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ЦЕНТРАЛЬНЫЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ
ИНФОРМАЦИИ И ТЕХНИКО-ЭКОНОМИЧЕСКИХ ИССЛЕДОВАНИЙ
ПО АТОМНОЙ НАУКЕ И ТЕХНИКЕ

Sh.S.EREMYAN, A.E.NAZARYAN

DIFFERENTIAL CROSS SECTIONS OF pp-SCATTERING AT SUPERHIGH ENERGIES IN CRITICAL POMERON THEORY

ЕРЕВАН-1984

1. Introduction

The Reggeon field theory (RFT) was originally formulated in Refs.[1-3] and developed in Refs.[4,5]. These works investigated the RFT infrared behaviour by the methods of renormgroup and ε -expansion. Ref.[6] pointed out the importance of the account of the pomeron production threshold for describing the experimental data at average and high energies. It was shown in Refs.[7-10] how to construct the renormalized RFT with respect to the thresholds directly at D =2.

The pomeron Green function obtained in these works proved to be very convenient to describe theoretically the hadronic interactions at superhigh energies and was used [11,12] for describing the total cross sections, the diffraction cone slopes and the other experimental characteristics at very small transferred momenta of proton-proton and proton-nucleus interactions.

The interest to description of differential cross sections at superhigh energies has recently regenerated owing to the new experimental data [13-16].

In this paper we have carried out a description of the pp-scattering differential cross sections beginning with 200 GeV up to SPS energy at the transferred momenta $|t| \leq 1.5$ (GeV/c)^2 in the model with a renormgroup critical pomeron [7-12].

In Sec.2 we consider the Reggeon perturbation theory. It is shown that the latter must describe the experimental data properly in the range $E \lesssim$ 10000 GeV. At higher energies it is more reasonable to turn to renormalized pomeron whose description is a subject of Sec.3. Ibidem the analysis of the obtained results is given.

2. Reggeon Perturbation Theory with Respect to Thresholds

The main difference between RFT and all the other field theories (e.g. QED or QCD) consists in the fact that at any finite energy a finite number of perturbation theory diagrams contributes to the scattering amplitude. This occurs due to the threshold energy, below which pomeron simply does not exist. A "ladder" diagram corresponds to pomeron in a simplest multiperipheral picture. One may say that pomeron becomes pomeron only in case if this "ladder" has sufficient number of "steps". The calculations show that pomeron is generated at energies of about 10 GeV. Hence the pomeron production threshold $\xi_0 \approx 2.5$ (where $\xi = \ln(s/s_0)$, $s_0 = 1$ GeV).

Thus, we have the perturbation theory on three-pomeron coupling constant in which the number of diagrams is determined by energy. For example, at energies $\xi_0 < \xi < 2\xi_0$ only the pole diagram of Fig.1a together with its quasi-eikonal cuts can contribute to the amplitude (Fig.1b).

At energies $2\xi_0 < \xi < 3\xi_0$, besides a diagram of Fig.1, also the half-enhanced diagrams of Fig.2 with their quasi-eikonal cuts will contribute.

At energies $3\xi_0 < \xi < 4\xi_0$ also entirely enhanced diagrams besides the pole and half-enhanced ones of Figs.1 and 2 will contribute. The number of possible diagrams will increase sharply, and the amplitude takes the form shown in Fig.3.

One should add to diagrams of Fig.3 also asymmetric to them turned-over ones as well as the whole quasi-eikonal series constructed of such graphs. We can see the avalanche-type increase in the number of diagrams as energy grows.

Though the number of the series terms is great up to energy $\xi \approx 10$ ($E \approx$ 12 TeV), nevertheless there is a possibility to calculate their contributions analytically, eikonalize them and compare with the experimental data. All the calculations should be carried out with account of the fact that $\xi_0 \neq 0$ and $\kappa^2 \neq 0$.

One of the pleasant aspects of this theory is that at energies $\xi < 2\xi_0$ only the diagrams of Fig.1 work, whose contributions were studied in detail in Ref. 17 . Therefore for further calculations one can use somewhat simplified residue functions obtained from the analysis of experimental data at low energies in [17].

Having calculated the contributions of all diagrams given in Figs.1-3 with respect to the thresholds ξ_0 , with the residue functions and shower amplification coefficients (SAC) for pp-scattering obtained in [17], we shall come to the pp-scattering total amplitude in the form of some rather compound function which we shall not give here. Its peculiarity consists in the fact that at $\xi_0 < \xi < 2\xi_0$ it has only the terms shown in Fig.1, while at $2\xi_0 < \xi < 3\xi_0$ only those shown in Figs.1 and 2 and so on. As was shown in Refs.[11,12], this amplitude describes perfectly all the experimental data at small $|t|$ in the energy range from 10 GeV to 10 TeV. At energies above 10 TeV we should have taken into account a larger set of new diagrams, the number of which is already very great and the account of them results in too complicated calculations.

But on the other hand, at such energies the number of working diagrams of perturbation theory becomes so large that it becomes possible to use the renormalized propagator obtained in Refs.[9,10].

3. Renormgroup Pomeron

In Refs.[9,10] by means of the renormgroup techniques we have obtained a renormalized pomeron propagator in which the effects caused by $\xi_0 \neq 0$ were correctly taken into account. In [9] it was shown that expansion of the renormgroup amplitude in the region $\xi < 4\xi_0$ describes exactly a contribution of the perturbation theory series as shown in Figs.1-3. In our further calculations we shall use the renormgroup amplitude asymptotic expansion at $\xi \to \infty$ conserving terms up to ξ^{-2}. As was shown in [12], such an amplitude coincides exactly with the theoretically perturbative amplitude at $\xi \simeq 3\xi_0$ ($E \sim 1$ TeV) being in coincidence with it up to $E \sim 10$ TeV.

The imaginary part of the amplitude with one renormalized critical pomeron will take the following form:

$$\operatorname{Im} M(\xi,\kappa^2) = g_1 g_2 \frac{1+c/2}{\Gamma(1+\frac{c}{2})} e^{-c\alpha} (\bar{E}_0 \xi)^{c/2} e^{-(1+c)x} F_1(\xi) F_2(\xi,x) \quad (1)$$

where

$$\xi = \ln(s/s_0); \quad \kappa^2 = -t; \quad \bar{E}_0 = \frac{r_0^2(1-\alpha)}{16\pi\alpha_0' c_0}.$$

x is a new scale variable corresponding to transferred momentum.

$$x = \alpha_0' \kappa^2 e^{\alpha c/2} (1+c) (\bar{E}_0)^{c/4} \xi^{1+c/4}, \quad (2)$$

g_1, g_2 are the pomeron-particle coupling vertex functions, c and α are the critical indices of theory, r_0 is the input three-pomeron vertex

α_0' is nonrenormalized slope of pomeron. $F_1(\xi)$ and $F_2(\xi,x)$ are scale functions defining the energy and t dependence of amplitude. All these quantities were defined theoretically and calculated in Refs.[10-12].

$c = 0.555; \quad c_0 = 0.1164; \quad \alpha = 0.54; \quad \bar{E}_0 = 0.123.$

The scale functions have the following forms:

$$F_1(\xi) = 1 + 1.32\xi^{-1/2} - 0.2649\xi^{-1} + 0.118\xi^{-3/2} + 0.432\xi^{-2}, \quad (3)$$

$$F_2(\xi,x) = 1 - 0.0509\kappa^2 \xi^{1.139} = 1 - x/8, \quad (4)$$

$$x = 0.407\kappa^2 \xi^{1.139}. \quad (5)$$

Taking into account the production threshold of single pomeron $\xi_0 = 2.5$, for the imaginary part of the pole amplitude with one renormalized pomeron exchange we finally obtain

$$\operatorname{Im} M^{(1)}(\xi,\kappa^2) = i\beta(\xi) e^{-\kappa^2 a(\xi)} F_2(\xi,x), \quad (6)$$

where

$$a(\xi) = 0.407\xi^{1.139}$$
$$\beta(\xi) = g_1 g_2 0.4734 \xi^{c/2} F_1(\xi). \quad (7)$$

This amplitude corresponds to the diagram of Fig.4.

Fig.5 shows the quasi-eikonal amplitude contributing at low and high energies; it dies out at asymptotically high energies; only the Fig.4 amplitude survives behaving as $\xi^{0.277}$. But in the energy region, we are interested in, the amplitude of Fig.5 makes sufficiently large contribution and provides high rate of total cross sections growth of the order of ξ^2.

A similar calculation of the quasi-eikonal amplitude was done in Refs.[11,12], so we shall not present it here.

As was shown in [17], SAC are functions of energy and transferred momentum. ξ -dependence of SAC proved to be highly essential for obtaining a correct ξ -behaviour of total cross sections in the region $8 \leq \xi \leq 15$ in Refs.[11,12]. t -dependence of SAC will allow one to obtain a correct behaviour of differential cross sections.

However the question on real part of amplitude (6) remains open yet, since RFT can give information only on imaginary part of an amplitude. As was shown by means of the dispersion relations in Ref.[18], at $t = 0$

$$\alpha(\xi,0) = \frac{Re\,M(0)}{Im\,M(0)} \underset{s\to\infty}{\approx} \frac{1}{\sigma_{tot}(\xi)} \frac{\pi}{2} \frac{d}{d\xi} \sigma^{tot}(\xi) , \qquad (8)$$

at $t \neq 0$ in [18] and [19] it was shown that

$$Re\,M(\xi,t) = \alpha(\xi,0) \frac{d}{dt} \left[t\, Im\,M(t) \right] . \qquad (9)$$

Refs.[11,12] have shown that the expression (8) agrees perfectly with all the available experimental data on $\alpha(\xi)$. At $E \lesssim 1000$ GeV the perturbation theory formulae were used in which $Re\,M(t)$ were calculated directly from the signature factors. $Re\,M(t)$ obtained in this way agrees well in this region with the result derived from formula (9).

The concrete calculations of pp-scattering differential cross sections were carried out as follows: at $E \leq 1000$ GeV the amplitudes of perturbation theory were used, at $E > 1000$ GeV already the quasi-eikonal renormgroup amplitude from Eqs.(6), (8) and (9) was used. In both cases ξ

and t dependent SACs from Ref.[17] were used.

The results obtained from perturbation theory agree well with the renormgroup ones already at $E \sim 1000$ GeV.

The pp-scattering differential cross sections in the energy range from $\sqrt{s} = 19.41$ to $\sqrt{s} = 540$ GeV and in the transferred momentum range $0 \leq |t| \leq 1.3\ (\text{GeV/c})^2$ are given in Fig.6. It is seen from the figure that at low energies there is a good description up to $|t| \lesssim 2$ GeV; with increasing energy the cross sections are described well up to the dip of differential cross sections. This is explained by the fact that at low energies we used the theoretically perturbative formulae with a compound residue function which described well the t -behaviour of cross sections ever in Ref.[17].

At higher energies we use already the renormgroup amplitude in which the t -behaviour is described by a compound function of χ from which we have taken only the first expansion term in formula (4). Apparently, if we take higher expansion terms, we shall be able to describe a region of larger $|t|$ as well.

We do not make such a task our aim, we simply wish to show that RFT with critical pomeron is a completely self-consistent theory describing correctly not only the region $t = 0$ [11,12], but also such experimental quantities as $d\sigma/dt$.

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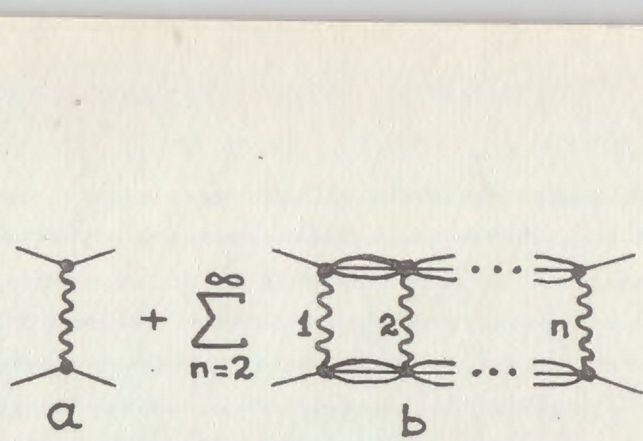

Fig.1 Pole amplitude with quasi-eikonal cuts.

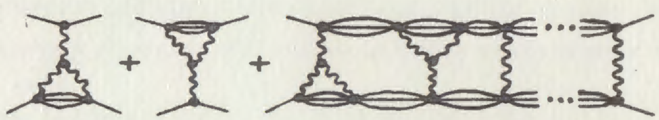

Fig.2 Half-enhanced diagrams with quasi-eikonal cuts.

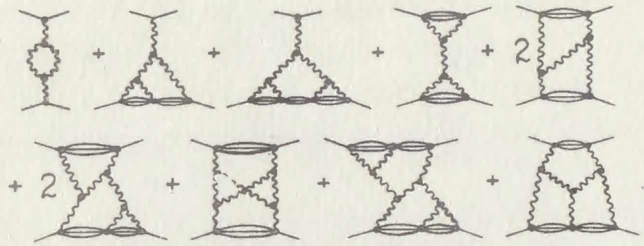

Fig.3 Enhanced diagrams.

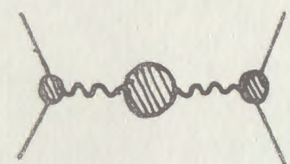

Fig.4 Amplitude with one renormalized pomeron.

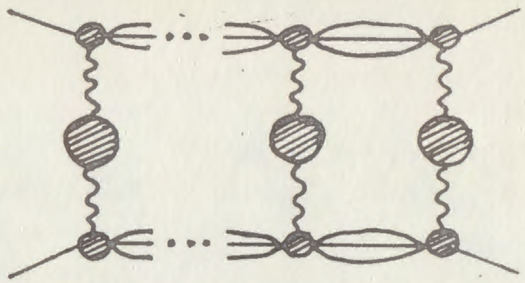

Fig.5 Quasi-eikonal amplitude with renormalized pomeron.

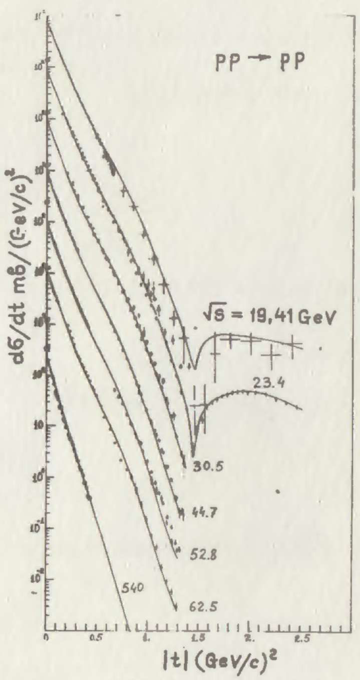

Fig.6 pp-scattering differential cross sections.

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Ш.С.ЕРЕМЯН, А.Э.НАЗАРЯН

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