COLUMBIA UNIVERSITY
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Non-conformal Holographic Model of Jet Quenching

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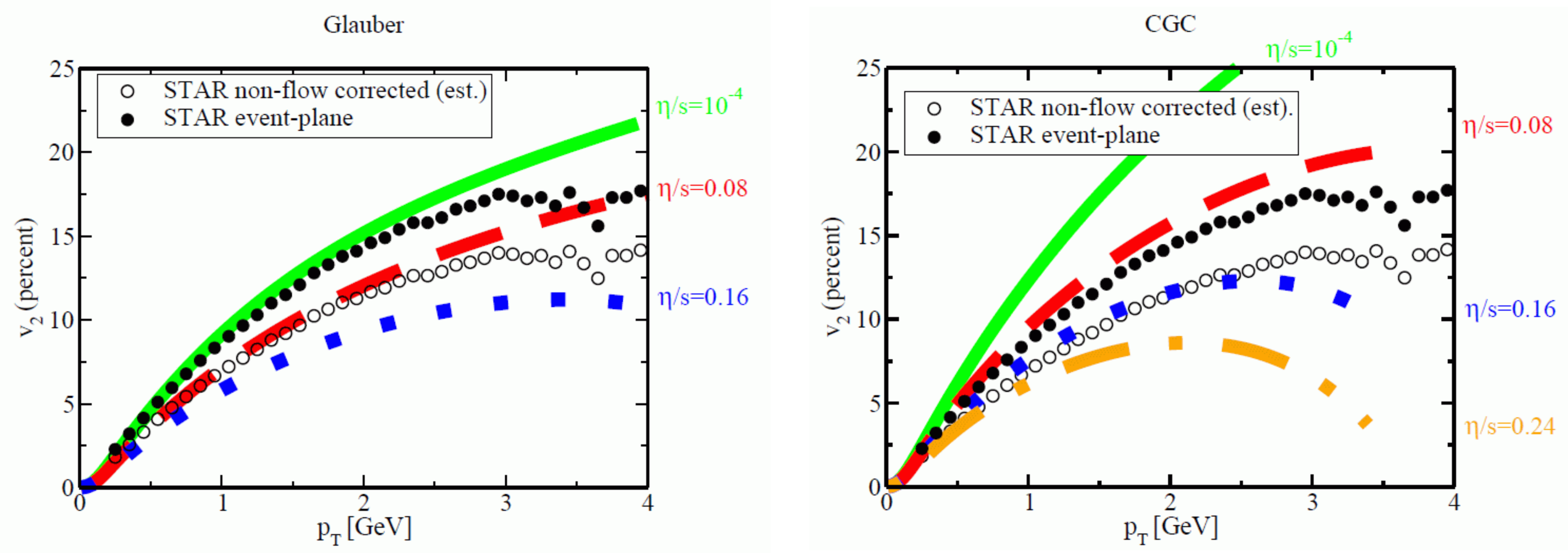
Motivation

- QGP behaves as a **near-ideal fluid**



Luzum & Romatschke, 2008

⇨ **Naturally implies strong coupling**

AdS/CFT in a nutshell

- **AdS/CFT conjecture:** equivalence of (3+1)-dim $\mathcal{N} = 4$ SYM and type IIB string theory on [redacted]

Maldacena, 1998

- Holographic dictionary:

controls higher curvature contributions, want $\gg 1$

[redacted]

controls quantum string effects, want $\ll 1$

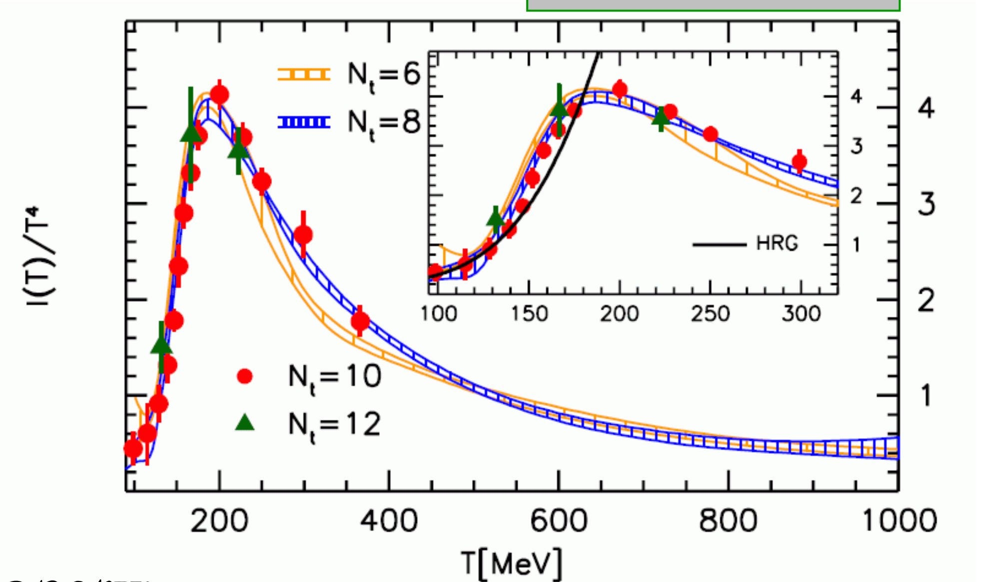
solution: take t'Hooft limit: [redacted]

- In this way, one can study **strongly coupled** gauge theories ($\lambda \gg 1$) by studying **classical two-derivative** (super)gravity
- Goal: understand finite temperature QCD using thermal $\mathcal{N} = 4$ SYM
Problem: **conformal invariance** of SYM
  - trivial c_s^2
  - vanishing trace anomaly [redacted]
  - ...

Conformal (non)invariance

- Lattice results show a significant **violation** of conformal invariance near T_c
- Follow the **bottom-up** approach and break the conformal invariance:
  - From holographic dictionary:

Borsányi et al., 2010



[redacted]

dual operator in the gauge theory ("at the boundary")

scalar field (*dilaton*) in the bulk

  - Therefore, let's look for gravity models with a **non-trivial dilaton** profile

Gubser et al., 2008 | Kiritsis et al., 2008

Bottom-up approach

- Task: construct an **effective potential** for the dilaton, which reproduces the expected phenomenology of the dual theory:

  [redacted]

  induces a relevant deformation of the CFT: [redacted]

- Form of the potential constrained by **phenomenology** and numerical factors are fitted to the lattice data:

  [redacted]

  interpolates between asymptotically AdS and a non conformal c_s^2 - gives $c_s^2(T)$

  determines Δ

  fine tune of crossover

- We require that the potential gives asymptotically $(\phi \to 0)$ AdS_5 - dual theory is conformal in the UV, but **not** asymptotically free $(\eta/s$ finite) ⇨ applicability of the model restricted to T close to T_c

Fitting the lattice

- Solve EOMs using the following ansatz:

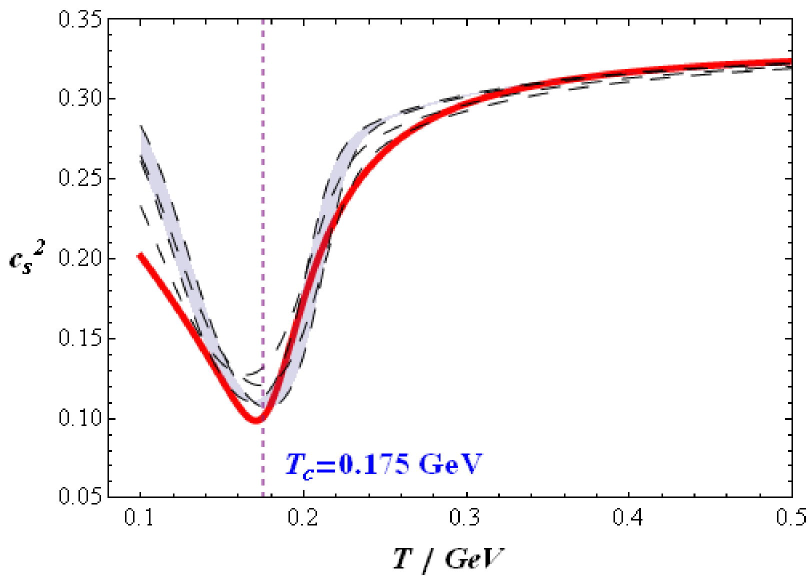
Gubser & Nellore, 2008

[redacted]

[redacted]

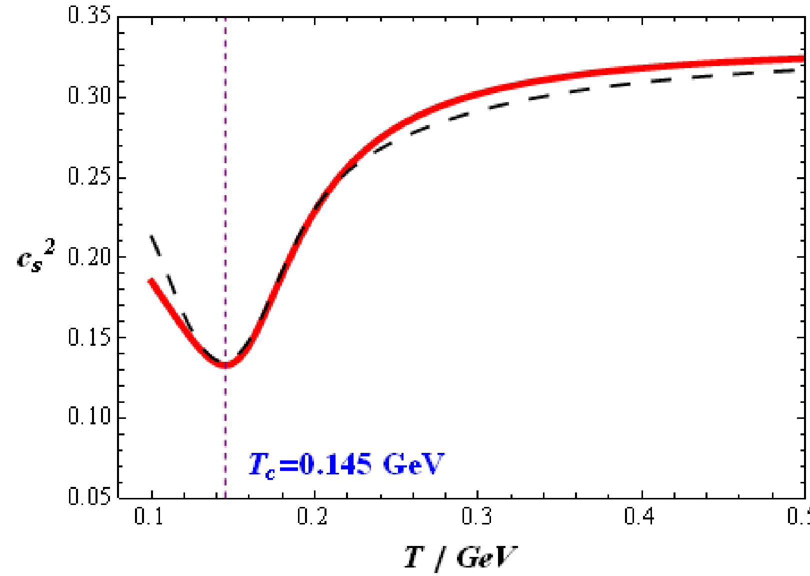
- Use the speed of sound to determine the ‘critical’ temperature:

hotQCD



Bazavov et al., 2009

Wuppertal-Budapest

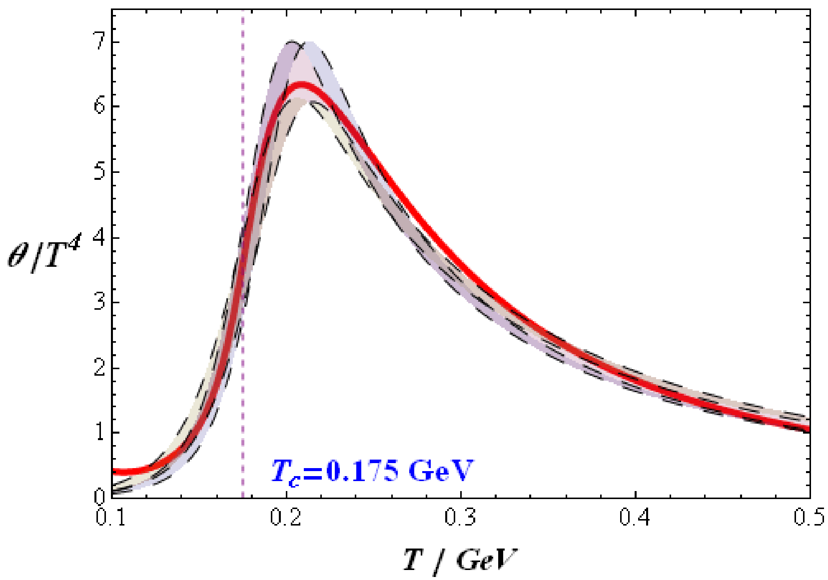


Borsányi et al., 2010

Fitting the lattice

- By fitting just c_s^2, all the other thermodynamic quantities are automatically fitted, e.g. the trace anomaly [redacted]

hotQCD



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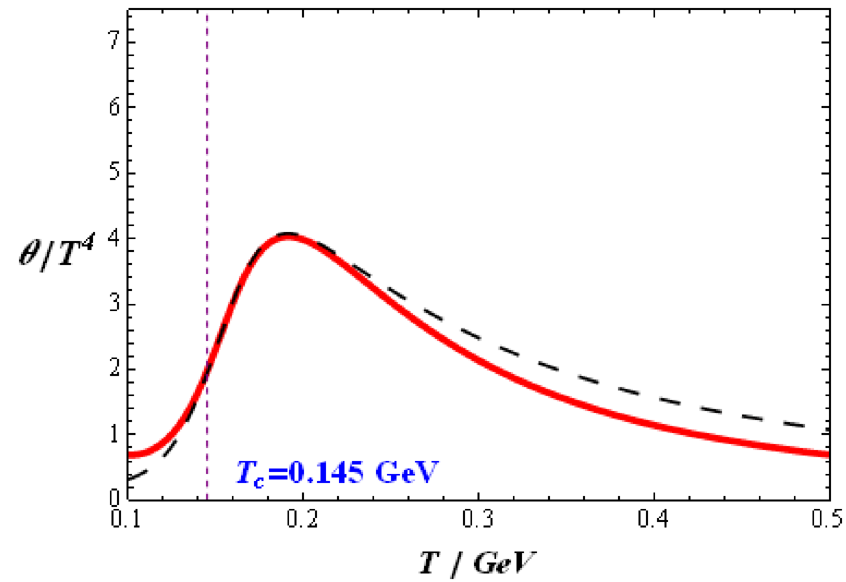
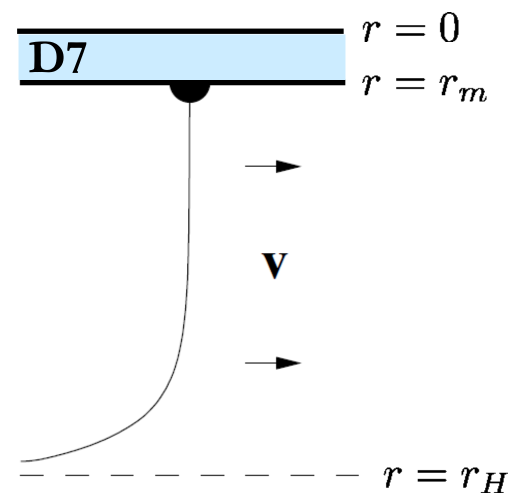


- We will directly see how the **trace anomaly** affects the energy loss of quarks

Heavy quark energy loss

- Quark of mass m_Q is dual to a string in the bulk stretching from a D7 brane at [redacted] to the horizon r_H Karch & Katz, 2002
- **Trailing string** ansatz Gubser, 2006 Herzog et al., 2006
- Dynamics of the string are governed by the classical Nambu-Goto action:



[redacted]

[redacted] induced metric on the worldsheet

$$q(\phi) = e^{\sqrt{2/3}\phi}$$ coupling between the string and the dilaton Kiritsis et al., 2008

- Energy loss given by the generalized **drag force**:

[redacted] [redacted]

[redacted]

Increases monotonically with p & T in any holographic model

Polyakov loop fixes the α’

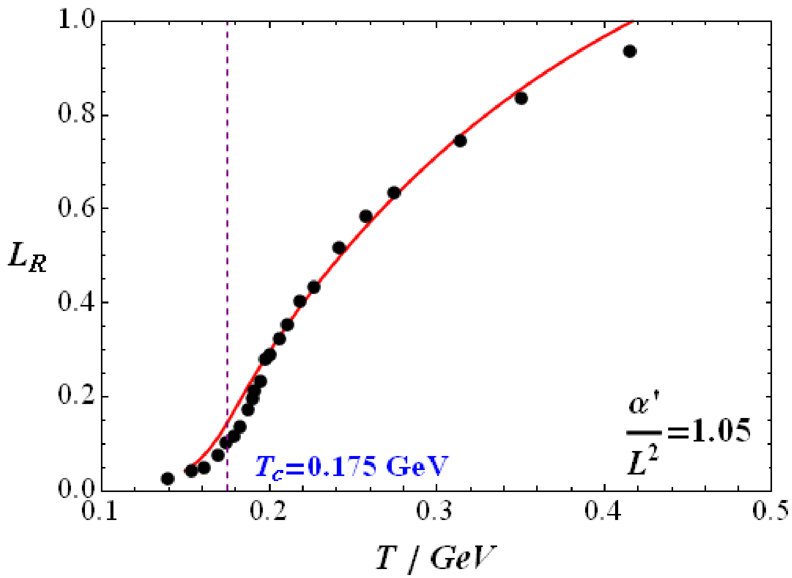
- Polyakov loop is related to the free energy of a single heavy quark:

[redacted]

Maldacena, 1998

- Therefore, we can actually **constrain** L^2/α' in our model by fitting the Polyakov loop to the lattice data

hotQCD



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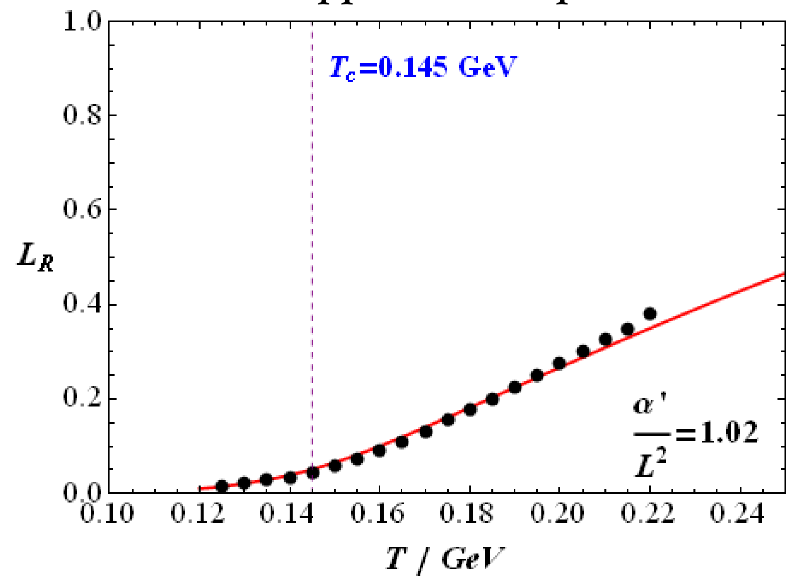
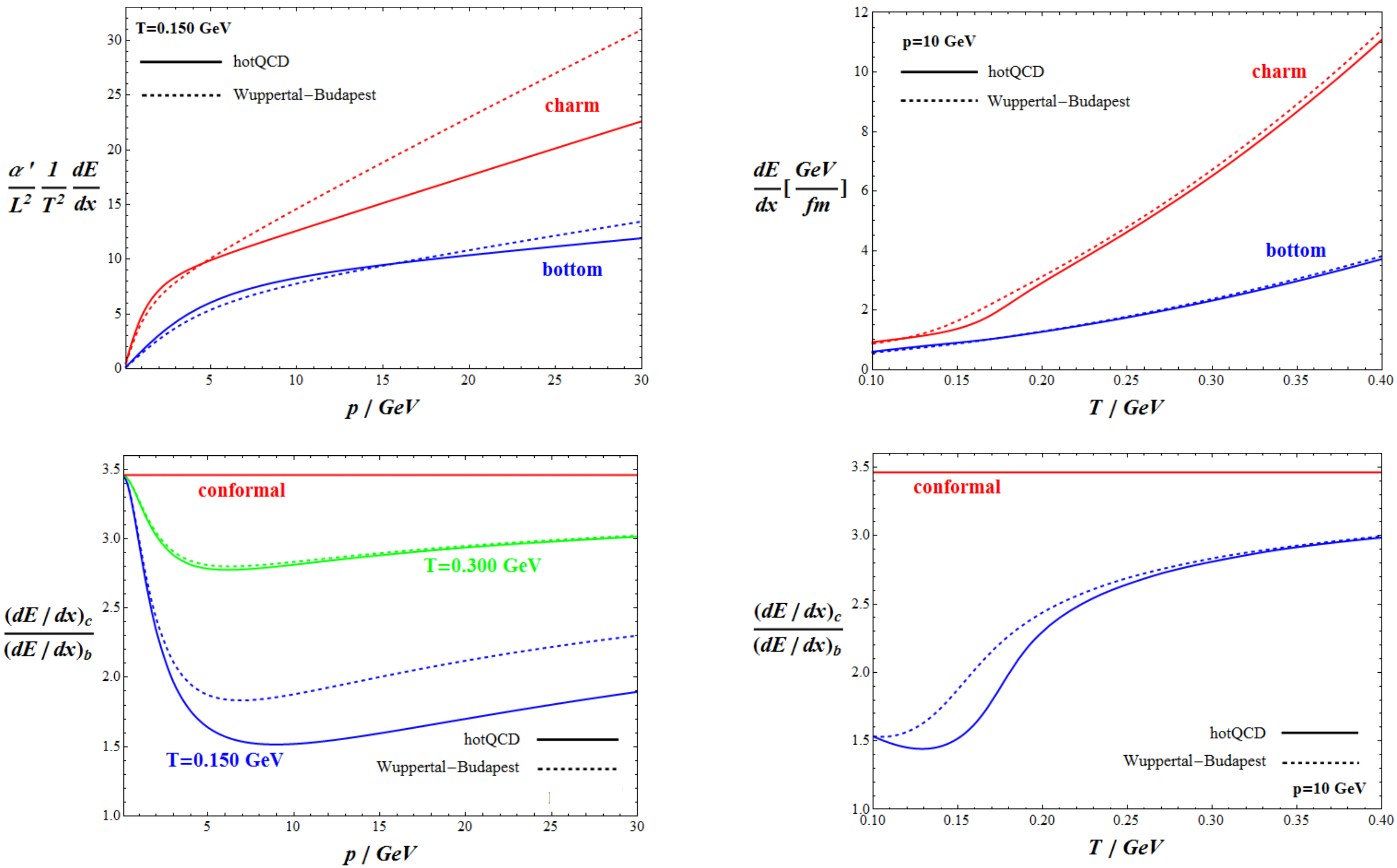


[redacted]

α’- corrections are important and should be investigated

Heavy quark energy loss

Ficnar, Noronha, Gyulassy, 2011



Heavy quark R_{AA}

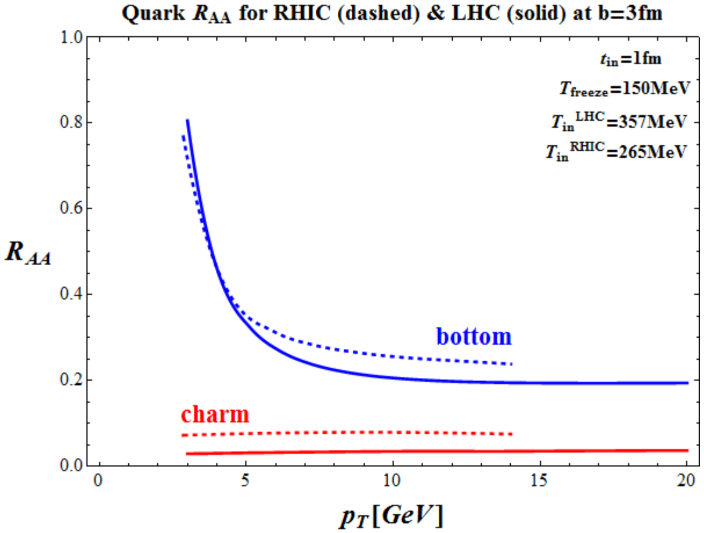
- R_{AA} computed in a **dynamical**, expanding plasma with Glauber initial conditions:

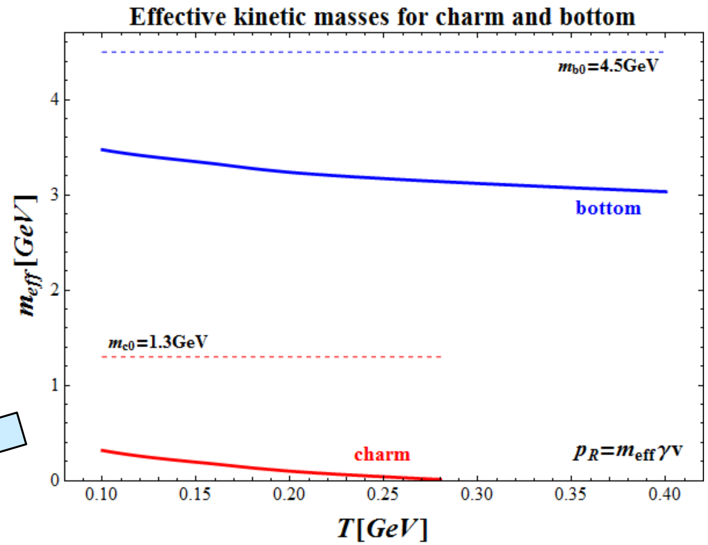
$$\langle R_{AA}\rangle (p_f) = \int d^2\vec{x}_\perp \frac{T_{AA}(\vec{x}_\perp)}{N_{bin}} \int \frac{d\phi}{2\pi} \times \frac{(dN/dp_f^2)_{quenched}(p_i(p_f,\vec{x}_\perp,\phi))}{(dN/dp_f^2)_{unquenched}(p_f)}$$

- One should use the momentum (energy) of the **string** in the energy loss calculations - **effective kinetic masses:**

[redacted]

charm cannot be treated as a heavy quark? ([redacted])

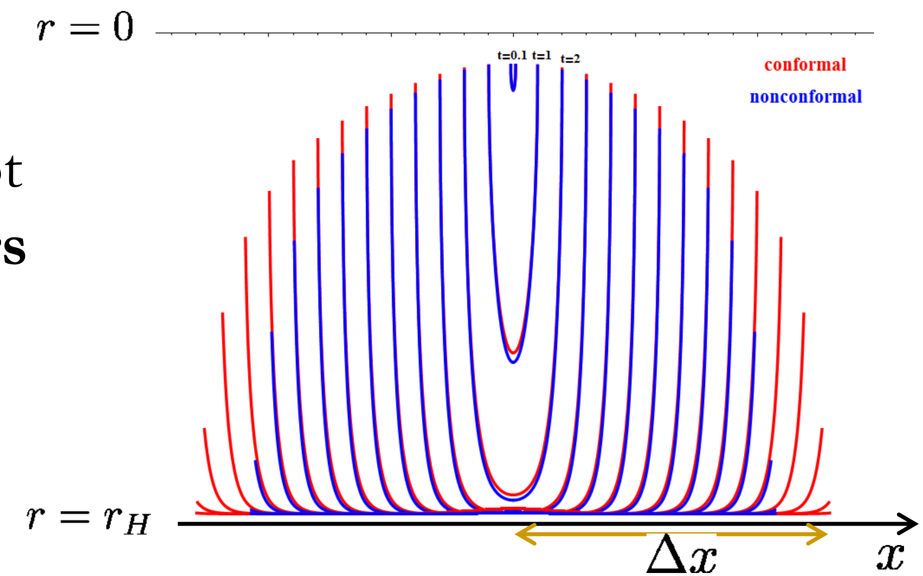




Light quark energy loss

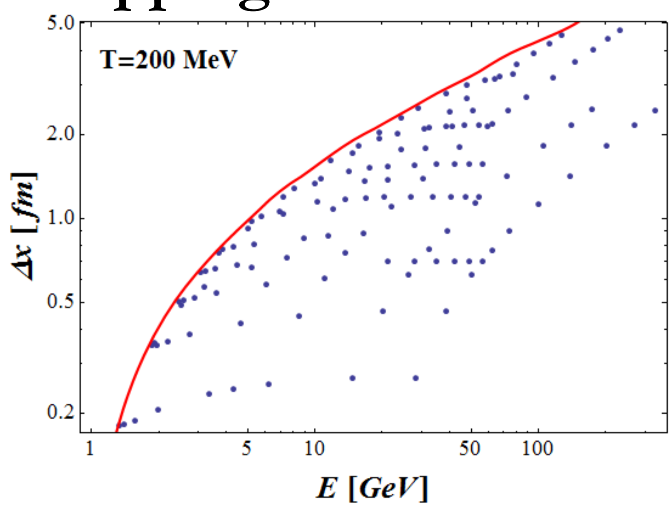
- For light quarks, [redacted] approaches r_H so strings cannot trail anymore ⇨ **falling strings**

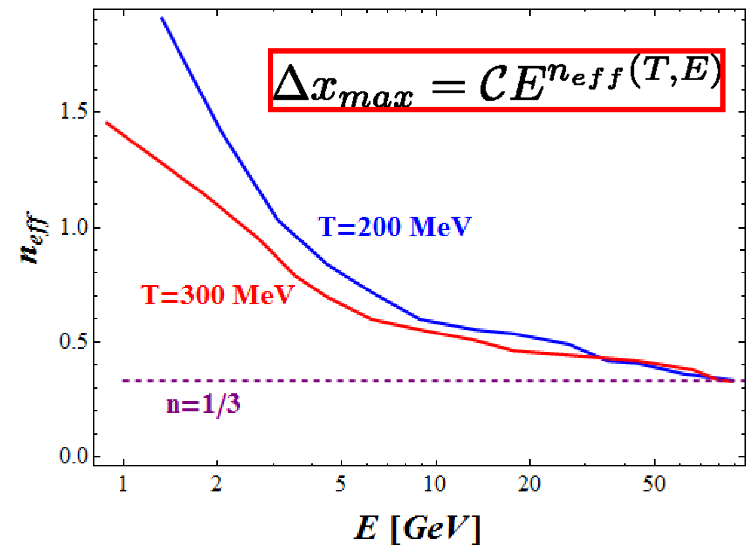
  Gubser et al., 2008 | Chesler et al., 2009



- Maximum **stopping distance:**

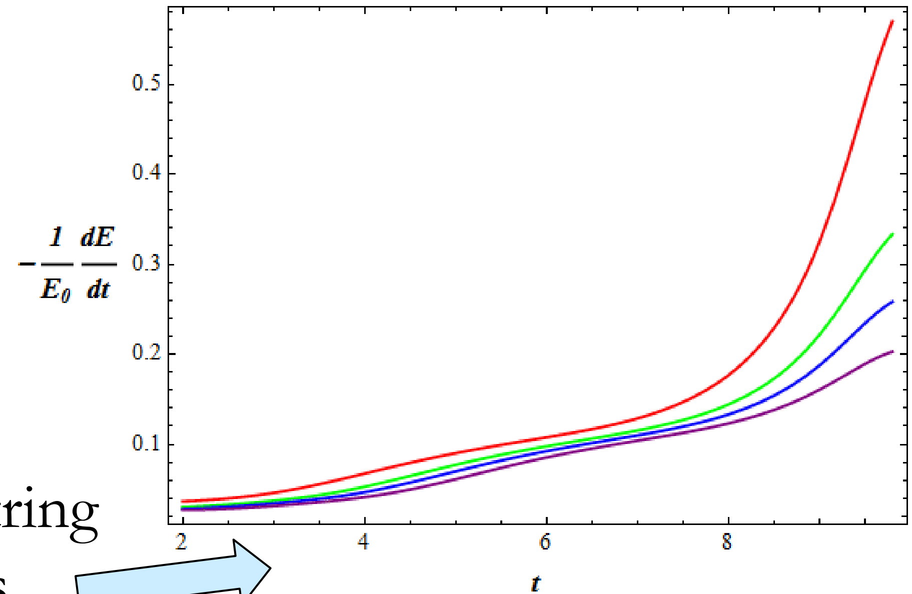
$$\Delta x_{max}^{AdS} = \frac{\mathcal{C}}{T}\left(\frac{E}{T\sqrt{\lambda}}\right)^{1/3}$$





Light quark energy loss

- **Instantaneous** energy loss seems to develop a **Bragg peak** at late times



- **Problems**:
  - ambiguity where on the string to evaluate the energy loss
  - depends heavily on initial conditions
- Possible solution (work in progress): instead of momentum loss (Π_x^r), look at the **momentum** of the half of the string:

[redacted]

Conclusions and Outlook

- Gauge/string duality gives us means to address the **violation of conformal invariance** near T_c and see how the trace anomaly affects the energy loss
- In this model, the energy loss of heavy quarks is a **prediction**
  - R_{AA} for RHIC & LHC **decreases** monotonically with p
- More **ambiguities** in the treatment of light quark energy loss
  - Maximum stopping distance: p & T - dependent power
- Things to do:
  - Investigate different dilaton potentials
  - Theoretical band on heavy quark R_{AA}
  - Consistent light quark energy loss & R_{AA}