RAPID COMMUNICATIONS

PHYSICAL REVIEW D

PARTICLES AND FIELDS

THIRD SERIES, VOLUME 47, NUMBER 1 — 1 JANUARY 1993

RAPID COMMUNICATIONS

Rapid Communications are intended for important new results which deserve accelerated publication, and are therefore given priority in editorial processing and production. A Rapid Communication in **Physical Review D** *should be no longer than five printed pages and must be accompanied by an abstract. Page proofs are sent to authors, but because of the accelerated schedule, publication is generally not delayed for receipt of corrections unless requested by the author.*

Quantitative estimate for single transverse spin asymmetry

A. Schäfer and L. Mankiewicz
Institut für Theoretische Physik, University of Frankfurt, Frankfurt, Germany

P. Gornicki and S. Güllenstern
Max-Planck-Institut für Kernphysik, Heidelberg, Germany
(Received 9 November 1992)

We discuss the probable size of a single-spin asymmetry in high-energy proton-proton collisions recently proposed by Qiu and Sterman. We derive an upper bound from estimating the contribution of the postulated coherent gluon field to the total energy carried by gluons. We conclude that the observable asymmetry should not exceed a few percent.

PACS number(s): 13.88.+e, 12.38.Bx, 12.38.Qk

The data from the European Muon Collaboration (EMC) on polarized muon-proton deep-inelastic scattering [1] has generated an enormous interest in the internal spin structure of the nucleons. Polarized reactions turned out to offer the possibility to study unsuppressed higher-twist effects and thus should in the future play a major role in the study of higher-order effects in QCD. Consequently a large number of new experiments are currently planned or under construction to study polarized lepton-hadron or hadron-hadron reactions [2]. The latter type of reactions offers a host of new possibilities but still requires intensive theoretical analyses. The main problem is that the expected asymmetries are usually very small, typically of the order of 1% or less.

In this situation a recent proposal by Qiu and Sterman [3] is most interesting, as it suggests a single-spin asymmetry of the order of 10–20%. Such large an effect could probably be easily measurable: e.g., by a modified HERMES setup. A measurement would require an unpolarized proton beam hitting a polarized target, which could be realized at the DESY *ep* collider HERA.

The asymmetry analyzed by Qiu and Sterman is linked to a coherent component of the gluon field in a nucleon, correlated with the nucleon spin. Clearly, to establish the existence of such a gluon component would be most relevant for the whole spin-structure discussion.

However, Qiu and Sterman (QS) stressed that their estimate is only a guess. In this contribution we present another estimate for this desirable effect, using a mean-field approximation. Unluckily we obtain a much smaller estimate for its size.

The quantity of interest derived by QS is

$$T(x,s_T)=\int \frac{dy_1^-}{4\pi} e^{ixp^+y_1^-} \langle p,s_T|\bar{\psi}(0)\gamma^+ \left[\int dy_2^- \epsilon_{\sigma\rho\alpha\beta}\, S_T^\sigma n^\alpha \bar{n}^\beta F^{a,\rho+}(y_2^-)\frac{\lambda^a}{2}\right]\psi(y_1^-)|p,s_T\rangle \ . \quad (1)$$

There is no rigorous way to determine the size of the matrix element. QS assumed that the color-octet matrix element is proportional to the color-singlet matrix element and thus to $F_2(x)$. This involves some kind of Abelian analogue to the full QCD process. We believe that their approximation is sensible as the y_1^- integration averages $F^{a,\rho+}$ over the whole proton and only the zero-momentum mean-field component should contribute. We try, however, to estimate more reliably the numerical coefficient with which $F_2(x)$ has to be multiplied. QS assume it to be Λ_{QCD}.

We propose the following quasiclassical estimate: The Abelian analogue $F^{a,\rho+} \to cF^{\rho+}$ gets only contributions from static color-magnetic and color-electric fields. With $\bar{n}^\mu = \delta_{\mu+}$ and $n^\mu = \delta_{\mu-}$ we can choose $S_T^\sigma = \delta_{\sigma 1}$. Then the term in parentheses in Eq. (1) is simply the expectation value of

$$\int dy_2^- F^{2+}(y_2^-) = \frac{1}{\sqrt{2}} \int dy_2^- [E^2(y_2^-) - B^1(y_2^-)] \; . \qquad (2)$$

As E^2 and B^1 are constant we get simply

$$I = c \int dy_2^- F^{2+}(y_2^-) = \frac{c}{\sqrt{2}}(E^2 - B^1)\frac{\sqrt{2}}{\pi\gamma R_p^2} \times \int_0^{R_p} dR \; 2\pi R \sqrt{R_p^2 - R^2} = c(E^2 - B^1)\frac{2R_p}{3\gamma} \; . \qquad (3)$$

Here R_p is the proton radius. We just performed the y_2^- integration for a Lorentz-contracted sphere. Next one has to estimate $E^2 - B^1$ in the infinite-momentum frame:

$$c^2 |E^2 - B^1|^2 \le 2c^2(\mathbf{E}^2 + \mathbf{B}^2) \sim 4\epsilon \frac{1}{2} \sum_a [(\mathbf{E}^a)^2 + (\mathbf{B}^a)^2] \qquad (4)$$

with a probably very small parameter ϵ. All quantities are defined in the infinite momentum frame, and ϵ is the ratio of the gluonic energy stored in the constant coherent spin-dependent gluon field relative to that of all gluon fields. Its precise estimate is controversial because it depends strongly on how one assumes the gluons to originate. One possible interpretation is, e.g., that most gluons are generated by Gribov-Lipatov-Altarelli-Parisi evolution. Of these only those generated by the polarized valence quarks can be correlated at all with the spin direction, and one would predict ϵ to be exceedingly small.

The opposite point of view assumes the existence of an intrinsic nonperturbative polarized gluon component. This possibility was discussed in connection with the gluonic contribution to $g_1(x)$. For the latter to give a measurable contribution, the gluons would have to carry a total of order $5\hbar$ (assuming that there is an anomalous contribution at all).

Let us stress that the mean field in (2) corresponds to the very small x part of the gluon contribution, weighted with x. To illustrate this point let us write somewhat symbolically

$$\epsilon = \frac{\int_0^X x \Delta G(x) dx}{\int_0^1 x G(x) dx} \; , \qquad (5)$$

where X is not well defined, but should be of the order $1/R_p p^0$. Luckily our argument does not depend on the precise value of ϵ and we treat it as a free parameter smaller than 10%.

The total gluonic energy is about half the nucleon energy

$$\frac{1}{2} \sum_a [(\mathbf{E}^a)^2 + (\mathbf{B}^a)^2] \frac{4\pi}{3} \frac{R_p^3}{\gamma} = \gamma 0.5 \text{ GeV} \; . \qquad (6)$$

Combining these two equations we get

$$cR_p |E^2 - B^1| \le \sqrt{\epsilon} \left[\frac{1.5 \text{ GeV}\gamma^2}{\pi R_p} \right]^{1/2} = \sqrt{\epsilon}\, \gamma 0.34 \text{ GeV} \; . \qquad (7)$$

This gives $I = \sqrt{\epsilon}\, 0.23$ GeV and, for T,

$$|T| \le F_1(x)\sqrt{\epsilon} \; 0.23 \text{ GeV} = \frac{F_2(x)}{x}(0.11 \text{ GeV})\sqrt{\epsilon} \qquad (8)$$

rather than $[F_2(x)/x]0.2$ GeV as suggested by Qiu and Sterman. However, it is still possible that the proposed asymmetry is due to a nonperturbative quark-gluon correlation rather than to a mean-field contribution; i.e., that keeping only the constant part of $F^{\rho+}$, as done by QS and us, is not a good approximation. Thus the proposed single-spin asymmetry should in any case be searched for experimentally, but one should aim such experiments at reaching a 1% sensitivity, which in our analyses corresponds to ϵ being of the order of 1%.

Let us finally note that from Eq. (2) we can try to determine the sign of the proposed asymmetry. In the proton rest frame any collective color-magnetic field should be parallel to the spin, as the quark color-magnetic moment is usually assumed to be positive. It is not clear what happens exactly during the boost into the infinite-momentum system where our arguments apply, but we would be surprised if **B** would change its sign. Thus we expect the asymmetry to be negative rather than positive.

A. S. thanks the MPI für Kernphysik for its support, and L. M. thanks the Alexander von Humboldt Foundation.

[1] EMC, J. Ashman *et al.*, Phys. Lett. B **206**, 364 (1988).
[2] *Polarized Collider Workshop,* University Park, PA, 1990, edited by J. Collins, S. Heppelman, and R. Robinett, AIP Conf. Proc. No. 223 (AIP, New York, 1990); G. Bunce *et al.*, Particle World **3**, 1 (1992).
[3] J. Qiu and G. Sterman, Phys. Rev. Lett. **67**, 2264 (1991).