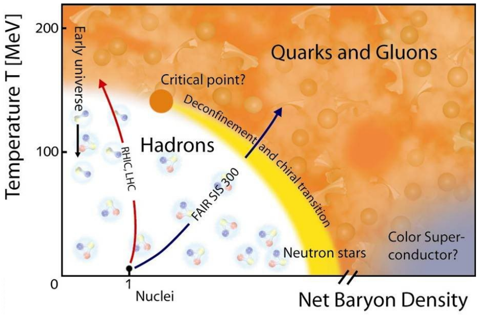
Holographic Analysis of Energy Loss Processes in Strongly Coupled Plasmas

Ling Lin

Nov 26, 2012

Motivation

- Quark-gluon plasma is strongly coupled.



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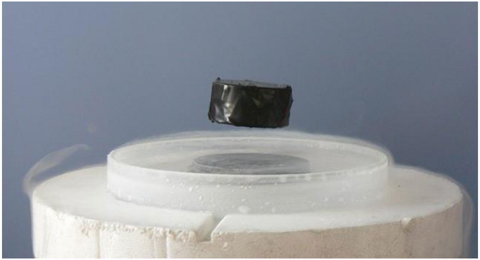

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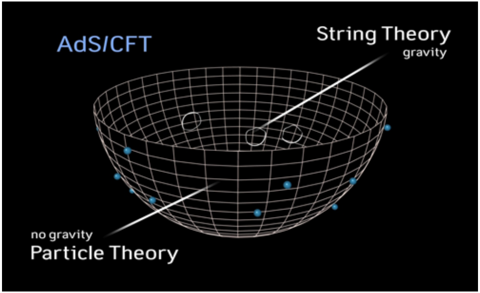
- Quark-gluon plasma is strongly coupled.
- Condensed matter systems may have strong coupling.
- Theoretical interest in holographic principle.



The Holographic Principle

- Realization: AdS/CFT correspondence (Maldacena, 1997):

$\mathcal{N} = 4$ supersymmetric $SU(N_c)$ gauge theory in 4d Minkowski space	*is dual to*	type IIB string theory in $AdS_5 \times S^5$ background

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- **Strong** coupling λ, large N_c limit reduces string theory to **classical** gravity in AdS_5.
- AdS/CFT 'dictionary' translates gauge theory quantities to gravity calculations.

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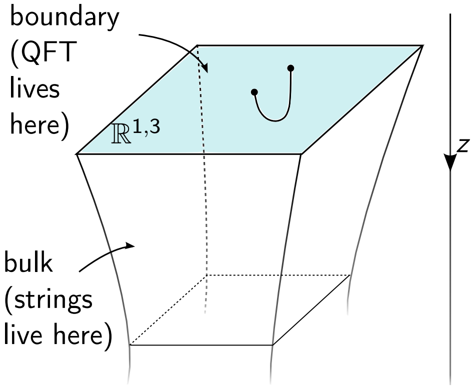
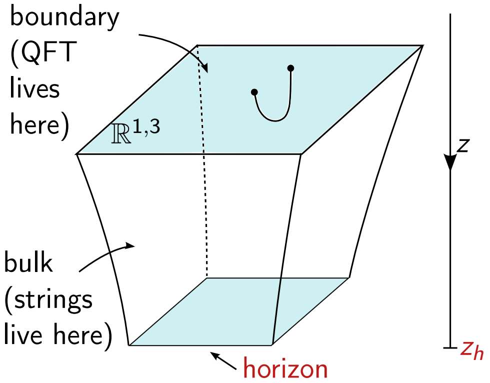


Bulk metric: $$G_{\alpha\beta}\mathrm{d}x^\alpha \mathrm{d}x^\beta = \frac{R^2}{z^2}\left(-h(z)\mathrm{d}t^2 + \mathrm{d}\vec{x}^2 + \frac{\mathrm{d}z^2}{h(z)}\right)$$

$$h(z) = 1$$

The Holographic Principle



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horizon function: $h(z) = 1 - \left(\frac{z}{z_h}\right)^4$

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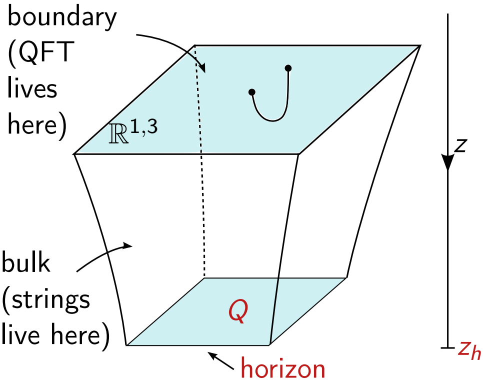

$$T = \frac{1}{\pi z_h}\left(1 - \frac{Q^2}{2}\right)$$

$$\mu = \sqrt{3}\frac{Q}{z_h}$$

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- Bottom-up approach: Propose a gravity theory and use dictionary to **define** the boundary theory.
- **Guideline**: Investigate dual theory by analysing observables.

Extended Models

- CGN-model [Colangelo, Giannuzzi, Nicotri] with *ad hoc* deformation c:

$$G_{\alpha\beta}^{\mathrm{CGN}} \mathrm{d}x^{\alpha} \mathrm{d}x^{\beta} = \frac{R^2 \mathrm{e}^{c^2 z^2}}{z^2} \left(-h(z) \mathrm{d}t^2 + \mathrm{d}\vec{x}^2 + \frac{\mathrm{d}z^2}{h(z)} \right) ,$$

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  $h(z)$, T and μ as before.
- Exhibits 'confining phase' at low μ/T.
- Does not solve any known gravitational equations of motion.

Extended Models

- '1-parameter model' with metric ansatz

$$ds^2 = e^{2A(z)}\left(-h(z)dt^2 + d\vec{x}^2\right) + \frac{e^{2B(z)}}{h(z)}dz^2$$

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solves Einstein equations derived from the action [DeWolfe, Gubser, Rosen]

$$S = \frac{1}{16\pi G_N}\int \mathrm{d}^5x\,\sqrt{-g}\left(\mathcal{R} - \frac{1}{2}(\partial\phi)^2 - V(\phi) - \frac{f(\phi)}{4}F_{\mu\nu}F^{\mu\nu}\right)$$

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- Scalar ϕ may or may not be dilaton.
- Stability argument *forbids* low μ/T area. No confinement observed.

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- Hard parton in plasma gets transverse kicks: $\hat{q} \equiv \frac{\langle p_\perp^2 \rangle}{L}$

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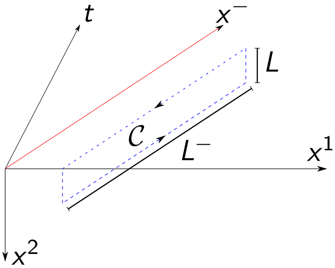

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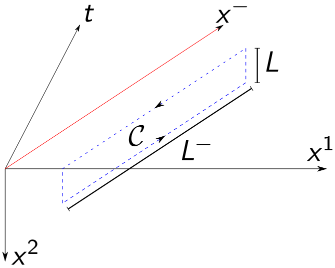

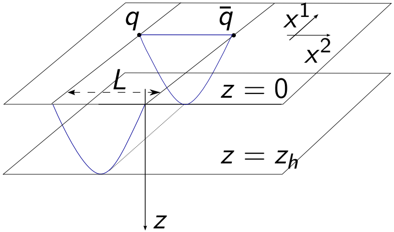

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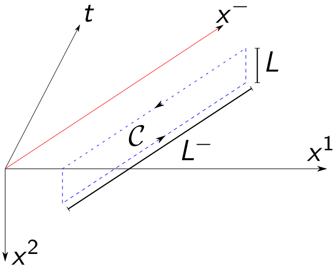

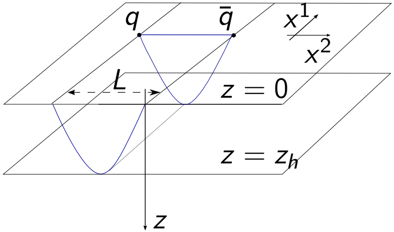

- Applying dictionary:

$$\langle W(\mathcal{C}) \rangle = \exp\left(-2 S_{\text{reg}}^{\text{on-shell}} \right)$$

Jet Quenching Parameter $\hat{q}$

- In general metric ansatz

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$\hat{q}$ evaluates to

$$\hat{q} = \frac{1}{\alpha' \pi} \left(\int_0^{z_h} \mathrm{d}z \frac{\exp(B(z) - 3A(z))}{\sqrt{h(z)(1-h(z))}} \right)^{-1} .$$

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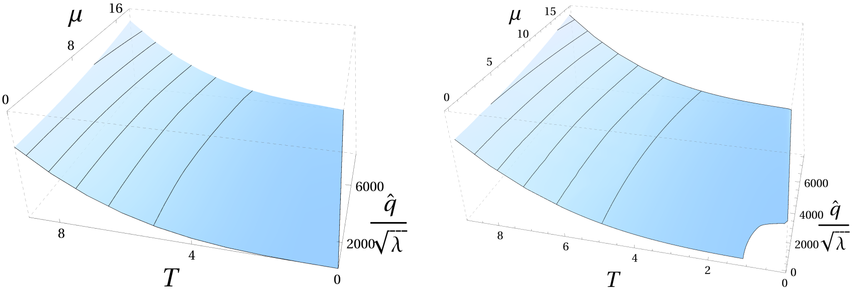
- At $\mu = 0$ and no deformation [Liu, Rajagopal, Wiedemann]:

$$\hat{q} = \sqrt{\lambda}\frac{\pi^{3/2}\Gamma(3/4)}{\Gamma(5/4)}T^3 \approx \sqrt{\lambda}\cdot 7.528\,T^3$$

$\hat{q}$ in Deformed Models

- In all our models $\hat{q}$ increases with growing T and μ



Examples: Behaviour of $\hat{q}$ in $\mathcal{N} = 4$ (**left**) and in 1-parameter model at $\kappa = 10$ (**right**)

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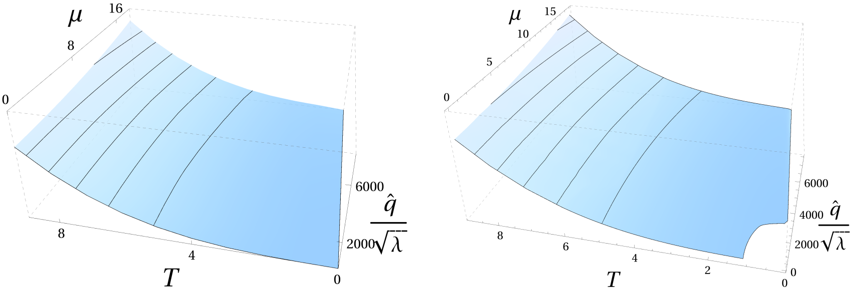


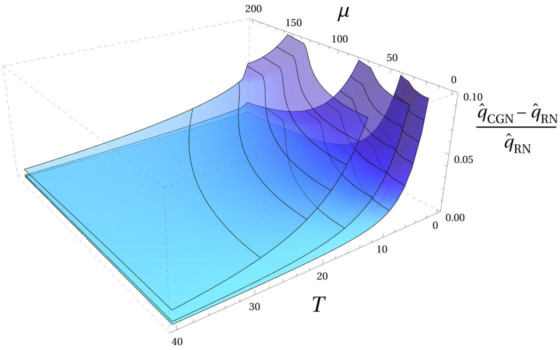
Examples: Behaviour of $\hat{q}$ in $\mathcal{N} = 4$ (**left**) and in 1-parameter model at $\kappa = 10$ (**right**)

- Agrees with intuition of how plasma affects jets.

$\hat{q}$ in Deformed Models

- Deformation unimportant at higher μ/T.

Relative deviation from $\mathcal{N} = 4$ in CGN model at different deformations ($c = 5, 10, 20$):



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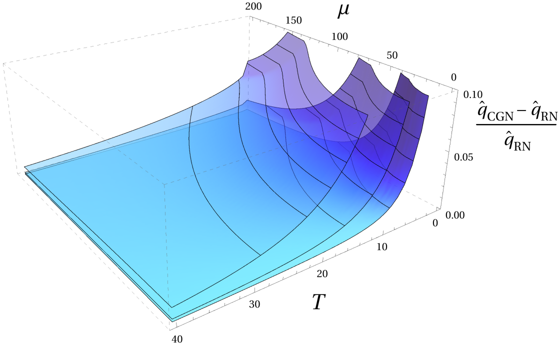

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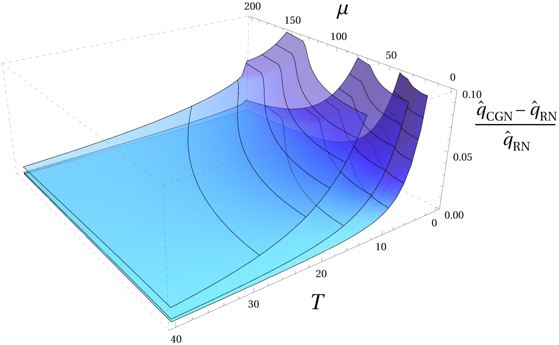
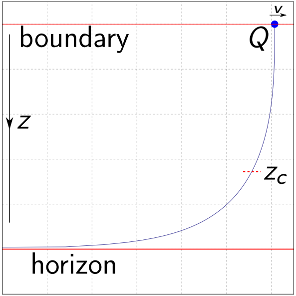


- **$\hat{q}$ is a very 'robust' observable.**
- Apply calculation to other (measurable) quantities, e.g. R_{AA} (?).

Moving Quark

Linear motion [Gubser]:



$$\frac{\mathrm{d}E}{\mathrm{d}t} = -\frac{1}{2\pi\alpha'} e^{2A(z_c)}\, v^2$$

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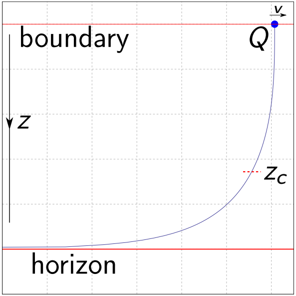

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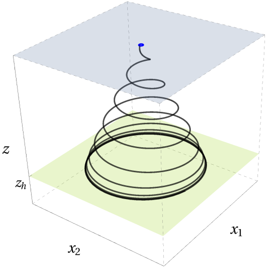

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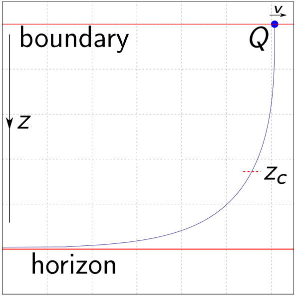

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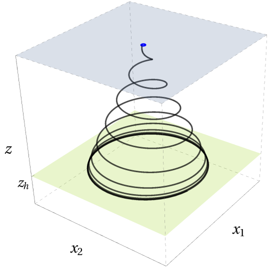

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Drag force shows robust behaviour.

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- Applied to QGP: Analyse jet quenching.
- In models we discussed: Observables are robust.
- Comparable (?) to experimental data.

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Thank you for your attention!