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Structure of chromomagnetic fields in the glasma

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Abstract

The initial stage of a heavy ion collision is dominated by nonperturbatively strong chromoelectric and chromomagnetic fields. The spatial Wilson loop provides a gauge invariant observable to probe the dynamics of the longitudinal chromomagnetic field. We discuss recent results from a real time lattice calculation of the area-dependence of the expectation value of the spatial Wilson loop. We show that at relatively early times after the collision, a universal scaling as a function of the area emerges at large distances for very different initial conditions, with a nontrivial critical exponent. A similar behavior has earlier been seen in calculations of the gluon transverse momentum spectrum, which becomes independent of the initial spectrum of gauge fields. We also show the distribution of eigenvalues of the spatial Wilson loop and the fluctuations of its real and imaginary parts.

Keywords: Color glass condensate; Chromomagnetic field

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1. Introduction

The initial stages of a heavy ion collision are dominated by nonperturbatively strong gluonic fields. These fields are characterized by a momentum and length scale generated by nonlinear gluonic interactions, the saturation scale Q_s. In the “Color Glass Condensate” (CGC) effective theory description of QCD, the initial “glasma” [1] chromomagnetic and chromoelectric fields

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are predominantly longitudinal [1,2]. Because of the large ($\sim 1/\alpha_s$) occupation numbers of the gluonic states the glasma fields are essentially classical, and obey the Yang–Mills equations of motion. From these equations their time dependence can be solved either analytically in an expansion in the field strength [3] or numerically on a lattice [4,5]. Most earlier numerical studies have concentrated on the gluon spectrum, obtained from Coulomb gauge-fixed field correlators. It would, however, be interesting to have an independent, manifestly gauge invariant way to study the dynamics of the softer field modes $k_T \lesssim Q_s$. One possibility for such an observable, first studied in this context in Ref. [6], is the spatial Wilson loop. We will here discuss results from a more recent calculation [7] that extends this work in many ways, with $N_c = 3$ colors (instead of $N_c = 2$ in [6]), measurements over a larger range of areas and most importantly a more systematical comparison of different initial conditions for the equations of motion, provided by different CGC parametrizations of the two colliding nuclei. We stress that this work concerns the detailed structure of the boost invariant background fields and does not include their unstable quantum fluctuations that eventually lead to an isotropization of the system [8].

2. Classical Yang–Mills

Before the collision the individual fields of projectile and target are two-dimensional pure gauges; in light cone gauge,

$$\alpha^i_m(\mathbf{x}_T) = \frac{i}{g} V_m(\mathbf{x}_T)\partial^i V^\dagger_m(\mathbf{x}_T) \tag{1}$$

where $m = 1, 2$ labels the projectile and target, respectively. Here V_m are light-like $\mathrm{SU}(N_c)$ Wilson lines that describe the propagation of a lightlike probe through the color field; thus they can be related to e.g. the DIS cross section. In the CGC they are stochastic variables drawn from some probability distribution. We have in this calculation compared results from three well-motivated possibilities for this probability distribution. The first one is the MV model [9], where the Wilson lines are obtained from a classical color charge density ρ as

$$V(\mathbf{x}_T) = \mathbb{P}\exp\left\{ i \int \mathrm{d}x^- g^2 \frac{1}{\boldsymbol{\nabla}^2_T} \rho^a\left(\mathbf{x}_T, x^-\right)\right\}, \tag{2}$$

where $\mathbb{P}$ denotes path-ordering in x^-. In the MV model the densities ρ are assumed to have a local Gaussian distribution parametrized by a single dimensionful parameter μ, related to the saturation scale as $Q_s \sim g^2\mu$. The numerical implementation of the MV model in this context is described in detail in Ref. [5].

At higher collision energies one needs to resum large corrections of order $\alpha_s \ln s$ from additional gluon bremsstrahlung. In the CGC framework this is achieved by the JIMWLK renormalization group equation, which describes the dependence of the probability distribution of the Wilson lines on $y \equiv \ln\sqrt{s}$. The two other probability distributions studied in this work result from solving the JIMWLK equation with either fixed or running QCD coupling, with the MV model as an initial condition. For details on the numerical procedure used to do this we refer the reader to Refs. [10].

3. Results

Let us start by a reminder of earlier results for the gluon spectrum [11], shown in Fig. 1 (left). What was observed was the following: in the dilute $p_T \gtrsim Q_s$ regime where final state interactions are relatively weak, the spectrum depends on the initial conditions, being harder with the