

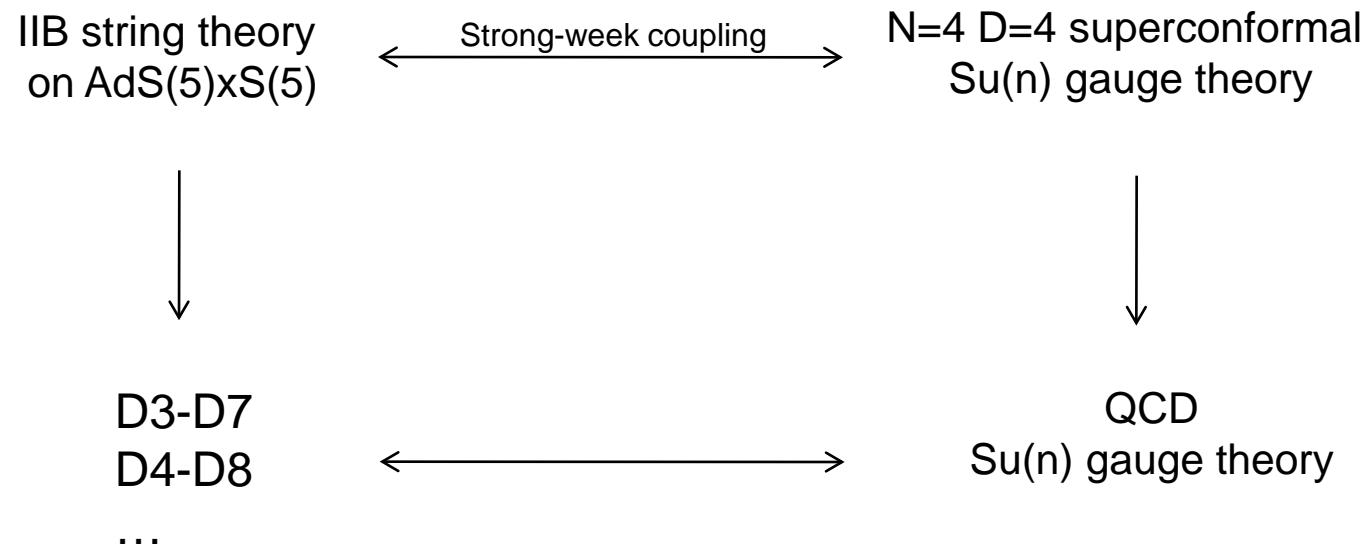
# Non-commutative Holographic QCD and Jet Quenching Parameter

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arXiv:1104.4924 [hep-th]

## Outline

1. Review on AdS/CFT
2. Holographic QCD (Sakai-Sugimoto model)
  - 1.1 Commutative case
  - 1.2 Non-commutative case
3. Quark-Gluon plasma
4. Jet quenching parameter

## AdS/CFT



# Holographic QCD

(Sakai-Sugimoto model)  
 [hep-th/0604161]

## Commutative case

### Low temperature background

1. Confined phase.
2. Chiral symmetry is broken.

$$ds^2 = \left(\frac{u}{R}\right)^{3/2} \left( dt_E^2 + dx^i dx_i + f(u) dx_4^2 \right) + \left(\frac{R}{u}\right)^{3/2} \left( \frac{du^2}{f(u)} + u^2 d\Omega_4^2 \right),$$

$$e^\phi = g_s \left(\frac{u}{R}\right)^{3/4}, \quad f(u) = 1 - \frac{u_k^3}{u^3}, \quad F_4 = dC_3 = \frac{2\pi N_c}{V_4} \epsilon_4,$$

$$2\pi\mathcal{R} = \frac{4\pi}{3} \left(\frac{R^3}{u_k}\right)^{1/2}$$

### High temperature background

1. Deconfined phase.
2. In termediate phase:  
broken chiral symmetry  
or  
restored chiral symmetry

$$ds^2 = \left(\frac{u}{R}\right)^{3/2} \left( f(u) dt_E^2 + dx^i dx_i + dx_4^2 \right) + \left(\frac{R}{u}\right)^{3/2} \left( \frac{du^2}{f(u)} + u^2 d\Omega_4^2 \right),$$

$$f(u) = 1 - \frac{u_T^3}{u^3}, \quad \delta t_E = \frac{4\pi}{3} \left(\frac{R^3}{u_T}\right)^{1/2} = \frac{1}{T} = \beta, \quad u_T = \left(\frac{4\pi T}{3}\right)^2,$$

Non-commutative case  
[\[hep-th/9909215\]](#)

$$ds^2 = \left(\frac{u}{R}\right)^{3/2} \left( h(dt_E^2 + dx_1^2) + dx_2^2 + dx_3^2 + f dx_4^2 \right) + \left(\frac{R}{u}\right)^{3/2} \left( \frac{du^2}{f} + u^2 d\Omega_4^2 \right),$$

**Low temperature  
background**

$$f = 1 - \frac{u_k^3}{u^3}, \quad h = \frac{1}{1 + \theta^3 u^3}, \quad e^\phi = g_s \left(\frac{u}{R}\right)^{3/4} \sqrt{h}, \quad B \equiv B_{t1} = \left(\frac{\theta}{R}\right)^{3/2} u^3 h,$$

$$F_4 = dC_3 = \frac{2\pi N_c}{V_4} \epsilon_4,$$

**High temperature  
background**

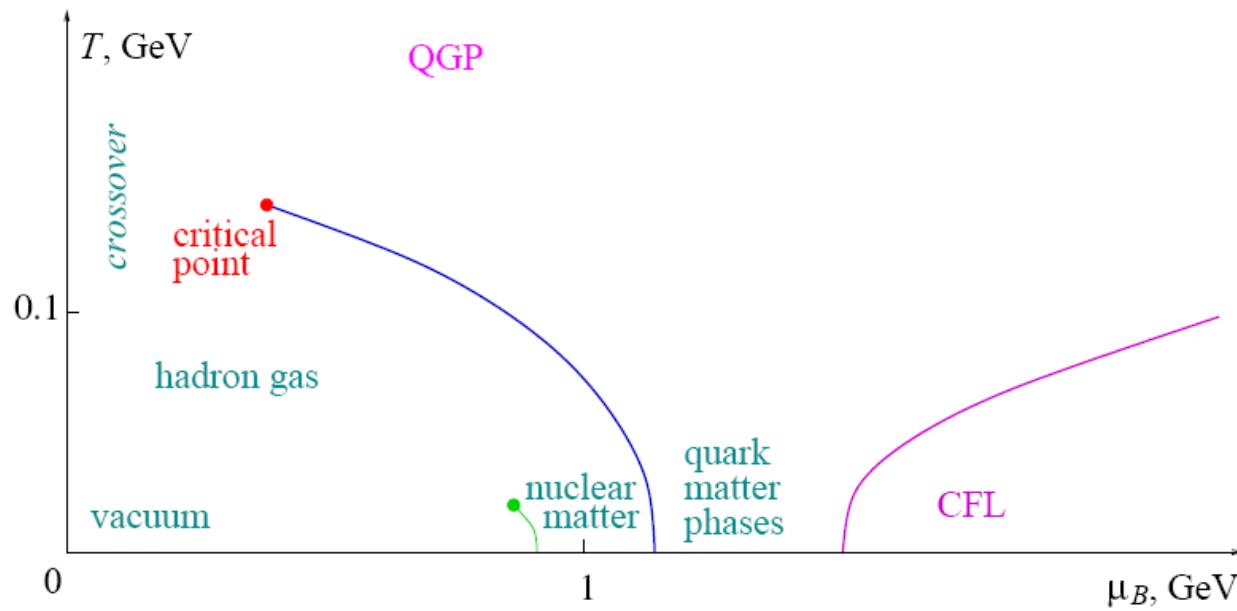
$$ds^2 = u^{3/2} \left( h(f dt_E^2 + dx_1^2) + dx_2^2 + dx_3^2 + dx_4^2 \right) + u^{-3/2} \left( \frac{du^2}{f} + u^2 d\Omega_4^2 \right),$$

$$f = 1 - \frac{u_h^3}{u^3}.$$

## QGP

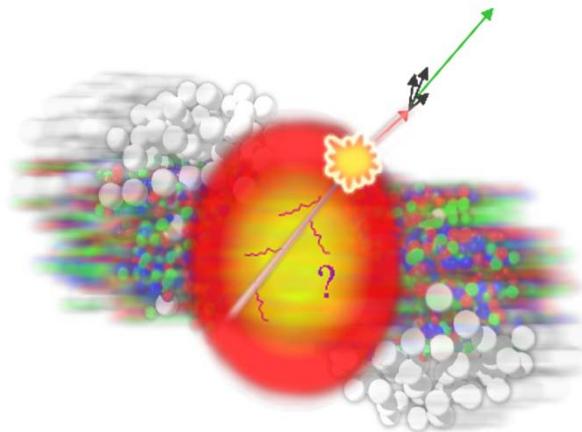
Quark-gluon plasma (QGP) has been produced by Au-Au collision at an ultra-relativistic center of mass  $s=200$  GeV.

QGP is a low viscosity, hot strongly coupled fluid.



## Jet quenching parameter

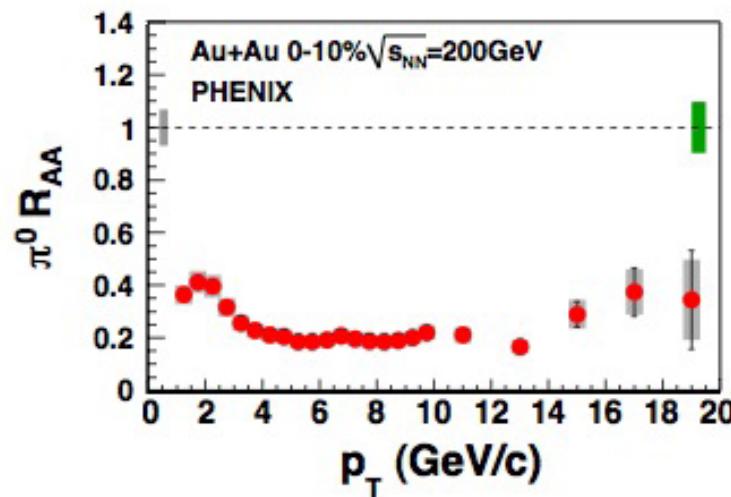
The energy loss of the quark or gluon in the plasma is described by the jet quenching parameter which is a property of the strongly coupled QGP.



## Nuclear modification factor

$$R_{AB}^h(p_T, \eta, \text{centrality}) = \frac{\frac{dN_{\text{medium}}^{AB \rightarrow h}}{dp_T d\eta}}{\langle N_{\text{coll}}^{AB} \rangle \frac{dN_{\text{vacuum}}^{pp \rightarrow h}}{dp_T d\eta}}$$

$\langle N_{\text{coll}}^{AB} \rangle$  is the average number of inelastic nucleon-nucleon in A-B collisions.



1. p-independent of nuclear modification factor at high p( $p > 7$ ).
2. Photons are not quenched.

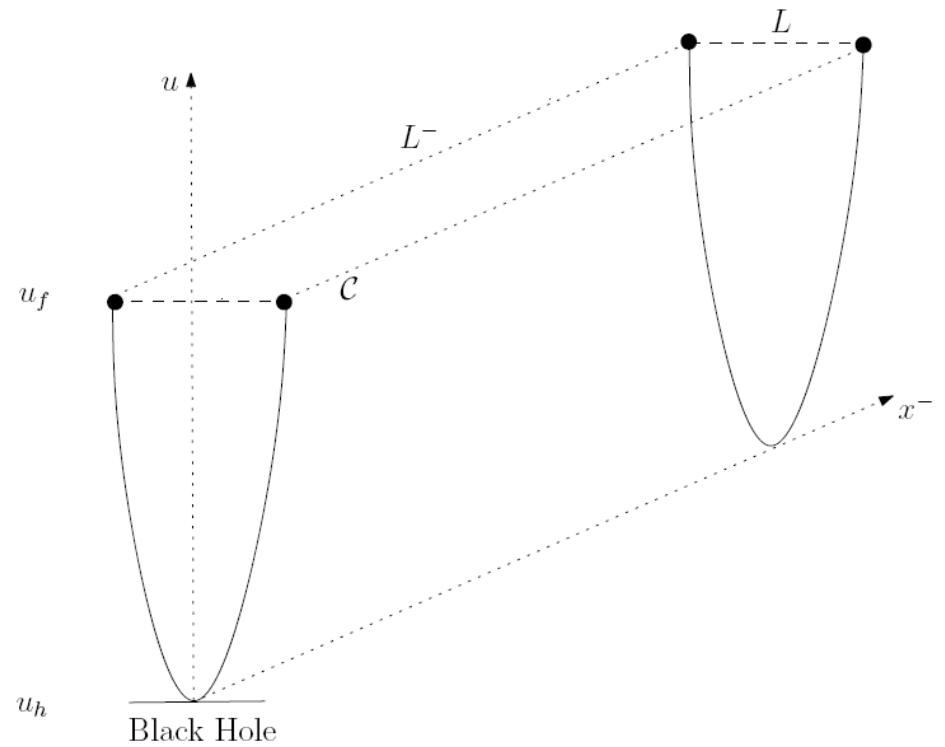
Jet quenching parameter

$$\alpha_s \ll 1 \rightarrow \Delta E = \frac{1}{2} \alpha_s C_R \hat{q} (L^-)^2$$

$$\alpha_s \approx 0.5 \quad ??$$

$$\langle W(\mathcal{C}) \rangle \approx e^{-\frac{1}{4\sqrt{2}} \hat{q} L^- L^2}$$

From AdS/CFT  $\langle W(\mathcal{C}) \rangle = e^{-S(\mathcal{C})}$



## Low temperature background

[hep-ph/0605178]

String action

$$S = \frac{1}{2\pi\alpha'} \int d\tau d\sigma \sqrt{-\det g_{\mu\nu}}$$

$$g_{\mu\nu} = G_{MN} \partial_\mu x^M \partial_\nu x^N$$

Static gauge

$$\tau = x^- \text{ and } \sigma = x_2$$

Background metric

$$ds^2 = u^{3/2} \left( -dx^+ dx^- + dx_2^2 + dx_3^2 + f dx_4^2 \right) + u^{-3/2} \left( \frac{du^2}{f} + u^2 d\Omega_4^2 \right)$$

Component of  
induced metric

$$g_{\tau\tau} = 0$$

$$g_{\tau\sigma} = 0$$

## High temperature background

Background metric

$$ds^2 = u^{3/2} \left( -\frac{1+f}{2} dx^+ dx^- + dx_2^2 + dx_3^2 + dx_4^2 \right) - \frac{1-f}{4} u^{3/2} [(dx^+)^2 + (dx^-)^2] + u^{-3/2} \left( \frac{du^2}{f} + u^2 d\Omega_4^2 \right)$$

String action

$$S = \frac{u_h^{3/2}}{4\pi\alpha'} \int_0^{L^-} d\tau \int d\sigma \sqrt{1 + \frac{u'^2}{fu^3}}$$

Conserved charge

$$E = \mathcal{L} - u' \frac{\partial \mathcal{L}}{\partial u'},$$

$$E^2 u'^2 = u^3 (1 - E^2) f$$

Quark speration  
at the boundary

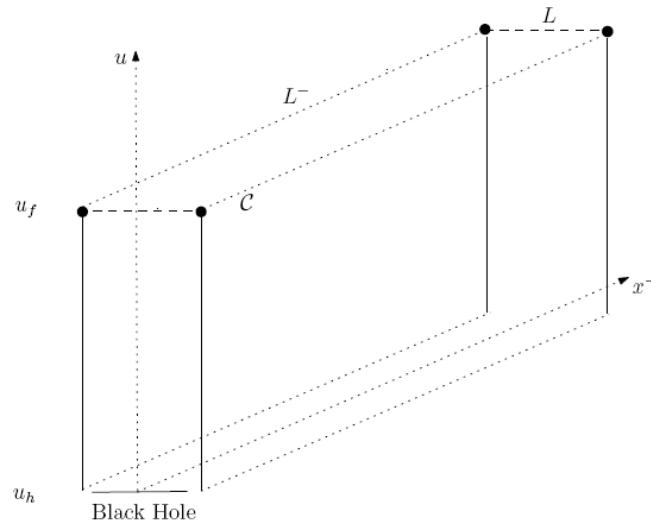
$$\frac{L}{2} = \int_0^{L/2} d\sigma = \frac{E}{\sqrt{1-E^2}} \int_{u_h}^{u_f=\infty} \frac{du}{\sqrt{u^3 - u_h^3}}$$

$$L = \frac{4.3a}{\sqrt{u_h}} \quad a^2 = \frac{E^2}{1-E^2}$$

String action

$$S = \frac{u_h^{3/2} L^-}{2\pi\alpha' \sqrt{1 - E^2}} \int_{u_h}^{u_f} \frac{du}{\sqrt{u^3 - u_h^3}}$$

$$\simeq \frac{2.15 L^- u_h}{2\pi\alpha'} \left(1 + \frac{0.05}{2} L^2 u_h\right)$$



Self-energy

$$S_s = \frac{2.15 u_h L^-}{2\pi\alpha'}$$

Total action

$$S_t \equiv S - S_s = \frac{0.03}{\pi\alpha'} L^2 L^- u_h^2$$

Jet quenching parameter

$$\hat{q} = 7.35\lambda T^4$$

Non-commutative case

Low temperature

$$\hat{q} = 0$$

High temperature

$$\hat{q} = 7.35 \left( 1 - \left( \frac{4\pi}{3} \right)^6 \theta^3 T^6 \right) \lambda T^4$$