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Gluon saturation beyond (naive) leading logs

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Abstract

An improved version of the Balitsky–Kovchegov equation is presented, with a consistent treatment of kinematics. That improvement allows to resum the most severe of the large higher order corrections which plague the conventional versions of high-energy evolution equations, with approximate kinematics. This result represents a further step towards having high-energy QCD scattering processes under control beyond strict Leading Logarithmic accuracy and with gluon saturation effects.

Keywords: High-energy scattering in QCD; Gluon saturation

1. Introduction

Hadronic collisions at very high energy are involving partons with very small momentum fraction in the hadronic wave-functions. Due to the high occupancy of these wee partons (mostly gluons), the phenomenon of gluon saturation occurs: multiple parton scattering is typical, and accompanied by strong color coherence effects. Hence, the collinear factorization (and other standard perturbative QCD formalisms) which involves only one parton from each colliding hadron does not capture the typical physics of collisions in the high-energy limit, with only a semi-hard momentum transfer.

Instead, the coherent multiple scattering effects are taken into account straightforwardly when describing the wee gluons inside each highly boosted hadron as a semi-classical gluon field (see Ref. [1] and references therein). The main formalism based on this idea is the Color-Glass-Condensate effective theory (CGC). Each ultra-relativistic nucleus is described by a random classical shockwave gluon field with a classical statistical distribution, and QCD quantum corrections

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are resummed within leading logarithmic accuracy (LL) at small momentum fraction by the JIMWLK evolution of the gluon field distribution. The JIMWLK functional equation can also be written as Balitsky's infinite hierarchy of equations.

Inclusive enough observables, like DIS structure functions at low x_{Bj} or single inclusive particle production at forward rapidity in pA collisions, can be expressed in terms of the scattering amplitude of a color dipole on the gluon field of the target. For this object, the Balitsky–Kovchegov (BK) equation [2–4] gives a safe approximation of the full JIMWLK equation. Adding running coupling effects to the BK equation [5,6] leads to a successful phenomenological description of DIS data at HERA [7,8] within the CGC, as well as of forward particle production at the RHIC [9].

In the recent years, the calculation of NLO corrections in that framework has been a hot topic. After the running coupling corrections [5,6], the full set of NLO corrections to the BK equation have been calculated [10]. Later, the calculation of the NLO corrections has been performed for the *impact factor* or *coefficient function* both in the case of DIS structure functions [11,12] and of forward hadron production in pA collisions [13]. Moreover, the calculation of the NLO corrections to the JIMWLK equation are being finalized [14,15].

Unfortunately, these NLO calculations cannot be used, in the form in which they are now available, to perform phenomenological studies at full NLO accuracy. Indeed, the BK equation at NLO suffers from the same problem as its linear version, the BFKL equation at NLO [16,17]: some of the NLO corrections are pathologically large and lead an instability of the solutions. This signals a breakdown of the perturbative expansion as done usually in the Regge limit. The large NLO corrections are due to the inability of the standard perturbative expansion in the Regge limit to provide results matching smoothly with DGLAP physics in the collinear and in the anticollinear regimes [18]. Hence, the large higher order corrections to the BFKL and BK equations can be resummed to all orders by performing an appropriate matching with the DGLAP equation at LO (or beyond) in the collinear and in the anticollinear regimes [18]. That program has been completed for the BFKL equation both in momentum space [19] and in Mellin space [20]. However, the BK equation is more naturally written in mixed space. The generalization of that resummation to the case of the BK equation requires a significant effort mostly due to the translation to mixed space, and to a lesser extent due to the nonlinearity of the BK equation.

Among the large higher order corrections to be resummed, the ones of purely kinematical origin are the most severe, but also the easiest to deal with [18]. In Section 2 of this contribution, the NLO impact factors for DIS [12] are analysed to understand why such kinematical issues arise. And in Section 3, an improved version of the BK equation at LO is proposed, which realizes the resummation of these large kinematical higher order corrections. It corresponds to the mixed space[1] analog of the kinematical constraint [21–23] in momentum space. It also represents a first step towards a full resummation providing a fully stable and reliable version of the BK equation at NLO.

2. Diagnosing kinematical issues from the explicit NLO impact factors for DIS

The DIS structure functions are linear combinations of the total cross sections for the scattering of a transverse or longitudinal virtual photon off the target, which at strict NLO accuracy in the CGC can be written as [12] (see also [11])

[1] In mixed space, the kinematics of partons is described by their light-cone momentum k^+ and their transverse position $\mathbf{x}$.