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REPORT

The Pomeron-f Identity and Hadronic Total Cross Sections at Moderate Energy*

by

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ABSTRACT

The topological expansion of the S-matrix implies that the Pomeron and f are the same Regge trajectory. We confront this hypothesis with data by successfully fitting σ_{tot} at moderate energies in a Regge model containing only one prominent vacuum trajectory, plus the ρ and ω. Couplings and intercepts obey the constraints imposed by the topological expansion. The cylinder coupling is found to be 0.16. Existing data on $\pi\pi$ total cross sections are studied via FESR. The Pomeron-f identity is consistent with the analysis. The conventional picture is not.

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I. Introduction

The relationship of the Pomeron to other Regge singularities has been a puzzle for strong-interaction dynamics. It has recently been proposed[1], on the basis of the topological[2] or dual-unitarity approach[3] to multiparticle reactions that the Pomeron is not an aristocratic trajectory distinct from all other but merely the highest Reggeon (the f), elevated to prominence for $t \leq 0$ by its vacuum quantum numbers. The mechanism responsible for its elevation, described in topological language as the "cylinder", is discussed in detail in Ref. 1. One starts from the planar S-matrix with a set of exactly exchange-degenerate Regge trajectories whose couplings correspond to ideal mixing, the cylinder breaks the degeneracy of isosinglet trajectories and shifts their couplings from ideal, without introducing any new Regge singularities. The shifts become extremely small for large positive t but are substantial near t=0. Leading natural-parity I = 0 trajectories with even charge conjugation are raised (e.g., $\alpha_f > \alpha_\rho$), while odd charge-conjugation trajectories are lowered (e.g., $\alpha_\omega < \alpha_\rho$). These trajectory displacements and the associated coupling shifts are codetermined by a "cylinder operator" whose elements, it was argued in Ref. 1, should be nonsingular and approximately SU_3 symmetric. The consequence is a pattern of leading vector-tensor Regge trajectories and couplings that generalizes the scheme of Carlitz, Green and Zee[4], with Pomeron and f being alternative names for the same leading trajectory. In the heretofore-accepted picture, which successfully correlates many experimental observations, there are two high-lying vacuum trajectories: the Pomeron with $\alpha_P(o) \simeq 1$ and the f, exchange-degenerate with ρ, A_2 and ω, at $\alpha_f(o) \simeq 0.5$. The question addressed here is whether Pomeron-f identity, within the trajectory pattern of the topological expansion, can be compatible with experimental measurements of total cross sections.

In approaching this question one must recognize that different hadronic degress of freedom have different effective thresholds and that some of these thresholds are not reached until high energy. Baryon production, for example, does not overcome kinematical inhibitions until $s \sim 200\ GeV^2$. To represent such an elevated effective threshold requires complex Regge poles[5] the real parts of whose positions may be as high as 0.5, confusing the Pomeron-f identity issue. We shall attempt to avoid this confusion by using only data below the effective threshold for baryon production, and by consistently ignoring the baryon-number degree of freedom in our theoretical model, keeping only isospin and strangeness. We shall also ignore the high-threshold degree of freedom presumed responsible for the newly discovered family of particles with masses ≥ 3 GeV. By neglecting some internal degrees of freedom, the intercept of the Pomeron in our model lies below the Reggeon-calculus "bare" Pomeron, which is supposed to include all hadronic degrees of freedom. The adjective bare reminds us that we are still lacking the renormalizing effects of components beyond the cylinder (handles) in the topological expansion[6]. We shall characterize our Pomeron with the adjective "embryonic" rather than bare. The bare Pomeron intercept is probably above 1; our embryonic Pomeron has intercept slightly below 1. The transition from embryonic to dressed Pomeron is discussed by Dash and Koplik[7].

The substantial K-π mass difference inhibits low-energy excitation of the strangeness degree of freedom, and this inhibition is not represented in the simple model derived in Ref. 1. To do so would require complex poles, although the real parts of their positions would be lower than for poles associated with the baryon production threshold.

We do not, therefore, claim a definitive status for the data fitting described here but use it to illustrate the difficulty of distinguishing on experimental grounds between one or two vacuum trajectories. Were we to exclude strange-

particle production from the experiments to be considered we would be left with too small an energy range for meaningful conclusions. Our compromise is to fit data on $\pi^{\pm}p$, $K^{\pm}p$ and $p^{\pm}p$ total cross sections for 5 GeV < p_{1ab} < 30 GeV with a model that ignores complex poles as well as cuts.

Neglecting the complex poles arising from kaon production has some important qualitative effects as will be mentioned later. Regge cuts, which correspond to higher components (handles) of the topological expansion, are expected to make contributions of the order of 10%. Furthermore, although the model of Ref. 1 includes six trajectories, f, ρ, A_2, ω, f' and ϕ, we shall here neglect the lower-lying f' and ϕ, these latter being expected to couple relatively weakly to the nucleon. We find that the leading four trajectories, with intercepts and couplings interrelated by a simple cylinder operator, give an acceptable representation of the experimental picture. The parameters defining our model are summarized in Sec. II and the fit is described in Sec. III.

In Sec. IV we consider the prediction of ππ and Kπ total cross sections that follows from the parameters determined in Sec. III. In contrast to the conventional picture, which predicts a flat energy dependence of the $\pi^+\pi^+$ (or $\pi^-\pi^-$) cross section, our model yields a rising tendency at low energy. Preliminary ππ experimental data is discussed with the help of finite-energy sum rules.

II. A Simple Model for the Embryonic Pomeron

The general discussion given in Ref. 1 was illustrated by a simple model based on six leading trajectories: f, ω, ρ, A_2, f', ϕ. At the planar level the first four are degenerate, their common trajectory being labeled α_0, while the latter two are degenerate at α_3; the difference $\alpha_0 - \alpha_3$ is the sole manifestation of SU_3 symmetry breaking in the model. The cylinder perturbs only I = 0 states, so ρ and A_2 remain at α_0, while f moves up from α_0, ω moves down from α_0, f' moves up from α_3 and ϕ moves down from α_3. Labeling the cylinder strength as k, a positive number, the f(Pomeron) trajectory is located at

$$\alpha_f = \frac{1}{2}\left\{\alpha_0 + \alpha_3 + 3k + \left[(\alpha_0 - \alpha_3 + k)^2 + 8k^2\right]^{1/2}\right\} , \qquad \text{(II.1)}$$

while replacement of k by -k in (II.1) gives the shifted ω trajectory. Similar formulas locate the ϕ and f' trajectories but, as already remarked, we shall not use these latter two trajectories in our fit.

Just as the trajectory locations are determined by planar parameters plus the cylinder coupling strength, so too are the shifted couplings constants. The Regge couplings to charged pions and kaons were found in Ref. 1 to be

$$\gamma^{\rho}_{\pi^{\mp}} = \pm 2\,g \qquad \gamma^{\rho}_{K^{\mp}} = \pm\,g$$

$$\gamma^{A_2}_{\pi^{\mp}} = 0 \qquad \gamma^{A_2}_{K^{\mp}} = g$$

$$\gamma^{f}_{\pi^{\mp}} = 2\,g \cos\theta^+ \qquad \gamma^{f}_{K^{\mp}} = g\cos\theta^+ + \sqrt{2}\,g\sin\theta^+$$

$$\gamma^{\omega}_{\pi^{\mp}} = 0 \qquad \gamma^{\omega}_{K^{\mp}} = \pm g\cos\theta^- \mp \sqrt{2}\,g\sin\theta^- , \qquad \text{(II.2)}$$

where g is the planar coupling and the mixing angles $\theta^{\pm}$ are given by

$$\tan 2\,\theta^{\pm} = \frac{\pm\sqrt{8}\,k}{\alpha_0 - \alpha_3 \pm k} . \qquad \text{(II.3)}$$

Up to this point we have four dimensionless parameters, α_0, α_3, g and k. These parameters, together with a dimensional parameter s_0 to set the energy scale, suffice for the description of $\pi\pi$, πK and $K\bar{K}$ total cross sections. The accurate and extensive available data, however, involves nucleons, so three

additional parameters, $\gamma^{\rho}_N = \gamma^{A_2}_N$, γ^{ω}_N and γ^{f}_N, are required. These three could be interrelated, as in Formulas (II.2), if there existed an accurate planar model of baryons. In the absence of such a model we treat the three as independent, making the total number of parameters eight.

Were the planar S-matrix exactly known, the cylinder strength k could be computed. Estimates of k have effectively been achieved by other authors but without sufficient precision for our purposes here[3]. Rough calculations have been made[3,8] of the planar parameters α_0 and g, using bootstrap considerations[9]. Bootstrap constraints in time may succeed in determining all aspects of the planar S-matrix, but we do not in this paper attempt to exploit such considerations.

III. A Regge Fit of $\pi^{\pm}p$, $K^{\pm}p$, $p^{\pm}p$ Total Cross Sections at Moderate Energy

With an amplitude normalization such that

$$\sigma^{tot}_{ab}(s) = \frac{1}{p_{c.m.}\sqrt{s}}\ \mathrm{Im}\,T_{ab}(s,0) , \qquad \text{(III.1)}$$

we employ the Regge representation

$$\mathrm{Im}\,T_{ab}(s,0) = \sum_i \gamma_a^{\,i}(0)\,\gamma_b^{\,i}(0)\left(\frac{s}{s_0}\right)^{\alpha_i(0)} . \qquad \text{(III.2)}$$

The choice of s as expansion variable is not unique, but the ambiguity corresponds to Regge singularities one unit or more below the leading singularity and should be no more serious than our neglect of strange-particle threshold complications and of Regge cuts.

The planar parameter $\alpha_0 = \alpha_{A_2}(0) = \alpha_\rho(0)$ was determined to be 0.58 from the $\pi^{\pm}p$ total cross section difference. We then proceeded to fit the other parameters, with results displayed in Fig. 1 and in Table I. With the possible exception of the π^+p cross section the fits are seen to be excellent. Were the f (Pomeron) intercept determined entirely from the sum of π^+p and π^-p cross sections in this energy interval, one would find $\alpha_f(0)$ to be lower than the value in Table I by about 0.04. The corresponding combination of KN cross sections would give a slightly higher f intercept, by about 0.02, while NN cross sections, taken alone, correspond almost exactly to the value of $\alpha_f(0)$ in Table I. Such small discrepancies are attributable to strange-particle threshold effects (complex poles) and Regge cuts. Neglect of these perturbations may easily displace intercepts by 0.1. Nothing in the data compels two comparably important vacuum trajectories with a spacing near 0.5. A single vacuum trajectory, with intercept slightly below 1 fits, to within a few percent, all total cross section data in this energy region.

A qualitative discrepancy arises, however, if we isolate particular combinations of cross sections. It has recently been pointed out[11], that L, defined as

$$L = 2(\sigma_{K^+p} + \sigma_{K^-p}) - (\sigma_{\pi^+p} + \sigma_{\pi^-p})$$

rises smoothly from p_{lab} of 6 GeV/c through FNAL energies, whereas our model predicts a gentle decrease over the energy range we consider. However, as has been repeatedly emphasized, we have neglected threshold phenomena in this study. In our model

$$L \propto \sin\theta^+ \, s^{\alpha_f - 1} .$$

If there were no strange degrees of freedom $\theta^+ = 0$, whereas we have seen that $\theta^+ = 20°$ after strangeness has been excited. Thus we expect θ^+ to be strongly energy dependent as we sweep through the energy range where strange particles are produced. L is precisely that combination which will have the most pronounced increase in energy as a result of $K,\bar{K}$ threshold phenomena. Whether or not proper

incorporation of thresholds will provide a satisfactory fit to the data is an open question, but, qualitatively at least, the behavior discussed in Ref. 1 is not unexpected.

We have listed the values of $\alpha_{f'}(0)$ and $\alpha_\phi(0)$ in Table I even though these trajectories have been omitted from our fit. The low value of the ϕ intercept justifies a posteriori its neglect, but the f' intercept, only 0.1 unit of J below the ω, indicates that this trajectory may play a significant role in moderate-energy Regge phenomenology.

The usual argument for neglecting the f', unrelated to its intercept, is the small f' coupling to nucleons and pions, according to the Okubo-Zweig-Iizuka rule. How accurate is the OZI rule? Violation is measured by the mixing angle θ^+, which in Table I is determined to be 20° at t=0. Such a violation is relatively small but will be non-negligible if Regge cuts and the strange-particle threshold complication can be handled and one attempts to go beyond the few percent accuracy level. A 20° mixing angle, if fact, looks substantial if one remembers that the rotation needed to move the f from ideal mixing to pure SU_3 singlet couplings is only 35°. That is to say, the f(Pomeron) couplings at t=0, with θ^+ as given in Table I, are roughly midway between these two extremes. For the ω trajectory the OZI-rule-violating mixing angle of 34° listed in Table I should be compared to the -55° rotation needed to pass from ideal mixing to SU_3 octet.

The strength of the cylinder is measured by the angles $\theta^\pm$, and also by the parameter k. Formulas (II.1) and (II.3) illustrate that the largeness or smallness of k is to be judged by its magnitude relative to the displacement $\alpha_0 - \alpha_3$. On such a basis the value k = 0.15 at t=0 is seen to be intermediate--neither very large nor very small. A useful practical observation is that k(0) is sufficiently small as to allow a reasonably accurate second-order perturbation approximation to formulas such as (II.1) or (II.3). On the other hand, the first-order approximation, in predicting that the spacing between Pomeron and ρ is the same as between ρ and ω, is in qualitative disagreement both with the exact formula from our simple model (see Table I) and with experimental observation. It is also interesting that the spacing between the planar intercepts $\alpha_0(0)$ and $\alpha_3(0)$ turns out close to that which may be inferred from ω-ϕ and f-f' mass differences together with the principle of asymptotic planarity[12]. The two planar trajectories $\alpha_0(t)$ and $\alpha_3(t)$ seem to maintain a fairly constant spacing $\simeq$ 0.35 units of J.

Because of the necessity to introduce three separate parameters for nucleon couplings, it is difficult to judge how well the π-K coupling constraints (II.2) have been tested, but it is interesting that these constraints have led in Table I to a large deviation from the oft-stated "universality" rule, $\gamma_N^{\omega} = 3\,\gamma_N^{\rho}$, whereas the ω universality rule $3\,\gamma_K^{\omega} = \gamma_P^{\omega}$ is roughly satisfied. Both these conclusions are compatible with previous results[13].

IV. $\pi\pi$ and πK Total Cross Sections

One may straightforwardly convert the parameters of Table I into $\pi\pi$ and πK total cross sections. Let us now consider these predictions, shown in Fig. 2.

Because our model not only breaks exchange degeneracy but contains no Pomeron separate from the f, it seems to deviate qualitatively from the Harari-Freund picture of two-component duality[14,15], a picture celebrated for its simple explanation of energy - independent total cross sections in exotic channels. Although our model has managed to accomodate the observed weak energy dependence of K^+p and pp cross sections (Fig. 1), one might anticipate from out picture a strong variation with energy in the $\pi^-\pi^-$ (or $\pi^+\pi^+$) cross section—where only f and ρ contribute and there is no chance for multi-trajectory compensations. Fig. 2 nevertheless shows that above s = 5 GeV^2 our model's prediction for this exotic

cross section is almost flat. The predicted decrease at very low energy will be difficult to dissociate from an inelastic threshold effect, so there is little prospect that any measurement of the $\pi^-\pi^-$ cross section will change the minds of those who are skeptical of Pomeron-f identity.

At present the only available $\pi\pi$ data is at rather low energies. The CERN-Munich collaboration[16] has produced high-statistics $\pi^+\pi^-$ total cross section information in the range 0.4 < s < 3.6 GeV^2 and for $\pi^-\pi^-$ in the range 0.4 < s < 1.4 GeV^2. By applying finite energy sum rules (FESR)[17] to this data it is possible to check some of the numbers in Table I. What emerges from such an exercise?

The FESR consistency of the ρ model for odd-signature exchange has long ago been established,[18] and we are not tampering with this simple picture. With our parameterization, the odd-signature FESR leads to $\gamma_\pi^{\rho} = 3.0 \pm 0.4$, to be compared to the number from Table II: $\gamma_\pi^{\rho} = 2g = 2.98$. We are here choosing the FESR upper limit at s = 2.2 GeV^2, midway between m_f^2 and m_g^2. Although the $\pi^-\pi^-$ data extends only to s = 1.4 GeV^2, the odd-signature sum rule is insensitive to the unmeasured interval.

For the subject of this paper it is the even signature exchange that is interesting; and here the as-yet unmeasured interval in s <u>is</u> significant for the sum rule. Assuming the same value (5 mb) for $\sigma^{tot}_{\pi^-\pi^-}$ between s = 1.4 GeV^2 and s = 2.2 GeV^2 as is found at s = 1.4 GeV^2, the even-negative FESR yields $\gamma_\pi^{f} = 2.7 \pm 0.6$, to be compared to $\gamma_\pi^{f} = 2g\cos\theta^+ = 2.79$ from Table I. According to Fig. 2 such an extrapolation of the data is reasonable. There is thus no difficulty in assigning the entire strength of the I=0 FESR to a single trajectory.

What happens when one employs the conventional picture of f, exchange-degenerate with ρ, together with a <u>separate</u> 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.

Qualitatively, the experimentally-observed approximate equality in strength of Pomeron and ρ gives support to Pomeron-f identity. The conventional picture gives no explanation of the magnitude of Pomeron coupling; any similarity between Pomeron and ρ is accidental.

V. Conclusions

We have demonstrated in this paper that Pomeron-f identity within a simple Regge-pole model is compatible with experimental total cross section information at energies where no more than the isospin and strangeness degrees of freedom are excited. To cover a broader energy range would require not only Regge cuts but complex Regge poles associated with high-threshold internal hadronic degrees of freedom such as baryon number. Even in the moderate interval considered here cuts and complex poles are expected to contribute at the 10% level, the parameters of Table I carrying a corresponding uncertainty.

Because the model employed in our fit ignores high-threshold degrees of freedom, such as baryon number, we have characterized the Pomeron of this paper as "embryonic."[19] The "bare" Pomeron, a pole that neglects the renormalizing effect of Regge cuts but includes all internal degrees of freedom, will lie somewhat higher, probably above 1 at t=0, but such a bare Pomeron, if applied to moderate-energy data, must be accompanied by lower-lying threshold-related complex poles.

The success of our fit draws attention to the already-known but often overlooked experimental fact that Pomeron parameters are not far from those of that archtypical "normal" Reggeon, the ρ. We attribute the modest Pomeron-ρ differences to a cylinder shift whose magnitude at t=0 is no mystery. This magnitude

has been semi-quantitatively estimated[3] in terms of measured triple-Regge couplings and has been shown to connect reasonably with vector and tensor meson deviations from exchange degeneracy and ideal mixing[12].

The t=0 cylinder coupling deduced here from total cross section data constitutes one element in a more general picture of "asymptotic planarity", according to which cylinder strength decreases monotonically with increasing t. As explained in Ref. 12 the leading vacuum trajectory shifts gradually from the classical Pomeron characteristics of pure SU_3 singlet couplings and small slope at large negative t to the classical f characteristics of ideal couplings and exchange degeneracy (with ρ, A_2 and ω) at large positive t. At t=0 the transition has proceeded approximately halfway, so both the label "Pomeron" and the label "f" can claim legitimacy.

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TABLE I

(Asterisk denotes a fitted parameter.)

(a) Intercepts

α_0	α_3	α_f	α_ω	$\alpha_{f'}$	α_ϕ
0.58*	0.23*	0.96	0.41	0.31	-0.06

(b) Coupling constants

g	γ_N^f	γ_N^ω	γ_N^ρ	k
1.49*	4.94*	5.89*	0.785*	0.152*

(c) Mixing angles

θ^+	θ^-
20.3°	-33.7°

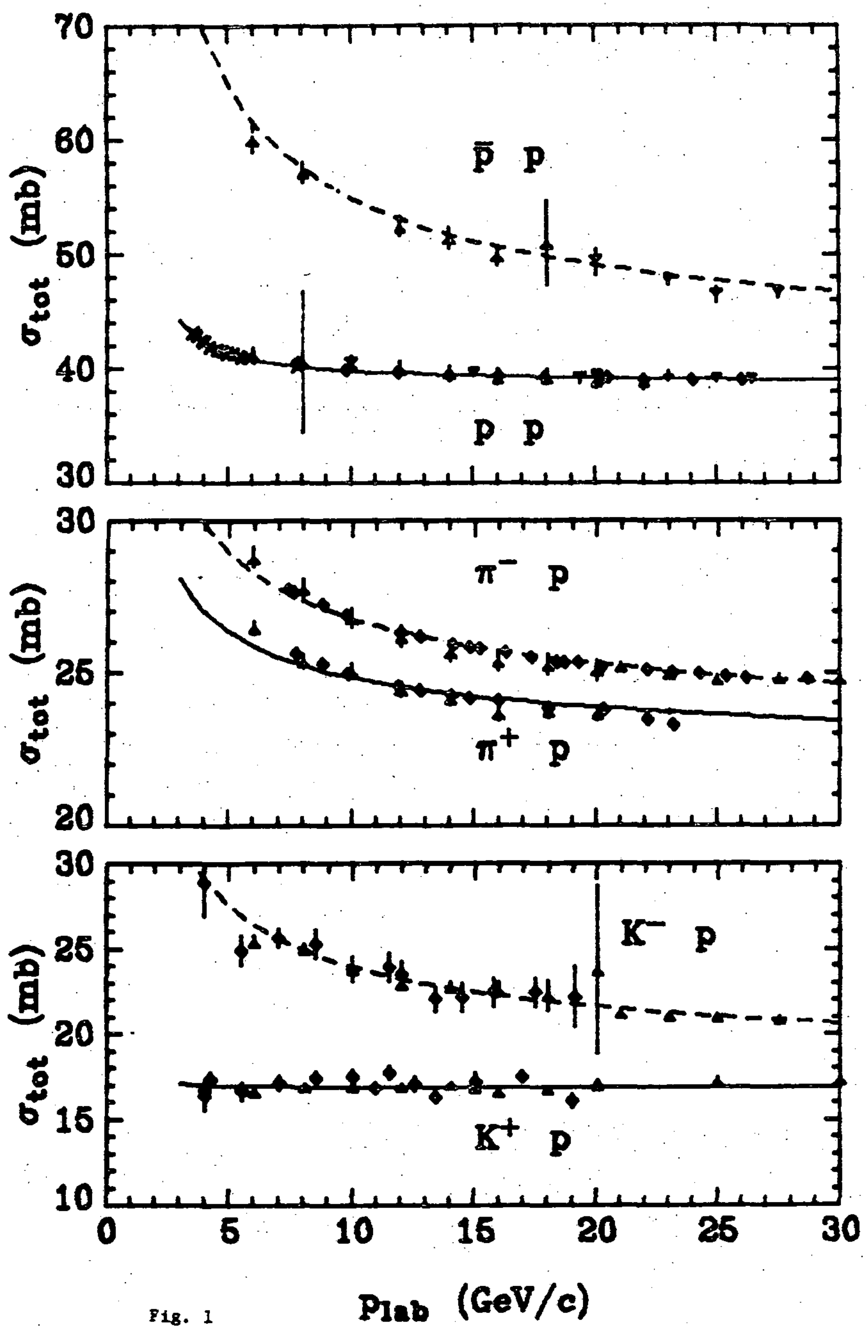
(d) Scale factor

$$s_0 = 0.376 \text{ GeV}^2 \, {}^*$$

Figure Captions

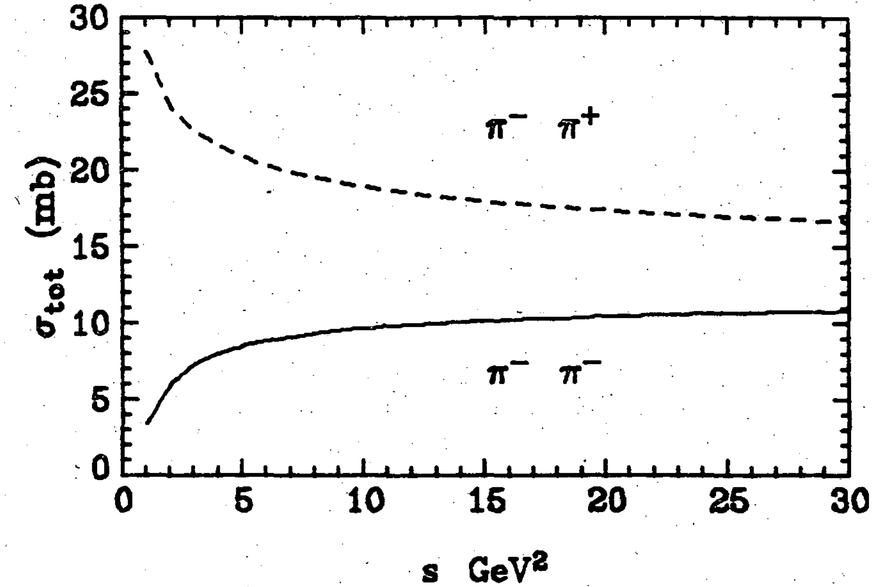
Figure 1: The model fit, with the parameters in Table I, to moderate energy pp, πp, and Kp total cross sections. The data are from reference 10.

Figure 2: A prediction, based on the model of reference 1 and the parameters of Table I, for the $\pi\pi$ total cross section.



$\bar{p}$ p
p p
π^- p
π^+ p
K^- p
K^+ p
σ_{tot} (mb)
p_{lab} (GeV/c)

Fig. 1



π^- π^+
π^- π^-
σ_{tot} (mb)
s GeV²

Fig. 2

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