

SOFT PHYSICS – THREE POMERONS?

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Abstract

A model of a three Pomeron contribution to high energy elastic pp and $\bar{p}p$ scattering is proposed. The data are well described for all momenta ($0.01 \leq |t| \leq 14. \text{ GeV}^2$) and energies ($8. \leq \sqrt{s} \leq 1800. \text{ GeV}$) ($\chi^2/\text{d.o.f.} = 2.60$). The model predicts the appearance of two dips in the differential cross-section which will be measured at LHC. The parameters of the Pomeron trajectories are:

$$\begin{aligned} \alpha(0)_{\mathbb{P}_1} &= 1.058, & \alpha'(0)_{\mathbb{P}_1} &= 0.560 \text{ (GeV}^{-2}\text{)}; \\ \alpha(0)_{\mathbb{P}_2} &= 1.167, & \alpha'(0)_{\mathbb{P}_2} &= 0.273 \text{ (GeV}^{-2}\text{)}; \\ \alpha(0)_{\mathbb{P}_3} &= 1.203, & \alpha'(0)_{\mathbb{P}_3} &= 0.094 \text{ (GeV}^{-2}\text{)}. \end{aligned}$$

1 INTRODUCTION

Fervently awaited high-energy collisions at LHC will give an access not only to yet unexplored small distances but also simultaneously to neither explored large distances [1]. Future measurements of total and elastic cross-sections at LHC [2] tightly related to the latter domain naturally stimulate further searches for new approaches to diffractive scattering at high energies.

Recently some models with multi-Pomeron structures were proposed [3–5]. Some of them [3], [4], [5] use Born amplitudes with two Pomerons as single [3], [5], or double poles [4].

The eikonal models that are capable of describing the data for nonzero transferred momenta are developed in Refs [6], [7]. It is worth noticing that the two-Pomeron eikonal has been applied to the description of the data more than ten years ago (see, e.g., Ref. [8]).

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The very multiformity of the models hints that maybe the most general way to describe high-energy diffraction is just to admit an arbitrary number of Pomerons (i.e. all vacuum Regge-poles contributing non-negligibly at reasonably high energies. Roughly, they should have intercepts not lower than 1).

As it seems not possible to describe the data in the framework of the eikonal approach with presence of one single pole Pomeron contribution [10], and the two-Pomeron option does not improve quality of description drastically (more details are given in [19]) it is fairly natural to try the next, three-Pomeron, option for the eikonal. We will see below that this choice appears rather lucky.

2 THE MODEL

Let us briefly outline the basic properties of our model. Unitarity condition:

$$\Im T(s, \vec{b}) \simeq |T(s, \vec{b})|^2 + \eta(s, \vec{b}) ,$$

where $T(s, \vec{b})$ is the scattering amplitude in the impact representation, \vec{b} is the impact parameter, $\eta(s, \vec{b})$ is the contribution of inelastic channels, implies the following eikonal form for the scattering amplitude $T(s, \vec{b})$

$$T(s, \vec{b}) = \frac{e^{2i\delta(s, \vec{b})} - 1}{2i} , \quad (1)$$

where $\delta(s, \vec{b})$ is the eikonal function.

The eikonal function is assumed to have simple poles in the complex J -plane and the corresponding Regge trajectories are normally being used in the linear approximation $\alpha(t) = \alpha(0) + \alpha'(0)t$.

In the present model we assume the following representation for the eikonal function:

$$\delta_{pp}^{\bar{p}p}(s, b) = \delta_{\mathbb{P}_1}^+(s, b) + \delta_{\mathbb{P}_2}^+(s, b) + \delta_{\mathbb{P}_3}^+(s, b) \mp \delta_{\mathbb{O}}^-(s, b) + \delta_f^+(s, b) \mp \delta_\omega^-(s, b), \quad (2)$$

here $\delta_{\mathbb{P}_{1,2,3}}^+(s, b)$ are Pomeron contributions. ‘+’ denotes C even trajectories, ‘-’ denotes C odd trajectories, $\delta_{\mathbb{O}}^-(s, b)$ is the Odderon contribution ; δ_f^+ , $\delta_\omega^-(s, b)$ are the contributions of secondary Reggeons, f ($C = +1$) and ω ($C = -1$). The analytical formulae for the eikonal function are given in [19].

The parameters of secondary Reggeon trajectories are fixed according to the parameters obtained from a fit of the meson spectrum [11], $\alpha_f(t) = 0.69 + 0.84t$,

$\alpha_\omega(t) = 0.47 + 0.93t$. All the other trajectories are taken in linear approximation $\alpha_i(t) = \alpha_i(0) + \alpha'_i(0)t$, ($i = \mathbb{P}_1, \mathbb{P}_2, \mathbb{P}_3, \mathbb{O}$).

3 RESULTS

We fit the adjustable parameters over a set of 982 pp and $\bar{p}p$ data of both forward observables (total cross-sections σ_{tot} , and ρ – ratios of real to imaginary part of the amplitude) in the range $8. \leq \sqrt{s} \leq 1800. GeV$ and angular distributions ($\frac{d\sigma}{dt}$) in the ranges $23. \leq \sqrt{s} \leq 1800. GeV$, $0.01 \leq |t| \leq 14. GeV^2$.

Having used 20 adjustable parameters we achieved $\chi^2/d.o.f. = 2.60$. (Interested reader may find the list of parameters in the paper [19]). The results are shown in fig. 1, 2, 3, 4, 5, 7. We do not include elastic cross-section data sets into the fit and predictions of the model for elastic cross-sections can be seen in fig. 2.

The model predicts the appearance of two dips in the differential cross-section which will be measured at LHC, fig. 7. These dips are to appear in the region $t_1 \simeq -0.5 GeV^2$ and $t_2 \simeq -2.5 GeV^2$ which is in agreement with other predictions (models [6], [15]).

In the high $|t|$ domain the model shows predominance of the Odderon contribution and its interference with $Pomeron_3$ contribution, and this predominance of the Odderon is in agreement with a model [16] based on different from ours assumptions.

We predict the following values of the total cross-section, elastic cross-section, and the ratio of real to imaginary part of the amplitude for the LHC, $\sqrt{s} = 14. TeV$:

$$\sigma_{tot}^{pp} = 106.73 (mb) \begin{matrix} +7.56 mb \\ -8.50 mb \end{matrix}, \sigma_{elastic}^{pp} = 29.19 (mb) \begin{matrix} +3.58 mb \\ -2.83 mb \end{matrix}, \rho^{pp} = 0.1378 \begin{matrix} +0.0042 \\ -0.0061 \end{matrix}.$$

Predictions for RHIC are:

$$\sqrt{s} = 100. GeV :$$

$$\sigma_{tot}^{pp} = 45.96 (mb) \begin{matrix} +1.41 mb \\ -1.38 mb \end{matrix}, \sigma_{elastic}^{pp} = 8.40 (mb) \begin{matrix} +0.34 mb \\ -0.32 mb \end{matrix}, \rho^{pp} = 0.0962 \begin{matrix} +0.0032 \\ -0.0032 \end{matrix}.$$

$$\sqrt{s} = 500. GeV :$$

$$\sigma_{tot}^{pp} = 59.05 (mb) \begin{matrix} +2.94 mb \\ -3.10 mb \end{matrix}, \sigma_{elastic}^{pp} = 12.29 (mb) \begin{matrix} +0.79 mb \\ -0.76 mb \end{matrix}, \rho^{pp} = 0.1327 \begin{matrix} +0.0052 \\ -0.0071 \end{matrix}.$$

The parameters of the Pomeron trajectories are:

$$\begin{aligned} \alpha(0)_{\mathbb{P}_1} &= 1.058, & \alpha'(0)_{\mathbb{P}_1} &= 0.560 (GeV^{-2}); \\ \alpha(0)_{\mathbb{P}_2} &= 1.167, & \alpha'(0)_{\mathbb{P}_2} &= 0.273 (GeV^{-2}); \\ \alpha(0)_{\mathbb{P}_3} &= 1.203, & \alpha'(0)_{\mathbb{P}_3} &= 0.094 (GeV^{-2}). \end{aligned} \tag{3}$$

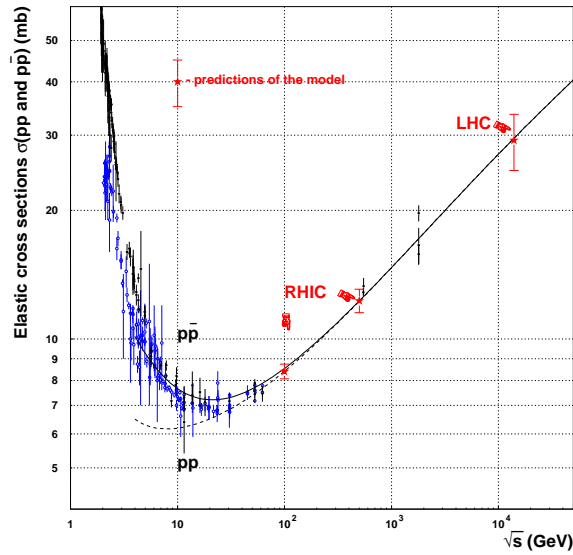
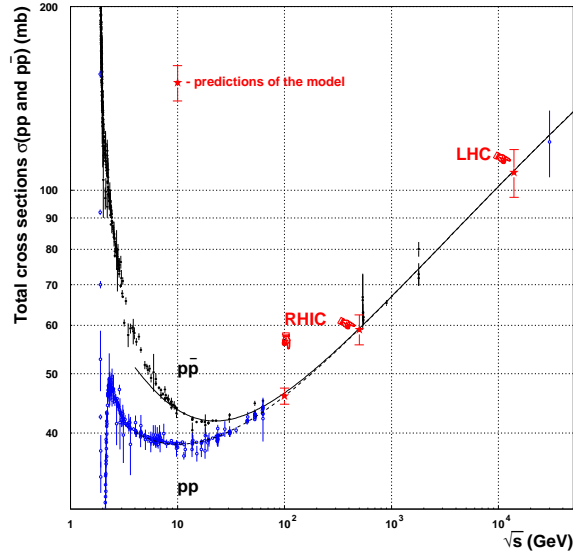


Fig. 1. Total cross sections of pp scattering (hollow circles) and $\bar{p}p$ scattering (full circles) and curves corresponding to their description in the three-Pomeron model.

Fig. 2. Elastic cross sections of pp scattering (hollow circles) and $\bar{p}p$ scattering (full circles) and curves corresponding to their description in the three-Pomeron model. These sets of data are not included in the fit.

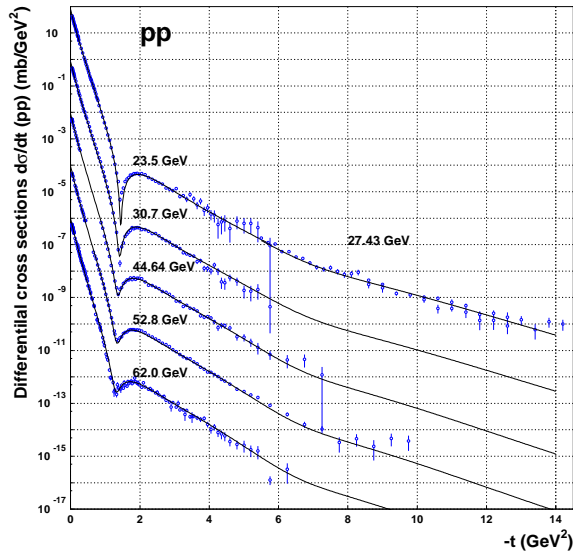
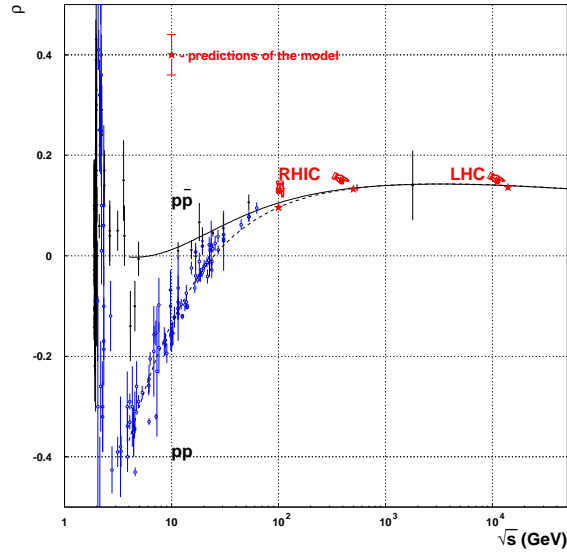


Fig. 3. Ratios of the real to the imaginary part of the forward pp scattering amplitude (hollow circles) and $\bar{p}p$ scattering amplitude (full circles) and curves corresponding to their description in the three-Pomeron model.

Fig. 4. Differential cross-sections for pp scattering and curves corresponding to their description in the three-Pomeron model. A 10^{-2} factor between each successive set of data is omitted.

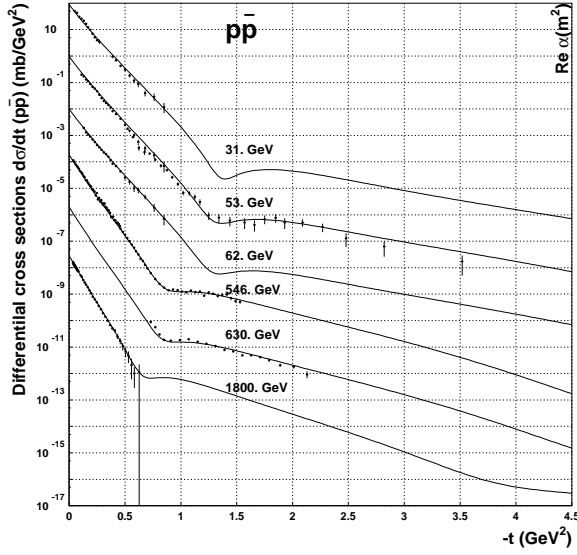


Fig. 5. Differential cross-sections for $\bar{p}p$ scattering and curves corresponding to their description in the three-Pomeron model. A 10^{-2} factor between each successive set of data is omitted.

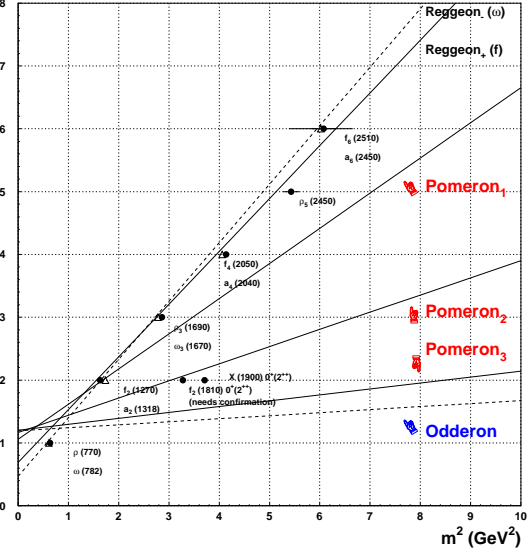


Fig. 6. Regge trajectories of secondary Reggeons, three Pomerons and the Odderon.

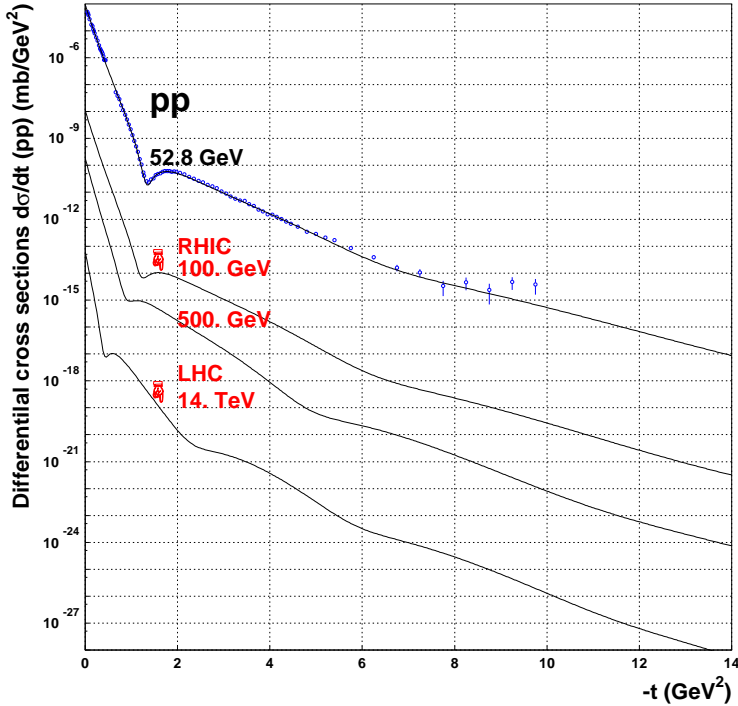


Fig. 7. Predictions of the three-Pomeron model for the differential cross-section of pp scattering which will be measured at LHC with $\sqrt{s} = 14. \text{ TeV}$ and at RHIC $\sqrt{s} = 100. \text{ GeV}$ and $\sqrt{s} = 500. \text{ GeV}$. The data corresponding to the energy $\sqrt{s} = 52.8 \text{ GeV}$ is multiplied by 10^{-6} , RHIC at 500 GeV by 10^{-10} , RHIC at 500 GeV by 10^{-12} , and that of LHC by 10^{-16} .

4 CONCLUSION AND DISCUSSION

It is interesting to enlist the following characteristic properties of the Pomerons used in this paper.

The first of the Pomerons (*Pomeron*₁) possesses the properties that we expect from the string picture [17] of Reggeons, i.e. $\alpha'(0)_{\mathbb{P}} = \frac{1}{2}\alpha'(0)_f = 0.42 \text{ (GeV}^{-2}\text{)}$ and indeed $\alpha'(0)_{\mathbb{P}_1} = 0.559 \pm 0.078 \text{ (GeV}^{-2}\text{)}$.

The second Pomeron (*Pomeron*₂) is close to what is called “supercritical Pomeron” with the slope $\alpha'(0)_{\mathbb{P}_2} = 0.273 \pm 0.005 \text{ (GeV}^{-2}\text{)}$ close to its “world” value $\alpha'(0)_{\mathbb{P}} \simeq 0.25 \text{ (GeV}^{-2}\text{)}$.

The third Pomeron (*Pomeron*₃) is reminiscent of what is known as a “hard” (or perturbative QCD) Pomeron. Its parameters ($\alpha(0)_{\mathbb{P}_3} = 1.203$, $\alpha'(0)_{\mathbb{P}_3} = 0.094 \text{ (GeV}^{-2}\text{)}$) are close to the calculated parameters of the perturbative Pomeron, which arise from the summation of reggeized gluon ladders and BFKL equation [18]: $\alpha(0)_{\mathbb{P}}^{BFKL} \simeq 1.2$, $\alpha'(0)_{\mathbb{P}}^{BFKL} \sim 0. \text{ (GeV}^{-2}\text{)}$. The fact of arising of a “hard” Pomeron in a presumably “soft” framework can seem quite unexpected. However we are not particularly inclined to identify straightforwardly “our hard Pomeron” with that which is a subject of perturbative QCD studies.

The Odderon has the following parameters: $\alpha(0)_{\mathbb{O}} = 1.192$, $\alpha'(0)_{\mathbb{O}} = 0.048 \text{ (GeV}^{-2}\text{)}$ in agreement with unitarity constraints [13]. The Odderon intercept is positive and close to that of the *Pomeron*₃. The slope is almost zero. The coupling is so small that only high-*t* data may be sensible to the Odderon contribution.

Assuming that one can neglect the non-linearities of Regge trajectories and making use of a simple parametrization

$$\alpha(m^2) = \alpha(0) + \alpha'(0) \cdot m^2, \quad (4)$$

we can try to estimate the corresponding spectroscopic content of our model.

Then $\Re\alpha(m^2) = J$, where J is an integer number corresponding to the spin of a particle which we should find lying on the trajectory.

The trajectories are depicted in fig. 6. The $C+$ Reggeon trajectory is in fact a combination of two families of mesons f and a_2 . The $C-$ Reggeon trajectory is a combination of two families of mesons ω and ρ . As is seen, the secondary Reggeon trajectories fairly well describe the spectrum of mesons.

Among the mesons with appropriate quantum numbers there exist two that

fit the Pomeron trajectory (0^+J^{++}): $f_2(1810)$ 0^+2^{++} with mass $m = 1815 \pm 12$ MeV and $X(1900)$ 0^+2^{++} with mass $m = 1926 \pm 12$ MeV . One of them is supposed to be on *Pomeron*₂ trajectory.

Returning to our “polypomeron” hypothesis it is fairly natural to ask what happens if one admits fourth etc Pomeron? Is there some optimum in the number of “relevant” Pomerons above which the quality of description is not improved much? And, finally, what is underlying physics of such a construction? We hope very much to be able to answer at least some of these questions in the nearest future.

ACKNOWLEDGMENTS

One of us A. P. is grateful to the Organizing Committee and to Vojtěch Kunderát personally for the kind invitation and perfectly organized conference. We would like to thank Maurice Giffon for comments, Enrico Predazzi for useful discussions and for critical reading of the manuscript and Munir Islam for fruitful discussions and suggestions improving the presentation.

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