ANL-HEP-CP-93-02

Fermilab Library
0 1160 0022824 1

This submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. 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.

ANL-HEP-CP-93-02
January 11, 1993

SPIN OBSERVABLES IN LARGE t ELASTIC N-N SCATTERING *

Gordon P. Ramsey
Physics Department
Loyola University Chicago
Chicago, IL 60626
and
High Energy Physics Division
Argonne National Laboratory
Argonne, IL 60439

FERMILAB LIBRARY MAR 09 1993

Abstract

We present model amplitudes for pp→pp elastic scattering in the intermediate hard scattering kinematic regime: $m_p^2 \ll |t| \ll s$, and apply them to the calculation of spin observables. In this region, the t-dependent Landshoff amplitudes have a significant contribution to the spin observables. Helicity non-conserving effects may also play a major role in this regime. Specific QCD motivated predictions for the spin observables can be tested at polarized proton beam facilities. A program is suggested for elastic polarized proton scattering experiments in this kinematic region, which can be used to test the foundations of exclusive QCD.

*To be published in the Proceedings of the 10th International Symposium on High Energy Spin Physics, Nagoya, Japan, November 9-14, 1992. Work supported by the U.S. Department of Energy, Division of High Energy Physics, Contract W-31-109-ENG-38.

I. Introduction

In recent papers[1], we presented model amplitudes for elastic $pp \to pp$ scattering, which were based on ideas from perturbative QCD. These amplitudes were constructed to address a set of phenomenological questions[2,3] concerning the application of perturbative QCD to exclusive processes at energies and scattering angles where data show dramatic structure in spin observables. The helicity-conserving amplitudes consist of two parts: (1) QIM amplitudes[4] which coincide with an "effective amplitude" approximation to a class of diagrams involving quark interchange between the nucleons, and (2) Landshoff[5] amplitudes, which correspond to independent quark scatterings involving three-gluon exchange in either the t or u channel. Within each type of mechanism, the relative normalization of the different helicity amplitudes is determined by simple combinatoric arguments. However, the model contains an unknown normalization factor which, in principle, can be calculated. Present data imply that it is important to go beyond the specification of "leading-twist" amplitudes[6] and include the possibility of helicity non-conserving effects associated with the Landshoff mechanism. In our model, these considerations are incorporated naturally.

The dramatic structure in A_{NN} at $p_{lab} \leq 12$ GeV/c can be described by an interference between the Landshoff amplitudes and the QIM amplitudes. There is evidence that there exists a kinematic regime where the amplitudes for elastic scattering are dominated by the Landshoff mechanism.[7] To test the premises of our model, we will examine its predictions for spin observables at higher energies. Although there is a steep power law decrease of the cross sections with energy at fixed angle, large polarized beam luminosities may make it possible to do elastic spin measurements in the large $|t|$, small angle region, $m_p^2 \ll |t| \ll s$, which interpolates between the Regge and the large angle scattering regime. The use of Siberian snakes to preserve polarization in high energy accelerators makes it possible to obtain high luminosity polarized beams in pp colliders such as Fermilab, RHIC, UNK and the SSC.[8] Measurements of elastic scattering spin observables at large $|t|$ and small angles using these facilities can provide a wide range of information concerning the elastic scattering mechanism and the possible application of exclusive QCD. The phenomenology of Donnachie and Landshoff[9] indicates that this kinematic region is dominated by the Landshoff mechanism. This contention is supported by the estimates of Botts[7] and is built in to our original model amplitudes[1], which we extend to high energies here.

II. Formulation of the Helicity Amplitudes

It is convenient to reformulate our model[1] so that it emphasizes the dominance of the Landshoff contributions. We define the kinematic region of interest in terms of the variable $\eta \equiv [(2m_p^2 - t)/s]$. In this region, $\theta_{c.m.} \approx 2\eta^{\frac{1}{2}}$. For the Landshoff amplitudes, Φ_i^L, we assume that the contributions involving $L(u)$ can be neglected because of the Sudhakov suppression of the "backward scattering" contributions. The QIM amplitudes, Φ_i^Q, can be simplified for use in the small angle regime by systematically neglecting corrections of $O(\frac{m_p^2}{s})$. This gives

$$
\begin{aligned}
\Phi_1^L &\simeq L(t)(2m_p^2 - t)^{-3}\left[1 + 2(1-\eta)^2\right] \\
\Phi_3^L &\simeq L(t)(2m_p^2 - t)^{-3}(1-\eta)\left[2 + (1-\eta)^2\right] \\
\Phi_4^L &\simeq 0 \\
\Phi_1^Q &\simeq \frac{1}{4}Q(t,\eta)s^{-4}\left[\frac{31(1-2\eta+2\eta^2)}{\eta^3(1-\eta)^3}\right] + O(\frac{m_p^2}{s}) \\
\Phi_3^Q &\simeq \frac{1}{4}Q(t,\eta)s^{-4}\left[\frac{17\eta^2+14(1-\eta)^2}{\eta^3(1-\eta)^3}\right] + O(\frac{m_p^2}{s}) \\
\Phi_4^Q &\simeq -\frac{1}{4}Q(t,\eta)s^{-4}\left[\frac{14\eta^2+17(1-\eta)^2}{\eta^3(1-\eta)^3}\right] + O(\frac{m_p^2}{s}).
\end{aligned}
\tag{1}
$$

The relative normalization of the Landshoff and QIM amplitudes has to be determined phenomenologically. Here, we define the ratio of normalization factors as $\alpha(t,\eta) \equiv \frac{Q(t,\eta)}{2L(t)(1-\eta)}$, so that we can write the overall helicity-conserving amplitudes in the small η kinematic region as

$$
\begin{aligned}
\Phi_1 &= L(t)(2m_p^2 - t)^{-3}[3 - 4\eta + \frac{31}{4}\alpha(t,\eta) + \cdots] \\
\Phi_3 &= L(t)(2m_p^2 - t)^{-3}[3 - 5\eta + \frac{14}{4}\alpha(t,\eta) + \cdots] \\
\Phi_4 &= L(t)(2m_p^2 - t)^{-3}[-\frac{17}{4}\alpha(t,\eta) + \cdots].
\end{aligned}
\tag{2}
$$

Note that the shape of the differential cross section will depend on $L(t)$ but that this function now appears as an overall factor, which will cancel in the calculation of the spin asymmetries we consider here. In writing these amplitudes, we assume that $Q(t,\eta)$ and $L(t)$ are well

behaved so that $\alpha(t,\eta) \to 0$ as $\eta \to 0$. We have systematically neglected terms of $O(\eta^2)$ and $O(\alpha\eta)$, which we have numerically shown to be negligible in each kinematic region.

It is important to consider helicity non-conserving amplitudes in order to have a complete treatment of spin observables and to address the experimental evidence that the polarizaton P does not vanish. We associate helicity non-conservation with hadronic corrections to asymptotic collinearity of the constituents. We do not know, a priori, the form of the non-conserving amplitudes. Thus, we make an ansats based on parity and time reversal invariance for $pp \to pp$ of the form: (neglecting $u-$ channel contributions) $\Phi_5 \equiv f(t)[\Phi_1 + \Phi_3 + \Phi_4]$ and $\Phi_2 \equiv \frac{1}{2}f(t)\Phi_5$, where $f(t)$ is a complex factor measuring the degree of helicity non-conservation.

Thus, our model is defined by considering two types of "small" corrections to the simple Landshoff mechanism. Quark interchange (QIM) corrections are associated with the parameter $\alpha(t,\eta)$ and hadron helicity-flip corrections with $f(t)$. The relative sizes of $\alpha(t,\eta)$ and $f(t)$ depend on complicated unknown dynamics involving the interplay of constituent and wave function effects, which are not well understood. In view of the possible complexity of this interplay, it is important to have experimental input. The measurement of spin observables in the small-angle region can be very instructive.

III. Specification of the Spin Observables

In terms of the helicity amplitudes, the spin observables are written as

$$
\begin{aligned}
\sigma &= \frac{1}{2}[|\Phi_1|^2 + |\Phi_2|^2 + |\Phi_3|^2 + |\Phi_4|^2 + 4|\Phi_5|^2] \\
\sigma P &= -Im[(\Phi_1 + \Phi_2 + \Phi_3 - \Phi_4)\Phi_5^*] \\
\sigma A_{NN} &= Re[\Phi_1\Phi_2^* - \Phi_3\Phi_4^* + 2|\Phi_5|^2] \\
\sigma A_{LL} &= \frac{1}{2}[-|\Phi_1|^2 - |\Phi_2|^2 + |\Phi_3|^2 + |\Phi_4|^2] \\
\sigma A_{SS} &= Re[\Phi_1\Phi_2^* + \Phi_3\Phi_4^*] \\
\sigma A_{SL} &= Re[(\Phi_1 + \Phi_2 - \Phi_3 + \Phi_4)\Phi_5^*].
\end{aligned}
\tag{3}
$$

We wish to examine the dependence of these observables on $\alpha(t,\eta)$, which determines the relative strength of the QIM amplitudes and $f(t)$, which measures the contribution of the helicity non-conserving amplitudes.

The Landshoff Dominant Kinematic Region

We first consider the region where $-t$ is fixed and s is large enough so that $\alpha \to 0$ and $\eta \approx | f | \gg | \alpha |$. Here, the spin amplitudes reflect the structure of the Landshoff multiple scattering mechanism. The amplitudes Φ_1 and Φ_3 are approximately s -independent. The helicity non-conserving amplitudes Φ_5 should be small compared with Φ_1 and Φ_3, but should also be s-independent, while Φ_4 will vanish as $\alpha \to 0$. The amplitude Φ_2 involves two helicity non-conserving "vertices" and should be further suppressed. In this limit, we can write the spin observables in the form:

$$
\begin{aligned}
P &\approx -4(Im\, f) \\
A_{NN} &\approx 9\,|\, f\,|^2 - 2(Im\, f)^2 \approx 9A_{SS} \\
A_{LL} &\approx -\frac{1}{3}\eta - \frac{1}{2}\eta^2 \\
A_{SL} &\approx \frac{2}{3}\eta\,(Re\, f).
\end{aligned}
\tag{4}
$$

From our model assumptions, P, A_{NN} and A_{SS} should be almost independent of η. In this limit, these observables depend only on the magnitude of the helicity-flip form factor, $f(t)$. In contrast, A_{LL} is not sensitive to the effects of helicity non-conserving corrections and has a well defined functional dependence on η, which reflects the spin structure of the individual quark scatterings in the Landshoff mechanism. Figure 1 shows the f dependence of A_{NN}, P and A_{SL}. Observe that simultaneous measurements of P and A_{SL} could be used to determine $Im\, f$ and $Re\, f$. Then, since A_{NN} and A_{SS} are insensitive to the ratio $Im(f)/Re(f)$, their measurements would then be nontrivial checks of the underlying assumptions. The existence of this pure "hard-scattering" regime where "Regge" effects are negligible provides a good region to check the effects of the independent scattering mechanism proposed by Landshoff and allows us to explore the form of the helicity-flip mechanism.

The Interference Region

There is also a possible "interference" region where η, α and f are all small and of comparable magnitude. The spin observables can all have considerable structure in this region. Expanding the amplitudes by keeping terms which are bilinear in the small variables,

we have

$$
\begin{aligned}
P &\approx \frac{51}{9}(Re\, f)(Im\, \alpha) - 4(Im\, f) \\
A_{NN} &\approx \frac{119}{72}\,|\,\alpha\,|^2 + \frac{51}{36}Re\,\alpha - \frac{765}{144}(Re\,\alpha)^2 - \frac{85}{36}\eta(Re\,\alpha) + 9\,|\,f\,|^2 - 2(Im\, f)^2 \\
A_{LL} &\approx -\frac{119}{72}\,|\,\alpha\,|^2 - \frac{17}{12}Re\,\alpha + \frac{153}{32}(Re\,\alpha)^2 - \frac{13}{8}\eta(Re\,\alpha) - \frac{1}{2}\eta^2 - \frac{1}{3}\eta \\
&\quad + \frac{3}{8}\eta\,(Re\, f + Im\, f) \\
A_{SS} &\approx -A_{NN} - 4(Im\, f)^2 + 9\,|\,f\,|^2 \\
A_{SL} &\approx \frac{2}{3}\eta(Re\, f).
\end{aligned}
\tag{5}
$$

Since these observables involve two unknown functions, $\alpha(t,\eta)$ and $f(t)$, we will only attempt to point out some regularities which can help us understand the dynamics. The sum $A_{NN} + A_{SS}$ does not depend on the QIM amplitudes to this order in α, so that this is a good measure of the existence of a helicity non-conserving structure. In contrast, A_{LL} has little dependence on f, but is sensitive to the Landshoff-QIM interference. In addition, since most of the α dependence cancels in the sum: $A_{NN} + A_{LL}$, this quantity serves as a cross check to the assumptions about the helicity non-conserving nature of the amplitudes in this region. The individual asymmetries A_{NN}, A_{LL} and A_{SS} are all influenced by both the Landshoff/QIM interference and the helicity non-conserving term in this region. By making simultaneous measurements of the asymmetries, their dependence on these parameters can be investigated. Figure 2 shows the dependence of A_{NN} on α. Figure 3 shows the f dependence of $A_{NN}+A_{LL}$, which is insensitive to the imaginary part of f. The sensitivity of A_{SL} to $Re(f)$ for given η theoretically makes it a good candidate for studying $Re(f)$, but its small values may be experimentally prohibitive to take advantage of this fact. The polarization P can potentially be large and its sign should provide a good indication of the sign and magnitude of $f(t)$, as shown in figure 4. It is desirable to measure P with good precision in this region to determine the effects of both the interference term and the helicity non-conserving amplitudes. Clearly, our model indicates that both the QIM/Landshoff interference term and the helicity non-conserving effects can be studied thoroughly by experiments in this kinematic region. Thus, it is particularly valuable to make simultaneous measurements of all the spin observables.

The Hadronic Helicity Conserving Region

If we explore measurements of spin observables for very large s at fixed angle (η), there is a possibility of reaching large enough $-t$ to neglect the helicity-flip effects. This may be the appropriate kinematic limit to check the speculation of Ralston and Pire[6] that hadronic helicity conservation need not be a property of Landshoff-type amplitudes. The interference term α is assumed dominant over η and f in this region. We keep terms linear in f, but neglect the η terms. The corresponding spin observables can be written as

$$
\begin{aligned}
P &\approx \frac{51}{9}(Re\, f)(Im\, \alpha) - 4(Im\, f) \\
A_{NN} &\approx \frac{119}{72}\,|\,\alpha\,|^2 + \frac{51}{36} Re\, \alpha - \frac{765}{144}(Re\, \alpha)^2 \\
A_{LL} &\approx A_{SS} \approx -A_{NN} \\
A_{SL} &\approx 0.
\end{aligned}
\tag{6}
$$

In this region, as the QIM-Landshoff interference becomes more dominant, the observables A_{NN}, A_{LL} and A_{SS} become approximately equal in magnitude and sensitive to the value of α. In particular, figure 5 shows the sensitivity of A_{NN} to the ratio $Im(\alpha)/Re(\alpha)$. The polarization P is likely small, due to its dependence on f, but if it is detectable, it could be highly sensitive to $Im(\alpha)$. Thus measurements of the asymmetries to a high precision could give complete information about the interference of the Landshoff and QIM amplitudes in this region.

IV. Conclusion

By investigating QIM-type amplitudes and hadronic helicity-flip as "corrections" to a Landshoff independent quark scattering mechanism, we have studied what could be learned by elastic scattering measurements involving polarized protons at large $|\,t\,|$ and small $|\,t/s\,|$. Even if current data on A_{NN} are explained by a low energy mechanism,[10] newly proposed experiments[11] can provide access to a domain of exclusive QCD. Figure 6 shows the possible kinematic regions accessible by experiments at Fermilab, UNK, RHIC (Brookhaven) and the SSC. The lower energy accelerators can concentrate on the fixed $|\,t\,| \geq 5$ GeV/c (Landshoff) and fixed small angle (η) with larger $|\,t\,|$ regions, while the larger energy experiments can investigate the regions discussed above at all $|\,t\,|$. A comprehensive experimental program involving polarized beams at various accelerators, can measure all of the elastic pp asymmetries in these kinematic regions. Such a program would shed light on the appliciability of QCD to exclusive processes and would make it possible to study helicity non-conserving dynamics and quark-interchange dynamics in a meaningful way.

References

1. G. P. Ramsey and D. Sivers, Phys. Rev. **D45**, 79 (1992) and ANL-HEP-PR-92-75, to be published in Phys. Rev. D.
2. N. Isgur and C.H. Llewellyn-Smith, Phys. Rev. Lett. **52**, 1080 (1984).
3. S. Brodsky and G.P. Lepage, Phys. Rev. **D22**, 2175 (1980) and S. Brodsky, et.al., Phys. Lett. **91B**, 239 (1980).
4. G. Farrar, S. Gottlieb, D. Sivers and G. Thomas, Phys. Rev. **D20**, 20 2 (1979) and S.J. Brodsky, C.E. Carlson and H.J. Lipkin, Phys. Rev. **D20**, 2278 (1979).
5. P. Landshoff, Phys. Rev. **D10**, 1024 (1974) and P. Landshoff and D. Pritchard, Z. Phys. **C6**, 69 (1980).
6. J.P. Ralston and B. Pire, U. Kansas preprint 5-15-92.
7. J. Botts, Nucl. Phys. **B353**, 20 (1991) and Phys. Rev. **D44**, 2768 (1991).
8. See, for example, the discussion of S.Y. Lee in "Polarized Collider Workshop", (John Collins, Steve Heppelman and Richard Robinett, eds., AIP Conference Proceedings, Particles and Fields, no. 42, AIP, NY.)
9. A. Donnachie and P. V. Landshoff, Z. Phys. **C2**, 55 (1979); Phys. Lett. **123B**, 345 (1983); Nucl. Phys. **B231**, 189 (1983), **B244**, 322 (1984), **B267**, 690 (1986).
10. S.J. Brodsky and G. deTeramond, Phys. Rev. Lett. **60**, 1924 (1988).
11. A. Krisch, et.al., A proposal for Polarized beams at Fermilab, March, 1992; and S. Nurushev, IHEP preprint 91-103, Protvino, Russia.

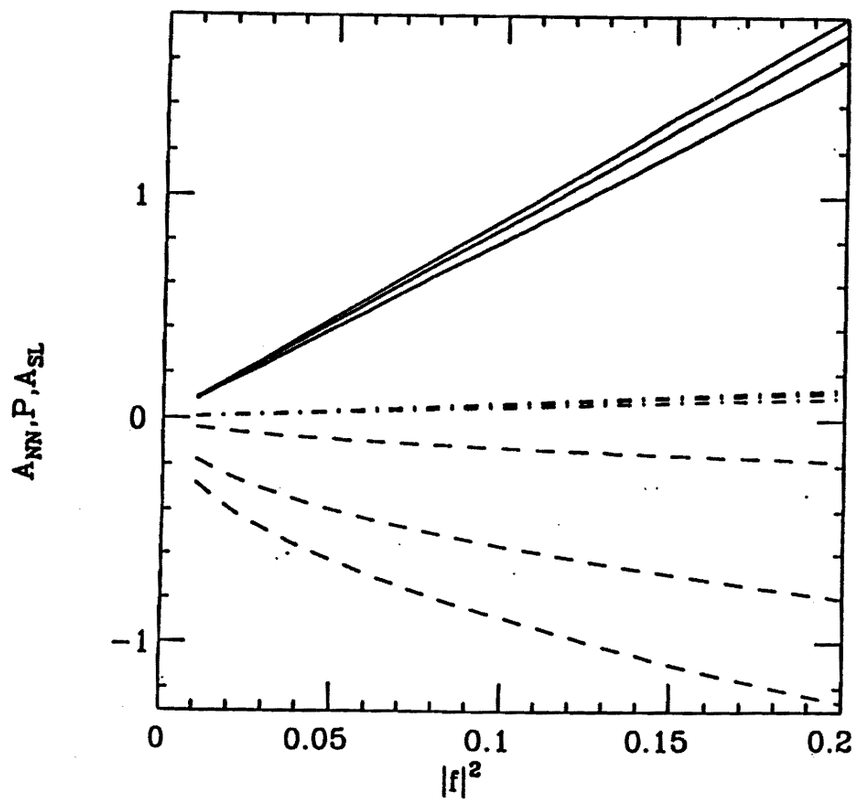

Figure 1. The observables A_{NN} (solid), P (dashes) and A_{SL} (dot-dash) as a function of $|f|^2$ in the Landshoff Region. In each case, the three curves, upper to lower, correspond to the ratio $Im(f)/Re(f) = 0.1$, 0.5 and 1.0 respectively.

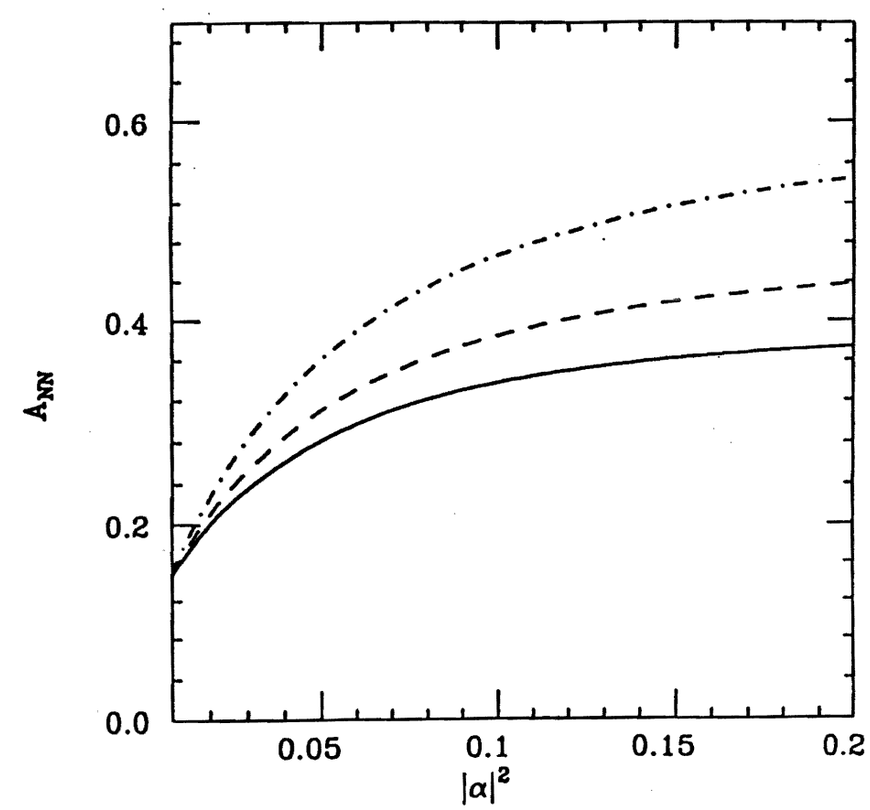

Figure 2. The asymmetry A_{NN} as a function of $|\alpha|^2$ in the interference region. The three curves, lower to upper, correspond to the values of $Im(\alpha)/Re(\alpha)$ to be 0.1, 0.5 and 1.0 respectively. It is assumed here that $|f|^2 \approx |\alpha|^2 \approx \eta^2$ for all figures in this region.

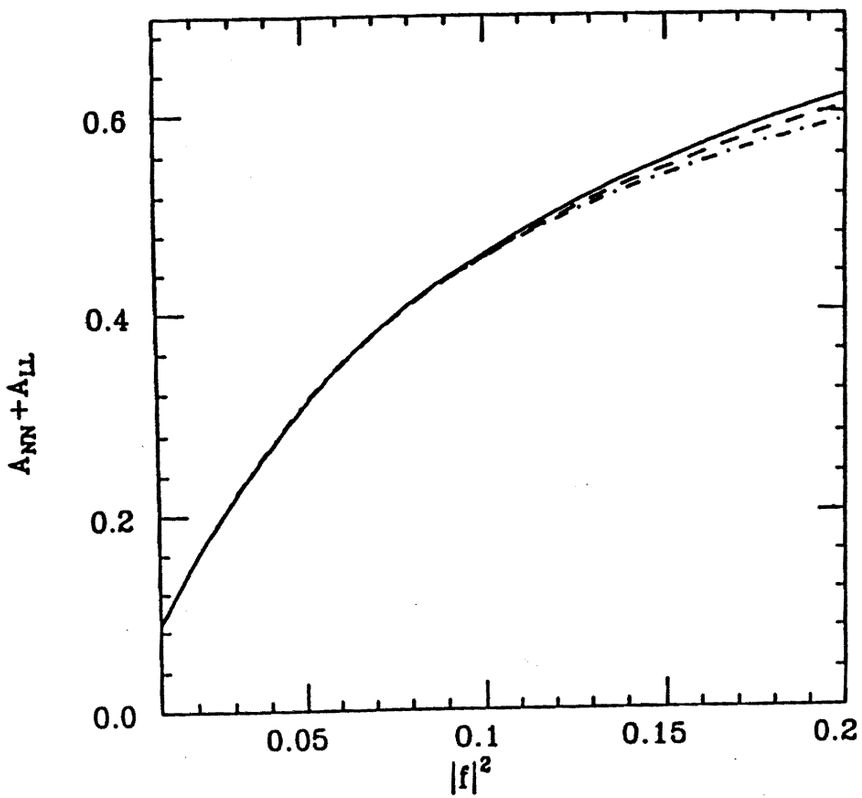

Figure 3. The linear combination, $A_{NN} + A_{LL}$ is shown as a function of $|f|^2$ in the interference region. The three curves, upper to lower, correspond to values of $Im(f)/Re(f)$ to be 0.1, 0.5 and 1.0 respectively.

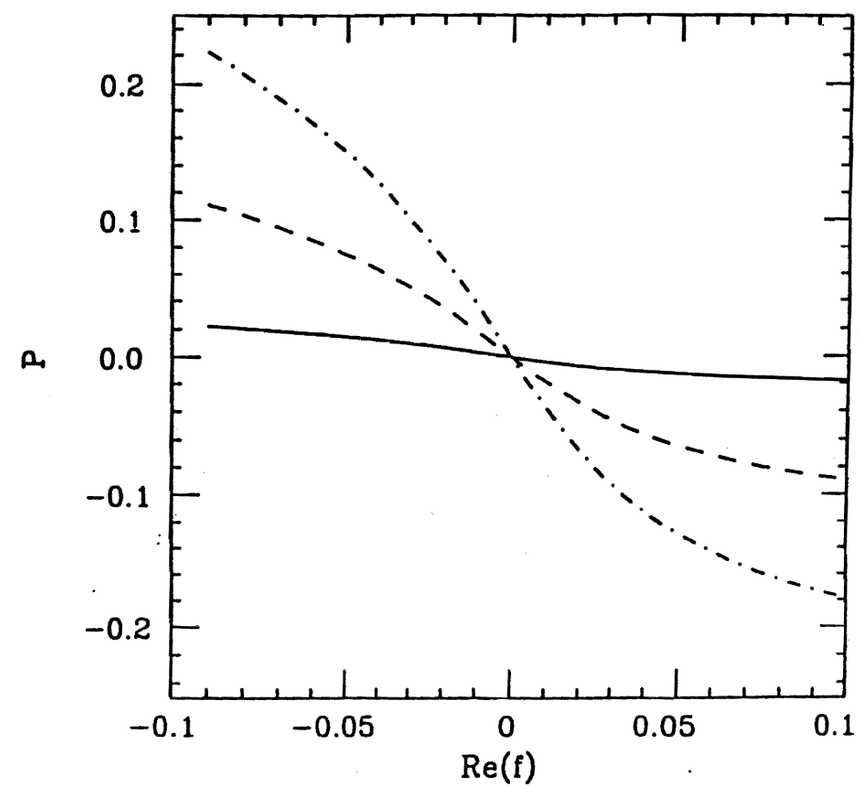

Figure 4. The polarization P plotted as a function of $Re(f)$ in the interference region. The three curves correspond to $Im(f)/Re(f) = 0.1$, (solid) 0.5, (dashes) and 1.0 (dot-dashed).

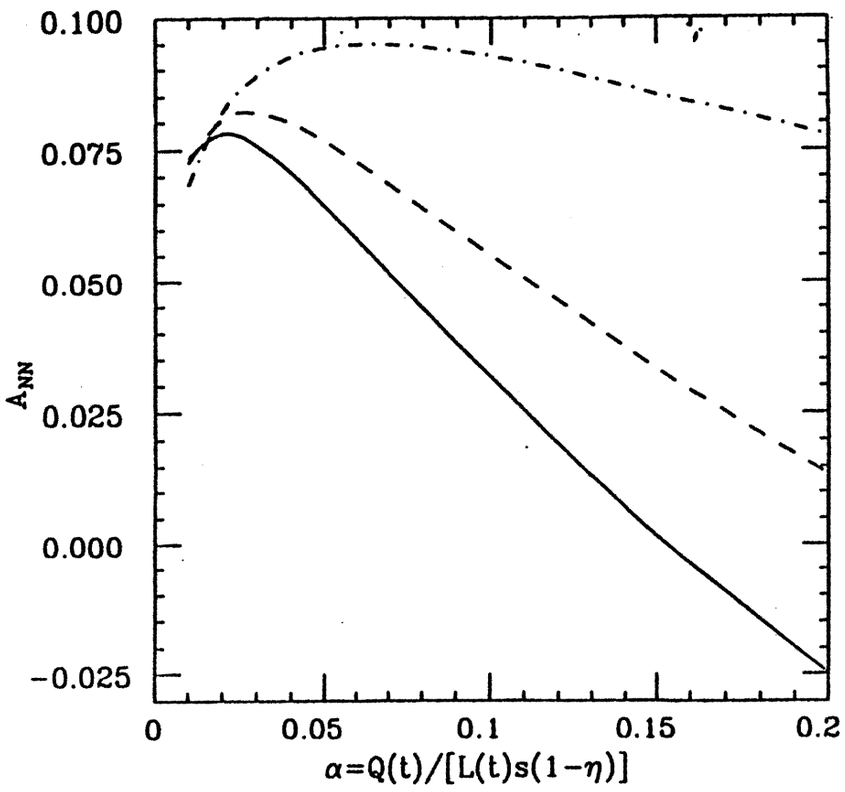

Figure 5. The asymmetry A_{NN} plotted as a function of α in the hadronic helicity-conserving region. The three curves correspond to the ratios $Im(\alpha)/Re(\alpha) = 0.1$, (solid) 0.5, (dashes) and 1.0 (dot-dashed).

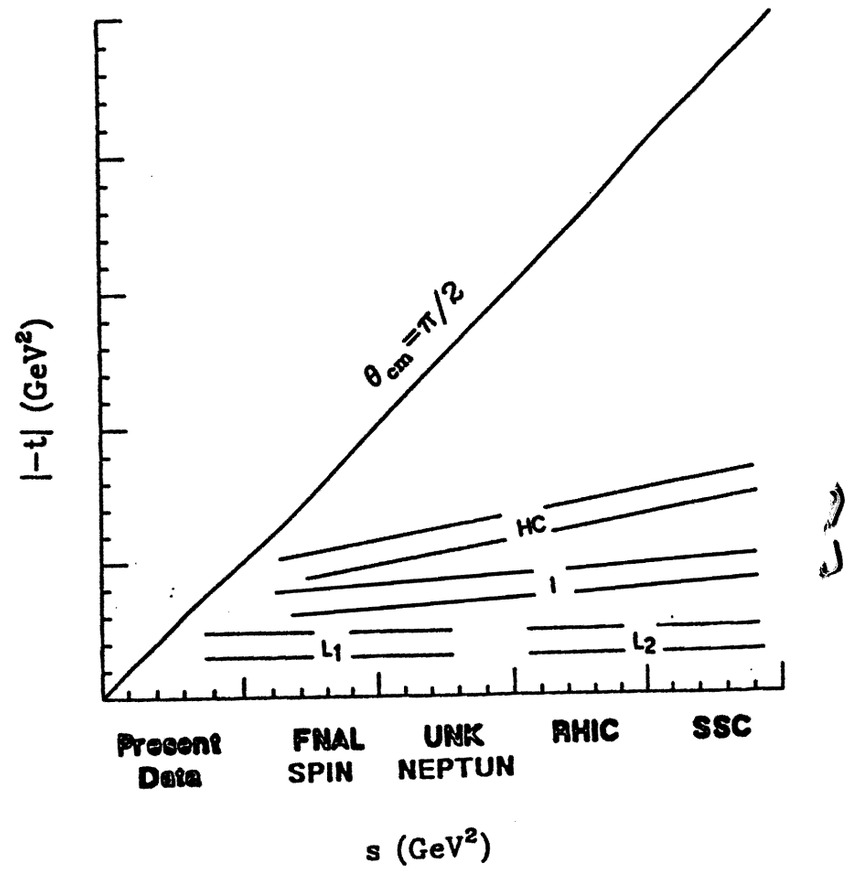

Figure 6. A $-t$-s plot of the experimental regions discussed in the text. The specific regions are labeled: L_1 - fixed $|t|$, large s; L_2 - fixed $|t|$, very large s; I - $|t|$ and s of moderate values; HC - fixed angle (η) with $|t|$ and s large.