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AN ESTIMATE OF THE MAGNITUDE OF TRIPLE POMERON COUPLING FROM THE OBSERVED ENERGY DEPENDENCE OF TOTAL AND ELASTIC pp CROSS SECTIONS*

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ABSTRACT

The measured total and elastic pp cross sections are used to give an estimate, to within a factor 2, of triple-pomeron coupling. The assumption underlying the estimate is that single-fireball formation is asymptotically controlled by an isolated Regge pole.

A two-component model of high energy particle production has been showing promise of correlating the observations emerging from NAL and CERN ISR.[1-6] For the purposes of this paper we shall characterize the two-component model in terms of "fireballs", where the number of fireballs in a given event is defined through the rapidity distribution of produced particles.[7] Events where no large gaps[8] appear in the rapidity distribution will be described as "single-fireball".[9] If one large gap appears we shall speak of two fireballs, and so on. The two-component model ignores the possibility of more than one large gap and supposes each of the two fireballs in a one-gap event to be of low mass. The model furthermore supposes the collection of single-fireball events to have an aggregate (i.e. inclusive) energy dependence that corresponds to isolated factorizable Regge poles (short-range order in rapidity) and thus to be susceptible to the Mueller treatment of

inclusive cross sections.[10] The two- (low-mass) fireball events on the other hand are supposed to be described in the exclusive sense by pomeron exchange in the same way as elastic scattering, which in fact represents about half of this category. The energy dependence of this "fragmentation" component thus corresponds to the AFS two-pomeron branch point[11] (long-range order in rapidity).

An experimental difficulty for the two-component model is the observed near-constancy of the high energy pp total cross section, which is observed to vary by less than 0.5 mb between $s = 140\ \text{GeV}^2$ and $s = 3000\ \text{GeV}^2$ --an energy interval in which the integrated elastic cross section (about half of the diffractive component) is falling by about 2 mb.[12] Such a decrease cannot be compensated by an increase of the single-fireball cross section if the leading Regge pole therein is well separated from the remainder of the J singularities. At best the single-fireball cross section can be nearly constant. The non-elastic part of the two-fireball cross section is predicted by the model to have approximately the same energy dependence as the elastic.

At the same time the two-component model is theoretically defective in its neglect not only of events with more than one large rapidity gap but of single-gap events with large-mass fireballs. It may then be hoped that the cross section for these neglected categories will grow at a rate such as to compensate for the decrease in the pp cross section for two low-mass fireballs. In this paper we argue that at presently accessible energies the principal correction to the two-component model will be events with a single large rapidity gap that separates a large-mass fireball from a low-mass fireball and events with two large gaps that separate 3 low-mass fireballs. Such events are controlled by the celebrated but elusive triple-pomeron coupling, so we shall obtain an estimate of this coupling from the requirement of constancy for the high-energy pp total cross section.

We first argue that the following three categories of events have a cross section below the level of concern to this paper: (1) Events leading to four or more fireballs. (2) Three-fireball events with at least one of the "end-fireballs" having a large mass. (3) Two-fireball events with both fireballs of large mass. For each of these categories there will occur at least one large rapidity gap that separates two aggregates of particles both of large mass. Now in Ref. (13) it was shown that the total probability for an event of this character, as depicted in Fig. 1, is given by

$$\frac{1}{\sigma_{AB}^{tot}} \frac{d^3\sigma_{AB}^{A'B'}}{d\,\ell n\, s_{A'}\, d\,\ell n\, s_{B'}\, dt} \underset{\substack{s_{A'}, s_{B'} \\ \text{and } s/s_{A'}s_{B'} \\ \text{all large}}}{\sim} \frac{1}{16\pi}\, g_P^{\,2}(t) \left(\frac{s}{s_{A'}s_{B'}}\right)^{2\alpha_P(t)-1-\alpha_P(0)} , \tag{1}$$

where $g_P(t)$ is the triple-pomeron coupling and $\alpha_P(t)$ is the pomeron trajectory. As explained in Ref. (14) one cannot integrate Formula (1) to obtain a "cross section", because multiple counting is involved, but the integral of (1) is larger than the sum of the probabilities for the three categories in question. An overestimate of the integral of (1) is obtained by setting $\alpha_P(t) = 1$ and including the entire region of $s_{A'}$, $s_{B'}$ for which $s_{A'}s_{B'}/s \lesssim 1$ while ignoring the kinematical constraint on the t interval. The result is

$$\frac{1}{32\pi} (\ell n\ s)^2 \int_{-\infty}^{0} g_P^{\,2}(t)dt\ . \tag{2}$$

With the available upper limit for $g_P(t)$ [15] this dimensionless number is $\lesssim 10^{-2}$ for $\ell n\ s \lesssim 10$.

At such moderate energies a larger proportion of the cross section will reside in three-fireball events where both end-fireballs are of small mass and in two-fireball events with one large and one small mass. Both categories fall into regions of phase space controlled by triple-pomeron coupling, but now g_P appears linearly rather than quadratically.

The linear triple-pomeron inclusive formula describes events where A' is of small mass and B' is of large mass, or vice-versa. There is some overlap between the regions of phase space covered by these two prescriptions, since both include events with three or more fireballs where both end-fireballs are of low mass. If we consider only the category where A' is of low mass we shall be underestimating the contribution to the total cross section, but for a pp collision the error must be less than a factor two.

When the "diffraction" of particle A leads to a small A' mass, as depicted in Fig. 2, the triple-pomeron formula is[13]

$$\frac{1}{\sigma_{AB}^{tot}} \frac{d^2\sigma_{AB}^{A'}}{d\,\ell n\, s_{B'}\, dt} \underset{\substack{s_{B'} \text{ and } s/s_{B'} \text{ large} \\ m_{A'} \text{ small}}}{\sim} \frac{1}{16\pi} \left| \beta_{AA'P}(t) \right|^2 \times \left[\tilde{\beta}_{AAP}(0)\right]^{-1} g_P(t) \left(\frac{s}{s_{B'}}\right)^{2\alpha_P(t)-1-\alpha_P(0)} , \tag{3}$$

where the particle-pomeron vertex functions are normalized such that

$$\sigma_{AB}^{tot} \sim \tilde{\beta}_{AAP}(0)\, \tilde{\beta}_{BBP}(0)\, s^{\alpha_P(0)-1} , \tag{4}$$

$$\frac{d\sigma_{AA'}^{BB'}}{dt} \underset{\substack{A',B' \text{ both} \\ \text{of small mass}}}{\sim} \frac{1}{16\pi} |\beta_{AA'P}(t)|^2 \, |\beta_{BB'P}(t)|^2 \, s^{2\alpha_P(t)-2} . \tag{5}$$

What is the rate of decrease with energy in the cross section to produce two low-mass fireballs? Suppose that for small t we represent the t dependence of the vertex functions as an exponential,

$$|\beta_{AA'P}(t)|^2 \approx |\beta_{AA'P}(0)|^2 \, e^{b_{AA'}t} , \tag{6}$$

and employ a linear pomeron trajectory with intercept unity,

$$\alpha_P(t) \approx 1 + \alpha_P' \, t . \tag{7}$$

Then integrating Formula (5) we have

$$\sigma_{AB}^{A'B'} \sim \frac{1}{16\pi} \frac{|\beta_{AA'P}(0)|^2 \, |\beta_{BB'P}(0)|^2}{b_{AA'} + b_{BB'} + 2\alpha_{P'} \, \ell n \, s} , \tag{8}$$

or

$$\frac{d\sigma_{AB}^{A'B'}}{d \, \ell n \, s} \sim - \frac{2\alpha_P'}{16\pi} \frac{|\beta_{AA'P}(0)|^2 \, |\beta_{BB'P}(0)|^2}{(b_{AB\to A'B'})^2} , \tag{9}$$

where

$$b_{AB \to A'B'} \equiv b_{AA'} + b_{BB'} + 2\alpha_{P'} \, \ell n \, s \tag{10}$$

is the inverse width of the t distribution.

Now let us calculate the rate of <u>increase</u> with energy of the integral over Formula (3). For a fixed interval of $d \, \ell n \, s_{B'}$ the right-hand side of (3) has the same kind of slow energy dependence as (8), associated with a gentle shrinkage of the width of the t

distribution, but the major energy dependence at moderate s arises from an extension of the available interval in $\ell n \, s_{B'}$ as s increases. To simplify the analysis we neglect the weak t-shrinkage effect and write

$$\sigma_{AB}^{A'} \underset{\substack{s_{B'} \text{ and } s/s_{B'} \text{ large} \\ m_{A'} \text{ small}}}{\sim} \frac{1}{16\pi} |\beta_{AA'P}(0)|^2 \, \tilde{\beta}_{BBP}(0) \, \ell n(s_{B'}^{max}/s_{B'}^{min}) \times \int_{-\infty}^{0} dt \, e^{b_{AA'}t} \, g_P(t) . \tag{11}$$

Since $s_{B'}^{max}$ increases in proportion to s,

$$\frac{d\sigma_{AB}^{A'}}{d \, \ell n \, s} \sim \frac{1}{16\pi} |\beta_{AA'P}(0)|^2 \, \tilde{\beta}_{BBP}(0) \int_{-\infty}^{0} dt \, e^{b_{AA'}t} \, g_P(t) . \tag{12}$$

For the special case of pp collisions we want to balance the growth rate (12) against the decline (9), when appropriate sums are made over the low-mass fireballs A' and B'. In view of the already-mentioned double counting difficulty, it is reasonable to restrict the low-mass B' fireball sum to the single proton (i.e. to keep only the elastic BB' vertex) and to set $b_{AA'}$ equal to b_{pp}. With such a simplification, and writing $b_{pp\to pp}$ as b, the required compensation leads to the estimate

$$\int_{-\infty}^{0} dt \, e^{\frac{1}{2}bt} \, g_P(t) \approx \frac{2\alpha_{P'}}{b^2} \left[\sigma_{pp}^{tot}\right]^{\frac{1}{2}} , \tag{13}$$

if we remember that at high energy, by the optical theorem,

$$|\beta_{ppP}(0)| \approx \tilde{\beta}_{ppP}(0) \approx \left[\sigma_{pp}^{tot}\right]^{\frac{1}{2}} . \tag{14}$$

The estimate (13) should be in error by no more than a factor 2.

A remarkable qualitative aspect of (13) is the implied connection between a small pomeron slope and a small triple-pomeron coupling. We have not here given a general theoretical argument to relate g_P and α'_P but have pointed out that a connection is implied by the observed constancy of the high energy pp total cross section, together with the two-component model assumption that single-fireball events are controlled by well-separated Regge poles (without Regge branch points).

Insertion of measured values of b, α'_P and σ^{tot}_{pp} into the right-hand side of (13) gives a result compatible with the present upper limit on $g_P(t)$. Imminent experiments will measure the latter quantity. If Formula (13) is not verified it will be necessary to modify the two-component model assumption of short-range order in longitudinal rapidity for single-fireball events.

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FOOTNOTES AND REFERENCES

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FIGURE CAPTIONS

Fig. 1. An event with at least one large rapidity gap separating groups of particles with mass-squared $s_{A'}$ and $s_{B'}$. The magnitude of the gap is approximately $\log(s/s_{A'}s_{B'})$.

Fig. 2. An event with at least one large rapidity gap separating a low-mass fireball A' from a group of particles with mass-squared $s_{B'}$.

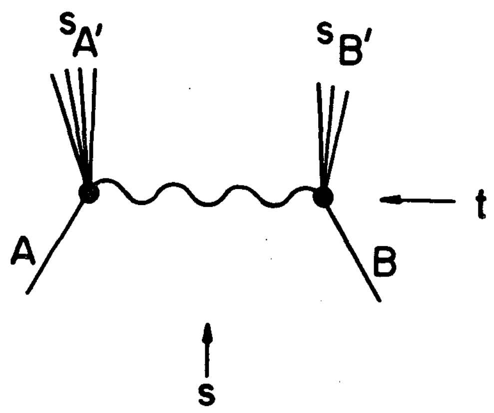

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Fig. 1

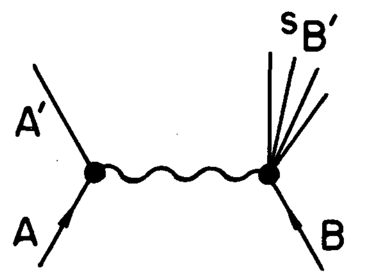

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Fig. 2

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