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Final results on the spin dependent structure function g_1^{d} from COMPASS

Malte Wilfert[∗ †]
on behalf of the COMPASS Collaboration
Institut fuer Kernphysik, University Mainz, Johann-Joachim-Becher-Weg 45, D 55128 Mainz
E-mail: mwilfert@cern.ch

In 2002-2004 the COMPASS experiment at the CERN SPS has taken data with a polarised muon beam scattering off a polarised LiD target. The same measurement was also performed in 2006 increasing the statistics by roughly a factor of two. The new results from the 2006 data on the longitudinal double spin asymmetry A_1^{d} and on the spin dependent structure function g_1^{d} are shown and compared to the previous results from the 2002-2004 data. Using the combined data set the first moment of g_1^{d} is calculated. This quantity is used to compute the singlet axial charge a_0, which in the $\overline{\mathrm{MS}}$ scheme is equal to $\Delta\Sigma$ the total contribution from the quarks to the nucleon spin. Using also the axial charges a_3 and a_8 the first moments of the quark helicity distributions are obtained.

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∗Speaker.

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1. Introduction

The COMPASS collaboration is investigating the spin structure of the nucleon. A measurement of the spin dependent structure function $g_1^{\rm d}$ of the deuteron provides information on the polarised quark distributions. Its first moment can be used to extract the contribution from the quarks to the nucleon spin, which can also be disentangled into the contribution from the different quark flavours. The measurement of this structure function has already been performed by COMPASS using the data from 2002-2004 [1]. Also another data set from 2006 is available, which increases the data sample by roughly a factor of two. This paper reports on the analysis of the full COMPASS deuteron data.

2. The COMPASS experiment

The COMPASS Collaboration runs a fixed target experiment with a two stage magnetic spectrometer. It is located at the M2 beamline of the CERN SPS, which provides a naturally polarised muon beam (80% polarised) with an energy of 160 GeV. The ^{6}LiD target in 2006 consisted of three target cells. The two outer ones (30 cm long) were polarised in opposite directions compared to the central one (60 cm long). This allowed the measurement of both polarisation directions simultaneously. The polarisation of the target cells was rotated regularly by rotating the solenoid field. This results in a better cancellation of different acceptances. A complete description of the COMPASS setup can be found in Ref. [2].

3. Results on $A_1^{\rm d}$ and $g_1^{\rm d}$

The longitudinal double spin asymmetry $A_1^{\rm d}$ is extracted from the simultaneous measurement using both target polarisations. For this analysis the data set is subdivided into periods of stable data taking, which contain data before and after a solenoid field rotation in the target. The asymmetry is calculated for all those periods taking into account the target and beam polarisation, the dilution and depolarisation factors. The final result is obtained by combining the results from all those periods.

Such an analysis has already been performed using the data from 2002-2004 [1]. A comparison of the new results from 2006 and the previous one, for the Bjorken scaling variable x and the photon virtuality Q^2 for each bin as well as the asymmetry as a function of x are shown in Figure 1. Compared to the results from the 2002-2004 data taking, in 2006 higher values of Q^2 are reached at the same x. The results for the asymmetry obtained from both data taking periods agree well with each other. The results are combined using a weighted mean giving a unique data set for the asymmetry $A_1^{\rm d}$ from the COMPASS data, which at low x is the most precise one ever. This result is compared to the world data in Figure 2 showing excellent agreement between all measurements. The good agreement between all data sets taken at quite different values of Q^2 illustrate the well-known weak Q^2 dependence of the asymmetry.

The spin dependent structure function $g_1^{\rm d}$ is calculated directly from the asymmetry using

$$g_1^{\rm d}(x,Q^2) = \frac{F_2^{\rm d}(x,Q^2)}{2x\,(1+R(x,Q^2))} A_1^{\rm d}(x,Q^2)\ . \tag{3.1}$$

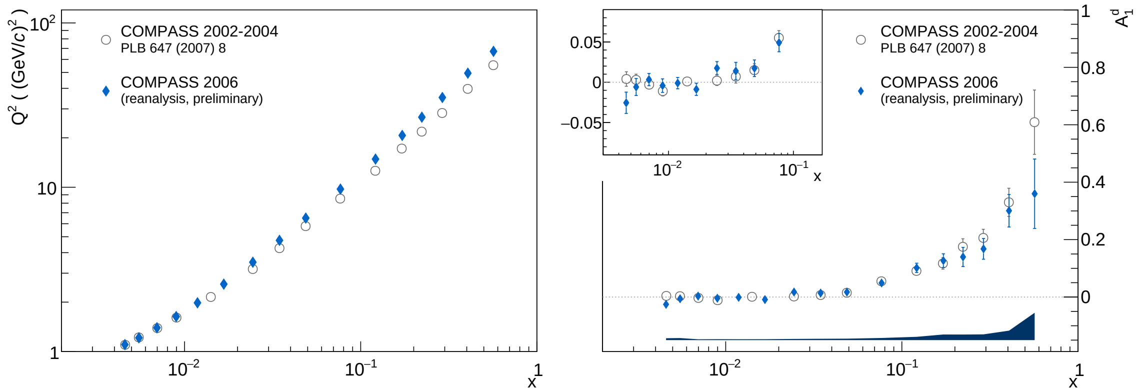

Figure 1: Left: Comparison between the mean values of x and Q^2 for each x bin between the results from the 2002-2004 data taking and the results for the 2006 data. Right: Comparison between the results for the longitudinal double spin asymmetry A_1^d for both data takings. The band at the bottom corresponds to the systematic uncertainty of the 2006 data set.

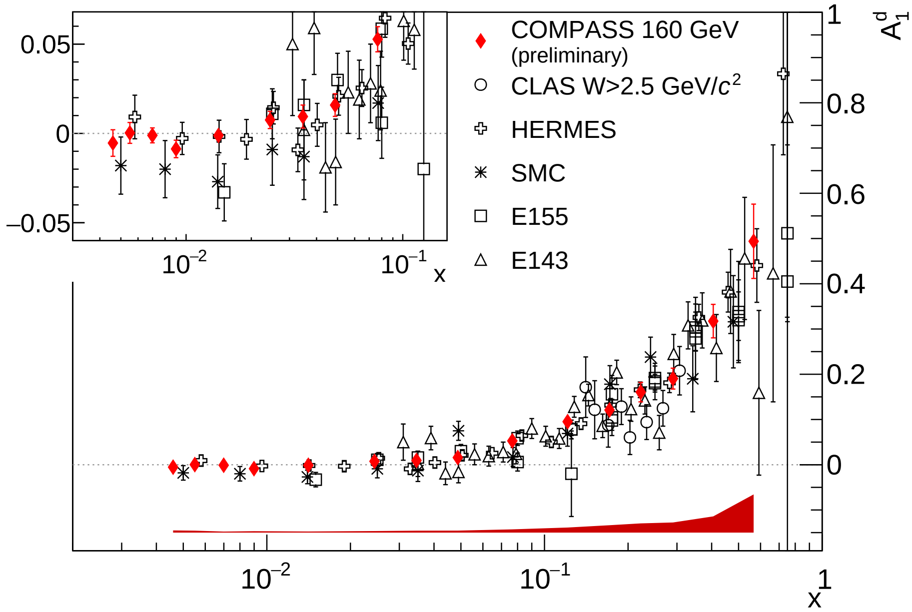

Figure 2: Comparison of the combined COMPASS result on A_1^d to the world data (CLAS [3], HERMES [4], SMC [5], E155 [6] and E143 [7]). All data points are at their measured kinematics. The band at the bottom illustrates the systematic uncertainty of the combined COMPASS data.

Here the F_2 parametrisation from SMC [5] has been used together with the R parametrisation from Ref. [8] with further modifications. The results for the spin dependent structure function as a function of x is shown in Figure 3 together with the SMC results. The COMPASS g_1^d results at low x are compatible with zero, whereas the SMC results indicated possible large negative values in this region albeit with large statistical uncertainties.

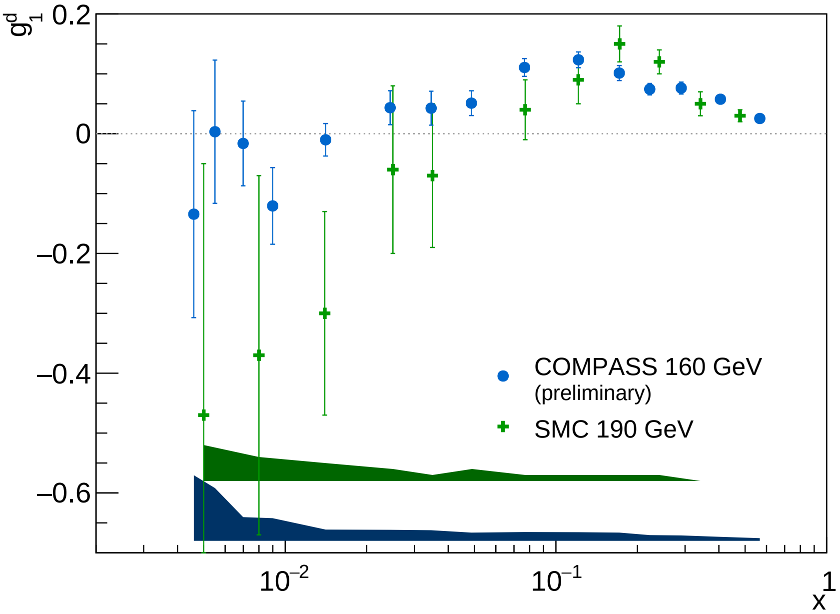

Figure 3: Comparison between the combined COMPASS and SMC results on g_1^d. The bands at the bottom illustrate the systematic uncertainties.

4. First moment and axial charge

The combined data set is used to calculate the first moment $\Gamma_1 = \int_0^1 g_1(x)dx$ of the spin dependent structure function. For this the data points have to be evolved to a common Q^2. This is done using the results from our NLO QCD fit to the proton, deuteron and neutron g_1 world data [9]. Figure 4 shows the comparison between our NLO QCD fit and the combined data set at a common Q^2 of $3\,(\mathrm{GeV}/c)^2$. The newly formed data set including the 2006 data shows a good agreement with the QCD fit. The combined data set is used to calculate the contribution to the first moment from the measured x range. The contributions from the unmeasured region are taken from an extrapolation of the NLO QCD fit to $x = 1$ and $x = 0$. These contributions are small due to the large measured x range from $x = 0.004$ to $x = 0.7$ and contribute only 3% the the full first moment. The final results for the first moment of the nucleon $g_1^N = g_1^d/(1-1.5\omega_D)$ is:

$$\Gamma_1^N(Q^2 = 3\,(\mathrm{GeV}/c)^2) = 0.047 \pm 0.002_{\mathrm{stat}} \pm 0.004_{\mathrm{syst}} \pm 0.004_{\mathrm{evol}}\ (\mathit{preliminary}), \tag{4.1}$$

where the evolution uncertainty corresponds to that of the NLO QCD fit. The systematic one takes into account the uncertainties from the beam and target polarisation, the dilution and depolarisation factors and the F_2 parametrisation. This result is in good agreement with our previous result,

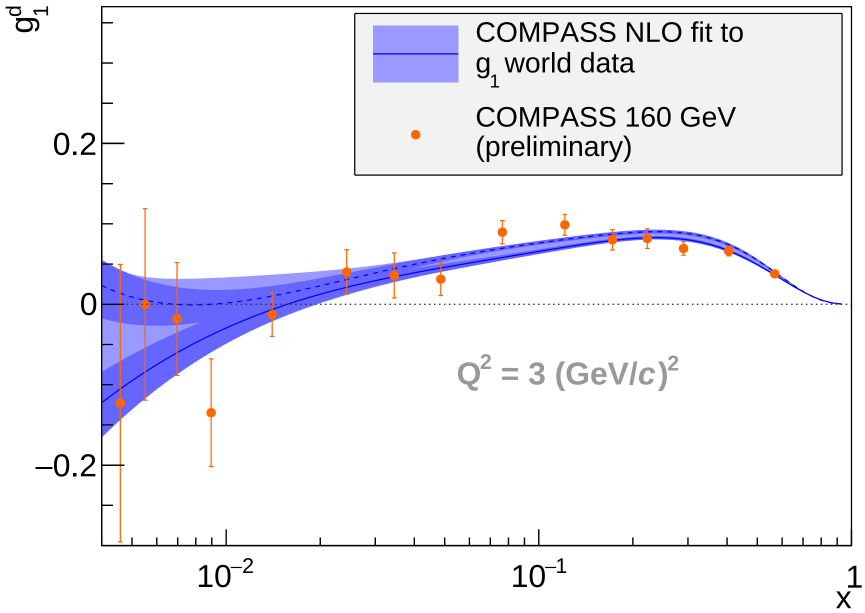

Figure 4: Comparison between the results of our NLO QCD fit with the combined COMPASS data set on g_1^d at $Q^2 = 3\,(\mathrm{GeV}/c)^2$). The two lines correspond to the two sets of solutions obtained from the NLO QCD fit. The darker band correspond to the statistical uncertainty of the QCD fit and the lighter band illustrate the systematic uncertainty of the fit.

which has been obtained using only the 2002-2004 data set ($\Gamma_1^N = 0.050 \pm 0.003_{\mathrm{stat}} \pm 0.005_{\mathrm{syst}} \pm 0.003_{\mathrm{evol}}$). Including the new results from the 2006 data results in a reduced statistical uncertainty.

The first moment is used to extract the singlet axial charge a_0. This is of special interest since it is equal to the contributions of the quarks to the nucleon spin in the $\overline{\mathrm{MS}}$ factorisation scheme $a_0 = (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s})$.

$$\Gamma_1^N(Q^2) = \int_0^1 g_1^N(x,Q^2)dx = \frac{1}{36}\left[a_8 C^{NS}(Q^2) + 4a_0 C^S(Q^2)\right] \tag{4.2}$$

The non-singlet and singlet coefficient functions C^{NS} and C^S are calculated up to the third order in α_s in perturbative QCD [11]. The result for the singlet axial charge using a_8 from Ref. [10] is

$$a_0(Q^2 = 3\,(\mathrm{GeV}/c)^2) = 0.32 \pm 0.02_{\mathrm{stat}} \pm 0.04_{\mathrm{syst}} \pm 0.04_{\mathrm{evol}}\ (\mathit{preliminary}). \tag{4.3}$$

This result is again in good agreement with the one previously obtained from the 2002-2004 data set ($a_0 = 0.33 \pm 0.03_{\mathrm{stat}} \pm 0.05_{\mathrm{syst}}$) with a reduced statistical uncertainty. Here the systematic uncertainty includes also the evolution uncertainty.
The singlet axial charge can further be decomposed into the contributions from each quark flavour taking into account also the axial charge a_3 (taken from Ref. [10]) as a_0, a_3 and a_8 are connected

to different contributions of the quark flavours

$$\Delta(u+\overline{u}) = \frac{1}{6}\left(2a_0 + a_8 + 3a_3\right) \tag{4.4}$$

$$\Delta(d+\overline{d}) = \frac{1}{6}\left(2a_0 + a_8 - 3a_3\right) \tag{4.5}$$

$$\Delta(s+\overline{s}) = \frac{1}{3}\left(a_0 - a_8\right) \ . \tag{4.6}$$

Using these equations and our result from the combined deuteron data set the different contributions are obtained:

$$\Delta(u+\overline{u}) = \quad 0.840 \pm 0.007_{\rm stat} \pm 0.012_{\rm syst} \pm 0.015_{\rm evol} \ (preliminary) \tag{4.7}$$

$$\Delta(d+\overline{d}) = -0.429 \pm 0.007_{\rm stat} \pm 0.012_{\rm syst} \pm 0.015_{\rm evol} \ (preliminary) \tag{4.8}$$

$$\Delta(s+\overline{s}) = -0.088 \pm 0.007_{\rm stat} \pm 0.012_{\rm syst} \pm 0.015_{\rm evol} \ (preliminary), \tag{4.9}$$

which are also in good agreement with the results obtained from our NLO QCD fit to the proton, deuteron and neutron world data, showing a large positive contribution from the u quarks and a negative one from the d quarks.

5. Conclusion

The new results from the 2006 data taking complete the COMPASS data set on the double spin asymmetry $A_1^{\rm d}$ and the spin dependent structure function $g_1^{\rm d}$, increasing the statistics by a factor of two. The combined data improves the precision of the spin dependent structure function at low x compared to the results from SMC and shows that $g_1^{\rm d}$ is compatible with zero at low x. The combined data set is used to update the value of the first moment of the spin dependent structure function. This is of special interest since it can be connected to the singlet axial charge a_0, which represents the contribution from the quarks to the nucleon spin in the $\overline{\rm MS}$ factorisation scheme. Using the new result for a_0 also the contributions from the different quark flavours are obtained, compatible with the results from our NLO QCD fit to the proton, deuteron and neutron world data.

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