The hard pomeron in soft data

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Abstract

We show that the data for the total cross section and for the real part of the elastic amplitude indicate the presence of a hard pomeron in πp and Kp elastic scattering at $t = 0$, compatible with that observed in deep inelastic scattering. We show that such a hard pomeron is also compatible with pp and $\bar{p}p$ data, provided one unitarises it at high energy.

1 The hard pomeron: what we know

The existence of a hard singularity in hadronic amplitudes has been predicted a long time ago [1], within the context of perturbation theory at small-x. It was then shown that a leading-log(s) resummation would lead to a square-root branch-cut in the complex j plane starting at

$$\alpha_h^{ll} = 1 + \frac{12\ln 2}{\pi}\alpha_S$$

with α_S a fixed value of the strong coupling constant.

Such a fierce singularity has not been seen in data, but it was shown later that the leading-log(s) predictions were unstable with respect to sub-leading resummation [2, 3], and that the singularity was likely to be softer [4]. Unfortunately, this result depends on the algorithm followed to choose the renormalisation scale. Nevertheless, the main message is that perturbative QCD leads to a strong singularity.

As most of the data have some soft physics intertwined with short-distance effects, this "pure" BFKL pomeron may be transformed into another object because of long-distance corrections. In fact, it is possible that such a singularity is already present in HERA data [5]. If one assumes that the singularities of hadronic elastic amplitudes are well approximated by simple poles only, then one needs to introduce a new singularity, apparently not present in

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soft cross sections, to account for the rise of F_2 at small x. This new singularity was taken to be a simple pole, in which case one obtains a phenomenological estimate of its intercept [5]:

$$1.39 < \alpha_h < 1.44.$$

From quasi-elastic vector meson production, one can obtain an estimate [5] of the slope of the new trajectory

$$\alpha' \approx 0.1 \text{ GeV}^{-2}.$$

One of the troublesome properties of this singularity is that it is manifest only in off-shell photon cross sections. One may argue that, as standard factorisation theorems do not apply then, one can have a singularity that is not present in purely hadronic data. It is in fact unclear whether this singularity should be present in the photon-proton total cross section, for which factorisation cannot be proven either. A recent extrapolation [5] estimates that the ratios of the soft pomeron to the hard pomeron coupling is given, for the total γp cross section, by

$$\frac{g_{hard}}{g_{soft}} \approx 0.002. \tag{1}$$

It is possible however that the hard pomeron coupling is zero in this case.

So far, no observation of the hard pomeron has been reported in soft data, although several authors have shown that the inclusion of a hard pomeron in soft data is possible [6]. We shall argue here that such a singularity is in fact a necessary ingredient to obtain a good fit to all forward soft data − provided that one uses a simple pole to describe the soft pomeron.

2 Previous fits to soft data

A considerable effort [7] has recently been devoted to the reproduction of soft data through analytical fits based on S-matrix theory. The main difference between the forms used concerns the pomeron term, for which three main classes of dependence in s have been considered: $\ln\frac{s}{s_d}$, $\ln^2\frac{s}{s_t}+C$, and simple poles $\left(\frac{s}{s_1}\right)^{\alpha}$. Although these three forms for the pomeron work reasonably well in the description of total cross sections at high energy ($\sqrt{s} > 10$ GeV), the simple-pole description fails if the energy threshold is lowered to $\sqrt{s} > 5$ GeV, or if the real part of the amplitude is included, whereas the logarithmic forms achieve a good fit quality down to 5 GeV. Note that this is rather strange on theoretical grounds, as one would expect unitarised forms to work better at high-energy. We show in Table I the results corresponding to those obtained by the COMPETE collaboration [7, 8], but with the updated dataset used in the present study [9]: we consider all[1] pp, $\bar{p}p$, $K^{\pm}p$ and $\pi^{\pm}p$ data for the total cross section and for the ρ parameter, as well as all γp and $\gamma\gamma$ data for the total cross section.

As one can see from Table 1, the main problem of the simple pole fit stems from the Kp and πp data, and particularly from the ρ parameter. Hence we want first to re-consider the treatment of the real part of the amplitude. We have improved the fit of [7, 8] by including the following sub-leading effects:

1. We started with a parametrisation for the imaginary part of the asymptotic elastic amplitude $ab \to ab$. Regge theory predicts that it is a function of $\cos\theta_t = \frac{s-m_a^2-m_b^2}{2m_a m_b} =$

[1] Because of the ambiguities linked to nuclear effects, we excluded cosmic-ray data.

		χ^2/n.o.p.		
Process	N_p	Simple pole	Dipole	Tripole
$\sigma(pp)$	104	0.93	0.89	0.88
$\sigma(\bar{p}p)$	59	1.1	1.0	1.2
$\sigma(\pi^+p)$	50	1.4	0.67	0.71
$\sigma(\pi^-p)$	95	0.94	1.0	0.96
$\sigma(K^+p)$	40	1.0	0.72	0.71
$\sigma(K^-p)$	63	0.73	0.62	0.62
$\sigma(\gamma p)$	41	0.56	0.65	0.61
$\sigma(\gamma\gamma)$	36	0.88	1.0	0.80
$\rho(pp)$	64	1.9	1.7	1.8
$\rho(\bar{p}p)$	11	0.55	0.44	0.52
$\rho(\pi^+p)$	8	2.7	1.5	1.5
$\rho(\pi^-p)$	30	2.1	1.2	1.1
$\rho(K^+p)$	10	0.87	1.1	1.0
$\rho(K^-p)$	8	1.7	1.3	0.99
all, χ^2_{tot}	619	696	590	595
all, χ^2/d.o.f.	619	1.15	0.98	0.98

Table 1: Partial χ^2 per number of data points (χ^2/n.o.p.) and total χ^2 per degree of freedom (χ^2/d.o.f.) for the COMPETE parametrisations [7, 8], fitted to the latest data [9], for 5 GeV< $\sqrt{s} < 2$ TeV.

$\frac{(s-u)/2}{2m_a m_b}$, with θ_t the scattering angle for the crossed-channel process. We re-absorbed the denominator in the definition of the couplings, and then expressed the cross section using exact flux factors, which for 3 exchanges can be written as:

$$\sigma_{tot}^{(3)} \equiv \frac{1}{2pm_b}\left[\Im m A_+^R\left(\frac{s-u}{2}\right) + \Im m A_+^S\left(\frac{s-u}{2}\right) \mp \Im m A_-\left(\frac{s-u}{2}\right)\right], \tag{2}$$

with p the momentum in the laboratory frame [2] of b and the minus sign for the particle. For all models, we use the same parametrisation of the $C=-1$ part for the process $ap \to ap$ ($a = \bar{p}$, p, $\pi^\pm$, $K^\pm$),

$$\Im m A_-(s) = M_a\left(\frac{s}{s_1}\right)^{\alpha_-} \tag{3}$$

with $s_1 = 1$ GeV^2. For the $C=+1$ part, we use a common Reggeon contribution, and which we allow to be non-degenerate with the $C=-1$ part:

$$\Im m A_+^R(s) = P_a\left(\frac{s}{s_1}\right)^{\alpha_+}, \tag{4}$$

added to a pomeron term from one of the forms corresponding respectively to a simple, a double and a triple pole:

$$\Im m A_+^S(s) = S_a\left(\frac{s}{s_1}\right)^{\alpha_o}, \tag{5}$$

[2] In the $\gamma\gamma$ case, $2pm_b$ gets replaced by s.

$$\Im m A_+^S(s) = D_a s \ln \frac{s}{s_d}, \tag{6}$$

$$\Im m A_+^S(s) = T_a s \ln^2 \frac{s}{s_t} + T_a' s \tag{7}$$

2. We have fully applied the factorisation constraints in the $\gamma\gamma$ case: there the couplings g (standing for M, P or S) of each simple pole can be directly obtained from the pp and the γp fits through the relation $g_{\gamma\gamma} = (g_{\gamma p})^2 / g_{pp}$, and the couplings of multiple singularities obey more complicated relations [10].

3. For the derivation of the real part, we used three levels of sophistication:

   (a) Derivative dispersion relations (DDR) [11] without a subtraction constant. This corresponds to the fit performed in [7, 8], but with the exact flux factors and arguments of Eq. (2).

   (b) DDR with a free subtraction constant. Because the crossing-even part of the amplitude rises with energy, one must perform a subtraction, and the value of the real part at the subtraction point is unknown. We keep it and fit to it.

   (c) Integral dispersion relations (IDR) for the analytic parametrisation, from the threshold $\sqrt{s_0} = m_a + m_b$. If one takes the threshold to be zero, the IDR is equivalent to the DDR. However, as the threshold is nonzero, there is a small correction due to this shift.

   (d) IDR for the analytic parametrisation down to $\sqrt{s} = 5$ GeV, and to a fit of the data from $\sqrt{s_0}$ to 5 GeV, shown in Fig. 1. As the analytic forms (2)-(7) do not reproduce the total cross section data below 5 GeV, we do not use them there, but instead perform a multi-parameter fit of the total cross section, shown in Fig. 1. Hence the input below the minimum energy where the fit is applicable is determined by the data themselves. It must be emphasised that the details of the low-energy fit have very little influence on the global fit (see Table 2), mainly because most of the effects can be re-absorbed in the value of the subtraction constant.

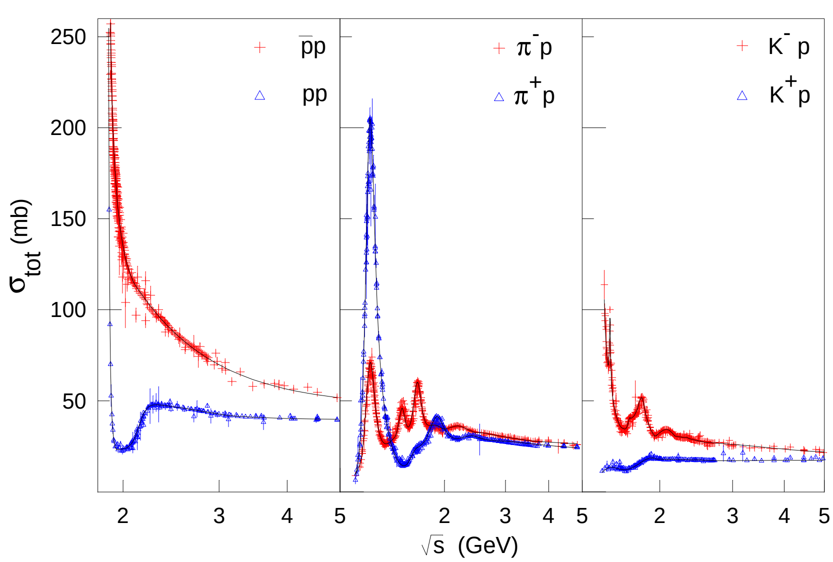

Figure 1: Fit to low-energy data used in integral dispersion relations.

		Simple pole				Dipole	Tripole
Process	N_p	(a)	(b)	(c)	(d)	(d)	(d)
$\sigma(pp)$	104	0.93	1.1	1.1	1.1	0.88	0.87
$\sigma(\bar{p}p)$	59	1.0	0.91	0.91	0.88	0.94	0.94
$\sigma(\pi^+p)$	50	1.4	1.2	1.2	1.2	0.68	0.68
$\sigma(\pi^-p)$	95	0.95	0.92	0.92	0.92	0.97	0.97
$\sigma(K^+p)$	40	1.0	0.96	0.96	0.97	0.73	0.71
$\sigma(K^-p)$	63	0.72	0.73	0.73	0.73	0.62	0.61
$\sigma(\gamma p)$	41	0.56	0.56	0.56	0.56	0.58	0.54
$\sigma(\gamma\gamma)$	36	0.88	0.88	0.88	0.88	0.80	0.73
$\rho(pp)$	64	1.9	1.6	1.6	1.6	1.6	1.7
$\rho(\bar{p}p)$	11	0.49	0.40	0.40	0.40	0.39	0.42
$\rho(\pi^+p)$	8	2.7	2.9	2.9	2.9	1.8	1.8
$\rho(\pi^-p)$	30	2.2	1.9	1.9	1.9	1.0	1.0
$\rho(K^+p)$	10	0.91	0.70	0.70	0.70	0.57	0.60
$\rho(K^-p)$	8	1.7	1.7	1.7	1.7	1.2	1.0
all, χ^2_{tot}	619	694	661	661	661	564	558
all, χ^2/d.o.f.	619	1.15	1.10	1.10	1.10	0.94	0.93

Table 2: Values of the χ^2/n.o.p. for the new parametrisations: (a) the standard (analytic) fit, based on DDR, with the flux and variables of Eq. (2) and without subtraction constants; (b) the same fit with subtraction constants; (c) fit with ρ calculated by the IDR, using the high-energy parametrisation from the thresholds; (d) fit of the high-energy parametrisation with IDR, using a fixed parametrisation of the cross section data below $\sqrt{s}$ =5 GeV.

The formula that we shall be using in this paper (except when otherwise indicated) for the ρ parameter, i.e. the ratio of the real to the imaginary part of the elastic ap and $\bar{a}p$ amplitudes, corresponds to case (d) and can be written

$$\rho_\pm\, \sigma_\pm = \frac{R_{ap}}{p} + \frac{E}{\pi p} \mathrm{P} \int_{m_a}^{\infty} \left[\frac{\sigma_\pm}{E'(E'-E)} - \frac{\sigma_\mp}{E'(E'+E)} \right] p'\, dE' \tag{8}$$

where the + sign refers to the process $ap \to ap$ and the $-$ sign to $\bar{a}p \to \bar{a}p$, E is the energy in the proton rest frame, P indicates that we have to do a principal-part integral, R_{ap} is the subtraction constant, and the fit of Fig. 1 is used for $\sqrt{s} \leq 5$ GeV.

The only possible improvement which we have not implemented is the inclusion of bound-state contributions and the continuation of the fit to unphysical thresholds. However, at high energy, the main effect of these corrections can be re-absorbed in the subtraction constant, leaving a contribution of order $1/s$ to the real part. In fact, the values of the χ^2/d.o.f. of the fourth and fifth columns of Table 1 (cases (b) and (c)) are very similar, precisely because of this: the shift of the threshold, in this case from 0 to $2m_p$, can be re-absorbed into the subtraction constant. The resulting values of the χ^2/d.o.f. are shown in Table 2, for the simple-pole fit (and for cases (a) to (d)), as well as for the log and $\log^2$ fits (for case (d)).

Although the various effects detailed above significantly improve the quality of the fit, they also improve the dipole and tripole fits, and a simple-pole pomeron still does not seem acceptable. The only possibility left to keep this model is to introduce extra singularities and check whether they can lower the χ^2/d.o.f. sufficiently.

		soft pole only	soft+hard simple poles	soft simple pole+ unitarised hard pole
Process	N_p	(d)	(d)	(d)
$\sigma(pp)$	104	1.1	0.87	0.87
$\sigma(\bar{p}p)$	59	0.88	0.92	0.92
$\sigma(\pi^+p)$	50	1.2	0.70	0.69
$\sigma(\pi^-p)$	95	0.92	0.93	0.95
$\sigma(K^+p)$	40	0.97	0.72	0.72
$\sigma(K^-p)$	63	0.73	0.61	0.61
$\sigma(\gamma p)$	41	0.56	0.54	0.56
$\sigma(\gamma\gamma)$	36	0.88	0.70	0.82
$\rho(pp)$	64	1.6	1.7	1.7
$\rho(\bar{p}p)$	11	0.40	0.41	0.40
$\rho(\pi^+p)$	8	2.9	1.6	1.7
$\rho(\pi^-p)$	30	1.9	1.0	1.0
$\rho(K^+p)$	10	0.70	0.62	0.60
$\rho(K^-p)$	8	1.7	0.98	1.0
all, χ^2_{tot}	619	661	551	557
all, χ^2/d.o.f.	619	1.10	0.924	0.933

Table 3: The values of χ^2/n.o.p., for 5 GeV$< \sqrt{s} <$ 2 TeV, as in Table 2 (third column), if we introduce a new pole with positive charge parity (fourth column, Eq. (9)) and if we unitarise it (fifth column, Eq. (11))

3 The hard pomeron pole

In fact, we tried to improve the quality of the simple-pole fit by further lifting the degeneracy of sub-leading vector meson trajectories: extrapolating hadroscopic data to $M^2 = 0$ leads to the conclusion that the f intercept is higher than the a_2 intercept [12]. As a first step[3], we simply added one $C = +1$ trajectory to the fit, and left its couplings free (and imposed the corresponding factorisation properties for the $\gamma\gamma$ cross section). This improved the χ^2 considerably, and made it comparable to that of the other parametrisations: Table 3 shows the quality of the fit if one introduces a new $C = +1$ singularity, so that the expression of the cross section now contains four terms:

$$\sigma_{tot}^{(4)} = \sigma_{tot}^{(3)} + \frac{1}{2pm_b}\Im m A_+^H\left(\frac{s-u}{2}\right) \tag{9}$$

with

$$\Im m A_+^H(s) = H_a\left(\frac{s}{s_1}\right)^{\alpha_h} \tag{10}$$

with again $s_1 = 1$ GeV^2.

However, this trajectory did not choose an intercept compatible with that of a Reggeon, but rather settled on an intercept of 1.45, very close to the one already observed by Donnachie and Landshoff in DIS. Furthermore, if we fit to Tevatron energies, the trajectory couples to πp and Kp processes, but seems absent in pp and $\bar{p}p$.

This is easy to understand if one notices that the πp and Kp data have a maximum energy of the order of $\sqrt{s} = 100$ GeV. A hard pomeron, if present in soft data, will certainly have

[3]as in principle one would have to decouple the a_2 from some of the processes considered here.

	soft+hard poles		soft pole+ unitarised hard	
Parameters	value	error	value	error
α_o	1.0728	0.0008	1.0728	fixed
S_p	56.2	0.3	55	1
S_π	32.7	0.2	31.5	0.9
S_K	28.3	0.2	27.4	0.8
S_γ	0.174	0.002	0.174	0.003
$\alpha_h(0)$	1.45	0.01	1.45	fixed
G_p	–	–	0.18	0.06
G_γ	–	–	6×10^{-9}	1.5×10^{-8}
H_p	0.10	0.02	0.17	0.05
H_π	0.28	0.03	0.43	0.08
H_K	0.30	0.03	0.42	0.07
H_γ	0.0006	0.0002	0.0005	0.0002
$\alpha_+(0)$	0.608	0.003	0.62	0.02
P_p	158	2	157	5
P_π	78	1	80	2
P_K	46	1	47	2
P_γ	0.28	0.01	0.28	0.01
$\alpha_-(0)$	0.473	0.008	0.47	0.01
M_p	79	3	79	3
M_π	14.2	0.5	14.3	0.6
M_K	32	1	32	1
R_{pp}	-164	33	-163	34
$R_{p\pi}$	-96	21	-86	21
R_{pK}	3	26	8	26

Table 4: Parameters obtained in the fits. The second and third columns give the parameters and errors of the fit with a hard pole, Eq. (9) for $\sqrt{s}$ from 5 to 100 GeV, the fourth and fifth columns give the parameters of a unitarised fit, Eq. (11) for 5 GeV$< \sqrt{s} <$ 2 TeV.

to be unitarised at very large energies −we shall come back to this point later−. In fact, the extrapolation of the fit with 4 poles of Eqs. (9, 10) gives πp and Kp total cross sections much bigger than pp at the Tevatron: as it was not unitarised, the fit chose to turn off the hard pomeron contribution in pp and $\bar{p}p$, whereas the couplings to πp and Kp were non negligible. This zero coupling explains in fact why this contribution has been overlooked before [13].

Before considering a possible unitarisation scheme, we show in the second and third columns of Table 4 the results of a fit for 5 GeV $< \sqrt{s} <$100 GeV. The only difference with the global fit of Table 3 is that the $\bar{p}p$ and pp data do not force the coupling of the hard pomeron to be zero anymore. Several comments are in order:

1. The main improvement, as seen from the partial χ^2 of Table 3, is in σ_{π^+p}, σ_{K^+p} and in ρ_{π^+p}, ρ_{π^-p} and ρ_{K^-p}. We show in Figs. 2 and 3 the curves corresponding to these quantities, where the effect of the hard pomeron can be clearly seen. Furthermore, all processes but two (ρ_{pp} and ρ_{π^+p}) can now be simultaneously described with a χ^2/n.o.p.≤ 1.

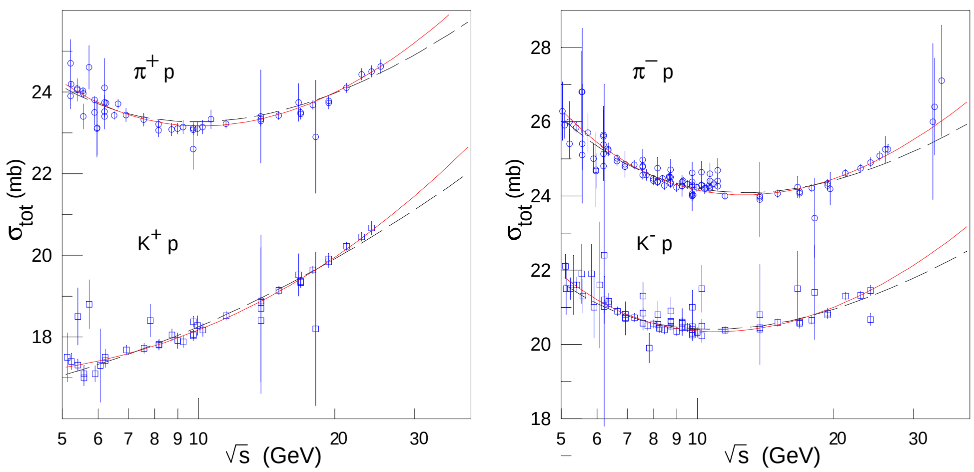

Figure 2: Difference between total cross sections fitted with (plain) and without (dashed) a hard pomeron, assuming all singularities are simple poles.

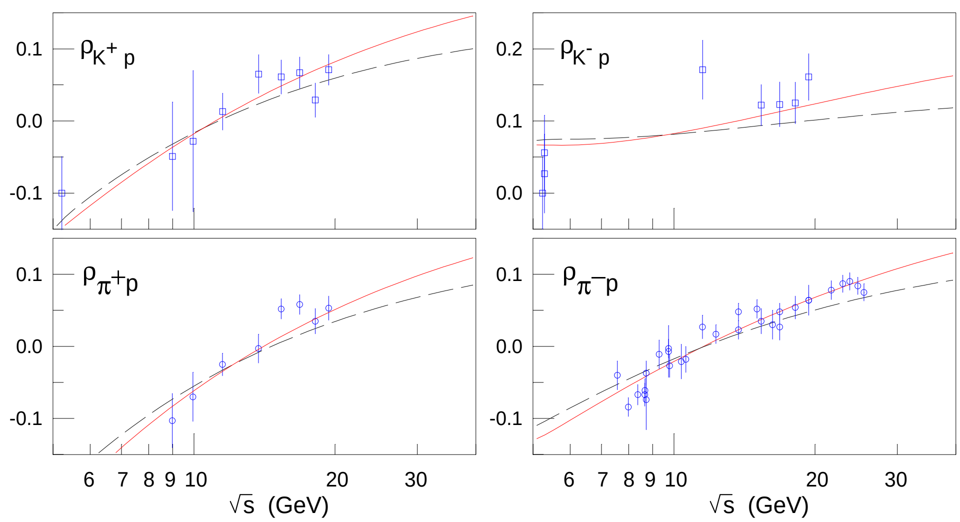

Figure 3: Difference between ρ values fitted with (plain) and without (dashed) a hard pomeron, assuming all singularities are simple poles.

2. The value of the hard pomeron intercept is evaluated to be

$$\alpha_h = 1.45 \pm 0.01$$

and is very close to the value obtained in DIS [5], and more recently in Υ photoproduction [14].

3. The value of the soft pomeron intercept becomes slightly lower than estimated by Donnachie and Landshoff;

4. The ratio of the coupling of the hard pomeron to the soft one varies from 0.2% in pp and 0.35% in γp to 1% in πp and Kp. This is compatible with the estimate (1) of [5].

It indicates however that the coupling mechanism of the hard pomeron must be very different from that of the soft pomeron. Note however that it is possible to reduce the hard pomeron coupling to a much smaller value if one does not limit the upper energy of the fit [15].

5. From the values of the coupling and of the intercept, and assuming a slope $B = 4$ GeV^{-2} for the proton form factor, and slopes of 0.25 GeV^{-2} for the soft pomeron and of 0.1 GeV^{-2} for the hard pomeron, one can estimate that the "Black-disk" limit will be reached around $\sqrt{s} = 400$ GeV. Hence it is likely that if we limit the fit to 100 GeV, we do see the "bare" singularity;

6. Although the hard pomeron has a large intercept, its contribution to the amplitude remains small because its coupling is tiny. We show in Fig. 4 the relative contribution of the various terms to the total cross section. At 100 GeV, the hard pomeron contributes 6% to the total cross section. Hence it is possible that it remains hidden, even in the differential elastic cross section.

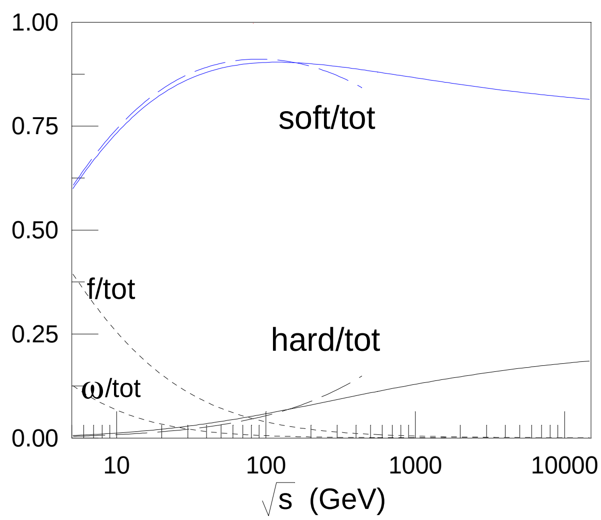

Figure 4: Relative contribution of the various terms of the amplitude, compared with the $C = +1$ part of the amplitude ("tot") in the pp case. The dashed curve is for a hard pole, and the plain curves for the unitarised form.

7. If the hard pomeron is present both in pp and γp scattering, then one can predict the $\gamma\gamma$ cross section through factorisation relations for the couplings of each trajectory. This leads to the curves shown in Fig. 5, which are thus parameter-free in the $\gamma\gamma$ case. Hence having a hard pomeron does not necessarily mean that the $\gamma\gamma$ cross section will increase faster than in the γp case. Of course, it would also be possible to accommodate a faster increase by reducing the hard pomeron coupling in the pp case (see [15] for such an alternative). Note also that it is possible to accomodate the pp, γp and $\gamma\gamma$ data through factorisation without a hard component [10, 16].

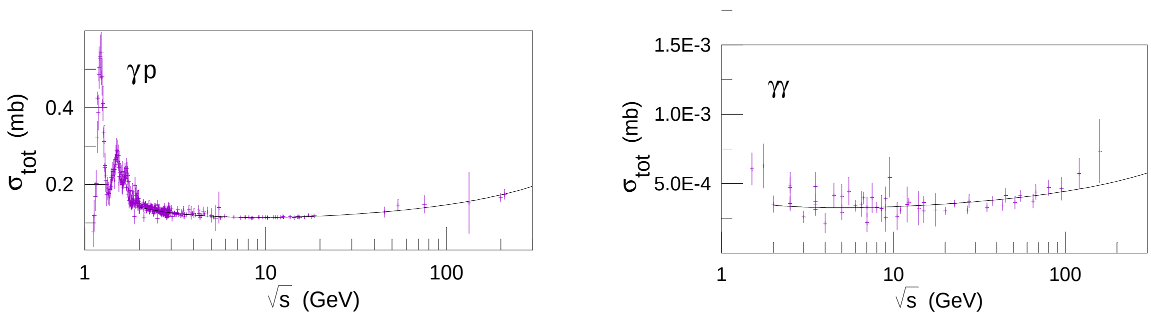

Figure 5: Fit to γp total cross section, and prediction of $\gamma\gamma$ via factorisation. The pole and the unitarised fits are identical in the energy range shown.

3.1 Unitarised fit

As we have pointed out above, the hard singularity cannot be extended to energies beyond a few hundred GeV, as one will reach the black-disk limit in that region, and hence one will have to unitarise the exchange. The problem of course is that nobody knows how to unitarise Regge exchanges unambiguously.

Unitarisation comes from the consecutive exchange of trajectories. We know that if 1-pomeron exchange is given by the amplitude

$$\Im m A(s,t) \approx g_1 \left(\frac{s}{s_1}\right)^{\alpha_h} e^{R^2 t}$$

with

$$R^2 = B + \alpha' \log s$$

then, if the hadrons remain intact during multiple exchanges, the n-pomeron contribution will be proportional to

$$\Im m A^{(n)}(s,t) = (-1)^{n-1} g_n\, s\, \frac{s^{n(\alpha_h-1)}}{[R^2]^{n-1}}\, e^{\frac{R^2}{n}t}$$

To this, one must add the contribution of inelastic channels, or equivalently that from n-reggeon vertices, which are a priori unknown. Even worse, the coefficients g_n are also unknown in general. For the scattering of structureless objects (as in QED or in potential scattering), one can derive at high energy that $g_n = 1/(2^{n-1} n n!)$, which leads to the eikonal formula. However, both hadrons and reggeons have a structure, hence it is very likely that this formula is not a good approximation to the true amplitude. Finally, in the case of several trajectories, one must take into account mixed exchanges (e.g. Reggeon-pomeron, etc.).

Hence we present here a possible model that would lead to a simple-pole picture below 100 GeV, and to a unitarised picture (for the hard pomeron) at higher energies (which is similar to that obtained in the U-matrix formalism of [17]). As explained above, it is by no means unique, and many improvements or modifications can be brought in. Its purpose is not to solve unitarisation, but only to show that it is possible to accommodate a hard pomeron with $t=0$ data up to the Tevatron[4]. The simplest choice is to replace (10) in Eq. (9) by:

$$\Im m A_+^H(s) = H_a s R^2 \left[\frac{1}{G} \log\left\{1 + G\frac{s^{\alpha_h - 1}}{R^2}\right\}\right]. \tag{11}$$

[4]Building of a unitarisation model will necessitate considerable work, and the adjunction of data at $t \neq 0$.

(we shall use again $B = 4$ GeV^{-2} and $\alpha' = 0.1$ GeV^{-2} in R^2). To simplify further, we have assumed that G would take the same value G_p for p, π and K, and allowed it to be different (and called it G_γ)for γp.

For small values of G, this form reduces to a simple-pole parametrisation at low energy, and obeys the Froissart bound at high energy. One can see in Fig. 2 that the simple-pole fit to 100 GeV and the unitarised fit to 1800 GeV are very close (in fact the log in (11) and its Taylor expansion to order G differ by 7% at $\sqrt{s} = 100$ GeV).

Such a form produces the best fit so far to soft data, and we show the corresponding parameters in Table 3. It clearly can accommodate the Tevatron data, where the cross section is predicted to be 75.5 mb, and where the hard pomeron contributes about 10% to the total cross section. As we pointed out above, this is only a possibility: we do not know how to unitarise these exchanges, and we assumed that one could unitarise the hard pomeron independently from the other exchanges, which is far from clear.

It is worth pointing out that we have fixed the hard and soft pomeron intercepts to their values measured at lower energies. If we let them free, then the soft pomeron intercept moves to 1 and the hard pomeron intercept grows to larger values, but the change in χ^2 is not very significant: in fact, the unitarised fit has too many parameters to be sufficiently constrained by the forward data alone.

4 Conclusion

Due to its simplicity and theoretical appeal, the simple pole model has become quite popular. However, it was shown [7] that it could not accommodate forward scattering data as well as other fits based on unitary forms. We showed here that the ingredient needed to restore the simple-pole model as one of the best descriptions − besides a careful usage of dispersion relations and the lifting of the degeneracy of the $C = +1$ and $C = -1$ trajectories − is precisely the hard pomeron introduced in DIS[5].

Such a hard object cannot be directly observed at high energy, because it must first be unitarised. However, if one stays below energies of 100 GeV, the improvement brought in by such a singularity is clearly visible. We have also shown that it is possible to find unitarised forms that look like a simple hard pole at low energy, and like a squared logarithm of s at high energy. The coupling of the hard pomeron to protons turns out to be a factor 2 to 3 lower than that to pions and kaons, whereas that to photons is roughly α/π times the coupling to pions.

Hence there are two major questions raised by this possibility of a hard pomeron in soft data: how does one unitarise the amplitude, especially in the region of $\sqrt{s}$ from 100 GeV to the Tevatron, and why are protons different? Precision data in pp scattering in the region from 100 to 600 GeV would have been invaluable in settling this question. New measurements of ρ_{pp} would also have helped decide if the high value of the χ^2/n.o.p. for this observable can be attributed to errors in the data.

One place where one should be able to decide whether the hard pomeron really exists in soft processes is in $\gamma\gamma$ scattering. If the hard pomeron is present in soft data, then from its contribution to pp and to γp, one can predict the $\gamma\gamma$ cross section, both for on-shell and for

[5]Note that we have also shown that the parametrisation using both soft and hard pomerons is not the only possible answer: unitary forms can also provide good fits to ρ and σ_{tot} [7] (and to elastic slopes [16] and DIS data [10]).

off-shell photons, and the presence of a hard pomeron should be manifest in higher-precision data on the photon-photon and photon-proton total cross sections.

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