Quark helicity distributions from DIS and SIDIS measured in COMPASS

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An overview of recent COMPASS (NA58/SPS) results on the determination of longitudinal polarized quark distributions is given. The results were obtained in inclusive and semi-inclusive deep-inelastic scattering of a 160 GeV polarized muon beam off a large polarized ^{6}LiD target. The covered kinematic range is $0.004 < x < 0.7$ and $1 < Q^2 < 100$ (GeV/c)^2. The presented data were collected by COMPASS in the years 2002–2004.

Results of the COMPASS experiment at CERN on the deuteron spin asymmetry A_1^d and the structure function g_1^d are presented [1]. The data were collected during the years 2002–2004. We refer the reader to [1] for the description of the 160 GeV muon beam, the ^{6}LiD polarised target and the COMPASS spectrometer. The DIS events are selected by cuts on the virtuality of a photon, $Q^2 > 1\,(\mathrm{GeV}/c)^2$, and its fractional energy, $0.1 < y < 0.9$. The resulting sample consists of 89 millions events.

We also present an evaluation of the polarized valence quark distribution $\Delta u_v(x)+\Delta d_v(x)$ which is based on the difference asymmetry, $A^{h^+-h^-}$, for hadrons of opposite charges [2]. In addition to the kinematic cuts mentioned above for hadron tracks coming from the primary vertex, the cut $z > 0.2$ is applied to select the current fragmentation region. To avoid ambiguity between the secondary μ and the scattered μ and also to suppress the contribution from diffractive events we demand $z < 0.85$. Hadron identification was not used. The resulting sample contains 30 and 25 millions of positive and negative hadrons, respectively.

1 Inclusive asymmetry and structure function g_1^d

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

$$A_1^d = (\sigma_0^T - \sigma_2^T)/(2\sigma^T), \tag{1}$$

where σ_J^T is the γ^*-deuteron absorption cross-section for a total spin projection J and σ^T is the total transverse photoabsorption cross-section.

The measured values of A_1^d are shown as a function of x in Fig. 1 in comparison with previous results from experiments at CERN, DESY and SLAC [3–5]. The points of A_1^d are consistent with zero for $x < 0.03$ and have no tendency toward negative values as it was observed in [3].

The longitudinal spin structure function is obtained from A_1^d as

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

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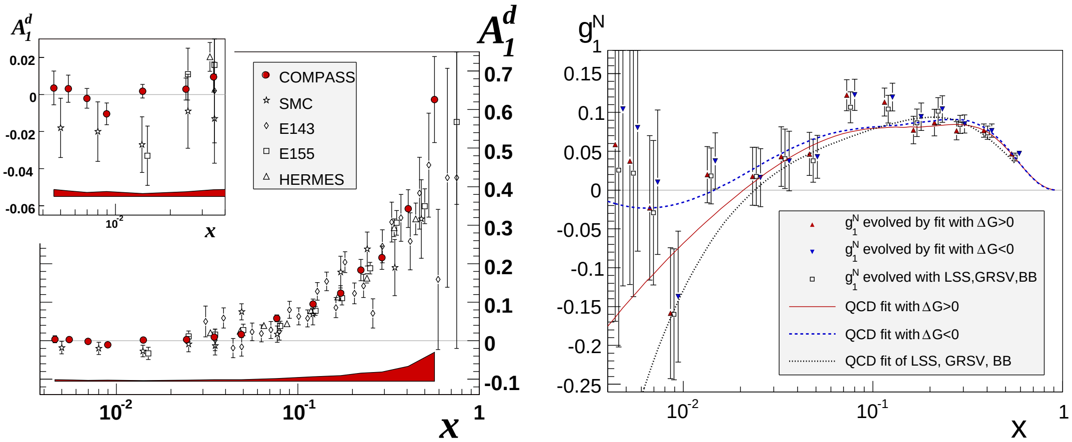

Figure 1: Left: The asymmetry $A_1^d(x)$ as measured in COMPASS superposed to results of previous experiments [3–5]. Right: The COMPASS values of g_1^N evolved to $Q^2 = 3\,(\mathrm{GeV}/c)^2$. Also the curve obtained with three published parameterizations (BB, GRSV and LSS05) [8] is shown. These parameterizations lead almost to the same values of $g_1^N(x, Q^2{=}3\,(\mathrm{GeV}/c)^2)$ and have been averaged.

where F_2^d and R are spin-independent structure functions.

We have performed a new NLO QCD fit of all g_1 data with $Q^2{>}1\,(\mathrm{GeV}/c)^2$ from deuteron [1, 3–5], proton [3, 4, 6] and ^{3}He [7] targets. In total 230 data points are used. The fit is performed in the $\overline{\mathrm{MS}}$ renormalisation and factorisation scheme with input parametrisations of the quark singlet spin distribution $\Delta\Sigma(x)$, the non-singlet distributions $\Delta q_3(x)$, $\Delta q_8(x)$ and the gluon spin distribution $\Delta G(x)$ at $Q^2{=}3\,(\mathrm{GeV}/c)^2$:

$$\Delta\Sigma(x) \;=\; \eta\frac{x^{\alpha}\,(1-x)^{\beta}\,(1+\gamma x)}{\int_0^1 x^{\alpha}\,(1-x)^{\beta}\,(1+\gamma x)dx}\,,\quad \Delta q_3(x), \Delta q_8(x), \Delta G(x) \;=\; \eta\frac{x^{\alpha}\,(1-x)^{\beta}}{\int_0^1 x^{\alpha}\,(1-x)^{\beta}dx} \qquad (3)$$

The values of η for the non-singlet distributions Δq_3 and Δq_8 have been fixed by the baryon decay constants assuming $\mathrm{SU}(3)_f$ flavour symmetry. In order to keep the parameters in their physical range, the polarised strange sea and gluon distributions are required to satisfy the positivity condition $|\Delta s(x)| \leq s(x)$ and $|\Delta G(x)| \leq G(x)$ at all Q^2 values.

The fit yields two solutions, one solution with $\Delta G(x) > 0$, the other with $\Delta G(x) < 0$ (Fig. 1). The fitted values of their first moments are both small and about equal in absolute value $|\eta_G| \approx 0.2 - 0.3$. Taking the average η_Σ over the two solutions we obtain for the singlet moment derived from the fits to all g_1 data:

$$\eta_\Sigma\Big|_{Q^2=3(\mathrm{GeV}/c)^2} {=}\, 0.30 \pm 0.01(stat.) \pm 0.02(evol.). \qquad (4)$$

Previous fits of g_1, not including the COMPASS data, found a positive $\Delta G(x)$ and $g_1^d(x)$ becoming negative for $x \lesssim 0.025$ at $Q^2 = 3\,(\mathrm{GeV}/c)^2$, as shown by the dotted line in Fig. 1. The new COMPASS data do not show any evidence for a decrease of the structure function at the limit $x \to 0$. The data are also still compatible with a positive ΔG, as shown by the full line in Fig. 1.

The value of $\Delta\Sigma$ (=a_0 in $\overline{\text{MS}}$ scheme) also can be extracted from COMPASS data alone. The integral of g_1^N in the measured region is obtained from the experimental values evolved to a fixed Q^2 and averaged over the two fits. Combining Γ_1^N with the axial charge a_8 one obtains:

$$a_0\Big|_{Q^2=3(\text{GeV}/c)^2} = 0.35 \pm 0.03(stat.) \pm 0.05(syst.). \tag{5}$$

2 Polarization of valence quarks

In the present analysis we use the so called difference asymmetry which is determined from the difference of cross sections of positive and negative hadrons h^+ and h^- [9, 11]. Results obtained with this approach, as compared to the traditional single hadron approach [9, 10], are "cleaner" from the theoretical point of view because of the very weak sensitivity of $A^{h^+-h^-}$ to uncertainties coming from fragmentation functions (FF). As shown in [11] FFs cancel out from $A^{h^+-h^-}$ in LO QCD. For the deuteron target the asymmetry is:

$$A_d^{\pi^+-\pi^-} = A_d^{K^+-K^-} = \frac{\Delta u_v + \Delta d_v}{u_v + d_v}, \quad \text{where} \quad \Delta q_v \equiv \Delta q - \Delta\bar{q}. \tag{6}$$

The fact that kaons contribute to the asymmetry exactly like pions allows to avoid statistical losses due to hadron identification. Starting from NLO QCD the difference asymmetry depends also on FFs. However their effect is small.

Since the deuteron is an isoscalar target we can not distinguish between up and down quarks. Nevertheless having measured the first moment of $\Delta u_v(x)+\Delta d_v(x)$ and combining its value with axial charges a_0 and a_8, the information about the symmetry of sea quark distributions can be extracted. One can show that

$$\Delta\bar{u} + \Delta\bar{d} = (\Delta s + \Delta\bar{s}) + \frac{1}{2}(a_8 - \Gamma_v), \quad \text{where} \quad \Gamma_v = \int_0^1 (\Delta u_v(x) + \Delta d_v(x))dx. \tag{7}$$

The $SU(3)_f$ symmetric sea ($\Delta\bar{u}$=$\Delta\bar{d}$=Δs=$\Delta\bar{s}$) will obviously lead to Γ_v=a_8. In contrast, if measurements give $\Gamma_v = a_8 + 2(\Delta s + \Delta\bar{s})$ it will point to a strong asymmetry for the first moments of light sea quarks $\Delta\bar{u} = -\Delta\bar{d}$.

For $x > 0.3$ the unpolarized sea contribution to F_2 practically vanishes. Due to positivity conditions $|\Delta q| < q$ the polarized sea contribution to the spin of the nucleon also can be neglected. It allows a more precise evaluation of Δu_v+Δd_v since g_1^d values can be used.

The evaluation of the first moment, Γ_v, requires the evolution of all $\Delta u_v(x)$+$\Delta d_v(x)$ points to a common Q^2. This is done by using the DNS parametrization in LO [12] which is based on the global QCD analysis of all DIS g_1 data prior to COMPASS as well as the SIDIS data from SMC and HERMES. The resulting distribution at Q^2=10 GeV^2 is shown in Fig. 2. A good agreement of the curve with the COMPASS points illustrates the consistency between the three experiments. For Γ_v we obtained

$$\Gamma_v(0.006 < x < 0.7)\Big|_{\text{Q}^2=10\,(\text{GeV}/c)^2} = 0.40 \pm 0.07(\text{stat.}) \pm 0.06(\text{syst.}), \tag{8}$$

which is 2σ below the value corresponding to a flavor symmetric sea and very close to the value expected for $\Delta\overline{u} = -\Delta\overline{d}$ (Eq. (7), where Δs+$\Delta\bar{s}$ is taken from our inclusive analysis).

As one can judge from Fig. 2 the integral is practically constant at low x. Thus the low x contribution to Γ_v is expected to be negligible. The contribution to Γ_v for $x > 0.7$ estimated with the LO DNS parametrization is 0.004, thus also can be neglected.

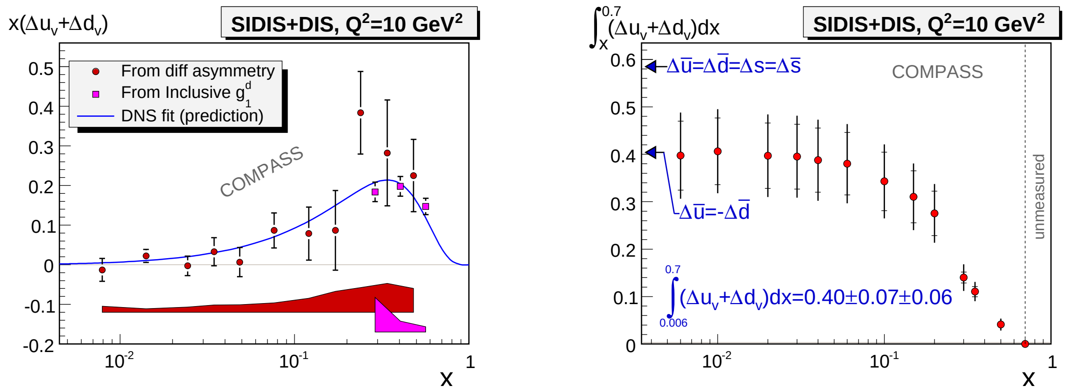

Figure 2: Polarized valence quark distribution $x(\Delta u_v+\Delta d_v)$ evolved to Q^2=10 (GeV/c)^2 according to the DNS fit at LO [12] (left). The line shows the prediction from the fit. Right: Corresponding integral of $\Delta u_v(x)+\Delta d_v(x)$ as the function of the low x limit of integration.

3 Conclusion

The deuteron spin asymmetry A_1^d and its longitudinal 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 measured. The g_1^d values are consistent with zero for $x < 0.03$. A new fit of world g_1 data at NLO yields two solutions with $\Delta G(x)>0$ and $\Delta G(x)<0$. From the first moment Γ_1^N at $Q^2=3\,(\mathrm{GeV}/c)^2$ we have derived the singlet axial charge with COMPASS data alone: $a_0 = 0.35 \pm 0.03(stat.) \pm 0.05(syst.)$. This value is well compatible with results of QCD fits for the quark polarization: $\eta_\Sigma = 0.30 \pm 0.01(stat.) \pm 0.02(evol.)$.

A LO evaluation of the polarized valence quark distribution $\Delta u_v(x)+\Delta d_v(x)$ based on the difference asymmetry approach leads to the first moment of $\Delta u_v+\Delta d_v$ equals to $0.40 \pm 0.07(\mathrm{stat.}) \pm 0.05(\mathrm{syst.})$ at $Q^2 = 10\,(\mathrm{GeV}/c)^2$. It favors the "asymmetric" light sea scenario $\Delta\overline{u} = -\Delta\overline{d}$ as compared to the "symmetric" one $\Delta\overline{u} = \Delta\overline{d} = \Delta s = \Delta\overline{s}$.

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