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Spin structure function of deuteron g_1^d from COMPASS

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Abstract. New results on the longitudinal inclusive spin asymmetry A_1^d in the range $1 < Q^2 < 100$ $(\mathrm{GeV}/c)^2$ and $0.004 < x < 0.7$ are presented. From these results we derive the spin-dependent structure function g_1^d which we use to evaluate the scale-invariant flavor-singlet axial charge $\hat{a}_0$. The contribution of the measured region is evaluated by a QCD fit of the world data. The data were obtained by the COMPASS experiment at CERN using a 160 GeV polarized muon beam scattered off a large double-cell polarized ^{6}LiD target. The results are in agreement with those from previous experiments and improve considerably the statistical accuracy in the region $x < 0.03$.

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1 Introduction

In view of the spin crisis in the quark parton model [1] the investigation of the spin structure of the nucleon is the one of the most interesting issues in particle physics and it is the primary goal of the COMPASS experiment [2] at CERN SPS. The analysis of deep inelastic scattering (DIS) of 160 GeV longitudinally polarized muons off a longitudinally polarized ^{6}LiD target gives access to the spin-dependent structure function of the deuteron g_1^d.

The longitudinal virtual-photon deuteron asymmetry, A_1^d, is defined via the asymmetry of absorption cross sections of transversely polarized photon as

$$A_1^d = (\sigma_0^T - \sigma_2^T)\,/\,(\tfrac{2}{3}(\sigma_0^T + \sigma_1^T + \sigma_2^T)), \qquad (1)$$

where σ_J^T is the γ^*-deuteron absorption cross-section for a total spin projection J. The relation between the experimentally measured muon-deuteron asymmetry, A^d, and A_1^d is

$$A^d = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = D(A_1^d + \eta A_2^d), \qquad (2)$$

where D and η depend on the event kinematics. Arrows indicate direction of beam and target spins. The transverse asymmetry A_2^d has been measured at SLAC and found to be small [3]. In view of this, in our analysis, Eq. (2) has been reduced to $A_1^d \simeq A^d/D$. The longitudinal spin structure function g_1^d relates to A_1^d as

$$g_1^d = \frac{F_2^d}{2\,x\,(1+R)} A_1^d\,, \qquad (3)$$

where F_2^d is the spin-independent deuteron structure function and R is the ratio of cross sections for absorption of longitudinal and transverse photons $R = \sigma^L/\sigma^T$.

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2 Data sample and results on A_1^d

In the analysis we require for all events to have a reconstructed primary interaction vertex defined by the incoming and the scattered muons. The energy of the beam muon is constrained in the interval $140 < E_\mu < 180$ GeV. To cancel out the muon flux normalization and thus minimize the systematic error the trajectory of the incoming muon is required to cross the two cells of the target which are polarized in opposite direction. The kinematic region is defined by cuts on a photon virtuality Q^2 and a fractional energy y transfered from the beam muon to the virtual photon. The requirement $Q^2 > 1\,(\mathrm{GeV}/c)^2$ defines the region of DIS. The cut $0.1 < y < 0.9$ from one side removes events which are problematic from reconstruction point of view due to a small energy transfer. From the other side it eliminates events at large y which are the most affected by radiative corrections. These cuts define the x-interval accessible by COMPASS: $0.004 < x < 0.7$.

The counting rate asymmetry relates to A_1^d as

$$A^{exp} = P_t P_b f D\, A_1^d\,, \qquad (4)$$

where P_b is the incoming muon polarization, P_t is the target polarization and f is dilution factor which is the ratio of the absorption cross-section on the deuteron and on all nuclei in the target material. It also comprises corrections for radiative events. For the description of the method of asymmetry extraction and quality cuts for the sample see [4]. The data were collected during the years 2002–2004. The resulting sample consists of 89×10^6 events.

The A_1^d as a function of x is shown in Fig.1, where it is superposed to data of previous experiments. One can observe the good agreement over the full range of x. COMPASS contributes significantly to the low x region previously covered only by SMC. For the 6 points at $x < 0.03$

the statistical precision of COMPASS is a factor of 3-4 better. Moreover the negative trend at low x which was observed by SMC is not confirmed by the present data.

The average values of Q^2 versus x are shown in Fig. 2. One can see that COMPASS points are slightly lower compare to SMC. However they are factor of 2-3 higher then E143 and HERMES data.

There are several sources of systematics uncertainties in the determination of A_1^d. The measurement error of the target polarization and parametrization of the beam polarization amount to 5% each. The uncertainty related to the dilution factor f is 6% over the full range of x. The ratio $R = \sigma^L/\sigma^T$ used to calculate the depolarization factor D gives an error of 2-3%. If added in quadrature all uncertainties of multiplicative factors (Eq. 4) amount to 10% systematic error. The main contributor to the systematic error additive with respect to A_1^d is the false asymmetry which could be generated by instabilities in some components of the spectrometer. It was evaluated as a fraction of statistical error [4]: $\sigma_{syst} < 0.4\sigma_{stat}$. The total systematic uncertainty is shown as a band at the bottom of Fig. 1.

3 Extraction of the singlet axial charge $\hat{a}_0$

With COMPASS data alone we evaluate the first moment $\Gamma_1^d(Q^2) = \int_0^1 g_1^d(x,Q^2)dx$ from which we derive the scale-invariant matrix element of the flavor-singlet axial current $\hat{a}_0$ [9]. The evaluation of $\Gamma_1^d(Q^2)$ requires the evolution of all g_1 measurements to a common Q_0^2. This is most conveniently done by using a fitted parametrization $g_1^{fit}(x,Q^2)$:

$$g_1(x,Q_0^2) = g_1(x,Q^2) + \left[g_1^{fit}(x,Q_0^2) - g_1^{fit}(x,Q^2)\right]. \quad (5)$$

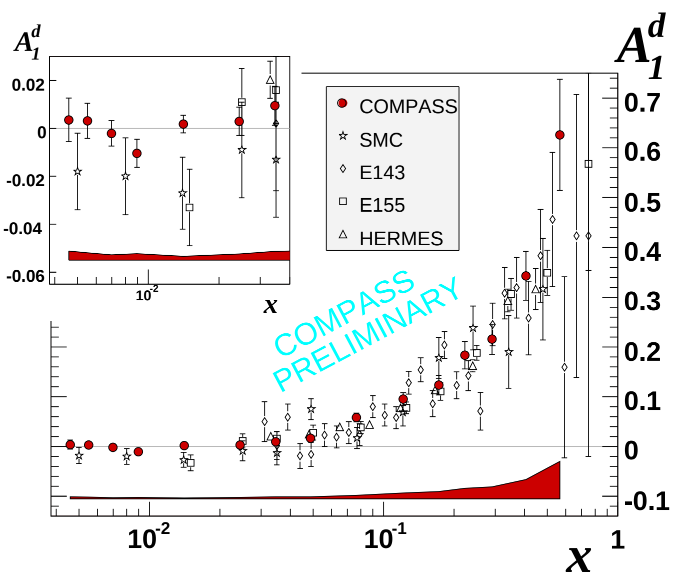

Fig. 1. The asymmetry $A_1^d(x)$ as measured in COMPASS and previous results from SMC [5], HERMES [6], E143 [7] and E155 [8] at $Q^2 > 1\,(\mathrm{GeV}/c)^2$. Only statistical errors are shown with the data points. The shaded areas show the size of the COMPASS systematic errors.

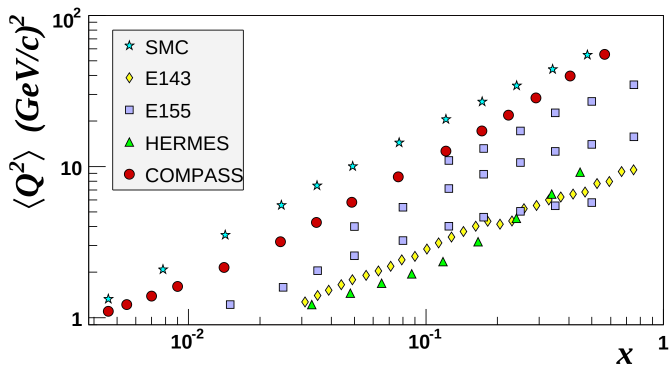

Fig. 2. The Q^2 values of COMPASS data compare to other experiments which performed measurement of g_1^d in DIS region.

We have used several fits of g_1 from the Durham data base [10]: BB [11], GRSV [12] and LSS05 [13]. We have chosen $Q_0^2 = 3\,(\mathrm{GeV}/c)^2$ as reference Q^2 because it is close to the average Q^2 of the COMPASS DIS data. The three parameterizations are quite similar in the range of the COMPASS data and have been averaged. The resulting values of $g_1^N = (g_1^p + g_1^n)/2$ are shown as open squares in Fig. 3. For clarity we now use g_1^N which is g_1^d corrected for the D-wave state of the deuteron:

$$g_1^N(x,Q^2) = g_1^d(x,Q^2)/(1-1.5\omega_D) \quad (6)$$

with $\omega_D = 0.05 \pm 0.01$ [14]. It can be seen in Fig. 3 that the curve representing the average of the three fits does not reproduce the trend of our data for $x < 0.02$ and therefore cannot be used to estimate the unmeasured part of g_1^N at low x. In view of this, we have performed a new NLO QCD fit of all g_1 DIS data from deuteron target [5–8] including the COMPASS data, proton [5–7, 15, 16] and ^{3}He [17] targets. In total 230 data points are used. The fit is performed in the $\overline{\mathrm{MS}}$ renormalization and factorization scheme. The fits have been performed with two different programs, the first one working in the (x,Q^2) space [18], the other one in the space of moments [19]. Both programs give consistent values of the fitted PDFs and similar χ^2-probabilities. Each program yields two solutions, one solution with $\Delta G > 0$, the other with $\Delta G < 0$ (Fig. 3).

The integral of g_1^N in the measured region is obtained from the experimental values evolved to a fixed Q^2. Taking into account the contributions from the fits in the unmeasured regions at low and high x we obtain

$$\Gamma_1^N\Big|_{Q^2=3\,(\mathrm{GeV}/c)^2} = 0.050 \pm 0.003(stat.) \pm 0.002(evol.) \pm 0.005(syst.). \quad (7)$$

The quoted value is the sum of a measured value plus two small corrections at high and low x. The measured part (0.049 ± 0.003) represents 98% of the total and the corrections only 2%. This is very different from the SMC analysis [5] where the measured value (over the same x range as COMPASS) was 0.037 ± 0.006 and the estimated correction -0.018 (i.e. about 50%). The measured parts are not expected to be the same in COMPASS and SMC because they are evaluated at different values of Q^2 (3 and 10 $(\mathrm{GeV}/c)^2$, respectively) but are compatible within 2 σ's. The huge difference in the estimated low x contribution reflects the fact that the COMPASS data do not support the fast decrease of $g_1^d(x, Q^2{=}3\,(\mathrm{GeV}/c)^2)$ at low x which was assumed in the SMC correction.

Γ_1^N is an important quantity because it gives access to the invariant matrix element of the singlet axial current $\hat{a}_0$ [9]. The relation between $\hat{a}_0$ and Γ_1^N has been calculated up to the third order in α_s:

$$\Gamma_1^N(Q^2) = \frac{1}{9}\, C_1^S(Q^2)\, \hat{a}_0 + \frac{1}{36}\, C_1^{NS}(Q^2)\, a_8 \qquad (8)$$

with the coefficients [9]:

$$C_1^S(Q^2) = 1 - 0.33333\left(\frac{\alpha_s}{\pi}\right) - 0.54959\left(\frac{\alpha_s}{\pi}\right)^2 - 4.44725\left(\frac{\alpha_s}{\pi}\right)^3$$

$$C_1^{NS}(Q^2) = 1 - \left(\frac{\alpha_s}{\pi}\right) - 3.5833\left(\frac{\alpha_s}{\pi}\right)^2 - 20.2153\left(\frac{\alpha_s}{\pi}\right)^3$$

The coupling constant at $Q^2{=}3\,(\mathrm{GeV}/c)^2$ is obtained by evolving the PDG value of $\alpha_s(\mathrm{M_z}) = 0.1187 \pm 0.005$:

$$\left.\frac{\alpha_s}{\pi}\right|_{Q^2=3(\mathrm{GeV}/c)^2} = 0.084 \pm 0.003.$$

The value of a_8 is derived from hyperon β decay, assuming $SU(3)_f$ flavor symmetry: $a_8 = 0.585 \pm 0.025$ [20]. The resulting value of $\hat{a}_0$ is

$$\hat{a}_0 = 0.33 \pm 0.03(stat.) \pm 0.05(syst.). \qquad (9)$$

This value is independent of Q^2 and directly comparable to a_8. The Ellis-Jaffe sum rule was based on the assumption of unpolarized strangeness ($\hat{a}_0 = a_8$). Since the EMC experiment, it is known that this assumption is not valid. From Eq. (9) we can derive the first moment of the strange quark spin distribution:

$$(\Delta s + \Delta\bar{s})_{Q^2\to\infty} = \tfrac{1}{3}(\hat{a}_0 - a_8) = -\,0.08 \pm 0.01(stat) \pm 0.02(syst). \qquad (10)$$

4 Conclusion

The new measurement of the deuteron longitudinal spin asymmetry A_1^d and its spin-dependent structure function g_1^d at $Q^2 > 1\,(\mathrm{GeV}/c)^2$ over the range $0.004 < x < 0.7$ have been presented. Good agreement with the world data is observed over the full range of x. For $x < 0.03$ our points are consistent with zero and their statistical errors have been reduced by a factor 3–4 compare to SMC results. Thus the negative trend of g_1^d at low x observed by SMC is not confirmed. The measured values have been evolved to a common Q^2 by a fit of the world g_1 data and the first moment Γ_1^N has been evaluated at $Q^2{=}3\,(\mathrm{GeV}/c)^2$. From Γ_1^N we have derived the invariant matrix element of the singlet axial current $\hat{a}_0$, which can be interpreted as a quark polarization in the nucleon at $Q^2 \to \infty$. Thus, at the order α_s^3, the COMPASS data alone give $\hat{a}_0 = 0.33 \pm 0.03(stat.) \pm 0.05(syst.)$ and the first moment of the strange quark distribution $(\Delta s + \Delta\bar{s})_{Q^2\to\infty} = -0.08 \pm 0.01(stat.) \pm 0.02(syst.)$. The quoted systematic errors account for the uncertainty from the evolution and for the experimental systematic error, combined in quadrature.

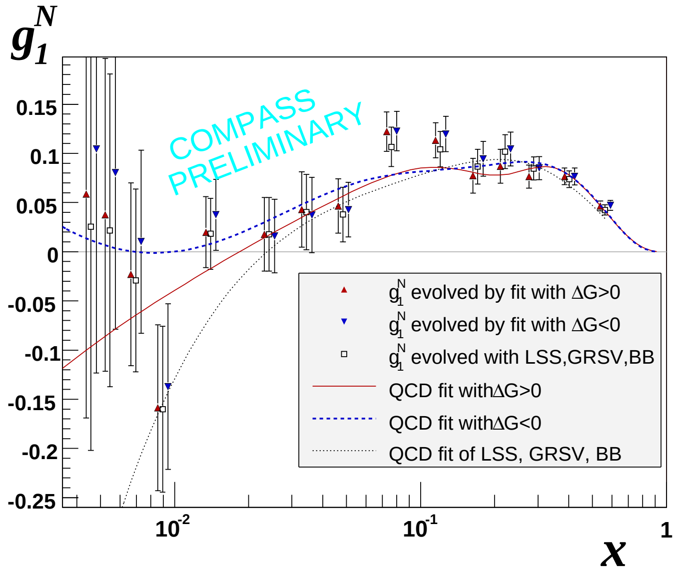

Fig. 3. The COMPASS values of g_1^N evolved to $Q^2 = 3\,(\mathrm{GeV}/c)^2$. In addition to our fits the curve obtained with three published parameterizations (BB, GRSV and LSS05) [10] is shown. These parameterizations lead almost to the same values of $g_1^N(x, Q^2{=}3\,(\mathrm{GeV}/c)^2)$ and have been averaged. For clarity the data points evolved with different fits are shifted in x with respect to each other. Only statistical errors are shown.

References

1. S. D. Bass, Rev. Mod. Phys. **77** (2005) 1257.
2. COMPASS proposal CERN/SPSLC 96-14 (Geneva 1996).
3. E155, P. L. Anthony *et al.*, Phys. Lett. B **553** (2003) 18.
4. COMPASS, E. S. Ageev *et al.*, Phys. Lett. B **612** (2005) 154.
5. SMC, B. Adeva *et al.*, Phys. Rev. D **58** (1998) 112001.
6. HERMES, A.Airapetian *et al.*, Phys. Rev. D **75** (2005) 012003.
7. E143, K.Abe *et al.*, Phys. Rev. D **58** (1998) 112003.
8. E155, P. L. Anthony *et al.*, Phys. Lett. B **463** (1999) 339.
9. S. A. Larin *et al.*, Phys. Lett. B **404** (1997) 153.
10. HEP Databases, http://durpdg.dur.ac.uk/HEPDATA/pdf.html
11. J. Blümlein and H. Böttcher, Nucl. Phys. B **636** (2002) 225.
12. M.Glück *et al.*, Phys. Rev. D **63** (2001) 094005.
13. E. Leader, A. V. Sidorov and D. B. Stamenov, Phys. Rev. D **73** (2006) 034023.
14. R. Machleidt *et al.*, Phys. Rep. **149** (1987) 1.
15. EMC, J. Ashman *et al.*, Nucl. Phys. B **328** (1989) 1.
16. E155, P. L. Anthony *et al.*, Phys. Lett. B **493** (2000) 19.
17. E142, P.L.Anthony *et al.*, Phys.Rev.D**54** (1996) 6620; E154, K.Abe*et al.*, Phys. Rev. Lett. **79** (1997) 26; JLAB/Hall A, X.Zheng *et al.*, Phys. Rev. Lett. **92** (2004) 012004; HERMES, K.Ackerstaff *et al.*, Phys. Lett. B **404** (1997) 383.
18. SMC, B. Adeva *et al.*, Phys. Rev. D **58** (1998) 112002.
19. A. N. Sissakian, O. Yu. Shevchenko and O. N. Ivanov, Phys. Rev. D **70** (2004) 074032.
20. Y.Goto *et al.*, Phys. Rev. D **62** (2000) 034017.