

Sensitivity of Azimuthal Jet Tomography to Early Time Energy-Loss at RHIC and LHC

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Abstract.

We compute the path-length dependence of energy-loss for higher azimuthal harmonics of jet-fragments in a generalized model of energy-loss that can interpolate between pQCD and AdS/CFT limits and compare results with Glauber and CGC/KLN initial conditions. We find, however, that even the high- p_T second moment is most sensitive to the poorly known early-time evolution during the first fm/c. Moreover, we demonstrate that quite generally the energy and density-dependence leads to an overquenching of high- p_T particles relative to the first LHC R_{AA} -data, once the parameters of the energy-loss model are fixed from R_{AA} -data at RHIC.

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1. Introduction

Heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC) indicate the production of an opaque (i.e. strongly jet-suppressing) [1], fast-thermalizing medium. However, so far neither the initial conditions of the collisions nor the microscopic dynamics of the jet-energy loss are conclusively understood.

To characterize the initial conditions, one usually uses either the Glauber model, describing incoherent superpositions of proton-proton collisions, or the ‘‘Color Glass Condensate’’ (CGC), given e.g. by the KLN model, where saturation effects are taken into account [2]. On the other hand, the jet-energy loss can either be described as multiple scatterings of the hard parton [3], specific of a weakly-coupled pQCD medium, or using the AdS/CFT correspondence where the problem of a parton stopped in a thermal medium is related to the problem of a string falling into a 5-dimensional black hole [4].

Focussing on the different path-length dependences of $dE/dx \sim l$ for pQCD [3] (as it occurs in the presence of coherence effects like in the high-density LPM limit) and $dE/dx \sim l^2$ for AdS/CFT calculations [4], the first simple jet absorption model that simultaneously describes the $R_{AA}(N_{part})$ and the $v_2(N_{part})$ at RHIC energies for high- p_T particles was given in Refs. [5]. It showed that after fixing the coupling such that the

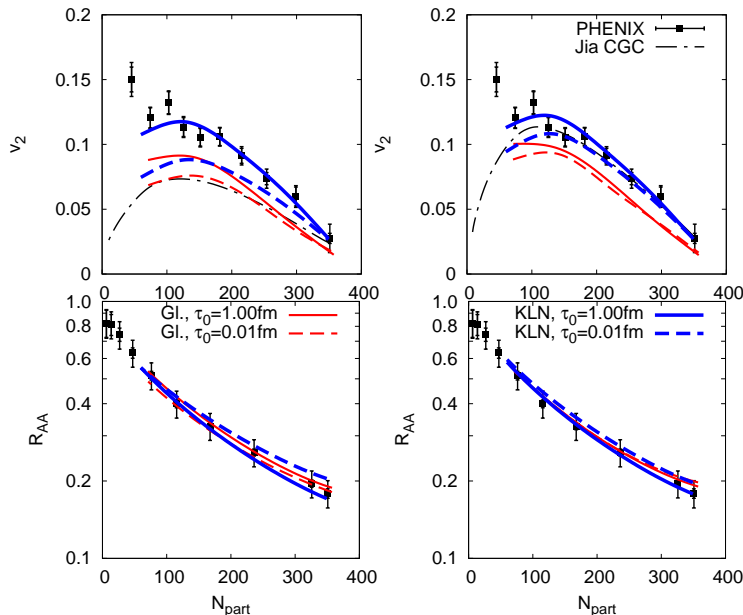


Figure 1. R_{AA} and v_2 as a function of N_{part} at a $p_T = 10$ GeV and RHIC energies for Glauber (red lines) and KLN (blue lines) initial conditions. The initialization time is either $\tau_0 = 1$ fm (solid lines) or $\tau_0 = 0.01$ fm (dashed lines). The data and the black dashed-dotted line are taken from Refs. [5].

most central data point for R_{AA} is reproduced, the $R_{AA}(N_{part})$ can be described for both pQCD and AdS/CFT-like energy loss. However, in case of a pQCD-like energy loss, the $v_2(N_{part})$ is underpredicted for both Glauber and CGC initial conditions, while for an AdS/CFT-like energy loss and CGC initial conditions, the $v_2(N_{part})$ can be well described.

Here we want to examine if a generic energy-loss ansatz that includes both a path-length and an energy dependence confirms the above conclusion that only CGC/KLN initial conditions and an AdS/CFT energy-loss can describe both the $R_{AA}(N_{part})$ and the $v_2(N_{part})$ appropriately.

2. Jet Tomography

Since all dependences on the intrinsic scales of the system (T_c, Λ_{QCD} , etc.) disappear in the high-temperature limit, a generic energy-loss rate dE/dx is given by an arbitrary combination of dimensionful parameters constrained by the total dimension of the observable and the requirement that faster particles and hotter media result in a bigger suppression. We choose [6]

$$\frac{dE}{dx}(\vec{x}_0, \phi, \tau) = -\kappa P^a \tau^z T^{z-a+2} [\vec{x}_0 + \hat{n}(\phi)\tau, \tau], \quad (1)$$

where κ is the coupling, P is the momentum of the jet(s) considered and a, z are parameters controlling the jet energy (momentum) and path-length dependence, respectively. In the Bethe-Heitler limit $a = 1$ and $z = 0$, while in the deep LPM pQCD

limit $a \sim 0$ and $z \sim 1$. If $a = 0$ and $z = 2$, our model coincides with the model referred to as "AdS/CFT" in Refs. [5]. However, on-shell AdS/CFT calculations [4] show that $a = 1/3$ and $z = 2$, thus we are going to consider $a = 1/3$ throughout the whole paper. In a static medium, $dE/dx \sim \tau^z$, while in a dynamic medium, dE/dx will acquire additional powers of τ due to the dependence of temperature on τ . Here, we assume a 1D Bjorken expansion. In contrast to Refs. [5], κ is a dimensionless parameter. It is always fitted to reproduce the most central value for R_{AA} at RHIC energies.

Choosing $\tau_0 = 1$ fm, in line with recent hydrodynamic calculations [7], we see (cf. Fig. 1) that CGC/KLN initial conditions get close to the RHIC data for both pQCD and AdS/CFT-like energy loss, while Glauber initial conditions underpredict the data. However, choosing a much smaller τ_0 (in Refs. [5], $\tau_0 = 0$ fm), the $v_2(N_{part})$ is reduced for both pQCD and AdS/CFT-like energy loss, increasing the difference between the pQCD and AdS/CFT results as seen in Refs. [5], and raising the question of the physical meaning of τ_0 .

Setting $\tau_0 = 1$ fm means to assume that there is no energy loss within the first fm. pQCD does not give any excuse for this assumption and thus $\tau_0 = 0$ fm would be a natural assumption. However, τ_0 also describes the formation time of hydrodynamics which seems to be $\tau_0 \sim 1$ fm [7]. On the other hand, setting $\tau_0 = 1$ fm is also equivalent to the AdS/CFT result that the energy loss is suppressed at early times. Please note that for AdS/CFT the $dE/dx \sim l^2 \sim \tau^2$ dependence leads to a suppressed energy loss at early times where the suppression is larger than in the pQCD case with $dE/dx \sim l \sim \tau$.

Thus, it is important to see that the v_2 of high- p_T particles is sensitive to short-distance properties, suggesting that there is either weak coupling with a $\tau_0 \sim 1$ fm or strong coupling which in itself features the suppression of energy loss at early times.

Calculating the nuclear modification factor and elliptic flow for pions at LHC energies while keeping the values for a and κ fixed compared to RHIC energies, leads to an underprediction of the R_{AA} as a function of centrality as shown in Fig. 2 for both pQCD and AdS/CFT-like energy loss and different values of the initialization time τ_0 . This is a puzzle common to all density-dependent energy-loss prescriptions [cf. Eq. (1)], as discussed in Ref. [9].

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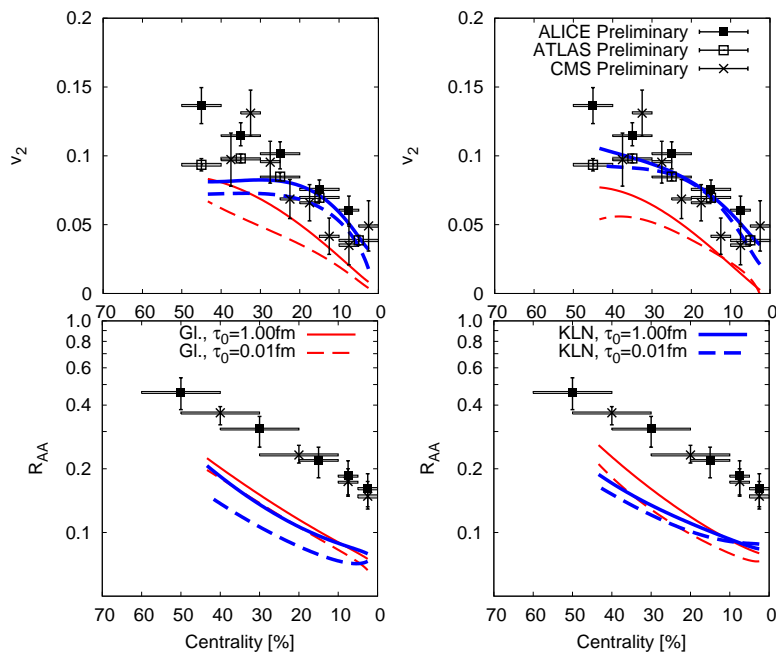


Figure 2. R_{AA} and v_2 as a function of centrality at a $p_T = 10$ GeV and LHC energies for Glauber (red lines) and KLN (blue lines) initial conditions. The initialization time is either $\tau_0 = 1$ fm (solid lines) or $\tau_0 = 0.01$ fm (dashed lines). The data are taken from Refs. [8] for the p_T bin just below 10 GeV.

References

- [1] I. Arsene *et al.* [BRAHMS Collaboration], Nucl. Phys. A **757**, 1 (2005); B. B. Back *et al.*, Nucl. Phys. A **757**, 28 (2005); J. Adams *et al.* [STAR Collaboration], Nucl. Phys. A **757**, 102 (2005); K. Adcox *et al.* [PHENIX Collaboration], Nucl. Phys. A **757**, 184 (2005).
- [2] M. L. Miller, K. Reygers, S. J. Sanders and P. Steinberg, Ann. Rev. Nucl. Part. Sci. **57**, 205 (2007); E. Iancu and R. Venugopalan, arXiv:hep-ph/0303204; H. J. Drescher, A. Dumitru, C. Gombeaud and J. Y. Ollitrault, Phys. Rev. C **76**, 024905 (2007).
- [3] M. Gyulassy and X. n. Wang, Nucl. Phys. B **420**, 583 (1994); M. Gyulassy, P. Levai and I. Vitev, Phys. Rev. Lett. **85**, 5535 (2000); R. Baier, Y. L. Dokshitzer, A. H. Mueller, S. Peigne and D. Schiff, Nucl. Phys. B **484**, 265 (1997); U. A. Wiedemann, Nucl. Phys. B **588**, 303 (2000); P. B. Arnold, G. D. Moore and L. G. Yaffe, JHEP **0111**, 057 (2001).
- [4] S. S. Gubser, D. R. Gulotta, S. S. Pufu and F. D. Rocha, JHEP **0810**, 052 (2008); P. M. Chesler, K. Jensen, A. Karch and L. G. Yaffe, Phys. Rev. D **79**, 125015 (2009); P. M. Chesler, K. Jensen and A. Karch, Phys. Rev. D **79**, 025021 (2009); P. Arnold and D. Vaman, JHEP **1104**, 027 (2011).
- [5] A. Drees, H. Feng and J. Jia, Phys. Rev. C **71**, 034909 (2005); J. Jia and R. Wei, Phys. Rev. C **82**, 024902 (2010); A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **105**, 142301 (2010); J. Jia, W. A. Horowitz and J. Liao, arXiv:1101.0290 [nucl-th].
- [6] B. Betz, M. Gyulassy and G. Torrieri, arXiv:1102.5416 [nucl-th].
- [7] H. Song, S. A. Bass, U. W. Heinz, T. Hirano and C. Shen, Phys. Rev. Lett. **106**, 192301 (2011).
- [8] H. Appelshäuser [ALICE Collaboration], these proceedings; R. Snellings [ALICE Collaboration], these proceedings; J. Jia [ATLAS Collaboration], these proceedings; Y.-J. Lee [CMS Collaboration], these proceedings; J. Velkovska [CMS Collaboration], these proceedings; CMS Collaboration, Physics Analysis Summary (PAS), <http://cdsweb.cern.ch/record/1347788?ln=en>.
- [9] W. A. Horowitz and M. Gyulassy, arXiv:1104.4958 [hep-ph].