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Nuclear and Particle Physics Proceedings 289–290 (2017) 359–362
www.elsevier.com/locate/nppp

The angular structure of jet quenching within a hybrid strong/weak coupling model

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Abstract

Building upon the hybrid strong/weak coupling model for jet quenching, we incorporate and study the effects of transverse momentum broadening and medium response of the plasma to jets on a variety of observables. For inclusive jet observables, we find little sensitivity to the strength of broadening. To constrain those dynamics, we propose new observables constructed from ratios of differential jet shapes, in which particles are binned in momentum, which are sensitive to the in-medium broadening parameter. We also investigate the effect of the back-reaction of the medium on the angular structure of jets as reconstructed with different cone radii R. Finally we provide results for the so called "missing-pt", finding a qualitative agreement between our model calculations and data in many respects, although a quantitative agreement is beyond our simplified treatment of the hadrons originating from the hydrodynamic wake.

Keywords: jet quenching, holography, broadening, medium response

Introduction

The discovery that the quark-gluon plasma (QGP) created in heavy ion collisions behaves as a strongly coupled fluid has opened a rich window of phenomenology for holographic techniques. One of the most useful tools to study the properties of the QGP is given by the analysis of the modification of high energy jets that traverse the exploding fireball. The evolution of these energetic excitations within medium is governed by a wide range of scales, from the hard virtuality of the perturbative production and consequent branching, to the relatively low temperature of the plasma that interacts strongly with the jet.

Based on this observation we have developed a model for jet quenching that incorporates aspects of weak and strong coupling physics applied at the scale where they are expected to be valid [1, 2, 3]. The core assumptions around which the construction of the model is performed are basically two. First, the evolution of the parton shower follows the DGLAP equations due to the decoupling of virtuality and temperature scales, and second, between splittings the partons interact strongly with the QGP by transferring energy and momentum to it as dictated by semiclassical string calculations derived in gauge/gravity duality [4, 5].

The simple and phenomenological approach taken in this one-parameter hybrid model has allowed for a systematic comparison against experimental data (see for instance photon-jet comparison in [6]), providing insights into the relevance of the different physical mechanisms that potentially play a role in the jet/plasma interplay. We present next an analysis of the effects that transverse momentum broadening and medium response to energy and momentum deposition induce on a selection of jet and intra-jet observables.

https://doi.org/10.1016/j.nuclphysbps.2017.05.083

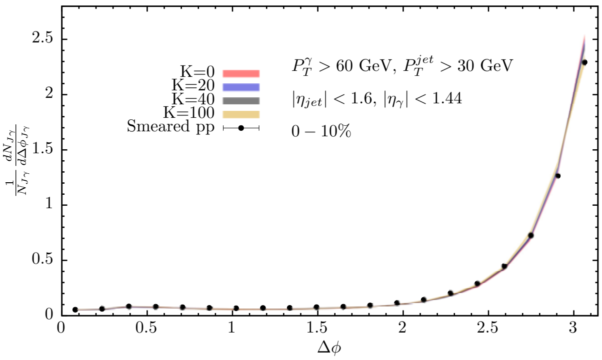

Figure 1: $\Delta\phi$ distributions in the transverse plane between an isolated photon and an anti-k_t jet with radius $R = 0.3$ satisfying the cuts, both for vacuum (smeared pp) and for the $0-10\%$ centrality class PbPb collisions. Different values of the broadening parameter K are explored.

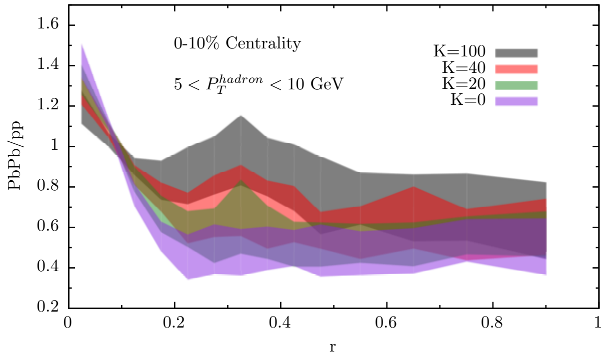

Figure 2: The ratio of PbPb over pp for the special jet shapes $\Psi^S_{P_T}(r)$ for $0 - 10\%$ centrality class. The jet sample is made of $R = 0.3$ subleading jets in a dijet pair, and the hadrons entering the histogram are restricted to be within the range $5 < P_T < 10$ GeV in order to focus the observable on those tracks for which the effects of broadening are large.

Transverse momentum broadening

In the strongly coupled limit there is no notion of scattering centers and no notion of multiple discrete transfers of momentum - the perturbative scheme under which a parton traversing a hot medium would experience transverse momentum broadening according to a Gaussian distribution. However, it has been shown in [7, 8] within the large 't Hooft coupling limit λ, that coloured excitations acquire transverse momentum following also a Gaussian distribution with a width $Q_\perp^2 = \hat{q}L$, where $\hat{q} \propto \sqrt{\lambda}T^3$. Given that at strong coupling there is no strong correlation between the dynamics generating transverse momentum broadening and that responsible for energy loss, we add to our model the free parameter K to gauge the width of the Gaussian distribution through $\hat{q} = KT^3$. Perturbative analyses of jet quenching have quoted a value of this parameter of roughly $K \sim 5$, while from strong coupling analyses one would expect $K \sim 20$ (more details in [3]).

Rather surprisingly at first, the sensitivity of standard observables to the inclusion of broadening mechanism (even for the extreme case $K = 100$) is fairly small. In Fig. 1 we show an example of such insensitivity captured by the photon-jet acoplanarity (the distribution in angular separation $\Delta\phi$ in the transverse plane between an isolated photon and the rest of the jets in the event which satisfy the momentum and pseudorapidity cuts). The already wide vacuum distribution, which differs from a δ function at $\Delta\phi = \pi$ due to initial state radiation, final state radiation and non-prompt photon contamination (besides experimental smearing effects), is barely modified by the medium contribution coming from the convolution with the transverse kicks Gaussian distribution. Actually, what one observes is a slight narrowing of the medium distributions as a consequence of energy loss, which results in a greater suppression of wider jets with more partonic activity, which are the jets that are more deflected, relative to narrower, less acoplanar, jets.

To study in-medium broadening, we have designed a special observable, that we shall call $\Psi^S_{P_T}(r)$, which shows a remarkable sensitivity to the broadening parameter K. It is shown in Fig. 2, and corresponds to a modified version of the PbPb over pp ratio of standard jet shapes, which quantifies the medium modification of the relative contribution to the total jet energy as a function of the angular separation r in the (ϕ, η) plane with respect to the jet axis. The jets entering the plot shown in Fig. 2 are the subleading jets in a dijet pair (with $P_T^L > 120$ GeV, $P_T^S > 30$ GeV and $\Delta\phi > 5\pi/6$) reconstructed using anti-k_t with jet radius $R = 0.3$. While the total energy of the jet is reconstructed using all tracks, we restrict the momentum range of the particles that enter the r distribution to be between $5 < P_T < 10$ GeV. The precise expression for this observable is

$$\Psi^S_{P_T}(r) \equiv \frac{1}{N_S}\frac{1}{\delta r}\sum_S \frac{\sum_{i\in r\pm\Delta r/2;\, P_T^{i,\mathrm{track}}\in \mathrm{range}} P_T^{i,\mathrm{track}}}{P_T^{\mathrm{jet}}}\,, \quad (1)$$

where N_S is the number of subleading jets entering the analysis and δr is the annulus width. This choice of the track momentum allows us to focus on tracks that are soft enough to receive a sizeable contribution from the transverse medium kicks while at the same time are hard enough to survive the strong quenching they experience through the plasma. (Although this argument is only valid at partonic level, the imprint of the described