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ON THE PHENOMENOLOGY OF THE POMERON

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Experimental data on the real and imaginary parts of hadronic forward scattering amplitudes are found to agree with the f-dominated pomeron, but to strongly disagree with the pomeron-f identity proposed by Chew and Rosenzweig.

1. Introduction

Whether physical quarks exist or are confined, quark diagrams are a useful tool in the study of hadronic reactions [1]. The exchange degenerate Regge trajectories are described by planar quark diagrams while non-planar diagrams bring the pomeron into play [2]. The simplest non-planar diagram is the twisted loop (or cylinder) diagram of fig. 1. In the t-channel it is "f-dominated" [3] and also constitutes the generic piece of the pomeron [2]. f-dominance, when systematically followed through, entails a mixing between the pomeron and the even signature isosinglet trajectories (f, f′, f_c, ...). A detailed treatment of this mixing depends on the assumed dynamics of the diagram of fig. 1. In this respect two alternatives have been suggested so far [3,4], and we want to give a critical comparison of these alternatives. In particular one interesting alternative suggested by Chew and Rosenzweig [4] appears to run into very serious difficulties when carefully compared with the data.

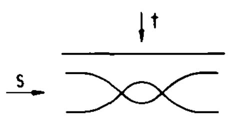

Fig. 1. Cylinder diagram.

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In sect. 2 we describe the two alternatives and in the remaining sections we devise useful experimental tests for them.

2. Dynamical alternatives

The two dynamical alternatives that we have in mind are:

(i) The f-dominated Pomeranchuk singularity.

(ii) The Chew-Rosenzweig P-f identity.

No matter what the dynamic details, the diagram of fig. 1 has to be iterated in the t- as well as s-channels (fig. 2). Consequently the f and f′ are shifted from their exchange degenerate status, as an f-f′-P mixing pattern gets established.

Model 1 considers the s-channel iteration of diagram 1 achieved and represents it by an effective "f-dominated" Pomeranchuk singularity to be added to the exchange-degenerate Regge exchanges. Further t-channel mixing effects are neglected on the argument that the observed breaking of f-A_2-ω-ρ exchange degeneracy is small. This model makes no statement about the nature of the Pomeranchuk singularity.

Model 2 assumes the t-channel iterations of diagram fig. 1 not to give rise to a Regge pole but only to a mixing of the f-f′ system sufficiently simple to be treated completely and of strength to push the f-Regge-pole intercept very close to 1.

In addition to these two models one may also consider a more specific variant of model 1, by assuming the Pomeranchuk singularity to be a pole and treating the P-f-f′ mixing completely. We shall refer to this as

(ia) the mixed P-f-f′ system.

As a rule, however, all data that can be fit by the f-dominated pomeron can *a fortiori* be fit by the mixed P-f-f′ system so that we shall not consider the phenomenology of the latter in any detail. Yet, we emphasize that all our findings on the f-dominated pomeron apply also to this model.

In principle then, all three models start from an input of exchange-degenerate mesonic Regge trajectories plus a piece dual to s-channel background and then assume various degrees of mixing between these pieces. All three models fit thus into the two-component duality picture (statements to the contrary [4] notwithstanding) and it becomes an experimental question to distinguish between them on the basis of the additional assumptions that they make.

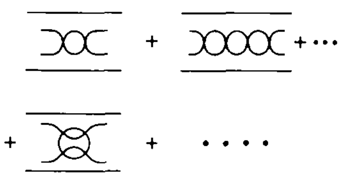

Fig. 2. s- and t-channel iterations of cylinder diagram.

3. Experimental tests of the models

We shall consider the experimental consequences of the models at $t = 0$. We start with the imaginary parts of the forward amplitudes, i.e., with the total cross sections. To avoid interference from (for our purposes) uninteresting quantum numbers we directly consider the t-channel-even signature isosinglet combinations

$$\Pi = \tfrac{1}{2}(\sigma_{\pi^- p} + \sigma_{\pi^+ p}) ,$$

$$K = \tfrac{1}{4}(\sigma_{K^- p} + \sigma_{K^+ p} + \sigma_{K^- n} + \sigma_{K^+ n}) ,$$

$$p = \tfrac{1}{4}(\sigma_{\bar{p}p} + \sigma_{pp} + \sigma_{\bar{p}n} + \sigma_{pn}) .$$

Keeping in mind that the target proton and neutron contain no strange quarks, model 1 predicts

$$\Pi = \gamma_M \gamma_B (s^{\alpha_f - 1} + P(s)) , \quad K = \gamma_M \gamma_B (\tfrac{1}{2} s^{\alpha_f - 1} + \eta P(s)) , \quad p = \gamma_B \gamma_B (s^{\alpha_f - 1} + P(s))$$

Here γ_M and γ_B are the mesonic and baryonic $t = 0$ couplings of the f-trajectory, $P(s)$ is the Pomeranchuk term and

$$\eta \simeq \frac{1}{2} + \frac{1}{2} \frac{m_\rho^2}{m_\phi^2} \simeq 0.8$$

takes into account the decrease in diffraction in KN scattering due to f′ as opposed to f-dominance.

In the Chew-Rosenzweig model (neglecting a very small f′ contribution)

$$\Pi = \gamma_P^\pi \gamma_P^N s^{\alpha_P(0) - 1} , \quad K = \gamma_P^K \gamma_P^N s^{\alpha_P(0) - 1} , \quad p = (\gamma_P^N)^2 s^{\alpha_P(0) - 1} ,$$

where the γ's are again $t = 0$ couplings of the pomeron ($\equiv$ f in this case).

We note that in both models

$$p/\Pi = \text{constant (independent of energy)} ,$$

a prediction quite consistent with experiment as can be seen from fig. 3 (remarkably the value ~ 1.7 of the constant as measured by experiment is somewhat larger than the quark model value $\frac{3}{2}$). Henceforth we can therefore restrict our considerations to the combinations Π and K. Note that in both models the combination $2K - \Pi$ is pure pomeron. In fig. 4 we plot this combination and note that it is a monotonically *increasing* function of the energy from energies as low as 6 GeV all the way to the highest available FNAL energies. This rules out a pomeron intercept below one as suggested in ref. [6]. We emphasize that while the particular fit of ref. [6] is ruled out on the basis of total cross-section data (the $2K - \Pi$ plot is just a first example, the experimental data for the combination $\sigma_{K^- n} - \sigma_{K^+ n}$ disagree violently with the

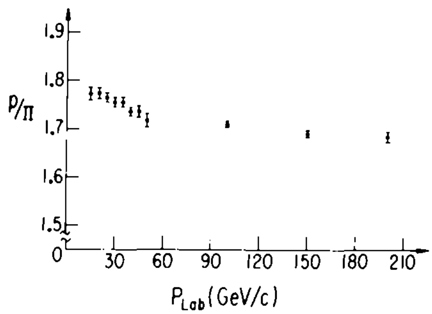

Fig. 3. Energy dependence of the ratio p/Π.

fit of ref. [6]; these discrepancies are somewhat masked by the fact that in ref. [6] the fits are made directly for large individual total cross sections rather than for possible small and faster varying combinations thereof), the Chew-Rosenzweig model as such is *not* ruled out at this stage because it does not require $\alpha_P(0) < 1$. But as of now we are considering the Chew-Rosenzweig model only with $\alpha_P(0) \geqslant 1$ in its range of validity $E = 5$–30 GeV claimed in ref. [6] (this limitation avoids conflict with the Froissart bound).

One might hope for a third test using total cross sections but, alas, it is not a very powerful one. The combination $\eta\Pi - K$ is predicted by model 1 to fall with energy quite fast (as $\alpha_f(0) \simeq 0.4$–0.5). There is no question that this is experimentally so but the exact intercept of the f-trajectory turns out to be *very* sensitive to the choice of η: for η in the narrow range $\eta = 0.81$–0.84, $\alpha_f(0)$ varies between -0.88 and $+0.34$. In model 2 one expects this combination $\eta\Pi - K$ either to vary slowly with energy or for a certain value of η to be identically zero. But identically zero here means of the order of the neglected f$'$ term the intercept of which is $\alpha_f'(0) \simeq 0.3$, so that again both models can account for the data.

In short then, total cross-section data can be explained by both the f-dominated Pomeranchuk singularity model and the Chew-Rosenzweig model based on f-P iden-

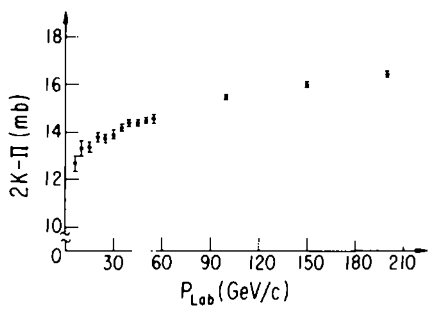

Fig. 4. Energy dependence of the pomeron.

tity but with $\alpha_P^{\rm eff}(0) \geqslant 1$. To distinguish between them one has to go one step further and discuss real parts of the forward scattering amplitudes.

The relevance for the Chew-Rosenzweig model of the increase with energy of the combination $2K - \Pi$, as well as the fact that total cross-section data alone are insufficient for testing the Chew-Rosenzweig model have been noted earlier by Quigg and Rabinovici [7]. These authors have therefore considered non-forward scattering, and showed that the Chew-Rosenzweig model is not favored by the data they analysed. As we shall show here the consideration of real parts gives new and much stronger evidence against this model *.

4. Real parts of forward scattering amplitudes

While the imaginary parts of forward scattering amplitudes could accomodate all models considered in sect. 2, real parts place a much more severe test on them.

To see this consider the real parts $D^{\pm}$ of the $\pi^{\pm}$p forward scattering amplitudes and take the combination

$$D_\pi = \tfrac{1}{2}(D^+ + D^-)\,.$$

Assuming for simplicity all relevant complex angular momentum plane singularities to be Regge poles we have

$$D_\pi = \sum_{i=\text{Regge pole}} \frac{\beta_i(0)\,(\cos \pi\alpha_i(0) + 1)}{\sin \pi\alpha_i(0)}\, s^{\alpha_i(0)}\,.$$

Define further the ratio ρ_π of real and imaginary parts (as before $\Pi \equiv \tfrac{1}{2}(\sigma_{\pi^-p} + \sigma_{\pi^+p})$)

$$\rho_\pi = \frac{D}{s\Pi} = -\frac{\sum_i \beta_i(0)\,(\cot \pi\alpha_i(0) + \operatorname{cosec} \pi\alpha_i(0))\, s^{\alpha_i(0)}}{\sum_i \beta_i(0)\, s^{\alpha_i(0)}}\,.$$

* In sect. 4 of the paper of Stevens et al. [6], the following statement appears:
"What happens when one employes the conventional picture of f, exchange-degenerate with ρ, together with a *separate* pomeron of intercept 1? Most of the even-signature FESR strength then goes to the f, leaving only a small remainder for the pomeron, corresponding to an asymptotic $\pi\pi$ total cross section of only 3 mb. To achieve a more reasonable asymptotic total $\pi\pi$ cross section ($\sim$14 mb), ρ-f exchange degeneracy must be violated by $\sim$50%. The situation for the conventional picture is thus uncomfortable, but it is clouded by the even-signature FESR sensitivity to energies above 1 GeV."

At the referee's request we shall here comment on this statement.

We first note that in a model with both a pomeron and an exchange-degenerate f-ρ pair, the f and ρ contributions to total cross sections add in $\pi^-\pi^+$ scattering but cancel in $\pi^+\pi^+$ scattering. ρ-universality (on excellent experimental footing) predicts the ρ-contribution to $\sigma_{\pi^-\pi^+} - \sigma_{\pi^+\pi^+}$ to be $2(\sigma_{\pi^-p} - \sigma_{\pi^+p})$. With f-$\rho$ exchange degeneracy, this then tells us that the f-contribution to $\sigma_{\pi^-\pi^+}$ is $\sigma_{\pi^-p} - \sigma_{\pi^+p}$ which in the energy range $E_{\rm lab} = 5$–40 GeV varies between 2.3 and 1.2 mb. It is thus comfortably small compared to an expected 15 mb pomeron in $\sigma_{\pi\pi}$ and certainly nothing like a 50% breaking of ρ-f exchange degeneracy is needed.

In model 1 then

$$\rho_\pi = -\frac{\beta_f(0)\, s^{\alpha_f(0)-1}(1+\cos\pi\alpha_f(0))}{\Pi \sin\pi\alpha_f(0)} \; .$$

We note two important features of this formula:

(i) ρ_π falls with energy like $s^{\alpha_f(0)-1} \simeq s^{-1/2}$;

(ii) $\rho_\pi < 0$ (as $\alpha_f(0) \simeq \frac{1}{2}$).

Finally a third feature is quantitative:

$$\beta_f(0)\, s^{\alpha_f(0)-1} = \frac{\eta\Pi}{\eta - \frac{1}{2}} K \; ,$$

and thus fixes the normalization of ρ_π in terms of experimentally known total cross-section once η is known. The value $\eta = 0.83$ is, as we have seen, a good value so that this equation predicts (for $\eta = 0.83$, $\alpha_f(0) \simeq 0.5$)

$$\rho_\pi\ (P_L = 20\ \mathrm{GeV}) = \quad 0.14$$

to be compared with the experimental value of ρ_π $(P_L = 20.2\ \mathrm{GeV}) = -0.139 \pm 0.021$
By contrast the f-P identity of Chew and Rosenzweig predicts

$$\rho_\pi = \frac{1+\cos\pi\alpha_P(0)}{\sin\pi\alpha_P(0)} + f'\text{-term}$$

$$\simeq \tfrac{1}{2}\pi(\alpha_P(0) - 1) + f'\text{-term} \; .$$

Since, as we have seen, $\alpha_P(0) \geqslant 1$, the first term is non-negative so that either

(i′) ρ_π is constant or increasing with energy;

and

(ii′) ρ_π is positive at large energies;

or

(i″) ρ_π falls with energy like $s^{\alpha_{f'}(0)-1} \sim s^{-0.7}$;

(ii″) $\rho_\pi < 0$.

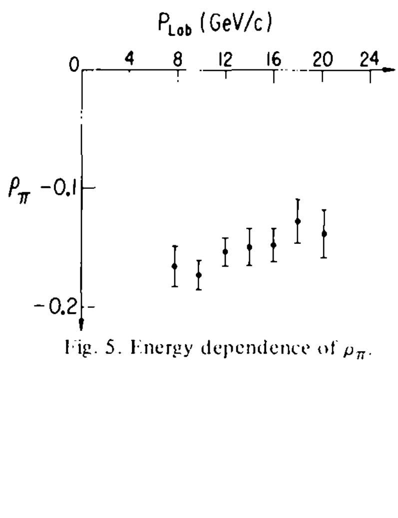

Fig. 5. Energy dependence of ρ_π.

Experimentally $\rho_\pi < 0$ and falls (fig. 5) so that (i′), (ii′) are ruled out. The alternative (i″) + (ii′) is ruled out as follows. If the ρ_π contribution is entirely due to the f′ (most favorable case for Chew-Rosenzweig as any pomeron contribution has, as we saw, the wrong sign) then its normalization is given by

$$\rho_\pi = \tan^2\theta \, \frac{1 + \cos \pi\alpha_{f'}}{\sin \pi\alpha_{f'}} \left(\frac{s}{s_0}\right)^{\alpha_{f'} - 1} .$$

where θ is the f-f′ mixing angle. For any reasonable set of parameters this gives by far too small a value for ρ_π. For instance $\theta = 20°$, $\alpha_{f'} \simeq 0.3$ $s_0 = 0.4$ GeV^2 gives $\rho_\pi(s = 20\ \mathrm{GeV}^2) = 0.018$, while changing s_0 to 1 GeV^2 still gives $\rho_\pi(s = 20\ \mathrm{GeV}^2) = 0.033$. The f′ contribution is thus, not surprisingly, too small to account for the observed value of ρ_π. Moreover, the energy dependence $s^{\alpha_{f'} - 1} \simeq s^{-0.7}$ (or even s^{-1}) is way too steep when compared to fig. 5. By comparison the f-dominated pomeron gave the right normalization of ρ_π and smoother energy dependence ($s^{-0.4} - s^{0.5}$) compatible with the data.

Finally, a similar treatment of the real part of KN scattering amplitudes, while feasible, is less conclusive on account of the larger experimental uncertainties.

5. Conclusions

We have shown that experimental data on total cross sections [5] and on the real parts of forward scattering amplitudes [8] at all energies above a couple of GeV are compatible with the f-dominated pomeron or with the more specific mixed P-f-f′ model. The same data – as a matter of fact already the data below 30 GeV – are in strong disagreement with the Chew-Rosenzweig model.

Veneziano [9] has noted the Chew-Rosenzweig model as a simple realization of his topological expansion approach to hadronic reactions. This expansion differs essentially from that encountered in dual resonance models, and is claimed to be incompatible also with two-component duality. It is an interesting question as to how these findings bear on the validity of the whole topological expansion approach.

We wish to thank Professor J. Rosner for a valuable conversation.

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