COMPASS plans to measure transversity

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The COMPASS collaboration at CERN will run part of the time with a transversely polarised target in order to measure transversity through semi-inclusive DIS. There exist 3 different channels, COMPASS plans to exploit all of them but only the so-called Collins effect was simulated so far. Error bar estimates are presented both for proton and deuteron target. The feasibility of flavour separation is also briefly discussed.

1. TRANSVERSITY WITH A LEPTON BEAM

There exists 3 parton distribution functions (PDF) at leading twist, the unpolarised one, $q(x)$, the usual longitudinally polarised one, $\Delta q(x)$, and transversity, $\Delta_T q(x)$, which is the equivalent of $\Delta q(x)$ for a nucleon polarised, not parallel, but perpendicular to the momentum direction. Transversity requires an helicity flip whereas all hard processes conserve helicity; it then decouples from inclusive DIS and was not measured so far (Fig. 1 left). The helicity flip requires another soft object, besides the nucleon PDF. Semi-inclusive DIS provides such an object (Fig. 1 right), the fragmentation functions $D_q^h(z)$, which represent the probability that a quark q fragments in a hadron h with a fraction z of the virtual photon energy. We then have to find a way to measure the final quark transverse polarisation. This can then be done trough the measurement of the final hadron transverse polarisation (in practice for Λ), through single pion azimuthal distribution (so-called Collins effect) or through two pion distribution (due to some interferences in the fragmentation process). Note that in all cases one will measure the product of $\Delta_T q(x)$ by some still unknown polarised fragmentation function. However, since $\Delta_T q$ depend on x and the fragmentation functions on z, this can already provide the shape of $\Delta_T q(x)$ up to an unknown normalisation.

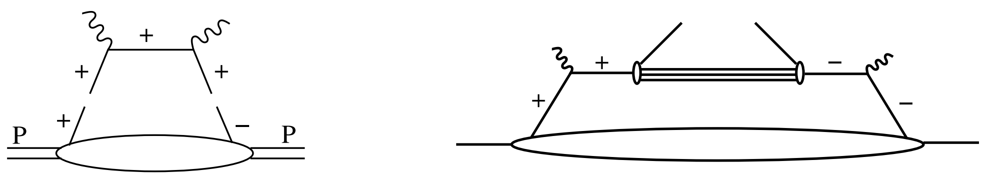


Figure 1. Inclusive DIS (left) and semi inclusive DIS (right)

2. COLLINS EFFECT

COMPASS plans to exploit the 3 possibilities but only the Collins effect was simulated so far. It implies an azimuthal dependence of the event yield in terms of the Collins angle ϕ_c. The Collins angle is the azimuthal angle (with respect to the virtual photon direction) between the final hadron and the final quark spin, $\phi_c = \phi_h - \phi_{S'}$, as illustrated in Fig. 2. The angle $\phi_{S'}$ is not directly measured but the absorption of the virtual photon results in the two angles α in Fig. 2 to be equal. So, if angles are defined relative to the lepton scattering plane, $\phi_{S'} = \pi - \phi_S$, and the Collins angle can be expressed in terms of measured angles, $\phi_c = \phi_h + \phi_S - \pi$.

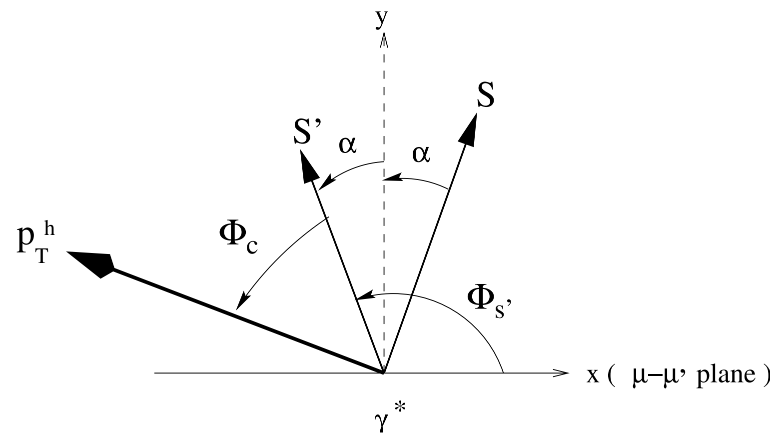


Figure 2. Definition of the Collins angle $\phi_c = \phi_h - \phi_{S'}$ in the plane perpendicular to the virtual photon direction.

The event yield will then be $N = N_0\,[1 \pm f P_T D_{nn} A_\phi \sin\phi_c]$, where P_T is the target polarisation, f its dilution factor, $D_{nn} = (1-y)/(1-y+y^2/2)$ is the fraction of the initial quark transverse polarisation which remains after the absorption of the virtual photon and A_ϕ is the physical azimuthal asymmetry which involves $\Delta_T q(x)$ and $\Delta_T^0 D_q^h(z)$ the polarised fragmentation function which tells how much of the quark transverse polarisation is reflected in the hadron azimuthal asymmetry.

3. EXPERIMENTAL METHOD

The COMPASS setup was described in another presentation [1]. In order to allow asymmetry measurement with longitudinally polarised target the COMPASS polarised target is equipped with 2 cells, polarised in opposite directions. In the transverse case only one cell is absolutely needed. The asymmetry between $N(\phi_c)$ and $N(\phi_c + \pi)$ is computed. Acceptances at ϕ_c and $\phi_c + \pi$ may differ. In the limit that the ratio of these acceptances remains constant, the effect is cancelled by reverting the polarisations of the cell [1]. Possible false asymmetries due to variation of the acceptance ratio will be reduced by combining the results obtained with the two cells.

4. EXTRACTION OF PARTON DISTRIBUTION FUNCTIONS

In the longitudinal case the inclusive and semi-inclusive asymmetries can be expressed as

$$A_1 = \frac{\sum e_q^2 \Delta q(x)}{\sum e_q^2 q(x)} \quad \text{and} \quad A^h = \frac{\sum e_q^2 \Delta q(x) D_q^h(z)}{\sum e_q^2 q(x) D_q^h(z)}. \tag{1}$$

The inclusive, A_1^p and A_1^d, and semi-inclusive, $A_p^{\pi^+}$, $A_p^{\pi^-}$, $A_d^{\pi^+}$, and $A_d^{\pi^-}$, asymmetries provide 6 equations for the 6 unknowns: Δu, $\Delta\bar{u}$, Δd, $\Delta\bar{d}$, Δs and $\Delta\bar{s}$. In practice SMC and Hermes had to neglect the strange contribution and assume $\Delta\bar{u} = \Delta\bar{d}$, in order to get reasonably small error bars.

In the transverse case we only have 4 semi-inclusive asymmetries for the 6 unknowns. In addition their expression

$$A_\phi = \frac{\sum e_q^2 \Delta_T q(x) \Delta_T^0 D_q^h(z)}{\sum e_q^2 q(x) D_q^h(z)}, \tag{2}$$

involves the so far unknown $\Delta_T^0 D_q^h(z)$. Furthermore the polarised fragmentation functions will in any case be smaller than the unpolarised one, $|\Delta_T^0 D_q^h(z)| < D_q^h(z)$. Finally the measurement of azimuthal asymmetries ($\delta A \propto 1/\sqrt{N/2}$) always require twice as much statistics as spin asymmetries ($\delta A \propto 1/\sqrt{N}$). All in all, the extraction of the transversely polarised PDFs will be much more difficult than for the longitudinal ones.

It is, however, possible to make a first step, even before a measurement of $\Delta_T^0 D_q^h(z)$ is performed. If we consider only fragmentation to π, it is well known that, due to $SU(2)$ flavour symmetry and charge conjugation, there exist only 3 independent unpolarised fragmentation functions. The so-called favoured one (e.g. u fragments to a $u\bar{d}$ system), $D_{fv} = D_u^{\pi+} = D_d^{\pi-} = D_{\bar{d}}^{\pi+} = D_{\bar{u}}^{\pi-}$, the unfavoured one ($u$ fragments to a $\bar{u}d$ system), $D_{unf} = D_u^{\pi-} = D_d^{\pi+} = D_{\bar{d}}^{\pi-} = D_{\bar{u}}^{\pi+}$ and the strange one, $D_s = D_s^{\pi+} = D_s^{\pi-} = D_{\bar{s}}^{\pi+} = D_{\bar{s}}^{\pi-}$. Similarly there are only 3 $\Delta_T^0 D_q^\pi(z)$.

Let us consider the asymmetry between $(N^{\pi^+} + N^{\pi^-})(\phi)$ and $(N^{\pi^+} + N^{\pi^-})(\phi + \pi)$. If we neglect the strange contribution, the fragmentation functions factor out in the expression of the proton and deuteron asymmetries:

$$A_p^\pi \approx f P_T D_{nn} \frac{4\Delta_T u + 4\Delta_T \bar{u} + \Delta_T d + \Delta_T \bar{d}}{4u + 4\bar{u} + d + \bar{d}} \times \frac{\Delta_T^0 D_{fv} + \Delta_T^0 D_{unf}}{D_{fv} + D_{unf}}, \tag{3}$$

$$A_d^\pi \approx f P_T D_{nn} \frac{\Delta_T u + \Delta_T \bar{u} + \Delta_T d + \Delta_T \bar{d}}{u + \bar{u} + d + \bar{d}} \times \frac{\Delta_T^0 D_{fv} + \Delta_T^0 D_{unf}}{D_{fv} + D_{unf}}. \tag{4}$$

Even if the fragmentation functions are not known, combining the proton and deuteron data, one can obtain the shape of $\Delta_T(u + \bar{u})$ and $\Delta_T(d + \bar{d})$.

[1] In the longitudinal case the counting rate asymmetry between the 2 cells is measured. The effect of the difference of acceptance is cancelled by reverting the polarisations of the 2 cells simultaneously.

Similarly, if we now consider the asymmetry between $N^{\pi^+}(\phi)+N^{\pi^-}(\phi+\pi)$ and $N^{\pi^+}(\phi+\pi)+N^{\pi^-}(\phi)$, and again neglect the strange contribution, we will be able to extract the shape of $\Delta_T u_v$ and $\Delta_T d_v$.

5. REINTERACTION IN THE TARGET

The COMPASS target cells are quite thick, 60 cm each. The effect of reinteraction in the target was then studied using Geant and Gheisha. The difference between the reconstructed and the generated Collins angle is plotted in Fig. 3. The upper curves correspond to the case where the charge of the leading pion is the same as the generated one, the lower curves to the case they are opposite. We see that in the case the charge is wrong the distribution is flat, there is no more information about the Collins angle and these events simply result in a dilution of the asymmetry. This dilution becomes negligible if we require $z > 0.3$, as can be seen on the right side of the figure. When the proper charge is reconstructed we see that the Collins angle information is essentially preserved.

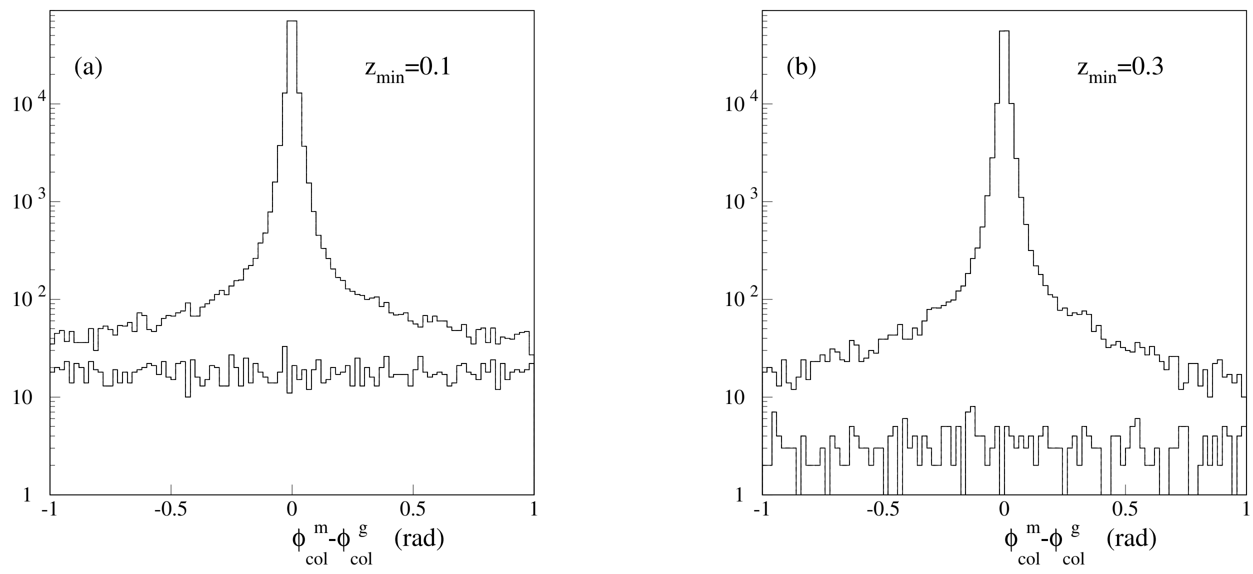


Figure 3. Difference between the reconstructed and the generated Collins angle for $z > 0.1$ (left) and $z > 0.3$ (right).

6. SIMULATION OF PERFORMANCES

The measurement by COMPASS of transversity through the Collins effect was simulated using Lepto 6.5 with GRV98 LO PDF. It was assumed that $\Delta_T q = \Delta q$ and that the analysing power $a_c = \Delta_T^0 D_q^h / D_q^h = 0.75 \times z$, since it is generally agreed that a_c should increase with z. If such assumptions are applied to the SMC case [2], we get $A_p^{\pi+} = 0.06$

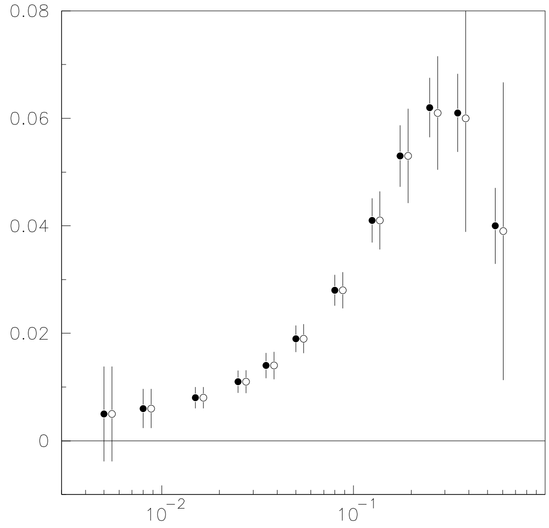
to be compared with the measured $A_p^{\pi+} = 0.11 \pm 0.06$. Hermes measured the azimuthal asymmetry for a target polarised parallel to the beam [3]. This implies a small contribution perpendicular to the virtual photon direction. It is proportional to $\sin\theta_\gamma$ and then to $1/Q$, so that it is of the same size as higher twist contributions. Taking into account only the leading twist contribution, we get $A_p^{\pi+} = 0.008$ to be compared with the measured $A_p^{\pi+} = 0.022 \pm 0.005 \pm 0.003$. The higher twist contributions include a Wandzura-Wilczek type contribution, $x^2 \int_x^1 \frac{dy}{y^2} \Delta_T q(y)$, which increases the absolute value of the asymmetry by about 60% [4]. We then get $A_p^{\pi+} = 0.013$, which remains lower than the measured 0.022, and our assumptions appear reasonable. However, it cannot be excluded that the SMC result is just a statistical fluctuation (by 1.8 σ) and Hermes only sees higher twist contributions, and the actual a_c is close to zero. Note that according to Ref. [4] the Wandzura-Wilczek contribution changes the sign of the asymmetry. In this case there could be an incompatibility between the signs of the SMC and Hermes asymmetries. We are, however, only interested here in the evaluation of the statistical accuracy, the sign of a_c and of the asymmetries is then not relevant and we do not address this question. Note also that a measurement of a_c is possible in $e^+e^- \to h$ [5].

COMPASS was designed with a 180 mrad acceptance. The required polarised target magnet is not yet available and for the moment we will make use of the SMC magnet, with only 70 mrad acceptance. The acceptance loss is limited by running at 160 GeV instead of 100 GeV as originally foreseen.

The following kinematical cuts were applied, $Q^2 > 1$, $\nu/E \geq 0.1$, $E'/E \geq 0.05$, and $z \geq 0.1$ or 0.3. Since a_c increases with z, the events with $0.1 < z < 0.3$ have a very small contribution to the total statistics, and we set the cut to $z > 0.3$, which is safer in terms of reinteraction in the target and more generally in terms of interpretation. The hadron made of the quark which absorbed the virtual photon (rank 1 hadron in Lund fragmentation model) is more likely to carry information about the quark transverse polarisation than hadrons appearing latter in the string fragmentation process. For this reason, in each event only the charged hadron with the highest momentum was considered, since it is the most likely to be of rank 1. In order to have well separated target and current fragmentation regions we also require the Berger criterion [6], which corresponds e.g. to $W > 4.8$ for $z = 0.2$ and $W > 3$ for $z = 0.5$. This requirement rejects very few events at COMPASS energy.

The luminosity at COMPASS is $\mathcal{L} = 4.3 \cdot 10^{37}$ cm^{-2} per day. A 0.25 global factor for SPS, data taking and reconstruction efficiency is assumed. The target polarisation and dilution factor are $p_T = 0.85$ and $f = 0.135$ for the proton target (NH_3), and $p_T = 0.5$ and $f = 0.5$ for the deuteron target (^{6}LiD).

Fig. 4 presents the expected error bars on $x \sum_q e_q^2 \Delta_T q(x)$ (the equivalent of $x g_1(x)$ for transversity) for 30 days of running on a proton and 30 days on a deuteron target, with either the COMPASS or the SMC magnet. Error bars are 40% smaller for deuteron due to a larger value of $f P_T$ but the asymmetries are quite smaller in this model where $\Delta_T q = \Delta q$. At small x, $W^2 = M^2 + Q^2(1-x)/x$ is large, the hadrons are produced at small angle and the SMC magnet acceptance results in hardly any loss. At high x the hadrons are produced at larger angle and there is a dramatic loss. In addition, the highest momentum hadron, which is lost due to the reduced acceptance, may be replaced by a lower momentum hadron which is, nevertheless, produced at smaller angle. In the largest x



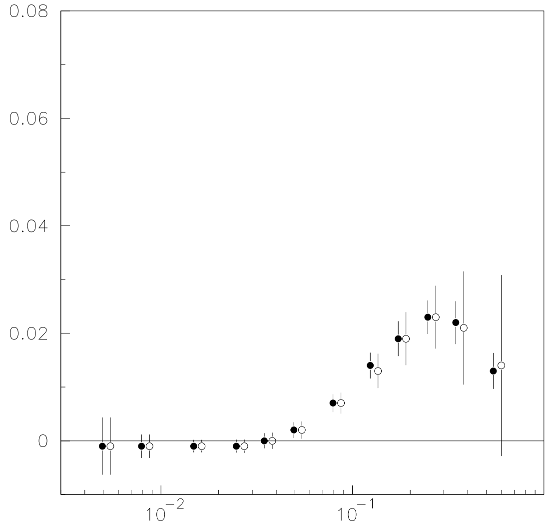


Figure 4. Expected error bars on $x\sum_q e_q^2\Delta_T q(x)$ for proton (left) and deuteron (right) targets, both for the COMPASS (full circle) and SMC (open circle) polarised target magnets. Beam energy is 160 GeV.

bin this is the case for more than half of the remaining events. In this case the analysing power might be reduced and the measurement biased. In particular the possibility to measure the shape of transversity without knowing a_c becomes questionable.

7. CONCLUSIONS

Assuming $\Delta_T q = \Delta q$ and $a_c = 0.75 \times z$, which is conservative with respect to the SMC and Hermes data, and using the foreseen polarised target magnet, COMPASS can provide a nice measurement of $\sum e_q^2 \Delta_T q$ in 30 days, both for proton and deuteron data. Flavour decomposition will, however, be much more difficult. COMPASS is currently using the old SMC magnet with smaller acceptance. In this case the measurement at high x becomes problematic.

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