Gluon saturation effects at forward rapidities at LHC in pp collisions

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We investigate hadrons and direct photon production in pp collisions at the LHC energy within the color-dipole approach. We show that greatest sensitivity to gluon saturation effects is reached at very forward rapidities in pp collisions at LHC ($\sqrt{s} = 14$ TeV). The discrepancies among various saturation models (fitted to HERA data) results can be about a factor of $2 - 3$ at forward rapidities. We found that the ratio of direct-photon to pion production can be about $20 - 10$ at forward rapidities $\eta = 7 - 8$. Therefore, direct photon production at forward rapidities should provide a rather clean probe as the background from radiative hadronic decays is significantly suppressed.

1 Introduction

At high energies/small Bjorken-x, QCD predicts that gluons in a hadron wavefunction form a new state, the so-called Color Glass Condensate (CGC) [1, 2], for a review see [3] and references therein. The cornerstone of the CGC is the existence of a hard saturation scale Q_s at which nonlinear gluon recombination effects become important and start to balance gluon radiation. The Color Glass Condensate (saturation) approach to QCD at high energy has been very successful to describe a variety of processes at Relativistic Heavy Ion Collider (RHIC) [3]. Nevertheless, the importance of saturation effects is still disputable given that other approaches offered alternative descriptions. In order to test saturation physics and its relevance, it seems therefore essential to consider various reactions in different kinematic regions at the Large Hadron Collider (LHC) and future collider experiments. Here, we address the role of gluon saturation at LHC energy $\sqrt{s} = 14$ TeV in hadrons and direct photon production in pp collisions within the light-cone color-dipole approach using various saturation models. Details of calculations can be found in Ref. [4].

2 Hadrons and photon at LHC within saturation models

The concept of saturation and the taming of the power-like rise of the gluon distribution at small Bjorken-x was first addressed in Ref. [1] in the double logarithmic approximation. The actual calculation of higher-order corrections to the non-linear small-x evolution equations still remains as a challenge [3], see also [5] and references therein. Thus, one may resort to a QCD-like model which incorporates the basic features of gluon saturation into the dipole-proton

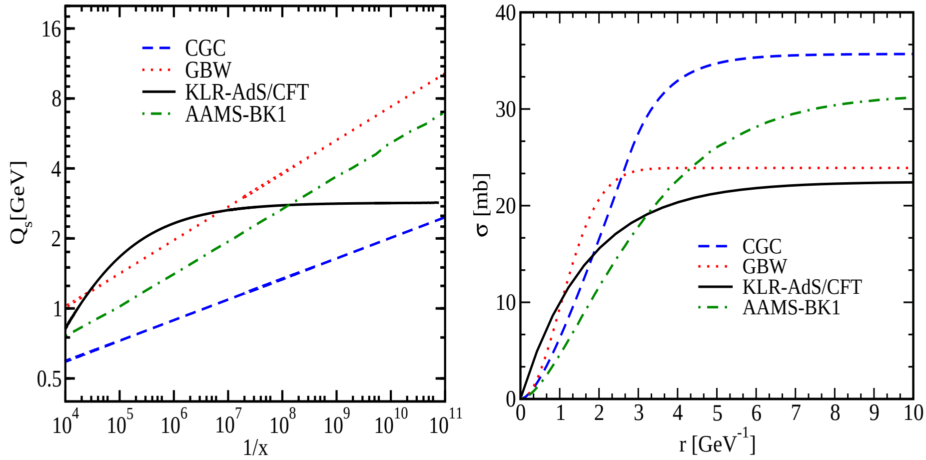

Figure 1: Left: Saturation scale as a function of $1/x$ for various color-dipole models labeled with CGC [6], GBW [7], KLR-AdS/CFT [5] and AAMS-BK1 [8]. Right: The total dipole-proton cross section $\sigma_{q\bar{q}}(r,x)$ at fixed $x = 10^{-5}$ in the various color-dipole models.

forward scattering amplitude, and provides predictions which will allow to test the validity of the treatment. There are several parametrizations proposed in the literature which all give a good description of HERA data but predict different saturation scales, see Fig. 1. The details of saturation models used in Fig. 1 can be found in Ref. [4]. The main feature of these models is that for decreasing x, the dipole amplitude saturates at smaller dipole sizes. Note that there is no unique definition for the saturation scale in literature. We define the saturation scale $Q_s^2 = 2/r_s^2$ as a energy scale at which the $q\bar{q}$ dipole scattering amplitude $\mathcal{N}_{q\bar{q}} \approx 0.4$ becomes sizable [4, 7].

The invariant cross-section of hadron and direct photon production can be calculated via the light-cone color-dipole factorization scheme [4], see also Ref. [9]. In Fig. 2, the differential cross-section of pion π^0 and direct photon γ (photons radiated in hadronic collisions not via hadronic decays) production at LHC are plotted versus rapidity at fixed transverse momenta $p_T = 1$ and 2 GeV within various color-dipole models (see Fig. 1). It is seen that the discrepancies among various saturation color dipole model results can be about a factor of $2-3$ at moderate rapidities. At the kinematic limit, i.e. at very forward rapidities and higher p_T where the differential cross-section approaches zero, kinematic constraints limit the parton phase space and saturation effects become less important. It is seen from Fig. 2 that for both hadron and photon production, away from the kinematic limit, at not very large η and p_T, a color-dipole model with larger saturation scale leads to a stronger peak at forward rapidity (having in mind that the saturation scale is a dynamical function of x, see Fig. 1).

In order to understand the *relative* importance of saturation effects at various rapidities, we employ the Semi-Sat model fitted to HERA data where the dipole-proton forward scattering amplitude is [10]:

$$\mathcal{N}_{q\bar{q}}^{\text{Semi-Sat}}(\vec{r},\vec{b},x) = 2\mathcal{N}_0 \left(\frac{rQ_s}{2}\right)^{2\gamma_{eff}}, \qquad Q_s = \left(\frac{x_0}{x}\right)^{\frac{\lambda}{2}} \left[\exp\left(-\frac{b^2}{2B_{\text{CGC}}}\right)\right]^{\frac{1}{2\gamma_s}}. \quad (1)$$

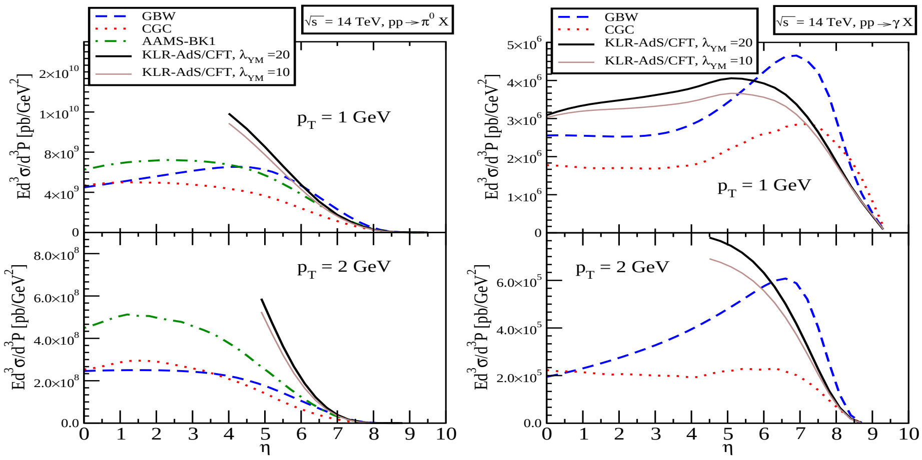

Figure 2: Invariant cross-section for pion (left) and direct photon (right panel) production in pp collisions at LHC as a function of rapidity η calculated with various color dipole models for various fixed p_T.

The parameter γ_{eff} is defined for $rQ_s \leq 2$ as $\gamma_{eff} = \gamma_s + \frac{1}{\kappa\lambda Y} \ln \frac{2}{rQ_s}$, and for $rQ_s > 2$ as $\gamma_{eff} = \gamma_s$. The value of other parameters of this model can be found in [10]. Surprisingly, the fit obtained with such an oversimplified model is as good as for the other models with χ^2/d.o.f. = 0.92. In Fig. 3 we show, ratio of the two cross-sections for both pions and direct photon at LHC, calculated once with diffusion term and once without, i.e. $\gamma_{eff} = 0.43$. It is seen that at forward rapidities, the diffusion term in the anomalous dimension is not important, since it gives similar results as with a fixed $\gamma_{eff} = 0.43$. The preferred value of anomalous dimension $1 - \gamma_{eff} = 0.57$ at very forward rapidities is close to the one predicted from the BK equation [11]. It is well known that the saturation effects start being essential when the anomalous dimension reaches the value $\gamma_{cr} = 1 - \gamma_{eff} = 0.37$ which is the case for forward rapidities (see Refs. [1, 12]). This indicates that direct photon and hadron production at different rapidities at LHC are rather sensitive to saturation.

Direct photons can only be radiated from quarks, while hadrons can be produced by both gluons and quarks. At the LHC energy at midrapidity gluons dominate. Therefore the photon/pion ratio is significantly reduced toward midrapidity. However, at very forward rapidity, valence quarks become important and the photon/pion ratio rises. Moreover, at high p_T again valence quarks becomes important and we have a sharp rise of the photon/pion ratio. In Fig. 3 right panel, we show the photon/pion ratio γ/π^0 as a function of p_T at various rapidities within the GBW model and pp collisions. The ratio γ/π^0 can be as big as $10 - 20$ at very forward rapidities $\eta = 8 - 7$ at LHC energy. Therefore, direct photon production extends to higher rapidities for a fixed p_T, see Figs. 3. Note that suppression of hadrons at very forward rapidity also ensures significant suppression of radiative decays of those hadrons. Therefore, measurements of direct photons at forward rapidities should be rather clean, as the background from radiative hadronic decays is significantly suppressed.