Quark helicity distributions from longitudinal spin asymmetries in muon-proton and muon-deuteron scattering

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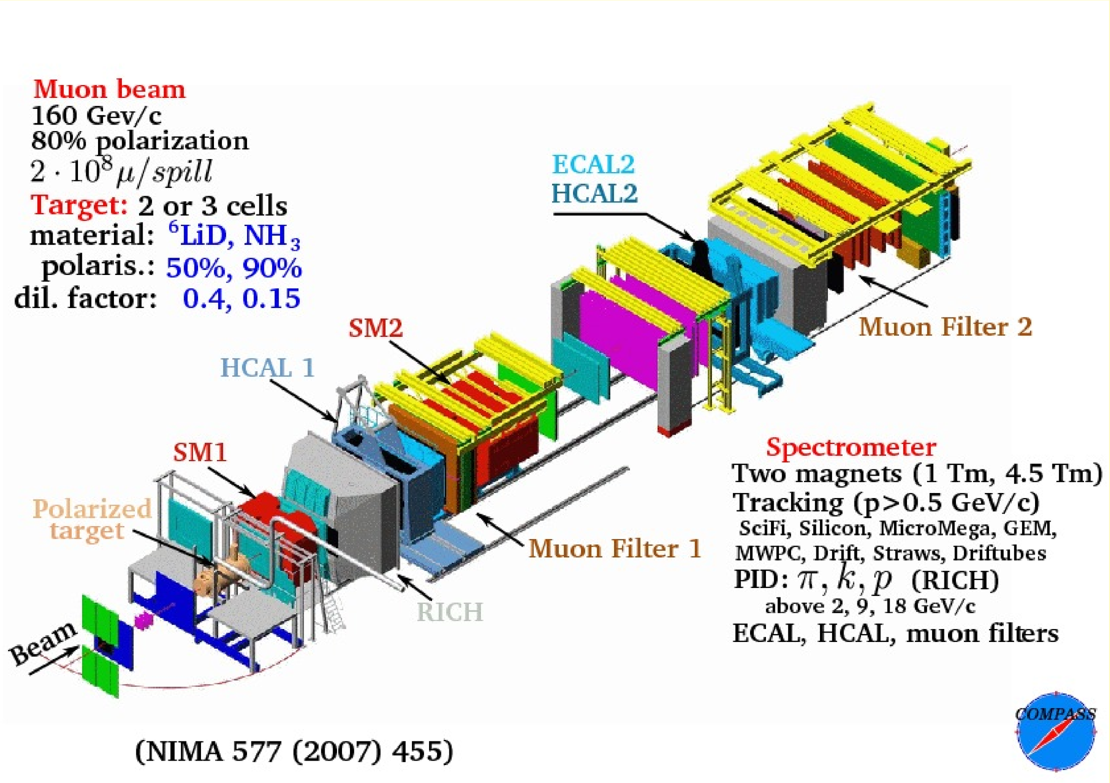
Abstract

Inclusive ($A_{1,p}$) and semi-inclusive ($A_{1,p}^{\pi+}$, A_{p1}^{p}, $A_{1,p}^{K+}$ and $A_{1,p}^{K-}$) double-spin asymmetries in deep-inelastic muon-proton scattering have been measured at COMPASS (SPS CERN). The results have been obtained with data collected in 2007 for the longitudinal polarised NH_3 solid target and beam of positive muons with energy $E = 160$ GeV. We improve the statistical precision of $g_1^p(x; Q2)$ by a factor of two in the low x region. Proton asymmetries have been combined with the deuteron ones [1] to extract the non-singlet spin-dependent structure function $g_1^{NS}(x; Q2)$. The first moment Γ_1^{NS} confirms the validity of the Bjorken sum-rule.
Our new semi-inclusive data were used to evaluate the Δu, Δd, $\Delta\bar{u}$, $\Delta\bar{d}$ and $\Delta s \equiv \Delta\bar{s}$ distributions.

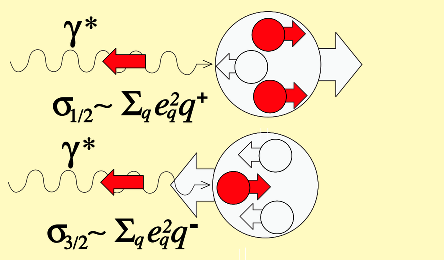
Experimental layout



(NIMA 577 (2007) 455)

Polarised Deep Inelastic Scattering

$\mu^+ + d(p) \to \mu'^+ + X$,
$\mu^+ + d(p) \to \mu'^+ + h + X$, $\quad h \equiv \pi^+, \pi^-, K^+, K^-$



Quark densities:

- $q(x) = q^+(x) + q^-(x)$
- $\Delta q(x) = q^+(x) - q^-(x)$

$q^+(x)$ ($q^-(x)$): spins of the nucleon and struck quark are in the same (opposite) directions

$$A_1 \equiv A^{\gamma N} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1}{F_1} = \frac{2x}{F_2} g_1 = \frac{\Sigma_q e_q^2 \Delta q}{\Sigma_q e_q^2 q}$$

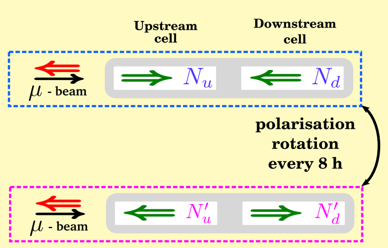
$A_{||} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \approx DA_1$ – can be measured in an experiment; D – depolarisation factor

Methods

Number of interactions:

$$N = a\Phi n\bar{\sigma}(1 \pm f P_B P_T A_{||})$$

a – acceptance;
Φ – beam flux;
$n = n_d + \sum_A n_A$ – full density of nuclei of the target material;



$\bar{\sigma} = \frac{\bar{\sigma}_d n_d + \sum_A \bar{\sigma}_A n_A}{n}$ – full cross-section
$f = \frac{n_d \bar{\sigma}_d}{n\bar{\sigma}}$ – dilution factor
P_B, P_T – beam and target polarisation

$$\delta \equiv \frac{N_{up}}{N_{dn}} \frac{N'_{dn}}{N'_{up}} \Rightarrow \alpha A^2 + bA + c = 0$$

Necessary conditions:

✓ Beam track goes through all target cells ⇒ Flux cancelation

✓ $\frac{\langle a_{up} \rangle}{\langle a_{dn} \rangle} = \frac{\langle a'_{dn} \rangle}{\langle a'_{up} \rangle}$, $\langle a \rangle = \frac{\int a\Phi n\sigma d\vec{x}}{\int \Phi n\sigma d\vec{x}}$ ⇒ Acceptance cancelation

References

[1] [COMPASS Collaboration], "Flavour Separation of Helicity Distributions from Deep Inelastic Muon-Deuteron Scattering", *Phys. Lett. B* **680** *(2009) 217*

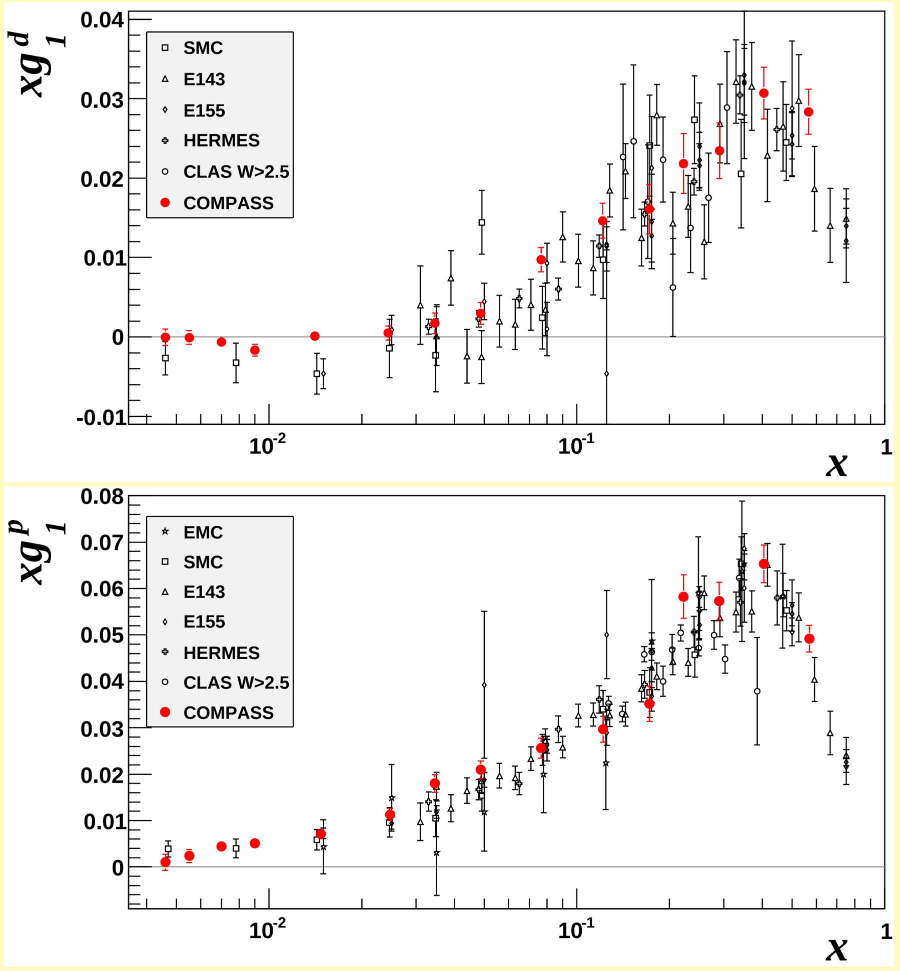
[2] [COMPASS Collaboration], "The Spin-dependent Structure Function of the Proton g_1^p and a Test of the Bjorken Sum Rule", *Phys. Lett. B* **690** *(2010) 466*

[3] [COMPASS Collaboration], "Quark helicity distributions from longitudinal spin asymmetries in muon-proton and muon-deuteron scattering", *Phys. Lett. B* **693** *(2010) 227*

[4] A. D. Martin, W. J. Stirling and R. S. Thorne, "MRST partons generated in a fixed-flavor scheme", *Phys. Lett. B* **636** *(2006) 259*

[5] D. de Florian, R. Sassot and M. Stratmann, "Global analysis of fragmentation functions for pions and kaons and their uncertainties", *Phys. Rev. D* **75** *(2007) 114010*

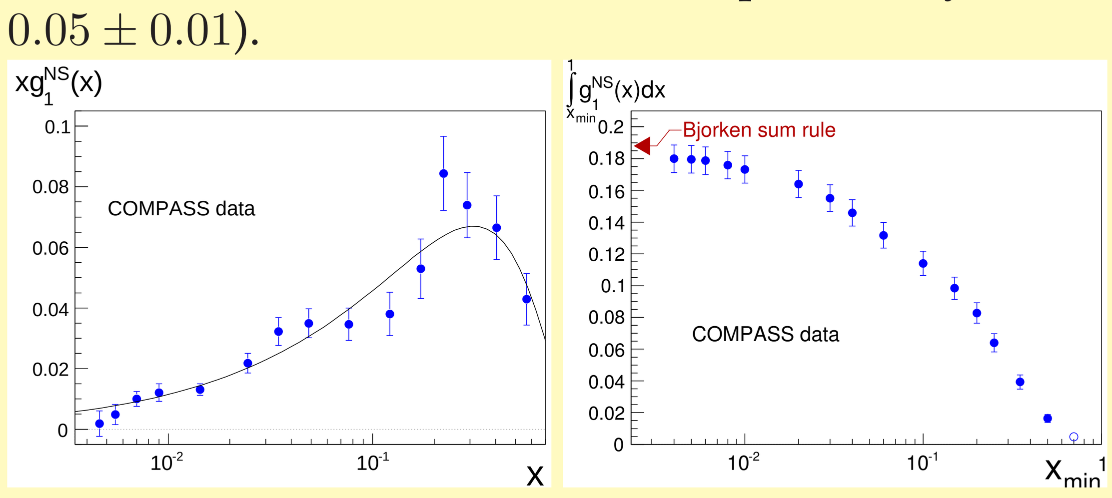
A Test Of The Bjorken Sum-Rule



Good and comparable precision at low x for results on g_1^d and g_1^p gives ideal condition for a new evaluation of the non-singlet structure function

$$g_1^{NS}(x) = g_1^p(x) - g_1^n(x) = 2\left[g_1^p(x) - \frac{g_1^d(x)}{(1 - 3/2\omega_D)}\right],$$

where ω_D is the deuteron D-state probability ($\omega_D = 0.05 \pm 0.01$).



The first moment provides a test of the Bjorken sum rule, a fundamental result of QCD derived using current algebra

$$\int_0^1 g_1^{NS}(x)dx = \frac{1}{6}\left|\frac{g_A}{g_V}\right| C^{NS} \quad \text{or} \quad \Delta u - \Delta d = \left|\frac{g_A}{g_V}\right|$$

C^{NS} was calculated in pQCD up to $\alpha_s^3(Q^2)$.
The Q^2 dependence of the non-singlet structure function $g_1^{NS}(x, Q^2)$ is decoupled from the singlet quark and the gluon spin densities. Consequently a fit of the Q^2 evolution of g_1^{NS} requires only a small number of parameters to describe the shape of an isovector quark density, $\Delta q_3(x)$, at some reference Q^2. In the present analysis, $Q_0^2 = 3(\mathrm{GeV}/c)^2$ is taken as reference Q^2 in the fit and the following parameterisation used for Δq_3:

$$\Delta q_3(x) = \eta_3 \frac{x^{\alpha_3}(1-x)^{\beta_3}}{\int_0^1 x^{\alpha_3}(1-x)^{\beta_3} dx}$$

COMPASS result [2]:

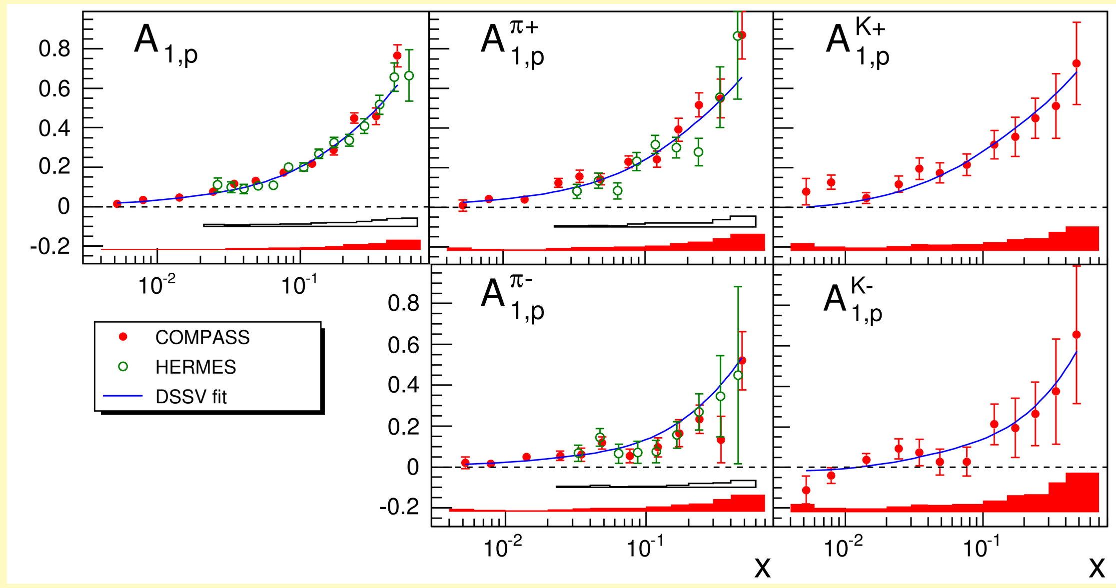
$$|g_A/g_V| = 1.28 \pm 0.07(\text{stat.}) \pm 0.10(\text{syst.})$$

The dominant systematic error is due to uncertainties on the beam and target polarisation.
PDG'10, neutron β-decay: $|g_A/g_V| = 1.2701 \pm 0.0025$

Statistics, [$\times 10^6$ events]

	target	
	deutron	proton
incl.	135.1	85.3
π^+	22.8	12.3
π^-	20.5	10.9
K^+	4.8	3.6
K^-	3.3	2.3

Double-Spin Asymmetries



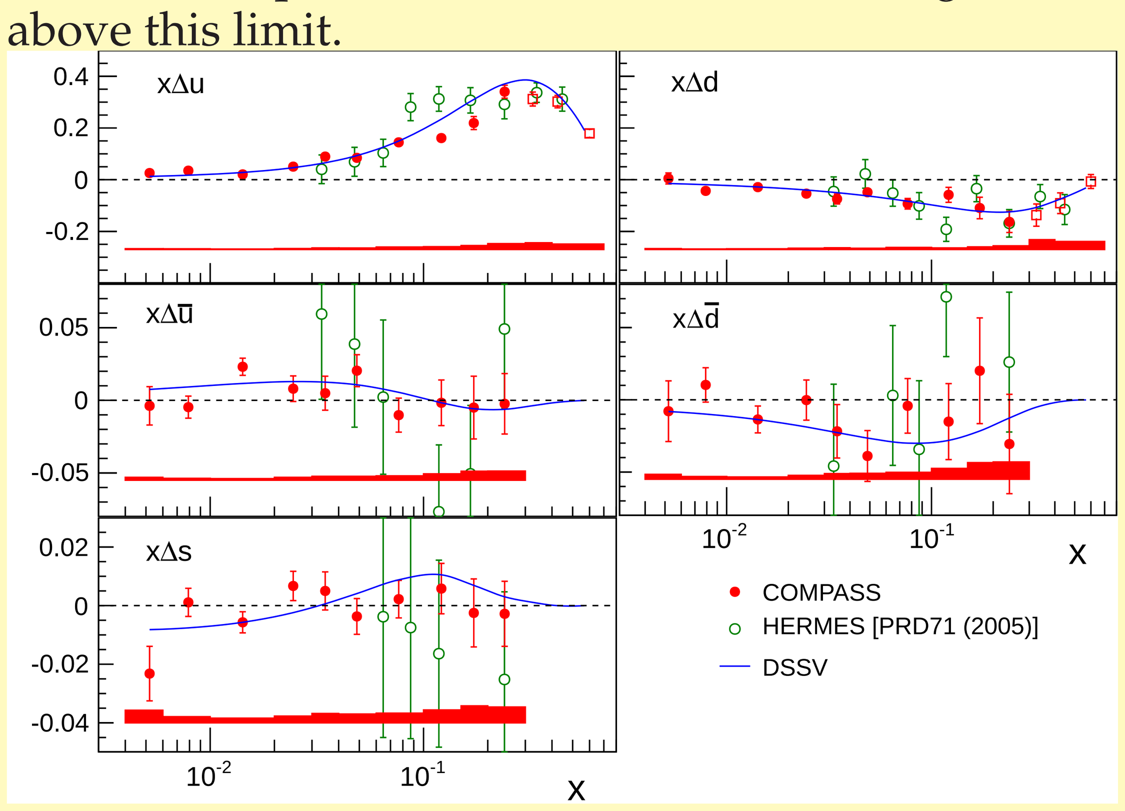
Comparison of double-spin asymmetries of COMPASS as a function of x with results of HERMES.

Polarized PDFs

At LO in QCD under the assumption of independent quark fragmentation, the double spin asymmetries for a hadron h produced in the current fragmentation region can be decomposed into a sum of products of quark helicity distributions $\Delta q(x, Q^2)$ times quark fragmentation functions $D_q^h(z, Q^2)$, where z is the fraction of the virtual photon energy taken by the hadron h:

$$A_1^h(x, Q^2, z) = \frac{\Sigma_q e_q^2 \Delta q(x, Q^2) D_q^h(z, Q^2)}{\Sigma_q e_q^2 q(x, Q^2) D_q^h(z, Q^2)}$$

In the present analysis we neglect the Q^2 dependence of the asymmetries and assume all measurements to be valid at $Q_0^2 = 3(\mathrm{GeV}/c)^2$. For the unpolarised parton distributions we use the LO parametrisation of MRST [4] and for fragmentation functions the LO parametrisation of DSS [5].
The four semi-inclusive asymmetries of the proton, the four of the deuteron and two inclusive asymmetries provide a system of ten equations with five unknowns (Δu, Δd, $\Delta\bar{u}$, $\Delta\bar{d}$ and $\Delta s \equiv \Delta\bar{s}$). The equations are solved by a least-square fit, independently in each bin of x. The analysis is limited to $x \leq 0.3$ because sea quark contributions become insignificant above this limit.



Presently $(\Delta\bar{u} - \Delta\bar{d})$ is accessible only via semi-inclusive DIS processes. COMPASS results indicate a slightly positive distribution. The first moment of the distribution in the x region of the measurement is [3]

$$\int_{0.004}^{0.3} (\Delta\bar{u} - \Delta\bar{d})dx = 0.052 \pm 0.035(stat.) \pm 0.013(syst.)$$

Unpolarised case: $\int_0^1 (\bar{u} - \bar{d})dx = 0.118 \pm 0.012$

Open Questions

Extraction of FFs from COMPASS data is ongoing.
New COMPASS data on longitudinal polarized NH_3 target were collected during the year 2011 to increase the precision of the measurements.