Results on longitudinal spin physics at COMPASS

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Abstract. The COMPASS experiment at the CERN SPS has taken data on deep inelastic scattering of polarised muons on a polarised NH_3 target in 2007 and 2011 and on a polarised LiD target in 2002-2004 and 2006. The new results on the longitudinal double spin asymmetry A_1^p and the spin-dependent structure function g_1^p obtained from the 2011 data set are presented. These results are used in a NLO QCD fit to the world data to obtain the polarised parton distributions. Also an update of the results on the Bjorken sum rule, connecting the integral of the non-singlet spin-dependent structure function with the ratio of the weak coupling constants, will be given.

Direct access to the gluon polarisation is possible via the photon gluon fusion process in semi-inclusive deep inelastic scattering. This process is studied using the p_T dependence of charged hadron asymmetries. The latest results indicate a positive gluon polarisation in the kinematic region of COMPASS

1 Introduction

One of the physics goals of the COMPASS experiment at CERN is the determination of the different contributions to the nucleon spin. Therefore data for deep inelastic scattering were recorded in 2002-2006 on a polarised ^{6}LiD target and in 2007/2011 on a polarised NH_3 target. In case of the 2011 data the beam energy has been increased from 160 GeV to 200 GeV to measure also lower values of the Bjorken scaling variable x_{Bj} and higher values of the photon virtuality Q^2. From these data the spin-dependent structure function g_1 can be determined. This structure function is of special interest as it can be used in a global QCD analysis to extract the helicity distributions of quarks and gluons. Using the deuteron and proton data from COMPASS only, it is also possible to calculate the non-singlet structure function, which allows an verification of the Bjorken sum rule. In case of the gluon polarisation a different approach can be used to extract this quantity directly in leading order.

2 Experiment

The COMPASS experiment is a fixed target experiment located at the M2 beamline of the CERN SPS. The complete setup is described in Reference [1]. In 2011 a polarised three cell target has been used. The outer most cells (30 cm long) were polarised in an opposite direction compared to the middle cell (60 cm long) allowing the measurement of both polarisation directions simultaneously. In order

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to cancel acceptance effects the polarisation of the cells is changed on a regular base by rotating the solenoid field of the target.

3 Results on A_1^{p} and g_1^{p}

The longitudinal photon-nucleon double-spin asymmetry is extracted from the measurement of DIS events from the oppositely polarised target cells. All details on this analysis can be found in Reference [2]. In order to obtain the asymmetry $A_1(x_{\mathrm{Bj}}, Q^2)$ the raw asymmetry has to be corrected for the target and beam polarisation together with the dilution and depolarisation factor. This asymmetry is directly connected to the spin dependent structure function via $g_1 = F_2 A_1/(2x_{\mathrm{Bj}}(1+R))$ using the ratio $R = \sigma_{\mathrm{L}}/\sigma_{\mathrm{T}}$ [3] of the absorption cross sections for longitudinal and transverse polarised virtual photons and the unpolarised structure function F_2 [4]. The results on the spin-dependent structure function from the 2011 is shown in Figure 1 as a function of Q^2 and x_{Bj} together with the world data. In addition also the results from our NLO QCD fit to these data is shown.
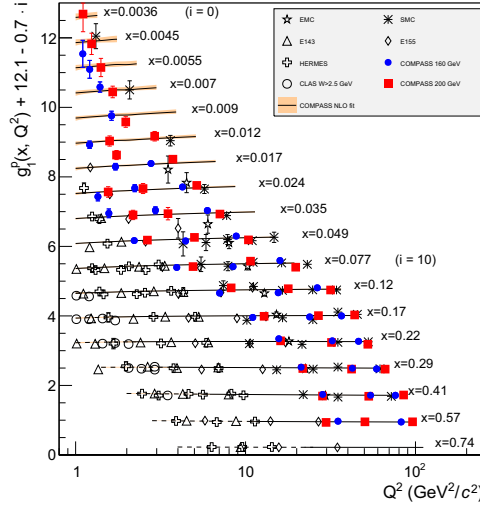

Figure 1. World data on g_1^{p} as a function of Q^2 for different x_{Bj}. The solid line represents the result of our NLO QCD fit. The dashed line indicates a extrapolation for $W^2 < 10\,\mathrm{GeV}^2$.

4 QCD fit

Performing a NLO QCD fit to the world data on g_1 in the DIS region allows for an extraction of the quark and gluon helicity. In addition to the new COMPASS data also the world data on proton, deuteron an ^{3}He targets from the CERN [4–7], HERA [8, 9], SLAC [10–14] and JLAB [15, 16] experiments are used. The QCD fit is performed in the $\overline{\mathrm{MS}}$ renormalisation and factorisation scheme and uses the DGLAP evolution equation for the Q^2 dependence. The x_{Bj} dependence is given via

$$\Delta q_i(x) = \eta_i \frac{x^{\alpha_i}(1-x)^{\beta_i}(1+\gamma_i x)}{\int_0^1 x^{\alpha_i}(1-x)^{\beta_i}(1+\gamma_i x)dx}, \tag{1}$$

for the gluon, singlet and both non-singlet distributions. This functional form has been used at the reference scale of $Q_0^2 = 1\,(\mathrm{GeV}/c)^2$. In case of the gluon and non-singlet distributions γ_i is fixed to zero as the data is not sensitive to this parameter. The same is valid for β_g, which is fixed to the corresponding value from the unpolarised distribution taken from MSTW [17]. In addition the first moments η_3 and η_8 are fixed via the baryon decay constants. The unpolarised parton distributions are also used in each fit step to check the positivity constrain $|\Delta q(x_\mathrm{Bj})| < q(x_\mathrm{Bj})$ for all flavours (u, d, s, g). An extra term in the χ^2 penalises possible violations. Different systematic studies were performed to estimate the uncertainty on the fit. The largest contribution is the dependence on the reference scale at which the functional shape is initialised. From all studies two solutions are obtained with an equally good χ^2/NDF. One solution with γ_S fixed to zero results in a negative gluon distribution and one solution with γ_S as a free parameter results in a positive gluon distribution. The results are illustrated in Figure 2. From this fit the contribution from the quarks to the total spin of the nucleon is extracted to be in the range $0.26 < \Delta\Sigma < 0.36$, whereas the contribution from the gluon is not well constrained.
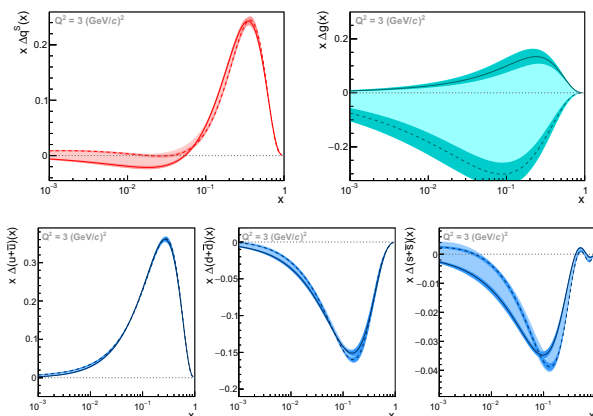

Figure 2. Result of the QCD fit to the world data. The solid lines indicate our two solutions with their statistical uncertainty indicated as a darker band. The lighter band corresponds to the systematic uncertainty of the fit.

5 Bjorken sum rule

The results from the QCD fit can also be used to extract first moments. The one of the non-singlet structure function

$$g_1^\mathrm{NS}(x_\mathrm{Bj}, Q^2) = g_1^\mathrm{p}(x_\mathrm{Bj}, Q^2) - g_1^\mathrm{n}(x_\mathrm{Bj}, Q^2) \tag{2}$$

is of special interest since it can be used to verify the Bjorken sum rule, which connects its first moment with the ratio of the weak coupling constants:

$$\Gamma_1^\mathrm{NS}(Q^2) = \int\limits_0^1 g_1^\mathrm{NS}(x, Q^2)dx = \frac{1}{6}\left|\frac{g_\mathrm{A}}{g_\mathrm{V}}\right|C_1^\mathrm{NS}(Q^2). \tag{3}$$

Here C_1^NS is the non-singlet coefficient function, which has been calculated in perturbative QCD [18]. The first moment is calculated using only COMPASS data, which are evolved to a common Q^2 of the 2007 proton data set using the NLO QCD fit. The non-singlet structure function g_1^NS is calculated

afterwards from the evolved data sets. These data are used in a second NLO QCD fit; only the non-singlet structure is fitted function via the non-singlet distribution Δq_3. The program used for the fit is the same as used to fit the world data on g_1. For the verification of the Bjorken sum rule it is necessary to calculate the first moment at a fixed scale. The evolution of the non-singlet structure function, obtained from the COMPASS data, to a common scale of $Q^2 = 3\,(\text{GeV}/c)^2$ is performed using the results from the non-singlet fit. A comparison showing the results from the non-singlet fit and the COMPASS data is illustrated in Figure 3. The COMPASS data cover only the range of $0.0025 < x_{\text{Bj}} < 0.7$. The results from the non-singlet fit are used to determine the contribution to the first moment of g_1^{NS} for the unmeasured region. The first moment at $Q^2 = 3\,(\text{GeV}/c)^2$ is

$$\Gamma_1^{\text{NS}} = 0.181 \pm 0.008(\text{stat}) \pm 0.014(\text{syst}) , \tag{4}$$

from which 94% are within the measured x-range. Figure 4 shows the dependence of the integral of the non-singlet structure function as a function of the lower limit, also illustrating the size of the extrapolations. The ratio of the weak coupling constants is calculated using the non-singlet coefficient function in NLO

$$\left| \frac{g_{\text{A}}}{g_{\text{V}}} \right| = 1.22 \pm 0.05(\text{stat}) \pm 0.10(\text{syst}) . \tag{5}$$

The systematic uncertainty is dominated by the uncertainty on the beam polarisation. Other contribution like the one from the target polarisation, the dilution factor, the depolarisation factor and F_2 are also taken into account. Comparing the result for $|g_{\text{A}}/g_{\text{V}}|$ with the results from the neutron β-decay ($|g_{\text{A}}/g_{\text{V}}| = 1.2701 \pm 0.002$ [19]) provides a validation of the Bjorken sum rule at the level of 9%.
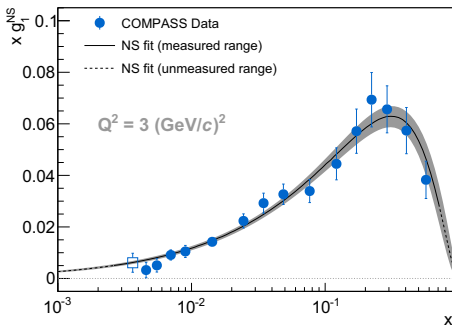

Figure 3. Values of g_1^{NS} at $Q^2 = 3\,(\text{GeV}/c)^2$ compared to the NLO fit. The open square corresponds to the data point where the deuteron contribution is taken from the NLO QCD fit.
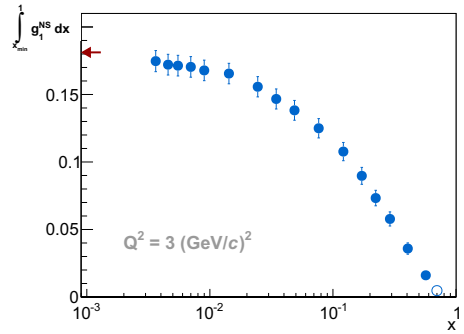

Figure 4. Dependence of the first moment as a function of x_{min}. The open circle at $x_{\text{Bj}} = 0.7$ is obtained from the fit. The arrow on the left side indicates the value for the full range $0 < x_{\text{Bj}} < 1$.

6 LO extraction of ΔG

An alternative access to the gluon polarisation uses the p_{T} dependence of the charged hadron asymmetry in semi-inclusive deep inelastic scattering, which can be split up in LO into contributions from different processes:

$$A_{\text{LL}}^h(x_{\text{Bj}}) = \alpha \cdot A_1^{LO}(x_{\text{Bj}}) + \beta \cdot A_1^{LO}(x_{\text{c}}) + \gamma \cdot \Delta g/g(x_{\text{g}}) , \tag{6}$$

the three processes are the leading process (LP), the QCD Compton process (QCDC) and the photon-gluon fusion (Figure 5). The factors α, β and γ depend on the partonic cross section asymmetries and the fraction to which each process contributes.
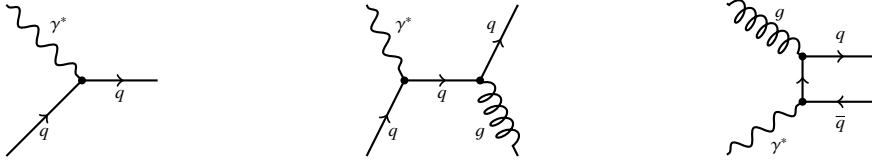

Figure 5. Feynman diagrams for the different processes. Leading-order process (left), QCD Compton (middle) and photon-gluon fussion (right).

The gluon polarisation is extracted from the 2002-2006 COMPASS deuteron data using a method developed for the extraction of the gluon polarisation from open charm events [20] distinguishing between signal and background events. A neural network (NN) is trained using Monte Carlo data to output the partonic cross section asymmetries a_{LL}^i, the fractions R_i and x_i using x_{Bj}, Q^2, p_T and p_L as input parameters. It assigns different weights to the events using the different kinematic dependence of the three processes. For systematic studies also different Monte Carlo simulations with different parameters for the hadronisation are used. The weights from the NN are used in a fit to obtain simultaneously the leading process asymmetries and the gluon polarisation. The final result is

$$\langle \Delta g/g \rangle = 0.113 \pm 0.038(\text{stat}) \pm 0.036(\text{syst}) , \qquad (7)$$

at a scale of $\mu^2 = \langle Q^2 \rangle = 3 \,(\text{GeV}/c)^2$ and $\langle x_g \rangle \approx 0.10$. This analysis is the first direct measurement of a positive value for the gluon polarisation. Since the statistics is good enough the result can be split up into three bins of x_g. These results are compared to the world data on $\Delta g/g$ extracted in LO in Figure 6. More informations can be found in Reference [21].
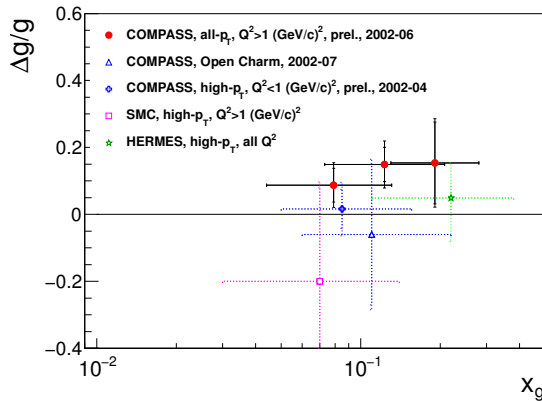

Figure 6. World data on $\Delta g/g$ [22–25] extracted in LO compared to our results in three bins of x_g.

7 Conclusion

The new data from the 2011 measurement complete the COMPASS results on A_1^p reaching lower values of x_{Bj} and higher values of Q^2. These data are used in a NLO QCD fit together with the world data on g_1 to extract the helicity distributions of the quarks and gluons. The contributions from quarks to the total spin of the nucleon are determined to be in the range of $0.26 < \Delta\Sigma < 0.36$. The COMPASS data taken on the proton and deuteron target are combined to extract the non-singlet structure function, which is used to verify the Bjorken sum rule. The obtained ratio of the weak coupling constants is $|g_A/g_V| = 1.22 \pm 0.05 \pm 0.10$ is obtained, which verifies the sum rule within an accuracy of 9%. A dedicated measurement of the gluon polarisation has been performed using p_T dependent muon-nucleon asymmetries from the DIS region. The value of the gluon polarisation obtained in LO QCD is $\langle \Delta g/g \rangle = 0.113 \pm 0.038 \pm 0.036$. This result is the first direct measurement of a positive gluon polarisation for the $x_g \approx 0.10$ region.

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