Can falling strings in deformed AdS geometries account for the transparency of the sQGP at LHC?

Andrej Ficnar[1], Jorge Noronha[2] and Miklos Gyulassy[1]

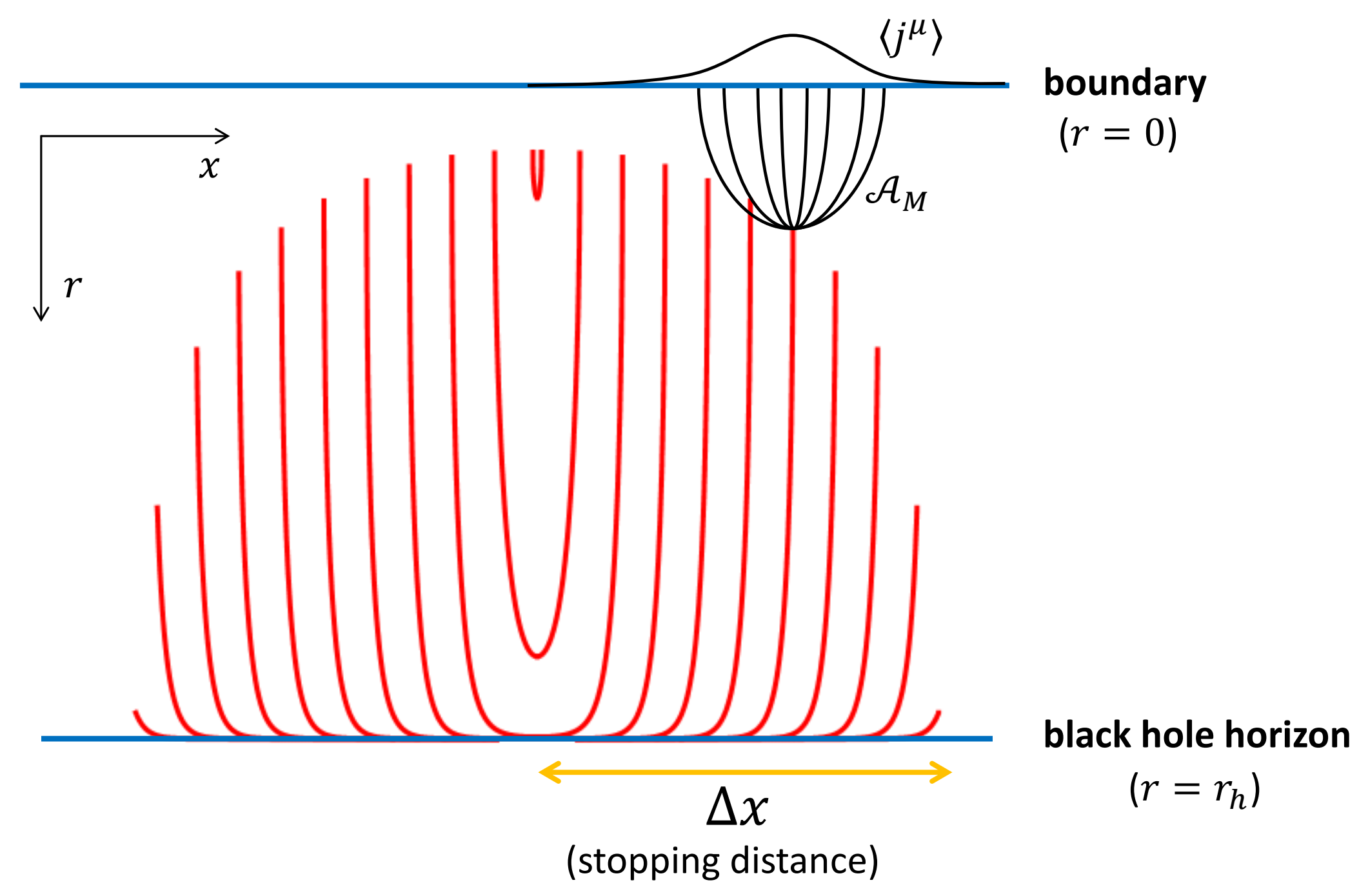
[1]Department of Physics, Columbia University, New York, NY 10027, USA
[2]Instituto de Física, Universidade de São Paulo, 05315-970 São Paulo, Brazil

Motivation

One of the important applications of the gauge/gravity duality has been the study of jet quenching in strongly-coupled systems, such as the sQGP. Experimental data on the suppression of light hadrons in AA collisions from RHIC and LHC [1] calls for a more consistent grasp on the energy loss of light quarks in the gauge/gravity duality in order to be able to compute jet quenching observables such as the nuclear modification factor R_{AA} and the elliptic flow parameter v_2. Here we present a possible way to compute the R_{AA} using the input from the studies of the energy loss of light quarks in AdS/CFT.

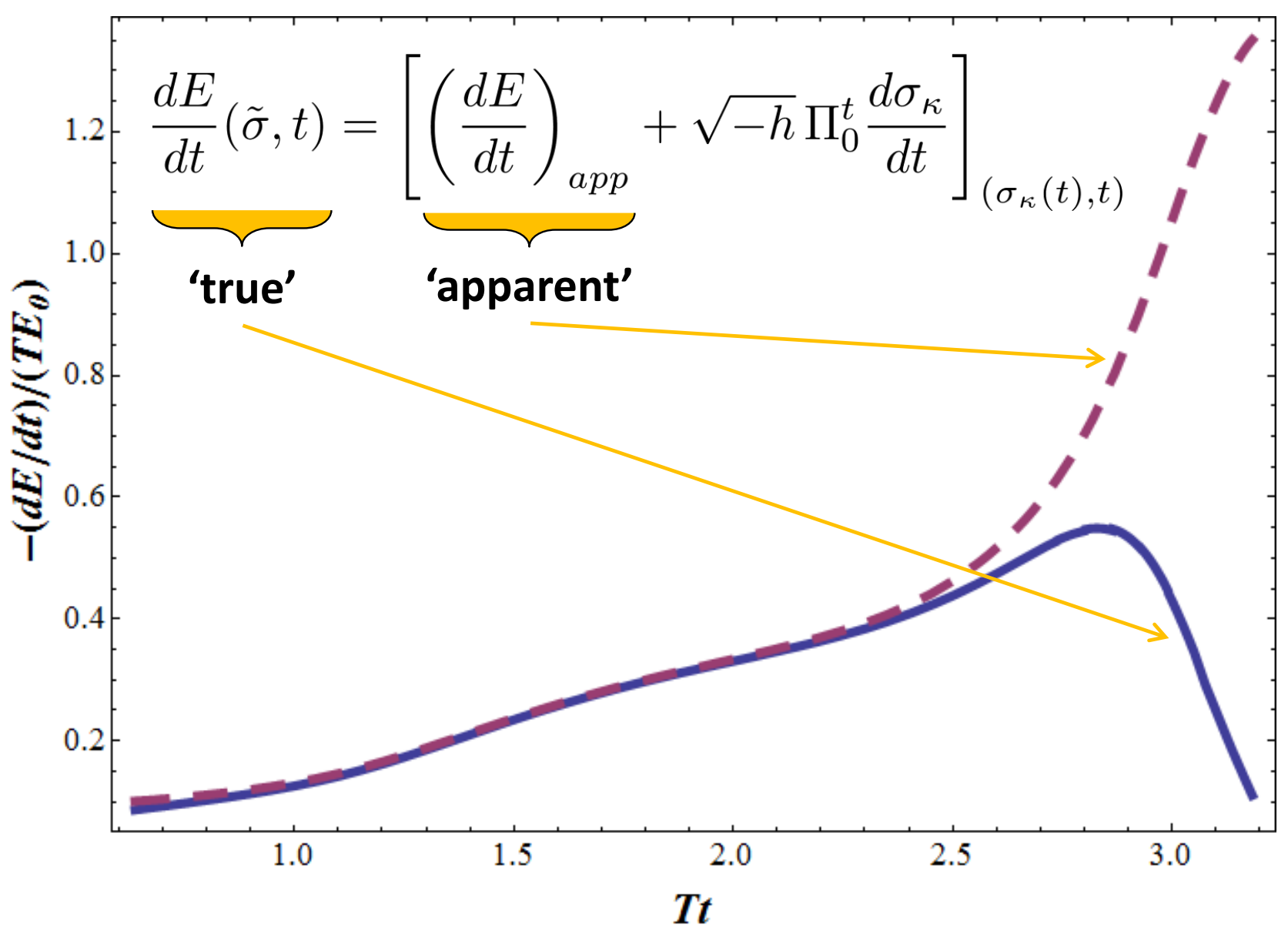
Light quarks in AdS/CFT

Dressed quarks of mass m_Q are dual to strings in the bulk with one or both endpoints on the D7-brane spanning from $r=0$ (boundary) to some $r_m \sim 1/m_Q$ and physics of the energy loss of these quarks is related to the dynamics of their dual strings. For light quarks, the D7-brane fills the entire *AdS-BH* geometry and a way to study their energy loss is to investigate the free motion of the strings that have both of their endpoints on the D7-brane (representing dressed $q\bar{q}$ pairs), the so-called falling strings [2].



Energy loss of light quarks

In [2] it was shown that the maximum stopping distance of light quarks in a strongly coupled $\mathcal{N}=4$ SYM plasma scales with energy as $\Delta x_{max} \propto E^{1/3}$. In general, this information alone is not enough to calculate observables such as R_{AA} and v_2, where the knowledge of the instantaneous energy loss is needed. For this, one needs to analyze the spacetime momentum currents Π^a_μ on the string worldsheet, whose connection to the energy loss becomes non-trivial and the details of the geometry on the worldsheet become important. In [3] it was shown that the energy loss in time-dependent string configurations receives a correction to the simple Π^σ_μ component (the 'apparent' energy loss).



Defining the light quark jet as a part of the falling string within a certain fixed $\Delta x \sim 1/(\pi T)$ distance from the endpoint (as in [2]), it was demonstrated [3] that this correction becomes especially important at late times and substantially decreases the magnitude of the Bragg-like peak reported in [2].

In fact, as noted in [3], preliminary numerical studies suggest that, although the early time behavior of the energy loss is susceptible to the initial conditions, the linearity of it, $dE/dt \sim t$, seems to be a remarkably robust feature, which we will use as a working assumption in the calculation of R_{AA}.

Calculating R_{AA}

Motivated by [4], we model the phenomenologically relevant part of the instantaneous energy loss of a light quark moving through an $\mathcal{N}=4$ SYM plasma as:

$$\frac{dE}{dx}(E_0,T,x) = -c(E_0,T)\,x^1\,\Theta\left(L_s(E_0,T)-x\right)$$

Here T is the temperature, x is the distance in the medium the quark has traversed, E_0 is its initial energy, L_s is the stopping distance and Θ is the step function.

Combining the stopping distance dependence on the initial energy and temperature which we know from [2]:

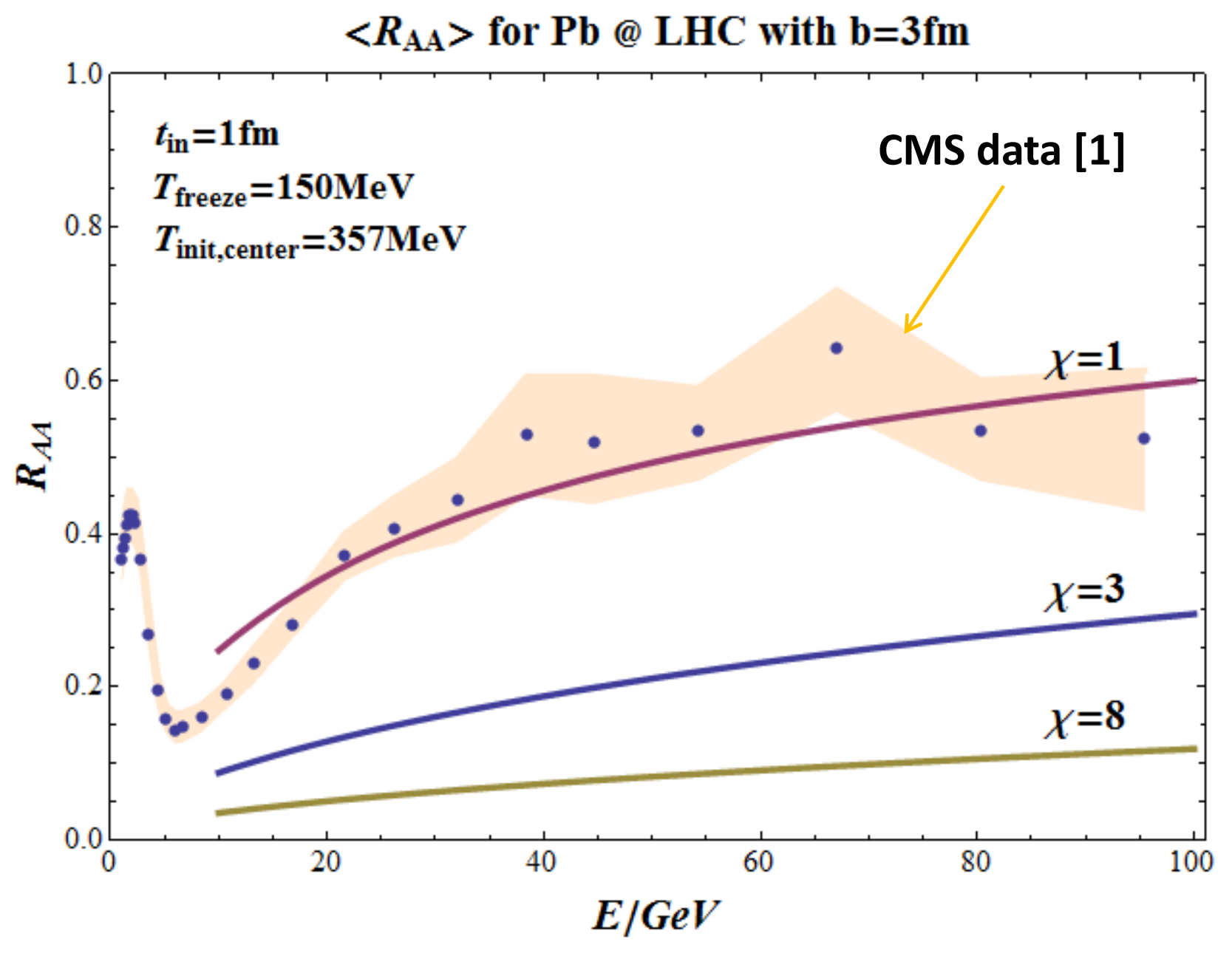
$$L_s(E_0,T) = \frac{\kappa}{T}\left(\frac{E_0}{\sqrt{\lambda}T}\right)^{1/3}$$

we arrive at:

$$\frac{dE}{dx} = -\chi E_0^{1/3} x^1 T^{8/3}, \quad \chi \equiv 2\lambda^{1/3}/\kappa^2$$

where we have defined an effective coupling χ, which determines the overall magnitude of the energy loss. As noted in [3], this formula has a surprising similarity to the typical qualitative behavior of energy loss of light quarks in pQCD in the strong LPM regime [4].

Using this formula, we can proceed to compute the R_{AA} for light quarks, in the same way it was done in [5], using the Glauber initial conditions which determine the temperature profile of the expanding plasma and averaging over the jet azimuthal directions and production points in the transverse plane.



Using $\kappa \approx 0.5$ [2] and an unphysically small $\lambda = 1$, we obtain a minimal value of $\chi \approx 8$. Such a high value of χ gives an R_{AA} of a rather low magnitude, indicating strong quenching. Using even lower values of χ, we see that R_{AA} actually has the correct qualitative behavior as displayed by the LHC data [1]. This suggests that the main problem here could be simply in the magnitude of the quenching.

Higher derivative corrections

We decided to examine if higher derivative corrections to the gravity sector of AdS_5 can decrease the strength of the quenching while keeping the correct qualitative behavior of R_{AA}. In the presence of a D7-brane, the leading $1/N_c$ corrections come from the R^2-terms which we will model by a Gauss-Bonnet term, $\lambda_{GB}\mathcal{L}_{GB}$. Here, λ_{GB} is a dimensionless parameter, constrained to be $-7/36 < \lambda_{GB} \leq 9/100$ [6,7]. A black brane solution in this case is known analytically [8]:

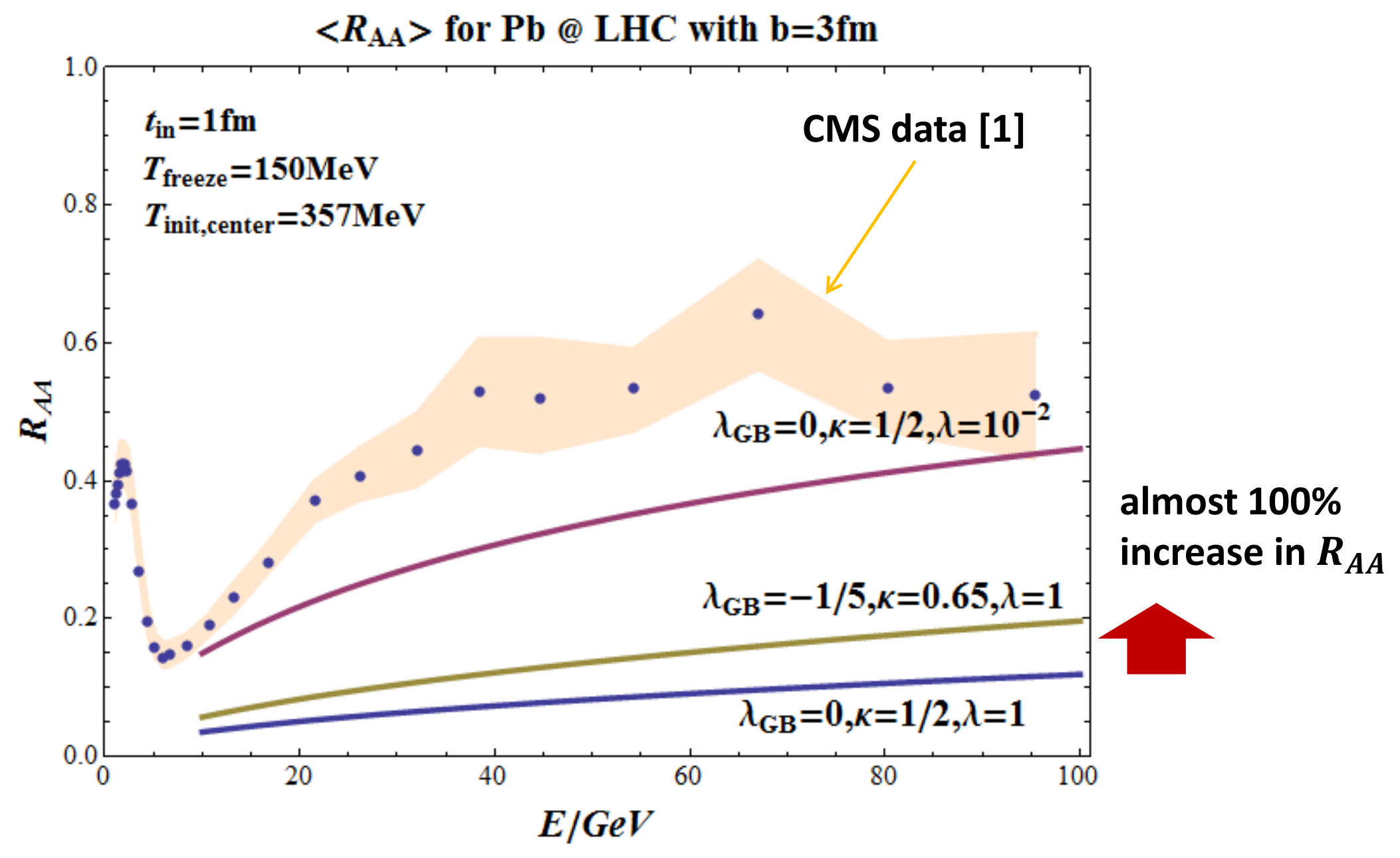
$$ds^2 = \frac{L^2}{r^2}\left[-a^2 f_{GB}(r)dt^2 + d\vec{x}^2 + \frac{dr^2}{f_{GB}(r)}\right]$$

Following a similar procedure as in [2], by analyzing null geodesics in GB geometry and relating its parameters to the energy of the string, we have the following preliminary result for the maximum stopping distance of falling strings up to linear order in λ_{GB} [9]:

$$\Delta x_{max} = \frac{\mathcal{C}}{T}\left(\frac{E}{T\sqrt{\lambda}}\right)^{1/3}\left(1-\mathcal{F}\lambda_{GB}\right) + \mathcal{O}(\lambda_{GB}^2)$$

Here $\mathcal{C} \sim 1/2$ and $\mathcal{F}$ is a numerical factor $\gtrsim 1$, for which our preliminary estimate gives $\mathcal{F} = 11/6$. We see that the $\sim E^{1/3}$ scaling is still present and that for negative values of λ_{GB} we can increase the stopping distance by up to ~30-40%, compared to the case of pure AdS_5 with no higher derivative corrections.

Since the Gauss-Bonnet parameter λ_{GB} affects the κ coefficient non-negligibly, we can expect R_{AA} to be sensitive to it: we see that keeping $\lambda = 1$ fixed, just by 'turning on' the higher derivative corrections, we can increase R_{AA} by almost 100%.

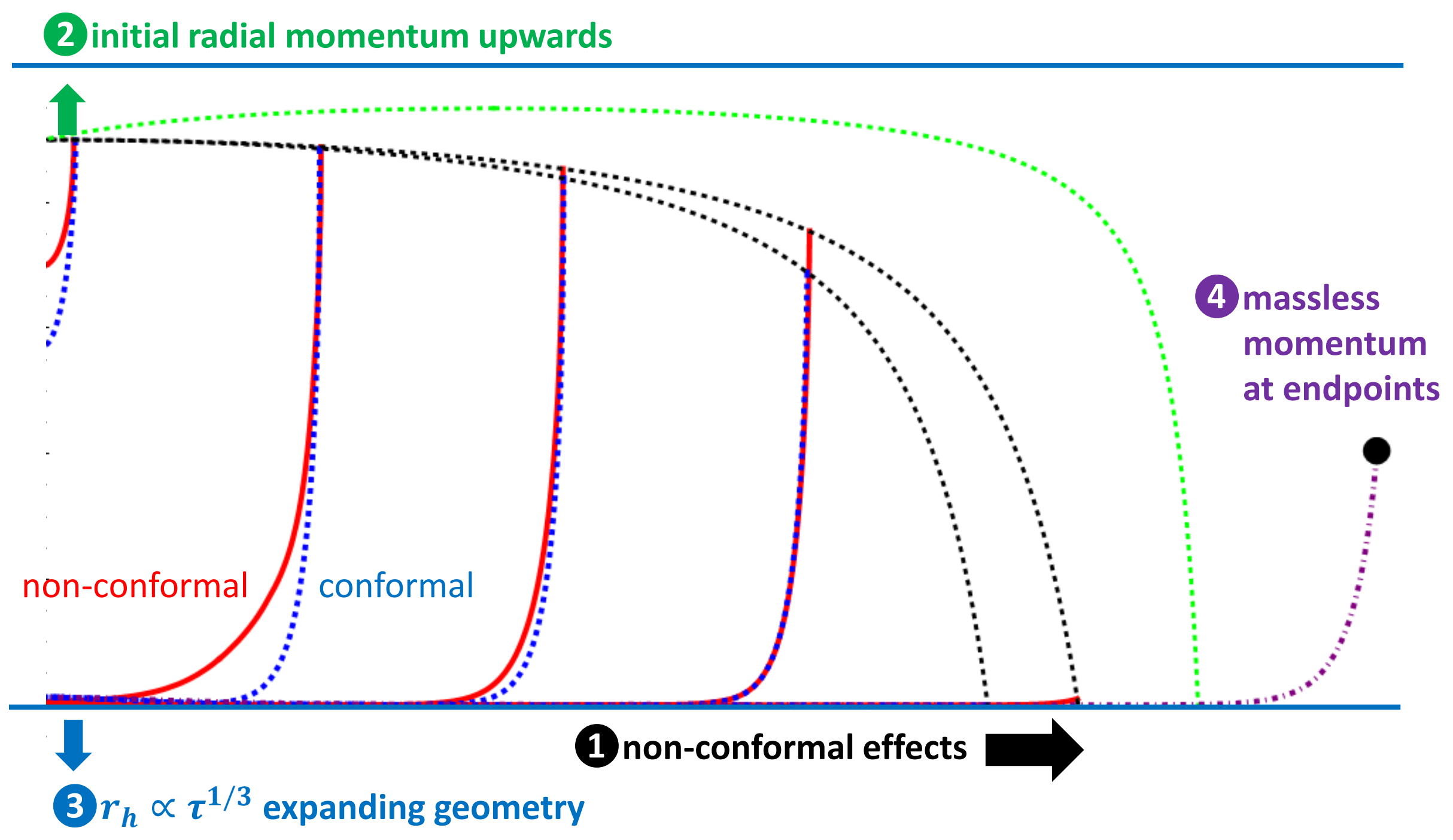


Conclusions

LHC light hadron suppression data seems to remain very challenging for gravity dual models; while our model calculations for R_{AA} of light quarks in AdS/CFT qualitatively agree with the data, the overall magnitude is too low.

This magnitude is shown to be very sensitive to higher derivative $1/N_c$ corrections, which are able to increase it, but are not enough.

Effects of non-conformal geometries, geometries dual to expanding plasmas and generalized initial conditions should be further investigated.



References

[1] K. Aamodt et al. (ALICE Collaboration), *Phys. Lett. B* **696** (2011) 30; CMS Collaboration, *Eur. Phys. J. C* **72** (2012) 1945
[2] P. M. Chesler, K. Jensen, A. Karch and L. G. Yaffe, *Phys. Rev. D* **79** (2009) 125015
[3] A. Ficnar, arXiv:1201.1780 [hep-th], *Phys. Rev. D*, in press
[4] W. A. Horowitz and M. Gyulassy, *Nucl. Phys. A* **872** (2011) 265
[5] A. Ficnar, J. Noronha and M. Gyulassy, *J. Phys. G: Nucl. Part. Phys.* **38** (2011) 124176
[6] M. Brigante, H. Liu, R. C. Myers, S. Shenker and S. Yaida, *Phys. Rev. D* **77** (2008) 126006
[7] D. M. Hofman and J. Maldacena, *JHEP* **0805** (2008) 012
[8] R.-G. Cai, *Phys. Rev. D* **65** (2002) 084014
[9] A. Ficnar, J. Noronha and M. Gyulassy, to appear

Columbia University
In the City of New York