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**A DYNAMICAL REALIZATION
OF BREAKING OF EXCHANGED
DEGENERACY AND VIOLATION
OF ZWEIG'S RULE** **MASTER**

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A DYNAMICAL REALIZATION OF BREAKING OF EXCHANGED
DEGENERACY AND VIOLATION OF ZWEIG'S RULE

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ABSTRACT

A multiperipheral model that implements part of the Veneziano topological expansion and in which the cylinder correction breaks exchange degeneracy and produces Zweig's rule violation as well as a Pomeron above one is presented. In the negative charge conjugation channel the model is identical to the 0 meson model of Freund and Nambu if continued to a spin one pole on the daughter of the Pomeron.

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I. INTRODUCTION

Veneziano¹ has proposed a topological perturbation expansion for unitarization of the dual resonance model. The zeroth order contribution to the expansion is the sum of all planar unitarity dual diagrams. This term is supposed to produce a set of exchange degenerate trajectories, and no cuts or exotic trajectories. The first order unitarity contribution has the topology of a cylinder and produces singularities in both charge conjugation plus and minus channels ($C = \pm$) and breaks exchange degeneracy. The cylinder is said to be associated with the Pomeron in the $C = +$ channel and expected to be above all other singularities in the problem. The singularity in the $C = -$ channel has been associated with the daughter of the Pomeron (PD) by Freund and Nambu² (FN) and they have shown that it can account for violations of Zweig's rule in that channel.

Several groups have attempted to replace dual dynamics with the multiperipheral model, maintaining the internal symmetries, and approximately carry out the Veneziano program for the elastic amplitude. In a detailed treatment, Schmid and Sorensen³ showed that such models must have only one output pole in each channel and hence cannot have a distinct P and f trajectory. Rosenzweig and Chew⁴ (RC) take this single pole in their multiperipheral model to be a Pomeron with intercept .85 as suggested in Ref. 5, and are thus able to relate the breaking of Zweig's rule to the breaking of exchange degeneracy.

We feel, however, that the high energy data requires a distinct Pomeron trajectory with $\alpha_P(0)$ being above 1.0. (This would be the bare Pomeron in a Gribov reggeon calculus.) Furthermore, the existence of a distinct Pomeron probably implies a distinct PD, thus allowing us to interpret our results in terms of the calculation of Zweig's rule violation of FN and Ref. 6.

To motivate our point of view we will outline using multiperipheral ideas how successive twisted links might be summed, although we believe that the dynamics must actually be different than the multiperipheral Fredholm equation. Consider the multiperipheral model for the production amplitude shown in Figure 1a where each exchange is either twisted or planar. After squaring the amplitude, the basic ingredient from which any contribution to the amplitude is constructed, are (see Figure 1b), P , a pair of planar exchanges, T , a pair of twisted exchanges, and K , the produced particle. Arguments concerning the absence of interferences between the planar and twisted contribution are given in Ref. 3. The identity of quark lines is handled by matrix techniques. In standard multiperipheral models, K would be expected to be J independent, and P and T would be expected to have similar J dependence. If we strip off the external particles, then the imaginary part of the two to two amplitude is given by an integral equation of the form:

$$A = [x] [K + K(P + T)K + K(P + T)K(P + T)K + \dots] [x] + [x'] . \quad (1)$$

Where $[x]$ and $[x']$ indicates the way the internal propagator couples to the external particle. There are several possible choices, each of which have different phenomenological implication. To parallel Ref. 2, we will take

$$[x] = [x'] = P . \quad (2)$$

Following Veneziano¹ we sum just the planar terms to obtain an amplitude A_p given by

$$A_p = P + PKP + PKPKP + \dots \quad (3)$$

In the Veneziano program A_p is expected to have exchange degenerate poles, ρ , ω , A_2 and f , (we will put the f' and ϕ exchange degenerate, but at lower intercept because of the expected heavier mass for the strange quarks) and no cuts or exotics trajectories.

Next we must consider the implication of the cylinder corrections, which we will designate by A_T , and which results from terms which only contain twisted contributions

$$A_T = T + TKT + TKTKT + \dots \quad (4)$$

The full amplitude A can now be written in terms of the planar contribution A_p and the cylinder corrections A_T

$$A = A_p + A_p K A_T K A_p + A_p K A_T K A_p K A_T K A_p + \dots \quad (5)$$

As we stated earlier, the detailed construction of A_p and A_T goes beyond the multiperipheral model, however at this stage of development the application of the multiperipheral model may be justifiable, and if so A will be the solution of the multiperipheral Equation (5), and thus we find

$$A = [1 - A_p K A_T K]^{-1} A_p \quad (6)$$

Notice that this would be identical to the results of RC if $K A_T K$ were replaced by their J independent cylinder correction C . In our approach however, we will assume that A_T has J dependent singularities. We feel that it is very reasonable to assume that in the $C = +$ channel, A_T contains a high lying pole since the entire kernel TK gets concentrated into the vacuum channel. In the $C = -$ channel, the singularity will be lower as in Ref. 3 and will be associated with the PD as was suggested by FN.

II. MODEL

We will work here with a $SU(3)$ model with our channels corresponding to the quark antiquark states $p\bar{p}$, $n\bar{n}$ and $\lambda\bar{\lambda}$, respectively. (The extension to $SU(4)$ is straightforward and will be presented elsewhere.) The amplitude A_p will be taken to be

$$A_p = \begin{pmatrix} [J - \alpha_0]^{-1} & 0 & 0 \\ 0 & [J - \alpha_0]^{-1} & 0 \\ 0 & 0 & [J - \alpha_3]^{-1} \end{pmatrix} \quad (7)$$

where $\alpha_0(0) > \alpha_3(0)$ as a reflection of the heavier mass of the λ quarks. The kernel of our problem $KA_T K$ which represents the cylinder correction in the $C = +$ or $C = -$ channel will be taken to be completely $SU(3)$ symmetric, and given by

$$(KA_T K)_\pm = \frac{k_\pm^2}{J - \alpha_4^\pm} \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \quad (8)$$

We take $\alpha_4^+ - \alpha_4^- = 1$ in accordance with our expectation of the daughter structure of the cylinder. We should note however, that the J plane structure in the $C = -$ channel may in fact be more complicated than a simple pole. In multiperipheral models, one would expect a variety of cuts in the region of $\alpha_4^-(0)$ which could be important. For our purposes it is sufficient to say that the PD is the important structure in $(KA_T K)_-$, which we approximate by a pole.

We can partially diagonalize the solution of our model by rotating to a basis corresponding to particles of an ideally mixed multiplet.

$$\mu A^\pm \mu^{-1} = A^\pm = [\mu(1 - A_p [KA_T K]_\pm) \mu^{-1}]^{-1} A_p \quad (9)$$

where

$$\mu = \begin{pmatrix} 1/\sqrt{2} & -1/\sqrt{2} & 0 \\ 1/\sqrt{2} & 1/\sqrt{2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

This separates the problem into the isospin one and zero components.

$$\bar{A}^\pm = \left(\begin{array}{c|c} A_1^\pm & 0 \\ \hline 0 & A_0^\pm \end{array} \right) \quad (10)$$

where

$$A_1^\pm = \frac{1}{J - \alpha_0} \quad (11)$$

and

$$A_0^\pm = \frac{\begin{pmatrix} (J - \alpha_4^\pm)(J - \alpha_3) - k_\pm^2 & \sqrt{2} k_\pm^2 \\ \sqrt{2} k_\pm^2 & (J - \alpha_4^\pm)(J - \alpha_0) - 2k_\pm^2 \end{pmatrix}}{(J - \alpha_4^\pm)(J - \alpha_3)(J - \alpha_0) - k_\pm^2(J - \alpha_0) - 2k_\pm^2(J - \alpha_3)} \quad (12)$$

The isospin one exchanges (ρ and A_2) will thus remain uncharged at α_0 , as found by RC, and ω and f trajectories will split away from them by an amount and in a direction that depends on the parameters $k_\pm$. Similarly the ϕ , f' , Pomeron and PD will move to new intercepts which depend on $k_\pm$. The new trajectories will be called α_ω , α_f , α_ϕ , $\alpha_{f'}$, α_P and α_{PD} respectively and are the solution of the cubic denominator of $A_0^\pm$. It is straightforward to write out $A^{+(-)}$ in terms of the new poles.

$$[A^{+(-)}]_{ij} = \frac{g_i^{P(PD)} g_j^{P(PD)}}{J - a_{P(PD)}} + \frac{g_i^{f(\omega)} g_j^{f(\omega)}}{J - a_{f(\omega)}} + \frac{g_i^{f'(\phi)} g_j^{f'(\phi)}}{J - a_{f'(\phi)}} \quad (13)$$

The couplings g_i^x represent the coupling between the original pure states (i) (that are ideally mixed) and the new mixed states (x) that we have generated via our twist operator $KA_T K$. Thus

$$\begin{bmatrix} g_{f(\omega)}^{P(PD)} \\ g_{f'(\phi)}^{P(PD)} \end{bmatrix} = \begin{bmatrix} \sqrt{\frac{(a_{P(PD)} - a_4^{+(-)}) (a_{P(PD)} - a_3) - k_{+(-)}^2}{(a_{P(PD)} - a_{f(\omega)}) (a_{P(PD)} - a_{f'(\phi)})}} \\ \sqrt{\frac{(a_{P(PD)} - a_4^{+(-)}) (a_{P(PD)} - a_0) - 2k_{+(-)}^2}{(a_{P(PD)} - a_{f(\omega)}) (a_{P(PD)} - a_{f'(\phi)})}} \end{bmatrix} \quad (14)$$

$$\begin{bmatrix} g_{f(\omega)}^{f(\omega)} \\ g_{f'(\phi)}^{f(\omega)} \end{bmatrix} = \begin{bmatrix} \sqrt{\frac{(a_{f(\omega)} - a_4^{+(-)}) (a_{f(\omega)} - a_3) - k_{+(-)}^2}{(a_{f(\omega)} - a_{P(PD)}) (a_{f(\omega)} - a_{f'(\phi)})}} \\ \sqrt{\frac{(a_{f(\omega)} - a_4^{+(-)}) (a_{f(\omega)} - a_0) - 2k_{+(-)}^2}{(a_{f(\omega)} - a_{P(PD)}) (a_{f(\omega)} - a_{f'(\phi)})}} \end{bmatrix} \quad (15)$$

$$\begin{bmatrix} g_{f(\omega)}^{f'(\phi)} \\ g_{f'(\phi)}^{f'(\phi)} \end{bmatrix} = \begin{bmatrix} \sqrt{\frac{(a_{f'(\phi)} - a_4^{+(-)}) (a_{f'(\phi)} - a_3) - k_{+(-)}^2}{(a_{f'(\phi)} - a_{P(PD)}) (a_{f'(\phi)} - a_{f(\omega)})}} \\ \sqrt{\frac{(a_{f'(\phi)} - a_4^{+(-)}) (a_{f'(\phi)} - a_0) - 2k_{+(-)}^2}{(a_{f'(\phi)} - a_{P(PD)}) (a_{f'(\phi)} - a_{f(\omega)})}} \end{bmatrix} \quad (16)$$

We see that the pure (ideally mixed) states can communicate via these mixed states. For example, an external ϕ state (which we take as ideally mixed) can become an external ω state via $g_\phi^\phi g_\omega^\phi$. This of course, leading to a violation of Zweig's rule. To compare our model of Zweig's rule violation with that of FN we continue our $C = -$ amplitude to the pole at $J = 1$.

$$A_0^- = -\frac{1}{\alpha'} \frac{\begin{pmatrix} (t - m_4^2)(t - m_3^2) - \frac{k_-^2}{\alpha' \alpha_4'} & \frac{\sqrt{2} k_-^2}{\alpha' \alpha_4'} \\ \frac{\sqrt{2} k_-^2}{\alpha' \alpha_4'} & (t - m_4^2)(t - m_0^2) - \frac{k_-^2}{\alpha' \alpha_4'} \end{pmatrix}}{(t - m_4^2)(t - m_3^2)(t - m_0^2) - \frac{k_-^2}{\alpha' \alpha_4'} (t - m_0^2) - \frac{2k_-^2}{\alpha' \alpha_4'} (t - m_3^2)} \quad (17)$$

where

$$\alpha_4^- = 1 - \alpha_4' m_4^2 + \alpha_4' t \quad \alpha_{0(3)} = 1 - \alpha_0' m_{0(3)}^2 + \alpha_0' t$$

The resulting amplitude is identical to that obtained from the mass matrix of FN. The parameter f^2 of FN is related to k_-^2 by

$$f^2 = \frac{k_-^2}{\alpha' \alpha_4'} \quad (18)$$

A direct comparison of these parameters of course, requires a continuation from $t > 0$ to $t = 0$.

The parameters of our model are chosen to agree with existing data. We have not attempted to make a systematic χ^2 fit to data, but we have made adjustments to give reasonable fits. Briefly, the way we have chosen the parameters is as follows. $\alpha_0(0)$ was chosen to agree with fits to the

ρ trajectory of Ref. 7. $\alpha_p = 1.06$ was chosen to agree with the rise of proton-proton total cross section. $\alpha_4^+(0)$ and k_+ are determined from $\sigma_T^{pp} + \sigma_T^{p\bar{p}}$. α_4^- is taken to be $\alpha_4^+ - 1$, and $\alpha_\omega(0)$ and k_- are determined from $\sigma_T^{p\bar{p}} - \sigma_T^{pp}$. The model is relative insensitive to α_3 . The parameters are thus determined to be

$$\begin{aligned}
 \alpha_4^+ &= .85 & \alpha_p &= 1.06 & k_+^2 &= .04252 \\
 \alpha_4^- &= -.15 & \alpha_{PD} &= .004 & k_-^2 &= -.01729 \\
 \alpha_0 &= .53 = \alpha_\rho = \alpha_{A_2} & \alpha_\omega &= .48 & \alpha_f &= .40115 \\
 \alpha_3 &= .2 & \alpha_\phi &= .096 & \alpha_{f'} &= .11885
 \end{aligned} \tag{19}$$

The expression for $\sigma_T^{pp(J)} + \sigma_T^{p\bar{p}(J)}$ and $\sigma_T^{p\bar{p}(J)} - \sigma_T^{pp(J)}$ are:

$$\sigma_T^{pp(J)} + \sigma_T^{p\bar{p}(J)} = 2\gamma_f^2 \left[\frac{(g_f^p)^2}{J - \alpha_p} + \frac{(g_f^f)^2}{J - \alpha_f} + \frac{1/9}{J - \alpha_0} \right] \tag{20}$$

and

$$\sigma_T^{p\bar{p}(J)} - \sigma_T^{pp(J)} = 2\gamma_\omega^2 \left[\frac{(g_\omega^\omega)^2}{J - \alpha_\omega} + \frac{1/9}{J - \alpha_0} + \frac{(g_\omega^\phi)^2}{J - \alpha_\phi} \right] \tag{21}$$

where $\gamma_{f(\omega)}$ is the coupling of the proton to the ideally mixed $f(\omega)$ channel.

We have used the standard relation that $\gamma_{A_2(p)} = 1/3 \gamma_{f(\omega)}$.

The fits to $\sigma_T^{p\bar{p}} - \sigma_T^{pp}$ and σ_T^{pp} are shown in Fig. 2a and b. The splitting of the α_ρ and α_ω trajectories that we obtain appears consistent with other determinations.⁷ The breaking of Zweig's rule in the $C = -$ channel is determined by k_-^2 . Good fits to direct channel data have been obtained in Ref. 2 and Ref. 6 with $f^2 = .0256$ to $.0501$ which implies via Eq. 18 $k_-^2 = .0128$ to $.0167$ which is in reasonable agreement with the magnitude of k_-^2 that we obtain for $t \leq 0$. It is important to note

however, that we find $k_-^2 < 0$. While this will not affect any of the predictions for Zweig's rule violation, it will make the particle on the PD trajectory a ghost. This lends strength to the argument that the PD is in reality a cut which has been approximated by a pole. In the continuation from $t > 0$ to $t \leq 0$, the parameters could however change sign and be consistent with the pole interpretation of the PD.

We have seen that an intermediate step in the Veneziano program can be carried out consistently in the multiperipheral approximation. The calculation gives rise to a relation between the breaking of exchange degeneracy and the violation of Zweig's rule that is consistent with data. However the initial steps of constructing A_P and A_T , we believe, requires a more sophisticated model, which incorporates the underlying dual structure. (See Ref. 8 and references therein for further discussion of this point.) We have also not attempted to discuss more complicated topologies than the cylinder. It may be that these are best discussed within the context of a Reggeon field theory.

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FIGURE CAPTIONS

Figure 1. (a) A dual production amplitude.
 (b) Ingredients of the multiperipheral model.

Figure 2. (a) Fit to $\sigma_T^{p\bar{p}} - \sigma_T^{p\bar{p}}$.
 (b) Fit to σ_T^{pp} .

(A)

P

T

K

(B)

Fig. 1