Some Problems of Diffraction at High Energies

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Abstract

An interplay of perturbative and nonperturbative effects in pomeron, odderon and reggeons dynamics is discussed. It is pointed out that experimental data on pion charge exchange reaction at high energies indicate to a dominance of the nonperturbative string-like dynamics up to rather large momentum transfer. Role of shadowing effects related to triple - pomeron interactions is investigated.

1 Perturbative versus nonperturbative dynamics for pomeron, odderon and reggeons

Interactions of hadrons at high energies and of virtual photons at small Bjorken–x are usually described in terms of reggeon exchanges. For total cross sections and diffractive processes the pomeron exchange plays the dominant role. It has the vacuum quantum numbers: signature $\sigma = +$, parity $P = +$ and C–parity=$+$. In QCD the pomeron is usually related to gluonic exchanges in the t–channel. In this talk I shall discuss the dynamical origin of the pomeron in QCD and a relative role of perturbative and nonperturbative effects.

Perturbative QCD in the leading logarithmic approximation leads to the pomeron singularity with an intercept above unity, which corresponds to summation of a ladder-type diagrams with exchanges of reggeized gluons $[1]$ – BFKL pomeron. An increase with energy of total cross sections is determined by the value of $\Delta \equiv \alpha_P(0) - 1$: $\sigma^{tot} \sim s^\Delta$. In the leading approximation the BFKL pomeron has $\Delta = \frac{12\ln^2\alpha_s}{\pi} \approx 0.5$, which corresponds to a very fast increase of total cross sections and parton densities with energy ($1/x$). In this approximation the pomeron corresponds to a cut in j-plane. In the next to leading approximation there is a sequence of poles in j-plane concentrated at point j=1 and the value of $\Delta$ substantially decreases to the values $\Delta = 0.15 \div 0.25$ $[2]$. The rightmost in j-plane pole strongly depends on nonperturbative region of small momentum transfer $[3]$. Thus, even in the perturbative approach it is important to have a nonperturbative input in order to describe asymptotic behavior of scattering amplitudes.

The role of nonperturbative effects in pomeron dynamics and a connection of the pomeron with spectrum of glueballs were studied in refs. $[4]$, using the method of vacuum correlators $[5]$. This method, based on general properties of correlators in QCD leads to a successful description of the spectrum of resonances for usual Regge-trajectories and leads to the spectrum of glueballs in a good agreement with lattice calculations $[4]$. It was shown $[4]$ that confinement effects and mixing of gluonic and $q\bar{q}$–Regge-trajectories are important for the pomeron dynamics. Note, that the intercept of the pomeron in this approach can be close to the one predicted in the perturbative QCD. The arising picture of the vacuum trajectories
dominated by nonperturbative effects at large $t > 0$ and by perturbative dynamics at large negative $t$, strongly curved in the region $t \sim 0$ is similar to one obtained from gauge/string duality [6]. Thus the pomeron has a rich dynamics in QCD: both perturbative and non-perturbative effects and mixing with light quarks are important in the region of not large $t$.

In perturbative QCD approach there is a singularity in j-plane close to unity with quantum numbers: $\sigma = -$, parity $P = -$ and $C = -parity = -$, [7] -- ”odderon”. It is due to exchanges in the $t$–channel by 3 gluons. In the nonperturbative approach, discussed above, situation is quite different. There are states made of three gluons, but their masses are rather large (more than 3 GeV) for the lowest states and extrapolations of their Regge trajectories to $t = 0$ lead to negative intercepts [4]. Mixing with $q - \bar{q}$ states in the small–t region in this case is not essential. Thus in this approach there is no odderon, which can influence asymptotic behavior of scattering amplitudes. Same conclusion has been obtain in ref. [8] from lattice calculations. Thus an experimental search for the ”odderon” singularity is very important as it allows to separate between perturbative and nonperturbative mechanisms in QCD at high energies. H1 collaboration has looked for odderon exchange in reactions $\gamma p \rightarrow \pi^0N(N^*)$, $\gamma p \rightarrow \pi^0\pi^0N(N^*)$, which are due to exchanges with $C = -$ in the t–channel and has not found such events. The limits on cross sections of these reactions are much lower than predictions of ref. [10]. It is not excluded, however, that couplings of the odderon to hadrons are smaller than in the model of ref. [10].

An important information on dynamical properties of reggeons can be obtained from a study of $q - \bar{q}$ Regge–trajectories with isospin I=1. In perturbative QCD such singularities have $\alpha > 0$ and tend to zero for $t \rightarrow -\infty$ [11]. On the other hand the nonperturbative string–like dynamics leads to linear Regge trajectories.

The leading $\rho$, $A_2$ - trajectories are well determined experimentally at $t > 0$ from the spectrum of resonances and at $t < 0$ from analysis of the reactions $\pi^-p \rightarrow \pi^0N(X)$, $\pi^-p \rightarrow \eta^0N(X)$.

The $\rho$–trajectory, extracted from the data on the reaction $\pi^-p \rightarrow \pi^0N$, is shown in Fig.1. It is very close to the straight line passing through $\rho$–meson and higher resonances on $\rho$–trajectory. It is important that effective $\rho$–trajectory closely follows the nonperturbative straight line up to rather large values of $-t \sim 2 GeV^2$, reaches the value $\alpha_\rho(-2 GeV^2) \approx -1.2$ and does not show any indication for moving toward the PQCD prediction. This problem was also studied in ref. [12], using data on inclusive $\pi^0$ production in $\pi^-p$–collisions. In this case the data exist up to even higher values of $(-t)$ [13]. However the values of $(1 - x)$ are not very small ($0.1$) and PQCD contribution can not be excluded [12]. In the exclusive charge exchange reaction, analyzed above, the values of $s \sim 10^3$ and limits on PQCD contribution are more stringent (the ratio of couplings to hadrons for PQCD and string–like contributions is $< 10^{-3}$).

Thus I came to the conclusion that in the high-energy Regge limit nonperturbative effects play an important role up to rather large values of $(-t)$.

## 2 Unitarity effects for hard diffractive processes and the role of triple-pomeron interactions.

The pomeron pole with $\Delta > 0$ leads for $s \equiv W^2 \rightarrow \infty$ to a violation of s-channel unitarity. It is well known that the unitarity is restored if the multi–pomeron exchanges in the t-channel are taken into account.
An important role of multi–pomeron exchanges is clearly seen in the hard diffractive processes. In these processes they lead to a violation of both Regge and QCD factorization. Diffractive production of jets, W-bosons, heavy quarks and heavy quarkonia was observed by CDF and $D_0$–collaborations at Tevatron. There are hopes to study Higgs bosons in exclusive double diffractive production at LHC (see for example [14]).

For diffractive dijet production at Tevatron it was found that calculation of the cross section, based on the factorized formula with diffractive structure functions from HERA data, leads to a large discrepancy with the CDF measurements both in the normalization and in the shape of the observed distribution. This factor of $\sim 10$ difference between prediction of factorization and experiment is naturally accommodated by suppression due to multi–pomeron exchanges. The Gribov reggeon diagrams technique [15] allows one to calculate contributions of these exchanges (Regge cuts) to scattering amplitudes. The diagrams with n–pomeron exchange in the t–channel can be expressed as sums over all possible intermediate diffractive states in the s–channel. The sum of the elastic rescatterings leads to the eikonal formula. Inclusion of diffraction dissociation to not large masses leads to a multichannel generalization of the eikonal approximation. The two-channel model for calculation of suppression (survival probability) for hard diffractive processes has been used in ref. [16] and lead to a reasonable description of experimental data on diffractive dijet production at Tevatron.

Diffractive production of large mass states is described in reggeon approach by diagrams with interactions between pomerons. For hard processes it leads to a new class of multi–pomeron diagrams, indicated for dijet production on Fig.2. This interaction can happen if the mass of the hadronic state above the hard part of Fig.2 a) is very large and rapidity intervals in Fig2 b) $y_1, y_2 \gg 1$. It was pointed out in ref. [16] that this condition is not satisfied for production of dijets at Tevatron and of Higgs at LHC and they are not essential for calculation of survival probabilities in these cases (see also discussion in ref. [17]). Investigation of neutron spectra in photoproduction at HERA in the reggeized pion exchange model [18] also indicates that interactions of pomerons are not very essential in these processes.

However in general at superhigh energies and very large masses of diffractively produced hadronic states these diagrams can be important. This problem has been emphasized by J. Bartels et al. [19] in QCD perturbation theory.
It may be instructive to consider the problem of influence of pomeron interactions in a simple and solvable model. For this purpose I shall use the Schwimmer model [20]. It corresponds to summation of fan type diagrams with triple pomeron interactions. The model can give reasonable approximation for amplitudes when the size of a projectile is much less than the size of a target. Diffractive cross section for production of a state of a given mass $M$ and rapidity gap $y$ (with the value of $y_M = Y - y$ fixed; $Y = \ln s/s_0$) in this model is known [21, 22] and has the form

$$
\frac{d\sigma^D}{dy_M} \equiv M^2 \frac{d\sigma^D}{dM^2} = -g_1 g_2 \frac{d\varphi_{\text{gap}}(Y, y)}{dy} = \frac{2 g_1 g_2 \Delta \epsilon e^{\Delta (2Y - y_M)}}{[1 + \epsilon (2e^{\Delta Y} - e^{\Delta (Y - y_M)} - 1)]^2}
$$

(1)

with $g_1, g_2$ -couplings of the pomeron with particles 1 (small size) and 2 (large size) correspondingly; $\epsilon = \frac{r g_2}{\Delta}$, where $r$-is the triple pomeron coupling. Thus in this model the survival probability is:

$$
S_{Sch}^2 = \frac{1}{[1 + \epsilon (2e^{\Delta Y} - e^{\Delta (Y - y_M)} - 1)]^2}
$$

(2)

Contrary to the eikonal model it depends not only on $Y$, but also on $y(y_M)$. As expected, interactions of pomerons lead to suppression of diffractive cross sections calculated in the pole approximation.

These results can be generalized to the eikonalized Schwimmer model [22]:

$$
S^2 = S_{eik}^2 S_{Sch}^2
$$

(3)

where

$$
S_{eik}(Y, y_M; b) = \exp [g_1 g_2 (\varphi_{\text{tot}}(Y; b) - \varphi_{\text{gap}}(Y, Y - y_M; b))]
$$

(4)

and

$$
\varphi_{\text{tot}}(Y) = \frac{2P(Y)}{1 + \epsilon[P(Y) - P(0)]}, \quad P(Y) = \exp(\Delta Y).
$$

(5)

It is important that due to pomeron interactions the value of the eikonal function is reduced and it does not increase for $s \to \infty$. This leads to a strong increase of survival probability compared to the pure eikonal approximation. Thus there is an extra decrease of $S^2$ due to $S_{Sch}^2$ term and its increase due to change of $S_{eik}^2$. For very large $Y$ the second effect is more important and inclusion of pomeron interactions leads in this model not to a decrease, but to an increase of survival probability compared to the pure eikonal approximation.
Let us note that in any case cross sections of inelastic diffraction are very small for small impact parameters at very high energies and the main problem is to calculate these cross sections at large impact parameters (the edge of interaction region). In this region nonperturbative effects are important and any calculation on PQCD is nor reliable.

Thus it is important to develop a reliable nonperturbative method of calculation in QCD of absorptive effects in diffractive processes with account of pomeron interactions (including pomeron loops).

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References

[1] E.A. Kuraev, L.N. Lipatov, V.S. Fadin, Sov. Phys. JETP 44, 433 (1976); 45, 199 (1977); Ya.Ya. Balitsky, L.N.Lipatov, Sov. J. Nucl. Phys. 28, 822 (1979).

[2] V. S. Fadin, L. N. Lipatov, Phys. Lett. B429, 127 (1998). G. Camici, M. Ciafaloni, Phys. Lett. B430, 349 (1998). S.J.Brodsky et al., JETP Lett. 70, 155 (1999).

[3] L.P.A. Haakman, O.V. Kancheli, J.H. Koch, Nucl. Phys. B518, 275 (1998).

[4] A.B. Kaidalov, Yu.A. Simonov, Phys. Lett. B477, 163 (2000). A.B. Kaidalov, Yu.A. Simonov, Yad. Fiz. 63, 1507 (2000). A.B. Kaidalov, Yu.A. Simonov, Phys. Lett. B636, 101 (2006).

[5] Yu.A. Simonov, Phys. Lett. B249, 514 (1990).

[6] R.C. Brower, J. Polchinski, M.J. Strassler, Chung-I Tan, hep-th/0603115.

[7] R.A. Janik and J. Wosiek, Phys. Rev. Lett. 82, 1092 (1999). J. Bartels, L.N. Lipatov and G.P. Vacca, Phys. Lett. B477, 178 (2000).

[8] H.B. Meyer, M.J. Teper, Phys. Lett. B605, 344 (2005).

[9] C. Adloff et al.(H1 Collaboration), Phys. Lett. B544, 35 (2002). T. Berdt (for H1 Collaboration), Acta Phys. Polonica 33, 3499 (2002).

[10] E.R. Berger et al., Eur. Phys. J C9, 49 (1999).

[11] R. Kirchner, L.N. Lipatov, Sov. Phys. JETP 56, 266 (1982); Nucl. Phys. B213, 122 (1983).

[12] S.J. Brodsky, Wai-Keung Tang, Phys. Lett. B318, 203 (1993).

[13] R.G. Kennett et al., Nucl.Phys. B284, 653 (1987).
[14] A.D. Martin, V.A. Khoze, M.G. Ryskin, \[\text{hep-ph/0605189}\]

[15] V. N. Gribov, ZhETF 57, 654 (1967).

[16] A.B. Kaidalov, V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. C21, 521 (2001).

[17] V.A. Khoze et al., JHEP 0605, 036 (2006).

[18] A.B. Kaidalov et al., Eur. Phys. J. C47, 385 (2006).

[19] J. Bartels et al., Phys. Rev. D73, 093004 (2006).
    J. Bartels, Talk at ICHEP 06.

[20] A. Schwimmer, Nucl. Phys. B94, 445 (1975).

[21] Yu.V. Kovchegov and E. Levin, Nucl.Phys. B577, 200 (2000).

[22] K.G. Boreskov et al., Eur. Phys. J. C44, 523 (2005).