# ORBITAL ANGULAR MOMENTUM AND PARTON SPIN DENSITIES*

DENNIS SIVERS
High Energy Physics Division
Argonne National Laboratory
Argonne, IL 60439

## ABSTRACT

The case for parton orbital angular momentum is considered in the light of the EMC data.

I would like to describe briefly some work done in collaboration with Gordon Ramsey, David Richards and Jian-wei Qiu[1] in which we consider the impact of the new data from the EMC[2] on the modeling of quark and gluon spin-weighted parton distributions and on theparton orbital angular momentum. In our work, it is convenient to split the helicity weighted distributions for $u$ and $d$ quarks into a valence and a sea component,

$$\begin{aligned} \Delta u(x,\mu^2) &= \Delta u^v(x,\mu^2) + \Delta u^s(x,\mu^2) \\ \Delta d(x,\mu^2) &= \Delta d^v(x,\mu^2) + \Delta d^s(x,\mu^2). \end{aligned} \tag{1}$$

If we denote

$$\langle \Delta q_i \rangle = \int_0^1 dx\, \Delta q_i(x,\mu^2), \tag{2}$$

$i = u^v, d^v, u^s, d^s, \bar{u}, \bar{d}, s, \bar{s} \ldots$ as the spin fraction of the $i$th quark flavor, we find that each spin fraction is not changed by QCD evolution. For the contribution of the sea, we make a simple assumption about SU(3) breaking,

$$\langle \Delta u^s + \Delta \bar{u} \rangle = \langle \Delta d^s + \Delta \bar{d} \rangle = (1+\epsilon)\langle \Delta s + \Delta \bar{s} \rangle. \tag{3}$$

We get two important constraints on the spin fractions from the weak decays of baryons[3]

$$\begin{aligned} A_3 &= \langle \Delta u^v - \Delta d^v \rangle = 1.258 \pm 0.004 \\ A_8 &= \langle \Delta u^v + \Delta d^v \rangle + 2\epsilon \langle \Delta s + \Delta \bar{s} \rangle = 0.54 \pm 0.10. \end{aligned} \tag{4}$$

*Work supported by the U.S. Department of Energy, Division of High Energy Physics, Contract W-31-109-ENG-38.

We can then incorporate the information concerning the weak decays into the integration of $g_1^P(x,\mu^2)$ as originally proposed by Ellis and Jaffe[4]

$$\begin{aligned} G_1^P &= \left[1+\frac{\alpha_s(\mu^2)}{\pi}\right]\int_0^1 dx\, g_1^P(x,\mu^2) \\ &= \frac{5}{36}A_8+\frac{3}{36}A_3+\frac{1}{3}\langle\Delta s+\Delta\bar{s}\rangle\,. \end{aligned} \quad (5)$$

Using the EMC data[2] and a value $\alpha_s(\mu^2)=0.24$ gives

$$\langle\Delta s+\Delta\bar{s}\rangle = -0.171\pm 0.060\ (\text{stat})\pm 0.087\ (\text{syst.}). \quad (6)$$

The two spin fractions, for valence and sea quarks,

$$\begin{aligned} f_v &= \langle\Delta u^v+\Delta d^v\rangle \\ &= A_8-2\epsilon\langle\Delta s+\Delta\bar{s}\rangle \cong 0.54+0.34\epsilon \end{aligned} \quad (7)$$

$$\begin{aligned} f_s &= \left\langle\Delta u^s+\Delta\bar{u}+\Delta d^s+\Delta\bar{d}+\Delta s+\Delta\bar{s}\right\rangle \\ &= (3+2\epsilon)\,\langle\Delta s+\Delta\bar{s}\rangle \cong -0.51-0.34\epsilon, \end{aligned} \quad (8)$$

are both large and of opposite signs for reasonable values of the SU(3)-breaking parameter. The cancellation

$$f_v+f_s=\sum_i\langle\Delta q_i\rangle\cong 0 \quad (9)$$

is suggestive of a hybrid bag + skyrme model[5] in which

$$1/2 = J_z^{\text{val}}+(J_z^{\text{sea}}+J_z^{\text{skyrme}}) \quad (10)$$

and

$$J_z^{\text{val}}+J_z^{\text{sea}}=0=J_z^{\text{sea}}+J_z^{\text{skyrme}}. \quad (11)$$

The fact that $f_v+f_s=0$ is consistent with a skyrme picture for proton structure has been made by Brodsky, Ellis and Karliner.[6] However, $f_v\cong 1$ is *also* required from the data because of the strong polarization at large $x$. The hybrid scenario is consistent with the *shape* of $g_1^P(x,\mu^2)$ as well as with the integral. However, we should wait to be sure that the data at small $x$ are in the scaling region to be confident that we can draw such strong conclusions.

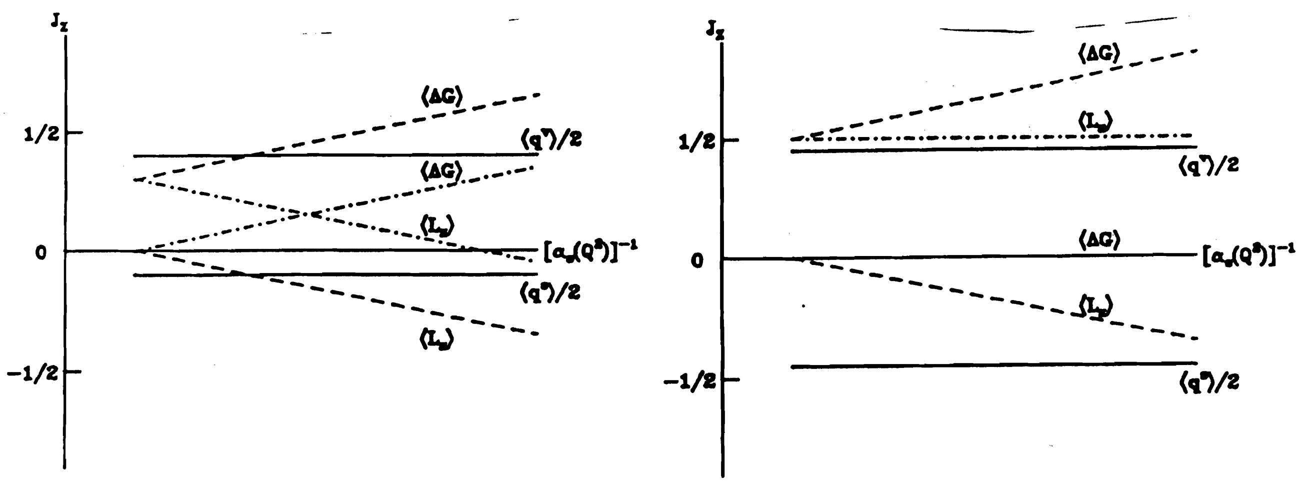


Fig. 1. The spin fractions carried by the valence quarks, sea quarks, gluons and orbital angular momentum are shown against $[\alpha_s(Q^2)]^{-1}$ for the cases $\langle \Delta q^v + \Delta q^s \rangle > 0$ and $\langle \Delta q^v + \Delta q^s \rangle = 0$. The dashed and dot-dashed line correspond to the initial conditions $\langle L_z(Q_0^2) \rangle = 0$ and $\langle \Delta G(Q_0^2) \rangle = 0$ respectively.

It is also interesting to consider the impact of the EMC data on the question of parton orbital angular momentum from a different perspective. Starting with the $J_z = 1/2$ sum rule[7]

$$\frac{1}{2} = \frac{1}{2}\sum_i \langle \Delta q_i \rangle + \langle \Delta G \rangle + \sum_i \langle L_{zi} \rangle, \tag{12}$$

The conservation of quark chirality leads to

$$\sum_i \frac{\partial}{\partial t}\langle L_{zi} \rangle = -\frac{\partial}{\partial t}\langle \Delta G \rangle = -\left[\frac{3}{2}C_2(R)\sum_i \langle \Delta q_i \rangle + b_0 \langle \Delta G \rangle\right], \tag{13}$$

where $t = b_0^{-1} \ln\left(\alpha_s(Q_0^2)/\alpha_s(Q^2)\right)$, $b_0 = \frac{11}{6}C_2(G) - \frac{2}{3}T(R)$. This evolution leads to $\langle L_{zi} \rangle \to -\infty$ at large $Q^2$ unless the R.H.S. of (13) vanishes. The analysis of the EMC data discussed above leads to the possibility that the term proportional to $\sum_i \langle \Delta q_i \rangle$ does not contribute. If we assume *a priori* that $\langle \Delta G\,(Q_0^2) \rangle = 0$ and $\langle L_z\,(Q_0^2) \rangle = 1/2$ the solution is stable against further evolution. This is demonstrated in Fig. 1 where we compare a "conventional" picture of parton spins with $f_v + f_s > 0$ with an EMC-inspired picture with $f_v + f_s = 0$.

It should be mentioned for the experimental program considered at this conference that we should not pay too much attention to the integrals over the parton spin distributions. An analysis of the full Altarelli Parisi equations shows that there is substantial structure in the $x$-dependent spin-weighted structure functions[8] driven by the large quark polarization at large $x$. It will take a long program of spin-related measurements to complete the picture of the proton's spin structure which is starting to emerge. At this point all we can say is that the picture is more interesting than we would have guessed.

## REFERENCES


1. G. Ramsey, J.-W. Qiu, D. Richards and D. Sivers, ANL-HEP-PR-88-16.
2. J. Ashman, *et al.* (EMC Collaboration).
3. M. Aquilar-Benitez *et al.* (Particle Data group), Phys. Lett. **170B**, 1 (1985).
4. J. Ellis and R. L. Jaffe, Phys. Lett. **193B**, 101 (1987).
5. M. Rho, A. S. Goldhaber, and G. E. Brown, Phys. Rev. Lett. **51**, 747 (1983).
6. S. Brodsky, J. Ellis and M. Karliner, M. Karliner, this conference.
7. J. Babcock, E. Monsay and D. Sivers, Phys. Rev. Lett. **40**, 1161 (1978); Phys. Rev. **D19**, 1483 (1979).
8. G. Ramsey, J.-W. Qiu, D. Richards and D. Sivers (in preparation).