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IS THE POMERANCHON AN ORDINARY REGGE TRAJECTORY?*

by

Haim Harari
Weizmann Institute of Science, Rehovoth, Israel
and
Stanford Linear Accelerator Center
Stanford University, Stanford, California

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I. INTRODUCTION

In this lecture we deal with two closely related topics. We first present some general remarks concerning the possible relation between Regge poles and cuts on one hand and various optical models for high energy hadron collisions on the other hand. We then discuss a specific model for the Pomeranchuk trajectory and try to see whether or not it has a special diffractive character which distinguishes it from other trajectories.

The phenomenological description of high energy hadronic processes in terms of a simple set of Regge trajectories has been extremely successful in a large number of cases. At the same time, however, the model has encountered some difficulties in explaining specific aspects of various reactions. When we talk about such "difficulties" we really refer to the necessity of introducing (otherwise unwanted) extra Regge poles or cuts for explaining a given experimental observation. The conjecture that is really being tested by these "difficult" processes is the statement that "the Regge-pole description of high energy hadronic processes is simple". It is almost certain that with a sufficient number of conspiring and/or evading poles and cuts, all presently available experiments can be properly fitted. This is true in the same sense that it is true that we can properly fit all scattering data with a sufficient number of contributing partial waves in a partial wave expansion. However, the question that one would really like to study is this: Do we have here a simple, physical explanation of the data, correlating many empirical observations, or do we just play a game of expanding a physical amplitude in terms of a very large number of contributing terms whose relative importance is unpredicatable?

In this lecture we will present the following point of view:

a) There is already a sufficiently large number of experimental facts which demand extra "exotic" Regge poles and possibly cuts.

b) It is probably possible to fit all existing data with such poles and cuts.

c) In many cases the fits are insignificant because the assumed model has too much freedom.

d) There may exist some other physical picture of high energy reactions, which is outside the usual model of t-channel exchange of poles and cuts. Such a picture may be complementary to the ordinary Regge picture in the sense that it imposes relations between previously unrelated parameters of Regge theory. Two particularly interesting possibilities of obtaining such "external" information may be the various versions of the optical model and the consideration of s-channel properties of scattering amplitudes. Both are outside the conventional procedure of Regge parametrizations of high energy amplitudes, but are consistent with the general philosophy of Regge theory. The conclusions of such approaches may be translated into "Regge-language" as constraints on various trajectories and their residues.

In Section II we list some phenomena which, we believe, demonstrate the necessity of introducing "extra" Regge poles or cuts, and which can be explained only in terms of "unwanted" contributions. We then proceed to present some general questions related to the possible peaceful coexistence of an optical picture and a Reggeistic description. In Section IV we start analyzing a particular example of such a connection - the nature of the Pomeranchuk trajectory and its possible diffractive origin. In the remaining sections we present a model which distinguishes between the Pomeranchon and the other "ordinary" trajectories. This model, besides its specific interesting predictions, may serve as an illustration of what we mean when we talk about constraints among Regge trajectories and their residues, imposed by "external" information.

II. PHENOMENOLOGICAL "DIFFICULTIES" OF "SIMPLE" REGGE-POLE THEORY

Keeping in mind the long, impressive list of successes of Regge pole theory,[1] we present here a set of experimental observations which have emerged in the last year or so as sources of difficulties for the simplest version of the theory. We do not attempt here a complete analysis of any of these reactions, but point out in every case what are the necessary extra ingredients.

a) The persistent non-vanishing polarization in $\pi^- + p \longrightarrow \pi^0 + n$ contradicts the simple ρ- exchange model and requires at least a ρ'-trajectory or a ρ-Pomeranchon cut.[1]

b) The sharp forward peak in n + p charge exchange requires either a $\pi - \pi'$ conspiracy or a π - P cut.[1] The absence of a forward dip in $\pi p \longrightarrow \rho\Delta$ hints that the π - P cut explanation is actually favored.[2] The ratio between $\sigma(pn \longrightarrow np)$ and $\sigma(\bar{p}p \longrightarrow \bar{n}n)$ at small t indicates that a second cut or a second conspiring pair may be necessary.[3]

c) The sharp forward peak in $\gamma + p \longrightarrow \pi^+ + n$ requires a $\pi - \pi'$ conspiracy with a rapid variation of the π-residue function,[4] or a π - P cut.[5] The π^+/π^- ratio in $\gamma + d \longrightarrow \pi^{\pm} + N + N$ requires strong interference between opposite G-parity exchanges, at large t. Either a strong B exchange or a ρ - P cut are necessary.

d) The forward dip in $\gamma p \longrightarrow K^+\Lambda$ requires a strange t-dependence of the K residue function,[4] if a K - K' conspiracy is assumed. Alternatively, a K - P cut has to be introduced.

e) The large ρ_{00} density matrix element for the produced ω in $\pi + N \longrightarrow \omega + N$ and $\pi + N \longrightarrow \omega + \Delta$ requires an unusually large contribution of B-exchange[6] or a ρ - P cut.

f) The disappearance[7] of the $t = -0.5\ \mathrm{BeV}^2$ dip at $E_\gamma > 10\mathrm{BeV}$ $\gamma + p \longrightarrow \pi^0 + p$ leads to an appreciable B-exchange contribution, larger by a factor 10, at least, than the prediction of the vector meson dominance model.[8] This difficulty is removed only if we introduce an ω'-pole or an ω - P cut contribution.

f) Factorization and the crossover phenomenon in pp and $\overline{p}$p elastic scattering predict t = -0.15 dips at all ω-exchange reactions such as $\gamma p \longrightarrow \pi^o p$ and the I = 0 t-channel combination of $\pi N \longrightarrow \rho N$ processes.[9] The absence of such dips leads to an ω' or an ω - P cut.

g) The energy dependence of $\gamma p \longrightarrow \pi^+ n$, $\gamma n \longrightarrow \pi^- p$, $\pi N \longrightarrow \rho N$, $\gamma p \longrightarrow \pi^o p$, $\gamma p \longrightarrow K^+ \Lambda$ is consistent with $\alpha_{eff}(t) = 0$ for $0 \leq |t| \leq 1$ BeV^2. At least one of the leading poles or cuts in each case has to be almost fixed in t up to $|t| \sim 1$BeV^2.

We believe that this list, which by no means exhausts the presently known "difficulties" demonstrates the necessity of introducing either Regge cuts or a large number of important new Regge trajectories which do not correspond to any known particles and which, in some cases, have unusual slopes and residue functions. In view of this proliferation we believe that the predictive power of the model will be retained only if we can find ways of correlating the residue functions and trajectories of different poles. This is particularly relevant if cuts are proved to be important, since in this case the factorization property is lost and the arbitrariness in choosing the parameters is significantly increased.

III. SOME GENERAL REMARKS ON OPTICAL MODELS AND REGGE CUTS

The usual "optical" description of high energy hadron reactions runs as follows: Total cross sections are supposed to involve approximately equal contributions from all partial waves $0 \leq \ell \leq \ell_{max} = kR$ where R is the "target radius" and k is the incident momentum. Inelastic channels are said to be dominated by some "ring" of ℓ-values ranging from $\ell_{min} = kr$ to $\ell_{max} = kR$, where r and R are fixed radii, R corresponding to the "target radius" and r representing the radius within which "absorption" occurs. The absorption model for inelastic processes usually involves some (highly unreliable) Born-approximation calculations which are then supposed to be corrected by absorbing most of the contribution of $\ell \leq \ell_{min}$ partial waves, leaving mainly the contributions of the "ring" $\ell_{min} \leq \ell \leq \ell_{max}$. This version is, in general, totally inadequate since, except for spin-zero exchange, it predicts a wrong energy dependence for the amplitudes. It is possible, however, that the main source of evil here is the basic Born approximation rather than the general concept of absorption.

What, if any, ingredients of the "optical" picture of inelastic processes should we try to use in the Regge model and how does one translate this picture into the language of Regge poles and cuts?

It is easy to see that the usual absorption corrections, when translated to the language of Regge theory will normally result in contributions of cuts. This has not yet been proved in complete generality, and it is probably possible to construct artificial models with absorption in which cuts are unimportant. However, the straightforward application of any of the usual absorption techniques would immediately lead to the presence of Regge cuts. This does not mean that the cuts represent the entire effect of absorption. It is probable that, in general, a portion of the "absorption correction" is already included in the Regge-pole contributions, and the quantitative separation of the cut and pole absorption effects cannot be made without a satisfactory detailed model. Such a model has not yet been proposed.

Why do we believe that some kind of absorption picture is relevant and that the Regge cuts are important? There are, at least, three different indications that we would like to mention here.

a) One of the clear features of any version of the absorption model is that it destroys all polarization and spin-alignment predictions and selection rules of the "uncorrected" one-particle-exchange (OPE) model. This is true for cases in which OPE predicts zeros in forward amplitudes or the vanishing of specific helicity amplitudes, density matrix elements or polarizations. Many of these OPE predictions survive in Regge pole theory. In almost all the cases for which the data are conclusive, these predictions completely fail (including cases (a) -(f) of the previous section). The presence of Regge cuts is the simplest explanation of this consistent failure of the poles-only picture, and the analogy between this situation and the necessity of absorption in the OPE model is very suggestive.

b) The analysis of the sharp forward peaks in p - n charge exchange and charged pion photoproduction indicates that the invariant amplitudes to which pion-exchange is allowed to contribute are non-vanishing and rapidly varying with t, at very small forward angles. This can be naturally explained if the $\theta = 0^{\circ}$ cross section is entirely contributed by an approximately t-independent cut contribution (or some kind of absorption correction) interfering with a Reggeized one-pion-exchange amplitude which vanishes at $t = 0$ but changes considerably at small t because of its $(t - m_{\pi}^2)^{-1}$ factor.[5]

c) Considerations based on finite energy sum rules[10] in their "local average" form[11] indicate[12] that Regge trajectories rise at large s according to $\alpha(s) \sim \sqrt{s}$ If inelastic amplitudes are dominated in the s-channel by a (possibly very large) set of s-channel trajectories, we get from this Reggeistic picture a condition similar to that of the absorption model, namely - at a given s a "bunch" of ℓ values dominate, while their ℓ_{min} and ℓ_{max} change proportionally to $\sqrt{s} \sim k$.

In view of these and other indications, we therefore suspect that the π - P, ω- P, ρ - P and similar cuts are the ones responsible for the phenomenon mentioned in Section II, and that we should try to use some external information to correlate the ω - pole and ω- P cut contributions, etc. A possible way of doing so could be to insist that their combined contribution has a small projection on all $\ell \leq \ell_{min}$ partial waves at a given incident k. This is, however, a relatively weak requirement and extra quantitative assumptions are needed. At present, we do not have such a quantitative scheme.

It is, of course, possible that there is an entirely different true and simple explanation of high energy scattering phenomena, which uses neither the absorption nor the Regge theory terminology and which includes some or none of the physical ideas of these theories. If this is the case, what we do when we talk about poles or cuts is to use a cumbersome translation of the "true explanation" into our present awkward language.

IV. IS THE POMERANCHON AN ORDINARY TRAJECTORY?

The Pomeranchuk trajectory was first introduced in order to account for the apparent asymptotic constancy of high energy hadron total cross sections. Either the successful diffraction model for elastic scattering (which we have briefly mentioned in the previous section) or the direct experimental observations can be referred to as the reason for introducing this trajectory. This leads us to the question whether or not the Pomeranchon is an ordinary moving-pole. We first study this problem from various qualitative, semi-philosophical aspects, all of which indicate, we believe, that the Pomeranchon is not an ordinary trajectory. We will then proceed in the next sections to build and test a quantitative model which clearly distinguishes between the Pomeranchon and all other Regge trajectories.

Our arguments for a "special status" for the Pomeranchon are the following.[13]

a) Phenomenologically there are two $J^P = 2^+$, $I^G = 0^+$ mesons, the f^o and f^*, which could correspond to the P-trajectory. There are, however, at least two trajectories - P and P' - which are strongly coupled to pions while the f^* decay into 2π is experimentally absent. Barring a very peculiar t-dependence of $\beta_{f^*\pi\pi}(t)$, and using the normal slope of most known trajectories as a guide, we are led to believe that (1) f^0 belongs to the P';(2) the f* belongs to a P'' which does not couple to pions and (3) no known particle corresponds to the Pomeranchon. This implies that the latter is relatively flat in the region $t > 0$, and that it is even conceivable that it never reaches the $\alpha = 2$ point in which a particle might materialize.

b) The absence of shrinkage in some high energy elastic differential cross sections hints that the slope of the Pomeranchon for $t < 0$ is also much smaller than that of the other leading trajectories. This exceptional behavior is properly linked to our previous remark, both leading to the observation that the P-pole may be approximately or exactly fixed and that its behavior is entirely different from that of other trajectories.

c) The coupling strength of the Pomeranchon to the pion or the nucleon, for example, is related to the asymptotic πN total cross section which, if we accept the optical picture, is essentially given by the "radii" of the two colliding particles. Rough estimates indicate that this interpretation is consistent with the data. If some f-particle would actually "sit" on the Pomeranchuk trajectory, its width $\Gamma(f \to \pi\pi)$ would then be obtainable as an analytic continuation of the $t = 0$ residue strength for the $P\pi\pi$ coupling, and will thus be determined by the size of the pion. It seems entirely unlikely that such a relation occurs.[13]

d) The direct, simple minded, application of Regge-pole rules to Compton scattering shows[14] that the Pomeranchon does not contribute to the scattering at $t = 0$. This leads to immediate inconsistency since it predicts $\sigma_t(\gamma p) \xrightarrow[S \to \infty]{} 0$ while $\sigma(\gamma p \to \rho^0 p)$, for example is predicted to remain constant. The difficulty is resolved if $\alpha_P(0) \neq 1$, if the Pomeranchon residue function is singular, or if an extra fixed pole is introduced in Compton scattering.[15] It could also be resolved, however, if the Pomeranchon itself were a fixed pole, a moving branch point or any peculiar combination of such objects, reflecting its original diffractive nature. In any of these cases, the role played by the Pomeranchon is highly exceptional.

e) Needless to say, the particular $t = 0$ value of α_P, if it is indeed equal to one, is unique among the known trajectories and must follow from some constraint outside the domain of Regge theory.

f) The multiperipheral Regge description of many particle production amplitudes presents us with a unique opportunity of understanding the special role played by the Pomeranchon. If it is an ordinary Regge trajectory, we should expect that double-Pomeranchon exchange in processes such as $p + p \longrightarrow p + f^o + p$ is an allowed (and probably dominant) contribution. If, however, the Pomeranchon is a special creature, representing diffraction scattering, we should not allow the exchange of more than one Pomeranchon and the leading term in the above process will be $P + P'$ exchange. A study of the energy dependence of $p + p \longrightarrow p + f^o + p$ can distinguish between the two possibilities. Meanwhile, from the pure theoretical point of view, it seems that multi-Pomeranchon exchange may be in conflict with unitarity,[16] although various cancellations may still save the situation.[16]

In summary, we conclude that although we cannot prove it, we have various indications for the unique role played by the Pomeranchon. We will now proceed to the final part of our discussion and ask whether or not the Pomeranchon trajectory can be bootstrapped in a way similar to that of other trajectories.

V. CAN THE POMERANCHON BE "BOOTSTRAPPED"?[17]

Can we "Bootstrap" the Pomeranchon or do we have to introduce it "by hand" into the description of scattering amplitudes? In order to answer this question, we utilize the recently developed technique of computing the properties of Regge trajectories by studying the low-energy scattering region and connecting it via finite-energy sum rules (FESR) to the high-energy parameters. This method has so far yielded many interesting results which are mostly related to trajectories other than the Pomeranchon. The main result of our attempt of "bootstrapping" the Pomeranchon in this way is summarized by the following conjecture: The Pomeranchuk trajectory is mostly built by the nonresonating background in the low-energy amplitudes,[18] while the other ("ordinary") trajectories can be usually described in terms of the resonance approximation for the low-energy region.

Our starting point is the trivial observation that some processes (such as K^+p, pp, or $\pi^+\pi^+$ elastic scattering) do not seem to involve any important resonances in the low-energy region, while others (e.g., K^-p, $\bar{p}p$, or $\pi^+\pi^-$ scattering) exhibit a very rich resonance structure. On the other hand the Pomeranchuk trajectory dominates the small-t, large-s scattering of all of these processes, independent of the presence or absence of resonances. If we now use the FESR in order to relate the low-energy amplitudes to the high-energy parametrization, we must conclude that it is extremely unlikely that the Pomeranchon is strongly correlated to the resonance structure at low energy. Explicit calculations in various specific cases actually show that if we approximate the integrals over the low energy region by resonances only, it is essentially impossible to produce the correct properties of the P trajectory on the other side of the FESR. We mention here only two examples of such a situation:

1) In $\pi\pi$ elastic scattering the resonance approximation produces correctly the properties of the ρ and P' trajectories, but it does not seem to account for the Pomeranchon contribution.[18, 19]

2) If we consider hypothetical reactions such as $K + \Delta(1236) \longrightarrow K + \Delta$ and assume that all the non-negligible baryon resonances are in SU(3) singlets, octets,

or decuplets, we find that in $K^+\Delta^{++}$ there are Y_1^* resonances in the u channel while in $K^o\Delta^{++}$ there are no resonances either in the s or in the u channel. In both cases, however, the same Pomeranchon contribution has to be obtained from the FESR. This can be easily understood if the low-energy nonresonating background amplitudes build up the contribution of the Pomeranchon, while if we assume the usual resonance approximation for the low-energy region we are immediately led into inconsistencies.

These two examples, as well as a few other cases, indicate (although do not prove) that the low-energy background is, in fact, largely responsible for building up the Pomeranchon contributions. The second half of our conjecture, namely, the possibility that the "ordinary" trajectories are mostly built by the low-energy resonances is strongly supported by the many recent successful applications of FESR, in which the low-energy resonance approximation has provided a good description of various t-channel Regge trajectories other than Pomeranchon. This statement is, however, at best, approximate.

Armed with these plausibility arguments we can now proceed to assume that our conjecture is indeed correct, and to derive its various consequences. Our philosophy is the following: We believe that the usual parametrization of high-energy scattering amplitudes in terms of a few Regge poles in the t channel is valid, and we impose on it the additional "s-channel information" provided by our conjecture. Stated in a general form, this means that if the left-hand side of the finite-energy sum rule

$$\int_0^N \nu^n \operatorname{Im}A(\nu, t)d\nu = \sum_i \beta_i(t) \frac{N^{\alpha_i + 1 + n}}{\alpha_i + 1 + n} \tag{1}$$

is separated into a "resonant part" A_{res} and a "background part" A_{bg} then, within a good approximation,

$$\int_0^N \nu^n \, \mathrm{Im}A_{bg}(\nu, t) d\nu = \beta_P(t) \frac{N^{\alpha_P + 1 + n}}{\alpha_P + 1 + n} \tag{1a}$$

$$\int_0^N \nu^n \, \mathrm{Im}A_{res}(\nu, t) d\nu = \sum_{i \neq P} \beta_i(t) \frac{N^{\alpha_i + 1 + n}}{\alpha_i + 1 + n}, \tag{1b}$$

where the summation in (1b) involves all trajectories except the Pomeranchon. In those cases in which $\mathrm{Im}A_{res} \cong 0$ for $-\infty < \nu < +\infty$ we are led, for sufficiently large N (say $N > 2$ BeV) to the approximate relation

$$\sum_{i \neq P} \beta_i(t) \frac{N^{\alpha_i + 1 + n}}{\alpha_i + 1 + n} = 0. \tag{2}$$

Moreover, if the t-channel quantum numbers of the amplitude A do not permit the P trajectory to contribute and the low-energy integral includes no resonances, we predict that, at high energies, the amplitude A will be purely real.

In a few cases (such as K^+p scattering), resonances are absent in the s channel while they contribute significantly in the u channel. In such cases we can use a simple generalization of Eqs. (1a) and (1b) and write

$$\int_{N_1}^{N_2} \mathrm{Im}A d\nu \sim \int_{N_1}^{N_2} \mathrm{Im}A_{bg} d\nu = \frac{\beta_P(t)}{\alpha_P + 1} \left[N_2^{\alpha_P + 1} - N_1^{\alpha_P + 1} \right], \tag{3a}$$

$$0 \sim \int_{N_1}^{N_2} \mathrm{Im}A_{res} d\nu = \sum_{i \neq P} \frac{\beta_i(t)}{\alpha_i + 1} \left[N_2^{\alpha_i + 1} - N_1^{\alpha_i + 1} \right], \tag{3b}$$

where the interval ($N_1, \ldots, N_2$) is chosen on the positive ν axis (s-channel physical K^+p scattering) between, say, $N_1 = 1$ BeV and $N_2 = 2$ BeV (the region in which other processes are dominated by resonances while in K^+p scattering $\mathrm{Im}A_{res} \sim 0$). Since Eq. (3b) is supposed to hold for a range of values of N_2, N_1, we are effectively led to a relation of the type of Eq. (2) for K^+p scattering. This is true in spite of the existence of K^-p resonances which at first sight might be suspected to modify this conclusion. In this last case we have really used our conjecture, in a stronger form than the one formulated by Eqs. (1a) - (1b), namely - we assume here that the background - Pomeranchon association can be used in the "local average" sense.[11] In the next two sections we will see, among other results, that this stronger conjecture holds in some cases.

VI. A TEST OF THE CONJECTURE[20]

We have tested Eqs. (1a), (1b) in a few cases and found no inconsistencies. In paritcular we considered the $C = +1$, $I = 0$ t-channel amplitudes for πN and KN scattering and found that the correspondence between the low energy resonances and the P' trajectory as well as the complementary association of the Pomeranchon with the low energy background are consistent with the experimental situation within the usual ambiguities of FESR and the experimental uncertainties. Assuming that this model for generating the P' trajectory is indeed correct, we studied its behavior as a function of t and find that it probably follows the Gell-Mann ghost-eliminating mechanism.

We start our analysis by writing down FESR for the $C = + 1$, $I = 0$ t-channel πN and KN scattering amplitudes. The non-spin-flip amplitudes $A'^{(+)}$ satisfy:[21]

$$S_{2n+1} \equiv \frac{1}{N^{2n}} \int_0^N \nu^{2n+1} \mathrm{Im}A'^{(+)}(\nu, t) d\nu = \sum_{i=P,P'} \beta_i^A(t) \frac{N^{\alpha_i(t)+2}}{\alpha_i(t) + 2n + 2}, \qquad (4)$$

while the spin-flip amplitudes $B^{(+)}$ obey:

$$S_{2n} \equiv \frac{1}{N^{2n}} \int_0^N \nu^{2n} \mathrm{Im} B^{(+)}(\nu, t) d\nu = \sum_{i=P,P'} \alpha_i(t) \beta_i^B(t) \frac{N^{\alpha_i(t)}}{\alpha_i(t) + 2n} \tag{5}$$

At $t = 0$ we can determine $\mathrm{Im}\, A'^{(+)}$ directly from the total cross section data. We can therefore explicitly separate $\mathrm{Im}\, A'^{(+)}(\nu, 0)$ into a resonance contribution, $\mathrm{Im}\, A'^{(+)}_{RES}(\nu, 0)$, and a background term, $\mathrm{Im}\, A'^{(+)}_{BG}(\nu, 0)$. The resonance part is computed by adding Breit-Wigner forms (including appropriate threshold corrections) for all known πN or KN resonances,[22] while the background term is defined as:

$$\mathrm{Im}\, A'^{(+)}_{BG}(\nu, 0) = \mathrm{Im}\, A'^{(+)}(\nu, 0) - \mathrm{Im}\, A'^{(+)}_{RES}(\nu, 0). \tag{6}$$

The hypothesis that we are testing at $t = 0$ can most simply be stated as:

$$S^{P}_{2n+1} \equiv \frac{1}{N^{2n}} \int_0^N \nu^{2n+1} \mathrm{Im}\, A'^{(+)}_{BG}(\nu, 0) d\nu = \beta^A_P(0) \frac{N^{\alpha_P(0) + 2}}{\alpha_P(0) + 2n + 2}, \tag{7}$$

$$S^{P'}_{2n+1} \equiv \frac{1}{N^{2n}} \int_0^N \nu^{2n+1} \mathrm{Im}\, A'^{(+)}_{RES}(\nu, 0) d\nu = \beta^A_{P'}(0) \frac{N^{\alpha_{P'}(0) + 2}}{\alpha_{P'}(0) + 2n + 2}. \tag{8}$$

While Eq. (8) is expected to hold only for averages over all resonances in a sufficiently large region in ν, Eq. (7) may be valid even "locally", for small ν-intervals. This follows from the expected smooth behavior of $A'^{(+)}_{BG}$ as a function of ν. If the equality:

$$\mathrm{Im}\, A'^{(+)}_{BG}(\nu, 0) = \beta^A_P(0)\nu \tag{9}$$

actually holds for any value of ν in the resonance region, we should be able to describe the total amplitude $\mathrm{Im}\, A'^{(+)}(\nu, 0)$ by a modified version[17] of the interference model,[23] in which we add the s-channel resonances to the extrapolated contribution of the Pomeranchon alone. In this way we avoid the usual double counting committed by the ordinary interference model, when the P and P' contributions are both added to the resonances. Figure 1 compares this modified model with the πN scattering data[24] indicating good agreement between the model and the experimental situation.

Another test of Eq. (7) can be performed by computing $\alpha_P(0)$ from S_1^P and S_3^P or by computing $\beta(0)$ from S_1^P, assuming $\alpha_P(0) = 1$. For cutoff values $1.1 \leq N \leq 1.8$ BeV (corresponding approximately to the upper ends of the "old" and "new" πN phase shift studies) we find an extremely sensitive dependence of $\alpha_P(0)$ on N and on the resonance parameters. The range of values obtained from the relation $\alpha_P = (2S_1^P - 4S_3^P)/(S_3^P - S_1^P)$ is consistent with the accepted value of $\alpha_P(0) = 1$ but it definitely does not predict it. In fact, any value of $\alpha_P(0)$ between -1 and +2 can be obtained in this way. The sensitivity follows here from the dominant contribution of the 1.6 - 1.9 BeV region to $\nu^3 \operatorname{Im} A'^{(+)}(\iota, 0)$ and therefore to S_3. Small ambiguities in the parameters of the resonances in this region are sufficient to prevent us from an accurate computation of α_P. We may, however, assume that $\alpha_P(0) = 1$ in Eq. (4) and use S_1^P for computing $\beta_P(0)$. Choosing cutoffs $1.1 \leq N \leq 1.8$ we obtain for $\beta_P(0)$ numbers corresponding to an asymptotic πN total cross section $\sigma_t^\infty(\pi N) = 14 \pm 4$ mb. This should be compared with typical high energy extrapolations such as:[25] 14.5(I); 18.4(II); 22.1(III).

We now proceed to compare Eq. (8) with the πN data. Figure 2 shows three typical curves for the extrapolated P' contribution[25] together with $\nu \operatorname{Im} A'^{(+)}_{RES}(\nu, 0)$. It is evident that the P' contribution is approximately accounted for by the resonances, in agreement with our basic conjecture. For cutoffs $1.1 \leq N \leq 1.8$ $S_1^{P'}$ and $S_3^{P'}$ give $\alpha_{P'}(0) = 0.65 \pm 0.25$ in reasonable agreement with the "high energy determinations"[25] $\alpha_{P'}(0) = 0.73$(I); 0.63(II); 0.31(III). Assuming $\alpha_{P'}(0) = 0.5$ we can compute $\beta^A_{P'}(0)$ from $S_1^{P'}$. For the same range of N-values we find[8,21] $\beta^A_{P'}(0) = 18 \pm 2$ to be compared with[25] 20.6(I), 16.8(II), 18.5(III). Our value for β is not very sensitive to modifications in $\alpha_{P'}(0)$.

We have performed similar calculations for the $C = +1$, $I = 0$ t-channel amplitude in KN scattering. The $t = 0$ $A'^{(+)}$ amplitude is given by

$$\mathrm{Im}\, A'^{(+)}(\nu, 0) = \frac{1}{4}\sqrt{\nu^2 - m_K^2}\left[\sigma_t(K^+p) + \sigma_t(K^-p) + \sigma_t(K^+n) + \sigma_t(K^-n)\right] \tag{10}$$

In addition to the points which we have already mentioned,[22] the following ambiguities in handling the KN data should be noted: (i) The low energy total cross section data ($\nu < 1$) have relatively large errors; (ii) The ΛKN and ΣKN coupling constants are not well determined. We have used the values given by Kim[26] but also computed the changes that would follow if Zovko's[26] results are correct. (iii) We used $g^2_{Y_0^* KN}/4\pi = 0.32$ as given by Warnock and Frye[27] for $Y_0^*(1405)$. For $Y_1^*(1385)$ we used[27] $g^2_{Y_1^* KN}/4\pi = 1.9$ but arbitrarily allowed an error of $\pm 25\%$.

In view of these errors we find that the only meaningful calculation that we can make is to compare $\mathrm{Im}\, A'^{(+)}_{RES}(\nu, 0)$ to the P' contribution, using Eq. (8). Assuming $\alpha_{P'}(0) = 0.5$ we obtain from $S_1^{P'}$: $\beta^A_{P'}(0) = 5.7 \begin{smallmatrix} +0.7 \\ -1.7 \end{smallmatrix}$ where the errors indicate the combined effect of the above ambiguities and the cutoff dependence ($1.1 \leq N \leq 1.9$ BeV). Our value for $\beta^A_{P'}(0)$ should be compared with the "high energy value"[28] $\beta^A_{P'}(0) = 5.5 \pm 1.3$.

Encouraged by these successes of our assumption on the relation between the low energy resonances and the P' trajectory we now try to extend the analysis to $t \neq 0$. Here we do not have any reliable values of β_P or $\beta_{P'}$ since the separation of the A' and B contributions to $d\sigma/dt$ as well as the "popular" parametrizations of $\beta_{P'}$ suffer from many ambiguities. In particular, since the present high energy data do not explicitly <u>require</u> any zeros in $\beta_{P'}(t)$ in addition to those which occur at the point $\alpha_{P'} = 0$, most parametrizations <u>apriori assume</u> that no such additional zeros exist. This does not mean that other parametrizations of $\beta_{P'}(t)$ are inadequate, or that it is difficult to fit the data with a residue function that vanishes at t-values other than the $\alpha_{P'} = 0$ point. What we can do here is to assume that for $t \neq 0$ the P' trajectory is still "built" from resonances only and to use the FESR in order to compute the t-dependence of $\beta^A_{P'}(t)$ and $\beta^B_{P'}(t)$ for πN and KN scattering. Using the πN and KN resonances and assuming $\alpha_{P'}(t) = 0.5 + t$ we find the t dependence shown in Fig. 3.

The behavior of the $A'^{(+)}$ amplitudes for both πN and KN scattering indicates very clearly that $\beta^A_{P'}$ has two (possibly coinciding) zeros in the region $-1 \leq t \leq 0$. Since $\beta^A_{P'}(t)$ has to vanish at least once for $\alpha_{P'} = 0$, we are left here with two possibilities: (a) We have a double zero of $\beta^A_{P'}$ at $\alpha_{P'} = 0$, corresponding to the "no-compensation" ghost-eliminating mechanism.[29] (b) We have one zero at $\alpha_{P'} = 0$, and another "dynamical" zero elsewhere (probably around $t = -0.2$ or -0.3). In this case we would have either the Chew[30] or the Gell-Mann[31] mechanism. The accuracy of our analysis of the $A'^{(+)}$ amplitudes is certainly not sufficient to distinguish between possibilities (a) and (b). The ambiguity can be resolved, however, by looking at the t-behavior of $\beta^B_{P'}$. The Chew and "no-compensation" mechanisms demand that $\beta^B_{P'}$ (as defined in Eq. (5)) vanishes for $\alpha_{P'} = 0$, while in the Gell-Mann mechanism it does not. Figure 3(b) shows that at least in the πN case the Gell-Mann mechanism is definitely favored and $\beta^B_{P'}(t)$ does not vanish anywhere in the region of interest. In the KN case (Fig. 3(d)) the situation is obscured by the large errors and it is hard to reach any conclusions. On the basis of the πN-analysis we propose however, that the P' trajectory actually chooses to follow the Gell-Mann mechanism with an extra zero in the $\beta^A_{P'}(t)$ residue function. It is interesting to add that the same mechanism is also favored for the A_2 trajectory in processes such as $\pi N \longrightarrow \eta N$, $KN \longrightarrow K\Delta(1236)$ and $KN \longrightarrow KN$. At least for $KN \longrightarrow KN$, FESR predicts an extra zero in the A' amplitude.[32] In view of the SU(3) relation between the P' and A_2 trajectories, it would be embarrassing if they followed different ghost eliminating mechanisms. Our conclusions with respect to P' are in accord with the requirement of a similar behavior for the two trajectories.

VII. ADDITIONAL PREDICTIONS AND TESTS

Some other consequences of our conjecture on the nature of the Pomeranchon are the following:

a) All total cross sections for reactions in which no important s-channel resonances show up should be approximately constant in energy over a very wide energy range. This successfully explains why $\sigma_t(K^+p)$, $\sigma_t(K^+n)$, $\sigma_t(pp)$, and $\sigma_t(pn)$ are essentially constant, and why $\sigma_t(K^+p) = \sigma_t(K^+n)$, $\sigma_t(pp) = \sigma_t(pn)$ already at relatively low energies.

b) Total cross sections for reactions which exhibit strong resonances need not be constant and they should gradually <u>decrease</u> to their asymptotic value. If our description is correct, no total cross section will ever increase towards its Pomeranchuk limit. So far, this is experimentally true in all cases.

c) In view of the absence of I = 2 $\pi\pi$ resonances, $\sigma_t(\pi^+\pi^+)$ should be approximately constant in energy. If we parametrize high-energy $\pi\pi$ scattering in terms of the P, P' and ρ trajectories, $\sigma_t(\pi^+\pi^+)$ = const leads to

$$\alpha_\rho = \alpha_{P'} \quad , \tag{11}$$

$$\gamma_{\rho^0\pi^+\pi^-}{}^2 = \gamma_{P'\pi^+\pi^-}{}^2 \; . \tag{12}$$

Equation (11) is very well satisfied. Equation (12) can be compared with the values for the factorized ρ and P' residues as obtained from the analysis of NN, $\overline{NN}$, and πN elastic scattering. The large errors in the $\bar{p}n$ cross sections prevent us from reaching definite conclusions, but all the published numbers are consistent with (12).

d) A similar analysis for πK, KK, and KN scattering gives

$$\alpha_\rho = \alpha_{A_2} , \tag{13}$$

$$\alpha_\omega = \alpha_{P'} , \tag{14}$$

$$\alpha_{K^*} = \alpha_{K^{**}} , \tag{15}$$

as well as relations among the factorized residue functions $\gamma_{A_2 KK}$, $\gamma_{\rho KK}$, etc. Equations (13) - (15) are acceptable while the residue relations cannot be tested at present.

e) All high-energy inelastic KN and NN reactions, in which the Pomeranchukon cannot be exchanged, should have purely real amplitudes. This is trivially correct for K^+n and pn charge exchange, since it follows from isospin and our prediction (a). For other reactions such as $pp \to p\Delta$, $Kp \to K\Delta$, $Kp \to K^*p$, $Kp \to K^*\Delta$, the separation of the real and imaginary parts is experimentally very difficult. In all these reactions, however, the currently accepted high-energy descriptions are consistent with a purely real amplitude, since all the suggested parametrizations involve either an equal mixture of ρ and A_2 exchange (in which case the imaginary part cancels in a similar way to the $K^+n \to K^o p$ case) or pion exchange which, at least at small t, contributes mostly to the real amplitude.

f) If we assume that SU(3) is an exact symmetry of the factorized residue functions, we predict that the total meson-meson cross sections in the 10, 10*, and 27 representations in the s-channel are constant. Since we believe that at high energies only singlets and octets contribute in the t channel, we conclude that we must have a nonet of degenerate tensor trajectories in addition to the Pomeranchukon. This is independently required by all SU(3)-invariant Regge fits to meson-baryon scattering, if $\alpha_P(0) = 1$.

We conclude with a few general remarks:

1) Our picture is perfectly consistent with the intuitive "diffraction" picture of the Pomeranchon. It is conceivable that scattering amplitudes can be described in terms of two parts: (i) an "optical" or "geometrical" part which is represented by the Pomeranchuk pole in the t channel but is viewed as a smooth nonresonating contribution to the amplitude in the s channel; (ii) a "dynamical" part which can be approximated by a few resonances or trajectories either in the t channel or in the s channel. Since the Pomeranchukon contributes equally to all s-channel isospins it is very hard to relate it to an s-channel trajectory. On the other hand, it is reasonable that the optical or geometrical properties of the particles are independent of the isospin in the s channel.

2) The surprising success of the resonance approximation in the finite-energy sum rules for the odd $\pi N \to \pi N$ amplitudes[10] as well as the success of the $\pi\pi \to \pi\omega$, $\pi\pi \to \pi A_2$ calculation[33] probably follows from the absence of the Pomeranchon in these reactions. The complexity of the even πN amplitude and the $\pi\pi$ problem[18, 19] can be reduced if we do use the resonance approximation but try to produce only the "ordinary" trajectories in the t channel assuming that the P trajectory is "already" taken care of by the unknown low-energy background.

3) There is one open question which is very relevant to our discussion but does not affect any of our conclusions: Can we describe the scattering at high energies (say, at 10 BeV) in terms of many (wide, dense, and highly inelastic) s-channel resonances added to an "optical" Pomeranchon? If this is the case we would not need the finite-energy sum rules in order to derive most of our results. The rapidly decreasing elasticities of the known high N* resonances indicate, however, that a huge number of N* trajectories is needed for such a picture to be valid.

4) All attempts to approximate the world of strong interactions by (infinitely many) discrete states seem to be inconsistent with our picture of the Pomeranchon and appropriate modifications should be introduced into these programs if our model is correct.

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FOOTNOTES AND REFERENCES

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20. This section is entirely based on the paper of F. J. Gilman, H. Harari and Y. Zarmi, Phys. Rev. Letters 21, 323 (1968).

21. We use the following notation and units: Im $A'^{(+)}(\nu, 0) = \sqrt{\nu^2 - m^2}\ \sigma_t^{(+)}(\nu)$, ν is the laboratory energy (in BeV) of the incident meson with mass m, $_t^{(+)}$ is the average (π^+p, π^-p) or (K^+p, K^+n, K^-p, K^-n) total cross section in mb.

22. For πN scattering we basically use the 18 N* states listed by A. Donnachie et al., Phys. Letters 26B, 161 (1968). For KN scattering we use the Y_0^* and Y_1^* states listed by A. H. Rosenfeld et al., Rev. Mod. Phys. 40, 77 (1968). Three of these states, Y_0^* (1670), Y_1^* (1660) and Y_1^* (1690), involve serious experimental ambiguities, but their total effect on our calculations is not very significant. For resonances we introduce a threshold factor $(q/q_R)^{2\ell+1}$ where q_R is the c. m. momentum of the elastic decay products of the resonance. We modify only the $q < q_R$ part of the Breit-Wigner form. The sensitivity of our calculations with respect to (a) variations in resonance parameters, (b) possible other ways of making threshold corrections, (c) possible nonexistence of some of the high-mass N* and Y* states, (d) different choices of KNY couplings, is reflected by the error bars in Figs. 1 and 3.

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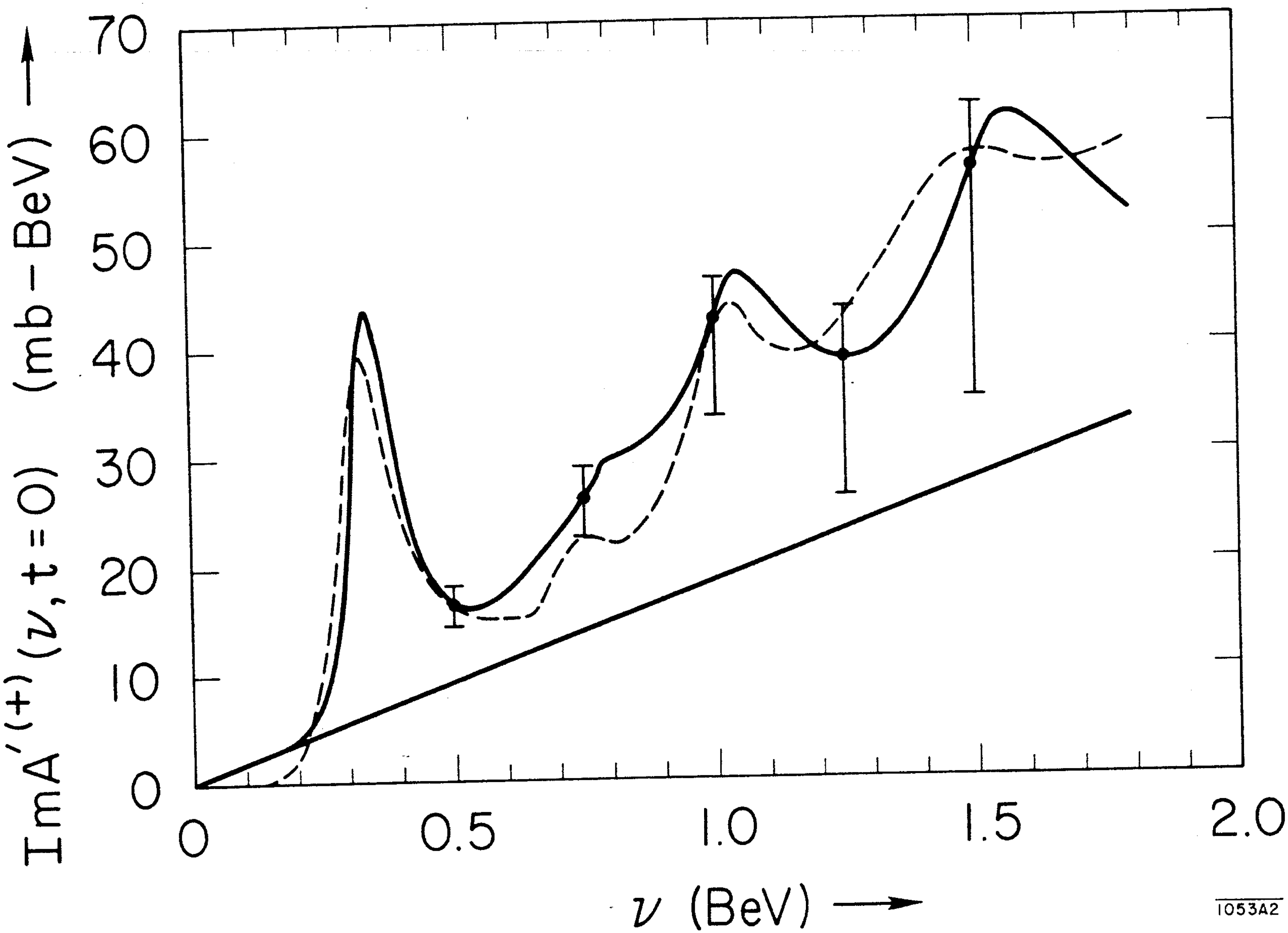
FIGURE CAPTIONS

1. Comparison of the modified interference model with the π N data. Dashed line: Im $A^{'(+)}(\nu, 0)$ taken from Ref. 24. Straight line: Extrapolated Pomeranchon contribution corresponding to $\sigma_t^{\infty}(\pi N) = 18.4$ mb (II). Solid curved line: Sum of extrapolated P contribution and Breit-Wigner forms of all resonances of Donnachie et al., Ref. 22. Error bars show the variation of the model's prediction when $\beta_P^A(0)$ is allowed to change between 14.5 (I) and 22.1 (III), (Ref. 25) and all π N resonances which are not well established are omitted.

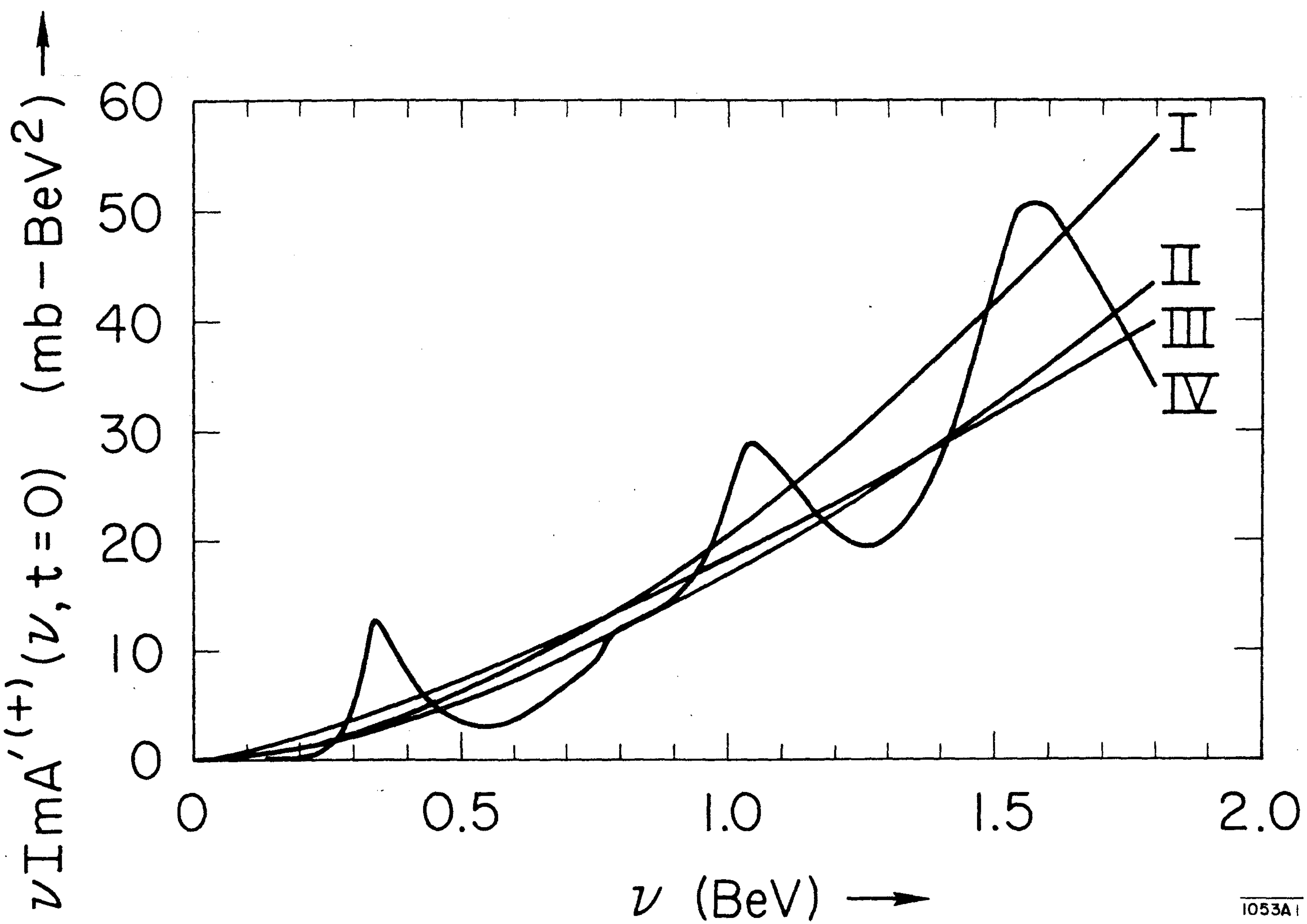
2. Extrapolated P' contribution to ν Im $A^{'(+)}(\nu, 0)$ for π N scattering as determined by three different high energy fits (I-III, Ref. 25) and νIm $A_{RES}^{'(+)}(\nu, 0)$ (line IV).

3. The t dependence of the P' residue functions for π N and KN amplitudes $\alpha_{P'}(t) = 0.5 + t$ is assumed. $N(t) = N(0) + t/4M$. $\beta_{P'}^{A,B}$ defined as in Eqs. (4), (5). (a) $\beta_{P'}^A(t)$ for π N. I - N(0) = 1; II - N(0) = 1.4; III - N(0) = 1.8. (b) $\beta_{P'}^B(t)$ for π N, I-III same as in (a). (c) $\beta_{P'}^A(t)$ for KN. Solid line for N(0) = 1.2 and for the coupling constants given in the text. Errors indicate the variation due to changes in N (up to 1.9 BeV), replacing Kim's couplings by Zovko's, 25% error in $g^2_{Y_1^* KN}$, and variation of the parameters of the poorly determined high mass Y* resonances (Ref. 22). (d) $\beta_{P'}^B(t)$ for KN. Notation as in (c).



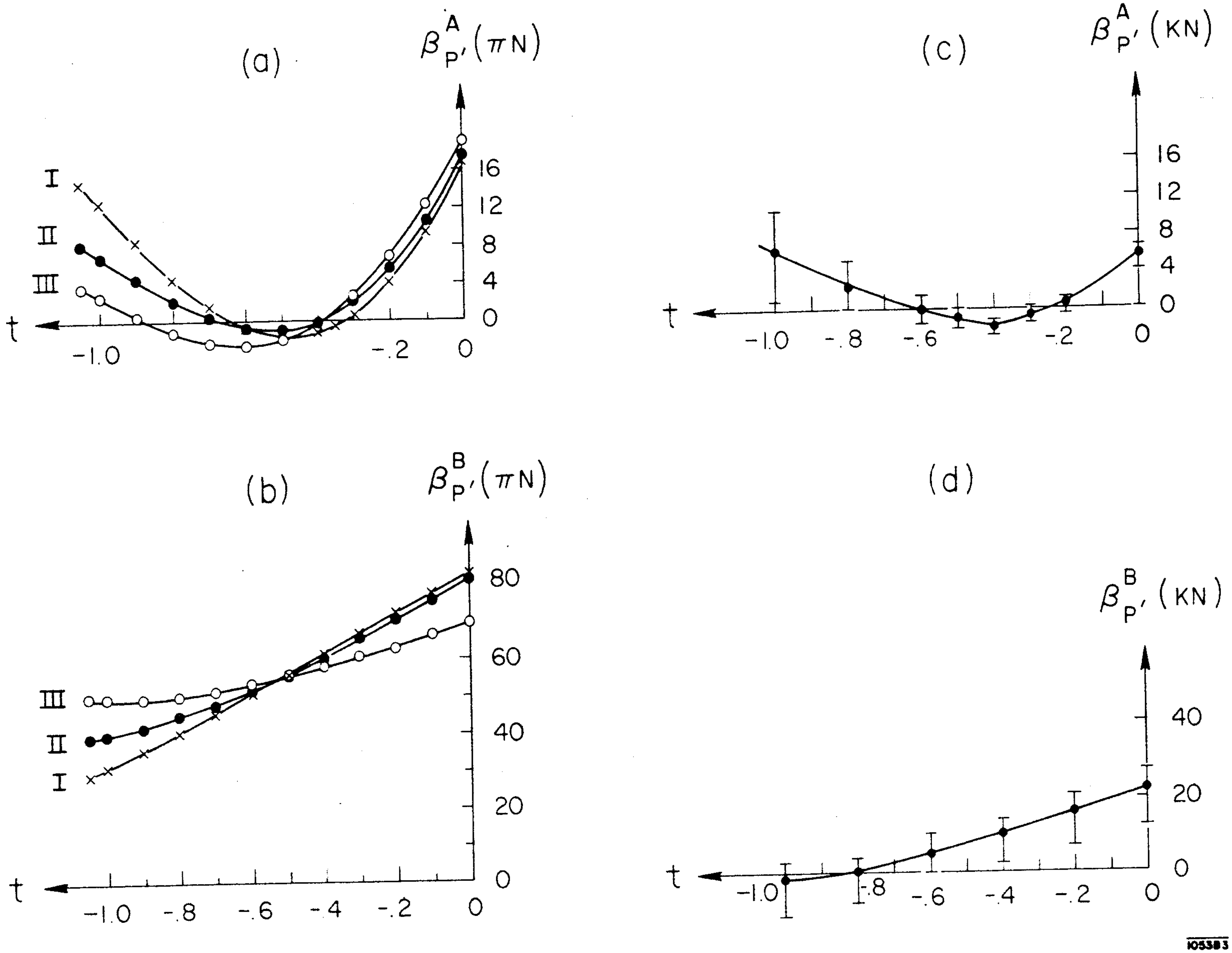
70
60
50
40
30
20
10
0
0
0.5
1.0
1.5
2.0
$\mathrm{Im}A'^{(+)}(\nu, t=0)$ (mb − BeV)
ν (BeV)
1053A2

Fig. 1



60
50
40
30
20
10
0
0
0.5
1.0
1.5
2.0
I
II
III
IV
$\nu \mathrm{Im} A'^{(+)}(\nu, t=0)$ (mb - BeV^2)
ν (BeV)
1053A1

Fig. 2



(a)
$\beta^{A}_{P'}(\pi N)$
I
II
III
16
12
8
4
0
t
-1.0
-.2
0
(b)
$\beta^{B}_{P'}(\pi N)$
III
II
I
80
60
40
20
0
t
-1.0
-.8
-.6
-.4
-.2
0
(c)
$\beta^{A}_{P'}(KN)$
16
12
8
4
0
t
-1.0
-.8
-.6
-.2
0
(d)
$\beta^{B}_{P'}(KN)$
40
20
0
t
-1.0
-.8
-.6
-.4
-.2
0
105383

Fig. 3