A Model for Pomeranchukon Couplings

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We present a model for the Pomeranchukon which relates its couplings to those of the f and f' trajectories. We successfully explain several features of total-cross-section data, and discuss s-channel helicity conservation at high energies in πN scattering and ρ photoproduction, but we do *not* expect it to be a feature of all diffractive processes.

The nature of diffraction scattering has long been shrouded in mystery. In this Letter, we outline[1] a simple model in which diffraction scattering is generated by the shadow of inelastic processes. Using duality, we relate Pomeranchukon couplings to those of the f and f' trajectories. The couplings so obtained (a) factorize, (b) transform as a combination of SU(3) singlet and octet in a prescribed ratio, and (c) explain "s-channel helicity conservation" in πN scattering and ρ photoproduction.

We find quantitative experimental support for these predictions. The model correctly accounts for the relative importance of Pomeranchukon exchange in πp, pp, γp, and Kp total cross sections. Point (b) correctly explains the observed deviation of the ratios $\sigma_{\text{tot}}(\pi p)/\sigma_{\text{tot}}(Kp)$ and $\sigma_{\text{tot}}(\rho p)/\sigma_{\text{tot}}(\varphi p)$ from unity. We find further that s-channel helicity should not be conserved in all diffractive processes.

This property of the Pomeranchukon coupling through the f and f' is a general feature of several models.[1] In this note we describe one simple model, the dynamical content[2] of which is illustrated in Fig. 1. We represent the inelastic intermediate states by two distinct groups of particles ("fireballs") as in Fig. 1(c), whose production we assume to proceed by Regge exchange [Fig. 2(a)].[3] The sum over intermediate states in Fig. 2(a) is given by an integral over the masses M_1^2 and M_2^2 and the momentum transfers t' and t''.

Each side of Fig. 2(a) has the form of a scattering process: Reggeon + particle → Reggeon + particle. Duality enables us to replace the sum over intermediate states on each side by Regge trajectories as illustrated in Fig. 2(b). We assume that the relevant trajectories, α_1 and α_2, are the[4] f and f' and that a possible Pomeranchukon contribution is negligible. (We also neglect lower-lying trajectories.) The form for the J-plane structure of the t-channel partial-wave amplitude may be written as

$$\mathrm{Im}A(J,t)=\frac{\beta_1^{(J,t)}}{J-\alpha_1(t)}B_{12}(J,t)\frac{\beta_2^{(J,t)}}{J-\alpha_2(t)}+\text{contributions of Regge poles,} \tag{1}$$

following the techniques of Gribov.[5] Here, β_1 and β_2 are Regge residues and $B_{12}(J,t)$ has the Pomeranchukon singularity at $J=\alpha_P(t)$. The trajectories $\alpha_1(t)$ and $\alpha_2(t)$ denote the f and/or the f' according to the quantum numbers of the external particles.[6] We shall restrict our considerations to the neighborhood $t\approx 0$. The applications described in this paper depend only on the general form of Eq. (1) and not on the exact nature of the Pomeranchukon singularity [although in the model described above the singularity is just the Amati-Fubini-Stanghellini (AFS) cut,[7] this is not a crucial feature[8]].

Note that $B_{12}(J,t)$ bears no reference to the external particles and hence the Pomeranchukon factor-

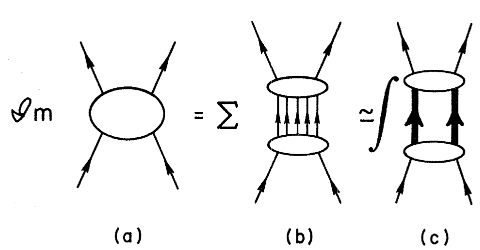

FIG. 1. Unitarity equation. The inelastic states are approximated by two fireballs (c).

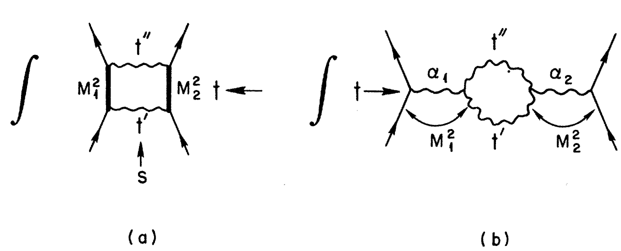

FIG. 2. (a) Regge exchange approximation to the unitarity sum. (b) The result of applying duality to (a).

izes. Furthermore, its coupling to the external particles is proportional to $\beta_i(\alpha_P, t)/(\alpha_P - \alpha_i)$. We make the standard assumption that the Pomeranchukon is a singlet in the limit of SU(3) symmetry, and take symmetry breaking into account in the usual fashion: Couplings remain SU(3) symmetric, but the particle masses (i.e., trajectory slopes and intercepts) are shifted. B_{12} remains a singlet, and the f and f' are taken to be the ideal mixture of SU(3) singlet and octet, decoupling the f' from nucleons.[9]

The explicit dependence on α_f and $\alpha_{f'}$ from Eq. (1) induces an effective SU(3)-symmetry breaking in the Pomeranchukon coupling. This is parametrized by the ratio

$$r(t) = [\alpha_P(t) - \alpha_f(t)]/[\alpha_P(t) - \alpha_{f'}(t)]. \qquad (2)$$

Assuming $\alpha_P(0) \simeq 1$, we estimate[10] $r(0) \simeq 0.6$ from the physical masses of particles on the f'-φ and f-ω exchange-degenerate trajectories. This leads to certain experimental consequences[11-17] which are summarized in the first half of Table I. Consider, for example, $\sigma_{tot}(Kp)/\sigma_{tot}(\pi p)$. By the optical theorem this is equal to $\mathrm{Im}A(Kp \to Kp, t=0)/\mathrm{Im}A(\pi p \to \pi p, t=0)$. Using SU(3) and Eqs. (1) and (2), we predict

$$\frac{\sigma_{tot}(Kp)}{\sigma_{tot}(\pi p)} \xrightarrow[s\to\infty]{} \frac{1+r(0)}{2} \simeq 0.8. \qquad (3)$$

Similarly, $\sigma_{tot}(\varphi p)/\sigma_{tot}(\rho p) \simeq 0.6$. The data appear consistent with these values.

Another crucial test of the model is provided by the comparison of the ratio of the Pomeran-

Table I. Relative strengths of Pomeranchukon and f couplings. Different columns correspond to different Regge fits. Our theory does not specify the value of a. Different types of Regge fits give different values of a. The numbers quoted are subject to typical errors of about 20%.

	Experiment				Theory
$\frac{\sigma_{tot}(\varphi p)}{\sigma_{tot}(\rho p)}$	0.5 ± 0.3 (Ref. 7)				$r(0) \simeq 0.6$
$\frac{\sigma_{tot}(Kp)}{\sigma_{tot}(\pi p)}$	0.8	0.8	0.8	0.8	$\frac{1+r(0)}{2} \simeq 0.8$
$\frac{c_f(\pi p)}{c_P(\pi p)}$	0.9	1.0	1.8	1.2	a
$\frac{c_f(pp)}{c_P(pp)}$	1.2		1.6	1.3	a
$[1+r(0)]\frac{c_f(Kp)}{c_P(Kp)}$	0.8	0.9	1.6	1.4	a
$\left[1+\frac{r(0)}{5}\right]\frac{c_f(\gamma p)}{c_P(\gamma p)}$	1.0				a
type of fit	poles	poles	poles + cut	Regge eikonal	
$\alpha_f(0)$	0.5	0.6	0.4	0.4	
references	8, 9	10, 11	12	13	

chukon coupling to that of the f in various reactions. A summary of the results of this test is presented in the second half of Table I.

The terms in the Regge fit have been parametrized as $c_P\nu^{\alpha_P}$ and $c_f\nu^{\alpha_f}$, where $\nu=(s-u)/2$ in units of $(\mathrm{GeV})^2$, and c_P and c_f are the couplings of the Pomeranchukon and the f singularities, respectively. For πp and pp, the numbers quoted are simply the ratios c_f/c_P obtained in the various fits. The f' trajectory decouples from $N\bar{N}$ and hence is not observed in Regge fits. On the other hand, for Kp and γp the Pomeranchukon can couple to KK and $\gamma\gamma$ through the f' as well as the f. In Kp scattering, the contribution of the f' to the Pomeranchukon coupling is $r(0)$ times that of the f. Hence, we expect

$$[1+r(0)]\frac{c_f(Kp)}{c_P(Kp)}=\frac{c_f(\pi p)}{c_P(\pi p)}=\frac{c_f(pp)}{c_P(pp)}=a. \qquad (4)$$

Similarly, for γp we predict[18]

$$[1+\tfrac{1}{5}r(0)]c_f(\gamma p)/c_P(\gamma p)=a. \qquad (5)$$

We should emphasize that apart from this model we know of no reason why the quantities tabulated in Table I should be correlated.

The observation of s-channel helicity conservation[19] for the diffractive part of πN scattering[20] and ρ photoproduction[21] has stimulated considerable theoretical interest. It is clear that in the present model the Pomeranchukon can decouple from a given amplitude only if the f and f' also decouple. The investigation of helicity conservation is reduced, therefore, to a study of the couplings of the f and f' trajectories.

Consider first πN scattering. For large s, helicity conservation is equivalent to a decoupling of the Pomeranchukon from the invariant amplitude[22] $A^{(+)}(s,t)$. Experimentally, there are strong indications that both the Pomeranchukon and the f decouple from $A(s,t)$.[23,24] It is important to note that in $A^{(+)}(s,t)$ the tensor nonet cannot decouple from the baryon octet entirely. In particular, Bander[25] has shown that sum rules derived by assuming that the f decouples from $A(s,t)$ in $\pi\Sigma\to\pi\Sigma$, $\pi\Lambda\to\pi\Lambda$, and $\pi\Xi\to\pi\Xi$ are badly violated, while the sum rules for $\pi N\to\pi N$ and $KN\to KN$[26] are well satisfied. Furthermore, in $\pi p\to\eta p$, $K^-p\to\bar{K}^0n$, and $K^0p\to K^+n$, the A_2 (along with the ρ) couples dominantly to the s-channel spin-*flip* amplitude.[27] Thus, in our model, helicity conservation is dependent on a particular F/D ratio ($\frac{1}{3}$) for the coupling of tensor mesons to the baryon octet. In the context of duality, which our model embodies, plausible arguments[28] have been advanced favoring an F/D ratio of $\frac{1}{3}$ for the $A^{(+)}$ amplitude.[29]

In ρ^0 photoproduction,[21] it has been found that the produced ρ carries the helicity of the incoming photon [at least for $|t|<0.4$ $(\mathrm{GeV}/c)^2$]. The present data do not contradict our prediction that the f contribution should also conserve helicity. On the theoretical side, we are able to show that in a specific model[30] the f trajectory conserves helicity in this process. However, this type of model does *not* predict s-channel helicity conservation for $\pi p\to A_1p$[31] and similar processes.

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[1]Details of topics mentioned here are contained in R. Carlitz, M. B. Green, and A. Zee, to be published.

[2]Our model has the general features of the Pomeranchukon of the dual-resonance model (C. Lovelace, to be published), the multiperipheral model [G. F. Chew, M. L. Goldberger, and F. E. Low, Phys. Rev. Lett. 22, 205 (1969)], and the weak-cut model [R. Hwa, Phys. Rev. D 1, 1790 (1970)]. Our results, however, do not depend on the detailed nature of the Pomeranchukon singularity.

[3]The exchanges in Fig. 2(a) consist of Pomeranchukon plus lower-lying Regge poles.

[4]The f trajectory is taken to be the same as the P', the vacuum trajectory with intercept about 0.5 below the Pomeranchukon.

[5]V. N. Gribov, Zh. Eksp. Teor. Fiz. 53, 654 (1967) [Sov. Phys. JETP 26, 414 (1968)].

[6]Lovelace (Ref. 2) has also derived a connection between the Pomeranchukon and the f trajectory in a model for scalar particles.

[7]D. Amati, S. Fubini, and A. Stanghellini, Nuovo Cimento 26, 626 (1962).

[8]In the specific model described in this paper $B_{12}(J,t)$ is represented by the loop (Ref. 3) in Fig. 2(b). It contains the AFS cut (Ref. 7) due to the exchange of two Pomeranchukons. Self-consistency (Ref. 2) between the input and output Pomeranchukon singularities would force the Pomeranchukon to be a cut with intercept $\alpha_P(0)=1$. The results of this paper are also obtained in a model in which the Pomeranchukon is a pole with $\alpha_P(0)<1$. See R. Carlitz, M. B. Green, and A. Zee, to be published.

[9]This implies the ratios $B_{ff}/B_{ff'}=B_{ff'}/B_{f'f'}=\sqrt{2}$.

[10]There is considerable theoretical uncertainty in determining $r(0)$ since the f' trajectory intercept is not directly observable. A straight-line extrapolation through f'-φ and f-ρ gives $r(0)=0.7$; assuming the universal slope for the f' trajectory gives $r(0)=0.5$.

[11]See review by R. Diebold, in *Proceedings of the Boulder Conference on High Energy Physics*, edited

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[17]C. J. Hamer and F. Ravndal, Phys. Rev. D 2, 2687 (1970).

[18]The coefficient $[1+r(0)/5]$ would be $[1+r(0)m_\rho^2/5m_\varphi^2]$ in the vector-dominance model.

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[21]J. Ballam *et al.*, Phys. Rev. Lett. 24, 960 (1970).

[22]The T matrix for πN scattering has the standard form $T=\bar{u}(p')[A+\gamma\cdot(q+q')B]u(p)$.

[23]G. Höhler and R. Strauss, Z. Phys. 232, 205 (1970); Barger and Phillips, Ref. 16.

[24]This has revived speculation that the f meson lies on the Pomeranchukon trajectory. See, e.g., P. Achutan, H. G. Schlaile, and F. Steiner, Nucl. Phys. B24, 398 (1970). This is not the case in our model.

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[27]G. C. Fox, in *High Energy Collisions*, edited by C. N. Yang *et al.* (Gordon and Breach, New York, 1969).

[28]P. R. Auvil, F. Halzen, and C. Michael, Nucl. Phys. B25, 317 (1970); M. Rimpault and Ph. Salin, Nucl. Phys. B22, 235 (1970).

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[30]We obtain s-channel helicity conservation for $\pi\rho \to \pi\rho$ if we assume that the natural-parity trajectories in the t channel are built, to leading order, by the sum of natural-parity resonances in the s channel. This result depends on the unique coupling through the antisymmetric symbol at the π-ρ natural-parity-resonance vertices. Use of s-channel factorization of helicity amplitudes then gives helicity conservation for $\rho p \to \rho p$ and hence $\gamma p \to \rho p$. Details are presented in Ref. 1. Note that s-channel factorization of helicity amplitudes can be used to predict helicity conservation for other processes, e.g., $pp \to pp$.

[31]Indeed, s-channel helicity conservation does not seem valid for this process. Illinois-Genova-Hamburg-Milano-Saclay-Harvard-Toronto-Wisconsin Collaboration, to be published; Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-London-Vienna Collaboration, Phys. Lett. 34B, 160 (1971).