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Probing gluon number fluctuation effects in future electron–hadron colliders

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Abstract

The description of the QCD dynamics in the kinematical range which will be probed in the future electron–hadron colliders is still an open question. Although phenomenological studies indicate that the gluon number fluctuations, which are related to discreteness in the QCD evolution, are negligible at HERA, the magnitude of these effects for the next generation of colliders still should be estimated. In this paper we investigate inclusive and diffractive *ep* observables considering a model for the physical scattering amplitude which describes the HERA data. Moreover, we estimate, for the first time, the contribution of the fluctuation effects for the nuclear structure functions. Our results indicate that the study of these observables in the future colliders can be useful to constrain the presence of gluon number fluctuations.

Keywords: Quantum chromodynamics; QCD dynamics; Fluctuation effects

1. Introduction

In Quantum Chromodynamics (QCD) at high energies, fluctuation effects arise when pomeron loop equations are used to describe dipole evolution with increasing rapidity (see [1] and references therein). These equations correspond to a generalization of Balitsky–JIMWLK equations [2–10] and predict, in the fixed strong coupling case, the emergence of the diffusive

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scaling [1,11]. At sufficiently high energies, this new type of scaling washes out geometric scaling, a property predicted by the effective theory of Color Glass Condensate (CGC) [12] and observed in some experiments [13,14]. So far, only few phenomenological analyses looking for diffusive scaling behavior have been done. Inclusive [15–17] and diffractive [18] electron–proton deep inelastic scattering (DIS) at HERA have been investigated, the results indicating no evidence of fluctuation effects. These have also been studied in the analysis of the pseudo-rapidity distribution of hadron multiplicities of high energy Au + Au collisions at RHIC and in predictions for these observables in Pb + Pb collisions by using Color Glass Condensate dynamics at LHC/ALICE [19]. It has been found that the charged hadron multiplicities at central rapidity are significantly smaller than saturation based calculations and are compatible to those obtained on a study of multiplicities in the fragmentation region with running coupling corrections [20]. Finally, fluctuations have been investigated in $\gamma^{(*)}\gamma^{(*)}$ collisions at LEP and future e^+e^- colliders [21] and it has been found that although observing the presence of the fluctuation effects can be a hard task, they should not be disregarded in the description of some observables in future colliders.

Although fluctuations have been discarded by toy models which reproduce some of the main features of high energy evolution and scattering in QCD [22,23], in particular when running coupling corrections are included, it still lacks a similar treatment in real QCD. Then, it still seems to be important to look for fluctuations in different processes and experiments. In this way, and due to the fact that new electron–hadron colliders have been proposed – the Large Hadron Electron Collider (LHeC) at CERN [24] and the Electron Ion Collider (EIC) at RHIC [25] – in this paper we estimate the contribution of theses effects for inclusive and diffractive observables which will be probed in these future colliders.

The paper is organized as follows: in Section 2 the expressions for the observables of interest are presented. In Section 3 the procedure of including fluctuations in *ep* and *eA* DIS is described in details. Section 4 is devoted to the results of the phenomenological analysis, as well as predictions in both processes, and the main conclusions are presented in Section 5.

2. DIS in the dipole frame

The photon–hadron interaction at high energy (small x) is usually described in the infinite momentum frame of the hadron in terms of the scattering of the photon off a sea quark, which is typically emitted by the small-x gluons in the proton. However, in order to describe inclusive and diffractive interactions and disentangle the small-x dynamics of the hadron wave function, it is more convenient to consider the photon–hadron scattering in the *dipole frame*, in which most of the energy is carried by the hadron, while the photon has enough energy to dissociate into a quark–antiquark pair, before the scattering. The probing projectile fluctuates into a quark–antiquark ($q\bar{q}$) pair, a *dipole*, with transverse separation $\boldsymbol{r}$ long before the interaction, which then scatters off the target [26]. The main motivation to use this color dipole approach is that it gives a simple unified picture of inclusive and diffractive processes. In this particular frame, the DIS total cross section factorizes and can be written as

$$\sigma_{T,L}(x,Q^2) = \int dz\, d^2r\, \left|\psi_{T,L}(z,\boldsymbol{r},Q^2)\right|^2 \sigma_{dh}(\boldsymbol{r},x), \tag{1}$$

where Q^2 is the photon virtuality, z $(1-z)$ is the momentum fraction of the photon carried by the quark (antiquark) of the dipole and $\boldsymbol{r}$ is the transverse size of the dipole. $\psi_{T\,(L)}(z,\boldsymbol{r},Q^2)$ is the wave function which describes the splitting of a transverse (longitudinal) photon into the dipole,