Can the polarization of the strange quarks in the proton be positive?

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Recently, the HERMES Collaboration at DESY, using a leading order QCD analysis of their data on semi-inclusive deep inelastic production of charged hadrons, reported a marginally positive polarization for the strange quarks in the proton. We argue that a non-negative polarization is almost impossible.

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There is, at present, a major experimental drive (HERMES at DESY, COMPASS at CERN) to determine the polarized sea-quark densities $\Delta\bar{u}(x,Q^2), \Delta\bar{d}(x,Q^2), \Delta s(x,Q^2)$ and $\Delta\bar{s}(x,Q^2)$, as well as the polarized gluon density $\Delta G(x,Q^2)$. These are being studied using polarized semi-inclusive deep inelastic (SIDIS) reactions of the type $l+p \to l+h+X$ where h is an identified hadron and the initial lepton and proton are longitudinally polarized.

Recently the HERMES group has presented preliminary data on the polarized strange quark sea [1], suggesting, in a leading order QCD analysis, that $(\Delta s+\Delta\bar{s})(x)$ at $Q^2 = 2.5\ \mathrm{GeV}^2$ is marginally positive, whereas in all analyses of *inclusive* DIS [2], it is found that $(\Delta s+\Delta\bar{s})(x,Q^2)$ is significantly negative. We shall argue in this Brief Report that a positive strange quark polarization is almost impossible.

It has to be understood that there is a key difference between the determination of the *nonstrange* polarized sea-quark densities $(\Delta\bar{u},\Delta\bar{d})$ and the strange sea contribution $(\Delta s+\Delta\bar{s})(x,Q^2)$. In inclusive DIS one can, in principle, only determine combinations such as $\Delta q+\Delta\bar{q}$. This implies that even with perfect, error-free data we would know absolutely nothing about $\Delta\bar{u}$ and $\Delta\bar{d}$ [note that in papers where these densities are presented additional assumptions like SU(3) symmetric sea, etc. have been used]. But quite the opposite holds for $(\Delta s+\Delta\bar{s})(x,Q^2)$. It is completely determined subject, of course, to errors in inclusive DIS experiments. In all of the many independent analyses it turns out that the first moment

$$\delta s(Q^2) \equiv \int_0^1 dx[\Delta s(x,Q^2)+\Delta\bar{s}(x,Q^2)] \tag{1}$$

is significantly *negative*.

Consider the first moment $\Gamma_1^p(Q^2)$ of the measured spin-dependent structure function $g_1^p(x,Q^2)$. One has, in leading order QCD [more correctly, in the leading logarithmic approximation (LLA)],

$$\Gamma_1^p(Q^2) \equiv \int_0^1 dx g_1^p(x,Q^2) = \frac{1}{6}\left[\frac{1}{2}a_3+\frac{5}{6}a_8+2\,\delta s(Q^2)\right] \tag{2}$$

where a_3 and a_8 are hadronic matrix elements of the third and eighth components of the Cabibbo octet of axial-vector currents which control the β decays of the neutron (a_3) and the hyperons (a_8).

Now a_3 is known to high precision: $a_3=g_A=1.2670 \pm 0.0035$ [3], and this determination relies only upon the assumption of isotopic spin independence of the strong interactions. On the other hand, the value usually attributed to a_8, namely $a_8=3F-D$, is a consequence of the $SU(3)_f$ flavor symmetry treatment of the hyperon β decays. Its value (see the second reference in [2]) obtained on the basis of updated β decay constants is

$$a_8=3F-D=0.585\pm 0.025. \tag{3}$$

While isospin symmetry is not in doubt, there is some question about the accuracy of assuming $SU(3)_f$ symmetry in analyzing hyperon β decays. According to Ratcliffe [4] symmetry breaking effects are small, of order of 10%. The recent KTeV experiment at Fermilab [5] supports this assessment. Their results of the β decay of $\Xi^0, \Xi^0 \to \Sigma^+ e\bar{\nu}$, are all consistent with exact $SU(3)_f$ symmetry. Taking into account the experimental uncertainties one finds that $SU(3)_f$ breaking is at most of order 20%. We therefore conclude that it is almost impossible that a_8 lies outside the range.[1]

$$0.47 \leqslant a_8 \leqslant 0.70. \tag{4}$$

Let us now return to Eq. (2) and rewrite it in the form

$$a_8=\frac{6}{5}\left[6\Gamma_1^p(Q^2)-\frac{1}{2}a_3-2\,\delta s(Q^2)\right]. \tag{5}$$

[1]Note that more extreme values of a_8 have emerged in some symmetry breaking models which study not just octet hyperon β decays, but also baryon magnetic moments [6] and baryon decuplet β decays [7]. However, the predictions of these models for the $\Xi^0 \to \Sigma^+$ β decay do not agree with the experimental results of KTeV Collaboration. In addition, it is the hyperon β decays which are most relevant for the matrix element a_8 needed in polarized DIS.

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The value of $\Gamma_1^p(Q^2)$ at fixed Q^2 depends on the extrapolation of g_1 used in the unmeasured x region. Using for g_1 in that region its perturbative QCD expression the E155 Collaboration obtained, from the analysis of the presently available data, the following value for $\Gamma_1^p(Q^2)$ at $Q^2=5$ GeV^2 [8]:

$$\Gamma_1^p(Q^2=5\ \ \mathrm{GeV}^2)=0.118\pm 0.004\ \ (\mathrm{stat})\pm 0.007(\mathrm{syst}). \quad (6)$$

The values of $\Gamma_1^p(Q^2)$ reported by other collaborations before the E155 data were published are very close to that value (see, e.g., [9]). Note that at very small $x\, g_1(x,Q^2)_{QCD}$ gives a negative contribution to $\Gamma_1^p(Q^2)$. On the other hand, the E143 Collaboration has reported [10] experimental values for $\Gamma_1^p(Q^2)$ at different Q^2 using for g_1 in the unmeasured low x region Regge-type behavior, and found at $Q^2=3$ GeV^2

$$\Gamma_1^p(Q^2=3\ \ \mathrm{GeV}^2)=0.133\pm 0.003(\mathrm{stat})\pm 0.009(\mathrm{syst}). \quad (7)$$

In this case the low x contribution to Γ_1^p is positive and that is the main reason why the central value of Γ_1^p in Eq. (7) is significantly different from the central value in Eq. (6). Note that $\Gamma_1^p(Q^2)$ itself varies very slowly with Q^2, so that it is not the change in value of Q^2 that is responsible for the difference. Thus using the values (6) or (7) for Γ_1^p in Eq. (5), a non-negative strange quark polarization, i.e., $\delta s\geqslant 0$ requires either

$$a_8\leqslant 0.089\pm 0.058 \quad (8)$$

or

$$a_8\leqslant 0.197\pm 0.068 \quad (9)$$

respectively, in both cases significantly contradicting the bounds in Eq. (4). Hence a non-negative value of δs would imply a total breaking of $SU(3)_f$ symmetry for the strong interactions. We are thus forced to conclude that a non-negative first moment of $(\Delta s+\Delta\bar{s})(x)$ is almost impossible.

HERMES has not published the numerical data on the actual measured asymmetries, so, we can only speculate on possible causes why their analysis favors slightly positive values for $(\Delta s+\Delta\bar{s})(x,Q^2)$ in the medium x range:

(i) The HERMES analysis involves a Monte Carlo LUND model for the *purity* functions, tuned to fit the measured multiplicities. It is not clear to what extent this method is compatible with the LO QCD approach involving products of parton densities and genuine fragmentation functions.

(ii) Consistency aside, a recent study [11] showed that the myth that fragmentation functions are very well known from $e^+e^-\to hX$ is unjustified and that they have significant uncertainties. This is especially true of $D_s^{\pi}(z,Q^2)$, which plays a crucial role, in QCD analysis using directly the genuine fragmentation functions, in determining $(\Delta s+\Delta\bar{s})(x,Q^2)$. From this point of view it may be that the uncertainty attributed to $(\Delta s+\Delta\bar{s})(x,Q^2)$ in a standard LO QCD analysis will be much larger than the uncertainty found by HERMES.

(iii) It might be suggested that the mean transverse momentum of the detected hadron in the HERMES experiment is too small ($\langle p_T\rangle\simeq 0.5$ GeV) to justify the parton model approach. We do not think this is relevant since the fundamental scale which determines the applicability of the parton model is Q^2 and the value quoted above should be adequate. However, some care must be exercised regarding higher twist and NLO effects. For example, we have shown in the inclusive case that while higher twist effects are negligible in the ratio g_1/F_1 [12] they are important in g_1 itself [13]. Something similar may happen in the semi-inclusive case.

As mentioned, these are only speculations. Further progress in understanding why HERMES finds marginally positive values for the polarized strange quark densities must await the publication by HERMES of their actual asymmetry data.

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