Universality of preasymptotics in hadron and photon diffraction

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We note that it is premature to make a conclusion on the multiplicity of the Pomerons on the basis of the available experimental data since the interactions have a preasymptotic nature. [S0556-2821(97)03811-3]

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The straightforward interpretation of the recent data from the DESY *ep* collider HERA on the deep-inelastic scattering together with the analysis of the data on hadron-hadron scattering in terms of the Regge model could lead to the unexpected conclusion on the existence of the various Pomerons [1] or the various manifestations of the unique Pomeron in the different processes depending on the typical scale of the process [2]. The approaches [3,4] contending the dominance of the soft Pomeron do not rule out existence of the hard Pomeron either.

Indeed, soft hadronic reactions imply that the Pomeron's intercept $\alpha_{\mathcal{P}}=1.08$ [1], small-x dependence of the structure function $F_2(x,Q^2)$ leads to $\alpha_{\mathcal{P}}=1.4$–1.5 [5,6] and the measurements of the diffractive cross section in the deep-inelastic scattering provide $\alpha_{\mathcal{P}}=1.23$ [7]. So, does this mean that we have few Pomerons or we have few different manifestations of the same Pomeron depending on the particular process? Probably both options are not to be considered as the firm ones, since the experimental data used for these statements were obtained at not high enough energies where, in fact, the preasymptotic regime of interactions does take place. The above conclusions are based on the presumed dominance of the Pomeron contribution already in the preasymptotic energy region and do not take into account the unitarity effects which become very essential as one goes beyond this region. What is called a Pomeron is to be interpreted as a true asymptotical contribution of the driving mechanism.

In this Brief Report we argue that all the three classes of the processes described above are related to the similar mechanisms and the corresponding energy dependence of the cross sections can be well described by the universal functional energy dependence of the type $a+b\sqrt{s}$. Such dependence is valid for the preasymptotic energy region only and beyond this region unitarity changes the picture drastically. We consider for illustration the unitarized chiral quark model [8].

In this model the elastic scattering amplitude in the impact parameter representation has the form

$$F(s,b)=U(s,b)[1-iU(s,b)]^{-1}, \tag{1}$$

where $U(s,b)$ is the generalized reaction matrix which in the case of a pure imaginary amplitude is

$$U(s,b)=ig(N-1)^N[1+\alpha\sqrt{s}/\langle m_Q\rangle]^N\exp(-\widetilde{M}b). \tag{2}$$

In Eq. (2) $g>0$, N is the total number of the constituent quarks in the colliding hadrons, $\widetilde{M}=\Sigma_{Q=1}^{N}m_Q/\xi$, and b is the impact parameter of the colliding hadrons [8]. The parameter ξ is related in the model with the geometric radius of the constituent quark Q due to relation $r_Q=\xi/m_Q$ and does not depend on the quark flavor. Fit to the total hp cross sections gives small values for the parameters g and α ($g,\alpha\ll 1$) [9]. It means that at $s\ll s_0$, the second term in the square brackets in Eqs. (1) and (2) is small and we can expand over it. The numerical value of s_0 is determined by the equation $|U(s,0)|=1$ and is [9]

$$\sqrt{s_0}\simeq 2\ \text{TeV}.$$

At this energy the amplitude has the value $|F(s_0,0)|=1/2$. Note that $|U(s,0)|=1/2$ at $\sqrt{s}\simeq 1.2$ TeV. The value of s_0 is on the verge of the preasymptotic energy region, i.e., the energy reached at the Fermilab Tevatron is at the beginning of the road to the asymptotics. Evidently, the HERA energy range $W(=\sqrt{s_{\gamma p}})\leqslant 300$ GeV is in a preasymptotic domain.

The above model gives the linear with $\sqrt{s}$ dependence for the total cross sections according to Eqs. (1) and (2):

$$\sigma_{\mathrm{tot}}^{hp,\gamma p}=a+b\sqrt{s}, \tag{3}$$

where parameters a and b are different for different processes. It was shown [9] that this dependence is in a good agreement with the experimental data.

The same dependence for the total cross section of $\gamma^* p$ scattering is implied by the small-x behavior of the structure function $F_2(x,Q^2)$ observed experimentally [5,6] and obtained in the model [10]:

$$F_2(x,Q^2)=a(Q^2)+b(Q^2)/\sqrt{x}. \tag{4}$$

The experimental data indicate the critical behavior of the function $b(Q^2)$ at $Q^2\simeq 1$ (GeV/c)^2.

The third value for the Pomeron intercept $\alpha_{\mathcal{P}}=1.23$ has been obtained from the analysis of the experimental data on the diffractive cross section in deep-inelastic scattering [7] where the dependence of $d\sigma^{\mathrm{diff}}_{\gamma^* p\to XN}/dM_X^2$ on W was parametrized according to the Regge model and the Pomeron dominance has been assumed:

$$d\sigma^{\mathrm{diff}}_{\gamma^* p\to XN}/dM_X^2\propto (W^2)^{2\alpha_{\mathcal{P}}-2}. \tag{5}$$

The data demontrate a linear rise of the differential cross section $d\sigma^{\mathrm{diff}}_{\gamma^* p\to XN}/dM_X^2$ with W, i.e., we observe here just

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the same functional dependence on the c.m. system (c.m.s.) energy as it was observed for $\sigma_{\rm tot}^{hp,\gamma p,\gamma^* p}$. Regarding the preasymptotic nature of the interaction mode we arrive to the universal c.m.s. energy dependence in the framework of the model used above.

Indeed, in the framework of this model the hadron inelastic diffractive cross section is given by the expression [11]

$$\frac{d\sigma^{\rm diff}_{hp\to XN}}{dM_X^2}\simeq\frac{8\pi g^*\xi^2}{M_X^2}\,\eta(s,0), \tag{6}$$

where

$$\eta(s,b)=\ {\rm Im}U(s,b)/[1-iU(s,b)]^2$$

is the inelastic overlap function.

At the preasymptotic energies $s\ll s_0$, the energy dependence of inelastic diffractive cross section resulting from Eq. (2) is determined by the generic form

$$\frac{d\sigma^{\rm diff}_{hp\to XN}}{dM_X^2}\propto a+b\sqrt{s}. \tag{7}$$

Inelastic diffractive cross section for the $\gamma^* p$ interactions can be obtained using, for example, vector meson dominance (VMD) model, i.e.,

$$\frac{d\sigma^{\rm diff}_{\gamma^* p\to XN}}{dM_X^2}\propto a(Q^2)+b(Q^2)W. \tag{8}$$

The same functional dependence can be obtained using the ‘‘aligned jet’’ model [12] along with the unitarized chiral quark model [8].

It should be noted here that the above linear dependences for the cross sections of different processes are the generic features associated with the preasymptotic nature of the interaction dynamics at $s\ll s_0$. As one goes above this energy range the function $|U(s,b)|$ is rising and when $|U(s,0)|\gg 1$ the unitarity starts to play the major role and provides the $\ln^2 s$ rise of the total cross sections at $s\gg s_0$ [8] and also the following behavior of the structure function $F_2(x,Q^2)$:

$$F_2(x,Q^2)\propto\ln^2(1/x) \tag{9}$$

at $x\to 0$ [10]. At the same time unitarity leads to the decreasing dependence of the inelastic diffractive cross section at $s\to\infty$:

$$\frac{d\sigma^{\rm diff}}{dM_X^2}\propto\left(\frac{1}{\sqrt{s}}\right)^N \tag{10}$$

for the hp, γp, and $\gamma^* p$ processes [11]. Such behavior is associated with the antishadow scattering mode which develops at small impact parameters at $s>s_0$.

Thus, we might expect the different asymptotic and universal preasymptotic behaviors for the different classes of the diffraction processes.

To summarize, we would like to emphasize that the unified description of the processes of hp, γp, and $\gamma^* p$ diffraction scattering with the universal cross-section dependence on the c.m.s. interaction energy is possible. For the illustration we used the unitarized chiral quark model which has a nonperturbative origin and leads to the linear c.m.s. energy dependence of the cross sections in the preasymptotic energy region for the above processes. Universality of such preasymptotic behavior agrees with the experiment.

The assumption on the existence of the different Pomerons results from the use of the asymptotic formulas in the preasymptotic energy region and the neglect of the unitarity effects at higher energies beyond this preasymptotic region. It should be taken with certain caution.

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