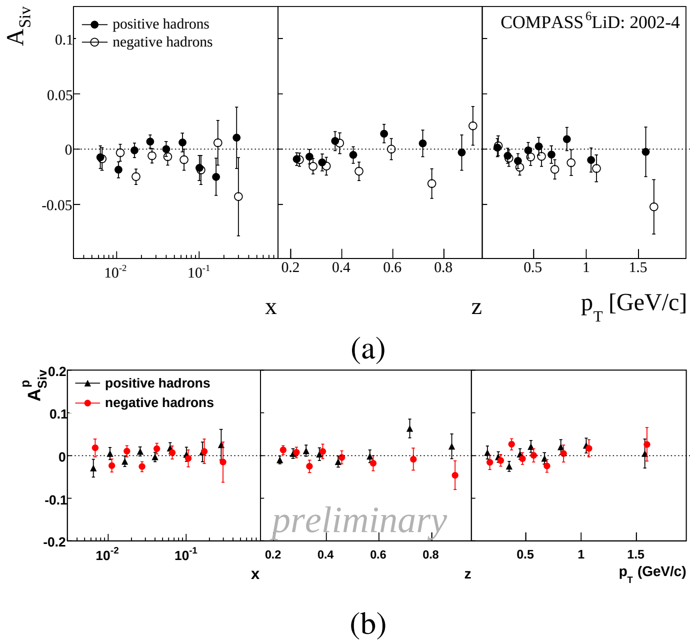


FIGURE 2. **(a)** Sivers asymmetries as a function of x, z, p_T^h on deuteron, for positive (closed circles) and negative hadrons (open circles). **(b)** Sivers asymmetries as a function of x, z, p_T^h on proton, for positive hadrons (triangles) and negative hadrons (circles).

CONCLUSIONS

The analysis of the COMPASS deuteron data is finalized, and the results for the Collins and Sivers asymmetries have been shown to be compatible with zero. The results for the asymmetries with a proton target are presented: the Collins asymmetries for positive and negative hadrons are different form zero, opposite in sign and of the same strength, while the Sivers asymmetry is compatible with zero, both for positive and for negative hadrons.

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