The deuteron spin-dependent structure function g_1^d

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Results on the deuteron longitudinal inclusive spin-dependent asymmetry A_1^d and the spin-dependent structure function g_1^d are presented. The data have been collected by the COMPASS experiment at CERN during the years 2002-2004 using the 160 GeV/c polarised muon beam scattered off a polarised ^{6}LiD target. The values obtained for Γ_1^d, the first moment of $g_1^d(x)$, and the flavor-singlet axial current matrix element, a_0, are also shown. The results of QCD fits in the NLO approximation on all g_1 deep inelastic data are presented.

1 Introduction

The EMC spin asymmetry measurement [1, 2] and the naive interpretation of the results following from the Ellis-Jaffe sum rule [3] have introduced the so-called "spin crisis": quarks carry a very small fraction of the nucleon's helicity. The next experiments at CERN, DESY and SLAC confirmed that quarks are only responsible for roughly 1/3 of the nucleon's helicity. The quark helicity distributions $\Delta q_i(x, Q^2)$ are related to a vector-axial quark current which is not conserved due to the Adler-Bell-Jackiw anomaly. This fact allows to explain the spin crisis by changing the interpretation of the measurement: instead of quark spin contents $\Delta\Sigma = \int_0^1 \sum_{i=1}^{n_f} \Delta q_i(x, Q^2)dx$ the combination $\Delta\Sigma - (3\alpha_s)/(2\pi)\Delta G$ is measured, where ΔG is a gluon polarization inside the nucleon. This interpretation was a "driving force" in preparation a series of new polarized DIS type experiments related to direct measurements of ΔG: HERMES in DESY, SMC and COMPASS at CERN, STAR and PHENIX at RHIC.
To complete the picture, beside the quark's helicity $\Delta\Sigma$, and the gluon polarization ΔG also an orbital angular momentum of quarks and gluons can build the nucleon spin structure. In this paper I will present new results of the longitudinal inclusive asymmetry A_1^d and the spin-dependent structure function g_1^d obtained by COMPASS collaboration after analyzing the data sets collected in years 2002-2004. The experiment is using a 160 GeV/c polarized muon beam from the SPS at CERN scattered off a polarized ^{6}LiD target (for more details see [4]). The paper is organized as follows. In Section 2 the longitudinal inclusive asymmetry A_1^d and the g_1^d structure function for small x and small Q^2 domain are presented. The A_1^d asymmetry and the g_1^d structure function results for the DIS region ($Q^2 > 1$ (GeV/c)^2) and the results of the perturbative QCD analysis of the world data as well as estimation of the first moment of g_1^d structure function are presented in Section 3. Conclusions are presented in Section 4.

*This work was partially supported by SPUB 621/E-78/SPB CERN/P-03.

2 The longitudinal helicity asymmetry A_1^d and g_1^d structure function for the small x and small Q^2 domain.

The cross-section longitudinal helicity asymmetry:

$$A_{LL}^d = \frac{\sigma^{\leftrightarrows} - \sigma^{\rightrightarrows}}{\sigma^{\leftrightarrows} + \sigma^{\rightrightarrows}}$$

can be decomposed into the virtual photon-deuteron asymmetries A_1^d and A_2^d: $A_{LL}^d = D(A_1^d + \eta A_2^d) \simeq DA_1^d$, where the photon depolarization factor D (as well as η), depends on the event kinematics. Arrows correspond to relative orientation of the incoming muon and the target deuteron helicities and all factors which contain A_2^d have been neglected since they are very small. The spin-dependent structure function g_1^d is related to the asymmetry A_1^d as follows:

$$g_1^d \simeq \frac{F_2^d}{2x(1+R)} A_1^d$$

where F_2^d and R are unpolarized (spin independent) structure functions. The asymmetry and the g_1 structure function have been calculated for events with small Q^2 ($Q^2 < 1$ (GeV/c)^2) and small x ($0.00004 < x < 0.02$). The presented data come from the years 2002 and 2003. The final sample used in the analysis contains 300 million events. The values of F_2 for $x > 0.0009$ and $Q^2 > 0.2$ (GeV/c)^2 have been taken from [5] and from [6] in the rest of the phase space. R comes from [7] for $Q^2 > 0.5$ (GeV/c)^2. For lower Q^2 R is proportional to Q^2 at the photoproduction limit.

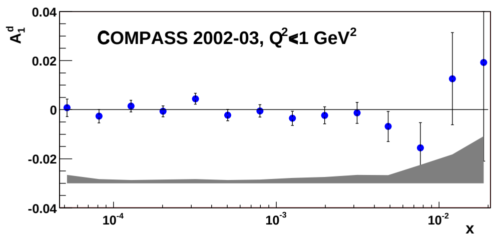

Figure 1: The COMPASS results of the A_1^d in the low x and low Q^2 region.

The results for the asymmetry A_1^d as a function of x are presented in Figure 1.

Figure 2 shows the results on the g_1^d structure function. The shadowed bands indicate the systematics errors and the error bars with the data points mark statistical ones. Systematic errors are mainly due to false asymmetries. The results are consistent with zero in the considered x range.

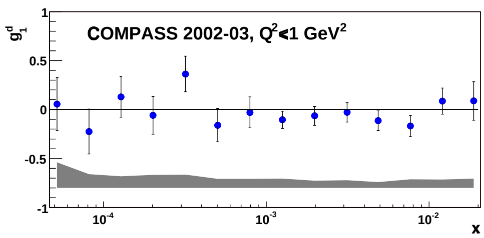

Figure 2: The COMPASS results of the g_1^d in the low x and low Q^2 region.

The statistical precision of A_1^d and g_1^d in the COMPASS is ten times higher than in the SMC ones [8]. The SMC and the COMPASS results are consistent in the overlap region. Details of the analysis can be found in [9].

3 The A_1^d asymmetry and the g_1^d structure function for high Q^2. QCD analysis and the first moment of g_1^d.

Figure 3 shows the results on the A_1^d asymmetry for $Q^2 > 1$ $(\mathrm{GeV/c})^2$ (DIS domain) as a function of x as measured in COMPASS and superposed to results of previous experiments at CERN [5], DESY [10] and SLAC [11, 14]. Again, small terms related to A_2^d have been neglected. The data were collected during the years 2002-2004. The resulting sample consists of 89 million events. The asymmetry results from 2002-2003 data have been published in [12] while the full data sample results are recently published in [13].

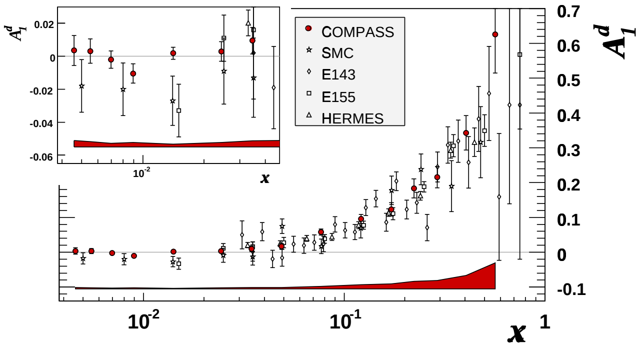

Figure 3: The asymmetry $A_1^d(x)$ for $Q^2 > 1$ $(\mathrm{GeV/c})^2$. Only statistical errors are shown with a data points. The COMPASS systematic errors are marked by shadowed areas.

The asymmetry is consistent with zero for $x < 0.03$. The spin-dependent structure function g_1^d has been calculated with F_2^d parametrization of [5] and the R parametrization taken from [7].

A new NLO QCD fit of all g_1 data at $Q^2 > 1$ $(\mathrm{GeV/c})^2$ from deuteron [5, 10, 11, 14] (including the new COMPASS data), proton [2, 5, 10, 11, 15] and ^{3}He [16] targets has been performed. In total 230 data points have been used. The NLO fits have been performed in $\overline{MS}$ scheme with input parametrization at $Q^2 = 3$ $(\mathrm{GeV/c})^2$ of the quark singlet spin distribution $\Delta\Sigma(x)$, the non-singlet distributions $\Delta q_3(x)$ and $\Delta q_8(x)$ and the gluon distribution function $\Delta G(x)$ in the form: $\Delta F_k \sim \eta_k x^{\alpha_k}(1-x)^{\beta_k}(1+\gamma_k x)$. The distributions have been evolved according to the DGLAP equations. The moments η_k for the non-singlet distributions $\Delta q_3(x)$ and $\Delta q_8(x)$ have been fixed by the baryon decay constants $(F+D)$ and $(3F-D)$ respectively [17], assuming $SU(3)_f$ symmetry. The linear term γx has been used only for singlet distribution. β_G has been fixed because it is poorly constrained by the data. Finally 10 parameters in the input distributions have been fitted. In order to keep the parameters in the physical range, the polarized strange sea and gluon distributions have been required to satisfy the so-called positivity condition: $|\Delta s(x)| \leq s(x)$ and $|\Delta G(x)| \leq G(x)$ at all Q^2 values.

The unpolarized distributions in this test have been taken from the MRST parametrization [18]. The fit has been performed with two different programs [19] which give consistent values of the fitted parameters and similar χ^2-probabilities. Each program yields two solutions, one with ΔG positive, the other with ΔG negative. The g_1^d structure function results evolved to $Q^2 = 3$ $(\mathrm{GeV/c})^2$ and the results of the fit are shown in Figure 4.

Previous fits of the g_1 structure function, not including the COMPASS data, found positive ΔG and the fitted $g_1^d(x)$ getting negative for $x \leq 0.025$ at $Q^2 = 3$ $(\mathrm{GeV/c})^2$. The new COMPASS data do not show any evidence for a decrease of the structure function at small x.

More details concerning the NLO QCD COMPASS fits can be found in [13].

Using the experimental values measured by the COMPASS experiment the first moment of $g_1^d(x)$,Γ_1^d, has been calculated at $Q^2 = 3(\text{GeV/c})^2$. Taking into account the contribution from the fits in the unmeasured regions of $x < 0.003$ and $x > 0.7$ the following value of the Γ_1^d has been obtained:

$$\Gamma_1^d(Q^2 = 3(GeV/c)^2) = 0.050 \pm 0.003(stat) \pm 0.003(evol.) \pm 0.005(syst.)$$

The second error is related to the differences in the QCD evolution between the two fits. The flavor-singlet axial current matrix element, a_0 has been found to be: $a_0 = 0.35 \pm 0.03(stat.) \pm 0.05(syst.)$. Here the value of $a_8 = 0.585 \pm 0.025$ from [17] has been used.

4 Conclusions.

The new results of the longitudinal inclusive helicity asymmetry A_1^d measured in the range 0.002 $(\text{GeV/c})^2 < Q^2 < 100$ $(\text{GeV/c})^2$ have been presented. The asymmetry for small Q^2 domain corresponds to very small x: $0.00004 < x < 0.03$ and is consistent with zero. The DIS events ($Q^2 > 1$ $(\text{GeV/c})^2$) cover x region from 0.004 up to 0.7. The COMPASS results are in agreement with those from previous experiments and improve considerably the statistical accuracy in the small x region. For DIS events the results of new NLO QCD fits have been presented. Two solutions for ΔG positive and negative have been found to describe data equally well. The first moment of the $g_1^d(x)$ structure function has been estimated using COMPASS data and the flavor-singlet axial current matrix element, a_0 has been found.

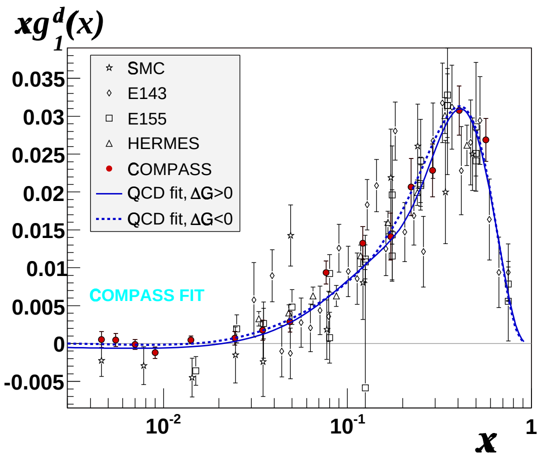

Figure 4: Measured values of $xg_1^d(x)$ evolved to $Q^2 = 3$ $(\text{GeV/c})^2$. Only statistical errors are shown with data points. The curves show the results of QCD fits (first program from [19]) with $\Delta G > 0$ and $\Delta G < 0$.

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