MODELS WITH REALISTIC REGGEONS FOR t=0 HIGH ENERGY SCATTERING

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Several Regge-phenomenological models of forward scattering at high energies are considered. It was found that one of them corresponds to the form of finite series in log$s$ with additional terms that represent the exchanges of non-degenerate Regge-trajectories. These trajectories are unique for both scattering and resonance regions and satisfy the most realistic ideas on them.

Introduction

Since the 60s of the last century pomeron plays a fundamental role in describing the scattering at high energies. In spite of this, our understanding of the pomeron nature is far from completeness and there are also many confusing ideas about them. Note that one of the persistent ideas is that there are two pomerons - a soft [1] and a hard one [2]. But the pomeron is a Regge pole, which determines an asymptotic behaviour of high-energy diffractive processes and has the quantum numbers of the vacuum. Indeed, this supports the opinion that there is only one object, which may have different manifestations in different dynamical situations [3]. In addition, we have to underline here that the recent data [4] make the situation more complicated.

Many models of various total cross sections (nucleon-nucleon, π-meson-nucleon and γp, $\gamma\gamma$ interactions) describe quite well the available data.

Because of the fact that most of existing models have been tested with different data sets, it is quite difficult to compare the quality of data fits. As a rule, in each paper only one model is discussed in detail and, moreover, a specified set of experimental data is used. Fortunately there exists a complete data set of total cross sections and ratios of the real part of scattering amplitude to the imaginary part for the pp, $\bar{p}p$, $\pi^{\pm}p$, $K^{\pm}p$ scattering and for total cross sections in the case of the γp, $\gamma\gamma$ and Σp scattering [5]. Another requirement to all mentioned above is the fulfilment of the $\chi^2/dof\approx 1$ criterion introduced in [6]. It was found in [6] with the data set [5] that the data cannot discriminate between a single-pole, asymptotic log$s$ and $\log^2 s$ models. The models examined in [6] satisfy the condition $\chi^2/dof\approx 1$ with 16 fitted parameters at $\sqrt{s_{\min}} \geq 9\,\mathrm{GeV}$.

In this paper, we will consider the Regge-phenomenological models of forward scattering at high energies, where both pomeron and secondary reggeons (hereinafter referred to as the reggeons) satisfy the most realistic ideas on them.

Improvement of single-pole models

Here we will demonstrate using the Donnachie-Landshoff (DL) model [7] that for successful description for t=0 we need a more sophisticated and detailed pomeron model, which has the most effective and economic form for the total cross sections:

$$\sigma_{tot}(s) = Xs^{\varepsilon} + Y_{\pm}s^{-\eta}, \qquad (1)$$

where $Y_{\pm}$ corresponds to pp and $\bar{p}p$ scattering with exchange degenerate reggeon representing both $C=\pm 1(\rho,\omega,a_2,f)$ exchanges besides the pomeron with intercepts given by $\alpha_P = 1+\varepsilon$ and $\alpha_R = 1-\eta$. The scale factor s_0=1 is implicitly presented in the formulae. The DL model fares reasonably well when fitting to the pp and $\bar{p}p$ total cross sections, but for all the other data [5] at $\sqrt{s_{min}} = 9$ GeV it does not obey the necessary criterion, because χ^2/dof=1.3 and demands a generalization, for example, including a daughter trajectory as mentioned in [8,9]:

$$\sigma_{tot}(s) = Xs^{\varepsilon} + Y_{\pm}s^{-\eta} + Zs^{\varepsilon-1}, \qquad (2)$$

or

$$\sigma_{tot}(s) = Xs^{\varepsilon} + Y_{+}s^{-\eta_+} \mp Y_{-}s^{-\eta_-}, \qquad (3)$$

where the last two terms represent the exchanges of non-degenerate $C=+1(a_2, f)$ and $C=-1(\rho,\omega)$ trajectories with intercepts $\alpha_{\pm} = 1-\eta_{\pm}$, respectively. The sign of Y_- term flips when fitting pp data are compared to the $\bar{p}p$ data.

In case of formula (2) we have an improvement of the fit at 10 GeV, where χ^2/dof reaches the value of 1.05.

An alternative way to account effectively the complex structure of singularities is to try to mimic them by a two-component pomeron built from two Regge singularities [10–12]. Note that the perturbative pomeron has also a complex form. Recently detailed calculations in QCD indicated an existence of the two-component pomeron [11].

The two-component pomeron model for the total cross sections has the following form:

$$\sigma_{tot}(s) = Z + Xs^{\varepsilon} + Y_{+}s^{-\eta_+} \mp Y_{-}s^{-\eta_-}, \qquad (4)$$

where the second component corresponds to the intercept larger than 1 (ε>0), and the first component corresponds to an intercept exactly localized at 1.

A new development of this model supposes that the X-component is fully universal, i.e. its coupling is the same in all hadron-hadron reactions [12, 13], while the first one is a non-universal pomeron.

The results of the above mentioned 4 models (see formulae (1)-(4)) with all the possible improvements are shown in Table 1.

Though the additional account of the daughter contribution of the pomeron improves essentially the description. Single-pole pomeron, in general, does not support the idea of exchange-degenerate pomeron.

Table 1. Single-pole models

N	$\sqrt{s_{min}}$	χ^2/dof	Models	Parameters
1	6	1.05	(4)+Universal	19
2	6	1.05	(4)+Universal+Daughter	20
3	8	1.01	(3)+Daughter	19
4	8	1.01	(4)+Daughter	20
5	8	1.05	(4)	19
6	9	1.02	(3)	18
7	10	1.05	(2)	17

Multipole pomeron models with realistic values of reggeon intercepts

It is well known that models (1)-(4) violate the unitarity. As it was pointed out in [14], the unitarity violation occurs at the energies only slightly above the Tevatron energy of 1.8 TeV, and therefore it is a problem of the present and not of the future. Not less successful models are those based on the more complex analytical properties of the scattering amplitude, not violating however the unitarity conditions [6,10]:

$$\sigma_{tot}(s) = Z + X\log s + Y_{+}s^{-\eta_+} \mp Y_{-}s^{-\eta_-}, \quad (5)$$

$$\sigma_{tot}(s) = Z + X\log^2 s + Y_{+}s^{-\eta_+} \mp Y_{-}s^{-\eta_-}, \quad (6)$$

The analysis of all mentioned models shows that the values of fitted intercepts of reggeons sufficiently differ from each other. The *f*-reggeon intercept values are distinctly model-dependent and are far from the agreement with those obtained from the Chew-Frautschi plot [6, 15, 16]. Therefore a fairly conclusive analysis can be performed using, on one hand, the data in the resonance region, and, on the other hand, those for forward scattering [15].

Here we shall check the criteria of applicability of the models under discussion if one uses the fixed reggeon intercept values from the Chew-Frautschi plot. To do this we have chosen and fixed all the high lying reggeon intercept values calculated in [15] from Chew-Frautschi plot:

$$\alpha_f = 0.6971,\ \ \alpha_\omega = 0.4359, \qquad (7)$$
$$\alpha_\rho = 0.4783,\ \ \alpha_{a_2} = 0.5116$$

and they contribute to the scattering amplitude as follows:

f and ω for pp, $\bar{p}p$, $K^\pm p$, Σp–scattering

f and ρ for $\pi^\pm p$ –scattering

f for γp, $\gamma\gamma$–scattering

To analyze the data we used the explicit expressions of Ref. [15] for the forward amplitudes.

The results of such check are shown in Table 2. The severe requirement χ^2/dof~1 is satisfied by most of the models for the checked $\sqrt{s_{\min}}$ boundary energy values.

Table 2. Models with realistic intercept values of reggeons (7)

N	$\sqrt{s_{\min}}$	χ^2/dof	Models	Parameters
1	5	1.02	(5)	20
2	7	1.01	(6)+Universal	19
3	7	1.02	(4)+Universal	20
4	9	1.03	(3)	19
5	9	1.01	(3)+Daughter	20
6	9	1.00	(6)	20
7	9	0.99	(6)+Daughter	21
8	10	1.03	(4)	20
9	12	1.05	(5)+Universal	19

Finite logs series for the pomeron

In this part, we analyze a well-motivated pomeron model based on the assumption that QCD pomeron corresponds to the infinite sum of gluon ladders with reggeized gluons on the vertical lines [2]. Essentially at finite energies only a finite number of diagrams contributes, giving rise to a finite series in log *s* [9] like:

$$\sigma_{tot}(s) = Z + X\log s + W\log^2 s + \qquad (8)$$
$$+ Y_+ s^{-\eta_+} \mp Y_- s^{-\eta_-}.$$

This model has proven its viability [17] in case of the weak degeneration (1) within the checked $\sqrt{s_{\min}}$ boundary energy values. (Another version of this model was also discussed in [18]).

Similarly, we checked this model with all the similar versions as it was done in the previous sections. The results we compiled in Table 3. As one can notice this model is far the best relatively regarding the rest of analyzed models herein before and satisfies all the criteria yet at the lower limit of the boundary energy.

Table 3. Finite log$s$ series models with realistic intercept values of reggeons (7)

N	$\sqrt{s_{min}}$	χ^2/dof	Models	Parameters
1	5	1.00	(8)+Daughter	22
2	7	1.02	(8)+Universal	20
3	7	1.01	(8)+Universal+Daughter	21
4	7	1.02	(8)	21

It is natural for us not to take into account all the versions of this model that result in non-physical values of the parameters, despite of the better fit.

Conclusions

Summarizing the results and checking the Regge-phenomenological models one may formulate the reasonable criteria:

- The check of the models always should be done by using the same data set (for example [5]).
- The $\chi^2/dof\leq 1$ criterion should be fulfilled.
- The parameters should be compatible with the secondary reggeons from the resonance region.

As the result of our analysis we have concluded that the bigger part of analyzed models including the pomeron in the form of finite series in log s, satisfying the Froissart bound and four reggeons, provide good description of the forward scattering.

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МОДЕЛІ З РЕАЛІСТИЧНИМИ РЕДЖЕОНАМИ ДЛЯ ВИСОКОЕНЕРГЕТИЧНОГО РОЗСІЮВАННЯ ПРИ t=0

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Розглянуто різні редже-феноменологічні моделі для розсіювання вперед при високих енергіях. Одна з моделей відповідає скінченному ряду log$s$ разом з внеском обміну невиродженими редже-траєкторіями. Ці траєкторії є єдиними як для резонансної області, так і для області розсіювання, і задовольняють найбільш реалістичні ідеї про них.