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Looking for asymptotic grayness

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Abstract-

We examine the available data on σ_{el} and σ_{tot} for proton-proton and proton-antiproton interactions to see whether they are compatible with the picture of an expanding gray disk suggested by the supercritical Pomeron solution. We conclude that the present data are compatible with values of the transparency $T \leq 0.2$.

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A solution to the problem of finding a high energy expansion of the elastic scattering amplitude that corresponds to increasing cross sections and is unitary in both channels has been obtained in the study of the supercritical Pomeron field theory ¹⁾. Like many other models it predicts a $\ln^2(s)$ behaviour of σ_{tot} , but when we introduce in the theory a triple Pomeron coupling λ the expanding disk approaches asymptotically a non-vanishing transparency T that is given in terms of λ and $\mu = (\alpha_P(0)-1)$, by $T = \exp(-\mu/\lambda)$. The phenomenological values ²⁾ of λ and μ are respectively $\lambda \approx 0.05$ and $\mu \approx 0.1$. Therefore this theory predicts a value of $T \approx 0.1-0.15$.

Bourrely, Soffer and Wu ³⁾ have shown recently that the values of $\sigma_{\text{tot}} = 72.1 \pm 3.3$ and of $r = \sigma_{\text{el}}/\sigma_{\text{tot}} = 0.23 \pm 0.02$ obtained by the E710 collaboration at FNAL ⁴⁾ are in very good agreement with the predictions of their eikonal model, that behaves asymptotically like an expanding black disk. These values are also in agreement with the extrapolation of a simple Gaussian eikonal model that has the same asymptotic behaviour ⁵⁾ (fixing our parameters in order to reproduce the

ISR ⁶⁾ and the CERN collider data ⁷⁾ we had predicted for FNAL energy $\sigma_{\text{tot}} = 75$ mb and

$r = .24$. These values are clearly compatible with the data, even if they overshoot them slightly. The fit of ref. 3 on the contrary goes right through the values of the E710 experiment, but undershoots slightly the data at $\sqrt{s} = 546$ GeV. In view of this fact it is clear that we cannot find in the present data evidence for $T \neq 0$; in this paper we would rather like to see what range of T can be excluded already. We find that $T = 0.15$ is perfectly acceptable. We will also see what can be learned from future experiments with $\sqrt{s} \approx 10^2$ TeV.

In order to carry out our investigation we ignore the real part of the elastic scattering amplitude and we parametrize the imaginary part in b space as :

$$A(b,s) = 2 \left((1-T) \left(1 - \exp -E(c,a,R) \right) \right) \quad (1)$$

with

$$E(c,a,R) = c(s) \exp \left(-a \frac{b^2}{R^2(s)} - (1-a) \frac{b}{R(s)} \right) \quad (2)$$

We impose the following conditions on the behaviour of our parameters:

- $c(s)$ should be power behaved $c(s) \approx s^\mu$ with $\mu \approx 0.1$
- $R(s)$ can at most increase logarithmically with s .
- T represents the asymptotic transparency and is a constant.
- a allows us some freedom in fixing the b -space shape of A at a given energy. We assume that it does not depend on the energy.

We will consider the following quantities:

- The ratio $r = \sigma_{\text{el}}/\sigma_{\text{tot}}$ is independent of R and can be written as

$$r(s) = (1-T) f_1(c,a) \quad (3)$$

- The total cross section is proportional to R^2 and to $(1-T)$:

$$\sigma_{\text{tot}}(s) = (1-T) R^2 f_2(c,a) \quad (4)$$

- As a third feature we consider the value of t at which the Bessel transform of A vanishes and

we try to match it with the observed dip or break in $d\sigma_{\text{el}}/dt$. This value scales as $1/R^2$:

$$t_{\text{dip}} = f_3(c,a)/R^2 \quad (5)$$

We require no dip for $t \leq 1$ at ISR and a dip at $t \approx 0.85$ at $\sqrt{s} = 546$ GeV. The small t dependence is always exponential in our model and the correct slope is automatically obtained by reproducing the values of σ_{el} and σ_{tot} .

We start by studying the situation with $T=0$. According to the choice of $0 \leq a \leq 1$ we obtain a family of functions $f_1(c,a)$ from which we deduce the values of $c_a(s)$ at $\sqrt{s}_1 = 60$, $\sqrt{s}_2 = 546$ and $\sqrt{s}_3 = 1800$ GeV respectively that reproduce the observed values of r . Using now eq.4 we determine

the values $R_A(s_i)$ and eventually with eq. 5 we look for the dip position . The value of $t_{dip}(s_2)$ is shown in fig. 1 and suggests a value of $a=0.35\pm 0.05$. We adopt the value $a=0.35$ and obtain the following set of values for c and R (R is always measured in F , s and t in GeV^2):

$$\begin{array}{ll} c(s_1) = 1.50 \pm 0.12 & c(s_2) = 2.15 \pm 0.15 & c(s_3) = 2.45 \pm 0.3 \\ R^2(s_1) = 0.51 \pm 0.02 & R^2(s_2) = 0.53 \pm 0.02 & R^2(s_3) = 0.56 \pm 0.04 \end{array}$$

With our choice of parameters we predict a dip in $d\sigma_{ep}/dt$ at FNAL at $t=0.7$ that should be observed soon.

The dependence of R on s is very mild, actually compatible with no dependence at all. We adopt for the sake of extrapolating at higher energies the parametrization $R(s)=0.66+0.006 \ln(s)$. The parameter c is compatible with a power behaviour as we see from fig. 2 that shows $\ln(c)$ vs $\ln(s)$. The best fit gives $c=0.8 s^{0.8}$. With these values we can extrapolate at $\sqrt{s}=20$ TeV and $\sqrt{s}=200$ TeV to obtain the values shown in the table.

T=0.15.

We study now the situation $T \neq 0$ and examine in detail $T=0.15$ that is about the value suggested by the supercritical Pomeron approach. In practice we want to reproduce in eq. 3 a value of r enhanced by the factor $(1-T)^{-1}$, i.e. we need larger values of c and we are, in a sense, closer to asymptopia. The net result of having larger c is a stronger effective absorption in the center, that flattens the shape of A at small b . In order to balance this effect we have to use smaller values of a .

By repeating the previous procedure we find that a dip at $t=0.8$ at s_2 is obtained by choosing $a=0.1$. This value in turn leads to the following determination of c and R

$$\begin{array}{ll} c(s_1)=2.75 \pm 0.3 & c(s_2)=4.5 \pm 0.5 & c(s_3)=5.5 \pm 1. \\ R^2(s_1)=0.28 \pm 0.01 & R^2(s_2)=0.27 \pm 0.01 & R^2(s_3)=0.28 \pm 0.02 \end{array}$$

We see that R^2 turns out to be essentially energy independent and we adopt the value $R=0.52 F$.

The plot of $\ln(c)$ vs $\ln(s)$ is shown also for this case in fig.2. It shows a very good linearity with

a slope $\mu=-.1 \pm 0.1$. The fact that the alignment of the three points in fig. 2 is better now than with $T=0$ is the only possible hint that we could find in favor of $T \neq 0$. It is obvious that it has no statistical relevance. The dip at FNAL is also in this case predicted around $t=0.7$. The extrapolation of our results to the multi TeV region of this solution is shown in the table.

T=0.3

This value of T is excluded already at s_2 where we know 8) that the value of $A(0,s_2)$ is larger than 1.4. We study it here only to see how we run into trouble by using our method. We now need very large values of c in order to reproduce r , and it is impossible to avoid the dip at s_2 moving too close inside. In fact, even with $a=0$, we obtain the dip at s_2 at $t=0.6$. Furthermore, the values of $R^2(s)$ required in order to reproduce σ_{tot} turn out to be decreasing with s , a situation that we are not willing to accept. Therefore we can confirm by our very indirect method that values of $T \approx 0.3$ are indeed excluded.

In conclusion we see that the present data on proton-antiproton elastic and total cross sections are compatible with models that behave asymptotically as a black expanding disk as well as with models that predict an asymptotically non-vanishing transparency T provided that $T \leq 0.2$. Future experiments at c.m. energies of the order of 100 TeV should however be able to detect a finite transparency of the order of magnitude predicted by the supercritical Pomeron theory.

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Table

	$\sqrt{s}$	r	σ_{tot}	t_{dip}
T=0	20 TeV	0.28	105 mb	0.4
	200 TeV	0.31	138 mb	0.3
T=.15	20 TeV	0.26	92 mb	0.4
	200 TeV	0.28	115 mb	0.3

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Figure Captions

Fig.1: The dependence of the position of the dip on the parameter a for $T=0$.

Fig.2: Plot of $\ln(c)$ vs $\ln(s)$ for $T=0$ (lower set of points) and $T=.15$ (upper set of points)

Fig. 1

Fig. 2