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SELF-CONSISTENT POMERON DYNAMICS WITHOUT DECOUPLING*

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ABSTRACT

More conservative conditions on the independently uniform convergence of multi-Regge asymptotic expansions lead to a consistent Pomeron pole dynamics, without requiring the coupling $\Gamma(0,0,0)$ of three such poles to vanish. The onset of large mass diffractive processes at high energies results in an asymptotically constant renormalization of the pole residue. This threshold mechanism may be responsible for the rise in σ_{total} and $\sigma_{e\ell}$ at ISR and for building the forward quasi-elastic peak in the leading proton x-distribution.

In this letter we shall present an alternative interpretation of the Pomeron decoupling problem which clarifies the nature of the states to which an effective, factorizable, unit intercept Pomeron pole may couple without inconsistencies arising. The inconsistent contributions are shown to be built from specific kinematic regions in which, it is suggested, the assumption of an isolated factorizable pole breaks down. The way in which this happens is indeed delicate and involves the relationship between the leading pole and cuts in the region $t \lesssim 0$. This situation is related to the question of the uniform convergence

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of multiple asymptotic expansions and to that of the physical basis for factorization.

We begin with a discussion of the triple Regge region. Consider a process as in fig. 1.a., where particle B dissociates into mass M^2, larger than some resonance mass M_R^2. These processes represent a subset of states in the two → two unitarity sum. They also represent the full set of states in the Mueller discontinuity [1] of the (continued and connected) three → three amplitude. In the limit M^2, $s/M^2 \to \infty$, an $O(2,1)$ decomposition [2] indicates an energy dependence*

* We drop signature factors and the Regge energy scale $s_0 \approx 1\ \mathrm{GeV}^2$.

$$s\,\frac{d^2\sigma}{dt\,dM^2} \sim \frac{\gamma(t)}{s}\left(M^2\right)^{\alpha_P(0)}\left(\frac{s}{M^2}\right)^{2\alpha_P(t)} \tag{1}$$

where

$$\gamma(t) = (16\pi)^{-1}\,|\beta_{PAA'}(t)|^2\,\tilde{\beta}_{PBB}(0)\,\Gamma(t,t,0) \tag{2}$$

utilizing the normalizations of [3]. The structure and notation is indicated in fig. 1.b. In the s-channel physical region, we have the kinematic condition (for x near 1), $t \leq t_{min} \approx -(M^2/s)^2 m^2 = -(1-x)^2 m^2$ where $x = 2P_{A'_{\parallel}}/\sqrt{s}$ is the longitudinal fraction associated with the detected leading particle.*

* The point $t = 0$ is thus very special, reachable only in the strict $s/M^2 \to \infty$ limit.

To determine the contribution of these processes to the two-particle total cross section, or equivalently to the two → two forward absorptive part $A_{22}(s,0)$, eq. (1) must be integrated over regions of t and M^2 which are consistent with the physical and mathematical assumptions made. The latter have to do with the regions of uniform

convergence of the multiple asymptotic expansion to the pole-dominated form of eq. (1). Let us introduce the rapidity gap variable $\Delta \equiv \ln s/M^2$ (fig. 1.a.). For fixed s, Δ_{max} is determined by the minimum missing mass which is dual to the pole in the unitarity sum. We may take $\ln M^2_{min} = \ln M_R^2$, constant, or, more conservatively $\ln M^2_{min} = \gamma \ln s$, where $\gamma \lesssim 1$. In either case, Δ_{max} scales with $\ln s$. Our real interest, however, will be in Δ_{min} which is controlled by the maximum missing mass to which a Pomeron pole in the production amplitude is assumed to couple. It is at this point that uniformity assumptions must be made.

It is usually assumed, by analogy with two-body reactions or pole-dominated models, that the condition $Y_R \geqslant \Delta \geqslant \lambda$, where $Y_R = \ln s/M_R^2$ and λ is a large constant, is sufficient to insure the approximate validity of eq. (1). This is equivalent to the assumption that the expansions in s/M^2 and M^2 are independently uniformly convergent. That is, one assumes that for $\delta > 0$ there is an $N(\delta)$, independent of M^2, such that for $s/M^2 > N(\delta)$,

$$(1-\delta) f_R(s/M^2, M^2) \leqslant f(s/M^2, M^2) \leqslant (1+\delta) f_R(s/M^2, M^2) \qquad (3)$$

where f_R is the pole-dominated asymptotic form (eq. (1)) of the true amplitude f. Above, $N(\delta)$ is just λ. One must know the nature and strength of nonleading terms to assert such uniformity. In models with only poles, $N(\delta)$ may, in general, be chosen independent of M^2. If there are cuts, great care must be taken with the relationship between the leading pole and cut. In the latter case, the conditions for independent uniformity may be different. Indeed, we shall find below that the condition for uniformity is more likely $\ln s/\ln M^2 > N(\epsilon)$ is independent of M^2. It is this choice that leads to a self-consistent

pole dynamics. Phenomenologically, it is virtually impossible to distinguish between these criteria.

That the usual inconsistency comes from the small rapidity gap region is easily established. The customary assumption of uniformity for $\Delta \geqslant \lambda$ results in an integrated contribution to the total cross section of the form $\Gamma(0,0,0) \ln \ln s$, if the leading pole has intercept one. This is inconsistent with the constant contribution of the same pole to σ_{total}, as given by the two-particle optical theorem, unless the triple coupling $\Gamma(0,0,0) \equiv 0$. An unfortunate consequence of the latter assumption is that the vanishing of the triple-Pomeron coupling may then be used to prove the decoupling of the Pomeron pole from diffractive processes [4] and perhaps from elastic scattering [5]. The more conservative restriction on the uniformity leads to consistency without assuming $\Gamma(0,0,0) = 0$.

Let us divide the usual rapidity-gap interval into two parts, $\lambda \leqslant \Delta \leqslant \epsilon Y$ and $\epsilon Y \leqslant \Delta \leqslant Y_R$, where the constant parameter $0 < \epsilon < 1$ may be arbitrarily small. The second region includes only those diffractively produced states M^2 such that $M^2 \leqslant s^{1-\epsilon}$ while the first, small gap, region consists of states with larger masses $e^{-\lambda} s \leqslant M^2 \leqslant s^{1-\epsilon}$. In the limit $Y \to \infty$, the large gap region consists entirely of states characterized by $t_{min} = 0$, while the first region is sensitive to the dynamics for $t_{min} \approx -e^{-2\Delta} m^2 \leqslant 0$. Most of the contribution to the point $t = 0$, at which the triple coupling is thought to vanish, thus come from the second region. The integral over this region has the form

$$\sigma^{TP'} \approx \frac{\gamma(0)}{2} \int_{\epsilon Y}^{Y_R} d\Delta (a + \alpha'\Delta)^{-1}$$

$$\approx \frac{\gamma(0)}{2\alpha'} \ln \left| \frac{a + \alpha' Y_R}{a + \epsilon \alpha' Y} \right| \qquad \text{(equation (4) continued)}$$

$$\underset{s \to \infty}{\sim} \quad \frac{\gamma(0)}{2\alpha'} \ \ell n(1/\epsilon) \tag{4}$$

where we have taken $\gamma(t) = \gamma(0)e^{2\alpha t}$ and integrated over t. That is, this region makes a constant contribution to the total cross section, a contribution which is proportional to the nonvanishing triple-Pomeron coupling.

If isolated pole dominance obtains in the first region, $\lambda \lesssim \Delta \lesssim \epsilon Y$, then the contribution of this region grows asymptotically like $\ell n \ \ell n \ s$ and the inconsistent contributions are then generated in this specific kinematic region. It is our conjecture that it is in this region that the usual uniformity assumption breaks down and that this is due to neglect of the relationship between the leading pole and cut for $t \lesssim 0$.* This would imply that production of very large mass states

* A particularly simple way in which the approach to $t = 0^-$ may be complicated is that the pole (in the j-plane conjugate to s/M^2) may lie on an unphysical sheet of the two-Pomeron cut, whose branch point lies to the right of the pole for $t < 0$. The cut may thus sufficiently screen the pole that inconsistency does not occur. The pole may simultaneously distort the cut discontinuity in such a way that factorization is approximately valid. The calculation of this effect is quite model dependent. Absorptive cuts may approximate the screening effect.

($M^2 > s^{1-\epsilon}$) is mediated by nonfactorizable exchange. This assertion about the factorization property has a natural physical interpretation. The contributions of the second region, $M^2 \lesssim s^{1-\epsilon}$ or equivalently $\Delta > \epsilon Y$, corresponds to a sum over states M^2 in the two → two unitarity sum which result from the dissociation of particle B and

which contain <u>no</u> particles in the fragmentation region of particle A (in the limit $s \to \infty$). That is, the left-most particle of M^2 in the rapidity space decomposition of fig. 1.a. has a Feynman [6] x-value which goes to zero like $s^{-\epsilon}$. The first region includes states M^2 which contain particles in both the pionization region $(x = 0)$ and the fragmentation region of particle A. It is in this boundary region that the two-Pomeron cut is generated, as we shall see below [7]. This separation of kinematic regions seems a reasonable physical definition of factorization, but one which is at odds with the usual multi-Regge assumption of local factorization over constant rapidity lengths in production processes. The latter corresponds to an implicit, and perhaps unwarranted, assumption about the independently uniform convergence of multiple asymptotic expansions.

A particularly swasivious argument for the connection between the breakdown of the usual uniformity assumption and the need to properly treat the pole-cut relationship, arises from self-consistency. Particular terms in the many-body unitarity sum for the two → two absorptive part $A_{22}(s,t=0) \propto s\,\sigma_{22}^{tot}(s)$ contribute to building up the corresponding j-plane singularity structure in this object. The question is which pole-dominated production processes contribute <u>only</u> to the output pole in $A_{22}(j)$. This turns out to be just the second region above. The contribution of the region $\epsilon Y \lesssim \Delta \lesssim Y_R$ to $A_{22}(j)$, the Mellin transform in s of $A_{22}(s)$, is

$$A_{22}^{TP'}(j) \propto \int_{-\infty}^{0} dt \, \frac{\gamma(t)}{[j - 1 - 2\alpha'\epsilon t][j - 1 - 2\alpha' t]}, \tag{5}$$

where we have taken $\alpha_P(t) = 1 + \alpha' t$ and used eq. (1).

The usual result, which comes from assuming pole dominance of the asymptotically larger class of states $\lambda \leqslant \Delta \leqslant Y_R$ is obtained simply by taking $\epsilon = 0$:

$$A_{22}(j) \underset{\epsilon = 0}{\propto} (j - 1)^{-1} \int_{-\infty}^{0} dt \, \frac{\gamma(t)}{j - 1 - 2\alpha' t} . \qquad (6)$$

The last integral has the singular behavior $-\ell n(j - 1)$ near $j = 1$, unless $\gamma(0) = 0$. The larger region is thus seen to be associated with the generation of the cut as well as the pole.* We may thus speculate

* The factor $-\ell n(j - 1)$ is just the first term in the expansion of the Fredholm denominator of the multi-Regge model.

that the need for decoupling in the usual case is related not to inconsistent pole dynamics (for which $\gamma(0) = 0$ is an excessive cure), but to mistreatment of the pole-cut relationship in the production amplitude in the very large mass (small rapidity gap) region. This would then be the source of the uniformity problem.

That this is the case may be seen from eq. (5), which exhibits pure pole behavior, arising from the smaller class of states. Pomeron pole couplings to diffractive states in the production amplitude such that $\ell n\, s/\ell n\, M^2 \geqslant (1 - \epsilon)^{-1}$ (the stronger uniformity condition above) result only in constant vertex corrections to the output pole. These structures are illustrated in fig. 1.b., where possible fixed mass diffractive contributions A' are included. The asymptotic strength of this renormalization of the pole is given by $\Gamma(0,0,0)$ and by ϵ. The latter is a measure of the meaningful boundary between fragmentation and pionization regions. That is, ϵ is a measure of the longitudinal coherence of the fragmentation products of the incident hadrons.

The threshold effect due to the opening up of new, pole dominated, large mass production channels may have important consequences for the behavior of the total cross section. This threshold is, by ordinary Regge arguments, in the region $\ell n\, s = 4 \to 5$. At lower energies the Pomeron represents just the elastic shadow scattering due to ordinary inelastic channels. Above this energy, the low-energy Pomeron may contribute to large mass ($\ell n\, M^2 > \ell n\, M_R^2 \approx 2$, say) diffractive production. The shadow of these new inelasticities is then reflected in the increase in the effective pole residue as given by eq. (4). The approach to the asymptotic value is very rapid. With the choice $a = 2$, $\epsilon = 0.3$, $\alpha' = 0.3$, and $Y_R = \ell n\, s/M_R^2 = \ell n\, s - 2$, the quantity $\ell n|(a + \alpha' Y_R)/(a + \alpha' \epsilon Y)|$ changes by a factor of four between $\ell n\, s = 4$ (Serpukov) and $\ell n\, s = 8$ (upper end of ISR range). This is as rapid as a $\ell n^2 s$ increase. If $\Gamma(0,0,0)$ is sufficiently large, this may account for most of the rise in σ_{total} and in $\sigma_{e\ell}$ [8], and in a rather natural way.*

* Since the optical point is being moved up, this effect may be responsible for the break in $d\sigma^{e\ell}/dt$ at $-t \approx 0.1$ at ISR energies. If this argument is correct, the break may not occur at lower NAL energies.

The effect on the leading proton x-distribution is clear. This threshold mechanism is responsible for building the forward quasielastic peak near $x = 1$. Since the scaling limit is s/M^2 fixed, those contributions which give a constant pole renormalization do not scale. The region in x responsible is $1 - e^{-\epsilon Y} \leqslant x \leqslant 1 - e^{-Y_R}$. At $\ell n\, s = 5$ this range is $0.78 \leqslant x \leqslant 0.95$ while at $\ell n\, s = 8$ the range is $0.91 \leqslant x \leqslant 0.997$. Over this range of energy, the area under

the inclusive distribution $d\sigma/dx$ associated with this (moving) region is increasing (by a factor of three) due to the threshold opening up. The peak need not rise since the new regions nearer $x = 1$ are opening up as s increases. The region $x < 1 - e^{-\epsilon Y}$ is, by our arguments, sensitive to the pole-cut relationship. This is just the region of the dip at $x \approx 0.9$ at NAL energies [9]. It is this region that is very model dependent.

The formal analysis above has been extended to the di-triple Regge domain where large mass production in the pionization region builds the output pole in A_{22} with two vertex corrections (proportional to $\Gamma^2(0,0,0)$). This represents a higher energy threshold. The implication for the other decoupling theorems [10], the connection with higher order optical theorems (Mueller discontinuities) and extensions to multiple fireball processes, will be presented elsewhere [11].

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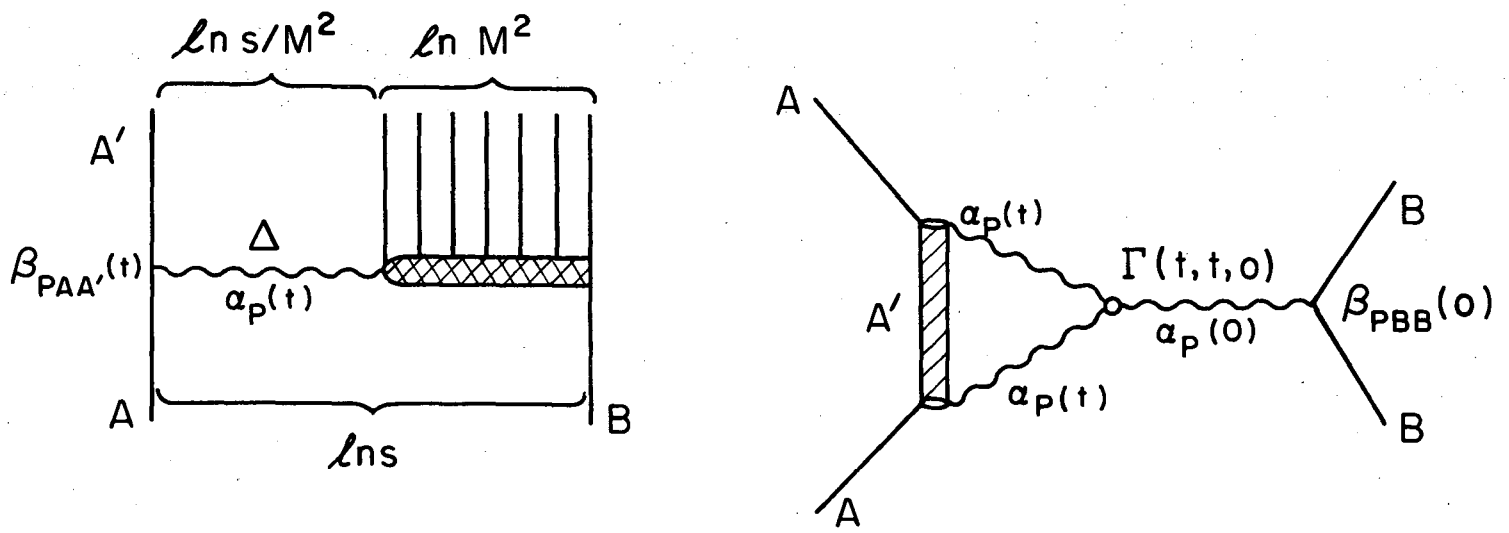
Figure Caption

Fig. 1.a.) Rapidity space decomposition of large mass diffractive processes. Infinitesimal rapidity displacements, due to energy conservation in producing particle masses, are neglected.

b.) Vertex correction to pole in $A_{22}(j)$ arising from the restricted triple-Regge region. The sum over elastic and low mass diffractively-produced states A' is indicated.



(a) (b)

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