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Measurement of ΔS at COMPASS

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Summary. — The extraction of the strange quark contribution to the axial nucleon coupling ΔS from COMPASS data is reviewed. Both inclusive and semi-inclusive measurements are used. With inclusive data using $SU(3)$ flavour symmetry one finds $\Delta S = -0.08 \pm 0.01(\text{stat.}) \pm 0.02(\text{syst.})$, whereas from semi-inclusive data one has $\Delta S = -0.02 \pm 0.02(\text{stat.}) \pm 0.02(\text{syst.})$. This disagreement was previously ascribed to the lack of data in the low Bjorken x domain. The COMPASS results do not validate this explanation completely.

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1. – Introduction

The strange quark manifests itself in the nucleon structure at low momentum transfer ($Q^2 < 1\,(\text{GeV}/c)^2$) through *e.g.* the strange electroweak elastic form factors $G^{\text{s}}_{E,M,A}$ which parametrise the contributions of strangeness to the vector and axial coupling of the nucleon. These form factors can be measured in elastic parity violating electron and neutrino scattering. In particular, the axial strangeness form factor G^{s}_{A} is related to the axial current matrix element

$$\langle \text{N}, p' |\, \bar{\text{s}}\, \gamma_\mu\, \gamma_5\, \text{s}\, | \text{N}, p \rangle \,, \tag{1}$$

which offers a link to the quite different, high-Q^2 regime of the strong interaction, where a description of the hadron structure by means of perturbative QCD is feasible. In such a momentum transfer regime (typically $Q^2 > 1\,(\text{GeV}/c)^2$) the inelastic lepton-nucleon scattering can be described within the quark-parton model. Thereby the lepton scatters on quasi-free partons which are identified with the QCD quarks. At lowest order in α_s and at leading twist the matrix element (1) can be related to the helicity density of the strange quark $\Delta\text{s}(x)$, describing the longitudinal polarisation of the s-quark inside the nucleon in the infinite momentum frame and depending only on the Bjorken scaling variable x (if one considers parton evolution, then a dependence on Q^2 also appears). The connection to the axial form factor is given by the sum rule:

$$G_A^{\rm s}(Q^2=0)=\int_0^1 {\rm d}x\;\left[\Delta{\rm s}(x)+\Delta\bar{\rm s}(x)\right]_{Q^2\to\infty}\equiv\Delta S. \tag{2}$$

Checking the validity of eq. (2) is important, because it links long-range and short-range strong interaction phenomena which, albeit being manifestations of the same force, admit quite different theoretical descriptions. On the other hand, if the sum rule is taken for granted, then it can be used for mutually constraining the $G_A^{\rm s}$ and the ΔS measurements.

2. – ΔS from DIS

The first moment of the polarised parton distribution functions (PDF) $\Delta q(x)$ can be accessed with deep inelastic scattering (DIS) measurements in two ways.

In inclusive measurements, where only the scattered lepton is detected, and measuring the double-polarisation asymmetry $A_1=(\sigma^{\uparrow\uparrow}-\sigma^{\uparrow\downarrow})/(\sigma^{\uparrow\uparrow}+\sigma^{\uparrow\downarrow})$, where $\sigma^{\uparrow\uparrow}$ and $\sigma^{\uparrow\downarrow}$ denote the DIS cross section with parallel and antiparallel beam and target spins respectively, one can access the polarised structure function $g_1(x)$. Assuming factorisation, the first moment of $g_1(x)$ is related to the integrals of the quark helicity densities ΔQ $(q={\rm u},{\rm d},{\rm s})$:

$$\Gamma_1=\int_0^1 {\rm d}x\; g_1(x)=\frac{1}{2}\sum_q e_q^2\underbrace{\int_0^1 {\rm d}x\;\left(\Delta q(x)+\Delta\bar{q}(x)\right)}_{\equiv\,\Delta Q}\,. \tag{3}$$

The isoscalar combination $\Gamma_1^N=(\Gamma_1^{\rm p}+\Gamma_1^{\rm n})/2$ is easily accessible with a deuteron target. Furthermore, isospin symmetry relates proton and neutron helicity densities: $\Delta{\rm u}\equiv\Delta{\rm u}^{\rm p}=\Delta{\rm d}^{\rm n}$, $\Delta{\rm d}\equiv\Delta{\rm d}^{\rm p}=\Delta{\rm u}^{\rm n}$ and $\Delta{\rm s}\equiv\Delta{\rm s}^{\rm p}=\Delta{\rm s}^{\rm n}$. Assuming then $SU(3)$ flavour symmetry in combination with the Bjorken sum rule and using the axial couplings F and D of the baryon octet measured in β decays, one ends up with

$$\Delta S=3\Gamma_1^N-\frac{5}{12}a_8\,, \tag{4}$$

where $a_8=3F-D=0.585\pm0.025$.

The second way of measuring ΔS is via semi-inclusive DIS (SIDIS). In this case one or more hadrons in the final state are detected and identified. Thus one can measure a double-polarisation asymmetry in the production cross section of a certain hadron species h which reads at leading order:

$$A_1^h(x,z)=\frac{\sigma_h^{\uparrow\uparrow}-\sigma_h^{\uparrow\downarrow}}{\sigma_h^{\uparrow\uparrow}+\sigma_h^{\uparrow\downarrow}}=\frac{\sum_q e_q^2\left(\Delta\, q(x)D_q^h(z)+\Delta\,\bar{q}(x)D_{\bar{q}}^h(z)\right)}{\sum_q e_q^2\left(q(x)D_q^h(z)+\bar{q}(x)D_{\bar{q}}^h(z)\right)}\,. \tag{5}$$

Here, the D_q^h are the fragmentation functions (FF), giving the mean number of hadrons h which are produced in a DIS event, when the quark taking part in the hard scattering is of flavour q. They depend at this order only on the variable z, the fraction of the

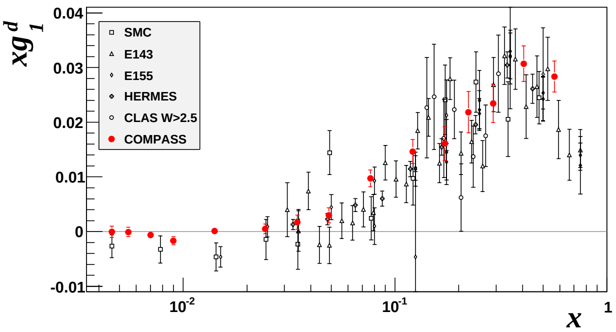


Fig. 1. – World data on the polarised structure function of the deuteron $g_1^{\rm d}$ from inclusive DIS [2]. All points are evolved to the common Q^2 value of 3 $({\rm GeV}/c)^2$.

energy lost by the lepton which is carried by the identified hadron. Taking the FFs from other experiments and measuring the SIDIS asymmetries for different hadrons allows the separation of the various $\Delta q(x)$. Integrating $\Delta {\rm s}(x) + \Delta \bar{\rm s}(x)$ over x, one obtains ΔS.

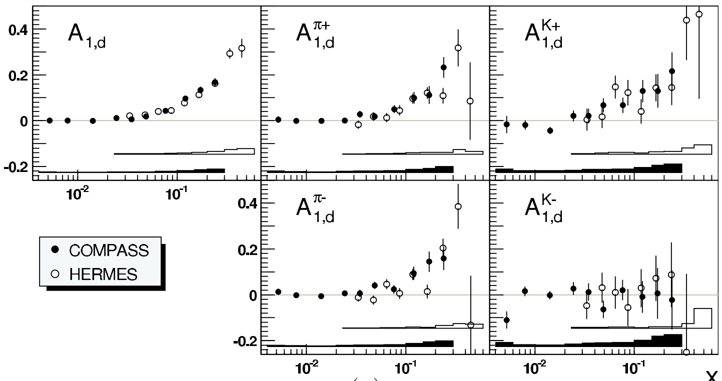
3. – The COMPASS ΔS measurements

The COMPASS experiment [1] is located at CERN. It is conducted by an international collaboration and has a broad experimental programme in hadron structure physics, using both SPS hadron and muon beams. For the DIS and SIDIS measurements a tertiary, naturally polarised muon beam is scattered on longitudinally polarised ^{6}LiD and NH_3 solid state targets.

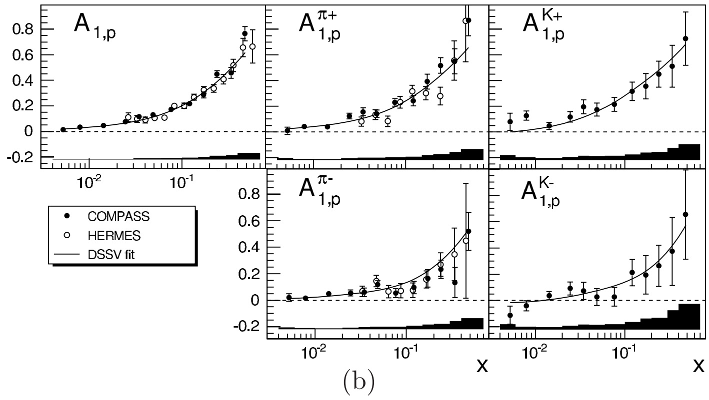
Scattering events are detected in a two-stage large acceptance spectrometer, consisting of two dipole magnets and more than 300 tracking planes of several types of position sensitive detectors. Each spectrometer stage is equipped with an electromagnetic and a hadronic calorimeter. Very important for the SIDIS measurement is the RICH detector, enabling for particle identification —in particular for distinguishing between pions and kaons— over a broad momentum range. Plastic scintillator hodoscopes are used for triggering data recording. Different kinds of coincidence signals between hodoscopes or between hodoscopes and calorimeters are used as trigger for different kinematical regions.

The inclusive DIS scattering events used in the analysis have both a reconstructed beam and scattered muon tracks. The momenta of both muons are measured and the tracks are required to intersect in a common vertex inside the target material. Cuts on inclusive kinematical variables are applied to the event sample for restricting to the regime where both perturbative QCD and parton model are reliable. In the SIDIS measurement a further cut on z is applied for selecting hadrons coming only from the current fragmentation.

Both type of ΔS measurements described in sect. **2** have been performed at COMPASS. The most relevant contribution of the COMPASS data is at low values of x (below 0.3), because of the high energy (160 GeV) of the muon beam. Figure 1 shows the world data of $g_1^{\rm d}$. Including the COMPASS results, the accuracy of $g_1^{\rm d}$ in the region $x < 0.3$ has improved by about a factor ten with respect to the previous measurements. Using a next-to-leading order (NLO) QCD fit [2] for evolving all points to a common Q^2 value,



(a)



(b)

Fig. 2. – SIDIS asymmetries from deuteron (a) and proton (b) targets. The curves in (b) are the results of the DSSV fit [9]. The COMPASS data used in the fit are only the deuteron inclusive and semi-inclusive measurements without hadron identification.

one can integrate over x and from the extracted value of Γ_1^N one gets the negative result

$$\Delta S = -0.08 \pm 0.01(\text{stat.}) \pm 0.02(\text{syst.})\,. \tag{6}$$

The SIDIS asymmetries measured at COMPASS for charged pions and kaons from a deuteron and a proton target [3, 4] are shown in fig. 2 together with the HERMES data [5, 6]. In all cases the COMPASS points extend the x range down to about 0.05. For the kaon asymmetries from a proton target, it is the first —and by now sole— existing measurement. For extracting the helicity densities, one makes use of eq. (5) as in ref. [4]. The MRST parametrisation for the unpolarised PDFs [7] and the DSS parametrisation for the FFs [8] were used. Under the assumption $\Delta \mathrm{s} = \Delta \bar{\mathrm{s}}$ one has for each x bin 5 unknowns (Δu, $\Delta\bar{\mathrm{u}}$, Δd, $\Delta\bar{\mathrm{d}}$ and Δs) and 10 measurements: 2 different targets (p and d), providing 5 data points each (1 inclusive, 4 semi-inclusive). The results are shown in fig. 3, compared with a NLO QCD fit (DSSV) which does not include the COMPASS SIDIS data shown here [9]. This comparison is only qualitative, because the points are extracted using the leading order (LO) formula of eq. (5), but it suggests that higher order QCD corrections should be small. This observation justifies the comparison of

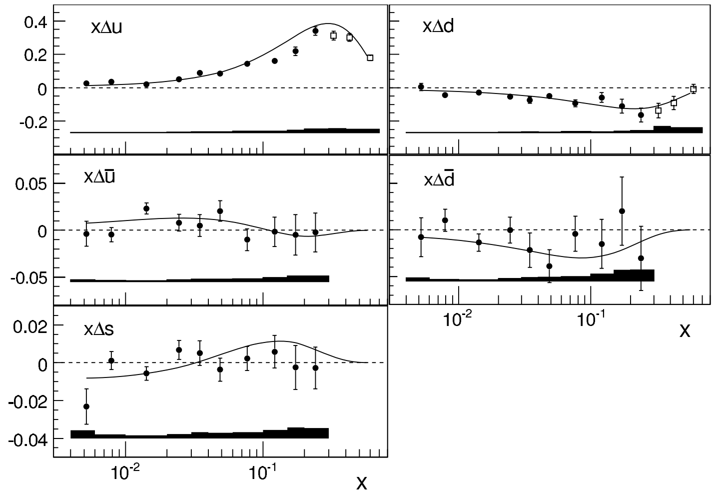


Fig. 3. – Δq distributions from SIDIS and DIS COMPASS data. The curves show the results of the DSSV fit [9].

the LO SIDIS with the NLO inclusive extraction of ΔS. The polarised PDF $\Delta \mathrm{s}(x)$ is compatible with zero over the whole x domain. Its integral is

$$\Delta S = -0.02 \pm 0.02(\text{stat.}) \pm 0.02(\text{syst.}) \ , \tag{7}$$

deviating by about 1.5 standard deviations from the inclusive DIS result of eq. (6).

4. – Conclusions and outlook

The discrepancy between the inclusive DIS (6) and the SIDIS (7) measurement which was already pointed out in ref. [10] is only partly reconciled. One possible explanation which was advocated in ref. [10] was the lack of SIDIS data in the low x region. With the COMPASS results the lower limit of the covered range has been moved down by almost one order of magnitude, while ΔS remains compatible with zero. However, one has to keep in mind that the SIDIS analysis is done at LO whereas the inclusive DIS at NLO.

The negative ΔS found in the inclusive analysis seems to be more in agreement with the $G_A^{\mathrm{s}}(Q^2 = 0)$ value extracted from parity violating electron and neutrino scattering data [11], although thereby a very large extrapolation to $Q^2 = 0$ from about $0.4\,(\mathrm{GeV}/c)^2$ has to be performed, introducing large uncertainty.

One possible explanation of the puzzle is the break up of the $SU(3)$ flavour symmetry upon which the inclusive measurement relies. Some model calculations [12] predict a sizable correction of the inclusive value of ΔS toward zero.

Another explanation could be the lack of knowledge of the fragmentation functions, in particular for kaons, used in the SIDIS analysis. The parametrisation used there is a fit to data which do not cover, at least for kaons, the whole COMPASS kinematical ranges. The extraction of the FFs from COMPASS data is in process.

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