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Boson-Jet Correlations in a Hybrid Strong/Weak Coupling Model for Jet Quenching in Heavy Ion Collisions

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Abstract

We confront a hybrid strong/weak coupling model for jet quenching to data from LHC heavy ion collisions. The model combines the perturbative QCD physics at high momentum transfer and the strongly coupled dynamics of non-abelian gauge theories plasmas in a phenomenological way. By performing a full Monte Carlo simulation, and after fitting one single parameter, we successfully describe several jet observables at the LHC, including dijet and photon jet measurements. Within current theoretical and experimental uncertainties, we find that such observables show little sensitivity to the specifics of the microscopic energy loss mechanism. We also present a new observable, the ratio of the fragmentation function of inclusive jets to that of the associated jets in dijet pairs, which can discriminate among different medium models. Finally, we discuss the importance of plasma response to jet passage in jet shapes.

Keywords: jets, quenching, AdS/CFT

1. Introduction

Jet quenching phenomena in heavy ion collisions involve processes occurring at a wide range of scales. The production and hard evolution of jets at high scales are well described by perturbative QCD. However, the interaction of the jet with QGP at a temperature not far above the transition temperature $T_c \sim \Lambda_{QCD}$ poses a serious challenge for current perturbative techniques. In fact, the collective properties of the plasma at this range of temperature are better described as a strongly coupled system than as a weakly coupled gas of quarks and gluons. It is then natural to expect non-perturbative physics to play an important role in the jet/plasma dialogue. The hybrid strong/weak coupling model developed in [1] takes into account these two facts by relying on holographic calculations for the description of this interplay, while treating the highly energetic parton branching perturbatively via DGLAP equations.

Currently there is no theoretical framework which can describe strong and weak coupling processes at different scales in a consistent manner. For this reason our model should be regarded as a phenomenological approach which exploits the big separation of scales from the virtuality to the temperature to combine the most relevant physical processes at each scale. Despite its simplicity, the model has proven to be a powerful tool in its confrontation with available measurements for various jet observables [1, 2], and in producing a broad range of definite predictions for LHC run II [2]. In these proceedings we extend the comparison carried out in [1, 2] by both confronting the model with ATLAS jet data and exploring new sets of observables.

2. A Hybrid Model

Two key ingredients underlie the construction of our hybrid model. First, soft medium exchanges are assumed not to change the virtuality of the partons sig-

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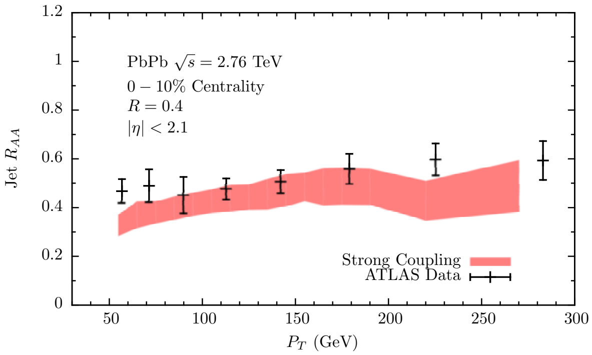

Figure 1: Jet R_{AA} for central events compared to ATLAS data [4]. The single parameter in the model was fitted previously to CMS jet R_{AA} data with different kinematical cuts [1, 2]. The band represents a combination of theoretical and experimental uncertainty.

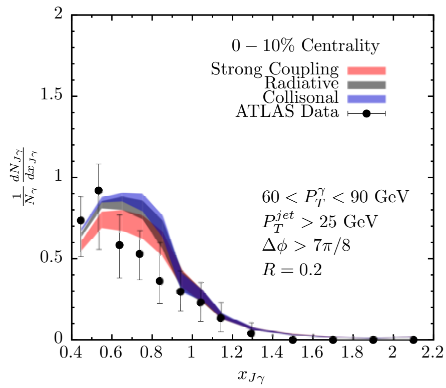

Figure 2: Photon-jet imbalance for central events for our hybrid strong/weak coupling model as well as the two control models to ATLAS data [6].

nificantly and, consequently, jet evolution proceeds as in vacuum. We assign a lifetime to each of the constituents of the shower by a formation time argument. Second, we supplement the shower with an energy loss per unit path length analogous to that of a hard quark propagating in a strongly coupled plasma as described in [3]. The rate of energy loss in this case is given by

$$\frac{1}{E_{in}}\frac{dE}{dx} = -\frac{4x^2}{\pi x_{stop}^2\sqrt{x_{stop}^2 - x^2}}\,, \tag{1}$$

$$x_{stop} = \frac{1}{2\kappa_{SC}}\frac{E_{in}^{1/3}}{T^{4/3}}\,, \tag{2}$$

with x_{stop}, the stopping distance of the parton, being the smallest matter thickness that results in a total parton energy loss. Within the gauge/gravity duality context, the E and T dependence of this quantity has been shown to be robust. However, κ_{SC} exhibits different parametric dependence for string based [3] and wave-packet based [5] computations. Nevertheless, for realistic values of the coupling, both these estimates for κ_{SC} yield values of $O(1)$. The model assumes that all the differences between the theories described by the duality and QCD can be absorbed in this quantity, which we consider to be a fitting parameter. Since the number of degrees of freedom of QCD is smaller than that of $\mathcal{N} = 4$ SYM, we expect κ_{SC} to be smaller than (but of order) 1.

To check the sensitivity of the observables tested to the precise energy loss mechanism, whose parametric dependence can be encapsulated using an energy loss rate, we consider the control models

$$\left(\frac{dE}{dx}\right)_{rad} = -\kappa_R\frac{C_R}{C_F}T^3x \qquad \left(\frac{dE}{dx}\right)_{coll} = -\kappa_C\frac{C_R}{C_F}T^2\,, \tag{3}$$

where κ_R and κ_C are also fitting parameters. These models are inspired by radiative and collisional energy loss rates, but are not aimed at superseding more sophisticated implementations of these mechanisms. We use them only as benchmarks.

To compare to experiments we have implemented this model into a Monte Carlo. We simulate hard jet production and subsequent parton evolution through PYTHIA [7]. Hard jet events are embedded into a heavy ion environment by distributing the production point across the transverse plane according to an optical Glauber Monte Carlo, and using a realistic hydrodynamic profile [8] to simulate the evolution of the QGP that will be explored by the partons of the shower.

3. Comparison with Data

In previous publications [1, 2] we fixed the fitting parameter κ_{SC} by comparing our Monte Carlo simulations to CMS jet R_{AA} data, for jets with $R = 0.3$ lying within $100 < p_T < 110$ GeV for 0-10% centrality class, obtaining the range $0.317 < \kappa_{SC} < 0.452$. With the value of its single parameter fixed, the model is able to reproduce the energy and centrality dependence of CMS jet measurements of the nuclear modification factor, dijet imbalance, fragmentation functions, photon jet asymmetry and the suppression of jets produced in association with a photon [1, 2].

Here, we present the comparison of our model to ATLAS jet data on inclusive jet suppression and photon jet imbalance. In Fig. 1 we show our model computations for R_{AA} for central events of jets with $R = 0.4$ within $|\eta| < 2.1$ as compared to ATLAS data [4]. Note that in the data points in Fig. 1 we add the systematic and statistical errors in quadrature. We have used the same value