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DUALITY AND DIFFRACTION DISSOCIATION

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ABSTRACT

We discuss diffraction dissociation in the context of a dual model. We show how direct channel resonances in the pomeron-particle amplitude build the pomeron in the crossed channel. A result of the enforcement of the Harari-Freund conjecture for particle-particle amplitudes is that the pomeron-pomeron-reggeon coupling is small.

The model is tested phenomenologically by (a) The analysis of $\pi^- p \rightarrow \pi^- p(\pi^+ \pi^-)$ of Lipes, Robertson, and Zweig, (b) Baryon missing mass data at various energies. This enables us to extract the pomeron-particle total cross-section explicitly. (c) The behavior of missing mass diffraction production peaks which are predicted to level off or dip near the forward direction as a consequence of the vanishing of the triple pomeron coupling.

I. INTRODUCTION

The discussion of the role of duality in inclusive reactions involves a generalization of the Harari-Freund (HF) conjecture^{1,2} to multiparticle amplitudes. We have suggested a simple prescription for such a generalization in Refs. 3 and 4. In this paper, we will investigate the predictions of such a scheme for diffraction dissociation. This will be seen to provide a crucial test of our model which may differentiate it from other suggested generalizations of the HF conjecture.⁵

In Fig. 1, we illustrate all the quark duality diagrams that contribute to the single particle inclusive reaction, $a + b \rightarrow c + X$ in the region of a fragmenting into c . Our generalization of HF is to suppose that when no quarks are exchanged in a channel then only the pomeron and no secondary reggeons are exchanged in that channel. We will ignore the effect of low lying Regge singularities such as Regge-Regge cuts except where explicitly stated.

The crucial element in our discussion is the structure of the diagram of Fig. 1g. It has been suggested⁶ that this diagram in lowest order in the Dual Perturbation Theory⁷ does not have a triple pomeron (PPP) singularity (where the "pomeron" is defined in Ref. 4 by Fig. 2b). A thorough calculation of this diagram however does reveal such a singularity-the presence of three simultaneous divergences (which in this case give rise to the triple-pomeron singularity) in a two-loop diagram is familiar from the work of Kaku and Scherk.⁸ We also see that, as a consequence of our conjecture, the pomeron-pomeron-reggeon (PPR) coupling vanishes (or, strictly speaking, is very small) since

no quarks connect $(b\bar{b})$ to any other channel. As described in Ref. 4, the diagrams of Fig. 1 are not to be interpreted as DPT diagrams, but rather as a sum of such diagrams including closed loops and handles. Since the theory is supposed to be unitary, if we assume the pomeron to be a Regge pole with unit intercept, the triple pomeron vertex, illustrated by Fig. 1g, must vanish at $s_{a\bar{c}} = s_{a\bar{c}} = 0^9$ (even though the lowest order DPT calculation of Fig. 1g manifestly gives a non-vanishing triple pomeron vertex). In similar spirit, even though the lowest order DPT calculation of the PPR vertex of Fig. 1g does not vanish, our manner of implementing the HF conjecture requires it to vanish in the fully unitarized theory.

We find, therefore, a surprising dual structure for diffraction dissociation (and hence for the pomeron-particle amplitude). Figure 1c has resonances in the missing mass channel $(a\bar{b}\bar{c})$ which:

- (a) Do not build ordinary Regge trajectories in the crossed $(b\bar{b})$ channel.
- (b) Contribute to the pomeron (as well as lower lying Regge cuts with intercept ~ 0 presumably) in the $(b\bar{b})$ channel.

Although the first result, a, is dependent on our manner of implementing the HF conjecture, the second conclusion, b, is a general feature of DPT. Figure 2 illustrates this duality scheme.

In Fig. 3, we show that in DPT the one loop "renormalization corrections" to diffractive resonance production contributes to diffractive background production and also builds a contribution to the pomeron in $(b\bar{b})$.

We see, therefore, that the duality structure of amplitudes with external pomerons is very different from those with external

reggeons or particles. The rest of the paper is devoted to exploring phenomenological consequences of this new duality. In Section II, we will review the general formalism of inclusive diffraction dissociation and define the pomeron-particle amplitude. We will then discuss our duality scheme for this amplitude. Comparison with data in Section III is divided into three parts. First, we mention an exclusive test. Then we discuss some features of the available missing mass data. We find our conjecture is consistent with this data. Finally, we give a qualitative discussion of forward dips in missing mass diffraction peaks.

II. OUTLINE OF THE MODEL

We consider the process $a+b \rightarrow c+X$, where a and c are identical particles and b is diffractively excited into X . We define (see Fig. 4) the invariants $s = (p_a + p_b)^2$, $t = (p_a - p_c)^2$ and $M^2 = (p_a + p_b - p_c)^2$. We are interested in the limit:

$$t \text{ fixed and small, } M^2 \text{ fixed; } s \text{ large.}$$

The inclusive cross-section is dominated by pomeron plus reggeons in the $a\bar{c}$ channel. The inclusive cross-section may be written as:

$$\frac{d\sigma}{dt dM^2} = \frac{1}{s^2} \sum_{i,j} \xi_i \beta_{a\bar{c}}^i(t) \xi_j^* \beta_{a\bar{c}}^j(t) \left(\frac{s}{s_0} \right)^{\alpha_i(t) + \alpha_j(t)} A_{bb}^{ij}(t, M^2) \quad (1)$$

where $\beta_{a\bar{c}}^i$ is the usual reduced residue function; ξ_i are signature factors. We have assumed the pomeron to be a factorizing Regge pole. $A_{bb}^{ij}(t, M^2)$ is the absorptive part of the forward amplitude, free of kinematic singularities, corresponding to maximum helicity flip $= \alpha_i(t) + \alpha_j(t)$ in the crossed channel $(i\bar{j} \rightarrow \bar{b}b)$.

Consequently, for large M^2 , it behaves as:

$$A_{bb}^{ij}(t, M^2) = \sum_k \beta_{b\bar{b}}^k(o) g_{ij}^k(t, o) \left(\frac{M^2}{s_0} \right)^{\alpha_k(o) - \alpha_i(t) - \alpha_j(t)} \quad (2)$$

where we have introduced the "triple reggeon" vertices g_{ij}^k . [We have introduced a universal scale factor, s_0 , into Eqs. 1 and 2 as is conventional in Regge phenomenology. In the dual model, $s_0 = \alpha'^{-1} \approx 1 \text{ GeV}^{-1}$ where α' is the slope of the Regge trajectories.]

We thus obtain from Eqs. 1 and 2, in the helicity pole limit,¹⁰ defined by t fixed and small, large M^2 , large s/M^2 :

$$\frac{d\sigma}{dt dM^2} = \frac{1}{s^2} \sum_{i,j,k} \xi_j \beta_{a\bar{c}}^i(t) \xi_j^* \beta_{\bar{a}c}^j(t) \times \beta_{b\bar{b}}^k(o) g_{ij}^k(t, o) \left(\frac{s}{M^2} \right)^{\alpha_i(t) + \alpha_j(t)} \left(\frac{M^2}{s_0} \right)^{\alpha_k(o)} = \frac{1}{s^2} \sum_{i,j,k} G_{ij}^k \quad (3)$$

It should be stressed that since we are talking about a particular helicity coupling, g_{ij}^k is not symmetric in its indices, i.e., $g_{ij}^k \neq g_{ik}^j$. However, $g_{ij}^k = g_{ji}^{k*}$.

In Table I, we have indicated the behavior of all possible terms, G_{ij}^k , including the pomeron (with intercept 1) and the leading reggeon (with intercept 1/2). Since both the energy dependence and missing mass dependence are explicit, one can in principle extract the triple-reggeon vertices from an analysis of missing mass data over a range of energies. Such an analysis is described in Section III.

First let us discuss the implications of our dual scheme. We can extract the pomeron-particle absorptive part, $A_{bb}^{PP}(t, M^2)$, by Eq. 1. We can therefore define a pomeron-particle total cross-section, $\sigma_{tot}(t, M^2)$, where t refers to the "mass" of the

pomeron. As usual, we would expect that if we plot this quantity we would see direct channel resonances on top of non-resonant background. However, since g_{PP}^R is very small in our scheme, we do not expect these resonances to contribute significantly to reggeons in the crossed channel.

What do these resonances build? We might expect that they predominantly build lower lying "junk" in the crossed channel (such as reggeon-reggeon cuts). The pomeron-pomeron-"junk" (PPX) coupling will be labeled g_{PP}^X in this paper. As described in the introduction, the resonances also build the pomeron in the $(b\bar{b})$ channel. Unfortunately, we cannot tell, a priori, whether the resonances build primarily the pomeron (giving a σ_{tot} like Fig. 5a) or primarily lower lying junk (giving a σ_{tot} like Fig. 5b). Since the triple pomeron vertex vanishes at $t = 0$, we might expect the diffraction cross-section to level off or dip at $t = 0$. This will be further discussed in the next section. We would moreover expect the pomeron-particle amplitude to be small (for small t) compared to the typical reggeon-particle amplitude since the would-be dominant singularities, g_{PP}^R and g_{PP}^P , are both suppressed.

By considering the Finite-Mass Sum Rules¹¹ for the pomeron-particle cross-section and assuming $g_{PP}^R = 0$, we can constrain the intercept of the lower-lying junk. The first moment sum rule is (note that particles a and c are identical):

$$\int_0^N dv \nu E_c \frac{d^3\sigma}{dp_c} (a+b \rightarrow c+X) = \sum_k \left(\frac{1+\tau_k}{2} \right) \left(\frac{s}{N} \right)^{2\alpha_P(t)-1} \quad (N) \quad \alpha_k(o)+1 \quad \frac{2|\beta_{a\bar{c}}^P(t)|^2}{1-\cos\pi\alpha_P(t)} \times \frac{g_{PP}^k(t) \beta_{b\bar{b}}^k(o)}{\alpha_k(o)+2-2\alpha_P(t)} \quad (4)$$

where $\alpha_P(t)$ is the pomeron trajectory function, τ_k is the signature of the trajectory $\alpha_k(0)$, and $\beta_{jk}^i(t)$ are the conventional Regge pole couplings for a trajectory i to particles j and k . The variables $\nu = 2p_b \cdot (p_a - p_c) = M^2 - t - m_b^2$. The integration is over the range of ν up to a cutoff $N \ll s$ and t is held fixed and small.

If the pomeron contribution to the right-hand side of Eq. 4 vanishes at $t = 0$ (i.e., if $g_{PP}^P(0) = 0$) then we are left with two possibilities:

- 1) The left-hand side has a finite positive definite contribution at $t = 0$ so that for large N the right-hand side must not fall to zero. This would require a non zero coupling for g_{PP}^X where $\alpha_X(0) \geq 0$. Thus, a Regge-Regge cut with intercept ~ 0 would be a candidate for X .
- 2) The left-hand side may vanish identically at $t = 0$. This would require that all resonance contributions individually vanish. The elastic contribution arising from the process $a+b \rightarrow a+b$, would not be forced to vanish since $\nu = 0$ at $t = 0$, $M^2 = M_b^2$.

If the second possibility occurs then there is no constraint on the intercept, $\alpha_X(0)$, of the secondary singularity. However, this forces a very strong constraint on the inclusive cross-section at $t = 0$.

III. PHENOMENOLOGICAL TESTS

The pomeron-pomeron-particle vertex has been examined directly by Lipes, Robertson, and Zweig.¹² They looked at $\pi^- p \rightarrow \pi^- p(\pi^+ \pi^-)$ in the kinematic region suggested by Fig. 6. This double-Regge region might be dominated by double pomeron exchange. This would require a strong $I = 0$ signal in the produced $\pi^+ \pi^-$ pair. No evidence was found for any $I = 0$ resonance (f^0) produced by double pomeron exchange. (They also found an anomalously

small production of background by double pomeron exchange.) This is, of course, required by the vanishing of the PPR vertex in our model (in this case, R is evaluated at a physical particle pole). We should also note that if the pomeron has unit intercept then double pomeron exchange is forced by unitarity to vanish at zero momentum transfer in each pomeron.¹³ In order to distinguish this mechanism from our stronger requirement that f^0 production be suppressed for all momentum transfers, far more accurate data needs to be accumulated at the larger momentum transfers.

Many authors^{14,15,16} have recently analyzed missing mass data with a view to extracting the triple reggeon couplings and verifying that the triple pomeron coupling is small. Any analysis which aims at extracting pomeron (or reggeon)-particle cross-sections must be prefaced by the warning that the presently available data is not conclusive since the range over which (s/M^2) may be considered asymptotic is not large. Suffice it to say that, although there is a wide disparity between various fits, it seems universally agreed that the dominant coupling is g_{RR}^P , as we would have expected.³ This is the only coupling which gives a cross-section $\frac{d\sigma}{dtdM^2}$ which rises with M^2 for small negative t . (See Table I). This rising is certainly one of the most striking features of the data.¹⁷ (See Fig. 7.)

The most convincing way to extract couplings would be to obtain data on inclusive diffraction dissociation over a range of energies and to fit the energy dependence in order to extract the pomeron-particle and reggeon-particle amplitudes by Eq. 1. These amplitudes may then be inserted into Finite-Missing Mass Sum Rules¹⁰ and the relative magnitudes of g_{PP}^P , g_{PP}^R , and g_{PP}^X determined. Their behavior as a function of t should also be very interesting.^{18,19}

Since the resonances produced by diffraction dissociation contribute to the pomeron in the $(b\bar{b})$ channel, they contribute to the triple pomeron vertex. But this vanishes at $t = 0$ if the pomeron is a factorizing Regge pole.¹⁰ We might, therefore, expect the cross-section for diffractive production (i.e., energy independent) of resonances to level off or dip near $t = 0$. The exact behavior is difficult to predict because the effect will depend on the relative strengths of the PPP and PPX couplings. Indeed the point at which the diffraction peak starts to level off will be a measure of the relative strength of these terms away from $t = 0$. There is also the alternative possibility, as noted in Section II, of the diffractively produced cross-section vanishing identically at $t = 0$. This was required by the Finite-Mass sum rule if there is no non-zero g_{PP}^X coupling with $\alpha_X(0) \geq 0$. Experimentally it will, of course, be extremely difficult to distinguish between the cross-section vanishing at $t = 0$ or just dipping at $t = 0$.

In Fig. 8, we reproduce the data on resonance production diffraction peaks of Anderson, et al.²¹ for $\pi^- p \rightarrow \pi^- X$ at 8 and 16 GeV/c. This data shows anomalous behavior near $t = 0$ of the diffractive excitations $N^*(1520)$, $N^*(1688)$ (as was noted in Ref. 21). One sees that their production cross sections level off at $t \approx -0.10$ (GeV/c)². The fact that the $N^*(1410)$ does not show this feature may be due to its huge production cross-section (see Fig. 8) which indicates that it contributes enormously to g_{PP}^X which presumably swamps the effect we are looking for (assuming there is a non-zero $g_{PP}^X(0)$ with $\alpha_X(0) \geq 0$). Far more accurate data and at smaller values of t is required to confirm the presence of a dip or a zero for the other resonance diffraction peaks near $t = 0$.²²

It should be reemphasized that the property of resonances building the pomeron in the pomeron-particle amplitude does not depend on our specific manner of enforcing the HF conjecture. However, if the PPR vertex were of usual strength it would be expected to overwhelm the PPP contribution and mask the forward dip.

IV. CONCLUSION

We have shown that in a dual, unitary model, the pomeron-particle amplitude has a dual structure which differs significantly from that of particle-particle or reggeon-particle amplitudes.

In the pomeron-particle amplitude direct channel resonances contribute to the crossed channel pomeron. With the implementation of the HF conjecture that we have suggested, the direct channel resonances do not significantly build a secondary reggeon in the crossed channel (with intercept $\sim 1/2$) but they are expected to build lower lying junk (with intercept ~ 0).

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FOOTNOTES AND REFERENCES

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18. The fits of Ref. 15 are not inconsistent with our scheme since they do not try to include a g_{pp}^X term which, we have argued, should be important.
19. We have attempted an analysis in the manner outlined here of the data on $pp \rightarrow pX$ of Ref. 20. Unfortunately, several problems render the analysis difficult and ambiguous. First, at the smallest value of $t = -0.04 \text{ GeV}^2$, pion exchange is very important at 6 and 10 GeV/c and perhaps even at 15 GeV/c. This obscures the determination of the pomeron-proton and reggeon-proton amplitudes. Secondly, the experimental resolution worsens significantly with increasing energy, so that a resonance peak will appear to fall with energy even if it is produced diffractively; that is, the energy behavior at a fixed value of the missing mass

cannot be interpreted without unfolding the effect of the changing resolution. Thirdly, there are uncertainties in overall normalization, especially of the 30 GeV/c data.

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22. The reaction $pp \rightarrow pN^*$ has not been measured accurately for a range of small t and, if measured, its interpretation would probably be obscured by the contribution from pion exchange. This illustrates why $\pi p \rightarrow \pi X$ is the preferred reaction for the study of diffraction dissociation at small momentum transfers, at least at energies below those available at Serpukhov.

Table I.

i	j	k	Behavior of G_{ij}^{k*} in limit
			$s/M^2 \rightarrow \infty, M^2 \rightarrow \infty, t = 0$
P	P	P	$(M^2)^{-1}$
P	P	R	$(M^2)^{-3/2}$
P	R	P	$s^{-1/2} (M^2)^{-1/2}$
R	P	P	$s^{-1/2} (M^2)^{-1/2}$
R	R	P	$s^{-1} (M^2)^0$
P	R	R	$s^{-1/2} (M^2)^{-1}$
R	P	R	$s^{-1/2} (M^2)^{-1}$
R	R	R	$s^{-1} (M^2)^{-1/2}$

* G_{ij}^{k*} is defined by Eq. 3. The RRP term is the only one with a positive power of (M^2) at small negative values of t .

FIGURE CAPTIONS

- Fig. 1. Diagrams contributing to the process $a+b \rightarrow c+X$ in the region of a fragmenting into c . 1g is the diagram containing the triple pomeron vertex.
- Fig. 2. Duality for the pomeron-particle amplitude in our scheme.
- Fig. 3. This figure shows the equivalence between a diffractively produced resonance renormalization in DPT (a) and background production (b) which builds the pomeron in the $(b\bar{b})$ channel (c). The quark structure is shown in (d).
- Fig. 4. Kinematics for the diffractive dissociation limit.
- Fig. 5. (a) The pomeron-particle cross-section if g_{PP}^X is small relative to g_{PP}^P .
 (b) The pomeron-particle cross-section if g_{PP}^X is large relative to g_{PP}^P .
- Fig. 6. The double-Regge limit analyzed in Ref. 12. The produced $(\pi^+\pi^-)$ had low mass relative to the subenergy across the reggeons.
- Fig. 7. Single particle spectrum (from Ref. 17) for $pp \rightarrow pX$ at 24 GeV/c laboratory momentum plotted at various values of momentum transfer, t . The striking feature is the rise of the cross-section with M^2 even at comparatively small values of M^2 .
- Fig. 8. Resonance production diffraction peaks for $\pi^-p \rightarrow \pi^-X$ taken from Ref. 21. Apart from the $N^*(1400)$, the peaks show anomalous behavior near $t = 0$.

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Fig. 1a-f

g

h

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Fig. 1g-h

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Fig. 2

Fig. 3

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Fig. 4

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Fig. 5

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Fig. 6

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Fig. 7

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Fig. 8

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