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Jet quenching within a hybrid strong/weak coupling approach

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Abstract

We propose a novel hybrid model for jet quenching, including both strong and weak coupling physics where each seems appropriate. Branching in the parton shower is assumed to be perturbative and described by DGLAP evolution, while interactions with the medium result in each parton in the shower losing energy as at strong coupling, as realized holographically. The medium-modified parton shower is embedded into a hydrodynamic evolution of hot QCD plasma and confronted with LHC jet data.

Keywords: Jets; Quenching; AdS/CFT

1. Introduction

We describe a model for the energy loss of jets traversing a strongly coupled plasma [1]. This model relies on the separation of scales involved in the different physics regimes of relevance for the quenching dynamics. Since high energy jets are produced at a scale $Q \gg \Lambda_{QCD}$, the spectrum is assumed to be under good theoretical control. The consequent parton evolution consisting in the relaxation of this high virtuality parton through successive splittings is described by DGLAP

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equations. In between the splittings, the partons in the shower can interact with the medium, a plasma at a temperature $T \gtrsim \Lambda_{QCD}$ that is not high enough to ignore strong-coupling effects. The soft in-medium dynamics are modeled using insights obtained via gauge/gravity duality.

The energy loss rate of probes passing through a strongly coupled medium has been determined for several non-Abelian theories that have a holographic dual in terms of a gravitational description, to date not including QCD. For these theories, it is not yet possible to treat the hard splittings within the dual gravitational description, which means that the present lack of a holistic explanation motivates a phenomenological approach. We embed the jets from our hybrid model into an expanding hot QCD fluid and compare to LHC data for jet observables. For a detailed description of this hybrid approach see [1].

2. A hybrid model

We use PYTHIA [2] to generate hard processes at such high virtuality that changes in nuclear parton distribution functions can be neglected. Since the in-medium hadronization process is not under good theoretical control, we stay at the parton level. For the same reason, we will restrict ourselves to fully reconstructed high energy jet observables, which have limited sensitivity to hadronization effects.

Each parton traveling through the plasma will be given a formation time ($\tau_f = 2E/Q^2$), determining in this way the space–time structure of the complete shower. The expanding plasma is described by a hydrodynamic model whose realistic equation of state [3] does not have a precise critical temperature, the point below which the plasma is no longer strongly coupled and energy subtraction stops. Accordingly, the range $180 < T_c < 200$ MeV is taken to gauge our theoretical uncertainties. In our current implementation, we ignore quenching in the hadronic phase.

To every parton in the medium, we apply an energy loss rate based on the results of [6], where this quantity was calculated for a light quark traversing a slab of $\mathcal{N} = 4$ supersymmetric Yang–Mills plasma

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

E_{in} being the initial energy of the parton at its production point and x_{stop} its stopping distance. We determine the latter upon assuming the same dependence on energy and temperature as in the holographic calculation:

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

where we have introduced a dimensionless parameter κ_{SC} whose value is not under good theoretical control. The classical string based computation of [6] yields $\kappa'_{SC} = 1.05\lambda^{1/6}$, with $\lambda \equiv g^2 N_c$ the 't Hooft coupling. However, wave-packet based computations as in Ref. [7] yield a κ_{SC} that is a pure number of order unity, parametrically independent of λ. Furthermore, the purely numerical component of κ_{SC} should be less in QCD than in $\mathcal{N} = 4$ SYM theory, since QCD has fewer degrees of freedom at the same temperature. For these reasons, we will treat κ_{SC} as a dimensionless fitting parameter to be constrained by data.

No calculation of the rate of energy loss for gluons at strong coupling, along the lines of that for quarks in Ref. [6], has yet been done. Nevertheless, since the parametric dependence of the