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Photoproduction, s-channel helicity conservation and Regge cuts in the t-channel

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Abstract. Using covariant Regge couplings and invariant amplitudes for the process $\gamma N \to O^- N$ we examine the constraints imposed upon the t-channel helicity amplitudes by the hypothesis of s-channel helicity conservation. Class III pion conspiracy is consistent with the hypothesis as are contributions from conspiring π, B and ρ, A_2 Pomeron cuts. Regge cut contributions arising from ω Pomeron exchange are forbidden to conspire.

1. Introduction

Recent examination of high energy ρ^0 photoproduction (Ballam *et al.* 1970) and πN scattering (Höhler and Strauss 1970, Barger and Phillips 1969) has indicated that diffractive Regge exchanges such as the Pomeron (and P′) conserve s-channel helicity (Gilman *et al.* 1970). Further, Ordorico *et al.* (1970) have presented experimental evidence to suggest that the ω, f^0 and ρ, A_2 couplings to the nucleon–nucleon vertex are essentially s-helicity nonflip and flip, respectively.

Jones (1970) has shown the efficacy of using the formalism of covariant couplings, which appear in the method of Reggeizing invariant amplitudes (Scadron 1968, Jones and Scadron 1968 a), to elucidate the flip–nonflip properties of s-channel helicity vertices in a straightforward way and it is this technique which we use here to study the effect of s-channel helicity conservation (SCHC) on conspiring and evading pole and cut contributions to t-channel amplitudes in $\gamma N \to O^- N$ processes.

Although the work of Cohen-Tannoudji *et al.* (1968) makes it easy to describe t-channel Regge exchanges in terms of s-channel helicity amplitudes and to deal directly with SCHC as well as with the various absorption prescriptions now current, while avoiding completely t-channel constraints (conspiracy relations), it does not make it easier to understand nonsense mechanisms which may be necessary to explain dips, or their absence, in differential cross sections. Because the nonsense $\alpha(t)$ factors, which appear naturally in the t-channel, are lost in t to s crossing we argue that a t-channel formalism is the proper context in which to study them, provided such s-channel constraints as may exist are also considered. Nonsense mechanisms for helicity amplitudes are reviewed by Bertocchi (1968) and by Jones (1970) for the covariant formalism. We shall ignore dip mechanisms and concentrate on SCHC constraints on t-channel amplitudes.

2. Formalism

To introduce the covariant formalism we first consider πN scattering (Jones 1970, Jones and Scadron 1968 b). The contribution of a spin J t-channel exchange to the M function is

$$M = A + \not{Q} B = (g_1 P_\beta + g_2 \gamma_\beta) \mathscr{P}^J g$$
$$= (g g_1 c_J \mathscr{P}_J - m g g_2 Q(\Delta)^2 \mathscr{P}_{J'-1}) + \not{Q}\left(-g g_2 \frac{c_J}{J} \mathscr{P}_J{}'\right)$$

giving asymptotic s-channel helicity amplitudes

$$f_{++}{}^{s} \sim g(mg_1+g_2)c_J\mathscr{P}_J, \qquad f_{-+}{}^{s} \sim \sqrt{(-t)}gg_1c_J\mathscr{P}_J$$

where it is clear that $g_1 = 0$, $(mg_1 = g_2) = 0$ are the constraints imposed by s-channel helicity nonflip (SHNF) and s-channel helicity flip (SHF), respectively, on the nucleon vertex for normal parity exchange. We note, of course, that the flip–nonflip couplings are essentially Pauli and Dirac couplings.

Proceeding to $\gamma N \to O^- N$, the spin J contributions to the gauge invariant M function are

$$\tilde{M}_\mu{}^{+,+} = (g_1P_\beta+g_2\gamma_\beta)\mathscr{P}^J\tilde{f}(t)\epsilon_{\mu\alpha_1}(Q\Delta)$$

for parity normal, C-parity normal exchanges, and

$$\tilde{M}_\mu{}^{-,+} = \gamma_5 f_1 P_\beta \mathscr{P}^J \tilde{g}k \,.\, Qg_{\mu\alpha_1}{}', \qquad \tilde{M}_\mu{}^{-,-} = f_2\gamma_5\gamma_\beta\mathscr{P}^J\tilde{g}k \,.\, Qg_{\mu\alpha_1}{}'$$

for parity normal, C-parity normal and abnormal respectively (Jones *et al.* 1970, Gault and Scadron 1970). Decomposing in terms of the invariant amplitudes of Chew *et al.* (1957) we get the results in table 1 and using the reduced, asymptotically parity conserving t-channel helicity amplitudes of Ader *et al.* (1967) we get table 2. Discussion of gauge invariance and Reggeization and references to related work are given by Jones *et al.* (1970) for invariant amplitudes and by Collins and Gault (1970) for helicity amplitudes.

3. Poles, conspiracy, cuts in the t-channel

3.1. *Poles*

Let us accept the SCHC hypothesis and consider first the t-channel consequences for a normal parity SHNF exchange (ω in $\gamma p \to (\pi^0, \eta)p$). From table 1 it is clear that, to leading order, $\tilde{A}_1$ and $\tilde{A}_2$ vanish leaving only $\tilde{A}_4$ ($\tilde{A}_3$ is always one power of s below leading order regardless of s-channel effects). In the case of a normal parity SHF exchange (ρ, A_2 in $\gamma p \to \pi^+ n$; ρ in $\gamma p \to (\pi^0, \eta)p$) the $\tilde{A}_4$ contribution vanishes leaving only $\tilde{A}_1$ and $\tilde{A}_2$. The factor of t in $\tilde{A}_1$ and the contribution to $\tilde{A}_2$ are significant for pole or cut conspiracy as we shall later see.

Turning to abnormal parity exchanges we note that while they are not constrained by SCHC they are divided by G(C) parity and it is easy to show that for equal mass fermions the couplings $f_1\gamma_5P_\beta$, $f_2\gamma_5\gamma_\beta$ are flip, nonflip, respectively, in the s-channel.

3.2. *Conspiracy*

It is now instructive to examine SCHC and pion conspiracy. Ball *et al.* (1968) were able to fit the sharp forward peak in charged pion photoproduction using the technique. An argument by Le Bellac (1967) showing that conspiracy and factorization were incompatible eventually ended the use of conspiring Regge poles, however the technique reappeared in the form of 'autoconspiring' cut contributions to t-channel Regge amplitudes dominated by evasive Regge poles. Such amplitudes, of course, do not factorize and there is no incompatibility.

It is well known (see Gault and Scadron 1970) that in photoproduction any single particle exchange gives rise to a differential cross section which vanishes at $t = 0$. In the covariant formalism a way round this is to allow the particle couplings (pion in this case) to become singular at $t = 0$, that is $\tilde{g}f_1 \sim 1/t$. To avoid having a singular invariant amplitude $\tilde{A}_2$ it is necessary to exchange a pion conspirator, the π_c, with identical quantum numbers but for parity and with coupling $\tilde{f}g_1 \sim 1/t$, in

Table 1. Pion photoproduction, Regge contribution to invariant amplitudes

Invariant amplitudes Regge contributions	Abnormal exchange		Normal exchange
	$A_1, C_n(-)^J = -1$	$\pi, B, C_n(-)^J = 1$	$\rho, \omega, \phi, A_2, \pi_c, C_n(-)^J = 1$
$\tilde{A}_1$			$-\frac{\tilde{f}}{2}\frac{c_J}{J^2}\{tg_1 J\mathscr{P}_J' - tmg_2 Q^2(\Delta)\mathscr{P}_{J-1}''\}$
$\tilde{A}_2$	$-\frac{\tilde{g}'}{4} f_2 \frac{c_J}{J^2}\left(\frac{m}{t}(t-\mu^2)\mathscr{P}_J''\right)$	$\frac{\tilde{g}}{4} f_1 \frac{c_J}{J} \mathscr{P}_J'$	$\frac{\tilde{f}}{2}\frac{c_J}{J^2}\{g_1 J\mathscr{P}_J' - mg_2 Q^2(\Delta)\mathscr{P}_{J-1}''\}$
$\tilde{A}_3$	$-\frac{\tilde{g}'}{2} f_2 \frac{c_J}{J^2}(\mathscr{P}_J' - v\mathscr{P}_J'')$		$\tilde{f} g_2 \frac{c_J}{J^2}\left(\frac{(t-\mu^2)}{4}\mathscr{P}_J''\right)$
$\tilde{A}_4$	$\frac{g'}{2} f_2 \frac{c_J}{J^2}\left(\frac{(t-\mu^2)}{4}\mathscr{P}_J''\right)$		$-\tilde{f}\frac{c_J}{J^2}\left\{(mg_1+g_2)J\mathscr{P}_J' - \frac{t}{4}Q^2(\Delta)\mathscr{P}_{J-1}''g_2\right\}$

Table 2. $\gamma N \to \pi N$, Regge contributions to helicity amplitudes

Helicity amplitudes Regge contributions	Abnormal exchange		Normal exchange
	$A_1, C_n(-)^J = -1$	$\pi, B, C_n(-)^J = 1$	$A_2, \rho, \omega, \phi, \pi_c, C_n(-)^J = 1$
$\bar{f}_{01}^{\,-}$		$p_t k_t \frac{t}{4}\left(\frac{c_J}{J}\tilde{g}f_1\right)\mathscr{P}_J'$	
$\bar{f}_{01}^{\,+}$			$-\left(2\frac{c_J}{J^2}\tilde{f}\right)\frac{k_t\sqrt{t}}{4}\left(m(mg_1+g_2)-\frac{t}{4}g_1\right)\mathscr{P}_J'$
$\bar{f}_{11}^{\,-}$	$p_t k_t \frac{\sqrt{t}}{2}\left(\frac{c_J}{J}\tilde{g}'f_2\right)(\mathscr{P}_J'-v\mathscr{P}_J'')$		$-p_t k_t^2 \frac{t}{4}\left(2\frac{c_J}{J^2}fg_2\right)(\mathscr{P}_J'')$
$\bar{f}_{11}^{\,+}$	$-p_t^2 k_t^2 \frac{\sqrt{t}}{2}\left(\frac{c_J}{J}\tilde{g}'f_2\right)\mathscr{P}_J''$		$k_t \frac{t}{4}\left(2\frac{c_J}{J^2}\tilde{f}g_2\right)(\mathscr{P}_J'-v\mathscr{P}_J'')$

order to cancel the singularity in the pion coupling and leave $\tilde{A}_2$ nonsingular (except at dynamical poles). Making $\tilde{f}g_1$ singular introduces a singularity into $\tilde{f}g_2$ if $\tilde{A}_4$ is to be kept finite and the resulting singularity in the $\tilde{A}_3$ normal contribution is cancelled by the third member of the $M = 1$, class III conspiracy (Bertocchi 1968). Daughter exchanges carry on the cancellation to lower orders. We see immediately that the π_c exchange is compatible with pure SHF, which is not surprising as the pion is SHF, and further that the π_c can contribute to SHNF amplitudes if $(mg_1+g_2) \neq 0$. Conspiracy, less stringent than SCHC, requires only that (mg_1+g_2) be nonsingular.

For those more at home in helicity formalism the conspiracy argument can be developed from table 2 and the constraint equation

$$\mathrm{i}\tilde{f}_{01}{}^{-} + \tilde{f}_{11}{}^{+} \sim \mathrm{O}(\sqrt{t}). \tag{1}$$

One can see that finite couplings give an evasive solution, singular couplings a conspiratorial one.

3.3. *Regge cuts*

If we limit ourselves to exchange, Pomeron cuts then SCHC unequivocally requires that the cut contribution have the same flip–nonflip behaviour as the exchanged pole. As the cut does not have definite parity it may contribute to both normal and abnormal amplitudes and in some cases conspire with itself.

Consider first a normal parity SHNF exchange and its cut contribution. SCHC requires that $g_1 = 0$ for both pole and cut and consequently that the normal pole, cut contributions appear only in $\tilde{A}_4$ and also that the abnormal cut contribution to $\tilde{A}_2$ must be evasive as there is no normal parity contribution to $\tilde{A}_2$ to make a conspiracy possible. (In fact, the abnormal cut contribution to $\tilde{A}_2$ must vanish by SCHC.)

Next, normal parity SHF exchanges and their cut contributions are forced by SCHC to obey the constraint $(mg_1+g_2) = 0$ and because a normal parity contribution to $\tilde{A}_2$ is allowed, so also is conspiracy. We note that several authors who fit $\gamma p \to \pi^0 p$ data using t-channel parameterizations of ω plus ω Pomeron cut exchange invoke the conspiracy equation (1) to reduce the number of free parameters in their fits (Froyland 1969, Contogouris *et al.* 1969, Capella and Tran Thanh Van 1969, Braunschweig *et al.* 1970) while Colocci (1970), fitting the same process in an s-channel formalism, requires that the ω coupling be pure electric ($g_1 = 0$) for the same reason. While the former approach is pragmatic the latter has the virtue of both pragmatism and consistency with SCHC.

The only other exchanges important to photoproduction are the π and the B. As both of these couple via f_1 and are SHF, SCHC requires Pomeron cut contributions to be likewise and able therefore to conspire. Froyland and Gordon (1969) working in the t-channel have been able to fit the $\gamma p \to \pi^+ n$ differential cross section using an evasive pion with conspiring π Pomeron cut.

4. Conclusions

We have demonstrated that the formalism of covariant couplings provides a straightforward way of carrying s-channel restrictions on Regge exchanges over to the t-channel. Accepting a hypothesis that the Pomeron conserves s-channel helicity, that ω, f^0 exchanges have couplings to the nucleon vertex which do not flip nucleon helicity in the s-channel and that ρ, A_2 exchanges have nucleon couplings which do, we have shown that class III pion conspiracy is compatible with s-channel helicity conservation. Further, in $\gamma N \to O^- N$ we have shown that ω Pomeron cuts, consistent with the hypothesis, cannot be made to conspire, while π, B and ρ, A_2 Pomeron cuts can.

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