VALENCE QUARK HELISITY DISTRIBUTION FROM COMPASS

E. ZEMLYANICHKINA

for the COMPASS Collaboration

Joint Institute for Nuclear Research
Dubna 141980, Russia
E-mail: elena.zemlyanichkina@sunse.jinr.ru

The evaluation of the polarized valence quark distribution $\Delta u_v(x) + \Delta d_v(x)$ from the COMPASS experiment (CERN/SPS) is presented. The analysis is based on the "difference asymmetry", $A^{h^+-h^-}(x)$, for hadrons of opposite charges. The data were collected in the years $2002 - 2004$ using a 160 GeV polarized muon beam scattered off a large polarized ^{6}LiD target in the kinematic range $0.006 < x < 0.7$ and $1 < Q^2 < 100$ (GeV/c)^2. In the leading order (LO) QCD the first moment of $\Delta u_v(x) + \Delta d_v(x)$ was found to be equal to $0.04 \pm 0.07(stat) \pm 0.06(syst)$. By combining it with the first moment of the structure function $g_1^d(x)$ an estimate on the light sea quark contribution is obtained. The present results disfavor the assumption of a flavor symmetric polarized sea within two standard deviations.

In 1987 the European Muon Collaboration (EMC) reported results from a polarized muon-proton scattering experiment at CERN which puzzled the particle and nuclear physics communities. Contrary to the prediction of the naive quark model, the EMC [1] found that little of the proton spin seemed to be carried by quarks. The COMPASS experiment at CERN has published an evaluation of the deuteron spin-dependent structure function $g_1^d(x)$ in DIS region [2], where x is Bjorken scaling variable. These measurements provide an accurate evaluation of the first moment of g_1 for the average nucleon N in an isoscalar target $g_1^N = (g_1^p + g_1^n)/2$. At $Q_0^2 = 10(\text{GeV}/c)^2$ the result is

$$\Gamma_1^N(Q_0^2) = \int_0^1 g_1^N(x, Q_0^2)dx = 0.051 \pm 0.003(stat.) \pm 0.006(syst.) \ . \tag{1}$$

With this value the first moment of the strange quark distribution can be extracted if the value of the octet matrix element ($a_8 = 3F - D = 0.585 \pm 0.025$ [3]) is taken from semi-leptonic hyperon decays. At LO QCD

$$\Delta s + \Delta\bar{s} = 3\Gamma_1^N - \frac{5}{12}a_8 = -0.09 \pm 0.01(stat.) \pm 0.02(syst.) \tag{2}$$

at $Q^2 = 10(\mathrm{GeV}/c)^2$.
Additional information on the contribution of the nucleon constituents to its spin, based on semi-inclusive spin asymmetries measured on the same data as those used in Ref. [2], allows to separate valence and sea quark contributions to the nucleon spin. In the present analysis we used the "difference asymmetry" which is defined as the spin asymmetry for the difference of the cross sections for positive and negative hadrons using

$$A^{h^+-h^-} = \frac{(\sigma_{\uparrow\downarrow}^{h^+} - \sigma_{\uparrow\downarrow}^{h^-}) - (\sigma_{\uparrow\uparrow}^{h^+} - \sigma_{\uparrow\uparrow}^{h^-})}{(\sigma_{\uparrow\downarrow}^{h^+} - \sigma_{\uparrow\downarrow}^{h^-}) + (\sigma_{\uparrow\uparrow}^{h^+} - \sigma_{\uparrow\uparrow}^{h^-})} . \tag{3}$$

The difference asymmetry approach for the extraction of helicity distributions has been used in the SMC analysis [4, 5]. In LO QCD and under the assumption of isospin and charge conjugation symmetries, the fragmentation functions cancel out from $A^{\pi^+-\pi^-}(x)$. In addition, in the case of an isoscalar target and assuming $\Delta s = \Delta\bar{s}$, the difference asymmetries for pions and kaons are both equal to the valence quark polarization

$$A_N^{h^+-h^-}(x) \approx A_N^{\pi^+-\pi^-}(x) = A_N^{K^+-K^-}(x) = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)} , \tag{4}$$

where we introduce the valence quark distributions $q_v = q - \bar{q}$. Since kaons contribute to the asymmetry in the same way as pions, their identification is not needed, allowing to reduce the statistical errors. The difference asymmetry for (anti)protons $A_N^{p-\bar{p}}(x)$ is equal to the valence quark polarization under more restrictive assumtions and in addition can be affected by target remnants. Since protons and antiprotons account only for about 10% of the selected hadron sample, the Eq. (4) is expected to hold as a good approximation in the present analysis.
Difference hadron asymmetry $A^{h^+-h^-}(x)$ can be obtained from single spin asymmetries of positive $A^{h^+}(x)$ and negative $A^{h^-}(x)$ hadrons:

$$A^{h^+-h^-} = \frac{1}{1-r}(A^{h^+} - A^{h^-}), \qquad r = \frac{\sigma_{\uparrow\downarrow}^{h-} + \sigma_{\uparrow\uparrow}^{h-}}{\sigma_{\uparrow\downarrow}^{h+} + \sigma_{\uparrow\uparrow}^{h+}} = \frac{\sigma^{h^-}}{\sigma^{h^+}} = \frac{N^{h-}/a^{h-}}{N^{h+}/a^{h+}} . \tag{5}$$

The ratio of cross sections for negative and positive hadrons r depends on the event kinematics and is obtained as the product of the corresponding ratio of the number of

observed hadrons N^+/N^- by the ratio of the geomerical acceptances a^+/a^-.
The data used in the present analysis were collected by the COMPASS collaboration at CERN during the years 2002-2004. The event selection requires a reconstructed interaction vertex defined by the incoming and scattered muons and located inside one of the two target cells [6]. The energy of the beam muon is required to be in the range 140 GeV $< E_\mu <$ 180 GeV and its extrapolated trajectory is required to cross entirely the two cells in order to equalise the fluxes seen by each of them. Events in the DIS region are selected by cuts on the photon virtuality ($Q^2 > 1$ (GeV/c)^2) and on the fractional energy of the virtual photon ($0.1 < y < 0.9$). Final state muons are identified by signals collected behind hadron absorbers. The hadrons used in the analysis are required to originate from the interaction vertex and to be produced in the current fragmentation region. The latter is satisfied by selecting hadrons with fractional energy $z > 0.2$. In addition, an upper limit $z < 0.85$ is imposed in order to suppress hadrons from exclusive diffractive processes and to avoid contamination from muons close to the beam axis which escape identification by the muon filters. The hadron identification provided by the RICH detector is not used in the present analysis. The resulting sample contains 30 and 25 million of positive and negative hadrons, respectively.
The target spins are reversed at regular intervals of 8 hours during the data taking. The spin asymmetries are obtained from the numbers of hadrons collected from each target cell during consecutive periods before and after reversal of the target spins, following the same procedure as for inclusive asymmetries [2].
Results for single spin asymmetries of positive $A^{h^+}(x)$ and negative $A^{h^-}(x)$ hadrons are shown in Fig. 1 as a function of x, in comparison to the SMC [7] and HERMES [8] results. The consistency of the results from the three experiments illustrates the weak Q^2 dependence of the semi-inclusive asymmetries. The COMPASS results show a large gain in statistical precision with respect to SMC, especially in the low x region ($x < 0.04$), while at larger x the COMPASS errors are comparable to those of HERMES. The systematic errors, shown by the bands at the bottom of the figure, result from different sources. The uncertainty on the various factors entering in the asymmetry calculation (beam and target polarization, depolarization factor and dilution factor) leads to a relative error of 8% on the asymmetry when combined in quadrature. Upper limit of possible false asymmetries due to time-dependent apparatus effects is at about half of the statistical error $\sigma_{false} < 0.5\sigma_{stat}$.

For the acceptance correction full chain of MC simulation with default LEPTO settings was performed. The corrected cross section ratio σ^{h-}/σ^{h+} is shown in Fig. 2 (Left).

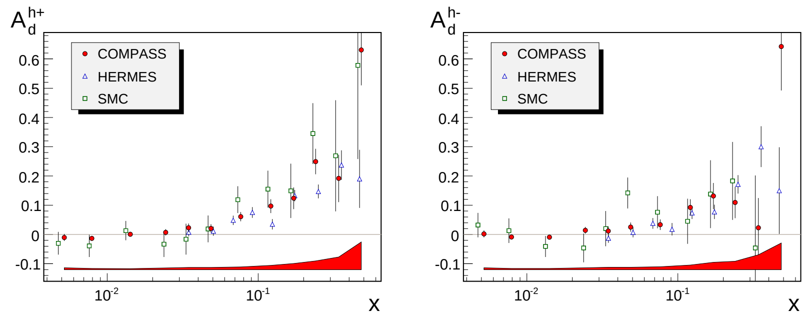

Figure 1: Hadron asymmetries A_d^{h+} (left) and A_d^{h-} (right) measured by COMPASS, SMC [7] and HERMES [8] experiments, as a function of x at the Q^2 of each measured point. The bands at the bottom of figures show the systematic errors of the COMPASS measurements.

The resulting values of the difference asymmetry as a function of x are also shown in Fig. 2 (Right). The precision at small x is poor because the statistical error is inversely proportional to $N^{h+} - N^{h-}$. The reason that N^{h+} is about equal to N^{h-}, we discard the lowest x bin used in the inclusive g_1 analysis and take $x = 0.006$ as lower limit for the present analysis.

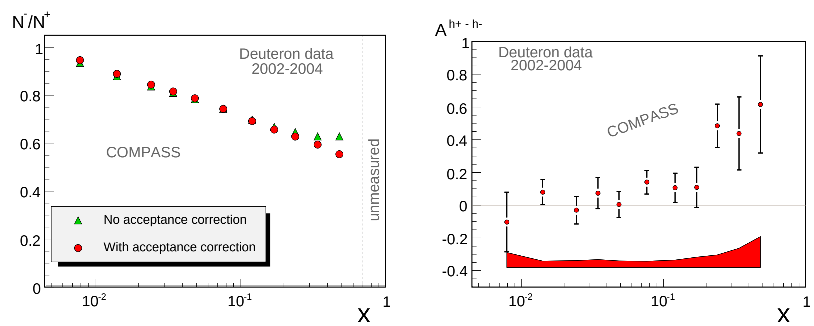

Figure 2: Left: The ratio σ^{h-}/σ^{h+} before (triangles) and after (circles) acceptance corrections. Right: The difference asymmetry, $A^{h^+ - h^-}$, for identified hadrons of opposite charges, as a function of x at the Q^2 of each measured point.

The polarized valence quark distribution $\Delta u_v(x)+\Delta d_v(x)$ is obtained by multiplying $A_d^{h^+-h^-}(x)$ by the unpolarized valence distribution of MRST04 at LO [9]. Here two corrections are applied, one accounting for the fact that although $R(x,Q^2)=0$ at LO, the unpolarized PDF's originate from F_2's in which $R=\sigma_L/\sigma_T$ was different from zero, the other one accounting for deuteron D-state contribution ($\omega_D=0.05\pm0.01$):

$$\Delta u_v + \Delta d_v = \frac{u_v + d_v}{(1+R)(1-1.5\omega_D)} A_d^{+-} \tag{6}$$

The LO parametrisation of the DNS fit [10] has been used to evolve all values of $\Delta u_v(x)+\Delta d_v(x)$ to a common Q^2 fixed at $Q_0^2=10(\mathrm{GeV}/c)^2$ assumming that difference between $\Delta u_v(x)+\Delta d_v(x)$ at the current Q^2 and at Q_0^2 is the same for the data as for fit.
The sea contribution to the unpolarized structure function F_2 decreases rapidly with increasing x and becomes smaller than 0.1 for $x>0.3$. Due to the positivity conditions $|\Delta q|\le q$ and $|\Delta\bar{q}|\le\bar{q}$, the polarized sea contribution to the nucleon spin also becomes negligible in this region. In view of this, the evaluation of the valence spin distribution can be replaced by a more accurate one obtained from inclusive interactions.

$$\Delta u_v + \Delta d_v \simeq \frac{36}{5}\frac{g_1^d(x,Q^2)}{1-1.5\omega_D} \tag{7}$$

Results for polarized valence quark distribution $\Delta u_v(x)+\Delta d_v(x)$ are shown in Fig. 3 (Left) in comparison with SMC and HERMES results. The DNS fit, which is basically defined by the SMC and HERMES semi-inclusive asymmetries, is shown as well. Its good agreement with the COMPASS values illustrates the consistency between the three experiments. The first moment of the polarized valence distribution, truncated to the measured range of x,

$$\Gamma_v(x_{min}) = \int_{x_{min}}^{0.7} (\Delta u_v(x)+\Delta d_v(x))dx = 0.40\pm0.07(stat.)\pm0.06(syst.) \tag{8}$$

derived from the difference asymmetry for $x<0.3$ and from g_1^d for $0.3<x<0.7$, is shown in Fig. 3 (Right). An estimate of the light sea quark contribution to the nucleon spin can be obtained by combining the values of Γ_v (Eq.(8)), Γ_1^N (Eq.(1)) and a_8,

$$\Delta\bar{u}+\Delta\bar{d} = 3\Gamma_1^N - \frac{1}{2}\Gamma_v + \frac{1}{12}a_8 \ . \tag{9}$$

The present result disfavours the assumption of a flavor symmetric polarized sea within two standard deviations and suggest that either both $\Delta\bar{u}$ and $\Delta\bar{d}$ are small or they are of opposite sign. The contribution from the unmeasured high x region was taken from DNS fit. More details on this analysis can be found in Ref. [11]

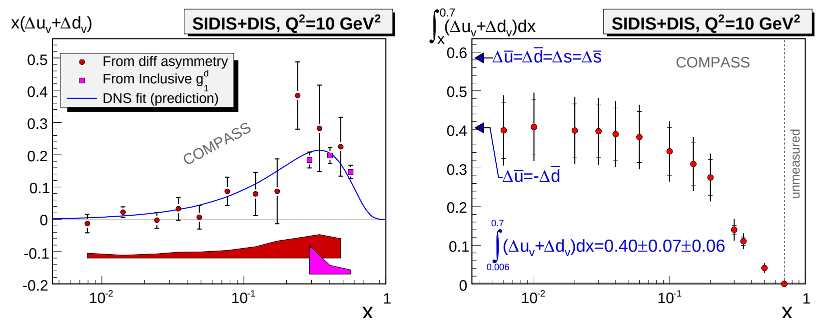

Figure 3: Left: Polarised valence quark distribution $x(\Delta u_v(x) + \Delta d_v(x))$ evolved to $Q^2 = 10(GeV/c)^2$ according to the DNS fit at LO [10] (line). Three additional points at high x are obtained from g_d^1 [2]. The two shaded bands show the systematic errors for the two sets of values. Right: The integral of $\Delta u_v(x)+\Delta d_v(x)$ over the range $0.006 < x < 0.7$ as the function of the low x limit, evaluated at $Q^2 = 10$ $(\mathrm{GeV}/c)^2$.

References

[1] J. Ashman *et al.* [European Muon Collaboration], Phys. Lett. B **206** (1988) 364.

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

[3] E. Leader and D. B. Stamenov, Phys. Rev. D **67** (2003) 037503.

[4] B. Adeva *et al.* [Spin Muon Collaboration (SMC)], Phys. Lett. B **369** (1996) 93.

[5] L. L. Frankfurt *et al.*, Phys. Lett. B **230** (1989) 141.

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

[7] B. Adeva *et al.* [Spin Muon Collaboration], Phys. Lett. B **420** (1998) 180.

[8] A. Airapetian *et al.* [HERMES Collaboration], Phys. Rev. D **71** (2005) 012003.

[9] A. D. Martin, W. J. Stirling and R. S. Thorne, Phys. Lett. B **636** (2006) 259.

[10] D. de Florian, G. A. Navarro and R. Sassot, Phys. Rev. D **71** (2005) 094018.

[11] M. Alekseev *et al.* [COMPASS Collaboration], Phys. Lett. B **660** (2008) 458.