PROSPECTS FOR THE COMPASS ‘MUON’ PROGRAMME

Alain Magnon
CEA Saclay, SPhN-DAPNIA-DSM, F91191 Gif-sur-Yvette, France

Abstract
COMPASS started to take data in 2002 with a recently completed new spectrometer using the longitudinally polarized 160 GeV muon beam of the CERN SPS and a solid polarized target filled with ^{6}LiD. A preliminary look at data allows us to draw projections on the statistical errors which could be obtained in the near future for the gluon polarization $\Delta g/g$ and the transverse spin structure function h_1.

1. INTRODUCTION

The present objectives of the COMPASS experiment which has started with the muon beam programme are the measurement of the polarization of gluons $\Delta g/g$ within polarized nucleons, the measurement of the still unknown transverse spin structure function h_1, the measurement of lambda polarization, and the measurement of the inclusive and semi-inclusive longitudinal spin observables g_1 and Δq. The spectrometer was commissioned during 2001 and the first serious data taking started in 2002. Owing to some delays or technical difficulties, some major pieces of equipment were not available and back-up solutions were used, leading to a reduced angular acceptance. In addition, the financial difficulties which CERN has encountered with the LHC construction have a serious implication on the total amount of accelerator time available per year. This report gives an update on the overall figure of merit of the experiment based on recent simulations and also on a preliminary analysis of the 2002 data. The expected statistical errors on $\Delta g/g$ and h_1 are given. Expected progress but also handicaps are discussed. Finally, in view of the SPS shutdown in 2005, a possible strategy for data taking in 2003 and 2004 is presented.

2. PROGRAMME WITH POLARIZED MUONS

If one uses longitudinally polarized target and beam, the measurement of the longitudinal spin asymmetry in the production of D^0 or D* mesons [1] or in the production of a pair of hadrons with high transverse momentum P_T [2] allows the determination of $\Delta g/g$. The importance of the RICH detector performances should be underlined at this point since the RICH is essential to perform the K identification necessary to single out efficiently D^0 and D*. The first spin structure function g_1 can be measured by detecting the scattered muon μ' only. If one detects in addition at least one produced hadron, one can reach the polarized parton distribution functions Δq. All these channels can be obtained simultaneously.

If one uses a transversely polarized target, the measurement of the azimuthal modulation of the single hadron cross-section can lead to the transverse spin structure function h_1, a yet unknown quantity.

3. COMPASS MODIFIED LAS SPECTROMETER

The year 2001 was almost entirely devoted to the commissioning of the present version of the spectrometer. All equipment was installed and their properties could be studied. However, two difficulties remained in 2002: the large bore radius superconducting magnet which matches the ≈ 250 mrad maximum opening angle of the spectrometer could still not be delivered to COMPASS; the construction of the straw trackers which provide the Large Area Tracking (LAT) downstream of the Large Acceptance Spectrometer (LAS) was delayed due to unexpected difficulties, consequently, only about one half of the straw trackers were available.

A backup solution was worked out, as shown in Fig. 1. It consists of using the SMC magnet which has similar properties but a reduced opening angle of ≈ 100 mrad instead of the COMPASS magnet

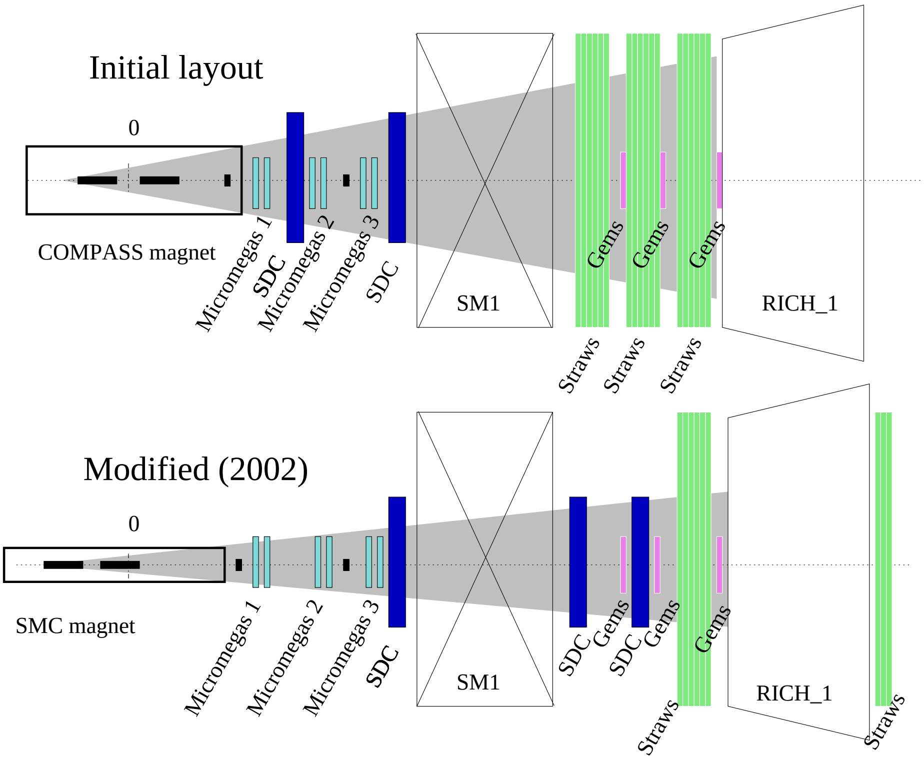

Fig. 1: The nominal and modified setups for the Large Acceptance Spectrometer.

and replacing the missing straws by the two larger-area Drift Chambers (DCs) foreseen for the upstream section of the LAS. This implied the construction of a third DC for the upstream section of the LAS. As shown in Fig. 1 it turns out that, in spite of their reduced area compared to the straws (DCs are $= 1.2 \times 1.2$ m^2, straws are $= 2.7 \times 3.2$ m^2), the DCs match the angular opening of the SMC magnet. Finally, due (mainly) to constraints in detector construction it was found that the total amount of material seen by the scattered particles was larger that initially foreseen. This resulted in a degradation of the mass resolution for both the D^0 and D* channels and a proportional increase of the background-to-signal ratio for their detection. These changes had to be validated by a re-estimate of the overall figure of merit.

4. STATISTICAL ERROR ON $\Delta g/g$ AND OPTIMUM MUON ENERGY

As described in the COMPASS proposal [1] the gluon distribution is probed through the photon gluon fusion (PGF) process, $\gamma + g \rightarrow q + \bar{q}$. This process can be signed by the production of open charm and the spin asymmetry of that process provides a measurement of $\Delta g/g$. A new evaluation of the statistical uncertainty on $\Delta g/g$ using the $\mathrm{D}^0 \rightarrow \mathrm{K}\pi$ and $\mathrm{D}^\star \rightarrow \mathrm{D}^0\pi_s \rightarrow \mathrm{K}\pi\pi_s$ channels was performed [3]. The simulation has the following features:

1. Open charm events are produced using Aroma 2.4. Since Aroma is not supposed to predict correctly the absolute cross-section, a renormalization factor K is applied to the muon production cross-section. Using the measured photoproduction cross-sections, we estimate $K = 1.66$ for a mass of the charmed quark $m_c = 1.34$ GeV.
2. Combinatorial background events are produced using Pythia 6.1. This new version of Pythia allows the simulation of the whole Q^2 range from quasi real photoproduction to DIS. The rate of background is found compatible with the proposal within 20%.
3. The resolution in the D^0 mass and in the difference $\Delta M = M_{\mathrm{D}^\star} - M_{\mathrm{D}^0}$ between the D* and D^0 masses is evaluated analytically event by event using a procedure developed previously [4].

The average δM_{D^0} is 15.8, 17.5 and 18.1 MeV for an incident muon energy E_μ of 100, 160 and 190 GeV, respectively. The average $\delta\Delta M$ is 3.73, 3.83 and 3.89 MeV correspondingly. Note that the variation of $\delta\Delta M$ with beam energy is very weak since this resolution is dominated by the contribution of multiple scattering in the target.

4. In the standard asymmetry method one computes $A = (N^{\uparrow\downarrow} - N^{\uparrow\uparrow})/(N^{\uparrow\downarrow} + N^{\uparrow\uparrow})$, the raw asymmetry in the number of open charm events where the longitudinal polarizations of the beam and the target are either antiparallel or parallel. $\Delta g/g$ is obtained as:

$$\Delta g/g = A(1 + B/S)/(P_\mu P_T f \langle a_{LL}\rangle), \tag{1}$$

where B is the number of combinatorial background events, S the number of signal (D^0 or D*), P_μ and P_T are the beam and target polarizations respectively, f is the dilution factor and $\langle a_{LL}\rangle$ the mean value of the PGF analysing power. The quantities a_{LL} and B/S have large variations over the spectrometer acceptance. In order to improve the statistical efficiency it is proposed to take these variations into account by weighting each event with the quantity $w = a_{LL}/(1 + B/S)$ which gives:

$$\Delta g/g = (1/P_T P_\mu f)(\sum_i^{\uparrow\downarrow} w_i - \sum_i^{\uparrow\uparrow} w_i)/(\sum_i^{\uparrow\downarrow} w_i^2 + \sum_i^{\uparrow\uparrow} w_i^2). \tag{2}$$

This weighting method is equivalent to gaining a factor $\langle w^2\rangle/\langle w\rangle^2$, in terms of the number of events. In our case, due to the fact that a_{LL} can even change sign over the acceptance, this factor is quite large, in the range of 1.5–2 depending on acceptance and beam energy.

A luminosity of 43 pb^{-1} per day corresponding to $\approx 2 \times 10^8\mu/$ 5 s spill ($\approx 1.4 \times 10^8\mu$ at 190 GeV) is assumed. The global data taking and reconstruction efficiency $\epsilon_{overall}$ is taken to be 0.25, as in the proposal. Since data analysis has just started, this critical factor is still poorly known. In order to derive estimates of the full duration of data taking for a given accuracy, it is convenient to use a time unit which incorporates $\epsilon_{overall}$ which we call $days$@100%.

Table 1: Statistical error on $\Delta g/g$ for both D^0 and D* channels for different setups and beam energies. The luminosity corresponds to 100 days, and an overall efficiency of 25%. The number from the proposal does not involve the 'weighting method' and is rescaled to 100 days at 25%.

	$\sigma(\Delta g/g)$ D^0			$\sigma(\Delta g/g)$ D*		
E_μ GeV	100	160	190	100	160	190
Proposal	$\boxed{0.31}$			$\boxed{0.26}$		
Nominal setup	0.30	0.22	0.25	0.25	0.20	0.24
idem + SMC magnet	0.38	0.24	0.26	0.31	0.22	0.25
Modified setup	0.39	$\boxed{0.24}$	0.26	0.32	$\boxed{0.23}$	0.26

Table 1 gives the statistical resolution on $\Delta g/g$, assuming 100 days running at nominal luminosity and $\epsilon_{overall} = 0.25$ equivalent to 25 $days$@100% and using the weighting method [3]. In the proposal E_μ was fixed to 100 GeV and the weighting method was not applied. Energies of 160 GeV and 190 GeV were considered also because the Lorentz boost, which favours smaller angles, helps to compensate for the loss in angular acceptance. The line labelled 'Nominal setup' corresponds to the setup shown in the upper part of Fig. 1. The next line shows the effect of replacing the large-aperture COMPASS magnet by the SMC magnet. The last line corresponds to the 'Modified setup', shown in Fig. 1. It has three stations of Micromegas and one station of drift chambers (DC) upstream of SM1; three stations of GEMs, two DCs and one station of straws (replacing the three foreseen stations of straws) downstream of SM1. Note that one half-station of straws is positioned after the RICH to re-inforce tracking in that region.

At 100 GeV, the statistical loss due to acceptance reduction is significant for both the D^0 and the $\mathrm{D}^\star$ channels. This effect is reduced at 160 GeV and 190 GeV as expected. However, at 190 GeV, the SPS can only deliver $\approx$ 70% of its maximum flux which results in an increase of the error compared to 160 GeV. Therefore, a beam energy of 160 GeV is optimum for the present Modified setup. The resulting statistical uncertainties on $\Delta g/g$ of 0.24 (0.23) for the $\mathrm{D}^0(\mathrm{D}^\star)$ channels should be compared to the initial values from the proposal of 0.31 (0.26). We conclude that the reduction in acceptance along with the degradation of the mass resolution is compensated by running at $E_\mu = 160$ GeV and calculating the spin asymmetry using a weighting method.

5. 2002 AND BEYOND, EXPECTED STATISTICS

5.1 $\Delta g/g$ from D^0 and $\mathrm{D}^\star$

In the proposal, it is assumed that COMPASS runs for 1.5 years with a ^{6}LiD target with two assumptions: The SPS delivers ≈ 150 days/year of beam for physics and the overall efficiency of the experiment is 0.25. This translates into an effective total running time of:

$$T = 1.5 \times 150 \times 0.25 = 56 \ days@100\%. \tag{3}$$

Using the error estimates from Table 1 (Modified setup, $E_\mu = 160$ GeV), we obtain:

$$\sigma(\Delta g/g) = 0.160 \ (\mathrm{D}^0), \quad \sigma\Delta g/g = 0.154 \ (\mathrm{D}^\star), \quad \sigma(\Delta g/g) = 0.11 \ (\mathrm{D}^0\&\mathrm{D}^\star). \tag{4}$$

In 2002, the SPS delivered 112 days of beam out of which 36 days were used for preparing the spectrometer and the remaining time $T = 76$ days was shared between longitudinal and transverse data taking: $T = 76 = 57_L + 19_T$ days. The overall efficiency $\epsilon_{overall}$ can be decomposed as:

$$\epsilon_{overall} = \epsilon_{(data\_taking)} \times \epsilon_{(tracking)} \times \epsilon_{(RICH)}. \tag{5}$$

Where:

1. $\epsilon_{(data\_taking)}$ accounts for the beam availability and data taking efficiency. In 2002, we had $\epsilon_{(data\_taking)} = 0.59$.
2. $\epsilon_{(tracking)}$ accounts for detector and trigger efficiencies, track (including beam tracks) reconstruction efficiencies and data acquisition dead time. Given the preliminary status of data analysis we obtain $\epsilon_{(tracking)} \approx 0.1$ for events having a scattered muon and two hadrons originating from a D^0. For events having only a scattered muon, $\epsilon_{(tracking)}$ ranges from 0.3 to 0.4.
3. $\epsilon_{(RICH)}$ represents the fraction of kaons, identified as kaons by the RICH. The present number is ≈ 0.30.

Awaiting improved figures, we presently have: $\epsilon_{overall} \approx 0.015$. Note that this does not account for the presence of impurities in the RICH kaon sample which deteriorates the S/B ratio. When measuring spin asymmetries, data may be rejected because of instabilities which should be accounted for by a still unknown factor.

Given the present $\epsilon_{overall}$ we obtain $T_L = 0.85 \ days@100\%$ for the 2002 longitudinal data taking which would lead, for $\Delta g/g$, to a result of **marginal** significance.

To illustrate the importance of $\epsilon_{overall}$ and set the goal for the near future, we assume the following scenario for 2003 and 2004: The SPS delivers 105 days each year, the preparation of data taking is restricted to 15 days of SPS beam and we run about 20% of the time with a transversely polarized target. Making the most pessimistic assumption that $\epsilon_{overall}$ does not change, the effective total running time for 2002, 2003 and 2004 would be:

$$T = (57 + 72 + 72) \times 0.015 = 3.0 \ days@100\% \tag{6}$$

which translates into:

$$\sigma(\Delta g/g) = 0.48\ (\mathrm{D}^0\&\mathrm{D}^\star). \tag{7}$$

To reach the proposal's error: $\sigma(\Delta g/g) = 0.11$, $\epsilon_{overall}$ **needs to be enlarged** by a factor of $\simeq 20$ which would correspond, for example, to having:

$$\epsilon_{(data\_taking)} \approx 0.8, \quad \epsilon_{(tracking)} \approx 0.7, \quad \epsilon_{(RICH)} \approx 0.6. \tag{8}$$

This shows the utmost necessity to **reduce** the spectrometer setup time, given the **already reduced** yearly beam allocation and to **improve by all possible means** $\epsilon_{(tracking)}$ and $\epsilon_{(RICH)}$.

5.2 $\Delta g/g$ from high P_T

The analysis of events containing a scattered muon and two hadrons with a high P_T is still in a primitive phase for the 2002 COMPASS data. However, an analysis of similar events obtained in the previous SMC experiment has almost been completed [5]. From these data, the statistical error on $\Delta g/g$ is about 0.5. It allows us, by normalizing to the number of reconstructed events with high P_T, to provide an estimate of the expected statistical error from the COMPASS data. With a cut $Q^2 > 1$ GeV$^2/c^2$ applied to the data, this procedure gives, for the 57 days of longitudinal data taking in 2002:

$$\sigma(\Delta g/g) \approx 0.4\ (\text{high } P_T \text{ hadrons, } Q^2 > 1\ \mathrm{GeV}^2/c^2). \tag{9}$$

Releasing this cut increases the statistics by a factor ≈ 10 which results in:

$$\sigma(\Delta g/g) \approx 0.13\ (\text{high } P_T \text{ hadrons}). \tag{10}$$

5.3 Transversity

COMPASS plans to measure the transverse polarized parton distribution $\Delta_T q(x)$. This quantity can be viewed as the counterpart of the longitudinal polarized distribution $\Delta q(x)$ for a nucleon polarized perpendicular to the incoming lepton direction. Unlike $\Delta q(x)$, it cannot be accessed by inclusive DIS. However, semi-inclusive DIS provides the possibility to measure $\Delta_T q(x)$ via the azimuthal dependence of the hadron yield with the so-called Collins angle ϕ_c. This dependence involves the analysing power a_c which is still unmeasured. The measurement of transversity has been simulated using Lepto 6.5. Since nothing is known about $\Delta_T q(x)$, the simulation assumes $\Delta_T q(x) = \Delta q(x)$. For a_c, a linear dependence with the fraction z of the virtual photon energy transferred to the hadron is assumed, $a_c = 0.75 \times z$. In addition, the following kinematical cuts are applied, $Q^2 > 1$ GeV$^2/c^2$, $0.1 \leq y \leq 0.95$ and $z \geq 0.3$.

Figure 2 shows the expected errors on the quantity $xh_1 = x\Sigma_q e_q^2 \Delta_T q(x)$, (the equivalent of $xg_1(x)$ for transversity) for 30 days of data taking, for both proton and deuteron, assuming $\epsilon_{overall} = 0.25$, i.e. 7.5 $days$@100%. The simulation was performed for both COMPASS and SMC target magnets. At high x, hadrons are produced at large angle and the reduced acceptance of the SMC magnet has a strong effect on the counting rate.

For events with only one hadron, our present estimate is $\epsilon_{(overall)} = \epsilon_{(datataking)} \times \epsilon_{(tracking)} = 0.59 \times 0.14 = 0.08$. Given the previous assumptions for both $\Delta_T q$ and a_c and assuming we still use the SMC magnet, a significant measurement of transversity (i.e. a $\simeq 6\sigma$ signal) could be performed if one spends 20% of the total allotted time with transverse spin.

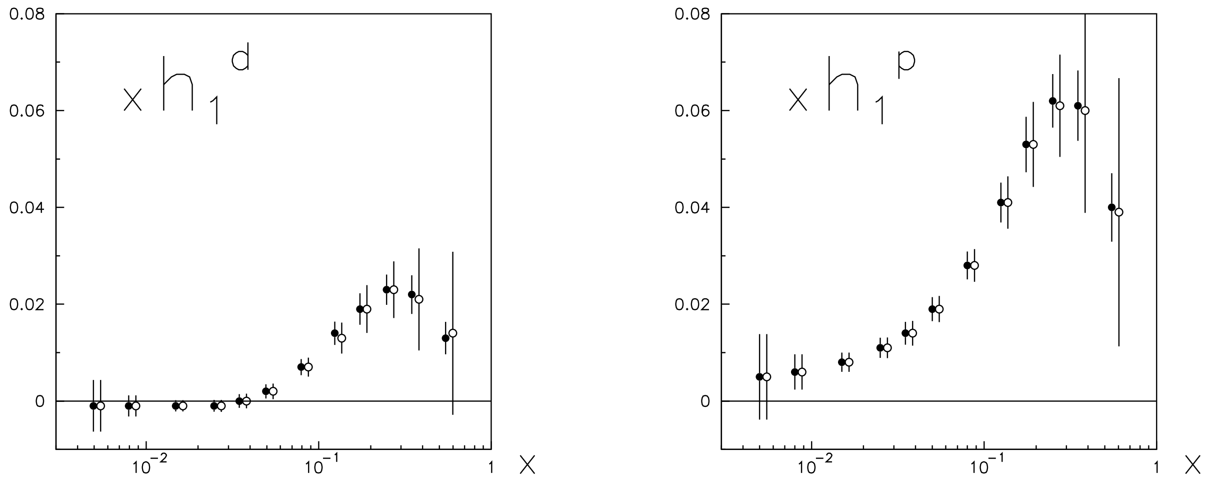

Fig. 2: Expected errors on $xh_1(x)$ for deuteron (left) and proton (right), for COMPASS (full circle) and SMC (open circle) polarized target magnets at $E_\mu = 160$ GeV.

6. CONCLUSION

COMPASS started to take data in 2002, using the 160 GeV polarized muon beam at the SPS and a polarized target which provided both longitudinal and transverse nucleon polarizations. The focus is presently the measurement of $\Delta g/g$, the gluon polarization within longitudinally polarized nucleons. Preliminary data were also taken with transverse polarization to access the yet unknown transverse polarized parton distribution $\Delta_T q$. The figure of merit of the experiment for the muon programme has been updated to account for modifications in the apparatus, mainly a reduction in the angular acceptance, and also a reduction in the SPS beam allocation compared to that of the proposal. It shows that a significant physics result on $\Delta g/g$ is within reach before the SPS shut down in 2005. However, this requires imperatively to improve the overall efficiency of our experiment by an order of magnitude if we compare to the present estimate which follows the 2002 data taking. The recent progress achieved in the data analysis gives an indication that such a goal is not unrealistic. However, it demands that both on the hardware and on the software side, all efforts are focused on understanding and improving, possibly to their ultimate limits, the many critical factors which enter in this figure of merit.

References

[1] CERN/SPSLC 96-14, SPSC/P 297.

[2] S. Bravar, D. von Harrach and A. Kotzinian, Phys. Lett. B **421** (1998) 349.

[3] J.-M. Le Goff, COMPASS note 2002-02.

[4] J.-M. Le Goff, COMPASS note 2000-13.

[5] E. Rondio *et al.*, COMPASS private communication.

[6] J.-M. Le Goff, Nucl. Phys. A **711** (2002) 56c.