IS THE POMERANCHUK DECOUPLED FROM THE
ORDINARY REGGE TRAJECTORIES?

George W. Barry

The Enrico Fermi Institute
and the Department of Physics
The University of Chicago, Chicago, Illinois, 60637

October, 1970

Contract No. AT (11-1)-264

LEGAL NOTICE

This report was prepared as an account of work
sponsored by the United States Government. Neither
the United States nor the United States Atomic Energy
Commission, 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, com-
pleteness or usefulness of any information, apparatus,
product or process disclosed, or represents that its use
would not infringe privately owned rights.
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.
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
IS THE POMERANCHUK DECOUPLED FROM THE
ORDINARY REGGE TRAJECTORIES?  

George W. Barry
October, 1970

The Enrico Fermi Institute
and The Department of Physics
The University of Chicago, Chicago, Illinois, 60637

ABSTRACT
If the amplitude for diffraction scattering is independent of the universal slope of the ordinary Regge trajectories, there results a helicity selection rule, which corresponds to s-channel helicity conservation for the diffractive part of πp → πp and γp → ρ⁰p, in accordance with experiment. A crucial test of the selection rule is that electroproduced ρ⁰'s should be transversely polarized at high energy.

*Supported in part by the U. S. Atomic Energy Commission.
There appears to be good evidence for s-channel helicity conservation in $\gamma p \rightarrow \rho^0 p^1$ and $\pi p \rightarrow \pi p^2$ at high $s$ and fixed $t$. Gilman, Pumplin, Schwimmer and Stodolsky have conjectured that this is true for all diffraction (Pomeranchuk exchange) processes. More recently, Harari and Zarmi have argued, in the case of $\pi p \rightarrow \pi p$, that if the Pomeranchuk is dual to the s-channel background, then the diffractive part of the amplitude conserves helicity even in the resonance region. What is the distinguishing characteristic of diffraction scattering that is responsible for this regularity?

Consider $\pi p \rightarrow \pi p$ in the limit in which the particle masses are "turned off". At zero mass the s-channel helicity flip amplitude $F_{+-}^S = 0$. This can be verified by expressing the helicity amplitudes in terms of invariant amplitudes,

$$\bar{u}(p')(A-i\vec{Q}B)u(p),$$

and noting that $\gamma_5$ invariance requires that $A = 0$.

Now turning off the masses is not quite the same as merely taking the external particles off their mass shells, it pertains to the internal lines as well. The external particles lie on Regge trajectories, which in the zero mass limit will have infinite slope, and thereby render the ordinary Regge exchange processes meaningless. Hence, we would not expect helicity conservation in say $\pi^- p \rightarrow \pi^0 n$, and in fact this process is mostly helicity flip.

The Pomeranchuk, on the other hand, is believed to support no particles, and may be unaffected when the masses are turned off. It is entirely possible that the Pomeranchuk is decoupled from the ordinary Regge
trajectories. To be precise, let us make the following hypothesis:

The s-channel helicity amplitudes for diffraction scattering are independent of the scale of the hadronic mass spectrum. If all hadrons lie on linear trajectories with universal slope, \( \alpha' \), then the mass scale is \( (\alpha')^{-1/2} \). Certain helicity amplitudes must be zero if they are to be independent of \( \alpha' \); they are the ones that vanish in the zero mass limit \( (\alpha' \to \infty) \).

Using this prescription we obtain s-channel helicity conservation for the diffractive part of:

(i) \( \pi N, KN, NN(6) \), \( NN \) elastic scattering,
(ii) \( \rho^0, \omega(7), \phi \) photoproduction\(^{(8)} \), and
(iii) \( \pi N \to \pi N^*(1410), pN \to pN^*(1410) \),

in agreement with Gilman et al.\(^{(3)} \).

Our proposal is not equivalent to helicity conservation, however. In the case of \( NN(N\bar{N}) \) scattering, only \( F_{++;++}^S \) \( (F_{+-;+-}^S) \) can be nonzero. That is, massless nucleons must have the same chirality (phase under \( \gamma_5 \)), because they are related by isospin and Lorentz transformations, which commute with \( \gamma_5 \).

Another important difference occurs in \( ep \to ep\rho^0 \). The \( \rho^0 \) should be transversely polarized\(^{(9)} \) \( (\sin^2 \theta \) distribution of the decay pions in the helicity frame) because massless, longitudinal vector mesons do not exist. Helicity conservation does not require this. In highly inelastic electron-proton scattering we predict that \( \sigma_L/\sigma_T \to 0 \) at high \( \nu \) and fixed \( q^2 \). This is consistent with present data\(^{(10)} \).
Cavalier application of the zero mass prescription can be misleading. Consider,

\[ \pi^+(q) + \pi^+(p) \rightarrow \pi^+(q') + A^+(k). \]

One might naively assume that \( F^S_0 = 0 \), because a massless particle must have maximal helicity. Let us check this explicitly. The general invariant amplitude is

\[ [K\mu C + q'_\mu (-k^2)^{1/2} D]c_\mu(k), \]

where

\[ K\mu = (k\cdot q)q'\mu - (k\cdot q')q_\mu, \]

\[ c^{(0)}_\mu(k) = (-k^2)^{-1/2}(k_0 k, i|k|). \]

In the zero mass limit,

\[ F^S_0 \rightarrow \frac{1}{2} s D, \]

and there is no reason for \( D \) to vanish. After all, we are interested in the zero mass limit, rather than massless particles. The limit need not be the same as we approach the light cone from the time-like and space-like regions. This complication does not arise in \( \rho^0 \) photoproduction because of gauge invariance. The trouble with the \( A_1 \) is that it is not coupled to a conserved source current.\(^{(1)}\)

Such is also the case in diffraction production of \( I = 1/2, J \geq 3/2 \) nucleon resonances, as is evident upon writing the general invariant amplitude for \( \pi p \rightarrow \pi p^* (1520) \),

\[ [K\mu C + q'_\mu (-k^2)^{1/2} D] \tilde{u}_\mu(k)(A-i\xi B)u(p). \]

Furthermore, there is no justification for invoking \( \gamma_5 \) invariance, because the \( p \) and \( p^* (1520) \) have different spins. They are not related by
any space time transformation, and therefore need not have the same chirality. The 1410($J^P = 1/2^+$), on the other hand, is related to the proton by a conformal (Lorentz and dilatation) transformation.

A recent measurement\(^{(12)}\) of the $\pi p \rightarrow \pi^* p$ differential cross sections favors a forward dip for 1520 ($J^P = 3/2^-$) and 1688($5/2^+$) production, and none for the 1410($1/2^+$). These results are consistent with our requirement, no dip for the 1410, but cast doubt on the helicity conservation hypothesis.

Why do we state our hypothesis in terms of s-channel rather than t-channel helicity amplitudes? Surely, they are not equivalent. If $F^s_{\{\lambda\}}(s,t)$ are scale independent, then $F^t_{\{\lambda\}}(s,t)$ are not, because the helicity crossing matrix depends on the external masses.\(^{(13)}\) For instance, the $\pi p \rightarrow \pi p$ crossing relation is

\[
\begin{pmatrix}
F^s_{++} \\
F^s_{+-}
\end{pmatrix} =
\begin{pmatrix}
-\cos\chi & \sin\chi \\
\sin\chi & \cos\chi
\end{pmatrix}
\begin{pmatrix}
F^t_{+-} \\
F^t_{++}
\end{pmatrix}.
\]

Only when $s$ and $t$ are large compared with the external masses does the crossing matrix become diagonal, $\chi(s,t) \rightarrow 0$. The only justification for favoring $F^s$, aside from the empirical evidence, is that diffraction scattering is an s-channel process, and $F^s$ are the direct observables. Of course, the Regge exchange processes are most naturally expressed in terms of $F^t$.

It might at first appear that a special preference for $F^s$ is incompatible with crossing. In $p\bar{p} \rightarrow p\bar{p}$, the $s$ and $t$ channels are the same. But if $F^s$ are mass independent, then $F^t$ (in the s-channel energy
domain) are not. It follows that the decomposition of the amplitude into a scale independent Pomeranchuk part and a Regge (non-Pomeranchuk) part is not invariant under crossing. Moreover, the Regge part can not be a function of $\alpha'$ alone, but must posses diffractive effects.

Factorization obtains in the sense that the s-channel helicity selection rule applies at each Pomeranchuk vertex. For example, the proton helicity is conserved in $\pi p + n p$, $p n + n p$, $\gamma p + \rho^0 p$, and $\pi p + A_1 p$. Van Hove\(^\text{(14)}\) has termed this "s-channel factorization", and has shown it to be consistent with unitarity, provided the contribution from nondiffractive channels is small. This prerequisite has a more direct interpretation in terms of scale independence. The simplest way for the Pomeranchuk part of $\sigma_{\text{tot}}$ to be scale independent, is for it to be the shadow of the diffraction processes only. In other words, a constant fraction of $\sigma_{\text{tot}}$ is not built up by more and more nondiffractive channels opening up with increasing energy.\(^\text{(15)}\) That diffraction processes dominate at high energy is plausible but difficult to verify.

Scale independence should not be confused with scale or conformal invariance. When $s$, $t$, and $u$ are large compared with the external masses, one can argue that the scattering amplitude may be invariant under the conformal group. This leads to the same helicity selection rule as ours.\(^\text{(16)}\) But empirically the rule seems to be valid even near $t = 0$, where conformal invariance does not apply. The considerations in this paper were designed to circumvent this difficulty. Scale independence corresponds to a particular form of broken conformal invariance, in which the scale breaking in the diffraction amplitude is different from the breaking that gives the hadrons their mass. In fact, this feature may be the
only remnant of an underlying conformal symmetry in hadronic processes.

The optical nature of diffraction scattering has long been recognized. In models of the Yang type, the slope of the diffraction peak is related to the geometric radii of the colliding hadrons, as determined from their electromagnetic form factors. Contrast this with the Regge exchange processes, where the high energy behavior is determined by the mass spectrum of particles exchanged in the crossed channel. Similar treatment of diffraction processes has not proved fruitful, and the general consensus is that the Pomeranchuk is not just a glorified Regge pole. Attempts at relating the nucleon form factors to hadron masses are legion: vector meson dominance, Veneziano amplitudes, etc. Why not give up? Indeed, the fundamental implication of scale independence is that size and mass are two unrelated aspects of hadrons.

The separate dualism of Pomeranchuk-background and Regge-resonances, among other considerations, lead Harari to suggest that scattering amplitudes may be composed of two independent parts: a geometrical-background-Pomeranchuk part and a dynamical-resonance-Regge part. Our proposal is to take the notion literally in the sense that diffraction scattering is the same no matter what the slope of the ordinary Regge trajectories. The consequence is a helicity selection rule, which so far agrees with experiment. A testable prediction is that electro-produced $\rho^0$'s should be transversely polarized at high energy. Although one can contrive other interpretations of the extant data (such as, optical models, quark spin conservation, etc.), the virtue of our approach is that it deals only with direct observables.

I thank Y. Nambu for helpful suggestions and discussions.
References


6) In pp → pp, the polarization is shrinking fairly rapidly with increasing energy. This is consistent with helicity conservation. See R. Odorico, R. Garcia, and C. A. Garcia-Canal, Physics Letters 32B, 375 (1970).


8) Take the zero mass limit in the Compton scattering amplitudes of W. A. Bardeen and Wu-ki Tung, Phys. Rev. 173, 1423 (1968).

9) An experiment capable of measuring this is underway: Luke Mo (private communication).

References (continued)

11) Using PCAC one can show that $D$ vanishes only if $\pi \pi \to \pi \pi$ does.

Rewrite PCAC,

$$\gamma(\frac{m^2\pi}{f_A} A_{\mu} + C_{\pi} a_{\mu}) = C_{\pi} m^2 \pi,$$

in terms of the $A_1$ and $\pi$ source currents (employ the KSRF relation, $C_{\pi} f_A = m_A$),

$$\gamma_{\mu} J_{5\mu}^{(A_1)} = m_A J_{5\mu}^{(\pi)}.$$

Use this to relate $\pi \pi \to \pi A_1$ and $\pi \pi \to \pi \pi$ (off mass shell):

$$\frac{1}{2}(s-m_A^2 - m_{\pi}^2) D = i F(\pi \pi \to \pi \pi)(k^2 = -m_A^2).$$

Finally, turn off the masses, while keeping $m_{\pi}/m_A$ fixed.


15) Crossing requires the Regge terms to have diffractive effects. It is possible, albeit contrived, for the Regge terms to build up an $\alpha'$ independent Pomeranchuk term.
References (continued)


