Single Spin asymmetries for identified hadrons at COMPASS

Giulia Pesaro,on behalf of the COMPASS collaboration

Università degli studi di Trieste e INFN sez. di Trieste, c/o dip. di Fisica, via A. Valerio 2, 34127 Trieste, Italia

E-mail: giulia.pesaro@ts.infn.it

Abstract. COMPASS is a fixed target experiment at CERN SPS, dedicated to the study of the nucleon spin structure and hadron spectroscopy. The transverse spin structure of the nucleon is investigated by measuring semi-inclusive deep inelastic scattering (SIDIS) of a 160 GeV/c longitudinally polarized muon beam off transversely polarised targets. Particle Identification (PID) is performed with a Ring Imaging CHerenkov detector (RICH) that has been upgraded in 2005. COMPASS took data using transversely polarised ^{6}LiD target from 2002 to 2004 and with a transversely polarised NH_3 target in 2007.
In this talk the Collins and Sivers asymmetries on polarised proton for charged pions and kaons will be shown for the first time and compared with the same results on polarised deuteron for COMPASS.

1. Introduction

The spin structure of the nucleon in the collinear approach is described, at twist two level and at the leading order, by three parton distribution functions (PDFs): the momentum PDF, the helicity PDF, and the transversity PDF. The latter, that gives the probability of finding a quark with the polarisation parallel or anti-parallel to the nucleon spin in a transversely polarized nucleon, is chirally odd and in lepton-nucleon DIS it can only be measured in semi-inclusive DIS (SIDIS) experiments, where it is coupled with other chirally odd functions describing the quark fragmentation into hadrons. At COMPASS transversity is accessed via quark polarimetry, and in this proceeding the Collins effect [1] will be discussed. Other channels have also been exploited on the polarised proton and deuteron targets: the production of hadrons pairs [2, 3] and the Λ hyperon polarization [4, 5].
When the quark transverse momentum is taken into account, 8 PDFs can be built to fully describe the nucleon structure at leading twist. These PDFs gives rise to azimuthal modulations in the DIS cross section, all with an independent combination of the azimuthal angle of hadrons and quark spin, as measured in the gamma-nucleon system (GNS). All these azimuthal asymmetries are measured at COMPASS. Of these modulations, the most famous are due to the Collins and the Sivers effects, and are the topic of this proceeding. The COMPASS results for identified hadrons on the proton target are here shown for the first time. The remaining target-transverse dependent modulations are discussed in [6].

2. The Collins modulation

The Collins modulation of the SIDIS cross section can be present because of the asymmetry in the fragmentation of the transversely polarized quarks into unpolarized hadrons (Collins effect). The modulation appears in the Collins angle $\phi_C = \phi_h + \phi_s + \pi$, that is defined as the sum of the azimuthal angle of the produced hadron and the azimuthal angle of the nucleon spin in the GNS. The number of produced hadrons is then: $N_h(\Phi_C) = N_h^0\,[1 + P_T\, D_{NN}\, A_{Coll}\sin(\Phi_C)]$. The quantity $D_{NN} = \frac{(1-y)}{(1-y+y^2/2)}$ is the spin transfer coefficient from the initial to the struck quark and P_T is the target polarization. The Collins asymmetry A_{Coll} is the convolution of transversity PDF, $\Delta_T q$, and the Collins fragmentation function (FF), $\Delta_T^0 D_q^h$, normalized over the spin independent convolution:

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

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 w.r.t the photon direction.

The Collins asymmetry has been measured in 2007 on polarized protons [7], using NH_3 as target material, and in 2002-2004 on polarized deuterons, using ^6LiD as target material [8, 9]. The target is divided in cells, that are polarized in opposite directions and the overall polarization is reversed every $4-5$ days in order to cancel the acceptance effects by coupling two consecutive periods. The events are selected in the DIS region, requiring the photon virtuality $Q^2 > 1$, the fractional energy y of the virtual photon between 0.1 and 0.9 and the invariant mass of the hadronic final state W above 5 GeV/c^2. The final state hadrons are selected with $p_T^h > 0.1$ for a good angular resolution and with $z > 0.2$ to discard events coming from the target fragmentation region.
The Collins asymmetries measured on the proton are shown in Fig. 1 as a function of x, z and p_T^h, for positive (black points) and negative (red points) hadrons. The asymmetry for the proton shows a clear signal in the valence region, with opposite sign and almost the same size for positive and negative hadrons, while it is compatible with zero at small x. There is no strong dependence on z and p_T^h. The measured deuteron asymmetries are compatible with zero within the statistical error, both for positive and for negative hadrons. The systematic error has been evaluated to be of the order of 0.5 σ_{stat} for the proton data, and much smaller than the statistical one for the deuteron data, thanks to an overall better performance of the apparatus.

The Collins asymmetries have been extracted also for the pion and the kaon samples that are identified making use of a large-size ring image Cherenkov detector (RICH). The RICH is capable of hadron identification from the Cherenckov momentum threshold ($\sim$ 3 GeV/c for π and $\sim$ 9 GeV/c for K) to a maximum momentum of 50 GeV/c. The detector, that was upgraded in 2005, allows for a purity of the pion sample larger than 99% and a purity of the kaon sample $\gtrsim$ 90%.
The pions sample corresponds to $\sim$ 70% of the all hadron sample: the extracted asymmetries show a perfect agreement with the corresponding asymmetries for non identified hadrons. The Collins asymmetries for the charged kaons are shown in Fig. 2 as functions of x, z and p_T^h, for positive (black points) and negative (red points) hadrons. The K^+ asymmetry shows some trend as a function of x in the valence region, as well as a trend as a function of p_T^h. The K^- asymmetry is positive in average, and no specific trends are visible. The bands in the plots represent the systematic error, that is evaluated as $\sim$ 0.5 σ_{stat} for positive K and $\sim$ 0.7 σ_{stat} for negative K. The corresponding asymmetries for the deuteron target [10] are compatible with zero within the statistical error.

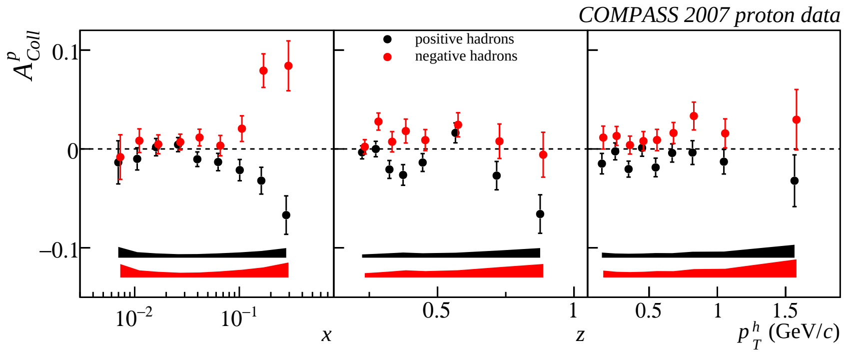

Figure 1. The Collins asymmetries on the proton as functions of x, z and p_T^h for positive (black points) and negative (red points) hadrons. The red points are artificially shifted [7]. The bands correspond to the systematic error.

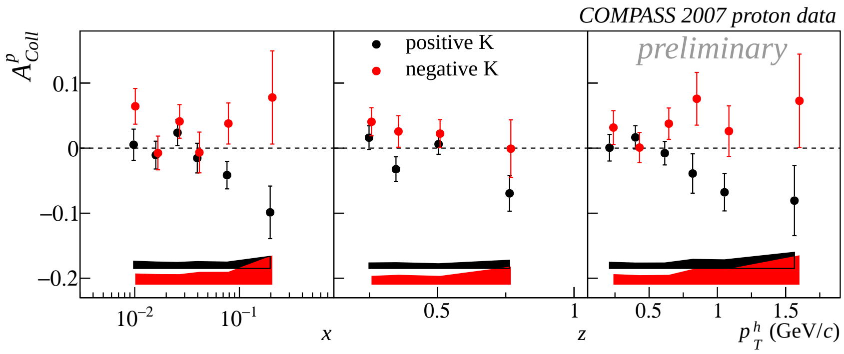

Figure 2. The Collins asymmetries as a function of x, z and p_T^h for positive (black points) and negative (red points) kaons on the proton target. The red points are artificially shifted. The bands correspond to the systematic error.

The Collins asymmetries on the proton target have been also measured by the HERMES experiment [11], at a smaller average Q^2. The general good agreement between the two experiments suggests that the Q^2 dependence is weak. The asymmetries measured on the proton and on the deuteron targets, together the Belle e^+e^- data have been combined in global fits [12] to extract the transversity PDF and the Collins FF. It will be interesting to see the impact of the new COMPASS data on these fits.

3. The Sivers modulation

The Sivers modulation is due to an asymmetric distribution of the struck quarks if the quark itself has an intrinsic transverse momentum. The number of produced hadrons $N_h(\Phi_S) = N_h^0\,[1 + P_T\, A_{Siv}\sin(\Phi_S)]$ is a function of the Sivers angle $\phi_S = \phi_h - \phi_s$, defined in the gamma-nucleon system as the difference of the azimuthal angle of the produced hadron and the azimuthal angle of the nucleon spin. The Sivers asymmetry A_{Siv} is given by the convolution of the unpolarized fragmentation function and the Sivers PDF $\Delta_T^0 q$, and depends on the quark

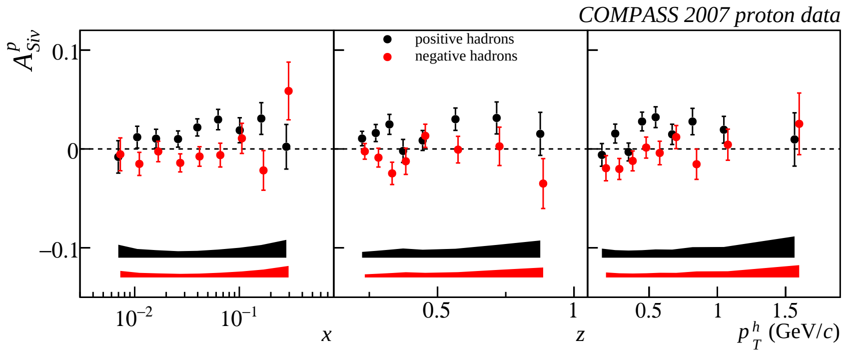

Figure 3. The Sivers asymmetries on the proton as functions of x, z and p_T^h for positive (black points) and negative (red points) hadrons [7]. The red points are artificially shifted; the bands represent the systematic error; an absolute scale uncertainty if ± 0.01 has to be considered for the positive hadrons only.

transverse momentum $\vec{k_T}$:

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

The Sivers asymmetries measured at COMPASS are shown in Fig. 3, as functions of x, z and p_T, for positive (black points) and negative (red points) hadrons. The Sivers asymmetry for positive hadrons on the proton target [7] show a signal over the full x range, more pronounced in the valence region, and does not show any dependence on z and p_T^h. The asymmetry shows a dependence on the variable W: the asymmetry is higher at small values of W. The Sivers asymmetry for negative hadrons on protons, as well as for positive and negative hadrons on the deuteron target [8, 9] are compatible with zero. The systematic error for the proton asymmetries is estimated as $\sim\ 0.5\sigma_{stat}$ for positive hadrons (plus an absolute scale contribution of ± 0.01) and $\sim\ 0.8\sigma_{stat}$ for negative ones. The Sivers asymmetries on the proton target are smaller then, but still compatible with those measured by the HERMES experiment [13].

The new results for the Sivers asymmetries for charged K are shown in Fig. 4 (left) as a function of x: the K^+ asymmetry is positive in average, while the K^- asymmetry is compatible with zero. In the same Figure, the comparison between the asymmetries as measured at COMPASS and at HERMES [13] is shown: the results are in agreement within the present precision, even if the mean value of the COMPASS experiment is smaller. As in the case of positive hadrons and pions , the K^+ asymmetry shows a signal at small W, while the asymmetry is compatible with zero at higher values of W (Fig. 4, right). It has to be noted that the W range of the HERMES experiment is $\lesssim$ 7 GeV/c; in the region of overlap of W of the two experiments, the Sivers asymmetries measured by COMPASS and HERMES are in perfect agreement. The Sivers asymmetries measured at COMPASS and HERMES on the deuteron and proton target respectively have already been used to extract in global fit the Sivers PDF [14, 15], and again we are waiting to see the results of the fits when all the data will be included.

4. Conclusions

COMPASS has measured the Collins and the Sivers asymmetries both on proton and on deuteron target, for the unidentified as well as for the identified hadron samples. The Collins asymmetries

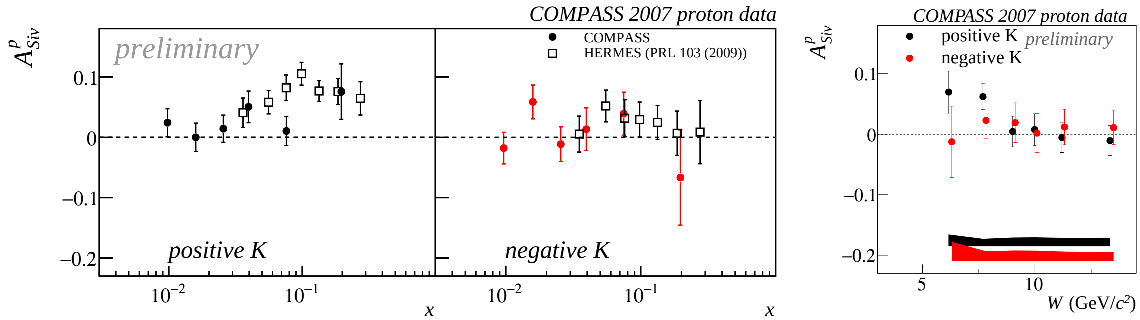

Figure 4. The Sivers asymmetry for K^+ (black circles) and K^- (red circles). Left: as a function of x for the Compass and the Hermes experiments (open boxes). Right: as a function of W, the red points are artificially shifted. The bands in the plot represent the systematic error, that is $\sim 0.5\sigma_{stat}$.

on the proton shows a signal in the valence region, of opposite sign for positive and negative hadrons and pions. The Collins asymmetries for the identified kaons on the proton target gives hints of a possible dependence of the asymmetry on P_T^h. The Sivers asymmetries for positive hadrons, as well for positive K are different from zero on the whole x range and are larger at small values of W; moreover the asymmetry for K^+ is larger than the asymmetry for the h^+. The new COMPASS data will allow not only to better constrain the transversity and the Sivers PDFs at small values of x in the global fits, but will also allow to perform a flavour separated analysis using the COMPASS data only, i.e. at the same Q^2.

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