JAN 23 1991

SPIN OBSERVABLES FOR NUCLEON-NUCLEON ELASTIC SCATTERING AT LARGE MOMENTUM TRANSFER.

GORDON P. RAMSEY

Physics Department, Loyola University Chicago, Chicago, IL 60626
and

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

Abstract

We discuss amplitudes for elastic nucleon-nucleon scattering at high energy. The helicity-conserving amplitudes are modeled using a combination of the quark-interchange and the Landshoff mechanisms of perturbative QCD. The relative normalization of these two sets of amplitudes involves a "leading order form factor" which we determine empirically. Our theoretically motivated amplitudes provide an economical description of a large body of existing data and make nontrivial predictions for spin observables.

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.

MASTER

* Contributed paper for the 9th International Symposium on High Energy Spin Physics; Bonn, Germany; September, 1990. Work supported in part by the U.S. Department of Energy, Division of High Energy Physics, Contract W-31-109-ENG-38 and Loyola University research support grant.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

A serious challenge to QCD is to explain the behavior of elastic scattering nucleon-nucleon asymmetries at large p_T . If we consider a kinematic regime at fixed angles and high energies [$-t, s \rightarrow \infty, (-t/s)$ fixed] where QCD perturbation theory is valid, the hadronic amplitudes and elastic scattering observables can be calculated. Although there are challenges to this approach¹, a careful analysis in the appropriate kinematic regime with the possible introduction of non-perturbative parameters, could enhance the predictive power of QCD. At this time, there is experimental motivation to pursue this attempt at understanding of elastic nucleon-nucleon scattering. With the present polarized beam technology, it is possible to make accurate measurements of elastic processes such as $pp \rightarrow pp$ over a wide regime of kinematic observables.

Large momentum transfer exclusive reactions are assumed to be dominated by short distance quark-gluon subprocesses in perturbative QCD. For $pp \rightarrow pp$ scattering, there is a fixed-angle region where the energy dependence of the cross section is given by the counting rules of perturbative QCD, namely: $\frac{d\sigma}{dt} \sim s^{-10}$. However, Landshoff² has pointed out that there are diagrams in which one cannot assume that the hard scattering takes place over a small region. These diagrams lead to a cross section having an energy dependence given by $\frac{d\sigma}{dt} \sim s^{-8}$. The Landshoff terms are believed to be suppressed by soft gluon contributions related to the QCD Sudakov form factor.³ However the data on A_{nn} for elastic pp scattering seem to indicate that there may exist an energy dependent phase which may cause the Landshoff amplitude to dominate at high energies and fixed angles. This motivates a model where the helicity conserving amplitudes are a combination of the QCD and Landshoff amplitudes, such that the relative normalization factor between the two types is fixed at large energies and fixed angles. This relative normalization takes the form of a complex energy dependent phase, whose value is determined from the elastic scattering data. This fixed phase approach differs from Ralston and Pire⁴, who assume that there is an oscillating phase normalization in the differential cross section. One advantage of a relative phase approach with fixed normalization is that it requires no resonances to explain the data, as in other models.⁵

We make the assumption that the spin amplitudes $\Phi_2(s, z)$ and $\Phi_5(s, z)$ are negligible for both the Quark-interchange-model (QIM), based on QCD counting rules, and the Landshoff model. The center of mass scattering angle enters the amplitudes via the term $z \equiv \cos \theta_{c.m.}$.

The QIM amplitudes can then be written for fixed s as

$$\begin{aligned} s^4 \Phi_1^Q(z) &= 16 \left[\frac{(1+z^2)}{(1-z^2)^3} \right] Q(s, z) \\ s^4 \Phi_3^Q(z) &= 8 \left[\frac{(1+z^2) - \frac{6}{31}z}{(1-z^2)^3} \right] Q(s, z) \\ s^4 \Phi_4^Q(z) &= -8 \left[\frac{(1+z^2) + \frac{6}{31}z}{(1-z^2)^3} \right] Q(s, z). \end{aligned} \tag{1}$$

The corresponding Landshoff amplitudes are given by

$$\begin{aligned}
s^3 \Phi_1^L(s, z) &= 4L(t) \left[\frac{2 + (1+z)^2}{(1-z)^3} \right] + 4L(u) \left[\frac{2 + (1-z)^2}{(1+z)^3} \right] \\
s^3 \Phi_2^L(s, z) &= L(t) \left[\frac{(1+z)^3 + 8(1+z)}{(1-z)^3} \right] \\
s^3 \Phi_4^L(s, z) &= -L(u) \left[\frac{(1-z)^3 + 8(1-z)}{(1+z)^3} \right],
\end{aligned} \tag{2}$$

where $Q(s, z)$ and $L(t, u)$ are unknown normalization factors. Our energy-dependent phase, representing the relative normalization of the QIM and Landshoff amplitudes can be introduced by assigning

$$a(s, z) \equiv \frac{L(t)}{Q(s, z)} = \frac{c}{s} (-s)^{\gamma(z)}, \tag{3}$$

where $\gamma(z) = 0.75z + 0.25$ and c is a complex number. For the $L(u)$ factor in the crossed channel, we replace $a(s, z)$ with $a(s, -z)$. This approach is consistent with an optical interpretation of the subtraction procedure discussed by Botts and Sterman.⁶

For the hard scattering region, where Regge contributions are negligible, we can write each of the spin amplitudes at fixed s as $\phi_i(z) = \Phi_i^Q(z) + a(s_0, \pm z)\Phi_i^L(z)$. The spin-spin asymmetry observables can be written in terms of these amplitudes as⁷

$$\begin{aligned}
\sigma A_{ss} &= \text{Re}(\phi_3 \phi_4^*) = -\sigma A_{nn} \\
\sigma A_{ll} &= \frac{1}{2}(-|\phi_1|^2 + |\phi_3|^2 + |\phi_4|^2) \\
\sigma &= \frac{1}{2}(|\phi_1|^2 + |\phi_3|^2 + |\phi_4|^2),
\end{aligned} \tag{4}$$

where σ is the total cross section for polarized NN scattering. The phase relation given by equation (3) can be specified by comparing the spin observables with data at $z = 0$. The phases $a(t)$ and $a(u)$ are identical at $z = 0$ and motivate the definition of a phase $\delta(z = 0) \equiv sa(s) = cs^{0.25}$. All of the spin observables at $z = 0$ can be written in terms of this phase factor. The fact that $\delta\delta^*$ is real restricts the values that the phase δ and each of the spin observables can have. By selecting the phase, δ from A_{nn} data at $z = 0$, for example, we can specify all of the spin observables. The range of allowable δ values gives a corresponding range of predictions for the spin asymmetries. To illustrate this, we combine equations (1) through (4) for A_{nn} to obtain:

$$A_{nn} = \frac{[64 + 144(\text{Re}\delta) + 81(\delta\delta^*)]}{3[64 + 176(\text{Re}\delta) + 123(\delta\delta^*)]}. \tag{5}$$

For certain values of A_{nn} at $z = 0$ we plot the contours of allowed phases in figure 1. This can be done for any of the spin observables, such as the ratio of np and pp cross sections: $R \equiv [\sigma(np)/\sigma(pp)]$. We show the possible contours for the phase δ in figure 2, given possible values of R at $z = 0$. Once the phase is chosen, we can plot the observables as a function of the center of mass energy, $\sqrt{s}$ or angle θ_{cm} . Figures 3 and 4 show these plots for A_{nn} .

The general behavior of A_{nn} in these figures is close to that of the available data.⁸ Scaling deviations from the actual data are dependent on the actual parametrization of $\gamma(z)$ in equation (3). We are working on alternate forms for $\gamma(z)$ to more closely match the data. Once this is done, similar predictions can be made for the other spin observables. Future work will also include analysis of the effects of ϕ_2 and ϕ_5 on the spin observables, which we have taken here to be negligible.

Acknowledgement

This is a summary of work done in collaboration with D. Sivers of Argonne.

Figure Captions

1. A_{nn} contours at $z = 0$, representing the allowed values of the phase, δ . The left solid contour represents $A_{nn} = 0.2$. The remaining contours are values of A_{nn} from 0.3 through 0.6. The contours decrease in size as A_{nn} increases.
2. R contours at $z = 0$, showing the allowed values of the phase δ . The outer contour represents $R = 0.4$, the middle $R = 0.5$ and the inner $R = 0.6$.
3. A_{nn} is plotted vs $\sqrt{s}$ at $z = 0$. The dot-dashed line represents a value of $A_{nn} = 0.5$ at $\sqrt{s} = 4.0$ while the solid line corresponds to $A_{nn} = 0.6$ at the same $\sqrt{s}$.
4. A_{nn} vs $\cos(\theta_{cm})$ for $\sqrt{s} = 4.0$ GeV.

References

1. N. Isgur and C. H. Llewellyn-Smith, Nucl. Phys. B317, 526 (1989)
2. P. Landshoff, Phys. Rev. D10, 1024 (1974); P. Landshoff and D. Pritchard, Z. Phys. C 6, 69 (1980).
3. J. Polkinghorne, Phys. Lett 49B, 277 (1974); A. H. Mueller, Phys. Rep. 73, 237 (1981).
4. J. P. Ralston and B. Pire, Phys. Rev. Lett. 61, 1823 (1988).
5. S. J. Brodsky and G. F. de Teramond, Phys. Rev. Lett. 60, 1924 (1988).
6. J. Botts and G. Sterman, Proceedings of the International Conference on Elastic and Diffractive Scattering, Eds. M. Block and A. White, Nucl. Phys. B12 (Proc. Suppl.), 53 (1990).
7. G. R. Farrar, S. Gottlieb, D. Sivers and G. H. Thomas, Phys. Rev. D20, 202 (1979).
8. S. J. Brodsky, SLAC-PUB-5116, 49 (1989).

Figure 1

Figure 2

Figure 3

Figure 4

END

DATE FILMED

02 / 01 / 91