COMPASS Overview

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Abstract. The COMPASS experiment at CERN SPS investigates several aspects of the nucleon spin structure using the high energy longitudinally polarised muon beam and a large polarised solid target providing longitudinal or transverse polarisations. Results obtained during the 3 years of running (2002-2004) with a ^{6}LiD target are summarized. They concern the measurements of longitudinal double spin cross-section asymmetries for the inclusive DIS, for the production of high p_T hadron pairs and D mesons (direct determination of $\Delta G/G$), the measurements of Collins and Sivers asymmetries with a tranversely polarised target, the measurements of transverse and longitudinal polarisations for produced Lambda.

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INTRODUCTION

The COMPASS experiment is set up at the M2 beam line of CERN/SPS which delivers polarised muon and hadron beams. COMPASS programme comprises measurements with both types of beams [1]. During the years 2002-2004, data were taken using the polarised 160 GeV muon beam with $2 \times 10^8 \mu/4.8\ s$ spill and a polarisation P_B of $\approx 80\%$ scattering on a ^{6}LiD target chosen for its high dilution factor (fraction of polarised nucleons) f of about 40% and providing longitudinal and transverse polarisations of magnitude P_T above 50%. In 2006, data taking resumed with the 160 GeV muon beam, a longitudinally polarised target and a significantly upgraded apparatus. The physics programme with hadron beam has not yet started, however, in 2004 a measurement of the Primakoff reaction was performed using a 190 GeV π^- beam. This report provides an overview of the results obtained with the muon beam. Using longitudinal target polarisation a particular effort has been made to determine the gluon polarisation $\Delta G/G$ with the aim of measuring the contribution of gluon spin ΔG to the nucleon spin. One approach is to select the Photon Gluon Fusion (PGF) process by observing the decay of charmed D^0 mesons or the production of two hadrons with high transverse momentum (high-p_T pairs). A second approach makes use of Next-to-Leading-Order (NLO) QCD analysis of the world data set for the g_1 spin structure function on proton, deuteron and neutron (^{3}He) targets taking advantage of the largely improved accuracy, particularly at low x_{Bjorken}, from COMPASS deuteron data. Using transverse target polarisation, the Collins and Sivers asymmetries for deuteron have been determined for the first time. Other transverse spin polarimeters have been studied such as two-hadron transverse spin asymmetries and Λ and $\overline{\Lambda}$ transverse polarisations.

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Open charm - the open charm channel is background free since the PGF process is at Leading Order (LO) in QCD the only possible mechanism for charm production. Charmed mesons are reconstructed via their decay $D^0 \rightarrow K\pi$. The low values of both the cross-section and the 2-body decay branching ratio ($\approx 4\%$) result in a low statistics. The charmed mesons are identified from their invariant mass distribution since the reconstruction of the D^0 vertex is not possible due to the multiple scattering in the long solid state target. This method suffers from a large combinatorial background as shown in Fig.1 (left). Selecting the D^* by requiring a low momentum pion π_{soft}, $D^* \rightarrow K\pi\pi_{soft}$, suppresses much of the background as shown in Fig.1 (right).

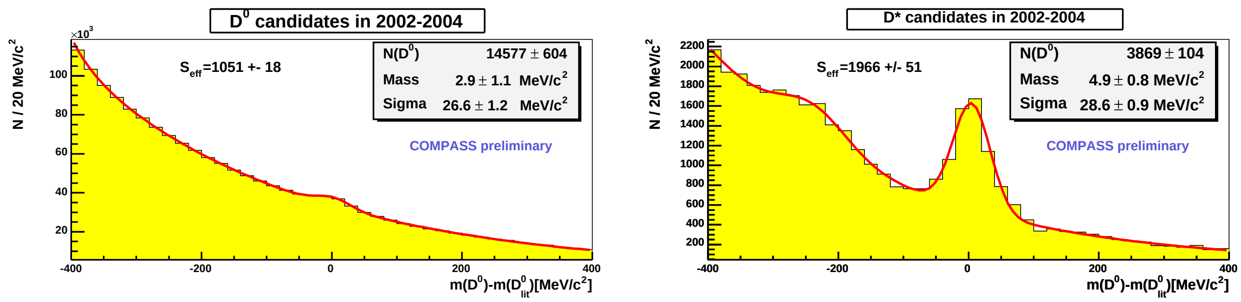

FIGURE 1. Invariant mass distribution in the D^0 mass range as computed from $D^0 \rightarrow K\pi$ candidates (left) and in the D^* mass range as computed from $D^* \rightarrow K\pi\pi_{soft}$ candidates (right) for the 2002-2004 data set.

The gluon polarisation is calculated from the experimental longitudinal double spin asymmetry:

$$A_{exp} = P_B P_T f a_{LL} \frac{S}{S+B} \frac{\Delta G}{G}.$$

The analysing power a_{LL} has to be determined from a Monte Carlo simulation since the kinematics of the PGF event is not fully known (only one of the two D^0 mesons is reconstructed). A parametrisation of a_{LL} is obtained via a neural network trained on a Monte Carlo sample generated by AROMA and reconstructed as for the real data. Using all 2002-2004 data a preliminary value of $\Delta G/G$ is obtained at $< x_g >= 0.15$ and at a QCD scale of $< \mu^2 >= 13$ (Gev/c)^2:

$$\frac{\Delta G}{G} = -0.57 \pm 0.41(stat)$$

where we expect the systematic uncertainty to be smaller than the statistical one.

High p_T hadron pair - the alternative approach using high p_T hadron pairs makes use of PGF events with light quarks. High p_T hadron pairs are defined by two hadrons having each $p_T > 0.7$(GeV/c) and $\Sigma p_T^2 > 2.5$(GeV/c)^2. The events are divided in two independent samples for which background is different, $Q^2 > 1$(GeV/c)^2 and $Q^2 < 1$(GeV/c)^2. The QCD scale is determined by Q^2 for the first sample and by Σp_T^2 for the second sample. $\Delta G/G$ is obtained from the measured helicity asymmetry:

$$A_{LL} = R_{PGF} a_{LL}^{PGF} \Delta G/G + A_{bkg}$$

where R_{PGF} is the fraction of PGF events, a_{LL}^{PGF} the analysing power for the PGF subprocess and A_{bkg} the asymmetry from background processes. R_{PGF} and a_{LL}^{PGF} are determined from a Monte Carlo simulation using the LEPTO generator and the PYTHIA generator for the $Q^2 > 1(\mathrm{GeV/c})^2$ and $Q^2 < 1(\mathrm{GeV/c})^2$ events respectively. For the low Q^2 events, the data statistics is much higher but there is additional contribution due to resolved photon processes. For the unknown polarised parton distributions in the photon, bounds are used, resulting in an additional contribution to the systematic error [2]. For $Q^2 > 1(\mathrm{GeV/c}^2)$ we obtain for the 2002 and 2003 data at $< x_g >= 0.13 \pm 0.08$ and at a scale $< \mu^2 >= 3\ (\mathrm{Gev/c})^2$:

$$\frac{\Delta \mathrm{G}}{\mathrm{G}} = 0.06 \pm 0.31(\mathrm{stat}) \pm 0.06(\mathrm{syst}).$$

For $Q^2 < 1(\mathrm{GeV/c}^2)$ we obtain for the 2002, 2003 and 2004 data at $< x_g >= 0.085$ and at a scale of $< \mu^2 >= 3\ (\mathrm{Gev/c})^2$:

$$\frac{\Delta \mathrm{G}}{\mathrm{G}} = 0.016 \pm 0.058(\mathrm{stat}) \pm 0.055(\mathrm{syst}).$$

The systematic errors include the experimental systematics, the systematic error from Monte Carlo simulation and for $Q^2 < 1(\mathrm{GeV/c})^2$ the estimate of the resolved photon contribution. The results summarized in Fig.2 are compared to previous results from SMC [3] and HERMES [4]. These new results indicate that ΔG is small (or that $\Delta G/G$ has a node) around $x_g = 0.1$.

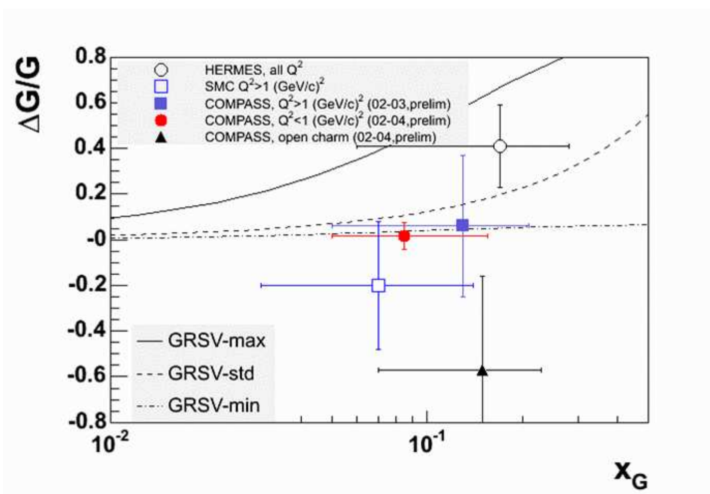

FIGURE 2. COMPASS results for $\Delta G/G$ from high p_T pairs $Q^2 < 1\ (\mathrm{GeV/c})^2$ for 2002-2004 data (full red square), from high p_T pairs $Q^2 > 1\ (\mathrm{GeV/c})^2$ for 2002-2003 data (full blue square) and open charm production (black triangle). The lines correspond to NLO GRSV parametrisations [14] at a QCD scale $\mu^2 = 3(\mathrm{GeV/c})^2$ for ΔG equal to 0.2 (min), 0.6 (std) and 2.5 (max). Horizontal error bar shows the x_g range. The QCD scale for the experimental points is $\mu^2 = 3(\mathrm{GeV/c})^2$ except for the open charm point where it is $\mu^2 = 13(\mathrm{GeV/c})^2$.

g_1^D FROM COMPASS AND $\Delta G/G$ VIA NLO FITS

From the 2002-2004 data taken with a longitudinally polarised target, the A_1^d spin asymmetry from inclusive Deep Inelastic Scattering (DIS) $\mu d \rightarrow \mu' X$ events ($Q^2 > 1(\mathrm{GeV/c})^2$) events is measured and the corresponding spin structure function g_1^d is extracted [5][6]. Fig.3 (left) shows COMPASS results compared to SMC results. For the points at $x < 0.03$ the statistical precision of COMPASS is a factor 3-4 better. To compare to world data we now use g_1^N which is g_1^d corrected for the deuteron D-wave: $g_1^N(x,Q^2) = g_1^d/(1-1.5\omega_D) = (g_1^p + g_1^n)/2$. From COMPASS data alone the integral of g_1^N is obtained from the experimental values evolved to $Q^2 = 3(\mathrm{GeV/c})^2$. Accounting for the contributions from unmeasured regions we get for the first moment [7] $\Gamma_1^N(Q^2 = 3(GeV/c)^2) = 0.050 \pm 0.03(stat) \pm 0.03(evol) \pm 0.005(syst)$. From this value, assuming $SU(3)_f$ flavour symmetry ($a_8 = 0.585 \pm 0.025$), using $\alpha_s(M_z^2) = 0.1187 \pm 0.005$ and assuming 3 active quark flavours, one gets for the singlet axial current matrix element at $Q^2 = 3(GeV/c)^2$:

$$a_0 = 0.35 \pm 0.03(stat) \pm 0.05(syst).$$

Extrapolating to $Q^2 \rightarrow \infty$ one obtains $\hat{a}_0 = 0.33 \pm 0.03(stat) \pm 0.05(syst)$. Combining this value with a_8, one gets for the first moment of the strange quark spin distribution:

$$(\Delta s + \Delta \bar{s})_{Q^2 \rightarrow \infty} = \frac{1}{3}(\hat{a}_0 - a_8) = -0.08 \pm 0.01(stat) \pm 0.02(syst).$$

The negative trend of g_1^d at low x seen by SMC is not confirmed. In view of this, a new NLO QCD fit of all g_1 DIS world data from deuteron-including COMPASS results-, from proton and from ^{3}He targets was performed. In total 230 data points were used. The fit shown on Fig.3 yields to two solutions, one solution has $\Delta G > 0$ and the other has $\Delta G < 0$. Although the polarised gluon distributions strongly differ in the two fits, the fitted values of their first moments are both small and about equal in absolute value $\mid \eta_G \mid \simeq 0.2 - 0.3$ [8].

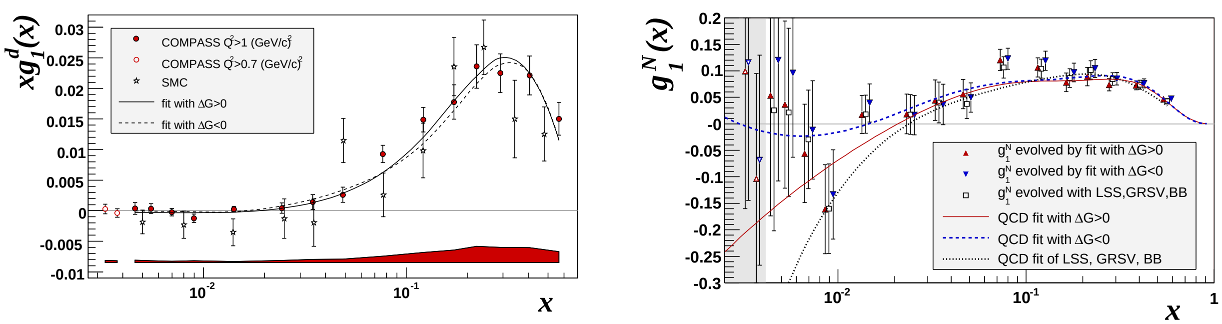

FIGURE 3. (Left) COMPASS results (2002-2004) for $xg_1^d(x)$ vs x compared to SMC. Two new NLO fi ts to the world data incorporating COMPASS results are shown, one has $\Delta G > 0$, the other $\Delta G < 0$. (Right) the COMPASS values of $g_1^N(x,Q^2)$ (N=Nucleon) evolved to $Q^2 = 3$ (GeV/c)^2 are shown with the new NLO fi ts. Also shown is the curve derived from the three parameterizations (BB, GRSV and LSS05) which negative trend at low x is not supported by COMPASS data.

TRANSVERSITY

Collins asymmetries - from the 2002-2004 data taken with a transversely polarised target the Collins azimuthal asymmetries from Semi-Inclusive DIS (SIDIS) $\mu d \to \mu' h X$ events have been measured. This asymmetry $A_{\Phi_{Coll}} = \frac{\Sigma_q e_q^2 \times \Delta_T q \times \Delta_T^0 D_q^h}{\Sigma_q e_q^2 \times q \times D_q^h}$ is sensitive to the product of the transverse spin distribution $\Delta_T q$ and the spin dependent component of the fragmentation function for transversely polarised quarks $\Delta_T^0 D_q^h$ [9][10][11].

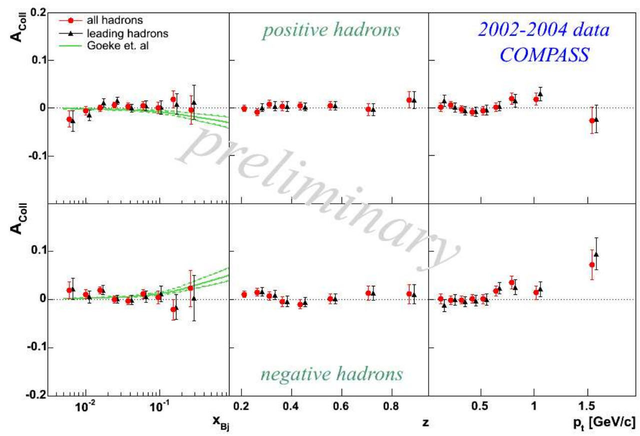

FIGURE 4. Collins asymmetries on deuteron vs x, z and p_T, positive (up) and negative (down) for all hadrons and leading hadrons.

Fig.4 shows the corresponding results for $A_{\Phi_{Coll}}$ as a function of x, z (fraction of energy carried by hadrons) and p_T for both positive and negative hadrons (also shown are leading hadrons alone) compared to a theoretical prediction [12] which describes HERMES proton data [13] and the first asymmetries related to fragmentation functions from BELLE [15]. As apparent from Fig.4 all the measured asymmetries are small and compatible with zero. A possible explanation is that transverse spin effects in deuteron are small due to the opposite sign expected from the u and d quarks distributions causing cancellation on the asymmetries of an isoscalar target. This result provides a strong case to perform similar measurements in the future with a proton target at COMPASS (see also [11]).

More polarimeters for transversity - in the search for a signature for transversity, more polarimeters have been exploited and data for two-hadron transverse spin asymmetries have been obtained [16]. Also Λ and $\overline{\Lambda}$ transverse polarisations have been measured [17]. Both data sets show results compatible with zero.

Sivers asymmetries - the Sivers asymmetry $A_{\Phi_{Siv}} = \frac{\Sigma_q e_q^2 \times \Delta_0^T q \times D_q^h}{\Sigma_q e_q^2 \times q \times D_q^h}$ occurs from the correlation between the transverse momentum $\vec{k_T}$ of an unpolarised quark with the transverse nucleon spin [9]. Fig.5 shows the results for $A_{\Phi_{Siv}}$ for the 2002-2004 SIDIS data, for both positive and negative hadrons (also shown are leading hadrons alone). The results are compatible with zero and agree with a theoretical prediction which describes HERMES proton data [18].

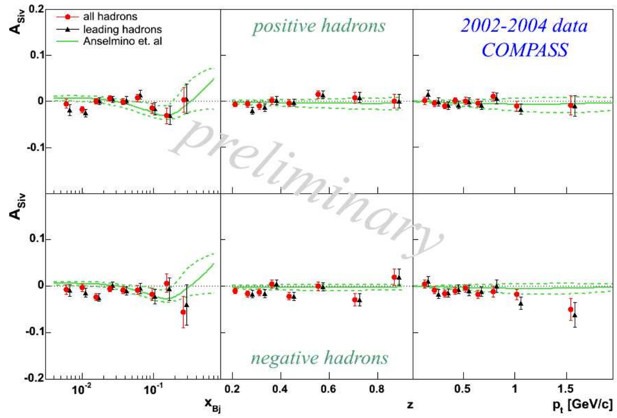

FIGURE 5. Sivers asymmetries on deuteron vs x, z and p_T, positive (up) and negative (down) for all hadrons and leading hadrons.

OTHER MEASUREMENTS AND PROSPECTS

COMPASS has performed several other measurements included in separate contributions to this conference. Results on longitudinal Λ and $\overline{\Lambda}$ polarisations can be found in [19]. Results on the longitudinal double-spin asymmetry in exclusive ρ^0 production can be found in [20]. The data taking continues in 2006 with an improved spectrometer. The most important changes are the new large acceptance superconducting solenoid available for the polarised target [21] and the RICH detector upgrade for particle identification. Finally future prospects to measure the Generalized Parton Distributions at COMPASS are presented in [22].

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