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The gluon condensation at high energy hadron collisions

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Abstract

We report that the saturation/CGC model of gluon distribution is unstable under action of the chaotic solution in a nonlinear QCD evolution equation, and it evolves to the distribution with a sharp peak at the critical momentum. We find that this gluon condensation is caused by a new kind of shadowing–antishadowing effects, and it leads to a series of unexpected effects in high energy hadron collisions including astrophysical events. For example, the extremely intense fluctuations in the transverse-momentum and rapidity distributions of the gluon jets present the gluon-jet bursts; a sudden increase of the proton–proton cross sections may fill the GZK suppression; the blocking QCD evolution will restrict the maximum available energy of the hadron–hadron colliders.

1. Introduction

The planning of high-energy proton–proton colliders, such as very large hadron collider (VLHC) [1] and the upgrade in a circular e^+e^- collider (SppC) [2] will provide a nice opportunity to discover new phenomena of nature. The hadron collider with the center-of-mass energy of hundred TeV order may probe the parton distribution functions (PDFs) in several currently unexplored kinematical regions. In such ultra low-x region, the PDFs maybe beyond our

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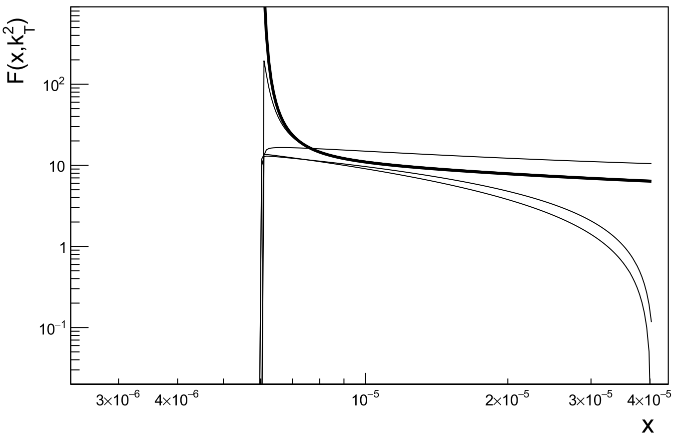

Fig. 1. x-Dependence of $F(x, k_T^2)$ using the GBW input with different momenta (from top on the right) $k_T^2 = 1$, $0.668, 0.654, 10$ and 50 GeV^2, where the thick line ($k_T^2 = k_c^2 = 0.654$ GeV^2) presents the antishadowing effect. This figure shows that the gluons at $x < x_c = 6 \times 10^{-6}$ converge to a state with $k_c^2 = 0.654$ GeV^2 at $x_c = 6 \times 10^{-6}$.

expectations. Therefore a new exploration of the PDFs in the proton is necessary for any future higher-energy hadron colliders.

The gluon density in nucleon grows with decreasing Bjoeken variable x (or increasing energy $\sqrt{s}$) according to the linear DGLAP Dokshitzer–Gribov–Lipatov–Altarelli–Parisi (DGLAP) [3,4] and Balitsky–Fadin–Kuraev–Lipatov (BFKL) [5] equations, where the correlations among the initial gluons are neglected. At a characteristic saturation momentum $Q_s(x)$, the nonlinear recombination of the gluons becomes important and leads to an eventual saturation of parton densities [6]. This state is specified as the color glass condensate (CGC) [7], where "condensate" implies the maximum occupation number of gluons is $\sim 1/\alpha_s$, although it lacks a characteristic sharp peak in the momentum distribution.

Recently, Zhu, Shen and Ruan proposed a modified BFKL equation in [8,9] (see Eq. (2.1)), where the nonlinear evolution kernels are constructed by the self-interaction of gluons as similar to the Balitsky–Kovchegov (BK) equation [10] and Jalilian-Marian–Iancu–McLerran–Weigert–Leonidov–Kovner (JIMWLK) equation [11], but the former keeps the nonlinear BFKL-singular structure. Using the available saturation models as input, the new evolution equation presents the chaos solution with positive Lyapunov exponents [12], and it predicts a new kind of shadowing caused by chaos, which stops the QCD evolution after a critical small x_c. This unexpected result implies that the predicted saturation state by the BK/JIMWLK dynamics is unstable at the small x range.

In this work, we study continually the properties of this new evolution equation. We report that chaos in this equation converges gluons to a state at a critical momentum. This distribution with a stable sharp peak indicates that it is the gluon condensation (see Figs. 1 and 2). We present the evolution process from a saturated input to the gluon condensed state in Sec. 2. We find that the chaotic oscillations of the gluon density raise both the strong negative and positive nonlinear corrections. The former shadows the grownup of the gluon density, while the later is the antishadowing effect. The antishadowing as a positive feedback process increases rapidly the gluon density. Thus, we observed the gluon condensation at the critical momentum (x_c, k_c).

The sharp peak in the gluon distribution is higher than the normal distribution by several orders of magnitude due to a lot of gluons accumulated in a narrow momentum space. The gluon