Overview on rapidity gap survival predictions for LHC

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Abstract

An important role of unitarity effects related to multipomeron exchanges in diffractive processes is emphasized. A general technique to calculate these effects is presented. Role of interactions between pomerons is investigated. Recent theoretical models, which take into account these interactions are reviewed and consequences for survival probabilities of hard diffractive processes at LHC energies are discussed.

1 Introduction

Diffractive processes at high energies are usually described by pomeron exchange in the t-channel (see for example review [1]). An increase with energy of the total interaction cross sections indicates that an intercept of the pomeron is larger than unity. An exchange by a Regge pole with $\Delta \equiv \alpha_P(0) - 1 > 0$ leads to the violation of the s-channel unitarity. Therefore, multipomeron exchanges in the t-channel are very important for such "supercritical" pomeron. They restore unitarity and make theory consistent with Froissart bound.

Unitarity effects, related to the multipomeron exchanges, are especially important for inelastic diffractive processes and strongly reduce their cross sections. Inelastic diffractive processes correspond to configurations of final hadrons with one or several rapidity gaps. Reduction of cross sections in comparison with the born (Regge pole) approximation is usually called gap survival probability, because it determines a probability not to fill the gap by produced hadrons. Knowledge of the gap survival probability is important for experimental investigation of diffractive processes at LHC, and in particular for searches of the Higgs boson in the central exclusive double pomeron production.

I shall give a short review of recent developments in theory of diffractive processes at high energies and shall discuss the role of interactions between pomerons for survival probabilities of rapidity gaps.

2 General method for calculation of multi-pomeron cuts

A general method for calculation of multi-pomeron contributions to amplitudes of diffractive processes has been formulated by V.N. Gribov [2]. I shall illustrate it using as an example a contribution of two-pomeron exchange to the process of elastic scattering. Using analyticity and unitarity properties for pomeron-particle scattering amplitudes the total contribution can be expressed as the sum over all intermediate diffractive states as shown in Fig.1

An account of elastic intermediate states for n-pomeron exchange amplitudes leads to the eikonal formula in the impact parameter space:

$$\mathrm{Im}\, T \;=\; 1 \,-\, e^{-\Omega/2}, \tag{1}$$

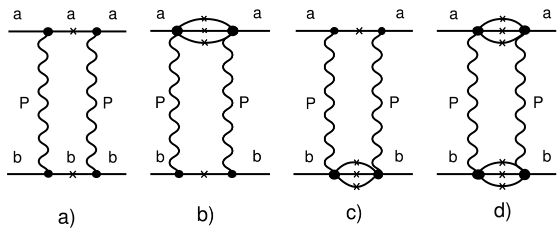

Fig. 1: Two-pomeron exchange diagram as a sum over all possible diffractive states.

where the eikonal Ω is the Fourier transform of the pomeron pole exchange.

Low mass diffractive states are often approximated by several resonance states. In this case the same method leads to eq. 1 with Ω being a matrix, whose elements correspond to transitions between different diffractive states. The simplest treatment is a diagonalization of this matrix. Thus an account of the low mass diffraction in the Gribov's method is equivalent to the Good-Walker [3] approach to inelastic diffraction.

In the eikonal approximation a probability not to fill the gap is equal to $e^{-\Omega}$ and the survival probability is:

$$S^2 \;=\; \frac{\int\; |\mathcal{M}(s,b)|^2\, e^{-\Omega(b)}\; d^2b}{\int\; |\mathcal{M}(s,b)|^2\, d^2b}, \qquad (2)$$

This expression is easily generalized to the case of several channels. The same eq. 2 is valid for each diagonal state and it is necessary to sum over all diagonal states (with corresponding weights).

The quantity Ω increases with energy as s^Δ and becomes large at very high energy. According to eq. 2 cross sections of inelastic diffractive processes become negligible at small impact parameter and are concentrated at the edge of interaction region at $b > 1$ fm. Note that models based on perturbative QCD are not valid in this peripheral region.

The value of S^2 is not universal: it depends on dependence of a matrix element $\mathcal{M}(s,b)$ on impact parameter b.

3 Unitarity effects for hard diffraction

The condition for masses M of hadronic states produced in diffractive process (by the pomeron exchange) is $M^2 \ll s$. Thus very large masses can be generated at very high energies and heavy states can be produced (jets, heavy quarks, W and Z bosons, Higgs meson etc.) They represent an interesting class of hard diffractive processes, where the subprocess of a heavy state production can be calculated using QCD perturbation theory. The simplest inclusive diffractive process is a diffractive dissociation of a highly virtual photon. In this case the photon interacts with a quark and a study of these processes at HERA gave a possibility to determine the distribution of quarks and gluons in the pomeron. These distributions and QCD factorization can be used to predict cross sections of hard inclusive diffractive processes in hadronic interactions. Note, however, that multi-pomeron contributions violate both Regge and QCD factorization and strongly modify predictions based on a single pomeron exchange. CDF data [4] show that cross section of diffractive dijet production at Tevatron is about an order of magnitude smaller as compared to the prediction based on QCD factorization and partonic distributions extracted from HERA data. Calculation of gap survival probability in the two-channel eikonal model [5] allows to reproduce the observed suppression.

It is interesting that the same suppression is observed for double gap (double pomeron exchange) events at Tevatron [6]. This observation is in accord with a dominance of eikonal-type rescatterings [7].

4 Large mass diffraction and interactions of pomerons

So far we have considered the low mass excitations in diffractive intermediate states of Fig.1. We know that large mass excitations constitute a large fraction of diffraction cross section. The large mass behavior of the pomeron-particle amplitudes is described by the triple-pomeron and multi-pomeron diagrams (Fig.2).

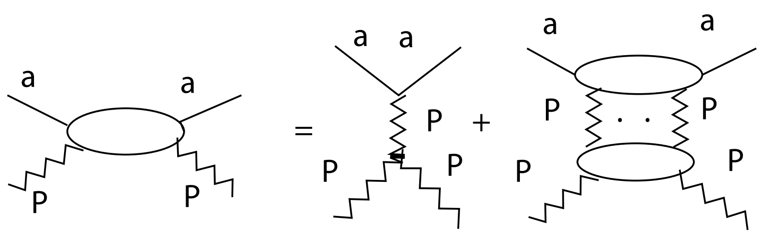

Fig. 2: Diagrams for the pomeron-particle scattering amplitudes at large M^2.

It is clear that for very large masses it is not enough to consider the triple-pomeron contribution only. An important theoretical question is: what is the structure of the vertices for n pomeron to m pomeron transitions? The simplest approximation is to assume an eikonal-type structure for the pomeron-particle amplitudes at large M^2:

$$g_{mn} = cg^{m+n} \tag{3}$$

where c and g are some functions of t. This behavior of vertices follows from multiperipheral model and is natural from the t-channel unitarity point of view. It was used in [8] to sum all diagrams with interactions of pomerons. This model leads to a good description of total, elastic and single diffraction dissociation cross sections (σ_{SD}) in $pp(p\bar{p})$ interactions [8] with $\Delta \approx 0.2$. It is worth to note that without multi-pomeron effects σ_{SD} has too fast increase with energy and exceeds experimentally observed cross section by a factor ~ 10.

More recently the same structure of multi-pomeron vertices has been used for the description of diffractive processes [9] and, assuming validity of AGK cutting rules, for multiparticle production at high energies [10].

Investigation of asymptotic behavior of diffractive processes in reggeon field theory has started already in seventies. Most of these investigations were based on the version of the theory with a triple-pomeron interaction only [11]. It is not clear that for supercritical pomeron such theory is consistent with s and t- channel unitarity. One dimensional version of this theory leads to a decrease of total cross section as $s \to \infty$. More recent studies [12, 13], based on partonic interpretation of reggeon field theory, indicate that it is necessary to take into account 4P-interaction to make this theory consistent.

5 Recent estimates of survival probabilities

In this section I shall review recent models for diffractive processes, which take into account interactions between pomerons, and shall discuss predictions of these models for survival probabilities of hard diffractive processes.

The Durham group (KMR) has recently made a new fit to the data on cross sections of diffractive processes [14, 15]. All $n \to m$ pomeron transition were taken into account in the framework of a partonic model, which leads to the behavior $g_{mn} \sim nmg^{n+m}$, which is somewhat different from the one discussed above in the eikonal approximation. Summation of diagrams was performed by numerical solution of a system of highly nonlinear equations for amplitudes. Formulas for cross sections of different inelastic diffractive processes were obtained using some probabilistic arguments (and not cutting rules as in the standard approach). In this model it is possible to obtain a reasonable description of total cross section for pp-interaction, its elastic cross section in the diffraction cone region and cross sections of single and double diffraction. The result for an intercept of the pomeron is sensitive to details of the model. In particular in one dimensional version of the model with $\alpha\prime = 0$ values of Δ close to 0.5 were obtained [14], while in a more accurate treatment, which takes into account transverse degrees of freedom [15], Δ decreases to values close to 0.3.

In the treatment of diagrams with interactions between pomerons it is necessary to take into account that the notion of the pomeron exchange is meaningful for large rapidity gaps only (usual choice $y > y_0$, with $y_o = ln(10) = 2.3$). Thus a cutoff at small rapidities for each pomeron line should be introduced. This leads to a natural limitation to the number n of the t-channel iterations of pomeron exchanges (or number of gaps) at each initial energy: $n < ln(s/s_0)/y_0$ with $s_0 = 1\ GeV^2$. This threshold effect was taken into account in ref.[8] and should be accounted for in all realistic calculations with pomeron interactions. It plays an important role in calculations of survival probabilities (see below). I believe that introduction of this effect in KMR calculation will further decrease the value of Δ.

A different approach was used by the Tel-Aviv group (GLM)[16]. Arguments based on a small value of the pomeron slope were used to justify applicability of perturbative QCD (pQCD) for diffractive processes. Motivated by pQCD the authors used the triple-pomeron interaction only with maximal number of pomeron loops. The last assumption may be reasonable for interaction of very small dipoles, but is difficult to justify for interaction of protons. One dimensional approximation was used in calculations. Besides the diagrams with pomeron loops two-channel eikonal model was used. I have emphasized above that inelastic diffractive processes are concentrated at the edge region of large impact parameters and that nonperturbative effects (for example two-pion cut in the pomeron trajectory and residues) are important in this region. The fit to total pp-interaction cross section, differential cross section of elastic scattering and inelastic diffraction was performed in the model [16] and parameters of the pomeron were determined. The value

$\Delta = 0.33$ for the intercept of the pomeron was found. Note that the threshold effects, discussed above, has not been taken into account in this model.

Let us discuss the common features and the differences in results of these two models. A general feature of models, which take into account interactions between pomerons ("enhanced" diagrams), is a slower increase with energy of total cross sections. For example predictions of both KMR and GLM models for the total cross section of pp interaction at LHC energy are close to 90 mb, which is substantially smaller than in models without these interactions. Same effect exists in the model of ref.[8], though the corresponding cross section is closer to 100 mb. Values of the pomeron intercept is substantially higher than in the eikonal-type models. Our experience for models with pomeron interactions [8] indicates that for values of the pomeron intercept $\Delta > 0.2$ the models become rather unstable: results for cross sections are sensitive to details of models.

There is a significant difference in predictions of KMR and GLM models for low and large mass contributions to the single diffraction dissociation cross sections. For example at Tevatron energies predictions of the KMR model for low-mass diffraction and high-mass diffraction are 4,4 mb and 6.5 mb correspondingly, while in GLM model the corresponding numbers are 8.6 and 1.2 mb. It is difficult to understand how it was possible to describe the CDF data on high-mass diffraction in both models with so different values of high-mass cross sections? The form of the mass distribution for low mass diffraction, proposed in GLM model (RRP-term, production of very large masses $\sim s^{1/2}$ by secondary reggeons) seems to me unacceptable.

The largest difference in KMR and GLM models is in predictions for survival probabilities. In ref.[14] the change in S^2 due to enhanced diagrams has not been calculated and calculation [17] in a simplified model, which takes into account threshold effects, show that for DPE Higgs production at LHC this change is small. On the other hand in GLM model a modification of survival probabilities due to enhanced diagrams is very strong: for DPE Higgs production at LHC it decreases the probability calculated in the two channel eikonal model by a factor ≈ 16. This is important for experiments, planned to observe DPE Higgs production at LHC. For DPE processes at Tevatron GLM model predicts a decrease of survival probability by a factor 3.5. This does not agree with CDF data [6] (see above). Thus a controversy in theoretical predictions for suppression of hard diffractive processes due to enhanced diagrams [5, 18, 19] is in my opinion still not resolved.

In view of large uncertainties in predictions of theoretical models for survival probabilities of diffractive processes it is worth to summarize what we know about these probabilities from experiment. A comparison of CDF data on diffractive dijet production [4] with prediction based on QCD factorization and survival factor of two channel eikonal model show that extra suppression due to enhanced diagrams does not exceed 50%. Similar estimate follows from CDF data on DPE dijet production [6, 20].

Thus up to energies of Tevatron interaction between pomerons play a minor role in hard diffractive processes. This is to a large extent related to the phase-space limitations. For soft diffraction enhanced diagrams are important and lead to a change of parameters of the "bare" pomeron in reggeon theory. At LHC the effects of enhanced diagrams will be observable in hard diffractive processes. Their influence on survival probabilities can be studied, in particular, in diffractive production of jets (with not too large masses).

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References

[1] A.B. Kaidalov, Phys. Rep. **50**, 157 (1979).

[2] V.N. Gribov, Sov. Phys. JETP **19**, 483 (1969).

[3] M.L. Good and W.D. Walker, Phys. Rev. **126**, 1857 (1960).

[4] CDF Collaboration: T. Affolder et al., Phys. Rev. Lett. **84**, 5043 (2000).

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

[6] CDF Collaboration, T.Affolder et al., Phys.Rev.Lett. **85**, 4215 (2000).

[7] A.B. Kaidalov, V.A. Khoze, A.D. Martin and M.G. Ryskin, Phys. Lett. **B559**, 235 (2003).

[8] A.B. Kaidalov, L.A. Ponomarev, K.A. Ter-Martirosyan, Sov. J. Nucl. Phys. **44**, 486 (1986).

[9] S. Ostapchenko, Phys. Lett. **B636**, Phys. Rev. **D74**, 014026 (2006).

[10] S. Ostapchenko, Phys. Rev. **D77**, 034009 (2008).

[11] D. Amati, L. Caneschi, and R. Jengo, Nucl. Phys. **B101**, 397 (1976);
D. Amati, G. Marchesini, M. Ciafaloni and G. Parisi, Nucl. Phys. **B114**, 483 (1976).

[12] K. Boreskov, in *Multiple facets of quantization and supersymmetry*, p.322; arXiv:hep-ph/0112825.

[13] S. Bondarenko et al., Eur. Phys. J. **C50**, 593 (2007).

[14] M.G. Ryskin, A.D. Martin and V.A. Khoze, Eur. Phys. J. **C54**, 199 (2008).

[15] A.D. Martin, talk at Conf. Diffraction 08, September 2008.

[16] E. Gotsman, E. Levin, U. Maor, J.S. Miller, arXiv:hep-ph/0805.2799.

[17] A.D. Martin, V.A. Khoze and M.G. Ryskin, arXiv:hep-ph/0803.3939.

[18] J. Bartels, S. Bondarenko, K. Kutak, L. Motyka, Phys. Rev. **D73**, 093004 (2006).

[19] L. Frankfurt, C.E. Hyde, M. Strikman, C. Weiss, arXiv:hep-ph/0710.2942;0808.0182.

[20] K. Hatakeyama, talk at ISMD 2008.