PROCEEDINGS OF SCIENCE

New COMPASS results on the spin structure function g_1^p, and QCD fit

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

The COMPASS experiment at CERN SPS has taken data with a polarised muon beam scattering off a polarised NH_3 target in 2011. The beam energy has been increased to 200 GeV compared to 160 GeV in 2007 and thus, higher values of Q^2 and lower values of x are reached.
From these data the longitudinal double spin asymmetry A_1^p and the spin-dependent structure function g_1^p are extracted. The results are used in a NLO QCD fit to the world data to obtain the polarised parton distributions and also to test the Bjorken sum rule, connecting the integral of the non-singlet structure function with the ratio of the weak coupling constants.

XXII. International Workshop on Deep-Inelastic Scattering and Related Subjects
28 April - 2 May 2014
Warsaw, Poland

*Speaker.
†Supported by BMBF under the contract 05P12UMCC1 and GRK Symmetry Breaking (DFG/GRK 1581)

PoS(DIS2014)206

1. Introduction

The spin-dependent structure function g_1 allows access to the spin structure of the Nucleon. This is especially interesting as the quarks carry only roughly 30% of the nucleon spin. With a QCD analysis of the world data on g_1 the helicity distributions of quarks and gluons can be determined. Further on, it is possible to test the Bjorken sum rule which provides a complementary way to access the ratio of the weak coupling constants compared to the neutron β-decay. The COMPASS experiment, located at the M2 beam line of the CERN SPS, has taken data with an increased beam energy of 200 GeV, compared to 160 GeV in 2007. The muon beam impinges on a solid polarised NH_3 target and is naturally polarised with an average polarisation of 0.80 ± 0.04. The data taken in 2011 improve the results on g_1^p and increase the kinematic coverage towards lower values of x and higher values of Q^2. A detailed description of the experimental set-up can be found in [2].

2. Results on A_1^p and g_1^p

For the extraction of the longitudinal double spin asymmetry a simultaneous measurement with both target polarisations is performed. For the three oppositely polarised target cells a reversal of the direction of the solenoid field results in changing the polarisation of each cell. This results in a cancellation of differences in the acceptance of the cells and luminosity. Taking into account the target polarisation, the beam polarisation, the dilution factor and depolarisation factor the final result for A_1^p is obtained. In case of NH_3 the dilution factor is around 0.15 and the longitudinal proton polarisation is roughly 90%. From the measured longitudinal asymmetry neglecting the contribution of A_2 the spin-dependent structure function $g_1^p = \frac{F_2^p}{2x(1+R)} A_1^p$ is obtained.

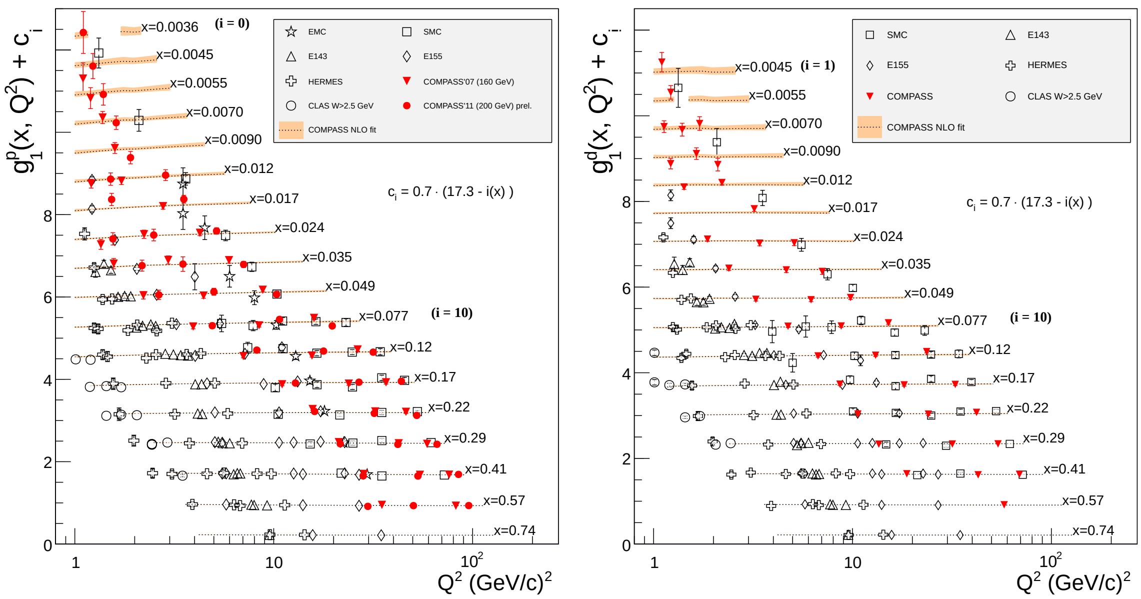

Figure 1: World data on the spin-dependent structure function g_1^p and g_1^d as a function of Q^2 for different x. The dotted lines represent the Q^2 dependence for each value of x taken from the NLO QCD fit.

The result of $g_1^{\rm p}$ from the 2011 data is shown in figure 1 (left) as a function of Q^2 for different values of x together with the world data. With the new data it is possible to extend the measured range of $g_1^{\rm p}$ towards even lower values of x with high precision. The data also covers a large range in Q^2 giving a better lever arm for the extraction of polarised parton distributions.

3. QCD fit

The new COMPASS results on $g_1^{\rm p}$ are used together with the world data on g_1 with $Q^2 > 1\,(\mathrm{GeV}/c)^2$ in a NLO QCD fit. For the fit we included proton data from EMC[1], SMC[3], SLAC E143[4], SLAC E155[5], Hermes[6], COMPASS[7] and CLAS[8], deuteron data from SMC[3], SLAC E143[4], SLAC E155[9], HERMES[6], COMPASS[10] and CLAS[8] as well as ^{3}He data from SLAC E142[11], SLAC E154[12], JLab Hall A[13] and Hermes[14]. The kinematic coverage of these data sets is shown in figure 2.

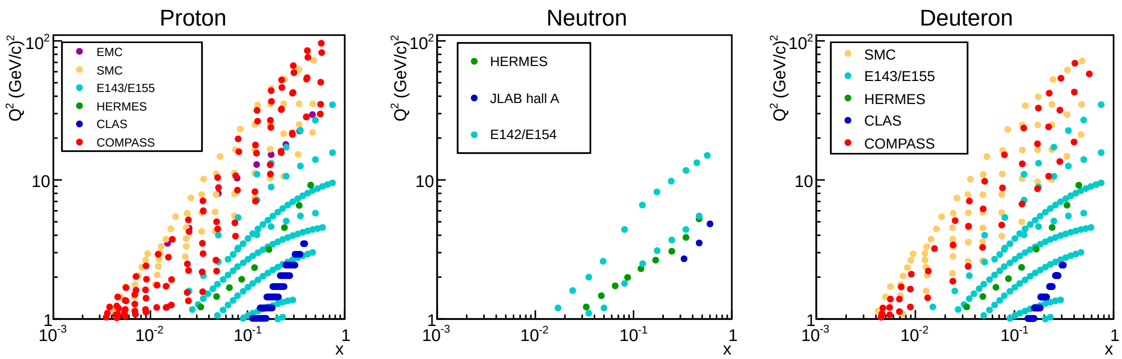

Figure 2: Kinematic coverage of the DIS data used in the QCD fit.

The fit is performed in the $\overline{MS}$ renormalisation and factorisation scheme. The quark singlet spin distribution $\Delta q_s(x)$, the two non-singlet spin-distributions $\Delta q_3(x)$ and $\Delta q_8(x)$ and the gluon spin-distribution $\Delta g(x)$ are parametrised at a reference scale Q_0^2. An input scale of $Q_0^2 = 1\,(\mathrm{GeV}/c)^2$ is chosen. Therefore, the Q^2 evolution of the spin-distribution is only performed in one direction according to the DGLAP equations. At the input scale the assumed functional shape of the distributions is

$$\Delta f_i(x) = \eta_i \frac{x^{\alpha_i}(1-x)^{\beta_i}(1+\gamma_i x)}{\int_0^1 x^{\alpha_i}(1-x)^{\beta_i}(1+\gamma_i x)\mathrm{d}x}\,, \tag{3.1}$$

where $\Delta f_i(x)$ are the different polarised parton-distributions, and η_i the first moment on the corresponding distribution. In case of the non-singlet distributions the first moments are fixed to the baryon decay constants $\eta_8 = F + D$ and $\eta_3 = 3F - D$. In addition the parameter γ is set to zero for these two distributions. The parameter β_g of the gluon distribution, describing the high-x behaviour, is fixed to 7.5 which is similar to the unpolarised distribution as it is not well determined by the data. The positivity constraint is checked in case of the strange and gluon distribution penalising a violation if $|\Delta q(x)| > q(x)$ with the unpolarised distributions $s(x)$, $\bar{s}(x)$ and $g(x)$ taken from MSTW [15].

Compared to our previous fit [10] a more detailed investigation of the systematic uncertainty of the fit is performed. We tested different parametrisations of the singlet and gluon distribution which results in three different models, depending on whether γ_g and γ_s are used as a free parameter or are fixed to zero. Fixing $\gamma_s = \gamma_g = 0$ results in a negative gluon distribution Δg, fitting only γ_s leads to a positive Δg. Fitting both, γ_s and γ_g gives rise to a node in Δg. The result of the NLO QCD fit is shown in figure 3, where the three different solution are illustrated with their statistical uncertainty (darker band) and the systematic uncertainty (lighter band). The main contribution to the systematic uncertainty is the dependence on the reference scale.

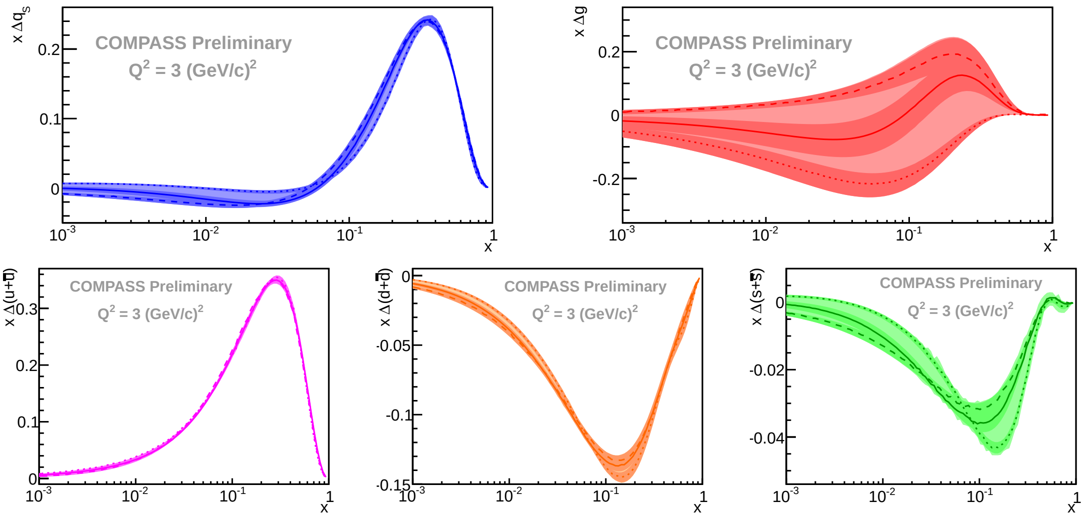

Figure 3: Results of the QCD fit to the world data. The three solid lines correspond to the three different functional shapes assumed for $\Delta g(x)$. The shaded bands define the $\pm 1\sigma$ error bands.

4. Bjorken sum rule

Making use of the COMPASS p and d data a test of the Bjorken sum rule is performed. The Bjorken sum rule connects the first moment of the non-singlet structure function

$$g_1^{\rm NS}(x,Q^2) = g_1^{\rm p}(x,Q^2) - g_1^{\rm n}(x,Q^2) \tag{4.1}$$

to the ratio of the weak coupling constants

$$\Gamma_1^{\rm NS}(Q^2) = \int_0^1 g_1^{\rm NS}(x,Q^2)\mathrm{dx} = \frac{1}{6}\left|\frac{\rm g_A}{\rm g_V}\right| \mathrm{C}_1^{\rm NS}(\mathrm{Q}^2), \tag{4.2}$$

where $C_1^{\rm NS}(Q^2)$ is the non-singlet coefficient function, which is available up to the third order in $\alpha_s(Q^2)$ [16] in perturbative QCD. In a first step the deuteron and 2011 proton data on g_1 are evolved to the Q^2 of the 2007 data [7] using the results of the NLO QCD fit. The combined proton data are used to calculate the non-singlet structure function

$$g_1^{\rm NS}(x,Q^2) = g_1^{\rm p}(x,Q^2) - g_1^{\rm n}(x,Q^2) = 2\left(g_1^{\rm p}(x,Q^2) - \frac{g_1^{\rm d}(x,Q^2)}{1-1.5\omega_D}\right), \tag{4.3}$$

where $\omega_D = 0.05 \pm 0.01$. For the proton data point at $x = 0.0036$ no value of g_1^{d} has been measured at COMPASS with $Q^2 > 1\,(\mathrm{GeV/c})^2$, therefore that value is taken from the QCD fit. For the evolution to $Q^2 = 3\,(\mathrm{GeV/c})^2$ a fit of the non-singlet distribution Δq_3 to g_1^{NS} is performed using the same program as for the fit described above. The results of the fit together with our data points at $Q^2 = 3\,(\mathrm{GeV/c})^2$ are illustrated in figure 4. The evolved data points are used to calculate the first moment in the measured range of $0.0025 < x < 0.7$. The dependence on the lower limit of the integral is shown in figure 5.

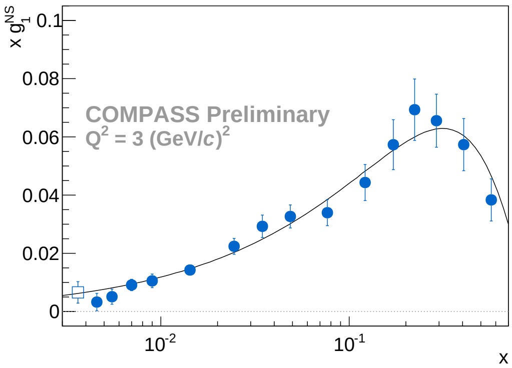

Figure 4: Values of g_1^{NS} at $Q^2 = 3\,(\mathrm{GeV/c})^2$ compared to the NLO fit. The open square corresponds to the data point where the deuteron contribution is taken from the NLO QCD fit.

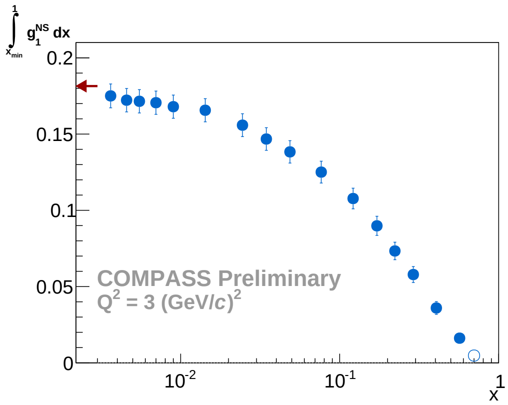

Figure 5: $\int_{x_{\mathrm{min}}}^{1} g_1^{\mathrm{NS}}\mathrm{d}x$ as a function of x_{min}. The open circle at $x = 0.7$ is obtained from the fit. The arrow on the left side shows the value for the full range $0 < x < 1$.

The missing contributions are evaluated using the non-singlet fit. The contribution from the measured range accounts for 94% of the first moment. Using the non-singlet coefficient function in NLO the ratio g_A/g_V is calculated:

$$g_A/g_V = 1.220 \pm 0.053\,(\mathrm{stat.}) \pm 0.095\,(\mathrm{syst.}) \tag{4.4}$$

The result is dominated by the systematic uncertainty including the uncertainty of both the beam and target polarisations as well as the dilution and depolarisation factors. The largest contributions are the uncertainty on the beam polarisation and the contribution from the combined proton sample. Comparing the result to the values obtained from the neutron β-decay ($|g_A/g_V| = 1.2701 \pm 0.002$[17]) provides a validation of the Bjorken sum rule. This test is free of uncertainties arising from the poorly known gluon helicity distribution due to the independence of Δq_3 from this distribution. To check how much and in which direction further perturbative orders might influence the result, the ration g_A/g_V is calculate using the coefficient function in NNLO. The obtained value is $g_A/g_V = 1.256$, thus the NNLO correction would increase the level of agreement.

References

[1] EMC, J. Ashman *et al.,* Phys. Lett. B **206** (1988) 364; Nucl. Phys. B **328** (1989) 1.

[2] COMPASS Collaboration, P. Abbon *et al.* Nucl, Instr. Meth. A **577** (2007) 455.

[3] SMC, B. Adeva *et al.,* Phys. Rev. D **58** (1998) 112001.

[4] E143 Collaboration, K. Abe *et al.,* Phys. Rev. D **58** (1998) 112003.

[5] E155 Collaboration, P. L. Anthony *et al.*, Phys. Lett. B **493** (2000) 19.

[6] HERMES Collaboration, A. Airapetian *et al.,* Phys. Rev. D **75** (2007) 012007.

[7] COMPASS Collaboration, E. M.G. Alekseev *et al.,* Phys. Lett. B **690** (2010) 466.

[8] CLAS Collaboration, K. V. Dharmawardane *et al.,* Phys. Lett. B **641** (2006) 11.

[9] E155 Collaboration, P. L. Anthony *et al.,* Phys. Lett. B **463** (1999) 339.

[10] COMPASS Collaboration, V. Yu. Alexakhin *et al.,* Phys. Lett. B **647** (2007) 8.

[11] E142 Collaboration, P. L. Anthony *et al.,* Phys. Rev. D **54** (1996) 6620.

[12] E154 Collaboration, K. Abe *et al.,* Phys. Lett. B **79** (1997) 26.

[13] JLab Hall A Collaboration, X. Zheng *et al.,* Phys. Rev. Lett. **92** (2004) 012004.

[14] HERMES Collaboration, K. Ackerstaff *et al.,* Phys. Lett. B **404** (1997) 383.

[15] A. D. Martin *et al*, Eur. Phys. J. C **63** (2009) 189.

[16] S. A. Larin, T. van Ritbergen and J. A. M. Vermaseren, Phys. Lett. B **404** (1997) 153.

[17] J. Beringer *et al* (Particle Data Group), Phys. Rev. D **86** (2012) 010001