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Duality and Diffraction Dissociation

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We discuss diffraction dissociation in the context of a dual model. We show how direct-channel resonances in the Pomeranchukon-particle amplitude build the Pomeranchukon in the crossed channel. A result of the enforcement of the Harari-Freund conjecture for particle-particle amplitudes is that the Pomeranchukon-Pomeranchukon-Reggeon coupling is small. The model is tested phenomenologically by the analysis of $\pi^- p \to \pi^- p(\pi^+\pi^-)$ of Lipes, Robertson, and Zweig and by baryon missing-mass data at various energies. It is also tested phenomenologically by 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-Pomeranchukon 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 $a+b\to c+X$ in the region of a fragmenting into c. Our generalization of HF is to suppose that, when no quarks are exchanged in a channel, only the Pomeranchukon 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. 1(g). It has been suggested[6] that this diagram in lowest order in the dual perturbation theory[7] (DPT) does not have a triple-Pomeranchukon (PPP) singularity [where the "Pomeranchukon" is defined in Ref. 4 by Fig. 2(b)]. 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-Pomeranchukon 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 Pomeranchukon-Pomeranchukon-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 Pomeranchukon to be a Regge pole with unit intercept, the triple-Pomeranchukon vertex, illustrated by Fig. 1(g), must vanish at $s_{a\bar{c}}=s_{a\bar{c}}=0$[9] (even though the lowest-order DPT calculation of Fig. 1(g) manifestly gives a nonvanishing triple-Pomeranchukon vertex). In similar spirit, even though the lowest-order DPT calculation of the PPR vertex of Fig. 1(g) 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 Pomeranchukon-particle amplitude). Figure 1(c) has resonances in the missing-mass channel $(ab\bar{c})$ which

(a) do not build ordinary Regge trajectories in the crossed $(b\bar{b})$ channel, and

(b) contribute to the Pomeranchukon (as well as low-lying Regge cuts with intercept ~0 presum-

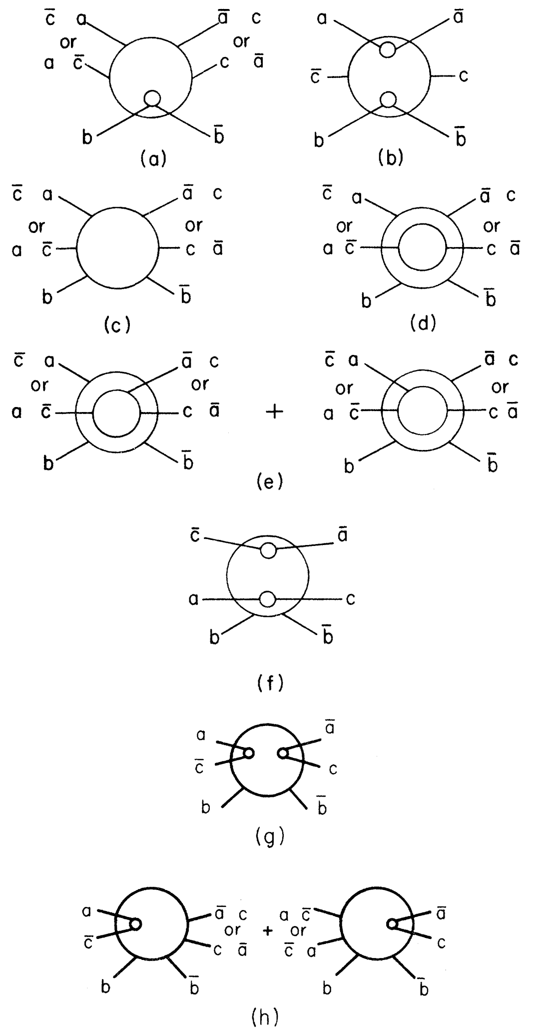

FIG. 1. Diagrams contributing to the process $a+b \to c+X$ in the region of a fragmenting into c. (g) is the diagram containing the triple-Pomeranchukon vertex.

ably) 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

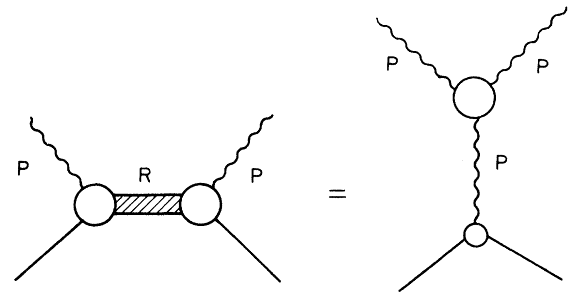

FIG. 2. Duality for the Pomeranchukon-particle amplitude in our scheme.

"renormalization corrections" to diffractive resonance production contributes to diffractive background production and also builds a contribution to the Pomeranchukon in $(b\bar{b})$.

We see, therefore, that the duality structure of amplitudes with external Pomeranchukons 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 Sec. II, we will review the general formalism of inclusive diffraction dissociation and define the Pomeranchukon-particle amplitude. We will then discuss our duality scheme for this amplitude. Comparison with data in Sec. 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 $a+b \to c+X$, 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 fixed and small, M^2 fixed; s large.

The inclusive cross section is dominated by Pomeranchukon plus Reggeons in the $a\bar{c}$ channel. The inclusive cross section may be written as

$$\frac{d^2\sigma}{dt\,dM^2} = \frac{1}{s^2}\sum_{i,j} \xi_i \beta^i_{a\bar{c}}(t)\xi_j^* \beta^j_{\bar{a}c}(t)\left(\frac{s}{s_0}\right)^{\alpha_i(t)+\alpha_j(t)} A^{ij}_{b\bar{b}}(t,M^2), \tag{1}$$

where $\beta^i_{a\bar{c}}$ is the usual reduced residue function; ξ_i are signature factors. We have assumed the Pomeranchukon to be a factorizing Regge pole. $A^{ij}_{b\bar{b}}(t,M^2)$ 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 $(i\bar{j}\to \bar{b}b)$. Consequently, for large M^2, it behaves as

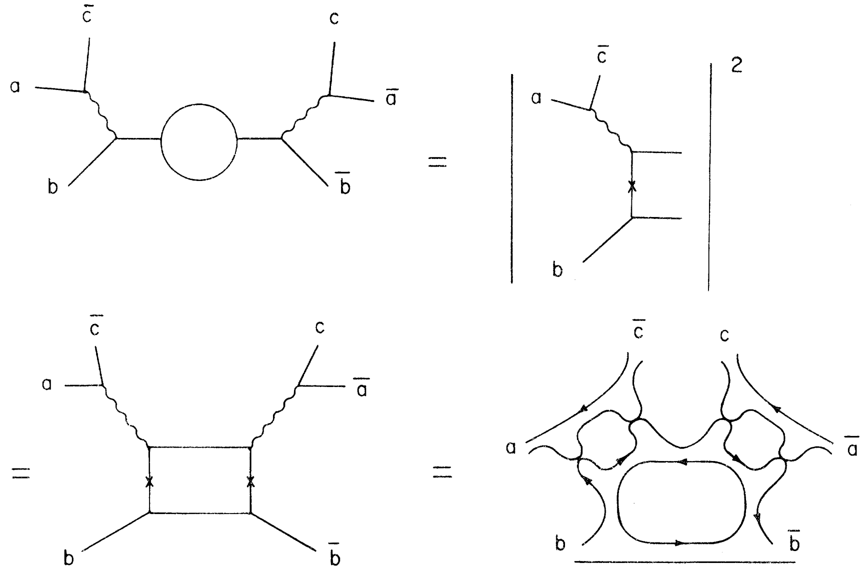

FIG. 3. This figure shows the equivalence between a diffractively produced resonance renormalization in DPT and background production which builds the Pomeranchukon in the $(b\bar{b})$ channel. The quark structure is shown in the fourth illustration.

$$A^{ij}_{bb}(t,M^2)=\sum_k \beta^k_{b\bar{b}}(0)g^{\,k}_{ij}(t,0)\left(\frac{M^2}{s_0}\right)^{\alpha_k(0)-\alpha_i(t)-\alpha_j(t)}, \tag{2}$$

where we have introduced the "triple-Reggeon" vertices $g^{\,k}_{ij}$. [We have introduced a universal scale factor s_0 into Eqs. (1) and (2) as is conventional in Regge phenomenology. In the dual model, $s_0=\alpha'^{-1}\approx 1\ \mathrm{GeV}^{-2}$ 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:

$$\frac{d^2\sigma}{dt\,dM^2}=\frac{1}{s^2}\sum_{i,j,k}\xi_j\beta^i_{a\bar{c}}(t)\xi^*_j\beta^j_{\bar{a}c}(t)\beta^k_{b\bar{b}}(0)g^k_{ij}(t,0)\left(\frac{s}{M^2}\right)^{\alpha_i(t)+\alpha_j(t)}\left(\frac{M^2}{s_0}\right)^{\alpha_k(0)}$$
$$\equiv\frac{1}{s^2}\sum_{i,j,k}G^k_{ij}\ . \tag{3}$$

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

In Table I, we have indicated the behavior of all possible terms G^k_{ij} including the Pomeranchukon (with intercept 1) and the leading Reggeon (with intercept $\frac{1}{2}$). 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 Sec. III.

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

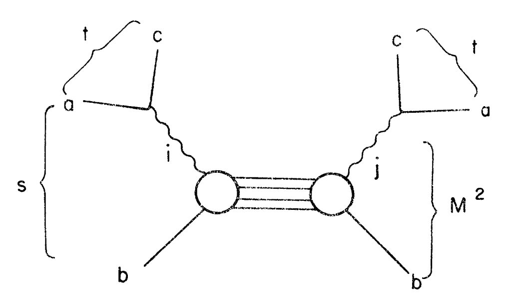

FIG. 4. Kinematics for the diffractive-dissociation limit.

TABLE I. Behavior of all possible terms G_{ij}^k in the limit $s/M^2 \to \infty$, $M^2 \to \infty$, $t=0$.

i	j	k	Behavior [a] of G_{ij}^k in limit $s/M^2 \to \infty$, $M^2 \to \infty$, $t=0$
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	$s^{-1}(M^2)^{-1/2}$

[a] 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.

usual, we would expect that if we plot this quantity we would see direct-channel resonances on top of nonresonant 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 singularities in the crossed channel (such as Reggeon-Reggeon cuts). The coupling of two Pomeranchukons to these lower-lying singularities (which we will refer to collectively as X) will be abbreviated as g_{PP}^X in this paper. As described in the Introduction, the resonances also build the Pomeranchukon in the $(b\bar{b})$ channel. Unfortunately, we cannot tell, *a priori*, whether the resonances build *primarily* the Pomeranchukon [giving a σ_{tot} like Fig. 5(a)] or *primarily* lower-lying singularities [giving a σ_{tot} like Fig. 5(b)]. Since the triple-

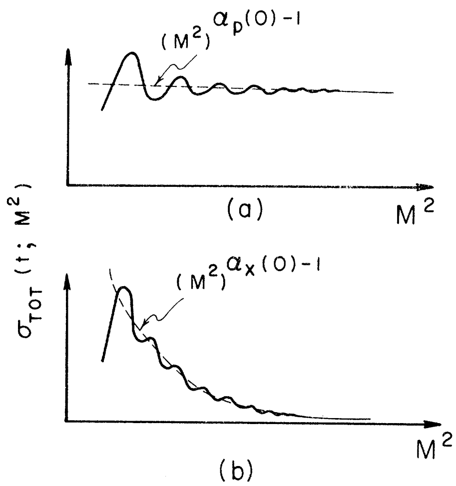

FIG. 5. (a) The Pomeranchukon-particle cross section if g_{PP}^X is small relative to g_{PP}^P. (b) The Pomeranchukon-particle cross section if g_{PP}^X is large relative to g_{PP}^P.

Pomeranchukon 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 Pomeranchukon-particle amplitude to be small (for small t) compared to the typical Reggeon-particle amplitude since the would-be dominant couplings, g_{PP}^R and g_{PP}^P, are both suppressed.

By considering the finite-mass sum rules [11] for the Pomeranchukon-particle cross section and assuming $g_{PP}^R=0$, we can constrain the maximum intercept of the lower-lying singularities X. The first-moment sum rule is (note that particles a and c are identical):

$$\int_0^N d\nu\, \nu E_c \frac{d^3\sigma}{dp_c}(a+b\to c+X)=\sum_k \left(\frac{1+\tau_k}{2}\right)\left(\frac{s}{N}\right)^{2\alpha_P(t)-1}(N)^{\alpha_k(0)+1}\frac{2|\beta_{a\bar{c}}^P(t)|^2}{1-\cos\pi\alpha_P(t)}\,\frac{g_{PP}^k(t)\beta_{b\bar{b}}^k(0)}{\alpha_k(0)+2-2\alpha_P(t)}\,, \qquad (4)$$

where $\alpha_P(t)$ is the Pomeranchukon trajectory function, τ_k is the signature of the trajectory $\alpha_k(0)$, and $\beta_{j\bar{k}}^i(t)$ 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 Pomeranchukon 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 nonzero 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 $a+b\to a+b$, 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 Pomeranchukon-Pomeranchukon-particle vertex has been examined directly by Lipes,

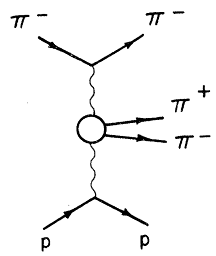

FIG. 6. The double-Regge limit analyzed in Ref. 12. The produced $(\pi^+\pi^-)$ had low mass relative to the sub-energy across the Reggeons.

Robertson, and Zweig.[12] They looked at $\pi^- p \to \pi^- p(\pi^+\pi^-)$ in the kinematic region suggested by Fig. 6. This double-Regge region might be dominated by double-Pomeranchukon 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-Pomeranchukon exchange. (They also found an anomalously small production of background by double-Pomeranchukon 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 Pomeranchukon has unit intercept then double-Pomeranchukon exchange is forced by unitarity to vanish at zero momentum transfer in each Pomeranchukon.[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 need to be accumulated at larger momentum transfers.

Many authors[14-16] have recently analyzed missing-mass data with a view to extracting the triple-Reggeon couplings and verifying that the triple-Pomeranchukon coupling is small. Any analysis which aims at extracting Pomeranchukon- (or Reggeon-) particle cross sections must be prefaced by the warning that the presently available data are 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 $d^2\sigma/dt\,dM^2$ 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 Pomeranchukon-particle and Reggeon-particle ampli-

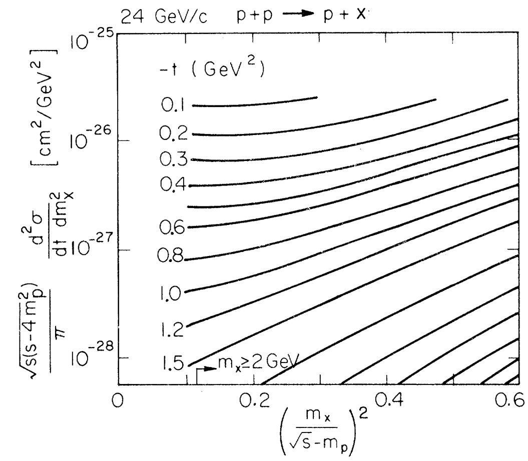

FIG. 7. Single-particle spectrum (from Ref. 17) for $pp \to pX$ at 24 GeV/c laboratory momentum plotted at various values of momentum transfer, t. The striking feature is the rise of the cross section with M^2 even at comparatively small values of M^2.

tudes by Eq. (1). These amplitudes may then be inserted into finite-missing-mass sum rules[10] 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 Pomeranchukon in the $(b\bar{b})$ channel, they contribute to the triple-Pomeranchukon vertex. But this vanishes at $t=0$ if the Pomeranchukon is a factorizing Regge pole.[9] 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 Sec. 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 nonzero 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.*[20] for $\pi^- p \to \pi^- X$ at 8 and 16 GeV/c. These data show 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 $t \approx -0.10$ $(\mathrm{GeV}/c)^2$. The fact

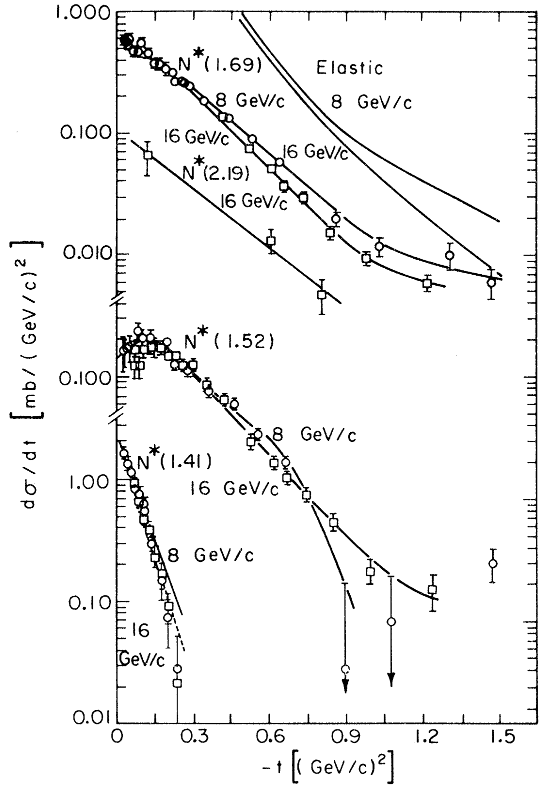

FIG. 8. Resonance production diffraction peaks for $\pi^- p \rightarrow \pi^- X$ taken from Ref. 21. Apart from the $N^*(1400)$, the peaks show anomalous behavior near $t = 0$.

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^X_{PP} which presumably swamps the effect we are looking for [assuming there is a nonzero $g^X_{PP}(0)$ with $\alpha_X(0) \geq 0$]. Far more accurate data and at smaller values of t are required to confirm the presence of a dip or a zero for the other resonance diffraction peaks near $t = 0$.[21]

It should be reemphasized that the property of resonances building the Pomeranchukon in the Pomeranchukon-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 Pomeranchukon-particle amplitude has a dual structure which differs significantly from that of particle-particle or Reggeon-particle amplitudes.

In the Pomeranchukon-particle amplitude, direct-channel resonances contribute to the crossed-channel Pomeranchukon. 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 $\sim\frac{1}{2}$) but they are expected to build lower-lying singularities (with intercept ~0).

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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 $pp \to pX$ given in E. W. Anderson *et al.*, Phys. Rev. Letters 15, 855 (1966); R. M. Edelstein *et al.*, Phys. Rev. D 5, 1073 (1972). Unfortunately, several problems render the analysis difficult and ambiguous. First, at the smallest value of t, -0.04 (GeV/c)^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 Pomeranchukon-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 over-all normalization, especially of the 30-GeV/c data.

[20]E. W. Anderson *et al.*, Phys. Rev. Letters 25, 699 (1970).

[21]The reaction $pp \to pN^*$ 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 $\pi p \to \pi X$ is the preferred reaction for the study of diffraction dissociation at small momentum transfers, at least at energies below those available at Serpukhov.

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Two-Particle Inclusive Reactions in 9 GeV/c K^-p Collisions*

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Cross sections and correlation functions are presented for two-body inclusive channels in K^-p collisions. The cross sections for two particles emitted in the same hemisphere depend mainly on the variable (x_1+x_2), where $x_i \equiv p_{\parallel}^{*i}/p_{\max}^{*}$. Interpretations are given of the appreciable correlations which occur in addition to those imposed by momentum conservation.

It is by now common knowledge that the programs of measuring cross sections for all exclusive channels and of measuring n-particle inclusive cross sections are complementary approaches to the experimental study of hadron-hadron collisions. In the recent past, the basic ideas[1] of limiting fragmentation and scaling have been shown to provide a useful framework within which to discuss data on inclusive reactions.[2] However, several different physical pictures lead to quite similar expectations about the behavior of single-particle spectra. On the other hand, the multiperipheral gas analogy[3] and the fragmentation picture[4] have, at least at extremely high energies, very different consequences for *multiparticle* inclusive cross sections and for correlation functions. While the distinctions are unlikely to be sorted out at sub-ISR (CERN Intersecting Storage Rings) energies, experimental results at modest energies are useful for learning how to look at multiparticle inclusive cross sections and for trying to discern trends that hint at the character of the very high energy phenomena.

Here we report two-particle inclusive cross sections for the reactions $K^-p \to \pi^\pm\pi^\pm$ + anything at 9 GeV/c. Single-particle spectra from this experiment, performed in the Brookhaven National Laboratory 80-in. hydrogen bubble chamber, have been published previously.[5] For completeness, we give the single-particle spectra in Tables I and II. We employ Feynman's longitudinal momentum scaling variable $x = p_{\parallel}^{*}/p_{\max}^{*}$, in terms of which momentum conservation constraints are easily expressed:

$$|\textstyle\sum x_i| \le 1,$$

where the sum runs over particles emitted in the forward ($x_i > 0$) or backward ($x_i < 0$) hemisphere. Throughout we shall ignore $p_\perp$ as small. We write the two-body cross section as

$$f_2(x_1, x_2) = \frac{d^2\sigma(x_1, x_2)}{dx_1 dx_2} = \frac{1}{\sigma_{\text{total}}} \frac{d\sigma(x_1)}{dx_1} \frac{d\sigma(x_2)}{dx_2} + C(x_1, x_2). \quad (1)$$