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Elastic diffractive scattering of nucleons at ultra-high energies

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ABSTRACT

A simple Regge-eikonal model with the eikonal represented as a single-reggeon-exchange term is applied to description of the nucleon–nucleon elastic diffractive scattering at ultra-high energies. The range of validity of the proposed approximation is discussed. The model predictions for the proton–proton cross-sections at the collision energy 14 TeV are given.

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1. Introduction

The fraction of the elastic diffractive scattering events in the total number of the *pp* collision events at the collision energy 7–8 TeV is about 25% [1]. At higher energies it is expected to be even higher. Hence, understanding of the physical pattern of the small-angle elastic scattering of hadrons is indispensable for general understanding of the strong interaction at ultra-high energies. However, the special status of diffractive studies at high-energy colliders is determined by the fact that diffraction of hadrons takes place due to interaction at large distances. Indeed, the transverse size of the hadron interaction region can be estimated through straight application of the corresponding Heisenberg uncertainty relation to the experimental elastic angular distributions. For example, at the SPS, Tevatron, and LHC energies it is of order 1 fm. Therefore, exploitation of perturbative QCD for treatment of hadronic diffraction is disabled.

The absence of exact theory leads to the emergence of numerous phenomenological models with very different underlying physics (the references to various models of the nucleon–nucleon elastic diffraction can be found in the mini-review [2]). The coexistence of a large number of rather complicated (and, often, incompatible) models points to the relevance of the question if construction of a much simpler (but adequate) approximation is possible. The word "adequate" in the last sentence implies as the theoretical correctness, so the satisfactory description of the high-energy evolution of the diffractive pattern.

The aim of this work is to demonstrate that a very simple and physically transparent description can be provided in the framework of the well-known Regge-eikonal approach [3] which originates from the synthesis of Regge theory and quasi-potential approximation.

2. A model for high-energy elastic diffraction of nucleons

The Regge-eikonal approach to description of the elastic scattering of hadrons exploits the eikonal representation of the non-flip scattering amplitude,

$$T_{el}(s,t) = 4\pi s \int_0^\infty db^2\, J_0(b\sqrt{-t})\,\frac{e^{2i\delta(s,b)}-1}{2i},$$

$$\delta(s,b) = \frac{1}{16\pi s}\int_0^\infty d(-t)\, J_0(b\sqrt{-t})\,\delta(s,t), \tag{1}$$

where s and t are the Mandelstam variables, b is the impact parameter, and eikonal $\delta(s,t)$ is the sum of single-reggeon-exchange terms:

$$\delta(s,t) = \sum_n \xi\left(\alpha_n^+(t)\right)\Gamma_n^{(1)+}(t)\,\Gamma_n^{(2)+}(t)\left(\frac{s}{s_0}\right)^{\alpha_n^+(t)}$$
$$\mp \sum_n \xi\left(\alpha_n^-(t)\right)\Gamma_n^{(1)-}(t)\,\Gamma_n^{(2)-}(t)\left(\frac{s}{s_0}\right)^{\alpha_n^-(t)}, \tag{2}$$

where $\alpha_n^+(t)$ and $\alpha_n^-(t)$ are the C-even and C-odd meson Regge trajectories, $\Gamma_n^{(i)}(t)$ are the corresponding reggeon form-factors of the colliding particles, $\xi(\alpha(t))$ are the so-called reggeon signature factors, $\xi(\alpha(t)) = i + \mathrm{tg}\frac{\pi(\alpha(t)-1)}{2}$ for even reggeons,[1] $\xi(\alpha(t)) = i - \mathrm{ctg}\frac{\pi(\alpha(t)-1)}{2}$ for odd reggeons, and the sign "−" ("+") before the C-odd reggeon contributions corresponds to the particle–particle (particle–antiparticle) interaction. More detailed discussion

[1] Namely, even (odd) Regge trajectories are the analytic continuations of the corresponding even-spin (odd-spin) resonance spectra.

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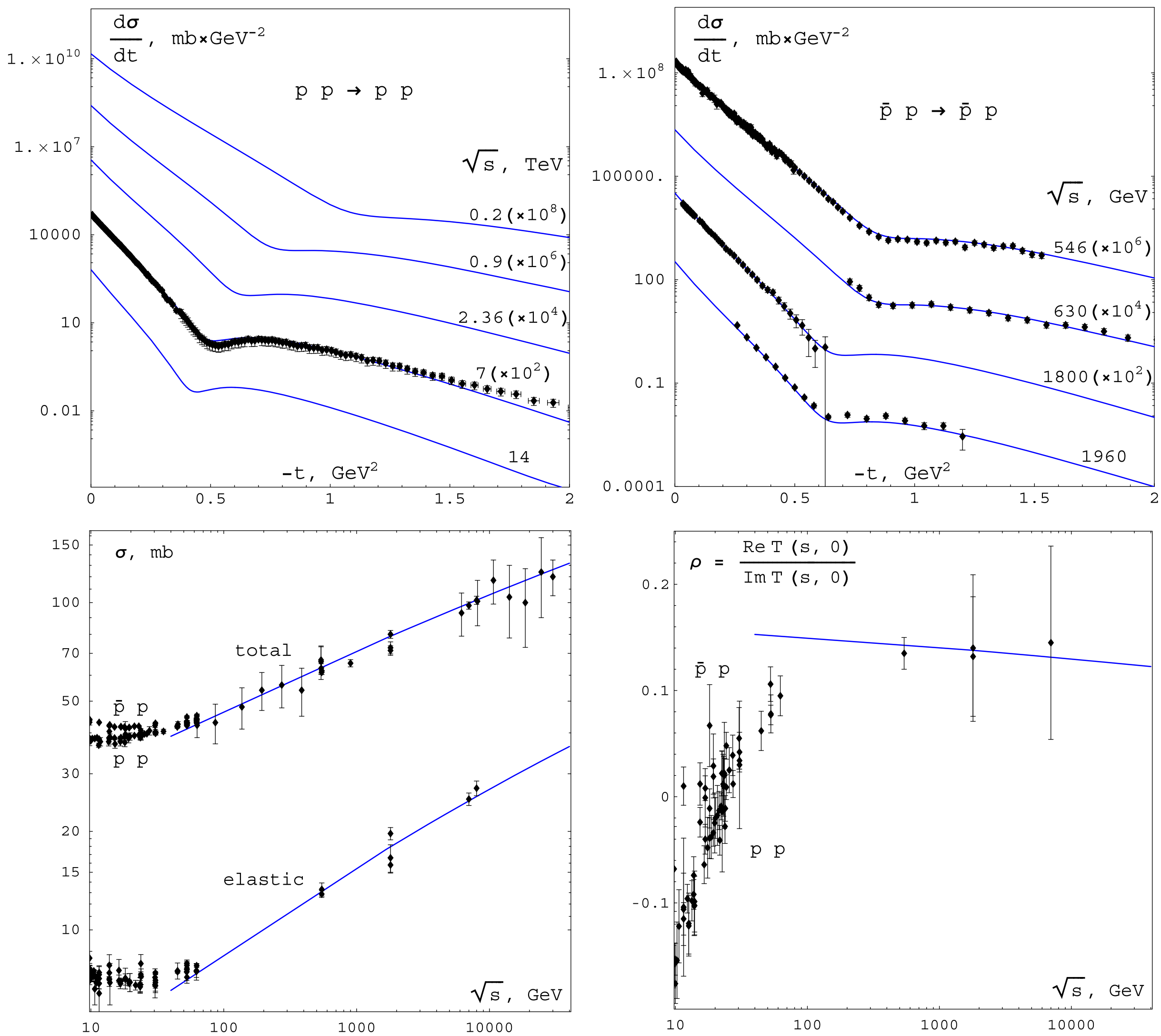

Fig. 1. Description of the nucleon–nucleon elastic diffraction observables at ultra-high values of the collision energy.

of the eikonal Regge approximation can be found in [3] or, for instance, [4]. An important advantage of the Regge-eikonal approach is that it allows to satisfy the Froissart–Martin bound [5] explicitly.

Let us consider the ultimate case of the nucleon–nucleon diffraction at ultra-high energies, where the eikonal can be approximated by the only Regge pole term corresponding to the leading even and C-even reggeon (called “pomeron” or “soft pomeron” in literature):

$$\delta(s,t) = \delta_{\mathrm{P}}(s,t) \equiv \left(i + \mathrm{tg}\frac{\pi(\alpha_{\mathrm{P}}(t)-1)}{2}\right)\Gamma^2_{\mathrm{P}}(t)\left(\frac{s}{s_0}\right)^{\alpha_{\mathrm{P}}(t)}, \qquad (3)$$

where $\alpha_{\mathrm{P}}(t)$ is the Regge trajectory of pomeron and $\Gamma_{\mathrm{P}}(t)$ is the pomeron form-factor of nucleon.

In the current stage of development, QCD provides no useful information about the behavior of $\alpha_{\mathrm{P}}(t)$ and $\Gamma_{\mathrm{P}}(t)$ in the diffraction domain ($0 < -t < 2\ \mathrm{GeV}^2$), though it was argued [6] that $\alpha_{\mathrm{P}}(t) > 1$ at $t < 0$ and

$$\lim_{t\to-\infty}\alpha_{\mathrm{P}}(t) = 1. \qquad (4)$$

Therefore, we will use the simplest test parametrizations[2]

$$\alpha_{\mathrm{P}}(t) = 1 + \frac{\alpha_{\mathrm{P}}(0)-1}{1-\frac{t}{\tau_a}}, \qquad \Gamma_{\mathrm{P}}(t) = \frac{\Gamma_{\mathrm{P}}(0)}{(1-\frac{t}{\tau_g})^2}. \qquad (5)$$

To obtain the angular distribution, one should substitute (5) into (3), then, using representation (1), calculate the scattering amplitude, and, at last, substitute it into the expression for differential cross-section:

$$\frac{d\sigma_{el}}{dt} = \frac{|T_{el}(s,t)|^2}{16\pi s^2}. \qquad (6)$$

To fit the model parameters, we restrict ourselves by the SPS, Tevatron, and LHC energies ($\sqrt{s} > 500$ GeV) and small transfers of momentum ($0.005\ \mathrm{GeV}^2 < -t < 2\ \mathrm{GeV}^2$), since the test parametrization (5) of form-factor $\Gamma_{\mathrm{P}}(t)$ is too stiff and does not allow to provide a satisfactory description of the data in both the diffraction domain and the hard scattering region simultaneously,

[2] One should not consider the analytic properties of parametrizations (5) seriously. True Regge trajectories and reggeon form-factors have much more complicated analytic structure. Nonetheless, at *negative* values of the argument, they can be approximated by simple monotonic test functions.

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