Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 967 (2017) 508–511

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Holographic Jet Shapes and their Evolution in Strongly Coupled Plasma

Jasmine Brewer [1][a], Krishna Rajagopal[a], Andrey Sadofyev[a], Wilke van der Schee[a,b]

[a]Center for Theoretical Physics, MIT, Cambridge MA 02139, USA
[b]Institute for Theoretical Physics and Center for Extreme Matter and Emergent Phenomena, Utrecht University, Leuvenlaan 4, 3584 CE Utrecht, the Netherlands

Abstract

Recently our group analyzed how the probability distribution for the jet opening angle is modified in an ensemble of jets that has propagated through an expanding cooling droplet of plasma [1]. Each jet in the ensemble is represented holographically by a string in the dual 4+1- dimensional gravitational theory with the distribution of initial energies and opening angles in the ensemble given by perturbative QCD. In [1], the full string dynamics were approximated by assuming that the string moves at the speed of light. We are now able to analyze the full string dynamics for a range of possible initial conditions, giving us access to the dynamics of holographic jets just after their creation. The nullification timescale and the features of the string when it has nullified are all results of the string evolution. This emboldens us to analyze the full jet shape modification, rather than just the opening angle modification of each jet in the ensemble as in [1]. We find the result that the jet shape scales with the opening angle at any particular energy. We construct an ensemble of dijets with energies and energy asymmetry distributions taken from events in proton-proton collisions, opening angle distribution as in [1], and jet shape taken from proton-proton collisions and scaled according to our result. We study how these observables are modified after we send the ensemble of dijets through the strongly-coupled plasma.

Keywords: jets, holography

1. Introduction

The discovery that the quark-gluon plasma created in heavy-ion collisions at RHIC and the LHC is strongly coupled has generated immense theoretical interest and leaves many unanswered questions. Jets in heavy ion collisions can provide important insights into QCD and the quark-gluon plasma, since they provide access to the interactions of hard partons with the medium and incorporate physics at widely separated momentum scales. Holography has emerged in recent years as an important tool for studying the strongly-coupled quark gluon plasma. Although QCD does not have a dual theory in holography, and the available theory $\mathcal{N} = 4$ SYM is not asymptotically free, holography is nonetheless an important place to look for qualitative insights into how jets may interact with a strongly coupled plasma. In this work, we construct an ensemble of holographic jets with initial energy and opening angle distributions taken from perturbative QCD, and study how that ensemble is modified after it propagates through an expanding, cooling droplet of strongly coupled plasma. We calculate the jet shape and dijet asymmetry modifications of our ensemble by the plasma and compare our results to data measured by CMS in Refs [2] and [3].

---

[1] Speaker

http://dx.doi.org/10.1016/j.nuclphysa.2017.05.016

2. The Model

We consider a back-to-back pair of light quark jets losing energy as they propagate through an expanding, cooling droplet of strongly coupled $\mathcal{N} = 4$ SYM plasma. In the gravitational description, the dynamics of a pair of light quark jets is described by an open fundamental string whose endpoints shoot away from each other and then fall into a black hole in an additional dimension in Anti-de Sitter (AdS) spacetime. The depth of the black hole in the AdS direction sets the temperature of the plasma in the field theory, and string energy which falls into the black hole in the gravitational description is energy lost by the quark-antiquark pair to thermalization by the plasma. The 5-dimensional metric in AdS which corresponds to a constant-temperature plasma in the 4-dimensional $\mathcal{N} = 4$ SYM theory on its boundary is

$$\mathrm{d}s^2 = \frac{L^2}{u^2}\left(-f(u)\,\mathrm{d}t^2 + \mathrm{d}\vec{x}_\perp^2 + \mathrm{d}z^2 + \frac{\mathrm{d}u^2}{f(u)}\right), \tag{1}$$

where u is the additional direction in AdS space, $f(u) = 1 - u^4/u_H^4$, and the black hole is located at $u_H = 1/\pi T$. Here $\vec{x}_\perp$ and z are field theory coordinates specifying the transverse plane and the beam direction, respectively. This metric is an exact solution to Einstein's equations for a constant-temperature plasma, but for a spatially-varying temperature profile this model neglects transverse flow, fluid viscosity, and gradients.

Nullification of strings in vacuum.— We are interested in the distribution of energy along the string while it is in the plasma, since this is what governs energy loss. Strings are known to become null as they fall, and after this the distribution of energy along them stays fixed for all time. With this as motivation, we first consider the initial dynamics and study the equilibration of real strings in vacuum. The dynamics of real classical strings are governed by the classical Nambu-Goto action, which specifies the motion given initial conditions on the position and velocity of the string. We tried several profiles for the initial velocity distributions, starting at fixed holographic depth u_0 with varying values of the initial angle of the endpoint σ_0 and varying values of the amplitude E spanning two orders of magnitude. After these strings nullify we find that, as shown in Figure 1, for all these families of initial conditions the shape of the energy distribution as a function of the AdS angle does not depend strongly on our choice of initial conditions as long as we rescale both energy and angle, so that they are measured with respect to the total energy and the opening angle of the endpoint.

An ensemble of jets in plasma.— An individual jet in holography always widens when it propagates through plasma, since the angle of the endpoint is a proxy for the width of the jet in the field theory and the endpoint curves toward the black hole in the gravitational description. It was found in [1], however, that the competing effect that wider jets lose more energy may cause an *ensemble* of jets to have an average opening angle which either narrows or widens. This suggests that considering an ensemble of jets is important for qualitative predictions of jet phenomenology in holography. A useful measure of the opening angle of a jet is the variable

$$C_1^{(1)} = \sum_{i,j} z_i z_j \frac{\theta_{ij}}{R}, \tag{2}$$

where the sum is over all pairs of hadrons in the jet, θ_{ij} is the angle between hadrons i and j, and z_i is the momentum fraction of hadron i. We take the jet radius parameter to be $R = 0.3$ for consistency with CMS data. The distribution of $C_1^{(1)}$ has been calculated in perturbative QCD in [4]. The opening angle of a holographic jet is given by the angle of the string endpoint, σ_0, to leading order, but we do not have a direct analog of $C_1^{(1)}$ since the holographic calculation does not have hadrons and we cannot calculate Eq. (2) explicitly. Therefore we take $C_1^{(1)} = a\sigma_0$ for a a free parameter in our model and fix a by comparing to measurements of the jet shape in proton–proton collisions. We also take a distribution of initial jet energies which falls as E^{-6}. We take a simple blast-wave profile to model the temperature evolution in the transverse plane and assume boost-invariant longitudinal expansion (See Ref. [1] for details). We parameterize the differences in degrees of freedom and couplings between $\mathcal{N} = 4$ SYM and QCD by rescaling their temperatures $T_{\mathcal{N}=4} = bT_{QCD}$, with b the second free parameter in our model. We take the initial position of the quark-antiquark pair in the transverse plane to be distributed according to a binary scaling distribution proportional to the participant density, with randomly distributed direction.