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Asymptotic Properties of Regge Trajectories and Elastic Pseudoscalar-Meson Scattering on Nucleons at High Energies

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Abstract—A phenomenological Regge–eikonal model featuring nonlinear monotonic parametrizations of vacuum Regge trajectories, where their asymptotic behavior in the perturbative sector is taken explicitly into account, is proposed for describing the elastic diffractive scattering of light pseudoscalar mesons on nucleons. In analyzing available experimental data on angular distributions, it is shown that, at collision energies in the region $\sqrt{s} > 13$ GeV, the diffraction pattern of the processes $\pi^{\pm}p \to \pi^{\pm}p$ and $K^{\pm}p \to K^{\pm}p$ at low momentum transfers can be described qualitatively by using the same phenomenological approximations to vacuum Regge trajectories as in the case of nucleon–nucleon scattering. This fact is indicative of the possibility of explicitly relating Regge phenomenology of various hadron–hadron processes to fundamental results obtained within QCD.

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INTRODUCTION

In the present study, we address the question of whether the simplest Regge–eikonal scheme (a general Regge–eikonal approach was developed in [1]), which was earlier used successfully to describe the diffractive pattern of elastic proton scattering on antiprotons [2], is applicable to high-energy elastic diffractive scattering of charged pions and kaons on protons.

The fact that nonlinear parametrizations in which the asymptotic behavior of Regge trajectories in the perturbative sector (that is, at large negative values of the argument) is taken explicitly into account are used as phenomenological approximations to Regge trajectories in the region of small negative values of the argument is a special feature of the proposed approach. Essentially, the behavior of Regge trajectories at high momentum transfers (their trend toward approaching a constant because of renormalization invariance and asymptotic freedom [2]) is of fundamental importance: QCD does not admit linear trajectories. This brings about the question of whether the QCD-inspired nonlinearity of Regge trajectories is compatible with available experimental data. The phenomenological approach that was developed in [2] and which is used in the present study removes this question in part since the approximations within this approach to Regge trajectories in the diffractive-scattering region satisfy explicitly asymptotic relations of QCD, on one hand, and admit a rather smooth matching with Chew–Frautschi curves in the resonance region, on the other hand.

For a detailed discussion on the Regge trajectory problem in the region of diffractive scattering (that is, in the region where perturbation-theory methods are inapplicable), the interested reader is referred to [2]. Here, we restrict ourselves only to briefly exposing basic premises and general relations following from them.

Although the linearity of Regge trajectories at small negative values of the argument is postulated in the modern literature, the results obtained by extracting, within the Born approximation, the ρ Reggeon trajectory from data on the charge-exchange process $\pi^- p \to \pi^0 n$ at high energies [3, 4] (the contribution of the a_2 Reggeon is suppressed because of G-parity conservation) are the only compelling argument in support of this statement (apart from the natural desire to continue Chew–Frautschi curves to the region of scattering). The respective expression is

$$\alpha(t) = 1 + \frac{1}{2}\left(\ln\frac{s_1}{s_2}\right)^{-1} \times \left(\ln\frac{d\sigma}{dt}\bigg|_{s=s_1} - \ln\frac{d\sigma}{dt}\bigg|_{s=s_2}\right). \quad (1)$$

The ρ Reggeon trajectory obtained in this way proves to be linear to a high precision and agrees with the

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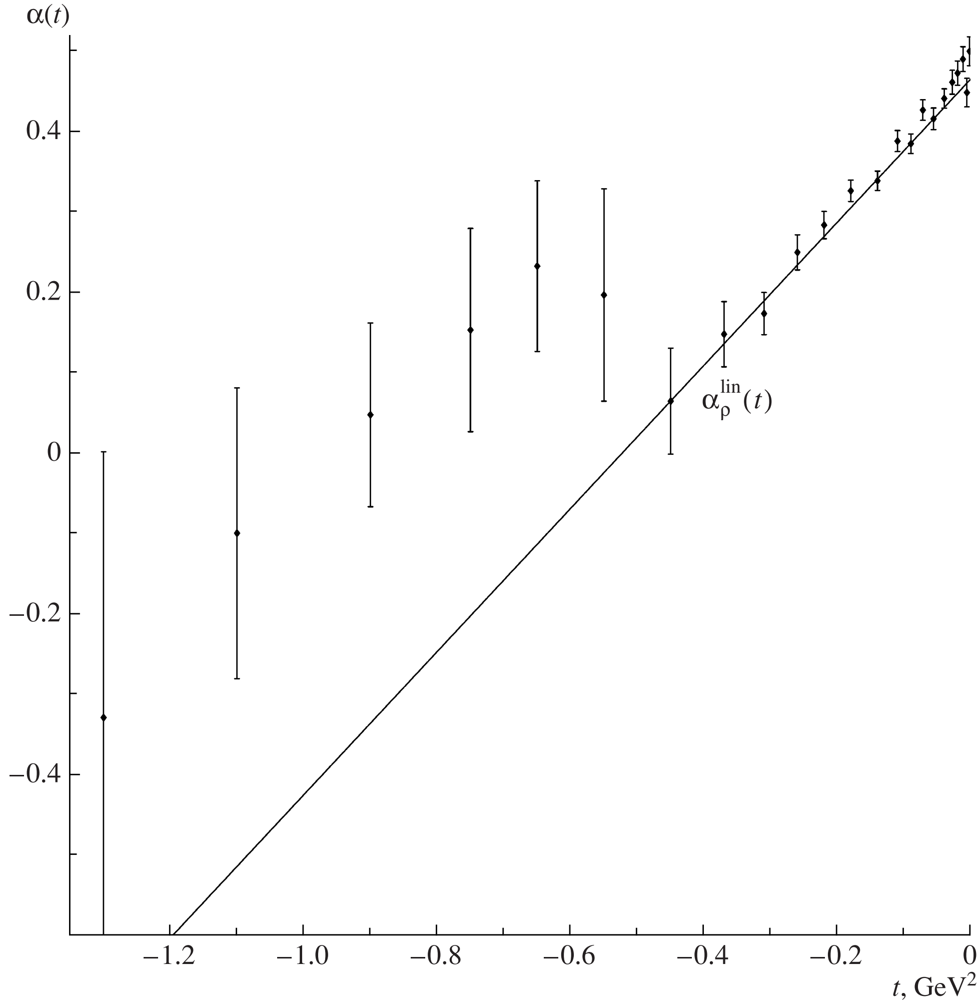

Fig. 1. Effective Regge trajectory extracted by means of expression (1) from experimental angular distributions for pion charge exchange at the collision energies of 19.4 and 8.8 GeV along with the continuation of the Chew–Frautschi curve for the ρ Reggeon, $\alpha_\rho^{\rm lin}(t) = 0.465 + 0.89t$.

continuation of the corresponding Chew–Frautschi curve at low momentum transfers (see Fig. 1). However, no validation of the disregard of the contribution from Regge cuts is given within this approach. But the presence of a diffractive minimum in the angular distributions for the reaction $\pi^- p \to \pi^0 n$ in the region around $-t \sim 0.6$ GeV^2 [3] indicates indirectly that absorptive corrections are operative here. In just the same way as in the case of nucleon–nucleon scattering, this minimum may be explained in terms of the contribution of the Regge cuts. It will be shown below that, in general, the disregard of the cuts is not justified. But upon taking into account absorptive corrections, the very procedure for extracting Regge trajectories from differential cross sections becomes so involved that any results obtained from dealing with available arrays of experimental data are far from unambiguous.

Therefore, approaches that employ linear Regge trajectories[1)] in describing diffractive processes do not have conceptual advantages over approaches relying on nonlinear parametrizations. But in the case where Regge trajectories are approximated by monotonic functions in which the asymptotic behavior of these trajectories is taken explicitly into account, two important advantages over the use of linear parametrizations are achieved:

(i) Difficulties associated with eliminating unphysical singularities in the signature factors that are generated at the points where Regge trajectories take negative integral values are automatically avoided.

[1)]It is noteworthy that linear trajectories naturally arise in the Veneziano model [5] and in some string models, but that the neither the idea of duality [6] nor the string approach [7] forbids a nonlinearity of Regge trajectories in principle.

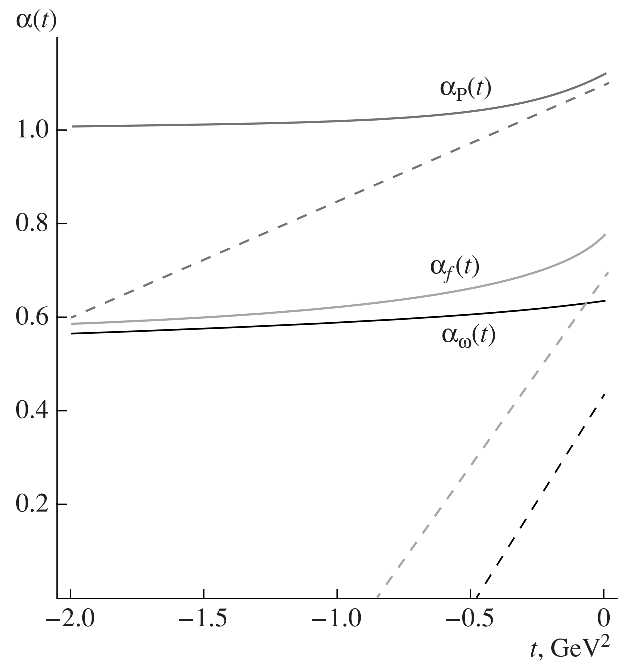

Fig. 2. Approximate Regge trajectories for, respectively, a soft Pomeron and the Reggeons f_2 and ω from an analysis of hadron–hadron scattering. The dashed straight lines $\alpha_f^{\rm lin}(t) = 0.69 + 0.81t$ and $\alpha_\omega^{\rm lin}(t) = 0.44 + 0.92t$ are the continuations of the Chew–Frautschi curves for the Reggeons f_2 and ω, respectively, while the dashed straight line $\alpha_{\rm P}^{\rm lin}(t) = 1.1 + 0.25t$ is the conventional linear approximation to the soft-Pomeron trajectory from the literature.

(ii) The experimentally observed diffractive pattern of elastic nucleon scattering at collision energies in the range 23 GeV $< \sqrt{s} <$ 2 TeV can be reproduced to a rather high degree of precision within the minimal phenomenological scheme by using only three Reggeons [2],[2)] the consistency of the Regge phenomenology of elastic diffractive nucleon scattering on nucleons at ultrahigh energies with the respective results obtained within perturbative QCD thereby being demonstrated explicitly.

Our subsequent argument will rely on the belief that QCD is a fundamental strong-interaction theory. By virtue of asymptotic freedom and the renormalization-invariance property of Regge trajectories, any trajectory tends to a constant in the limit of large negative values of the argument [2]. Moreover, the asymptotic behavior of trajectories that correspond to exchanges of specific color-singlet combinations of partons in the deeply perturbative region can be established in this limit. For example, it was found for trajectories corresponding to exchanges of a quark–antiquark pair in the perturbative sector that [9]

$$\alpha_{\bar{q}q}(t) = \sqrt{\frac{8}{3\pi}\alpha_s(\sqrt{-t})} + o(\alpha_s^{1/2}(\sqrt{-t})), \qquad (2)$$

where $\alpha_s(\mu) \equiv g_s^2(\mu)/(4\pi)$ is the QCD running coupling constant. For trajectories corresponding to multigluon exchanges in the region of asymptotically high momentum transfers, the following limiting relation holds [10]:

$$\lim_{t\to-\infty} \alpha_{gg\ldots g}(t) = 1. \qquad (3)$$

At the present time, all QCD predictions that concern the behavior of leading meson Regge trajectories in the diffractive-scattering region and which are of importance for practical applications are exhausted by relations (2) and (3); therefore, resort to phenomenological schemes is unavoidable in describing diffractive processes. In constructing such schemes, it should be borne in mind that the applicability of relations (2) and (3) in the perturbative sector must be taken into account in any correct phenomenological model that employs the Reggeon approach.

If, in addition, we assume that ${\rm Im}\alpha(t + i0)$ grows rather slowly for $t \to +\infty$ (for example, not faster than $Ct\ln^{-1-\epsilon} t$, $\epsilon > 0$), so that dispersion relations involving not more than one subtraction hold for $\alpha(t)$ on the physical sheet, that is,

$$\alpha(t) = \alpha_0 + \frac{t}{\pi}\int\limits_{t_{\rm T}}^{+\infty} \frac{{\rm Im}\alpha(t' + i0)}{t'(t' - t)}dt',$$

and that ${\rm Im}\alpha(t + i0) \geq 0$ for $t \geq t_{\rm thr}$,[3)] $\alpha(t)$ is bound to be a Herglotz function; that is,

$$\frac{d^n\alpha(t)}{dt^n} > 0 \quad (t < t_{\rm thr}, \quad n = 1, 2, 3, \ldots). \qquad (4)$$

It is usually assumed that relations (4) hold for true Regge trajectories making a leading contribution to the diffractive-scattering amplitude [11]. In phenomenologically describing elastic-diffraction processes at high energies, one can nevertheless employ, as purely quantitative approximations to Regge trajectories in the diffractive-scattering region, not only Herglotz functions but also any functions that are monotonic, together with one or the first few derivatives, and which admit a rather smooth matching with the perturbative sector and with the region of hadron spectroscopy.

[2)] A much greater number of Reggeons are required if use is made of linear approximations to Regge trajectories (see, for example, [8]).

[3)] It should be noted that, in general, these conditions are not rigorously proven, even though they are satisfied in potential-scattering theory and in perturbation theory [11].

The aforementioned constraints on the functional form of Regge trajectories make it possible to reproduce the experimentally the observed diffractive pattern of elastic nucleon scattering within the minimal phenomenological model by using only three Reggeons characterized by vacuum quantum numbers [2]. Below, we will show that a similar scheme involving the same approximations to vacuum Regge trajectories (in perfect agreement with the requirement that the trajectories in question be universal) also makes it possible to describe qualitatively available data on the elastic diffractive scattering of charged pions and kaons on protons at collision energies in the region $\sqrt{s} > 13$ GeV, whereby we demonstrate that there is a direct possibility of relating Reggeon phenomenology of various diffractive processes to the results of perturbative QCD via phenomenologically approximating, in the diffraction (nonperturbative) region, Regge trajectories by nonlinear functions satisfying explicitly the asymptotic relations (2) and (3), which follow from QCD.

PARAMETRIZATION OF THE MINIMAL EIKONAL

In general, the minimal eikonal (Born term) for elastic scattering at energies in the region $\sqrt{s} >$ 13 GeV has the form ($s_0 \equiv 1$ GeV^2)

$$\delta(s,t) = \delta_{\rm P}(s,t) + \sum_{\rm R} \delta_{\rm R}(s,t) \quad (5)$$

$$= \left(i + \tan\frac{\pi(\alpha_{\rm P}(t)-1)}{2}\right)\beta_{\rm P}(t)\left(\frac{s}{s_0}\right)^{\alpha_{\rm P}(t)}$$

$$+ \left(i + \tan\frac{\pi(\alpha_f(t)-1)}{2}\right)\beta_f(t)\left(\frac{s}{s_0}\right)^{\alpha_f(t)}$$

$$\mp \left(i - \cot\frac{\pi(\alpha_\omega(t)-1)}{2}\right)\beta_\omega(t)\left(\frac{s}{s_0}\right)^{\alpha_\omega(t)}$$

$$+ \left(i + \tan\frac{\pi(\alpha_a(t)-1)}{2}\right)\beta_a(t)\left(\frac{s}{s_0}\right)^{\alpha_a(t)}$$

$$\mp \left(i - \cot\frac{\pi(\alpha_\rho(t)-1)}{2}\right)\beta_\rho(t)\left(\frac{s}{s_0}\right)^{\alpha_\rho(t)}$$

(the contribution of the Reggeons f_2' and ϕ can be disregarded at such energies), where $\alpha_{\rm P}(t)$ and $\alpha_{\rm R}(t)$ are the trajectories of, respectively, the Pomeron and secondary Reggeons; $\beta_{\rm P}(t)$ and $\beta_{\rm R}(t)$ are the corresponding Regge poles; and the minus (plus) sign in front of the C-odd contributions are associated with particle scattering on a particle (an antiparticle).

It should be noted that, because of G-parity conservation, the effective interaction of pions with the Reggeons ω and a_2 is suppressed in residue in relation to their interaction with the ρ Reggeon (the two-pion decay width of the $\omega(782)$ meson is 1/1000 as large as its counterpart for the $\rho(770)$ meson). Therefore, we can disregard the contribution of ω and a_2 to the eikonal of pion–proton scattering. We also note that, at high collision energies and small scattering angles, the splitting of the angular distributions in the processes $\pi^\pm p \to \pi^\pm p$, which is determined by the ρ-Reggeon contribution, is quite a subtle effect in relation to the diffractive-scattering phenomenon itself (in particular, the inequality

$$\frac{\sigma_{\rm tot}^{\pi^- p}(s) - \sigma_{\rm tot}^{\pi^+ p}(s)}{\sigma_{\rm tot}^{\pi^- p}(s) + \sigma_{\rm tot}^{\pi^+ p}(s)} < 0.02$$

holds in the region $\sqrt{s} > 13$ GeV, and we will show below that the ρ-Reggeon contribution is commensurate with the error in measuring angular distributions). In qualitatively estimating differential cross sections, we can therefore disregard the ρ-Reggeon contribution to the eikonal, even though we then lose the possibility of describing the aforementioned effect of the splitting of cross sections.[4)]

For charged-kaon scattering on protons, we cannot propose similar arguments simplifying the physical pattern of the phenomenon (in just the same way as in the case of nucleon–nucleon scattering, G-parity conservation does not provide sufficient grounds for a priori disregarding the contributions of individual Reggeons, and the relative splitting of total cross sections at the collision energy of 13 GeV is about 9%). But since the accuracy in measuring angular distributions for elastic scattering is much poorer in this case than in the case of pion–proton scattering, the elastic diffractive scattering of charged kaons on protons is described here in a rough approximation that ignores the contributions of the Reggeons a_2 and ρ (as will be seen below, this approximations is justified to some extent from the point of view of a purely quantitative description).

4) Also, the application of so rough an approximation is partly motivated by the fact that the ρ-Reggeon contribution to the elastic-scattering eikonal must be taken into account in simultaneously considering the processes $\pi^\pm p \to \pi^\pm p$ and $\pi^- p \to \pi^0 n$. But a consistent description of the reaction $\pi^- p \to \pi^0 n$ is impossible without substantially complicating the corresponding phenomenological scheme via introducing the polarization structure of the scattering amplitude (in the region $\sqrt{s} < 9$ GeV, the spin-flip ρ-Reggeon-exchange amplitude is several times as great as the respective non-spin-flip amplitude [12]); at the same time, experimental data on spin effects in the process $\pi^- p \to \pi^0 n$ at higher energies are not available, which complicates the verification of models that describe polarization effects in pion–nucleon charge-exchange processes in the region $\sqrt{s} > 13$ GeV.

Table 1. Fitted values of free phenomenological parameters

Parameter	$\pi^{\pm}p \to \pi^{\pm}p$	$K^{\pm}p \to K^{\pm}p$
$B_{\rm P}$	26.7	24
$b_{\rm P}$ [GeV^{-2}]	2.36	1.86
d_1 [GeV^{-2}]	0.38	0.39
d_2 [GeV^{-4}]	0.30	0.18
d_3 [GeV^{-6}]	−0.078	−0.044
d_4 [GeV^{-8}]	0.04	0
B_f	67	43
b_f [GeV^{-2}]	1.88	2.5
B_ω		15.6
b_ω [GeV^{-2}]		4.9

Table 2. Quality of the description of experimental angular distributions in the region $0 < -t < 2.5$ GeV^2

Data array		Number of points	χ^2
$p_{\rm lab}$, GeV	process		
100	$\pi^-p \to \pi^-p$	172	1159
200	$\pi^-p \to \pi^-p$	276	695
250	$\pi^-p \to \pi^-p$	59	84
300	$\pi^-p \to \pi^-p$	59	108
345	$\pi^-p \to \pi^-p$	57	75
100	$\pi^+p \to \pi^+p$	100	224
200	$\pi^+p \to \pi^+p$	202	705
250	$\pi^+p \to \pi^+p$	18	19
In all		943	3069
100	$K^-p \to K^-p$	78	128
200	$K^-p \to K^-p$	25	22
100	$K^+p \to K^+p$	64	80
200	$K^+p \to K^+p$	35	40
250	$K^+p \to K^+p$	18	25
In all		220	295

Since Regge trajectories possess the universality property—that is, they are independent of which processes contribute to corresponding Reggeons, we will perform a phenomenological analysis of pion—proton and kaon—proton scattering, employing the same approximations to vacuum Regge trajectories as in the case of nucleon—nucleon scattering [2] (among similar attempts at simultaneously describing data on different diffractive processes within the same phenomenological scheme, those made in [13, 14] are noteworthy); that is,

$$\alpha_{\rm P}(t) = 1 + p_1\left[1 - p_2 t\left(\arctan(p_3 - p_2 t) - \frac{\pi}{2}\right)\right], \tag{6}$$

$$\alpha_{\rm R}(t) = \left(\frac{8}{3\pi}\gamma(\sqrt{-t+c_{\rm R}})\right)^{1/2},$$

where

$$\gamma(\mu) \equiv \frac{4\pi}{11-\frac{2}{3}n_{\rm f}}\left(\frac{1}{\ln\frac{\mu^2}{\Lambda^2}} + \frac{1}{1-\frac{\mu^2}{\Lambda^2}}\right)$$

is the so-called one-loop QCD analytic running coupling constant [15]; $n_{\rm f} = 3$ is the number of quark flavors that were taken into account; $\Lambda = \Lambda^{(3)} = 0.346$ GeV is the QCD dimensional parameter (its value was borrowed from [16]); and $p_1 = 0.123$, $p_2 = 1.58$ GeV^{-2}, $p_3 = 0.15$, $c_f = 0.1$ GeV^2, and $c_\omega = 0.9$ GeV^2 are phenomenological parameters, whose values were fitted to angular distributions for proton—(anti)proton scattering [2] (see Fig. 2).

We note that our approximations to secondary Regge trajectories explicitly satisfy the asymptotic relation (2) and that the approximation to the Pomeron trajectory explicitly satisfies relation (3), since our choice of parametrization for $\alpha_{\rm P}(t)$ relies on the assumption that, in the perturbative sector, Pomeron exchange goes over to gluon exchange. But in the case where quark—antiquark pairs are present in the parton combinations corresponding to Pomeron exchange [4], the asymptotic condition $\lim\limits_{t\to-\infty}\alpha_{\rm P}(t) = 1$ does not hold. As was shown in [2] for proton—(anti)proton scattering and as will be shown below for the scattering of light pseudoscalar mesons on protons, our parametrization of $\alpha_{\rm P}(t)$ is nevertheless quite successful from the point of view of a qualitative description of angular distributions at moderately small values of the momentum transfer. This fact does not suggest the adequacy of the parametrization under consideration in the perturbative sector; it only indicates that our phenomenological approximation to the Pomeron trajectory in the nonperturbative region exhibits some kind of qualitative compliance with the results of perturbative QCD.

We choose a parametrization for residues in the form

$$\beta_{\rm P}(t) = B_{\rm P}e^{b_{\rm P}t}(1 + d_1 t + d_2 t^2 + d_3 t^3 + d_4 t^4), \tag{7}$$
$$\beta_f(t) = B_f e^{b_f t}, \quad \beta_\omega(t) = B_\omega e^{b_\omega t}.$$

In order to obtain angular distributions, we substitute expressions (6) and (7) into (5) and go over to

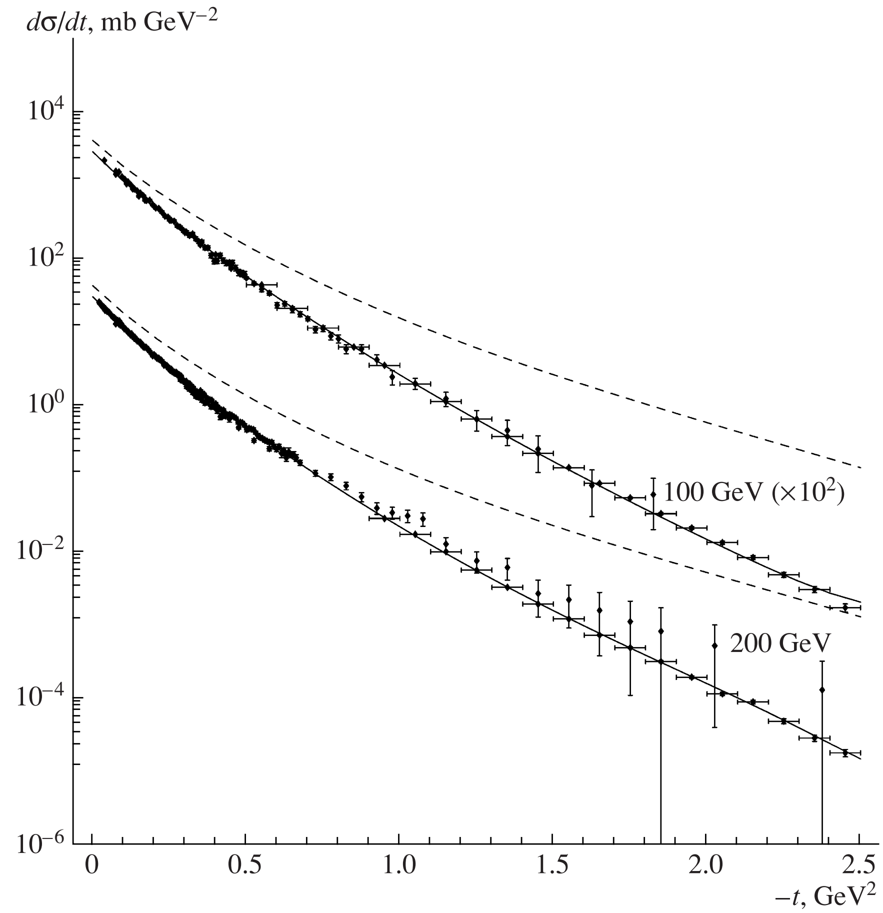

Fig. 3. Angular distributions for the process $\pi^- p \to \pi^- p$ at various values of the incident-pion momentum. The dashed curves correspond to differential cross sections in the Born approximation.

the coordinate representation via the Fourier–Bessel transformation

$$\delta(s,b) = \frac{1}{16\pi s}\int\limits_0^\infty d(-t)J_0(b\sqrt{-t})\delta(s,t). \quad (8)$$

Further, we take the elastic-scattering amplitude in the eikonal-representation form

$$T(s,b) = \frac{e^{2i\delta(s,b)}-1}{2i} \quad (9)$$

and apply the inverse Fourier–Bessel transformation

$$T(s,t) = 4\pi s\int\limits_0^\infty db^2 J_0(b\sqrt{-t})T(s,b) \quad (10)$$

to obtain this amplitude in the momentum representation [in numerically calculating the integrals in (8) and (10), we replaced the upper limits of integration by 4 GeV^2 and 400 $\mathrm{GeV}^{-2} \approx (4\ \mathrm{fm})^2$, respectively], whereupon we substitute it into the following expression for the differential cross section for scattering:

$$\frac{d\sigma}{dt} = \frac{|T(s,t)|^2}{16\pi s^2}. \quad (11)$$

To conclude this section, we emphasize that the parametrizations that we use for Regge trajectories and residues at the Regge poles are purely phenomenological approximations that ensure only a qualitative description of experimental data. Only relations (2)–(4) are physically meaningful.

DESCRIPTION OF EXPERIMENTAL DATA

Let us now address the problem of describing the diffractive scattering of pseudoscalar mesons on protons at high energies. The results obtained upon fitting the free parameters to angular distributions in the processes $\pi^\pm p \to \pi^\pm p$ and $K^\pm p \to K^\pm p$ over the kinematical region specified by the inequalities $\sqrt{s} >$ 13 GeV and $-t < 2.5$ GeV^2 [17] (in order to calculate the scattering amplitude in the region of interference with the Coulomb potential, we made use of the recipe

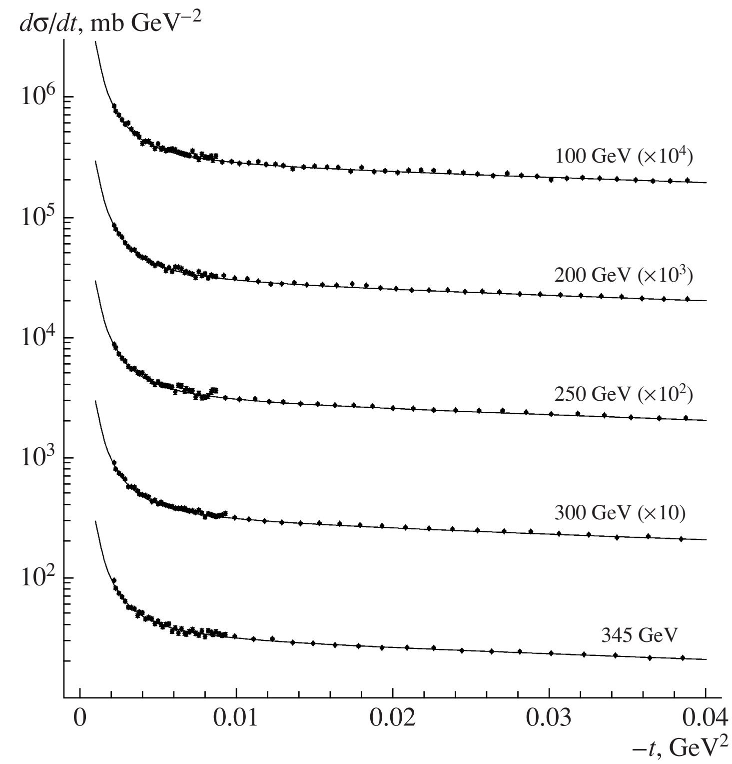

Fig. 4. Differential cross sections for the process $\pi^- p \to \pi^- p$ in the Coulomb interaction region at various values of the incident-pion momentum.

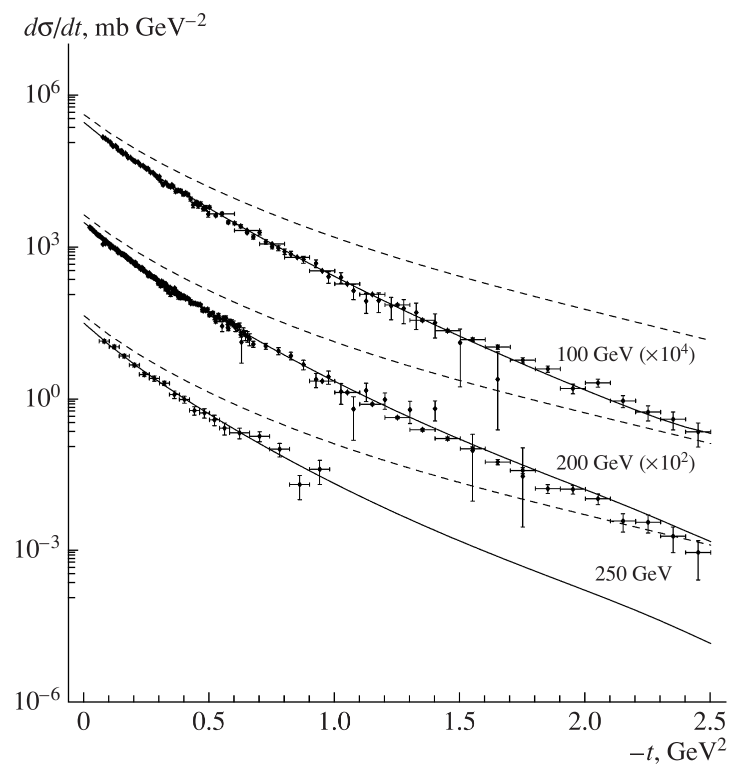

Fig. 5. Angular distributions for the process $\pi^+ p \to \pi^+ p$ at various values of the incident-pion momentum. The dashed curves correspond to differential cross sections in the Born approximation.

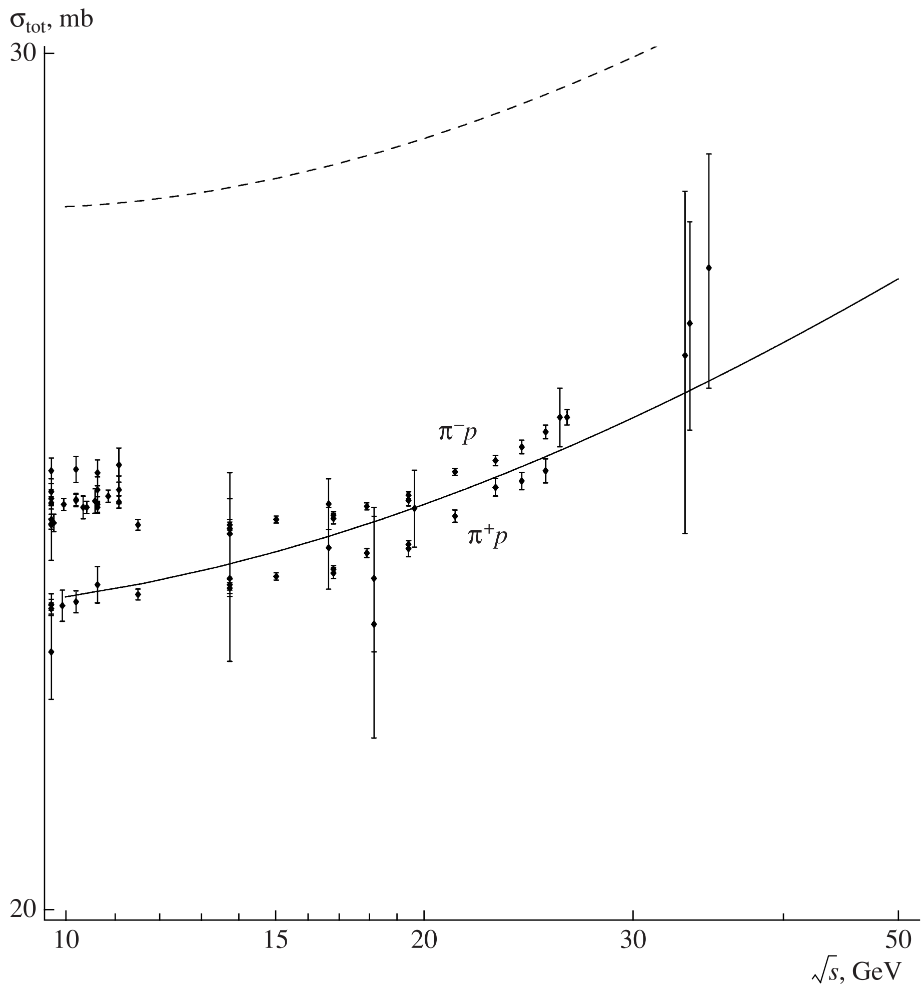

Fig. 6. Total cross section for pion–proton scattering as a function of the collision energy (the displayed experimental data were borrowed from the Particle Physics Data System database at http://wwwppds.ihep.su:8001/ppds.html). The dashed curve corresponds to the imaginary part of the Born amplitude (eikonal).

proposed in [18]—see also [19]) are illustrated in Tables 1 and 2 and in Figs. 3–9. The dashed curves in the figures correspond to the scattering amplitudes calculated in the Born approximation. Thus, the contribution of Regge cuts proves to be so important (for all processes considered here, it is several times as great as the total contribution of C-odd Reggeons) that attempts at describing experimental data without taking into account absorptive corrections are meaningless.

Large values of χ^2 in describing elastic pion scattering on protons are due primarily to employing, in the procedure for fitting the free parameters, all available experimental data from [17] in the kinematical regions indicated in Table 2, including contradictory data. Because of the smallness of the ρ-Reggeon contribution, which is commensurate with the measurement error, the quality of the description of the differential cross sections for pion–proton scattering within our approach is quite sufficient at momentum transfers in the range $0 < -t < 1.5$ GeV^2 for confirming such a macroscopic effect as the QCD-motivated strong nonlinearity of Regge trajectories in the diffractive-scattering region.

In considering the elastic diffractive processes $\pi^{\pm}p \to \pi^{\pm}p$ and $K^{\pm}p \to K^{\pm}p$, we restricted ourselves to the region $\sqrt{s} > 13$ GeV for the reason that, at lower energies, the minimal phenomenological scheme applied here is inadequate since effects associated with the contributions of the Reggeons ρ and f_2' for pion–proton scattering and the contributions of the Reggeons ρ, a_2, ϕ, and f_2' for kaon–proton scattering become overly strong (their total relative contribution to the eikonal may amount to several percent), and their disregard impairs substantially the quality of the description of data.

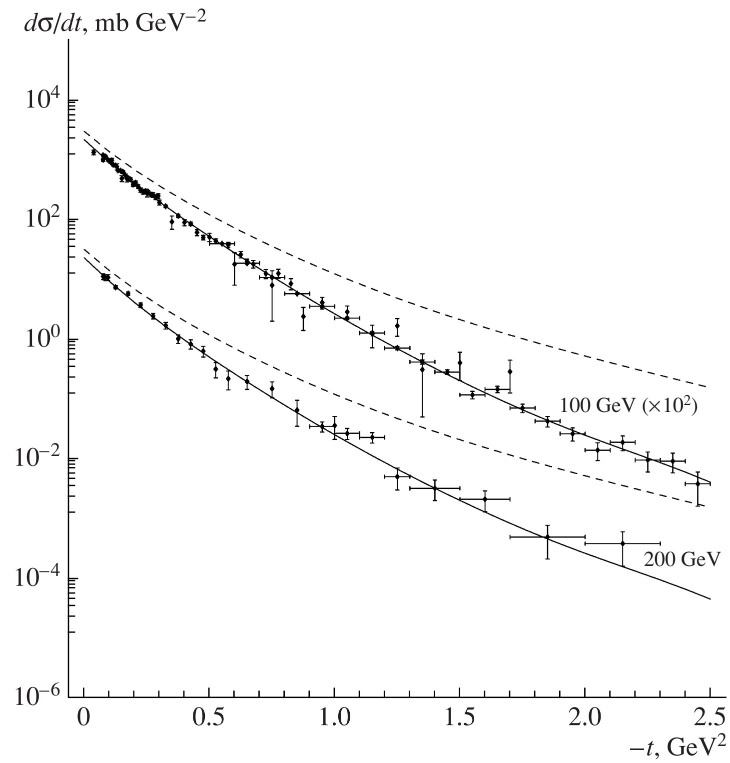

Fig. 7. Angular distributions for the process $K^-p \to K^-p$ at various values of the incident-kaon momentum. The dashed curves correspond to differential cross sections in the Born approximation.

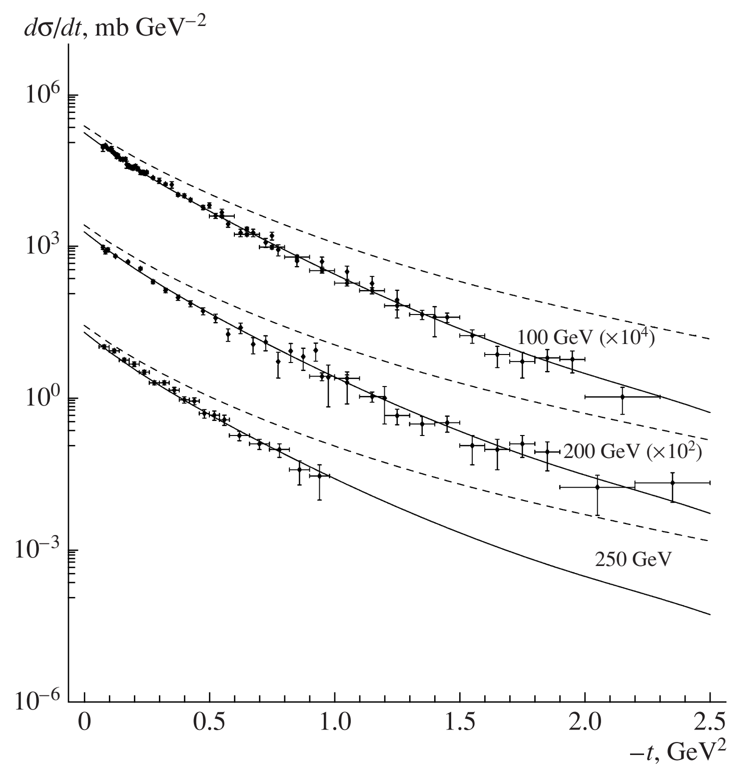

Fig. 8. Angular distributions for the process $K^+p \to K^+p$ at various values of the incident-kaon momentum. The dashed curves correspond to differential cross sections in the Born approximation.

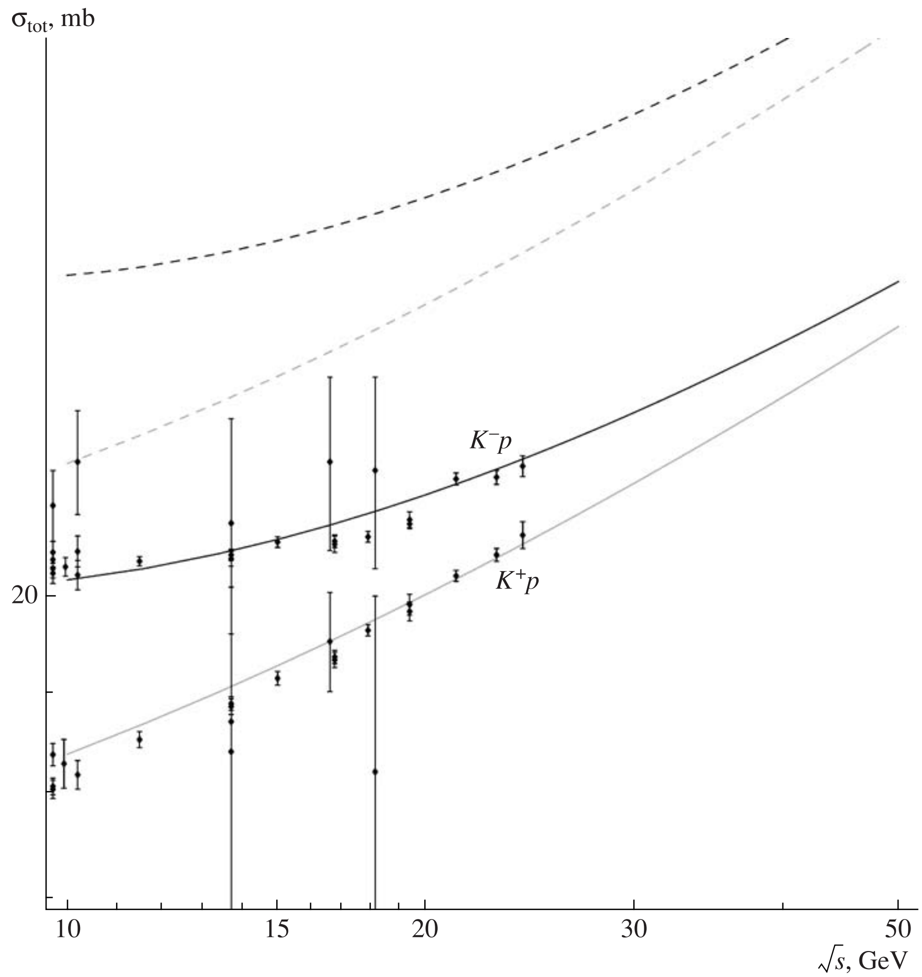

Fig. 9. Total cross section for kaon–proton scattering as a function of the collision energy (the displayed experimental data were borrowed from the Particle Physics Data System database at http://wwwppds.ihep.su:8001/ppds.html). The dashed curves correspond to imaginary parts of Born amplitudes (eikonals).

CONCLUSIONS

In summary, we indicate once again that, in describing the elastic diffractive scattering of light pseudoscalar mesons on protons, we have used the same approximations to vacuum Regge trajectories as in the case of proton–(anti)proton scattering. We emphasize that a substantial nonlinearity of respective functions is indicative of the compliance of the Regge phenomenology of diffractive processes with the results obtained on the basis of QCD. Of course, our phenomenological analysis as such does not rigorously prove a substantial nonlinearity of fundamental Regge trajectories in the diffractive-scattering region, since general principles do not forbid a nonmonotonic behavior of Regge trajectories at negative values of the argument. Yet, all known models featuring linear trajectories and describing experimental data more or less successfully have a much more complicated Reggeon structure, this, together with fundamental QCD relations, favoring the nonlinearity hypothesis. But the use of nonlinear Regge trajectories in the present study has made it possible to provide a simultaneous qualitative description of the diffraction pattern for various processes of hadron–hadron scattering within a unified minimal phenomenological scheme that has a transparent physical meaning and which involves only those Regge trajectories whose contributions are significant beyond any doubt.

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REFERENCES

1. R. C. Arnold, Phys. Rev. **153**, 1523 (1967).
2. A. A. Godizov and V. A. Petrov, J. High Energy Phys. **0707**, 083 (2007).

3. A. V. Barnes et al., Phys. Rev. Lett. **37**, 76 (1976).
4. A. B. Kaidalov, hep-ph/0612358.
5. A. B. Kaĭdalov, Usp. Fiz. Nauk **105**, 97 (1971) [Sov. Phys. Usp. **14**, 600 (1971)].
6. A. I. Bugrij et al., Fortschr. Phys. **21**, 427 (1973).
7. A. E. Inopin, hep-ph/0110160.
8. P. Desgrolard, M. Giffon, and E. Martynov, Eur. Phys. J. C **18**, 359 (2000); V. A. Petrov and A. V. Prokudin, Eur. Phys. J. C **23**, 135 (2002); E. Martynov, hep-ph/0703248.
9. J. Kwiecinski, Phys. Rev. D **26**, 3293 (1982); S. J. Brodsky, W.-K. Tang, and C. B. Thorn, Phys. Lett. B **318**, 203 (1993); R. Kirschner, Z. Phys. C **67**, 459 (1995).
10. H. Cheng and T. T. Wu, Phys. Rev. Lett. **22**, 666 (1969); F. E. Low, Phys. Rev. D **12**, 163 (1975); S. Nussinov, Phys. Rev. D **14**, 246 (1976); P. D. B. Collins and P. J. Kearney, Z. Phys. C **22**, 277 (1984); R. Kirschner and L. N. Lipatov, Z. Phys. C **45**, 477 (1990).
11. P. D. B. Collins and E. J. Squires, *Regge Poles in Particle Physics* (Springer-Verlag, Berlin, 1968; Mir, Moscow, 1971), p. 97.
12. K. G. Boreskov et al., Yad. Fiz. **14**, 814 (1971) [Sov. J. Nucl. Phys. **14**, 457 (1972)]; L. S. Zolin et al., Usp. Fiz. Nauk **117**, 119 (1975) [Sov. Phys. Usp. **18**, 712 (1975)].
13. C. Bourrely, J. Soffer, and T. T. Wu, Eur. Phys. J. C **28**, 97 (2003).
14. J. R. Cudell, A. Lengyel, and E. Martynov, Phys. Rev. D **73**, 034008 (2006).
15. D. V. Shirkov and I. L. Solovtsov, Phys. Rev. Lett. **79**, 1209 (1997).
16. S. Bethke, J. Phys. G **26**, R27 (2000).
17. http://durpdg.dur.ac.uk/hepdata/reac.html; C. W. Akerlof et al., Phys. Rev. D **14**, 2864 (1976); D. S. Ayres et al., Phys. Rev. D **15**, 3105 (1977); R. Rubinstein et al., Phys. Rev. D **30**, 1413 (1984); A. Schiz et al., Phys. Rev. D **24**, 26 (1981); J. P. Burq et al., Nucl. Phys. B **217**, 285 (1983); M. Adamus et al., Phys. Lett. B **186**, 223 (1987).
18. R. Cahn, Z. Phys. C **15**, 253 (1982).
19. V. A. Petrov, E. Predazzi, and A. Prokudin, Eur. Phys. J. C **28**, 525 (2003).

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