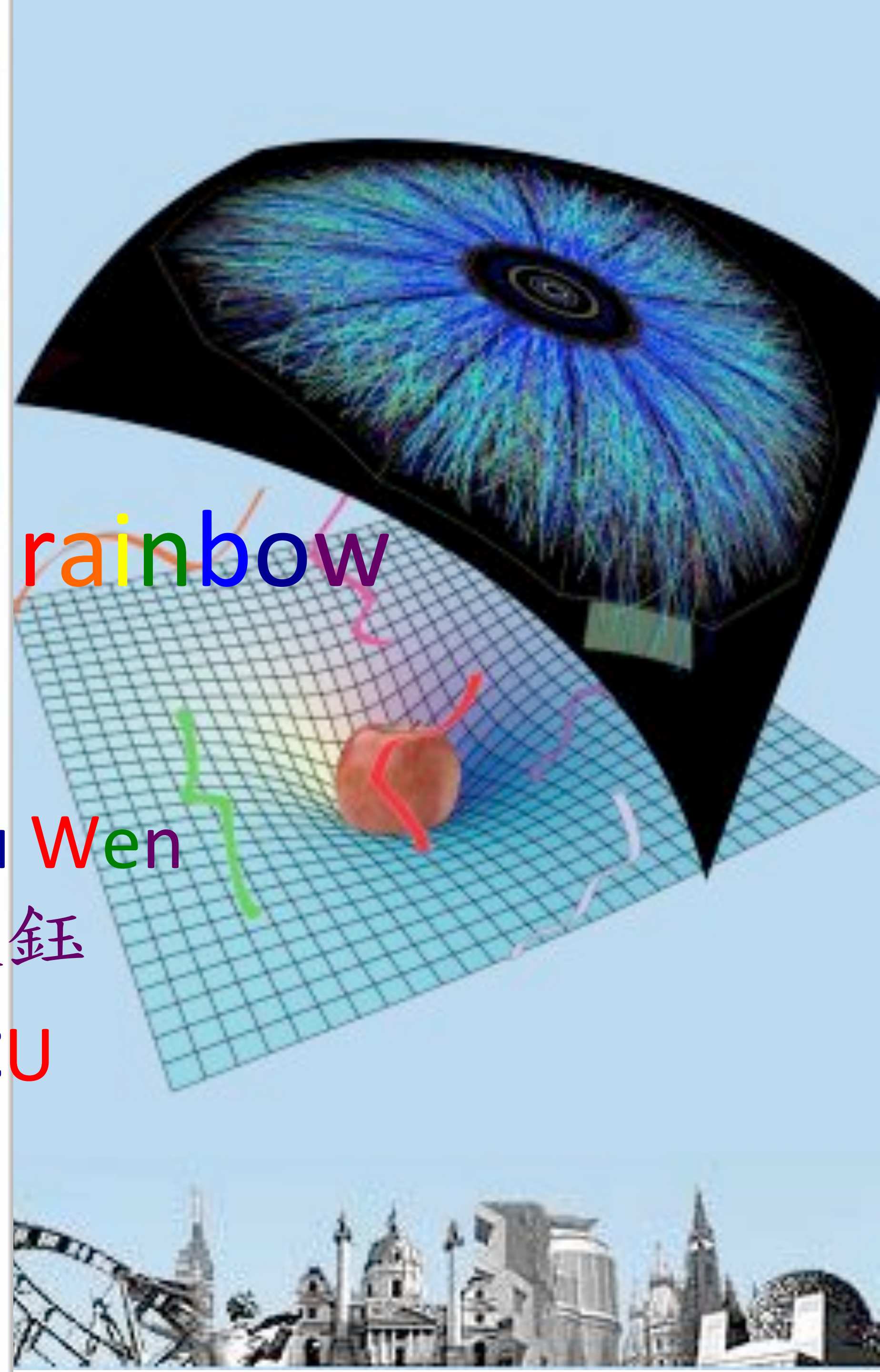
9th Taiwan String Workshop



QGP at gravity's rainbow

Wen-Yu Wen

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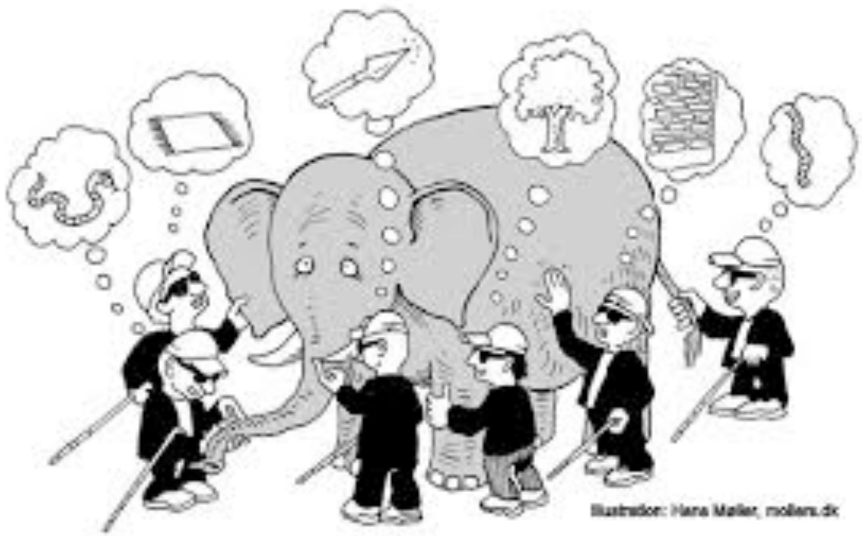
CYCU

Objectivity and Subjectivity



From DSR to gravity's rainbow

J. Magueijo, L. Smolin (2004)

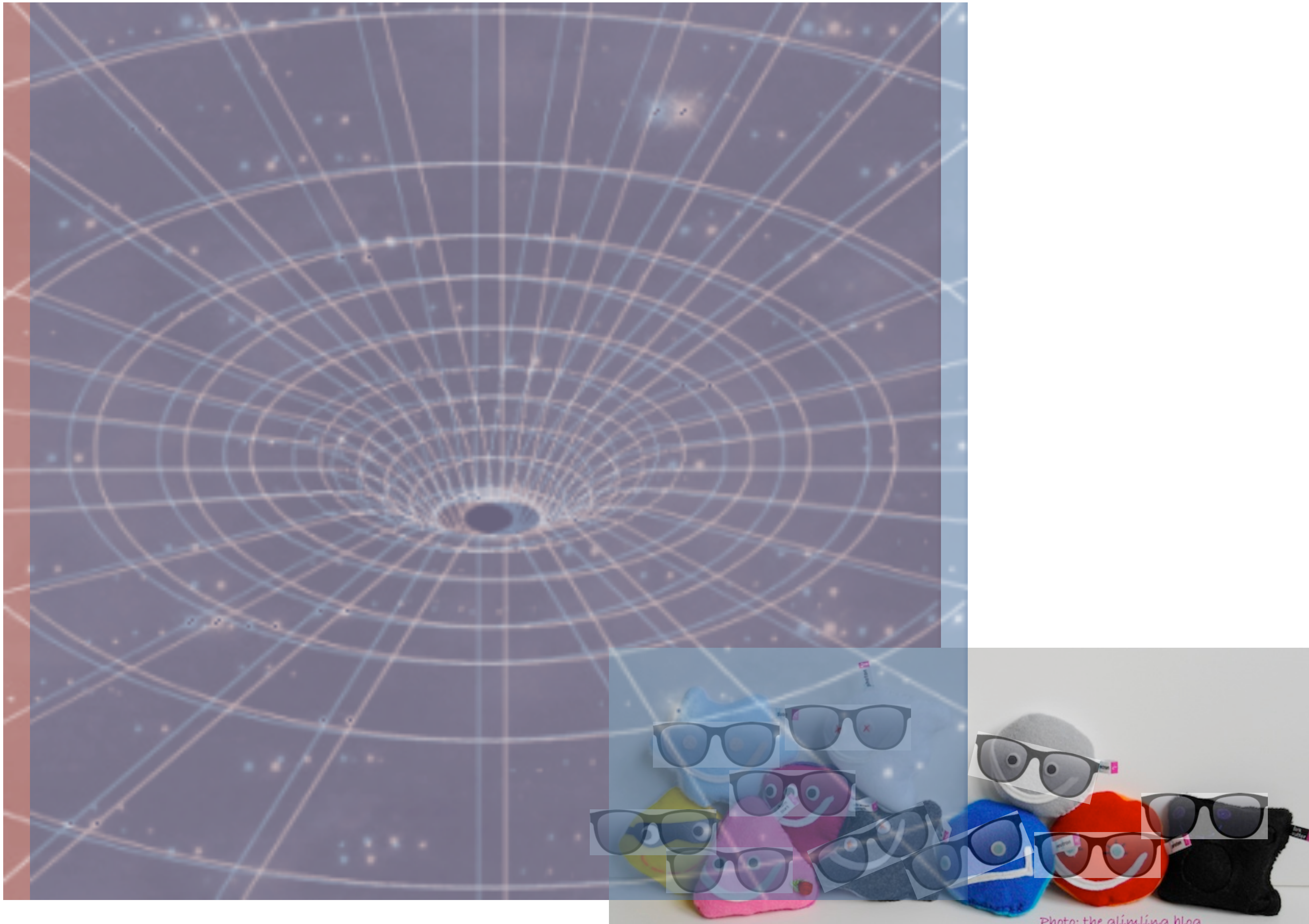
- DSR (doubly special relativity) assumes the universal Planck scale E_p in addition to the speed of light c.
- The modified Einstein's dispersion relation (c=1)

$$f^2(E/E_p)E^2 - g^2(E/E_p)\vec{p}^2 = m^2$$

- To bring nonlinear relation in momentum space to spacetime coordinate is not straightforward. Under assumption of linear realization of plane wave, one can introduce an energy-dependent vierbein locally. A global curved metric can be well defined by patching together local frames according to the *equivalence principle* if Λ << E << Ep. The *correspondence principle* requires f(E) and g(E) → 1 as E/Ep → 0

$$ds^2 = -\frac{g_{tt}dt^2}{f^2(E/E_p)} + \frac{g_{xx}d\vec{x}^2}{g^2(E/E_p)}$$

- Now a particle of energy E see its own rainbow metric:

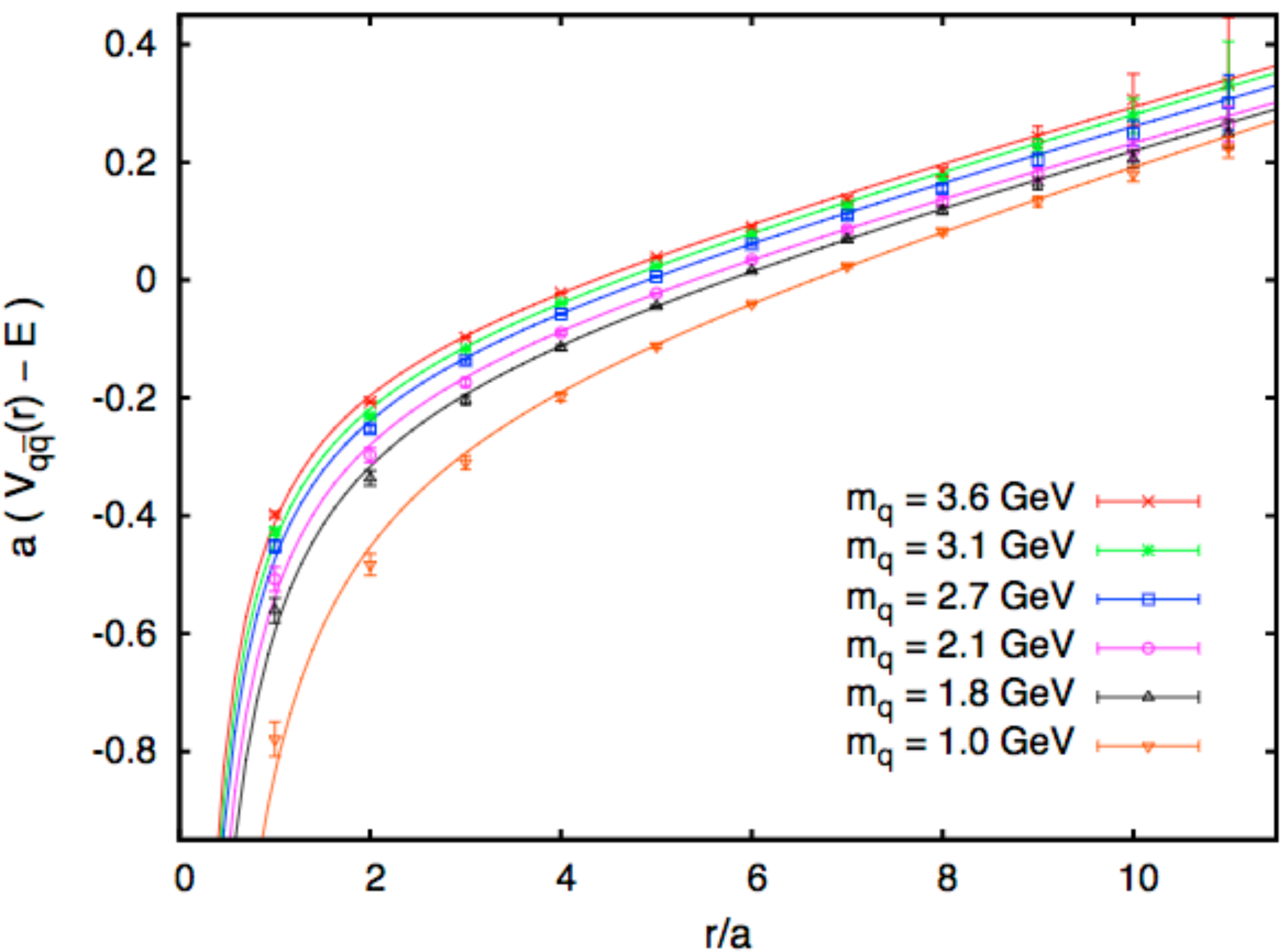


Motivation

- AdS/CFT correspondence helps build up dictionary between fields in the bulk and operators in the boundary on solid ground.
- AdS/QCD provides a useful/controllable computational tools in addition to other nonperturbative approaches, such as lattice QCD.
- AdS/CMT shows surprising similar features and noval properties in prospective new materials.
- “Devil is in the detail, ” models need to be refined to be more realistic.

observation 1:
Cornell potential of heavy quarks

Kawanai-Sasaki, 2011



observation 2:
Jet quenching parameter

The JET Collaboration, PRC 90, 014909 (2014)

- Jets are produced at very early stage of high-energy heavy-ion collisions. Their subsequent propagation through dense medium leads to jet energy loss and suppression of final jets and large transverse momentum hadron spectra. There are different pheno models: GLV-CUJET, HT-M, HT-BW, MARTINI, McGill-AMY, …

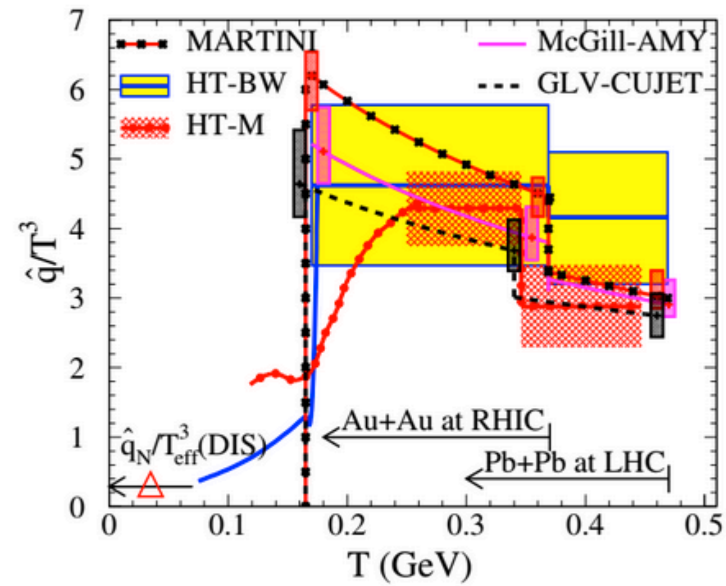
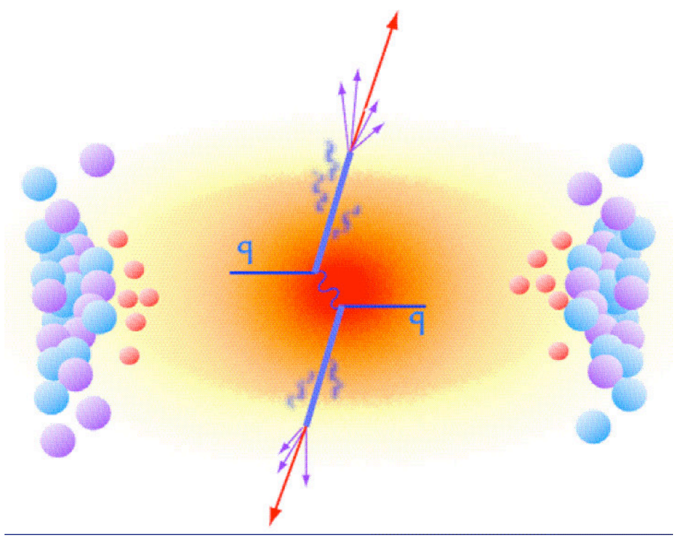


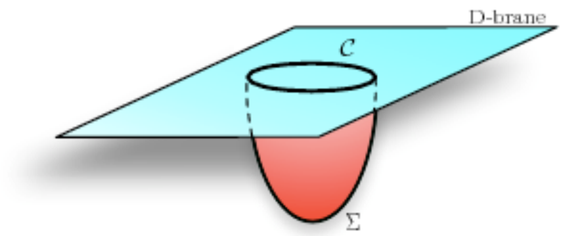
FIG. 10. (Color online) The assumed temperature dependence of the scaled jet transport parameter $\hat{q}/T^3$ in different jet quenching models for an initial quark jet with energy $E = 10$ GeV. Values of $\hat{q}$ at the center of the most central A+A collisions at an initial time $\tau_0 = 0.6$ fm/c in HT-BW and HT-M models are extracted from fitting to experimental data on hadron suppression factor R_{AA} at both RHIC and LHC. In GLV-CUJET, MARTINI and McGill-AMY model, it is calculated within the corresponding model with parameters constrained by experimental data at RHIC and LHC. Errors from the fits are indicated by filled boxes at three separate temperatures at RHIC and LHC, respectively. The arrows indicate the range of temperatures at the center of the most central A+A collisions. The triangle indicates the value of $\hat{q}_N/T^3_{\rm eff}$ in cold nuclei from DIS experiments.

AdS/QCD

- The cornell potential[Maldacena, Andreev et al, Boschi-Filho et al,…, Yang et al, He], jet quenching parameter [Liu,…] and other QGP observables have been studied via holographic method.

$$\left\langle P e^{-i\oint_C dx^\mu A_\mu} \right\rangle = e^{-\sqrt{\lambda} S[C]}$$





Rainbow at IR

hard-wall model at gravity's rainbow

$$ds^2 = \frac{L(E)^2}{z^2}\left(-f(z)dt^2 + d\vec{x}^2 + \frac{dz^2}{f(z)}\right)$$

$$z \leq z_0(E)$$

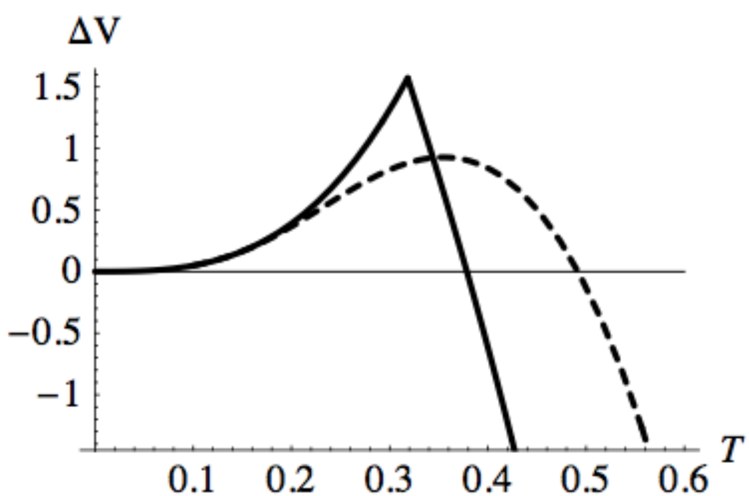


FIG. 1: The solid line is the free energy difference in the hard wall model, the dashed line the difference in the soft wall model. The graph was made in units where $L^3/\kappa^2 = c = z_0 = 1$. [Herzog, 2007]

$$\Delta V = \begin{cases} \dfrac{\pi L(E)^3}{2\kappa^2} z_h^{-3}, & z_0(E) < z_h \\ \dfrac{\pi L(E)^3}{\kappa^2} z_h\left(\dfrac{1}{z_0^4(E)} - \dfrac{1}{2z_h^4}\right), & z_0(E) < z_h \end{cases}$$

$$T_c(E) = \frac{2^{1/4}}{\pi z_0(E)}$$

Cornell potential at gravity's rainbow

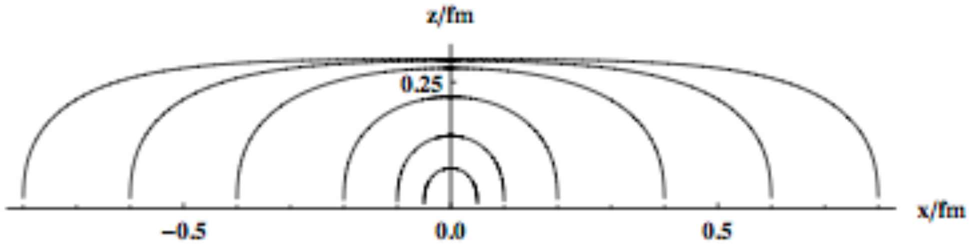
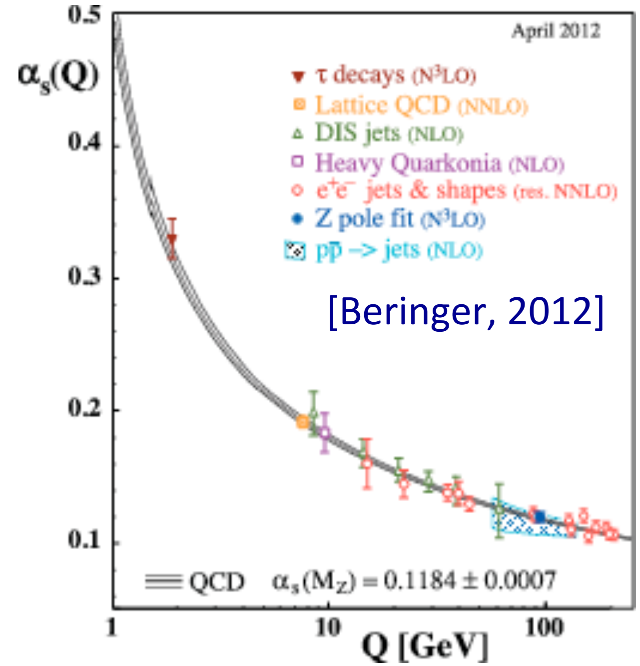


FIG. 2. String profiles with various values of r

$$V \sim -\frac{a}{r} + \sigma r$$

$$a = \frac{4\pi^2 L(E)^2}{\Gamma(1/4)^4 \alpha'} = \frac{4}{3}\alpha_s(E)$$

$$\sigma = \frac{1}{2\pi\alpha'}\sqrt{1-\left(\frac{z_0(E)}{z_h}\right)^4} = \frac{1}{2\pi\alpha'}\sqrt{1-2\left(\frac{T}{T_c(E)}\right)^4}$$



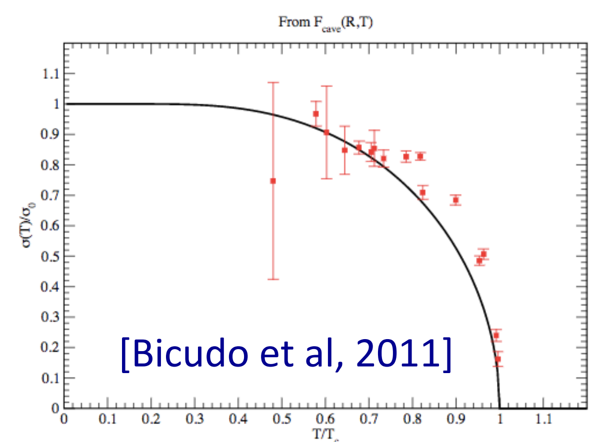


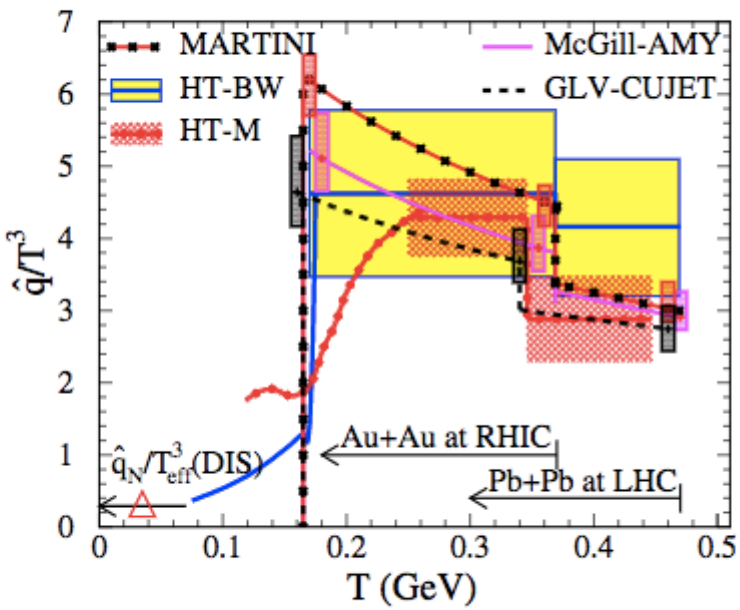
Figure 5: $\sigma(T)$ for $T \in 0.48T_c - T_c$ extracted with the color average free energy

Jet quenching parameter at gravity's rainbow

$$\frac{\hat{q}}{T^3} = \frac{\pi^{3/2}\Gamma(3/4)}{\Gamma(5/4)} \frac{L(E)^2}{\alpha'}$$

The JET Collaboration 2014

$$\frac{\hat{q}}{T^3} \approx \begin{cases} 4.6 \pm 1.2 & \text{at RHIC,} \\ 3.7 \pm 1.4 & \text{at LHC,} \end{cases}$$



and others observables in QGP …

Rainbow at UV

- QCD at very high temperature or Planck scale?

$$E^2 g_1^2(E) - p^2 c^2 g_2^2(E) = m^2 c^4$$

$$ds^2 = \frac{R^2}{z^2}\Big[- f(z) g_1^{-2}(E) dt^2 + g_2^{-2}(E)\Big(f^{-1}(z) dz^2 + d\vec{x}^2 \Big)\Big],$$

$$f(z) = 1 - \frac{z^4}{z_T^4}.$$

Drag force: $$-f_1 = -\frac{1}{2\pi\alpha'}\Pi = -\frac{\pi T^2 R^2}{2\alpha'} \left(\frac{g_1(E)}{g_2^2(E)}\right)^2 \frac{v}{\sqrt{1 - \left(\frac{g_1(E)}{g_2(E)}\right)^2 v^2}},$$

Jet quenching: $$\hat{q} = 2\frac{R^2}{2\pi\alpha'}\Big(g_2^2(E) F(z_T, E) \Big)^{-1} \quad F(z_T, E) \equiv \int_0^{z_T} \frac{dz}{\sqrt{\mathcal{A}(z,E) f}}$$

$$\mathcal{A}(z, E) \equiv z^{-4}\left(1 - \left(\frac{g_2(E)}{g_1(E)}\right)^2 f\right).$$

Thank You