Title
Inclusive experiments and a diffractive Pomeron bootstrap

Journal
Physics Letters B, 35(5)

ISSN
0370-2693

Authors
Silverman, D
Ting, PD
Yesian, HJ

Publication Date
1971-06-01

DOI
10.1016/0370-2693(71)90412-6

INCLUSIVE EXPERIMENTS AND A DIFFRACTIVE POMERON BOOTSTRAP*

D. SILVERMAN, P. D. TING and H. J. YESIAN
Department of Physics, University of California, San Diego, La Jolla, California 92037, USA

Received 30 April 1971

A diffractive Pomeron pole is derived from a multiperipheral bootstrap where the Pomeron is required to be exchanged only once. The predictions for inclusive experiments are presented and are shown to provide tests for the nature of the Pomeranchuk singularity.

The ambiguous nature of the Pomeranchuk singularity has been the object of considerable theoretical and experimental concern. Within the multiperipheral model, it has already been noted that the repeated exchange of a Pomeron pole will violate the unitarity bound [1] if $\alpha_P(0) = 1$. Consequently, recent multuperipheral bootstrap attempts [2] have had to cope with the prospect of asymptotically vanishing total cross sections.

In this paper, we unite the appealing physical ideas of constant cross sections at high energies as given by a diffractive Pomeron [e.g. 3], with the multiperipheral models for particle production and the determination of Regge singularities by a bootstrap. We use the multiperipheral amplitudes containing the Pomeron exchange to generate an output Pomeranchuk singularity through unitarity. Those production amplitudes not containing the Pomeron exchange are considered to generate and bootstrap the "ordinary", non-leading Regge singularities (P', ω, ρ ...). If we require the Pomeron to be a Regge pole with $\alpha_P(0) = 1$, then the consistency requirement that the output singularity also be a pole with $\alpha_P(0) = 1$ excludes amplitudes with more than one Pomeron exchange, since they give multiple poles or cuts. It also excludes the single exchange of a moving pole with $\alpha_P(0) = 1$ since this gives an output cut at $J = 1$. Thus our assumptions restrict us to a bootstrap model in which the Pomeron is a fixed pole at $J = 1$ ** and can only be exchanged once in the chain [5]. Thus the Pomeron is considered a unique diffractive phenomenon which can occur at most once in the chain. This feature of the model enjoys the support of current experimental data which find no evidence for multi-Pomeron exchange [6] (MPE).

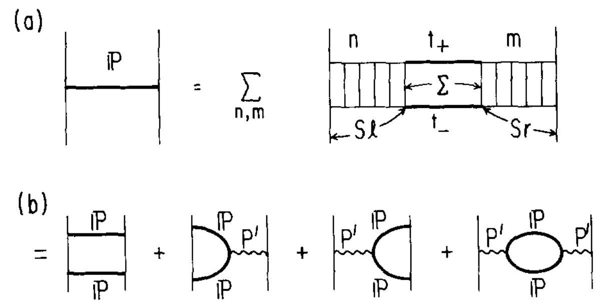

Fig. 1. Asymptotic unitarity equation for the diffractive Pomeron pole.

Asymptotically, then, the unitarity equation for the leading vacuum singularity is represented pictorially in figs. 1a and 1b ‡. Hence, in this model, there is no triple Pomeranchuk coupling [8]. The occurrence of a single Pomeron in the chain can be interpreted as a diffraction scattering with resulting multiperipheral fragmentation of the beam and target into particles on the left and right of the Pomeron respectively. The coupling of a specific production model with the diffractive scattering enables us to use the results of multiperipheral dynamics to make

* This work was supported in part by the US Atomic Energy Commission.

** A fixed pole does not violate t-channel unitarity if there exist appropriate "protective" cuts as considered by Oehme and Finkelstein and Tan [4].

‡ The duality interpretation of Harari [7] is consistent with this model in the sense that the s-channel structure associated with the t-channel Pomeron exchange is quite different from the s-channel structure associated with the non-leading t-channel Regge trajectories.

definite predictions on production cross sections, multiplicity distributions, and inclusive experiments in a diffraction model.

From unitarity, the contribution of the central diagram (double diffraction dissociation) of fig. 1a, to the absorptive part of the elastic scattering amplitude is given by,

$$A(s,t) \sim \frac{1}{s} \int \frac{dt_+ dt_- \beta(t_+)\beta(t_-)}{[-\Delta(t,t_+,t_-)]^{1/2}} \times$$

$$\int ds_l \, ds \; A^{P'}(s_l,t) \left(\frac{s}{s_l s_r}\right)^2 A^{P'}(s_r,t) \qquad (1)$$

where $\Delta(t,t_+,t_-) = t^2 + t_+^2 + t_-^2 - 2t(t_+ + t_-) - 2t_+t_-$ is the usual triangle function, $\beta(t_\pm)$ are the Pomeron residue functions, and $\sum = s/s_l s_r$ is the Regge propagator for the fixed Pomeron pole. The factors $A^{P'}(s,t)$ represent the sum of all the multiperipheral graphs with only "ordinary" Regge or meson exchanges which behave asymptotically as

$$A^{P'}(s,t) \sim \gamma_{P'}(t)\, s^{\alpha_{P'}(t)} \qquad (2)$$

where by assumption, $\alpha_{P'}(t) < 1$, for $t \leqslant 0$.

The leading behavior of $A(s,t)$ can be found by substituting eq. (2) into eq. (1), to get

$$A(s,t) \sim s \int \frac{ds_l}{s_l^{\,2-\alpha_{P'}(t)}} \; \frac{ds_r}{s_r^{\,2-\alpha_{P'}(t)}} \; \tilde{f}(t) \qquad (3)$$

where the integrations over t_+ and t_- have yielded an s-independent result as a consequence of the assumed rapid damping of $\beta(t_\pm)$. Any s dependence of the remaining integrals lies implicit in the upper limits of s_l and s_r. However, since $\alpha_{P'}(t) < 1$, the integrand is sufficiently convergent in these variables to render the result independent of the upper limits of integration in the limit $s \to \infty$ so that $A(s,t) \sim sf(t)$. Thus for all values of t, the energy dependence of this contribution is a fixed pole at $J = 1$. A similar result goes through for the elastic and end diagram (single diffraction dissociation) contributions, yielding a successful bootstrap for the fixed Pomeron pole at $J = 1$:

$$A(s,t) = s\beta(t) \,. \qquad (4)$$

As a consequence of the diffractive Pomeron, the total cross section, $\sigma_T = (1/s)A(s,0) = \beta(0)$, and all partial cross sections, σ_n, become asymptotically constant. In this model, the average multiplicity, $\bar{n} = \sum n\sigma_n/\sigma_T$, will approach a constant. This important consequence of single Pomeron exchange differs from MPE models which predict $\bar{n} \sim \ln s$. Present cosmic ray data [9] indicate that the multiplicity may be rising very slowly. The constancy of the average multiplicity together with the initial positive charge excess of cosmic ray primaries predicts that the μ^+/μ^- ratio from cosmic rays will asymptotically approach a constant greater than 1.

For illustration, we have examined a specific "strongly ordered" multi-Regge model for the fragmentation in p-p collisions, where the produced particles were taken to be ρ mesons. This resulted in a nearly geometric multiplicity distribution * with the cross-section for producing n ρ's given by,

$$\sigma_n = c(n+1)r^n \qquad n \geqslant 0 \,, \qquad (5)$$

where

$$r \equiv g^2/(1-\alpha_{P'}(0)+g^2) < 1 \qquad (6)$$

and g^2 is the multi-Regge coupling constant. This gives $\sigma_{el} = c$

$$\sigma_{el}/\sigma_T = (1-r)^2 \qquad (7a)$$

$$\sigma_T = \sum_{n=0}^{\infty} \sigma_n = c/(1-r)^2 \qquad (7b)$$

$$\bar{n}_{charged} = 2 + \tfrac{2}{3} \times 2 \times n = 2 + 8/3(1-r)(2-r) \,. \qquad (7c)$$

For reasonable bootstrap parameters $\alpha_{P'}(0) = 0.5$ and $g^2 = 0.7$, this gives $r = 0.58$, $\sigma_{el}/\sigma_T = 0.17$ and $\bar{n}_{charged} = 6.5$. All of these results are in reasonable agreement with current experimental data [10].

We have proven that in the diffractive Pomeron model, the single particle spectrum satisfies the limiting fragmentation hypothesis of Yang and colaborators [11]. The distribution of the target (projectile) fragments

$$d\sigma/\frac{d^3k}{2k_0} = f(k_\perp^2, k_\parallel) \qquad (8)$$

depends *only* on the nature of the target (projectile) and the observed particle and its momenta as measured in the target (projectile) rest frame. For large $k_\parallel$, we find that [5]

$$f(k_\perp^2, k_\parallel) \underset{k_\parallel \to \infty}{\sim} k_\parallel^{\,\alpha_{P'}(0)-1} \qquad (9)$$

and hence there is no pionization asymptotically. At present accelerator energies, there will be slow particles in the center of mass system

* Wroblewski [10] has observed that the accelerator data for σ_n appear to obey a geometric distribution.

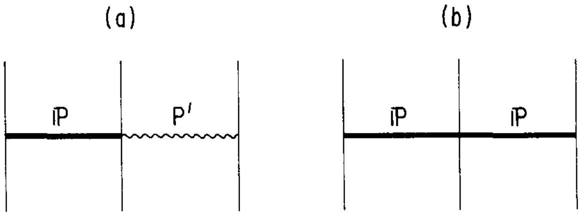

Fig. 2 a) Diagram for single particle spectrum for $k_{\parallel} \sim O(s^{1/2})$ in the diffractive Pomeron model. b) Diagram for pionization in the MPE model.

($k_{\parallel} \sim O(s^{1/2})$) represented by fig. 2a **, where the particles produced to the left and right in the c.m.s. are summed to give Regge behavior at a subenergy $\sim s^{1/2}$.

$$f(k_{\perp}^2, k_{\parallel}) \underset{k_{\parallel} \sim O(s^{1/2})}{\sim} \frac{(s^{1/2})^{\alpha_{P'}(0)} s^{1/2}}{s} = (s^{1/2})^{\alpha_{P'}(0)-1} \tag{10}$$

This corresponds to the tail of the target (projectile) fragmentation at $k_{\parallel} \sim O(s^{1/2})$, given by eq. (9). The diffractive Pomeron model predicts that the current observation of these slow particles in the c.m.s. will decrease slowly as $\sim s^{-1/4}$. The existence of pionization as predicted by MPE models [13] and the associated behavior $\bar{n} \propto \ln s$ corresponds to fig. 2b. This does not exist in our model, since we can only exchange the Pomeron once in the chain.

The simplicity of the fixed pole solution allows the s and t dependent aspects of the bootstrap to decouple, yielding the following non-linear integral equation for the Pomeron residue in a single channel problem †

$$\beta(t) = \frac{1}{16\pi^2} \int \frac{dt_+ dt_- \beta(t_+)\beta(t_-)}{[-\Delta(t, t_+, t_-)]^{1/2}} [1 + 2\Gamma(t) + \Gamma^2(t)] \tag{11}$$

with $\Gamma(t) = \gamma_{P'}(t)[\pi(1-\alpha_{P'}(t))]^{-1}$. At $t = 0$, the left hand side is simply the total cross section, while the terms on the right are respectively the elastic, single diffraction and double diffraction cross sections. If for simplicity we take $\Gamma(t) = \Gamma$ = constant, then one solution of this equation is

$$\beta(t) = \frac{8\pi R^2 \; J_1(R\,(-t)^{1/2})}{(1+\Gamma)^2 \; R\,(-t)^{1/2}} \tag{12}$$

** This diagramatic representation was inspired by Mueller [12].

† Detailed solutions to a multichannel Pomeron bootstrap which exhibits factorization of the fixed pole are presented in ref. [5].

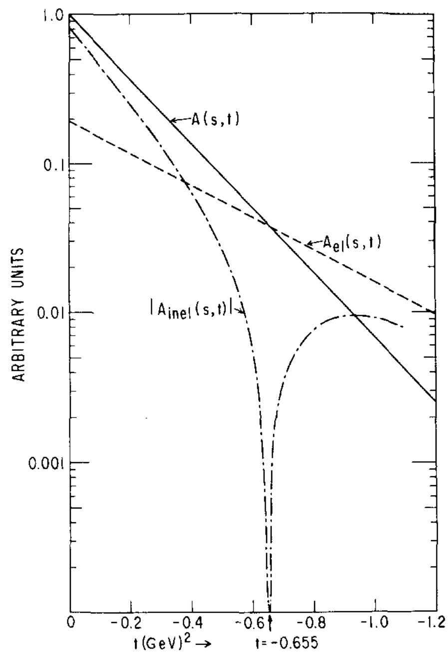

Fig. 3. $A(s,t) = s\sigma_T e^{at}$ and $A_{el}(s,t)$ from p-p elastic scattering at 21 GeV/c.

which corresponds to scattering from a totally absorbing disk of arbitrary radius R.

From fig. 1 or eq. (11), we see that the inelastic contributions to unitarity, $A_{inel}(s,t) = A(s,t) - A_{el}(s,t)$, are proportional to the absorptive part of the P' residue function $\gamma_{P'}(t)$. We expect that the ghost-killing mechanism in Regge theory would give $\gamma_{P'}(t_0) = 0$, when $\alpha_{P'}(t_0) = 0$. Experimentally $t_0 \approx -0.6\,\text{GeV}^2$. At $t = t_0$ then, the elastic contribution should completely saturate unitarity. In fig. 3, we plot $A(s,t)$ and $A_{el}(s,t)$ derived from an exponential parameterization of p-p eleastic scattering at 21 GeV/c. The difference,

$$A_{inel}(s,t) = s\left[\sigma_T \exp(at) - \frac{\sigma_T^2}{32\pi a} \exp(\tfrac{1}{2}at)\right] \tag{13}$$

vanishes when

$$t = \frac{2}{a} \ln(\sigma_T/32\pi a) . \tag{14}$$

For the fitted parameters, $\sigma_T = 39$ mb and $a = 5\,\text{GeV}^{-2}$ this gives $t = -0.65\,\text{GeV}^2$, in excellent agreement with the above value for t_0.

To conclude, the study of the Pomeron bootstrap and its relation to inclusive experiments shows that the difference between MPE models with $\alpha_P(t) < 1$ and a diffractive Pomeron with

$\alpha_P(t) \equiv 1$, yield very different qualitative features for inclusive experiments. In particular, the asymptotically constant behavior of $\bar{n}$ and σ_n and the absence of pionization are general consequences of eq. (2), and do not depend on any detailed structure for $A^{P'}(s,t)$. These experiments should therefore play an important role in unravelling the nature of the Pomeranchuk singularity.

Discussions with W. R. Frazer, C. H. Poon, C-I. Tan and D. Y. Wong are gratefully acknowledged.

References

[1] J. Finkelstein and K. Kajantie, Physics Letters 26B (1968) 305;
N. F. Bali, G. F. Chew and A. Pignotti, Phys. Rev. Letters 19 (1967) 614.
[2] G. F. Chew and A. Pignotti, Phys. Rev. 176 (1968) 2112;
J. S. Ball and G. Marchesini, Phys. Rev. 188 (1969) 2508;
G. F. Chew and D. R. Snider, Phys. Rev. D1 (1970) 3453.
[3] T. T. Chou and C. N. Yang, Phys. Rev. 175 (1968) 1832;
R. Hwa, Nuovo Cimento Letters II (1969) 369;
F. Zachariasen, Boulder Summer School, 1969 (to be published by Gordon and Breach N. Y.).
[4] R. Oehme, Phys. Rev. Letters 18 (1967) 1222;
J. Finkelstein and C-I. Tan, Phys. Rev. Letters 19 (1967) 1061.
[5] A more detailed account of the work presented in this paper can be found in D. Silverman, P. D. Ting and H. J. Yesian, UCSD report.
[6] R. Lipes, G. Zweig and W. Robertson, Phys. Rev. Letters 22 (1969) 433.
[7] Harari, Phys. Rev. Letters 20 (1968) 1395.
[8] R. D. Peccei and A. Pignotti, University of Washington preprint RLO-1388-601, Feb. 1971.
[9] L. W. Jones et al., Phys. Rev. Letters 25 (1970) 1679.
[10] A. Wroblewski, Phys. Letters 32B (1970) 145.
[11] J. Benecke, T. T. Chou, C. N. Yang and E. Yen, Phys. Rev. 188 (1969) 2159.
[12] A. H. Mueller. Phys. Rev. D2 (1970) 2963.
[13] D. Silverman and C-I. Tan, Phys. Rev., to be published;
D. Silverman and C-I. Tan, Nuovo Cimento, to be published.

* * * * *