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JIMWLK evolution: From color charges to rapidity correlations

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Abstract

We study multi-particle production with rapidity correlations in high-energy p+A collisions. In the context of the Color Glass Condensate, the evolution for such correlations is governed by a generalization of the JIMWLK equation which evolves the strong nuclear fields both in the amplitude and in the complex conjugate one. We give the equivalent Langevin formulation, whose main ingredient is the color charge density linked to a projectile parton (a Wilson line).

Keywords: QCD; Renormalization Group; Color Glass Condensate; Hadronic Collisions

Multi-particle correlations in hadronic collisions at the RHIC and the LHC, and in particular long-range ones in pseudo-rapidity $\Delta\eta$, provide information about phenomena related to high-parton densities. Causality suggests that such correlations are built at early times and thus may contain data about the incoming hadronic wavefunctions, but they may be affected by final-state interactions and collective phenomena. For example, the 'ridge' in A+A collisions seems to be a combination of initial-state correlations in rapidity and final-state collective flow leading to azimuthal collimation. But such an interpretation has been questioned by the discovery of similar phenomena in p+A or even p+p collisions in events with high multiplicity, where strong final-state effects were a priori not expected. A difficulty in studying all such initial-state correlations is the lack of factorization for calculating multi-particle production in the presence of multiple

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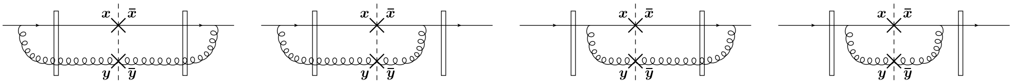

Fig. 1. The four diagrams for the production of a quark and a gluon at the same rapidity. A cross stands for each parton produced.

scattering. For p+A collisions, we proposed a solution to this problem [1] by constructing a suitable Langevin equation. (See [2–5] for previous related work.)

Consider quark–gluon production in the fragmentation region of the proton in p+A collisions. A quark from the proton with a large longitudinal momentum fraction scatters off the nucleus (a shockwave by Lorentz contraction) and emits a gluon, either before or after the scattering. The diagrams for the product of the direct amplitude (DA) and the complex conjugate one (CCA) are shown in Fig. 1. If the gluon is much softer than its parent quark, the cross-section can be computed by acting with the *soft gluon production Hamiltonian* on the *quark generating functional* [1]:

$$\frac{\mathrm{d}\sigma^{pA\to qgX}}{\mathrm{d}Y\,\mathrm{d}^2\boldsymbol{p}\,\mathrm{d}^2\boldsymbol{k}} = xq(x)\,\frac{1}{(2\pi)^4}\int \mathrm{d}^2\boldsymbol{x}\,\mathrm{d}^2\bar{\boldsymbol{x}}\,\mathrm{e}^{-\mathrm{i}\boldsymbol{p}\cdot(\boldsymbol{x}-\bar{\boldsymbol{x}})}\big\langle H_{\mathrm{prod}}(\boldsymbol{k})\,S^{<}_{\boldsymbol{x}\bar{\boldsymbol{x}}}\big|_{\bar{V}=V}\big\rangle_Y. \tag{1}$$

Here $\boldsymbol{p}$ and $\boldsymbol{k}$ are the transverse momenta of the quark and the gluon, Y is their common rapidity w.r.t. the valence d.o.f. of the target, $xq(x)$ is the collinear quark p.d.f. in the proton, and the other notations will be shortly explained.

To understand the *generating functional*, consider first quark-production, in which a large-x quark from the proton scatters off multiply the nucleus and acquires a transverse momentum $\boldsymbol{p}$. The single-inclusive yield is given by

$$\frac{\mathrm{d}N}{\mathrm{d}^2\boldsymbol{p}} = xq(x)\,\frac{1}{(2\pi)^2}\int \mathrm{d}^2\boldsymbol{r}\,\mathrm{e}^{-\mathrm{i}\boldsymbol{p}\cdot\boldsymbol{r}}\,\langle S_{\boldsymbol{x}\bar{\boldsymbol{x}}}\rangle_Y, \tag{2}$$

with $\boldsymbol{r}\equiv\boldsymbol{x}-\bar{\boldsymbol{x}}$. In the above $\langle S_{\boldsymbol{x}\bar{\boldsymbol{x}}}\rangle_Y$ is the S-matrix for a fictitious quark–antiquark dipole scattering off the nucleus, in which the quark leg at $\boldsymbol{x}$ is the physical quark in the DA, while the antiquark leg at $\bar{\boldsymbol{x}}$ is the physical quark in the CCA. The charge of each fermion undergoes color precession in the target field and if the projectile is a right-mover with light-cone time x^+, the S-matrix *operator* (corresponding to a given configuration of the target field A^-) reads

$$S_{\boldsymbol{x}\bar{\boldsymbol{x}}}[V]\equiv(1/N_c)\,\mathrm{tr}\big\{V^\dagger_{\boldsymbol{x}}V_{\bar{\boldsymbol{x}}}\big\}\quad\text{with } V^\dagger_{\boldsymbol{x}}=\mathrm{P}\exp\bigg[\mathrm{i}g\int \mathrm{d}x^+\,A^-_a\big(x^+,\boldsymbol{x}\big)t^a\bigg], \tag{3}$$

where $V^\dagger_{\boldsymbol{x}}$ and $V_{\bar{\boldsymbol{x}}}$ are Wilson lines describing the color precession in the DA and respectively the CCA. The physical S-matrix follows after averaging over all the configurations of A^- with the CGC weight function $W_Y[A^-]$ [6]:

$$\langle S_{\boldsymbol{x}\boldsymbol{y}}\rangle_Y=\int \mathcal{D}A^-\,W_Y\big[A^-\big]\,(1/N_c)\,\mathrm{tr}\big\{V^\dagger_{\boldsymbol{x}}V_{\boldsymbol{y}}\big\}. \tag{4}$$

The color fields A^- which matter for this process represent small-x gluons, i.e. gluons close to the rapidity of the produced quark and hence are widely separated in rapidity from the valence d.o.f. the nucleus. The CGC weight function $W_Y[A^-]$ encodes this nonlinear (due to parton saturation) evolution as given by the JIMWLK equation [6].