Energy loss of a heavy quark moving through colliding shock waves

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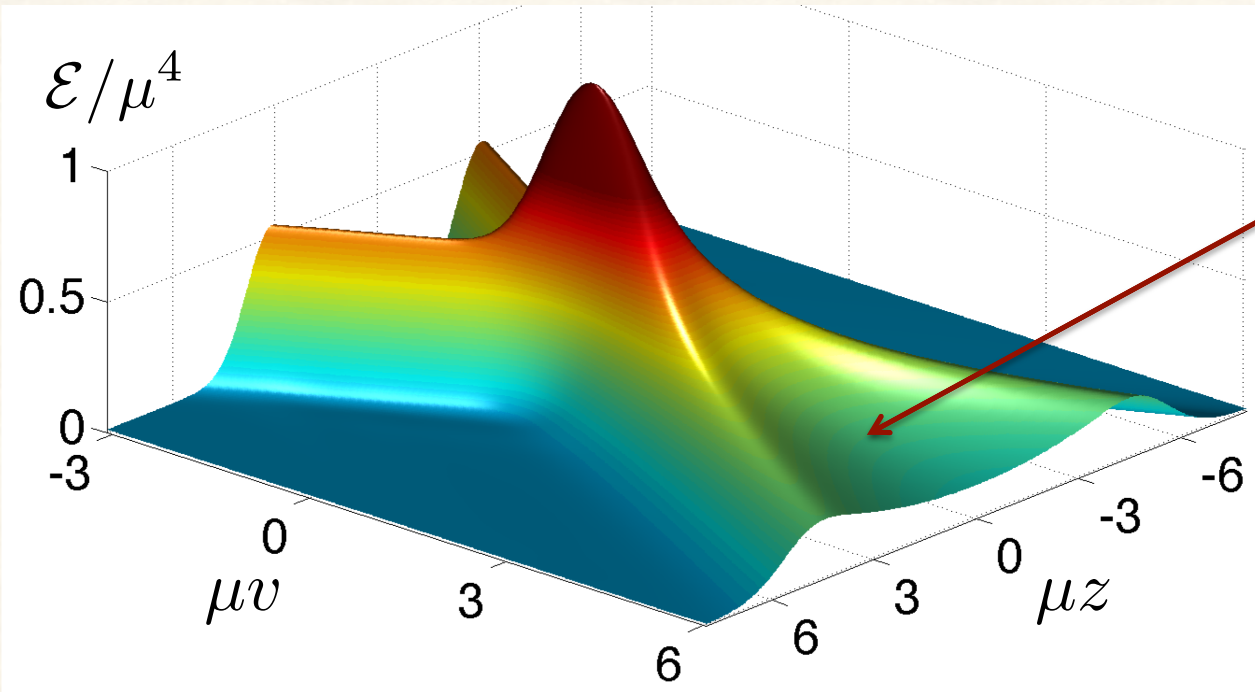
Introduction

- Parton energy loss in heavy ion collisions is one of the most important Hard Probes of the QGP.
- But, how much energy do hard partons lose early – in the pre-equilibrium, pre-QGP, epoch of the collision?
- Most approaches to the pre-equilibrium epoch assume that physics then is weakly coupled.
- At least as a benchmark against which to compare, can we answer this question upon assuming that physics is strongly coupled throughout the collision?
- Holography (aka AdS/CFT correspondence) is for now the only tool we have to get insights about strongly coupled far-from-equilibrium physics.
- (Over-)Simplified definition of holographic principle – dynamics of the strings in 5-dim space-time describes the motion of it's end-point(s) – quark(s) living on the boundary 4-dim space-time.
- We compute the energy loss of a quark moving through the pre-plasma, far-from equilibrium, matter made when two sheets of energy collide in strongly coupled N=4 SYM theory (holographically, in asymptotically AdS_5 space-time).

Colliding sheets

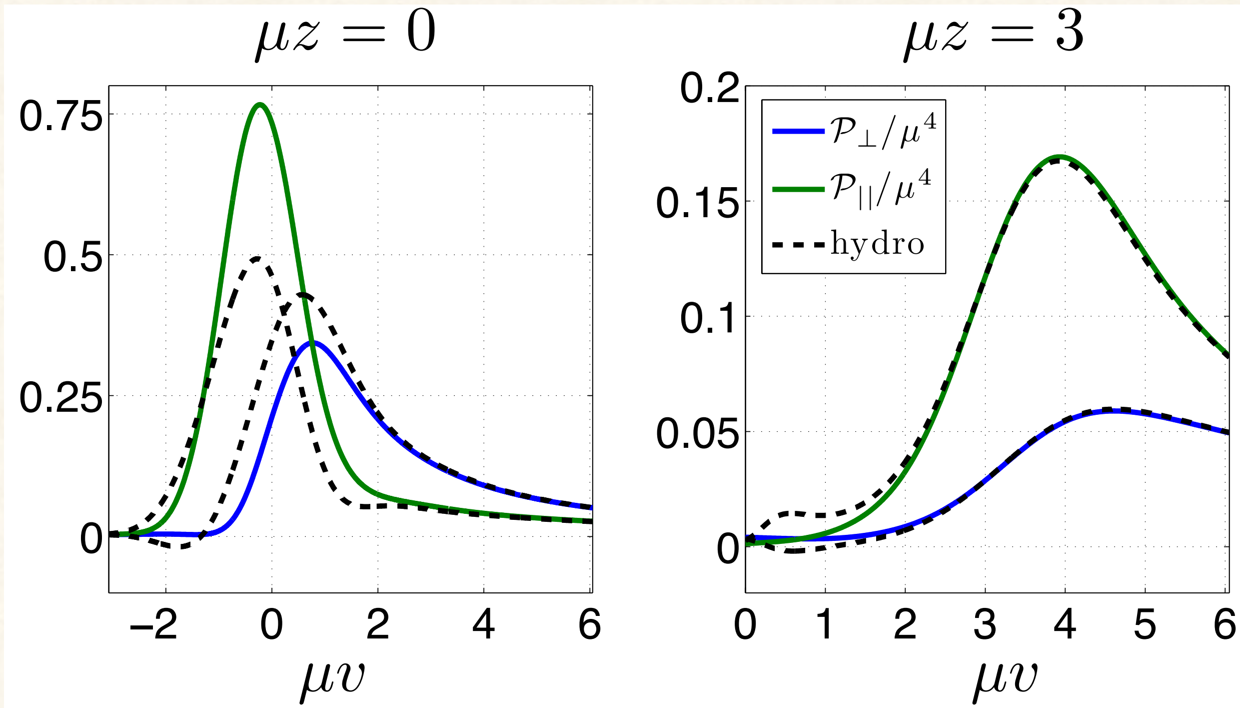


Chesler, Yaffe, 2010

QGP

- Colliding planar shockwaves with Gaussian profile, with width $\sim 1/\mu.$
- Shocks collide at time = *v* = 0.
- Estimated energy scale for RHIC, $\mu \sim 2 \text{ GeV}.$

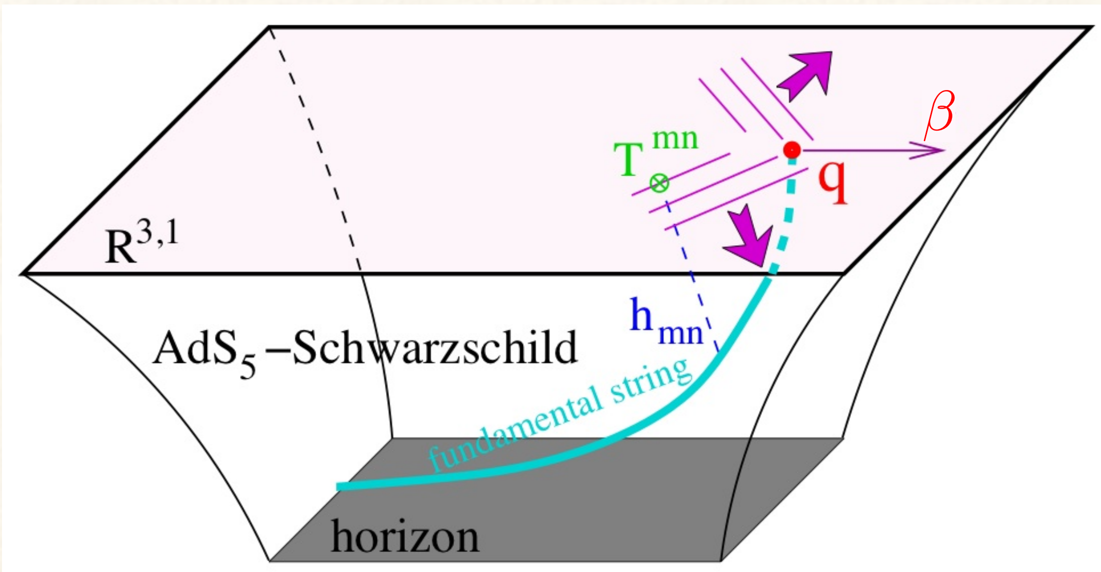
Colliding sheets



- Parallel pressure peaks the most at around the collision time.
- Hydrodynamics become applicable at around $\mu v \sim 3$, corresponding to about 3 sheet thicknesses after the collision.
- Parallel and transverse pressures non-equal still at later times: viscous hydrodynamics, not ideal hydrodynamics.

Dragged quark

- Heavy quark, being dragged through the medium with constant velocity β.
- If the medium is static plasma, trailing string solution:



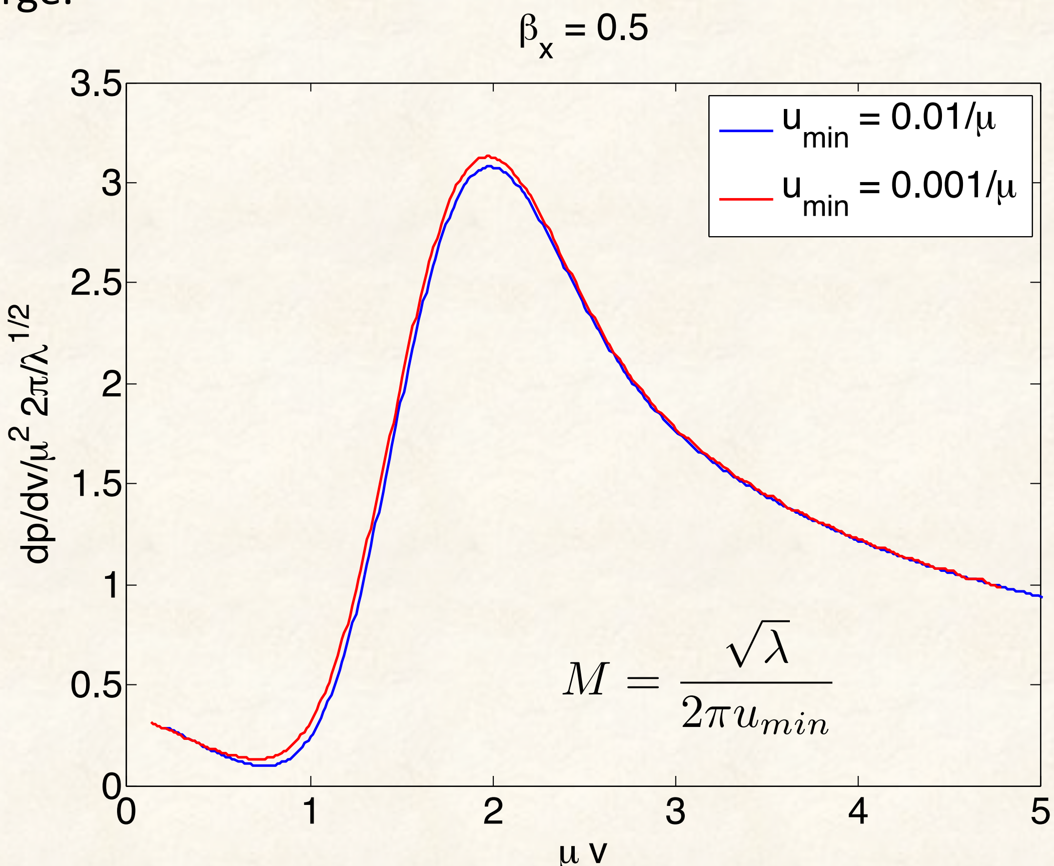
Herzog et al.; Gubser; Casalderrey-Solana, Teaney, 2006

$$\frac{dp}{dv} = -\frac{\sqrt{\lambda}}{2\pi}(\pi T)^2 \frac{\beta}{\sqrt{1-\beta^2}}$$

- What happens when the quark is being dragged through the colliding shocks? How does the drag force dp/dv compare to the static case?

Drag force

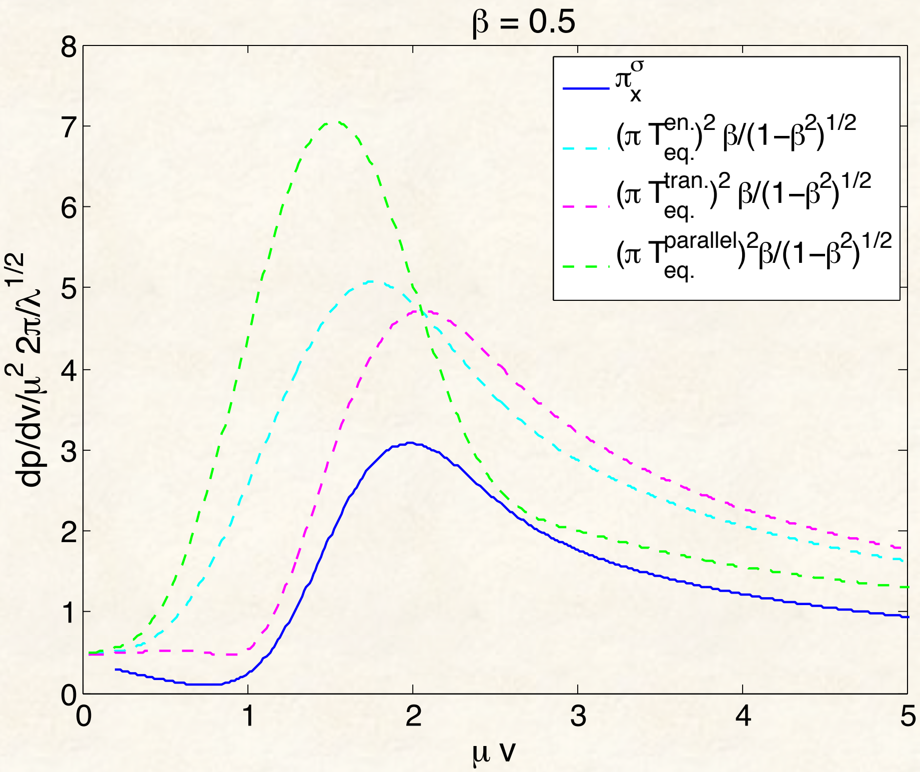
- The drag force is independent of the quark mass as long as quark mass *M* is sufficiently large.



(note different zero of v with respect to previous plots)

- We now need to decide what to compare this result to.

Comparison to static expectations



- How does the drag force compare to what it would be in a static plasma with the same instantaneous energy density? Same instantaneous pressure?
- Extract "temperatures" from the energy density and pressure (transverse, parallel) using the equilibrium EoS and plot the drag force.

$$T^{\mu\nu}_{eq.} = \frac{\pi^2 N_c^2 T^4}{8} \mathrm{diag}(3,1,1,1)$$

- The actual drag force is somewhat smaller than any of the static expectations, and is certainly not larger!
- Pre-equilibrium energy loss is less than it would be in a static plasma with the same energy density or pressure! Counter-intuitive? It was to us…

Conclusions and Outlook

- Pre-equilibrium energy loss may be significant, but it is not as large as one might have thought.
- No sign of any significant ``extra'' energy loss due to the plasma being far from equilibrium.
- This calculation is an example of holographic calculations taking steps in the direction from static "bricks" of plasma toward realistic space-time evolution. Further steps are possible.
- Work in progress: calculating energy loss and drag coefficient when quark has non-zero parallel velocity component.

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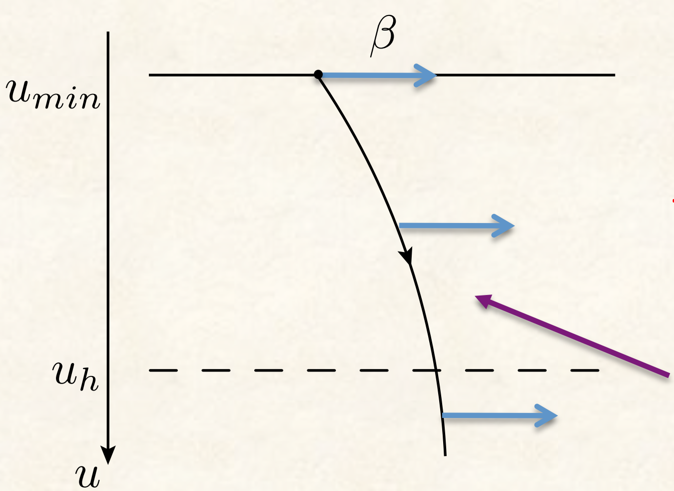
Thank you!

Back-up slides

Dragged quark

- Heavy quark, being dragged through the medium with constant velocity beta.
- In static limit, trailing string solution in the infallling Edington-Finkelstein coordinates:



Herzog et al.; Gubser; Casalderrey-Solana, Teaney, 2006

Trailing string solution

$$dp/dv = -\tilde{\mu} p$$

$$\tilde{\mu} = \pi^2 T^2 u_{min}, \text{ as } M \gg \pi T$$

Drag force

- On-shellness of the quark:

$$E^2 = p^2 + M^2 \rightarrow \frac{dE}{dv} = \beta \frac{dp}{dv}$$

- The drag force is independent of the quark mass as long as u_{min} is sufficiently small (quark mass is sufficiently large.)