NUCLEON SPIN*

H. HØGAASEN

Fysisk Institutt, University of Oslo,
Blindern, N-0316 Oslo, Norway

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We summarize the experimental results on integrals over the spin-dependent structure function of nucleons $g_1(x, Q^2)$. We comment on what data tell us about the origin of the spin of the proton, and compare results with a calculation from a chiral bag model.

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Experiments on deep inelastic scattering of leptons on nucleons have given us a lot of extremely important information on hadronic structure. The SLAC electron proton experiments showed that the proton consisted of smaller constituents and convinced the community that the quarks that had such a success in hadron spectroscopy were real, not just calculational entities. These first experiments also showed approximate Bjorken scaling and the study of structure functions in lepton deep inelastic scattering was one of the most fruitful testing grounds for QCD. The quark model of hadrons, where the zero order approximation for the baryon state was three quarks, made a problem as the electromagnetic g-factor of the nucleons recede from a high-brow problem into an exercise for undergraduates.

The number of structure functions that one can measure increases when one can do experiments with polarized leptons on polarized targets [1]. A whole new class of data is coming that will test the understanding of nature that we believe that we have obtained until now. I will exclusively talk about one of the spin dependent structure functions $g_1(x, Q^2)$, the one where measurements are best and where measurements have led to extreme excitement. First a reminder how it is extracted.

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The experimentally measurable quantity is the asymmetry

$$A = \frac{\sigma^{\downarrow\uparrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\downarrow\uparrow} + \sigma^{\uparrow\uparrow}}, \tag{1}$$

where $\sigma^{\downarrow\uparrow}, \sigma^{\uparrow\uparrow}$ correspond to the cases when the helicities of the polarized lepton and nucleon are antiparallel or parallel. From this one obtains

$$g_1(x,Q^2) = F_1(x,Q^2)A(x,Q^2) = \frac{F_2(x,Q^2)A(x,Q^2)}{2x(1+R)}, \tag{2}$$

where the $F_k(x,Q^2)$'s are the structure functions for unpolarized deep inelastic scattering. Given a measured asymmetry $A(x,Q^2)$ the deduced value for $g_1(x,Q^2)$ will therefore change if new experiments or new analyses of experiments in unpolarized deep inelastic scattering come. Of particular interest have been the integrals

$$\Gamma_{p,n}(Q^2) = \int_0^1 g_1^{p,n}(x,Q^2)dx\,. \tag{3}$$

as they obeys sum rules.

In the limit when Q^2 tends to infinity Bjorken showed almost 30 years ago [2] that the integrals were given by the matrix elements of the axial current at zero momentum transfer. He wrote down his celebrated sum rule:

$$\Gamma_p(\infty) - \Gamma_n(\infty) = \frac{g_a}{6}, \tag{4}$$

where g_a is the axial charge measured in nucleon β decay. One has, because the particular linear combination $\Gamma_p - \Gamma_n$ project out the isospin changing part of the axial current matrix elements, a relation between observables where the right hand side is well measured.

The sum rules for one baryon involve also the matrix element of the isoscalar part of the axial current and this is not known from any other experiment. Experiments on polarized deep inelastic scattering therefore teach us something new. With theoretical input beyond isospin invariance,one can of course make sum rules for individual nucleons, and the experiments therefore test the theoretical input. Twenty years ago Gourdin [3] and Ellis and Jaffe [4] did this, the theoretical input was $SU(3)_f$ symmetry and the absence of polarized strange quarks in the sea [4].

Nothing is,or will be measured at infinite momentum transfer, however, so the calculations of the corrections are of the utmost importance. Today these are known up to order $\alpha_{(s)}(Q^2)^3$ [5, 6] and the term of order α^4 has been estimated [7].

When one uses $SU(3)_f$ symmetry, part of the isosinglet axial current matrix element is extracted from hyperon β decay and the unknown $SU(3)_f$ singlet matrix element can be determined from the absence of polarized s quarks. It has become so commonplace to invoke SU(3) flavour symmetry in this field that I will assume it in the following and when I speak about "flavour singlet" I will mean singlet under $SU(3)_f$, not under the isospin group $SU(2)_f$. At the end we shall discuss a little the inherent approximations that is made by using $SU(3)_f$.

It has also become customary to express quantities in parton language and I will do this. The structure function $g_1(x,Q^2)$ can then be expressed by the distributions of quarks with spins parallel and antiparallel to that of the target

$$g_1^p(x,Q^2) = \tfrac{1}{2}\sum_q e_q^2[q_\uparrow(x,Q^2) - q_\downarrow(x,Q^2) + \bar{q}_\uparrow(x,Q^2) - \bar{q}_\downarrow(x,Q^2)]$$
$$= \tfrac{1}{2}\sum_q e_q^2 \Delta q(x,Q^2) \tag{5}$$

$$\Delta q(Q^2) \equiv \int_0^1 dx[q_\uparrow(x,Q^2) - q_\downarrow(x,Q^2) + \bar{q}_\uparrow(x,Q^2) - \bar{q}_\downarrow(x,Q^2)]\,. \tag{6}$$

It is also convenient to define amplitudes with well defined flavor SU(3) transformation properties: For $Q^2 \to \infty$

$$\Gamma_p(\infty) = \langle p\uparrow \left| \sum_i \tfrac{1}{2}\bar{\Psi}_i e_{qi}^2 \gamma_5\gamma_3 \Psi_i \right| p\uparrow\rangle = \tfrac{1}{6}[I_0 + I_8 + I_3]\,, \tag{7}$$

where e_{qi} is the charge of the i'th quark and the matrix element between proton states is evaluated at Q^2=0.The corresponding sum rule for a neutron target is obtained by changing the sign of I_3 in Eq.(7).

If we write the sum rules at finite Q^2 the amplitudes I_k should be renormalized at the point Q^2. The SU(3) flavor singlet amplitude is

$$I_0 = \sqrt{\frac{2}{3}}\langle p\uparrow|\bar{\Psi}\gamma_5\gamma_3\lambda_0\Psi|p\uparrow\rangle \tag{8}$$

and the two flavor octet amplitudes are

$$I_8 = \frac{1}{2\sqrt{3}}\langle p\uparrow|\bar{\Psi}\gamma_5\gamma_3\lambda_8\Psi|p\uparrow\rangle \tag{9}$$

and

$$I_3 = \tfrac{1}{2}\langle p\uparrow|\bar{\Psi}\gamma_5\gamma_3\lambda_3\Psi|p\uparrow\rangle\,, \tag{10}$$

where the λ's are the usual Gell-Mann matrices. In terms of the standard SU(3) amplitudes F and D for the baryon semi-leptonic decays, the two flavor octet amplitudes are

$$I_3 = \tfrac{1}{2}(F + D) \text{ and } I_8 = \tfrac{1}{2}(F - \tfrac{D}{3})$$

We add the correspondence between the I_i's and the commonly used Δq's:

$$\begin{aligned}
\Delta u &= \tfrac{1}{2}I_0 + I_8 + I_3\,,\\
\Delta d &= \tfrac{1}{2}I_0 + I_8 - I_3\,,\\
\Delta s &= \tfrac{1}{2}I_0 - 2I_8\,,\\
\Delta\Sigma &= \Delta u + \Delta d + \Delta s = \tfrac{3}{2}I_0\,.
\end{aligned}$$

The Ellis–Jaffe assumption that there were no polarized strange sea quarks: $\Delta s = 0$ therefore correspond to the equality $I_0 = 4I_8$. The two amplitudes I_3 and I_8 are matrix elements of conserved currents in the chiral SU(3) limit. Therefore, their values are independent of the renormalization point. The amplitude I_0 however has anomalous dimensions because of the U(1) anomaly.

It is quite interesting that it can be shown that $\Delta\Sigma$ can be shown to be a direct measure of the fraction of the proton spin that comes from the quark *spins*.People that were used to compute things in the most naive nonrelativistic quark model where no orbital angular momentum intervenes could then be lead into believing that $\Delta\Sigma = 1$ would be the thing to expect. This expectation is as reasonable as to expect similar predictions of the same model: F=2/3 and D=1, theoretical numbers that are far from values extracted from experiments, $F_{\text{exp}} = 0.456 \pm 0.01, D_{\text{exp}} = 0.80 \pm 0.01$. Errors might be underestimated. We can also summarize data in $I_3 = 0.628 \pm 0.003$, $I_8 = 0.095 \pm 0.01$. The Ellis–Jaffe assumption leads therefore to $\Delta\Sigma = 0.57 \pm 0.06$ The sum rule for the proton would then read

$$\Gamma_p(\infty) \approx \frac{0.723 + I_0}{6} \approx 0.12 + \frac{\Delta\Sigma}{9}\,. \tag{11}$$

First came data from SLAC with polarized electron beams [8]: They led to $\Gamma_p = 0.17 \pm 0.05$, a result consistent with the Ellis–Jaffe sum rule but errors were big due to the fact that they could measure the asymmetry only at $x > 0.1$. CERN now launched their program with polarized muons and as they could measure at x values down to 0.01, the errors from extrapolating data outside the measured interval were smaller than earlier measurements. The smallness of the asymmetry in this newly measured x region was a surprise. The first published results of the EMC collaboration at $\bar{Q}^2 \approx 11$ GeV^2/c^2 [9]

$$\Gamma_p(Q^2) = \int dx g_1^p(x, Q^2) = 0.114 \pm 0.012(\text{stat}) \pm 0.026(\text{syst})\,, \tag{12}$$

was, when the data analyses was complete (10), slightly revised upwards to a central value of $\Gamma_p(Q^2) = 0.126$.

Now, what are the theoretical perturbative QCD corrections due to the fact that experiments are performed at finite Q^2 ? (We shall in the following let I_0 denote the renormalization group invariant nucleon matrix element of the flavour singlet axial current.)

The nucleon sum rules $\Gamma_{p,n}$ with the QCD corrections at the scale Q^2 have recently been calculated; for references see [5, 6, 7], and reads

$$\Gamma_{p,n}(Q^2) = \frac{1}{6}(1 - \frac{\alpha(Q^2)}{\pi} - 3.5833\left(\frac{\alpha(Q^2)}{\pi}\right)^2$$
$$- 20.2153\left(\frac{\alpha(Q^2)}{\pi}\right)^3) - 130\left(\frac{\alpha(Q^2)}{\pi}\right)^4)(\pm I_3 + I_8)$$
$$+ \frac{1}{6}\left(1 - \frac{\alpha(Q^2)}{3\pi} - 0.549\left(\frac{\alpha(Q^2)}{\pi}\right)^2 - 2\left(\frac{\alpha(Q^2)}{\pi}\right)^3\right) I_0 . \qquad (13)$$

Three years ago, only the corrections to order $\alpha(Q^2)$ were known [11], the theoretical progress has been spectacular. With the value of the strong coupling constant $\alpha(Q^2 = 11\ \mathrm{GeV}^2/c^2) \approx 0.25$ we then get

$$\Gamma_p(Q^2 = 11\ \mathrm{GeV}^2/c^2) = \int dx g_1^p(x, Q^2 = 11\ \mathrm{GeV}^2/c^2)$$
$$= 0.88\frac{(I_3 + I_8)}{6} + \frac{0.97 I_0}{6} \approx 0.106 + \frac{0.97 I_0}{6}, \qquad (14)$$

and correspondingly for the neutron

$$\Gamma_n(Q^2) = \int dx g_1^n(x, Q^2 = 11 GeV^2/c^2)$$
$$= 0.88\frac{(-I_3 + I_8)}{6} + \frac{0.97 I_0}{6} \approx \frac{(-0.47 + 0.97 I_0)}{6} . \qquad (15)$$

Comparing this with the value published in 1988 [9] for $\Gamma_p(Q^2 = 11\ \mathrm{GeV}^2/c^2)$ we see that if we focus on the central experimental value $\Delta\Sigma$ looks to be very small. Indeed, at the time of the publication the situation was even more extreme as at the time the QCD correction was known only to order $\alpha(Q^2)$. The first article by EMC gave $\Delta\Sigma = 0.01 \pm 0.12 \pm 0.24$. It might well be that the final result will turn out to be inside these error bars,what exited the community was the central value. The "spin crises" was born,something was mysterious with the proton spin.There must be hundreds of theoretical papers written on the subject.

From the data one could think that there was a possibility that we had to rethink what we believed that we had understood about baryonic structure [12]. The data could accommodate $I_0 = 0$ and therefore $\Delta\Sigma = 0$.The latter is often said to imply that nothing of the spin of the proton is coming from the quarks. That statement is wrong. A bound Dirac particle has quantized total angular momentum,only in the nonrelativistic *limit* can we neglect the orbital angular momentum of the ground state. The measurement errors were great however,and no decent model would fall outside three standard deviations of the measured values. The Ellis–Jaffe sum-rule (assuming $\Delta s = 0$, *i.e.* $I_0 = 4I_8$) gives with to days knowledge of QCD corrections:

$$\Gamma_p(Q^2 = 11GeV^2/c^2) = \int dx g_1^p(x, Q^2 = 11\text{GeV}^2/c^2) = 0.168 \pm 0.01 \,, \quad (16)$$

whereas keeping only the terms linear in $\alpha(Q^2)$ we would obtain $\Gamma_p(Q^2 = 11GeV^2/c^2) = 0.172 \pm 0.01$ with $\alpha(11 \text{ GeV}^2/c^2) = .25$.

The experimental values for the asymmetry and the integrated proton spin structure function that came from SMC this year [13] is completely consistent with earlier values but errors have now come down and the central value has moved up. The spin structure function $g_1^p(x, Q^2)$ has been measured at quite small values of x and a smooth extrapolation to $x = 0$ gives the new value of the integral over x at $\bar{Q}^2 = 10 \text{ GeV}^2/c^2$ is [13]

$$\Gamma_p(Q^2) = \int dx g_1^p(x, Q^2) = 0.136 \pm 0.011 \pm 0.011 \quad (17)$$

a value that is about two standard deviations below the predictions of the Ellis–Jaffe sum rule. From this they extract $\Delta\Sigma = 0.22 \pm 0.10 \pm 0.10$. The SMC collaboration have also used their new result together with all proton data to evaluate a "world average" [13] at $Q^2 = 10 \text{ GeV}^2/c^2$ giving $\Gamma_p(Q^2) = 0.142 \pm 0.008 \pm 0.011$.

Since last year we also have got data on polarized deep inelastic scattering on targets that lead us to $g_1^n(x, Q^2)$. The first was the SMC data on a deuteron target at $\bar{Q}^2 = 4.6 \text{ GeV}^2/c^2$ [14], then came data from SLAC on ^{3}He by the E142 collaboration [15] at $\bar{Q}^2 = 2 \text{ GeV}^2/c^2$. Preliminary data from the new E143 experiment at SLAC on protons and deuterons at $\bar{Q}^2 = 3 \text{ GeV}^2/c^2$ has also been given [16].

The SMC data [14] had quite large errors and gave

$$\Gamma_n(Q^2 = 4.6 \text{ GeV}^2/c^2) = -0.08 \pm 0.04 \pm 0.03 \quad (18)$$

a result that gave no conflict with the Bjorken sum rule (or with the Ellis–Jaffe sum rule for the neutron inside errors).

The E142 experiment from last year [15] raised problems again: The experiment was done at $0.03 < x < 0.6$ and their extrapolation in the regions of small and large x gave the result

$$\Gamma_n(Q^2 = 2\ \mathrm{GeV}^2/c^2) = -0.022 \pm 0.011 \tag{19}$$

a result in perfect agreement with their evaluation of the Ellis–Jaffe sum rule! They also combined their data with the 1989 SMC data and they pointed out that it now was the sacred Bjorken sum rule that seemed to be violated at the two standard deviation level. But as they write: "Higher order QCD corrections or higher twist effects may account for the apparent discrepancy".

From the beginning of the "spin crises" there has been a lot of discussions about the extrapolation of $g_1(x, Q^2)$ outside the measured interval in x [17], as this evidently is extremely important when we need the integral over x.The SMC data cover the widest range in x and therefore look the safest from this point of view. They have bigger errors than the E142 data however. Ellis and Karliner [18] immediately criticized the E142 Collaboration for their extrapolation, with a different extrapolation they make the E142 data give $\Gamma_n(Q^2) = -0.028 \pm 0.006 \pm 0.009$. The central value is then more in line with expectations from the SMC proton data and the Bjorken sum rule. They still promote the Skyrme model. In a recent work [19] the same authors summarize their conclusion about the (renormalization group invariant) $\Delta\Sigma$: Without any higher twist terms in their analyses they find $\Delta\Sigma = 0.29 \pm 0.07$, including higher twists they give $\Delta\Sigma = 0.35 \pm 0.07$. The under standing of QCD corrections to the Bjorken sum rule is now so good that they use it to compute $\alpha_s(2.5\ \mathrm{GeV}^2/c^2) = 0.375$ with rather small errors. To end the status of experiments, I should mention that preliminary data from the E143 collaboration working at SLAC has been presented [16]

$$\Gamma_p(Q^2) = 0.129 \pm 0.004 \pm 0.010 \tag{20}$$

$$\Gamma_n(Q^2) = -0.033 \pm 0.008 \pm 0.013 \tag{21}$$

at $\bar{Q}^2 = 3\ \mathrm{GeV}^2/c^2$. These data again nicely satisfy the Bjorken sum rule.

Nobody that has followed the subject on polarized deep inelastic structure functions can avoid being struck by the fact that although, experiments are consistent inside errors, there has been a drift, monotonous with time, of the central value of the extracted $\Delta\Sigma$ towards higher values. What it is settling down to I would not guess.

I cannot, however, resist making a comment on which future values of $\Delta\Sigma$ that should be regarded as warranting a revision of our understanding of the nucleons. I have already pointed out that the Ellis–Jaffe assumption gives $\Delta\Sigma \approx 0.57$. This is therefore the value *any* model gets from the matrix element of the flavour-singlet axial current as long as the matrix elements for the flavour-octet parts are correct and $\Delta s = 0$ is imposed and as long as gluons do not contribute. Then 57 per cent only of the spin of the proton is coming from the *spins* of the quarks. How far down would $\Delta\Sigma$ have to go before we doubt the quark model?

I shall not enter the discussion about the U(1) anomaly induced gluon contribution to the sum rules [20, 21, 22] as this is a problem that is too subtle for me. But I will make some comments about bag models because it was realized immediately after the "spin crises" was born that they gave results inside the errors for the EMC experiments [23, 24]. In that case also the U(1) anomaly was invoked through its role in making the $SU(3)_f$ singlet η' meson massive. The gluonic interaction with quarks also play a very important role in this picture. As the experimental errors have been shrinking and the theoretical understanding of QCD corrections at finite Q^2 has increased, the model calculations look better and better.

Bag models — as the name indicates — have all in common that the three valence quarks of a baryon are confined to a finite region in space (which we shall take to be a sphere in the rest system of the baryon), and their energy is quantized by a boundary condition on the Dirac wave functions of the valence quarks. As the valence quarks are excluded from the outside of the bag,the axial currents carried by the valence quarks will necessarily be discontinuous on the surface and the axial current can then never be conserved even if the quark masses are all taken to be zero. To get a model that have continuous axial current matrix elements in space, something which is necessary (but not sufficient) to have chiral symmetry, one couples pseudoscalar fields to the bag.

The result is cloudy or hybrid bags: At distances less than R from the center of the baryon the dynamics is described by the quarks, at distances greater than R the dynamics is determined by the pseudoscalar Goldstone particles. It is a nice feature of these models that they manage to include the nuclear forces of greatest range mediated by the pions. They give a physical picture of hadrons that should not be disdained.

When we stay in the chiral limit where the u, d and s quarks are massless, so is the pion and eta meson as well as the kaon. The flavour singlet pseudoscalar, the η' on the other hand is massive due to the U(1) anomaly. It is this consequence of the anomaly that we shall explicitly use to illustrate how it gives a cloud of polarized $\bar{s}s$ cloud around a nucleon even if it contains no strange quarks inside the bag.

Suppose namely that we had bagged a single u quark. The surrounding pseudoscalar meson(s) would then carry the flavour content of a $\bar{u}u$ state. Develop this state in states that have well defined transformation properties under SU3 flavour on the surface where it continues into pseudoscalar mesons (Dirac matrices suppressed):

$$\bar{u}u = \frac{\pi^0}{\sqrt{2}} + \frac{\eta'}{\sqrt{3}} + \frac{\eta^8}{\sqrt{6}}, \tag{22}$$

where

$$\pi^0 = \frac{\bar{u}u - \bar{d}d}{\sqrt{2}}, \quad \eta^8 = \frac{\bar{u}u + \bar{d}d - 2\bar{s}s}{\sqrt{6}}, \quad \eta' = \frac{\bar{u}u + \bar{d}d + \bar{s}s}{\sqrt{3}}. \tag{23}$$

This looks empty, and so it is if the three neutral pseudoscalar mesons are degenerate in mass. But they are not, even in the chiral limit the η' get a mass due to the U(1) anomaly. If now the tree pseudoscalar mesons have different masses their Yukhava range will be different. A heavy η' in collaboration with the massless pion and eta will not make the $\bar{s}s$ content of the eta vanish! A nucleon bag containing only nonstrange quarks has therefore a cloud of $\bar{s}s$ like states surrounding it in the chiral limit. At great distances from the center of the bag the η' has been damped out so it cannot anymore kill the $\bar{s}s$ content of the η^8 as it did on the bag surface.

There is another point that we will raise: If one wants to compute matrix elements of the flavour singlet current, there is no reason to have confidence in the result if the model one is using is not giving correct results for the matrix elements of the flavour octet part which is responsible for weak baryonic decays. With the usual zero order (SU(6)-like) baryon wave functions, bag models lead to (in the chiral limit) a ratio F/D in hyperon decays which is 2/3 just as in the nonrelativistic quark model.

If one, however proceeds like Ushio [25, 26] and take into account the modification of the wave functions due to colour-magnetism one introduces correlations in the wave functions that not only fixes the F/D problem but also make one able to explain the paradox of magnetic moments, namely that $\mu(\Xi^-) < \mu(\Lambda)$.

If one chooses pseudoscalar meson fields that are continuous everywhere bag models lead to the Ellis–Jaffe sum rule result. It is however rather dubious to have free meson colour singlet fields inside the bag! In the version of chiral bag models where the pseudoscalar (Goldstone) mesons do not penetrate inside the bag, the mass breaking of the pseudoscalar is important. One then finds $I_0 = 0.22$ in the chiral limit when the η' is heavy and colour magnetic correlations are included in the wave function in a way that give F and D (approximately) correct, *i.e.* $F = 0.455$, $D = 0.795$. This means that $I_3 = 0.625$ and $I_8 = 0.095$. $I_0 = 0.22$ correspond to $\Delta\Sigma = 0.33$. These values lead to sum rule results that are in quite good agreement with all data as anybody can convince oneself by using these values of the I_k's in formula (13). We have here taken the attitude [27] that what quark models give are the renormalization group invariant observables.

For $\alpha = 0.25$, a value relevant for $Q^2 = 10GeV^2/c^2$ you get $\Gamma_p = 0.141$ and $\Gamma_n = -0.042$. For $\alpha = 0.35$, a value relevant for $Q^2 = 3GeV^2/c^2$ you get $\Gamma_p = 0.130$ and $\Gamma_n = -0.035$. I would not make too much out of the fact that these numbers fit so well with the preliminary E143 data (20-21).At such low Q^2,contributions from higher twists might be important [28] and it is clearly very important to get these under control. In this model then the proton spin has many components. One third of it comes from the spin of the three valence quarks, the rest from the orbital angular momentum and the gluonic exchanges between the valence quarks that also can be regarded as bagged $\bar{q}q$ pairs.

The U(1) anomaly is essential in reconciling the correct values of F and D with a value of $\Delta\Sigma < 0.57$. In terms of the Δq's the model gives $\Delta u = 0.83$, $\Delta d = -0.42$ and $\Delta s = -0.08$ at $Q^2 \rightarrow \infty$. As these results come from a quite simple physical model with relativistic quarks it follows that a value $\Delta\Sigma = 0.33$ cannot be said to be a value that is abnormally low.

All this was done in the chiral limit for all three quarks where $SU(3)_f$ by definition is a good symmetry group. What happens now when quarks and pseudoscalar mesons are given masses so that $SU(3)_f$ is broken as it is in nature? The neutral pion is still fairly light but both η and η' are heavy. Both the $\bar{s}s$ carrying pseudoscalar mesons are then seriously damped by their high mass, leaving almost no hidden strangeness around the nucleons. We did a calculation for nucleons in this way also [23] and found that the results for $\Gamma_{p,n}(\infty)$ hardly changed at all! That is: A bag model with broken $SU(3)_f$ symmetry and almost no $\bar{s}s$ content can describe data as well as the $SU(3)_f$ symmetric model above. From these results it follows that data as they are to day do not necessarily imply that $\Delta s \neq 0$ but that $SU(3)_f$ symmetry is broken. This specific example should underline the fact that the extraction of Δs from the data on the basis of $SU(3)_f$ symmetry should be taken with some caution.

To summarize: Data coming from deep inelastic scattering of polarized leptons on polarized targets do not show any deviations from what the Bjorken sum rule gives when QCD calculated corrections to finite Q^2 are taken into account, neither are they of a character that forces us to change our picture of how nucleons are build up. It is with eagerness and excitement that we await new data.

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