QCD TESTS WITH POLARIZED BEAMS AT CBA

F. E. Paige and M. J. Tannenbaum
Brookhaven National Laboratory
Upton, New York 11973

March 1983

BNL--33119

DE03 014435

ABSTRACT

Searches for parity violating effects of
quark substructure and tests of spin dependence
predicted by QCD are discussed.

High luminosity polarized beams at CBA would allow several unique tests of QCD. They would provide a sensitive probe for any new, parity violating interaction among quarks, including in particular one resulting from quark substructure¹. They would also allow tests of the parity conserving spin asymmetries predicted by QCD². Such tests may be much less sensitive than unpolarized cross sections to higher order QCD corrections³.

A polarized beam is under construction at the AGS and is expected to be operational soon. If a 200 MeV accumulator ring were added, then existing polarized proton sources could produce enough intensity to obtain full luminosity in CBA⁴. Alternatively, a new atomic hydrogen source may be able to provide enough intensity without the accumulator⁵. It appears possible to use Siberian Snakes to keep the beams polarized and to rotate the polarizations to the desired direction at an intersection region⁶. However, the beam dynamics problems have not been studied in detail yet. A polarization of about 60% is expected.

Quark Substructure

One possible explanation of the several generations of quarks and leptons is that they are composites of more fundamental constituents. If so, then the exchange of these constituents will give rise to new interactions¹, and for energies small compared to the constituent scale, the effective interaction will have a point-like four-Fermi form. In general, it is expected to violate parity, since the left and right chiral fields are clearly independent even at the scale of m_q , but the structure of the interaction is of course model dependent.

The submitted manuscript has been authored under contract DE-AC02-76CH00016 with the U.S. Department of Energy. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency, contractor, or subcontractor thereof.

QCD TESTS WITH POLARIZED BEAMS AT CBA

F. E. Paige and M. J. Tannenbaum
Brookhaven National Laboratory
Upton, New York 11973

March 1983

ABSTRACT

Searches for parity violating effects of
quark substructure and tests of spin dependence
predicted by QCD are discussed.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

The submitted manuscript has been authored under contract DE-AC02-76CH00016 with the U.S. Department of Energy. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

NOTICE
PORTIONS OF THIS REPORT ARE ILLEGIBLE.

It has been reproduced from the best available copy to permit the broadest possible availability.

MASTER

High luminosity polarized beams at CBA would allow several unique tests of QCD. They would provide a sensitive probe for any new, parity violating interaction among quarks, including in particular one resulting from quark substructure¹. They would also allow tests of the parity conserving spin asymmetries predicted by QCD². Such tests may be much less sensitive than unpolarized cross sections to higher order QCD corrections³.

A polarized beam is under construction at the AGS and is expected to be operational soon. If a 200 MeV accumulator ring were added, then existing polarized proton sources could produce enough intensity to obtain full luminosity in CBA⁴. Alternatively, a new atomic hydrogen source may be able to provide enough intensity without the accumulator⁵. It appears possible to use Siberian Snakes to keep the beams polarized and to rotate the polarizations to the desired direction at an intersection region⁶. However, the beam dynamics problems have not been studied in detail yet. A polarization of about 60% is expected.

Quark Substructure

One possible explanation of the several generations of quarks and leptons is that they are composites of more fundamental constituents. If so, then the exchange of these constituents will give rise to new interactions¹, and for energies small compared to the constituent scale, the effective interaction will have a point-like four-Fermi form. In general, it is expected to violate parity, since the left and right chiral fields are clearly independent even at the scale of m_q , but the structure of the interaction is of course model dependent.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

EAB

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency, contractor, or subcontractor thereof.

Such a four-Fermi interaction will modify all of the familiar QCD predictions. In particular, it will lead to non-scaling terms in the QCD jet cross section with flatter p_T dependences than the usual ones. The effects of such terms are much larger than those resulting from a quark form factor with a similar mass scale.

Abolins et al.¹ have done detailed calculations for a particular choice of the effective interaction,

$$\mathcal{L} = A \frac{g^2}{\Lambda^2} \left\{ \frac{1}{2} (\bar{l}_L \gamma^\mu l_L) (\bar{l}_L \gamma_\mu l_L) + (\bar{l}_L \gamma^\mu l_L) (\bar{q}_L \gamma_\mu q_L) \right. \\ \left. + \frac{1}{2} (\bar{q}_L \gamma^\mu q_L) (\bar{q}_L \gamma_\mu q_L) \right\}$$

where they take $g^2/4\pi = 1$, defining the scale for Λ , and allow an arbitrary sign $A = \pm 1$. With their sign convention, $A = -1$ interferes constructively with W exchange. Assuming that a deviation by a factor of 2 from QCD predictions can be observed, they find that the TEVATRON Collider is sensitive to $\Lambda = 1.5$ TeV. CBA is less sensitive because the maximum observable p_T is smaller; for QCD jets the cross section is so large that the factor of 2.5 in energy overcomes the factor of 1000 in luminosity.

With polarized beams a parity violating difference of cross sections can be measured. Then the QCD contribution is zero, and the leading contribution comes from the interference of W and gluon exchange. All of the W and Z contributions to $\sigma_{--} - \sigma_{++}$ have been calculated previously⁷⁻⁸; as expected they are of order α/α_s of the total jet cross section at high p_T . For the maximally parity violating model of Abolins et al.¹ the spin dependent quark cross sections are given by

$$\hat{\sigma}_{--} = 4\hat{\sigma},$$

$$\hat{\sigma}_{-+} = \hat{\sigma}_{+-} = \hat{\sigma}_{++} = 0.$$

There are additional parity violating terms arising from the interference of W exchange and constituent exchange; these are presumably small and are ignored in what follows.

To relate the spin dependence for quarks to that for protons, spin dependent structure functions are needed. The simplest model is that the valence quarks satisfy the SU(6) relations⁹⁻⁸

$$u_{++}(x) = \frac{5}{6} u(x), \quad u_{-+}(x) = \frac{1}{6} u(x)$$

$$d_{++}(x) = \frac{1}{3} d(x), \quad d_{-+}(x) = \frac{2}{3} d(x)$$

where $q_{\lambda p}(x)$ is the probability of finding a quark q with momentum fraction x and helicity λ in a proton with helicity p . The sea quarks and gluons are assumed to be unpolarized. This model is roughly in agreement with the existing data on electron scattering from a polarized target. Other models, e.g. that of Carlitz and Kaur⁹, agree slightly better with the data at moderate x and predict larger polarizations at larger x . The SU(6) model will be used below to provide a conservative estimate of the spin asymmetry.

A better determination of the spin dependent structure functions would be needed to calculate the spin asymmetry from W exchange and to interpret any deviation from it. Ideally one would like to add an electron ring to CBA and to measure the charged and neutral current cross sections with polarized proton beams. Alternatively, one could measure the asymmetries for $W^\pm + e^\pm \nu$ and $Z^0 + e^\pm e^\mp$ as functions of

z. Since the asymmetries are large⁷ and the statistics are high, a good determination of the needed structure functions should be possible.

The calculated asymmetry in the single jet cross section for the SU(6) model is shown in Figs. 1-4 for $A = \pm 1$ and $\Lambda = 1$ and 2 TeV. For $\Delta\Omega = 10$ and $\Delta p_T = 10$ GeV a cross section of 10^{-12} nb/GeV/sr corresponds to 1000 events per year at the CBA design luminosity. Thus the statistical errors are small. Measurement of the asymmetry for $\Lambda = 1$ TeV looks rather easy, and even for $\Lambda = 2$ TeV it looks quite possible.

Since the ratio $(\sigma_{--} - \sigma_{++})/(\sigma_{--} + \sigma_{++})$ varies rather slowly with p_T , the measurement of it should not be very sensitive to errors in the p_T scale or in the definition of a jet. Most detector errors also cancel in this ratio. The only significant systematic error is likely to be that related to the reversal of the polarization. (If the polarization is not reversed exactly, then the mixture of helicity states is changed, and an asymmetry proportional to the parity conserving QCD spin dependence² is introduced.) Presumably the polarization can be reversed frequently by reversing adiabatically the currents in the Siberian Snakes. In the absence of a detailed design, the error arising from this procedure is difficult to assess, but it is probably small compared to the predicted asymmetry of order 5%. Certainly controlling the beam polarization seems easier than measuring the absolute jet cross section accurately. Of course the jet cross section is also sensitive to parity-conserving interactions, so both experiments should be done.

If accurate reversal of the polarization should prove difficult, it may be better to measure the asymmetry $(\sigma_{-} - \sigma_{+})/(\sigma_{-} + \sigma_{+})$ with only one beam polarized. Then the parity violating asymmetry is reduced by about a factor of two. However, the parity-conserving QCD interactions cannot depend on the helicity of a single beam. They can depend on the transverse polarizations, but this dependence is of order α^2/s because a gluon cannot flip the helicity of a massless quark. Also, any transverse polarization will be rotated by the Siberian Snake into a direction transverse to the field of the main magnets, so it will tend to average to zero rapidly¹⁰.

Spin Dependence

Since QCD is a complete field theory, it predicts the spin dependent as well as the spin averaged cross sections for quarks. The single spin asymmetries are of order α^2/s and so negligible at high p_T . (Presumably the large polarizations observed for Λ 's result from higher twist terms.) The spin-spin correlations have been calculated² and are of order 10% to 20%. Since they grow with x_T , a high luminosity machine capable of reaching large x_T is needed to study them.

Calculation of any of these spin dependent effects requires knowledge of the spin dependent structure functions. Thus no one measurement can test QCD. However, once the structure functions are determined, say from the asymmetries for W and Z production, then other measurements should provide good tests of QCD.

Such tests may actually be more reliable theoretically than those based on unpolarized cross sections. It is known that the next to

leading corrections to many QCD cross sections are large, of order a factor of two. These large corrections cancel for the spin asymmetry of the Drell-Yan cross section³, and a similar result is likely to hold for jets¹¹. If so, then measurement of such spin asymmetries may be the best experimental test of the quantitative correctness of perturbative QCD.

References

1. M. Abolins, et al., in DPF Workshop on High Energy Physics and Future Facilities (Snowmass, Co., 1982).
2. J. Babcock, E. Mondsday, and D. Sivers, Phys. Rev. D19, 1483 (1979).
3. P. Ratcliffe, SISSA, Trieste preprint ISAS 24/82/EP;
N. Graigie, Trieste preprint IC/82/207.
4. L. S. Smith, et al., BNL preprint (in preparation).
5. D. Kleppner, in Symposium on High Energy Spin Physics (BNL, 1982).
6. E. Courant, *ibid*.
7. F. E. Paige, T. L. Tsueman, and T. N. Todoron, Phys. Rev. D19, 935 (1979).
8. F. E. Paige, in Workshop on the Production of New Particles (Madison, WI, 1979).
9. R. Carlitz and J. Kaur, Phys. Rev. Letters 38, 673 (1977).
10. G. Bunce, private communication.
11. T. Appelquist, private communication.

Figure Captions

Fig. 1: Jet cross sections for $A = -1$, $\Lambda = 1$ TeV.

Solid curve: Unpolarized cross section with no substructure.

Dotted curve: unpolarized cross section with substructure.

Dashed curve: Spin asymmetry $\sigma_{--} - \sigma_{++}$ with no substructure.

Dash-dot curve: Spin asymmetry with substructure.

Fig. 2: Same as Fig. 1 but for $A = +1$, $\Lambda = 1$ TeV. Note that

$\sigma_{--} - \sigma_{++}$ with substructure is negative for $p_T > 50$ GeV.

Fig. 3: Same as Fig. 1 but for $A = -1$, $\Lambda = 2$ TeV.

Fig. 4: Same as Fig. 1 but for $A = +1$, $\Lambda = 2$ TeV. Note that

$\sigma_{--} - \sigma_{++}$ with substructure is negative for $p_T > 120$ GeV.

Fig. 1

Fig. 2

Fig. 3

Fig. 4