Diffraction at LHC

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Abstract

Rapid increase with energy of cross sections of QCD processes leads to the change of QCD environment for new particles production at LHC, to the new QCD phenomena. It follows from k_t factorization theorems that transverse momenta of partons are increasing within the fragmentation region, that regime of 100% absorption dominates in the scattering at zero impact parameters. Biconcave form of rapid hadron and two phase structure of hadronic final states are explained. We outline here impact of understood QCD phenomena on the probability of processes with large rapidity gaps.

1 Introduction

The main challenge of LHC physics is to discover new particles (Higgs boson, supersymmetric particles...) and novel QCD phenomena. One of barriers for a such study is the necessity to model QCD environment. Usually this is made within Monte Carlo approaches which accounts for the understood properties of QCD (see also [1,2] at this conference). The main origin of complications is evident: cross sections of QCD processes are rapidly increasing with energy. Really data on the cross sections of soft QCD processes can be described as $\sigma \propto (s/s_o)^{2\alpha_P(t=0)-2}$ i.e. as due to the exchange by Pomeron with the intercept $\alpha_P(t=0) = 1+\delta$ where $\delta = 0.08 - .01$. Similarily cross sections of DIS processes with the virtuality Q^2 observed at FNAL and at HERA can be fitted as the exchange by hard "Pomeron" with the intercept $\alpha_P(t=0) = 1+\delta_{hard}$ where $\delta_{hard}(Q^2 \approx 10GeV^2) \approx 0.2$ and increasing with increase of Q^2. pQCD formulae are more complicated but in the important kinematical domain can be fitted in this form also. Different energy dependence of soft and hard QCD processes leads to change of proportions between soft and hard QCD contributions, to the energy dependence of QCD environment.

Rapid increase with collision energy of the radius of soft QCD interaction $b^2 = B_o + 2\alpha'_P \ln(s/s_o)$ allows experimental separation of peripheral and central collisions ($b^2 \approx B_o$ at LHC, see review [3][1]. Feasibility of the separation of pp collision into peripheral and central impact parameters collisions using different triggers (two, 4 jet production at central rapidities) is practically important. Really collision at central impact parameters is dominated by the novel QCD regime (QCD environment for new particles production) which is characterized by unbroken chiral symmetry and certain remnants of conformal symmetry. This is in contrast with the peripheral pp collisions where hadronic states are in the phase of spontaneously broken chiral symmetry and no conformal symmetry.

[1]Here B is the slope of t dependence measured in the elastic pp collisions

In spite of the fact that at energies of LHC the total contribution of hard processes into $\sigma_{tot}(pp)$ is not large but both hard processes as well as heavy particle production are concentrated at central impact parameters. So QCD environment for new particles production strongly depends on collision energy making difficult the separation of hadronic products of new particles decays from the background from hadronic processes. This problem is especially important for establishing quantum numbers of new particles.

Another important feature of QCD physics which makes modeling of QCD processes at LHC difficult is that observed increase cross sections with collision energy comes to conflict with probability conservation at given impact parameter: $\sigma_{el}(s,b) \propto (s/s_o)^{2\delta} \leq \sigma_{tot}(s,b) \propto (s/s_o)^{\delta}$. This restriction has simple interpretation: absorption of rapid particle can not exceed 100%, cf. discussion in the text. This condition restricts region of applicability of pQCD approximations which were successful at lesser energies.

In the new regime of strong interaction with small coupling constant pQCD is inapplicable. However regime of complete absorption where partial waves achieve maximum allowed by probability conservation some important properties of hard processes like total cross section, disappearance of leading hadrons, jets at zero impact parameters, cross sections of diffractive processes can be evaluated legitimately. In the new QCD regime multiparton interactions are not suppressed by powers of virtuality and observation of them will be most effective method of probing novel QCD regime. Measurement of diffractive electroproduction of vector mesons at HERA helped to establish gluon GPD, i.e. gluon distribution in impact parameter space [**?**] which is important for the analysis of new particles production.

In the second section we will discuss nontrivial features of impact parameter distribution. In the third section we formulate restrictions which follow from probability conservation and found two phase regime. In the section 4 we discuss dependence on energy of QCD environment. In section 5 we consider impact of discussed above phenomena on the gap survival probability.

2 Impact parameter distribution for soft and hard interactions

To formulate probability conservation it is convenient to use impact parameter representation for the scattering amplitude:

$$T(s,t) = (is/4\pi) \int exp(iq_t b)\Gamma(s,b) d^2b \tag{1}$$

One may easily reconstruct Γ for the soft QCD interactions using parametrizations for elastic pp collisions.

$$\Gamma_{soft}(s,b^2) = (\sigma_{tot}(pp)/\pi) exp(-b^2/2B) \tag{2}$$

Here B is the slope of t dependence of elastic cross section.

The impact parameter distribution of gluons can be reconstructed from gluon GPD measured in the hard exclusive processes like diffractive electroproduction of vector mesons $\gamma^* + p \to V + p$. It is important that according to QCD factorization theorem of [4] such processes are calculable in terms of generalized parton distributions(GPD). Thus impact parameter dependence of gluon distribution can be reconstructed using two gluon form factor of a nucleon see review and references in [3] and new calculation in [5]:

$$\Gamma_{gluon}(x,b) = (x_o/x)^{\lambda}(\mu b)K_1(\mu b) \tag{3}$$

Here K is function of Hankel of imaginary argument. Experimentally $\lambda \approx 0.2$ and increasing with virtuality, $\mu \approx 1GeV$ and slowly decreasing with energy.

Comparison between Eq.2 and Eq.2 allows to establish important properties of QCD environment:

- Knowledge of the slope B for the soft QCD interactions and μ for hard interactions allows to derive novel and important property: impact parameter distribution characteristic for soft processes is significantly wider than for hard processes and its radius is increasing with energy.
- According to QCD factorization theorem hard processes and new particles production are dominated by convolution of gluon distributions. So they have close impact parameter distributions.
- Amplitudes of hard processes are significantly smaller than that for soft ones (Bjorken scaling) but more rapidly increasing with energy.
- Existence of correlations between partons suggest that multiparton interactions may be characterized by more narrow distribution in impact parameter space. [1]

3 Conservation of probability and two phase picture

In a quantum theory cross sections of hadron collisions can be calculated in terms of profile function $\Gamma(s,b)$ as

$$\sigma_{el} = \int d^2b\Gamma(s,b)|^2 \tag{4}$$

$$\sigma_{inel} = \int d^2b[1 - |1 - \Gamma(s,b)|^2] \tag{5}$$

$$\sigma_{tot} = \int d^2b\, 2Re\Gamma(s,b) \tag{6}$$

Above equations are applicable also for the scattering of spatially small dipole of a hadron target if to neglect by the increase of the number of constituents within this dipole with the increase of virtuality. Evaluation of radiative corrections to the impact factors in [6] indicates that these corrections seems to be small.

It follows from these equations that :

- $\Gamma(s,b)$ is restricted from above by the condition: $\Gamma(s,b) \leq 1$. Upper boundary -

  $$\Gamma(s,b) = 1 \tag{7}$$

  is equivalent to the requirement that absorption can not exceed 100%. Since amplitudes of soft and hard interactions are increasing with energy see Eq.2 and Eq.2 each projectile will be absorbed with 100% probability. Thus at given impact parameter $\Gamma = 1$ at sufficiently large energies. This condition does not includes any dependence on virtuality.

- Thus Bjorken scaling completely disappears at large energies, in the limit of fixed Q^2 but $x \to 0$. Numerical evaluations show that onset of this this novel QCD regime at $b = 0$ requires $x \leq 10^{-3} - 10^{-4}$. See review [3].
- Another important novel effect to reveal itself at LHC : amplitudes of hard processes should exceed amplitudes of soft QCD processes for the scattering at zero impact parameter since amplitudes of hard interactions are increasing with energy more rapidly than soft one. Moreover at given impact parameter soft interactions disappear with increase of energy for the the review and references [3].
- Two phases QCD picture emerges for high energy collisions. In the scattering at large impact parameters -peripheral collisions- nonperturbative QCD interactions would dominate. Here interaction chooses familiar phase of spontaneously broken chiral symmetry and conformal symmetry is broken. On the contrary -for the scattering at central impact parameters hard interactions with unbroken chiral symmetry would dominate.

4 Change of hadron environment

To visualize dependence of hadron environment on energy we begin from the consideration of scattering of small dipole off a hadron target. The characteristic feature of hard processes is the approximate Bjorken scaling for the structure functions of DIS, i.e. the two dimensional conformal invariance for the moments of the structure functions. In this approximation as well as within the leading $\log(x_0/x)$ approximation, the transverse momenta of quarks within the dipole produced by the local electroweak current are restricted by the virtuality of the external field:

$$\Lambda^2 \leq p_t^2 \leq Q^2/4. \tag{8}$$

Here $\Lambda \equiv \Lambda_{QCD} = 300$ Mev is a QCD scale. However it follows from the QCD factorization theorem proved in Refs. [7] that within this kinematical range the smaller transverse size d of the configuration (the transverse distance between the constituents of the dipole) corresponds to a more rapid increase of its interaction with the collision energy:

$$\sigma = \alpha_s(c/d^2) F^2 \frac{\pi^2}{4} d^2 x G_T(x, c/d^2), \tag{9}$$

here $F^2 = 4/3$ or $9/4$ depends whether the dipole consists of color triplet or color octet constituents, G_T is an integrated gluon distribution function and c is a parameter $c = 4 \div 9$. It is well known in the DGLAP approximation that the structure function $G_T(x, Q^2)$ increases more rapidly with $1/x$ at larger Q^2. This property agrees well with the recent HERA data. We shall demonstrate using k_t factorization that the transverse momenta of the (anti)quark of the $q\bar{q}$ pair produced by a local current increase with the energy and become larger than $Q^2/4$ at sufficiently large energies. In other words the characteristic transverse momenta in the fragmentation region increase with the energy. Technically this effect follows from the more rapid increase with the energy of the pQCD interaction for smaller dipole and the k_t factorization theorem.

It is worth noting that this kinematics is very different from the central rapidity kinematics where the increase of p_t^2 was found in the leading $\alpha_s \log(x_0/x)$ BFKL approximation: $\log^2(p_t^2/p_{t0}^2) \propto \log(s/s_0)$. Indeed, the latter rapid increase is the property of the ladder: the further we go along the ladder, the larger are characteristic transverse momenta, i.e. we have a diffusion in the space of transverse momenta . On the other hand the property we are dealing here with is the property of a characteristic transverse momenta in the wave function of the projectile.

The dipole approximation provides the target rest frame description which is equivalent to the Infinite Momentum Frame (IMF) description of DIS in LO DGLAP and BFKL approximations. To achieve equivalence with the IMF description in the NLO approximation it is necessary to calculate radiative corrections to cross section in the fragmentation region, i.e. to take into account the increase of the number of constituents and related renormalization of the dipole wave function. Recent calculations [6] suggest that these corrections are small. Consequently we will neglect these corrections.

Our main result [5] is that the median transverse momenta k_t^2 of the leading $q\bar{q}$ pair in the fragmentation region grows as

$$k_t^2 \quad \sim \quad a(Q^2)/(x/x_0)^{\lambda(Q^2)} \tag{10}$$

(The median means that the configurations with the momentum/masses less than the median one contribute half of the total crosssection). The exponential factors λ and $\lambda_{\rm M}$ are both approximately ~ 0.1. These factors are weakly dependent on the external virtuality Q^2. The exact values also depend on the details of the process, i.e. whether we consider the DIS process with longitudinal or transverse photons, as well as on the model and approximation used. The exact form of $\lambda(Q^2)$, and $\lambda_{\rm M}(Q^2)$ are given below.

The rapid increase of the characteristic transverse scales in the fragmentation region has been found first in Refs. [3, 8–10], but within the black disk regime (BDR). Our new result is the prediction of the increase with energy of the jet transverse momenta in the fragmentation region/the rise of the transverse momenta in the impact factor with the energy, in the kinematical domain where methods of pQCD are still applicable. This effect could be considered as a precursor of the black disk regime indicating the possibility of the smooth matching between two regimes.

Our results can be applied to a number of processes. First we consider the deeply virtual Compton scattering (DVCS) process, i.e. $\gamma + p \to \gamma^* + p$.

We also find that at sufficiently large energies

$$\sigma_L(x, Q^2)/\sigma_T(x, Q^2) \propto (Q^2/4p_t^2) \propto (1/x)^{\lambda}. \tag{11}$$

Hence the σ_L/σ_T ratio should decrease as the power of energy instead of being $O(\alpha_s)$.

Our results have an implication for the space structure of the wave packet describing a rapid hadron. In the classical multiperipheral picture of Gribov a hadron has a shape of a pancake of the longitudinal size $1/\mu$ (where μ is the scale of soft QCD) which does not depend on the incident energy [11]. On the contrary, QCD predicts [5] the biconcave shape for the rapid hadron in pQCD with the minimal longitudinal length (that corresponds to small impact parameter b) decreasing with increase of energy and being smaller for nuclei than for the nucleons.

5 Gap survival probability

Evaluation of a number of a number processes with large rapidity gap like $p + p \to p + H + p, p + p \to p + 2jet + p$ etc requires evaluation of survival factor S^2. It has been shown in [**?**] that screening effects related to nonperturbative QCD can be evaluated relyably on the basis of new QCD factorization theorem.

$$S^2 = \int d^2 b P_{hard} |1 - \Gamma(b)|^2 \tag{12}$$

Here P_{hard} is impact parameter distribution of hard processes calculable in terms of two gluon form factor of a nucleon. There is no need to model multi Pomeron exchanges by applying eikonal approximation which has in QCD problems with account of energy-momentum conservation.

More tricky is evaluation of screening factor because of small x hard QCD phenomena -this job is in progress.

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