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Azimuthal anisotropy from Color Glass Condensates in proton–nucleus collisions

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Abstract

We explore the detailed structure of *the ridge* in the Color-Glass-Condensate (CGC) effective field theory of QCD. In particular, we study multiple scattering corrections to *both* the jet and Glasma contributions in a self-consistent framework of dilute–dense collisions.

Keywords: Color Glass Condensate; Proton–nucleus; Ridge

1. Introduction

One of the widely discussed topics at Quark Matter 2014 was the observed long-range azimuthal correlations in high-multiplicity p+Pb and p+p collisions and its markedly similar structure to Pb+Pb collisions. The physics responsible for the azimuthal correlation remains an open question; when answered it may provide us with a wealth of information ranging from the nature of the medium produced in heavy-ion collisions, insight into the mechanism behind thermalization of highly non-equilibrium fields, and information on the small-x degrees of freedom in the nuclear wave-function and the accompanying onset of gluon saturation.

The structure of the azimuthal correlations between pairs of hadrons separated by a rapidity gap of at least one unit (from here on referred to as *the ridge*) can be quantitatively explained in

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the Color-Glass-Condensate (CGC) effective field theory [1] of QCD. In a series of works [2–6] a phenomenology of two-particle correlations was developed which incorporated mini-jet production explaining the recoiling jet seen on the away-side ($\Delta\phi = \pi$ where $\Delta\phi$ is the azimuthal angle between the pair) and particle production from α_s^{-8} enhanced *Glasma* graphs [7–10] responsible for a double-peaked (*i.e.* symmetric with respect to $\Delta\phi = \pi/2$) ridge structure.

Some of the non-trivial systematics of the ridge that are understood within this framework include *a*) self-consistent explanation of the ridge in *both* p+p and p+Pb collisions; *b*) the transverse momentum dependence of the ridge yield above 1 GeV (where the above framework is applicable) *c*) the ridge yield with respect to the event activity (*i.e.* centrality); and *d*) the more rapid rise in ridge yield in high multiplicity p+Pb compared to the increase seen in p+p as a function of the charged particle multiplicity.

Since the original discovery of the ridge in p+p [11] and p+Pb [12,13] collisions there has been a wealth of additional experimental analyses. For example, data on the species dependence of mean $p_\perp$ [14] and two-particle correlations [15] alludes to a build-up of radial flow in high-multiplicity collisions from the observed mass ordering of the mean $p_\perp$ as demonstrated by hydrodynamic simulations [16,17]. However, the fact that the mass splitting persists to low-multiplicity p+Pb *and* peripheral p+p collisions suggests that the mechanism responsible for the species dependence may instead stem from hadronization (see [18] for one such model).

The CMS Collaboration has done an analysis of the four-particle cumulant [19] and showed for the first time at this meeting [20] results for $v_2\{6, 8, \mathrm{LYZ}\}$ in high-multiplicity p+Pb collisions. However, such seemingly *flow-like* correlations can also be found in perturbative calculations as demonstrated by the consideration of multi-particle production from Pomeron exchange [21]. A comprehensive study of multi-particle correlations in the Glasma framework has yet to be completed.

The observation of a non-vanishing third Fourier harmonic (*i.e.* triangular flow) in the angular distribution is crucial to disentangling initial from final-state descriptions (*e.g.* all odd harmonics vanish for Glasma diagrams while the jet-graph produces a small negative third harmonic). In [19] it was found that v_3 was positive and increased with centrality. Unfortunately, the calculation of these quantities in our framework is tricky as it relies on *a*) an understanding of the underlying event which enters into the denominator; and *b*) soft physics as the reference particle lies in the range $0.3 < p_T < 3.0$ GeV. To circumvent these issues we instead examine the triangular anisotropy when both particles are semi-hard using a different quantity, a_3, defined from the per-trigger di-hadron yield as

$$\frac{1}{N_{\mathrm{trig}}}\frac{d^2N}{d\Delta\phi} = a_0 + 2\sum_{n=1} a_n \cos(n\Delta\phi), \tag{1}$$

where $\Delta\phi$ is the azimuthal angle between charged hadrons. Fig. 1 shows the extracted a_3 from the available CMS data. The left plot shows that for semi-hard di-hadrons the third harmonic changes from slightly negative (indicative of jet production) to large and positive at high centrality. The right plot shows that for an associated particle between 1–2 GeV the third harmonic remains sizable out to a p_T as large as 6 GeV; a very high momentum for hydrodynamics to still be applicable.

This work considers multiple scattering corrections to both jet and Glasma diagrams in a self-consistent framework that would naturally include the quantum interference between the two matrix elements. Numerical simulations of classical Yang–Mills has shown that a non-vanishing v_3 can develop as the system evolves in time [22]. Our goal is to examine a related question, of how multiple scattering in dilute–dense collisions modifies the two-particle correlation.