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CRITICISM OF THE P'-ω EXCHANGE DEGENERACY ARGUMENTS IN THE pp → pX TRIPLE-REGGE REGION†

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ABSTRACT

The omission of off-diagonal terms (G_{ijk}, $i \neq j$) in the triple-Regge analysis of pp → pX on the grounds of P'-ω exchange degeneracy is questioned. It is pointed out that not only are compelling reasons absent for such a degeneracy but imposition thereof conflicts with simple G-parity considerations and leads to the neglect of probably significant off-diagonal terms. The practical problem of triple-Regge fitting in the presence of the off-diagonal terms resurrected here is briefly examined.

Consider the reaction $p(p_1) + p(p_2) \rightarrow p(p_3) + X$ in the triple-Regge region, $M^2 = (p_1 + p_2 - p_3)^2 \rightarrow \infty$, $(s/M^2) \rightarrow \infty$ and $t = (p_3 - p_1)^2$ fixed. The notation is defined by the following expansion of the inclusive cross section:

† Work supported by the U. S. Atomic Energy Commission.

$$\frac{d\sigma}{dt\, d(M^2/s)} = \frac{s_0}{s} \frac{1}{16\pi s_0} \sum_{i,j,k} \beta_{ppi}(t)\, \xi_i(t)\, \beta_{ppj}(t)\, \xi_j^*(t)$$

$$\times \left(\frac{s}{M^2}\right)^{\alpha_i(t)+\alpha_j(t)} g_{ijk}(t) \left(\frac{M^2}{s_0}\right)^{\alpha_k(0)} \left(\mathrm{Im}\ \xi_k(0)\right) \beta_{ppk}(0)\cdot \mathrm{mb}\cdot \mathrm{GeV}^{-2} . \qquad (1)$$

In the above expansion, $s_0 = 1\ \mathrm{GeV}^2$, $\beta_{ppi}(t)$ is the dimensionless coupling of Regge pole i to protons, and $\xi_i(t)$ is the signature factor for i, given by $\left[i - \cot\left(\frac{1}{2}\pi\alpha_i(t)\right)\right]$ for even and $\left[-i - \tan\left(\frac{1}{2}\pi\alpha_i(t)\right)\right]$ for odd signatures.† The β are normalized such that a single pole i contributes to the p-p total cross section an amount

$$\sigma^t_{pp,i}(s) = \frac{1}{s}\left[\mathrm{Im}\ \xi_i(0)\right] \beta_{ppi}(0)\, \beta_{ppi}(0) \left(\frac{s}{s_0}\right)^{\alpha_i(0)} \mathrm{GeV}^{-2} . \qquad (2)$$

The triple-Regge coupling $g_{ijk}(t)$, which has dimensions of GeV^{-2} will be measured in mb (1 mb ≃ 2.5 GeV^{-2}).

Experimentalists usually parametrize the inclusive cross section as follows:

† With this choice of odd signature factor, $\beta^2_{pp\omega}(0)$ is positive while $\beta_{pp\omega}(0)\, \beta_{\bar{p}\bar{p}\omega}(0)$ is negative.

$$\frac{d\sigma}{dt\, d(M^2/s)} = \left(\frac{s_0}{s}\right) \sum_{i,j,k} G_{ijk}(t) \left(\frac{s}{M^2}\right)^{\alpha_i(t)+\alpha_j(t)} \left(\frac{M^2}{s_0}\right)^{\alpha_k(0)}$$

$$\cdot \text{mb GeV}^{-2} \quad . \qquad (3)$$

Therefore

$$G_{ijk}(t) = \frac{1}{16\pi s_0} \beta_{ppi}(t)\, \xi_i(t)\, \beta_{ppj}(t)\, \xi_j^*(t)\, g_{ijk}(t) \left(\text{Im}\, \xi_k(0)\right)$$

$$\times\ \beta_{ppk}(0)\ \text{mb}\cdot\text{GeV}^{-2} \quad . \qquad (4)$$

For the off-diagonal $(i \neq j)$ terms let us define

$$\underline{G_{ijk}} = G_{ijk} + G_{jik} = 2\ \text{Re}\ G_{ijk} \quad . \qquad (5)$$

In phenomenological analyses (see, for example, refs. (1) or (2)) one considers the pomeron P, and the next family of lower poles, collectively referred to as R. The principal candidates for R are the P' and ω, since the ρ and A_2 couple weakly to protons.

My purpose here is to question an assumption usually made in such fits, that the P' and ω combine to form a real term R (as in p-p elastic scattering) so that the off-diagonal terms $\underline{PRP}$ and $\underline{PRR}$ are absent. One says for example, $\underline{PRP} = 2\ \text{Re}\ G_{PRP} \simeq 0$ on the grounds that the P is mainly imaginary while R is mainly real. Such reasoning, on the basis of exchange degeneracy, has a legitimate place in p-p elastic scattering, but not here. In the former case, the conditions $\beta_{ppP'} = \beta_{pp\omega}$ and $\alpha_{P'} = \alpha_\omega$, with opposite signatures

for P' and ω allow one to drop the interference terms between P and R in $d\sigma^{pp}/dt$. Evidently, in the case of $pp \to pX$, the degeneracy arguments are valid when X = proton, but in other cases, especially in the triple-Regge region, it is not at all obvious that the degeneracy should persist. In fact the indiscriminate imposition of such degeneracy conflicts with simple G-parity considerations. Consider, for example, the term $G_{\underline{PR}P}$, together with eq. (4). Assuming (perhaps legitimately) that $\beta_{ppP'} \approx \beta_{pp\omega}$, we can infer the vanishing of $G_{\underline{PR}P}$ only if $g_{PP'P} = g_{P\omega P}$. <u>However, $g_{P\omega P}$ vanishes from G-parity conservation</u>, while no such restriction exists for $g_{PP'P}$. We may therefore expect a nonzero $G_{\underline{PR}P} = G_{\underline{PP'}P}$. Existence of the P might be regarded as incompatible with exchange degeneracy.

As for the other off-diagonal term, $G_{\underline{PR}R}$, it will vanish unless both the labels R refer to the same object, P' or ω, once again due to G-parity conservation. Thus

$$G_{\underline{PR}R} = G_{\underline{PP'}P'} + G_{\underline{P\omega}\omega}. \quad \text{Assuming } \beta_{ppP'} = \beta_{pp\omega},$$

$$G_{\underline{PR}R} = (\text{common factors}) \Big[g_{PP'P'}\ 2\ \text{Re}\ i\left[-i - \cot(\tfrac{1}{2}\pi\alpha_{P'})\right] \text{Im}\ \xi_{P'}$$

$$+\ g_{P\omega\omega}\ 2\ \text{Re}\ i\left[i - \tan(\tfrac{1}{2}\pi\alpha_\omega)\right] \text{Im}\ \xi_\omega \Big]$$

$$\sim \left[2\, g_{PP'P'} + 2\, g_{P\omega\omega}\right] \qquad (7)$$

assuming for simplicity that $\xi_P(t) = i$. The $\underline{PRR}$ term vanishes if $g_{PP'P'} = -\, g_{P\omega\omega}$. While this is possible, there exist no reasons why this must be the case.

Having resurrected the off-diagonal terms let us ask how important they may be. To get a feeling for this question, let us turn to the pion pole dominance model. In this model the ω is excluded since pions mediate the coupling between the reggeons i, j, and k (3). While the ω is excluded by G parity from PRP, and PPR, it is allowed in RRP, RPR, and RRR. Nonetheless the π exchange model should give some idea of the relative importance of various terms. Formulas for $g_{ijk}(t)$ calculated within this model have appeared in the literature (3,4) and have been numerically evaluated by Sorensen (5). For our present purpose, I have used the formulas for $g_{ijk}(0)$, the off-shell form factors of Sorensen, and the π-p elastic amplitudes of Barger and Phillips to calculate $G_{ijk}(0)$ and $d\sigma^{ijk}/dt\, d(M^2/s)|_{t=0}$, the contribution of each term to the inclusive cross section at $t = 0$. Table I contains the results for $x = 0.87$ and $s = 108, 752\ GeV^2$, together with the extrapolations of the measured cross section (1) to $t = 0$. We see from the table that the PRP term could be very significant ($\approx 30\%$). While absolute values of couplings and cross sections calculated in the model are dependent on the cut off provided by the off-shell factors, the relative magnitudes of the various terms are more reliable (7).

Resurrection of the off-diagonal term leaves the following options:

(A) We can fit the data with all six terms, and a $\pi\pi P$ term of magnitude given by Bishari (8). Considering the vast amount of data available, a good fit with these parameters should still be meaningful.

(B) We can try a fit with fewer terms, referring to Table I for guidance. For example, for x not too close to 1, we can try omitting the nonscaling terms PPR, RRR, and RPR if s is in the ISR range.

(C) We can follow Dash's prescription (9) for handling the P and P' as one unit. Dash claims that over an intermediate range of energies, the P and P' may be replaced to a good approximation by a single factorizable pole $\tilde{P}$, of intercept near 0.85 (10). According to Dash, the presently investigated intervals of (s/M^2) and (M^2/s_0) fall within the range of validity of this approximation. Dash in fact succeeds in fitting a lot of $pp \to pX$ data using no more than $\tilde{P}\tilde{P}\tilde{P}$ and $\pi\pi P$ terms. Note that the leading off-diagonal term PP'P is contained in $\tilde{P}\tilde{P}\tilde{P}$, since each $\tilde{P}$ represents the combined effect of P and P'. While the equivalent pole $\tilde{P}$ must give way to separate P and P' when (s/M^2) and (M^2/s_0) go beyond the intermediate range specified, the phenomenological simplicity emphasized by Dash may allow an economical description of the triple-Regge region.

In conclusion, this paper emphasizes the absence of compelling reasons for P'-ω exchange degeneracy in the triple-Regge region of $pp \to pX$ and stresses that imposition of such degeneracy conflicts with G-parity conservation. Of the two off-diagonal terms reinstated by the above arguments, the PRP term seems especially significant, according to the pion exchange model. Meaningful data analysis must find a means of including at least this term.

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Table I. The predictions of the π-exchange model for G_{ijk} and $\frac{d\sigma^{ijk}}{dt\, d(M^2/s)}$ in $mb\cdot GeV^{-2}$, at $x = 0.87$, $t = 0$.

	PPP	PPR	RRP	RRR	PRP	PRR	Total $\frac{d\sigma}{dt\,d(M^2/s)}\Big\rvert_{t=0}$ (theory)	Total $\frac{d\sigma}{dt\,d(M^2/s)}\Big\rvert_{t=0}$ (extrapolation of experiment (1))
$G_{ijk}(0)$	0.86	1.39	8.1	12.6	3.32	5.3		
$s = 108\ GeV^2$ $\frac{d\sigma^{ijk}}{dt\,d(M^2/s)}\Big\rvert_{t=0}$	6.6	2.6	8.1	3.4	9.2	3.9	34	80
%	19.4	7.6	23.8	10.0	27.0	11.4		
$s = 752\ GeV^2$ $\frac{d\sigma}{dt\,d(M^2/s)}\Big\rvert_{t=0}$	6.6	1.0	8.1	1.3	9.2	1.5	28	68
%	24.0	3.6	29.2	4.7	33.2	5.4		

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