Resolution Effects in the Hybrid Model

Zachary Hulcher, Daniel Pablos, Krishna Rajagopal

Center *for* Theoretical Physics

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Introduction

Within the context of a hybrid strong/weak coupling model, we study finite resolution effects within the quark-gluon plasma and their impact on a subset of jet observables. The inability of the medium to resolve the substructure of a collimated parton shower with arbitrary precision introduces a modification of the associated space-time picture in terms of the propagation of a collection of effective emitters.

The hybrid model incorporates aspects of weak and strong coupling physics applied at the scale where they are expected to be valid. 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.

$$\frac{1}{E_{in}}\frac{dE}{dx} = -\frac{4x^2}{\pi x_{therm}^2\sqrt{x_{therm}^2 - x^2}} \qquad x_{therm} = \frac{1}{2\kappa_{sc}}\frac{E_{in}^{\frac{1}{3}}}{T^{\frac{4}{3}}}$$

where κ_{sc} is taken to be a fitting parameter expected to be O(1). The energy and momentum extracted from the jet is assumed to thermalize rapidly into the plasma, as is most natural in a strongly coupled framework, generating the collective response known as the wake. Some of this energy carried by the plasma along the jet direction will be reconstructed as part of a jet, leading to non-trivial modifications of the jet properties. By studying the induced velocity and temperature variations as small perturbations on top of the unperturbed fluid we can estimate the distribution of particles coming from the wake solely dictated by energy-momentum conservation.

The simple and phenomenological approach taken in this one-parameter model has allowed for a systematic comparison against a wide range of experimental data, providing insights into the relevance of the different physical mechanisms that potentially play a role in the jet/plasma interplay like the resolution effect.

For the resolution effect, we introduce a screening length parameter, L_{Res}, proportional to the inverse of the local plasma temperature. We expect L_{Res} to be approximately the Debye Screening Length, λ_D.

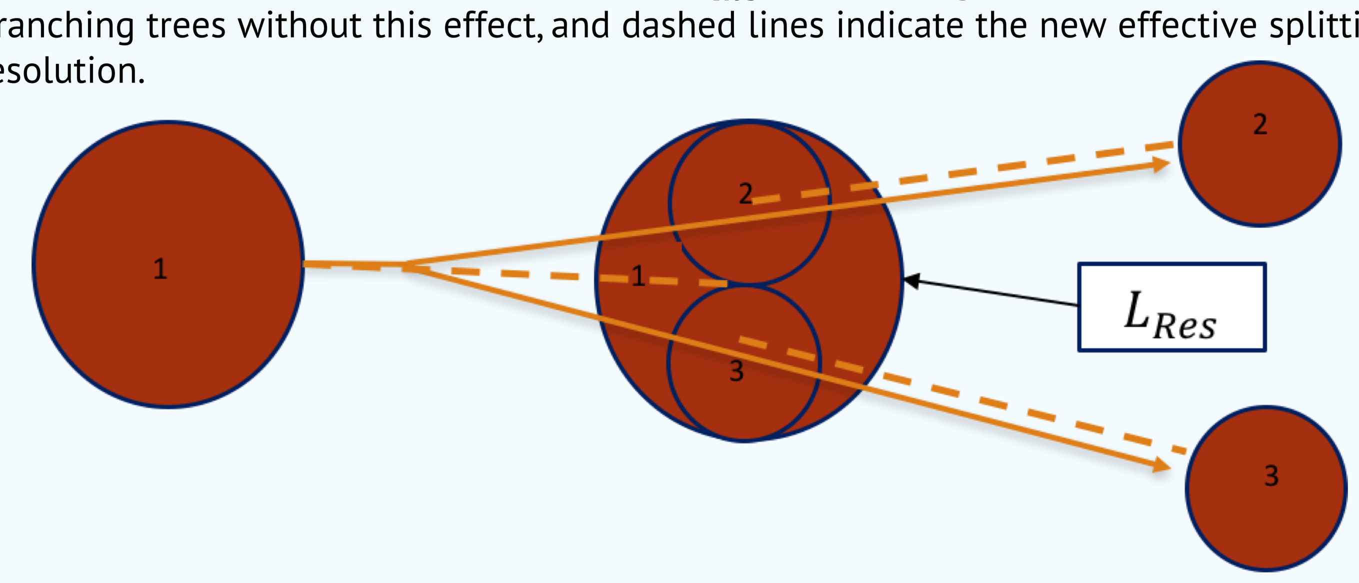
- From weakly coupled QCD calculations: $\lambda_D \approx \frac{1.3}{\pi T}$
- From holographic calculations in AdS/CFT: $\lambda_D \approx \frac{0.3}{\pi T}$, but must be greater in QCD

We then modify the hybrid model so that when a parton in a jet shower splits, its two offspring are initially treated as unresolved, and are only treated as two separate partons losing energy independently after they are separated by a distance L_{Res}. This modification delays the quenching of partons with intermediate energy and at larger angles, resulting in the survival of more hadrons in the final state with pT in the several GeV range.

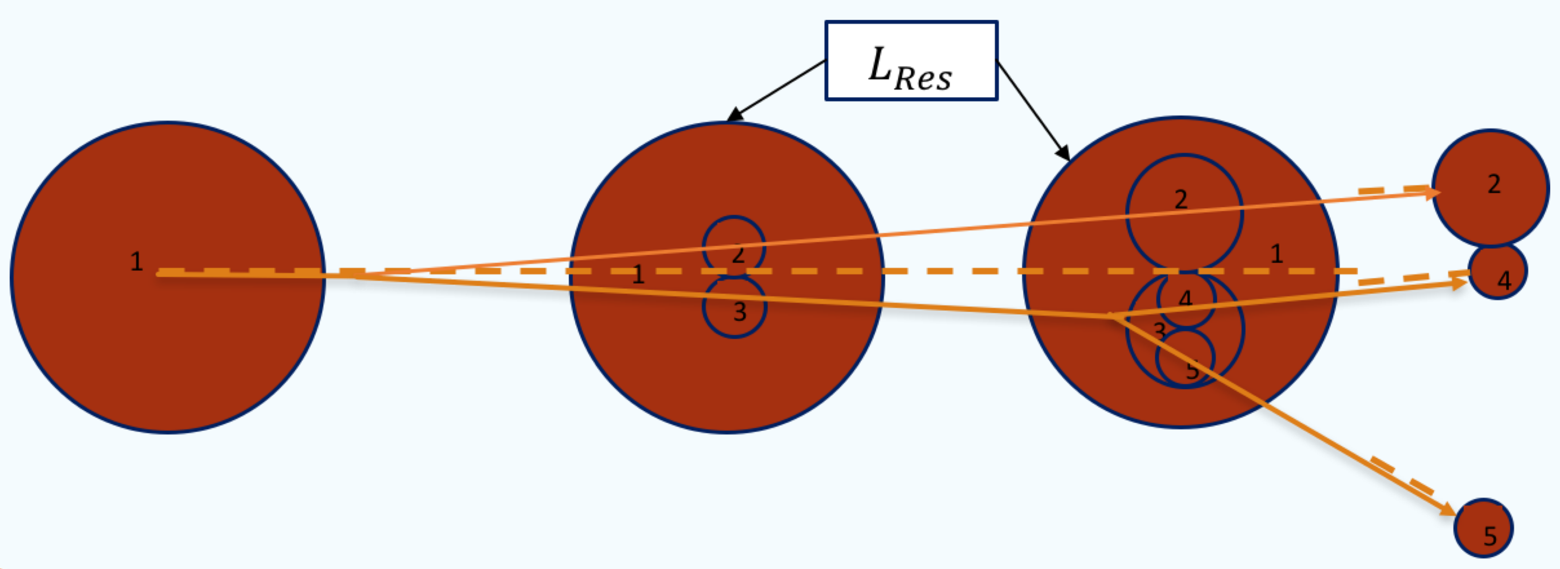
Implementation

There are a few important simplifications and assumptions:

- We calculate resolution times and evolve the system in the lab frame in order to avoid the simultaneity problems arising from Lorentz transforming from the local fluid frame back into the lab frame.
- Sister particles in a branching tree do not resolve and lose energy as one effective emitter until the distance between them exceeds L_{Res}. In the diagram below, solid lines indicate branching trees without this effect, and dashed lines indicate the new effective splittings after resolution.

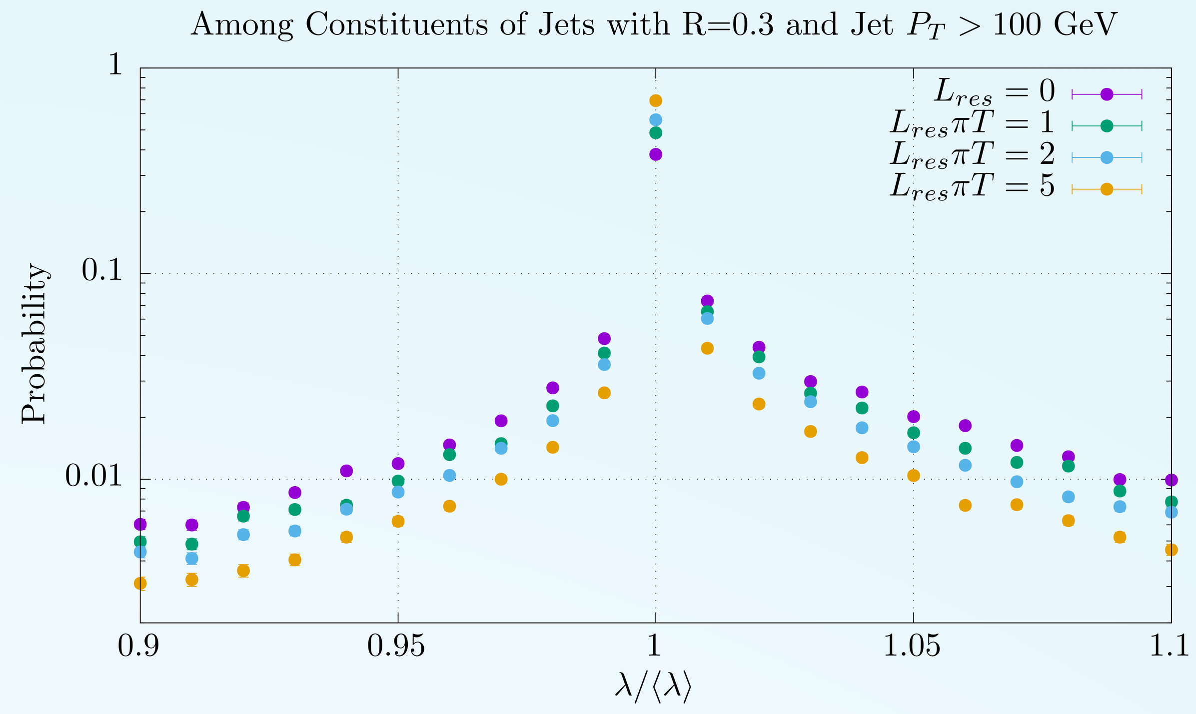


- A nontrivial part of this implementation is that particles become resolved if either their daughter or sister particles become resolved. In the diagram below, the resolution of 4 from 5 resolves the old particle 3 from particle 2 as well. This implementation sidesteps issues regarding ambiguities in the rearrangement of partons in the effective emitters.



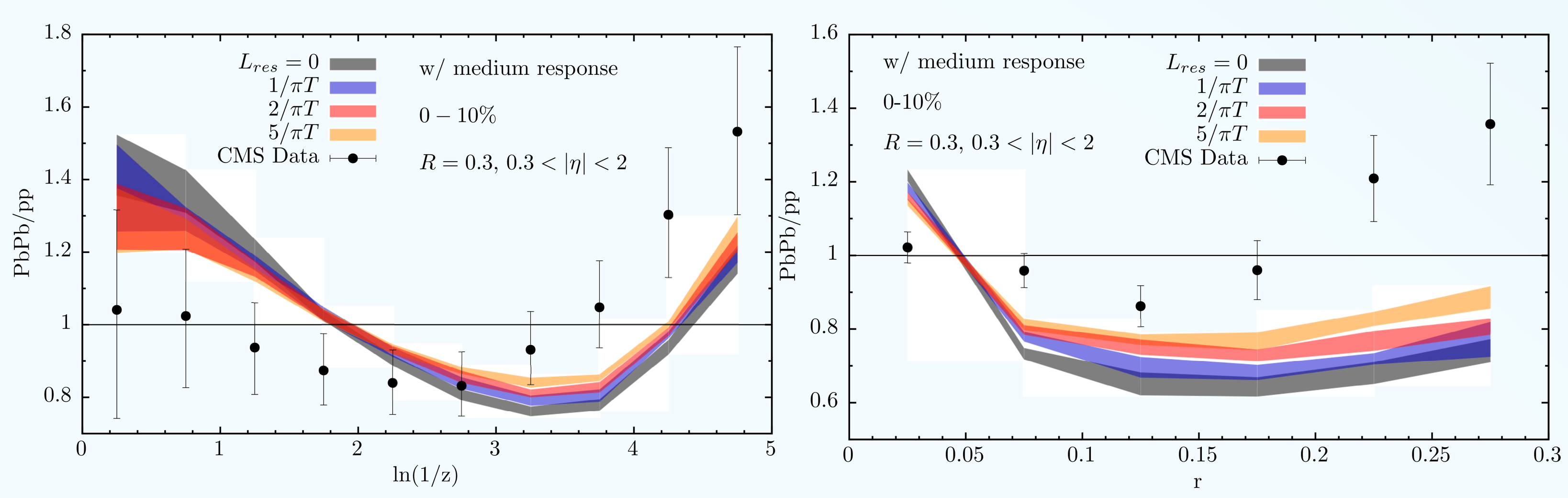
Testing

As a test of the validity of the code, we plot the number of final particles with a particular energy loss fraction, λ, normalized by the average energy loss fraction for all the particles in a given jet. We see that as $L_{Res}\pi T$ increases, this histogram approaches a delta function around 1, meaning that all final particles tend to experience about the same fractional energy loss.

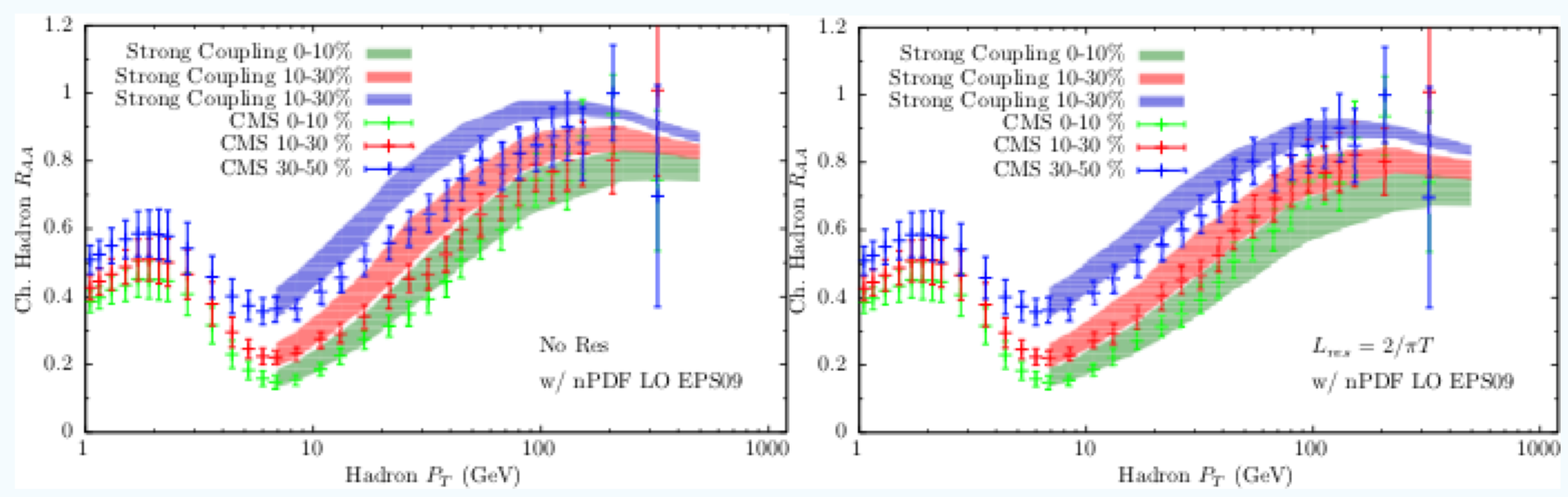


This supports that when $L_{Res}\pi T$ is large, all the particles in a given jet lose energy as one effective emitter, as the effective splitting time is also large. Also from the magnitude of the changes from No Res to $L_{Res}\pi T = 2$ at 1, we indeed see that the majority of this effect is already captured before $L_{Res}\pi T = 2$.

Results



Left panel shows the effect of resolution on hadronic jet fragmentation functions (longitudinal energy distribution), while right panel shows results for jet shapes (transverse energy distribution) for various values of the proportionality constant., $L_{Res}\pi T$. As expected, softer particles lying at relatively large angles have an increased survival rate as the resolution length is increased.



In the left panel we see predictions for charged hadron R_{AA} without resolution effects. While the most central bin fits reasonably well with CMS data, some tension is revealed as centrality is reduced. By introducing resolution effects with $L_{Res}\pi T = 2$, we see in the right panel an overall improvement across all centrality bins. The reduction of the number of effective energy loss sources forces a reduction of the value of the stopping distances, yielding a higher suppression of the leading particles within the jet which characterize the higher energy region of the hadron spectrum.

Conclusions

- Finite resolution effects modify the jet substructure, as it makes it more probable for particles carrying a small fraction of the jet energy at larger angles from the jet axis to survive their passage through the QGP.
- Hadron R_{AA} description is improved both as a function of momentum and centrality due to the fact that the effect introduces a more democratic quenching among the partons within the jet, making the leading parton lose more energy than it would in the fully resolved situation.
- We have shown that the inclusion of finite resolution, which is a necessary piece of physics in the description of jet quenching phenomena, can improve the overall agreement of observables within the context of the hybrid strong/weak coupling model. It is clear that further work is required in order to describe the intra-jet angular structure, with some plausible directions being the inclusion of a more realistic description of the medium response, going beyond small perturbations such that the production of semi-hard hadrons is no longer underestimated.