Strongly-Coupled Quarks and Colorful Black Holes

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Based on work being finalized with MD Razikul Islam

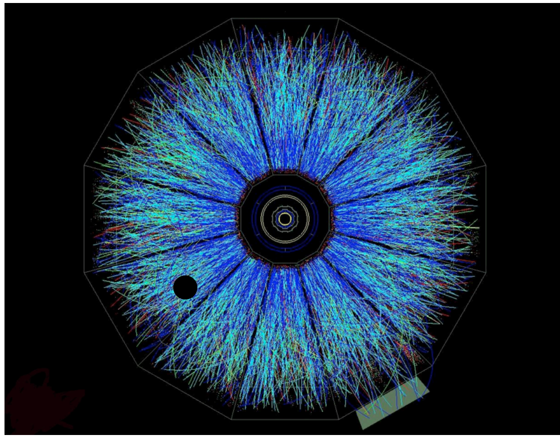
Quantum Black Holes

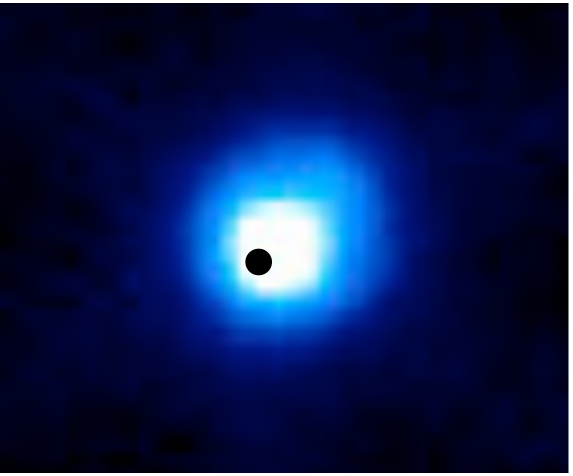
Large extra dimensions ⟶ TeV-scale quantum gravity

(Arkani-Hamed, Dimopoulos, Dvali 1998)

TeV-scale black holes at the LHC

(Argyres, Dimopoulos, March-Russell 1998)



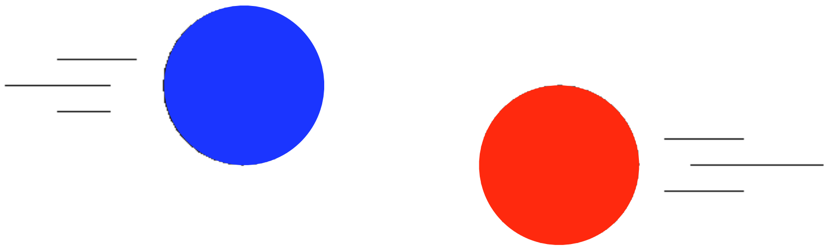


or in quark stars

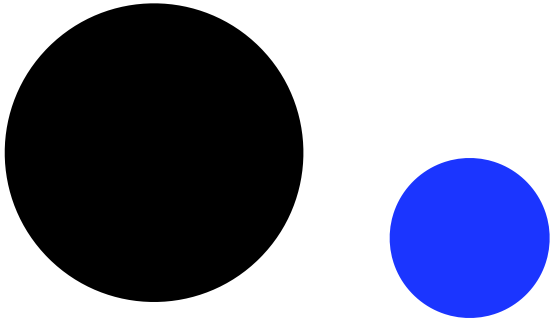
(Gorham, Learned, Lehtinen 2002)

Colorful Black Holes

A quantum black hole could carry color charges inherited from its parton progenitors



The black hole would interact with nearby quarks via gravity and color interaction



Challenges in Describing Colorful Black Holes

- Semi-classical approach to gravity might be unreliable near horizon

Even the notion of a horizon is suspect

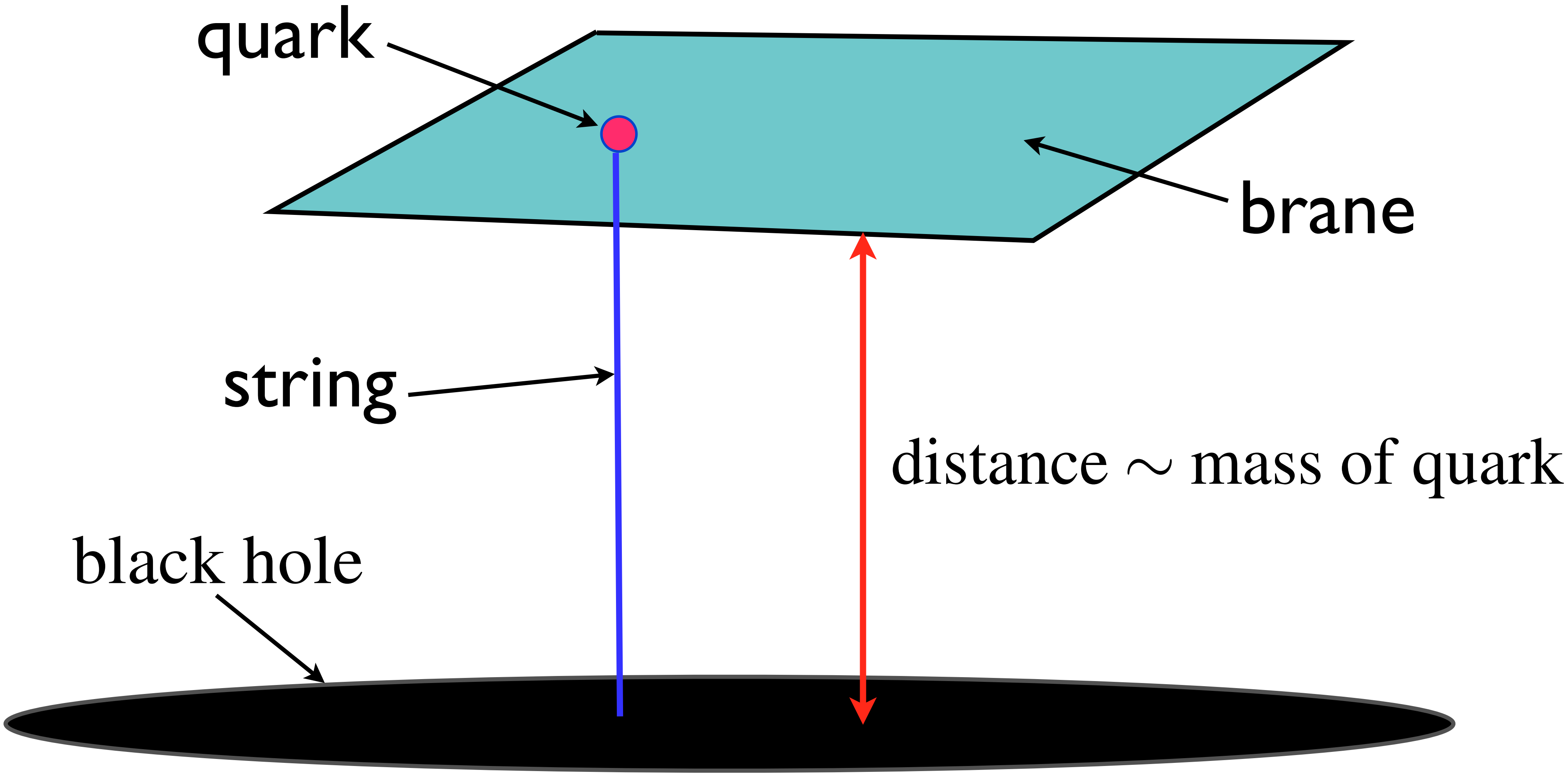
$$ds_4^2 = -f dt^2 + f^{-1} d\rho^2 + \rho^2 d\Omega_2^2 \qquad f = 1 - \frac{2M}{\rho}$$

$$R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} = \frac{48M^2}{\rho^6} \text{ diverges as } \rho \to 2M \text{ for small } M$$

- Color interaction between black hole and nearby quarks might be at strong coupling

Could attempt a gauge-gravity duality description

Holographic Description of Strongly-Coupled Plasma



Temperature of black hole = Temperature of plasma

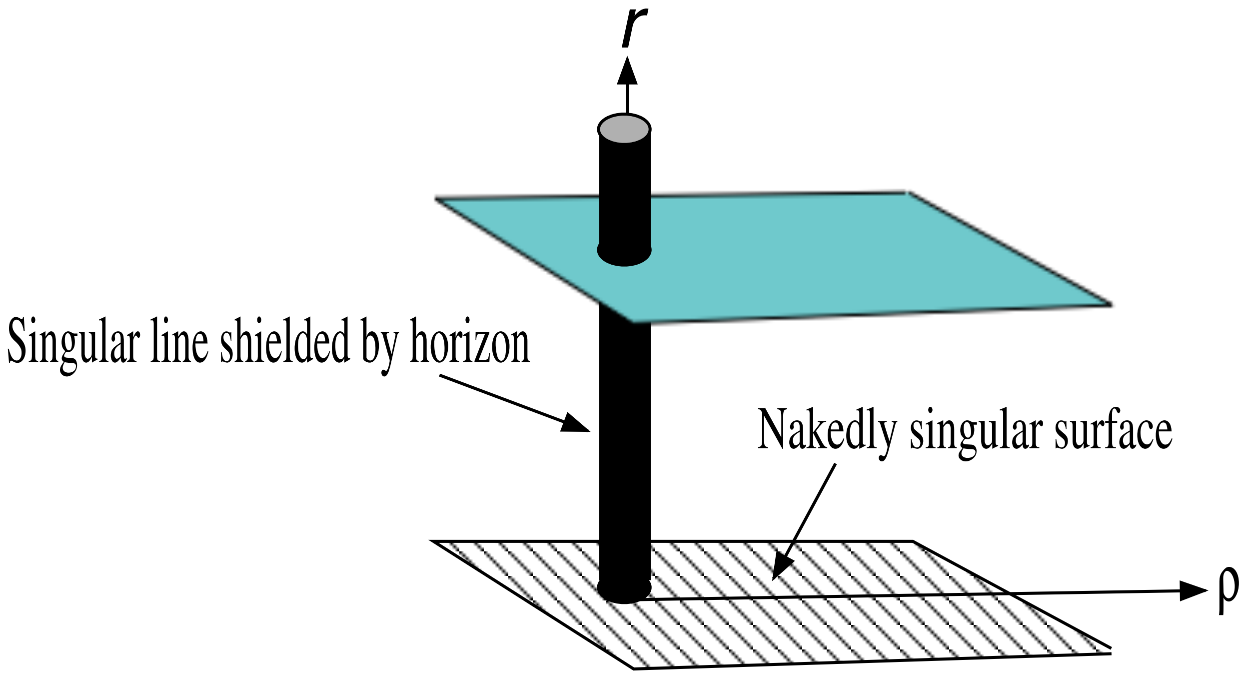
(Aharony, Gubser, Maldacena, Ooguri, Oz 1999)

Describing Field Theory Near a Black Hole

Patch of AdS$_d$: $$ds_d^2 = \frac{r^2}{R^2}(ds_4^2 + d\vec{y}^2) + \frac{R^2}{r^2}dr^2$$

Replace with Schwarzschild metric

Large extra dimensions



$$R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} \sim \frac{1}{R^4} + \left(\frac{M^2}{\rho^6}\right)\left(\frac{R^4}{r^4}\right)$$

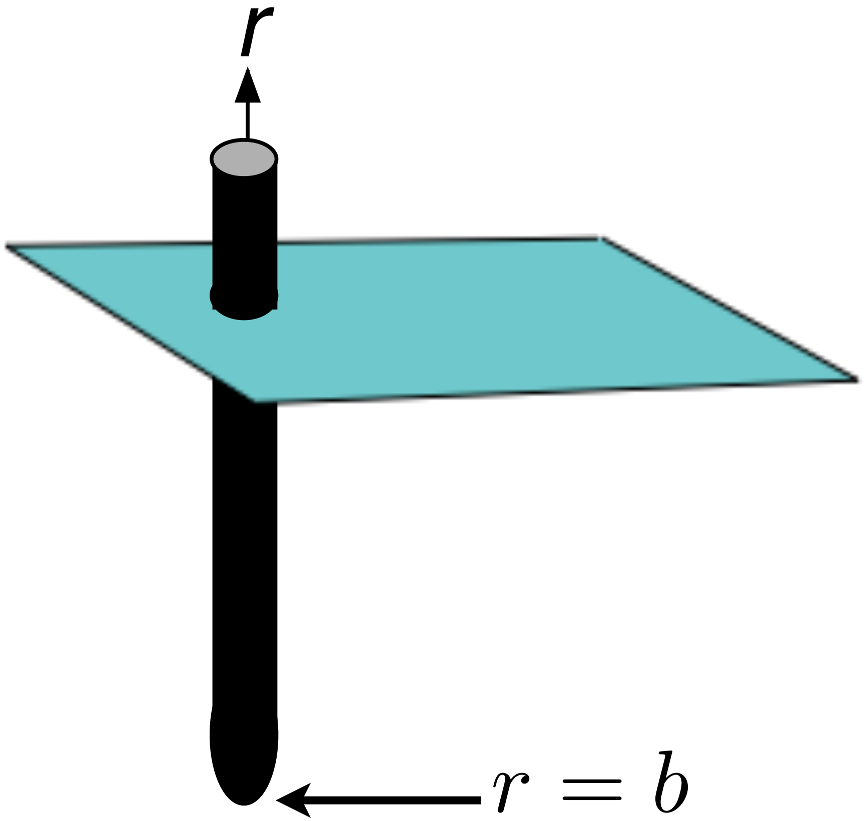
6D Schwarzschild-Black String AdS Soliton

(Horowitz, Myers 1998)

$$ds_6^2 = \frac{r^2}{R^2}(hdy^2 + ds_4^2) + \frac{R^2}{r^2}h^{-1}dr^2$$

$$h = 1 - \frac{b^5}{r^5}$$

y has periodicity $\frac{4\pi R^2}{5b}$



Belongs to an infinite family of solutions described by transcendental equations

Regime of Validity

$$R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} = \frac{60}{R^4} + \frac{240b^{10}}{R^4 r^{10}} + \left(\frac{48M^2}{\rho^6}\right)\left(\frac{R^4}{r^4}\right)$$

Small curvature for $\rho \gg M\left(\frac{R}{r}\right)^{2/3}$

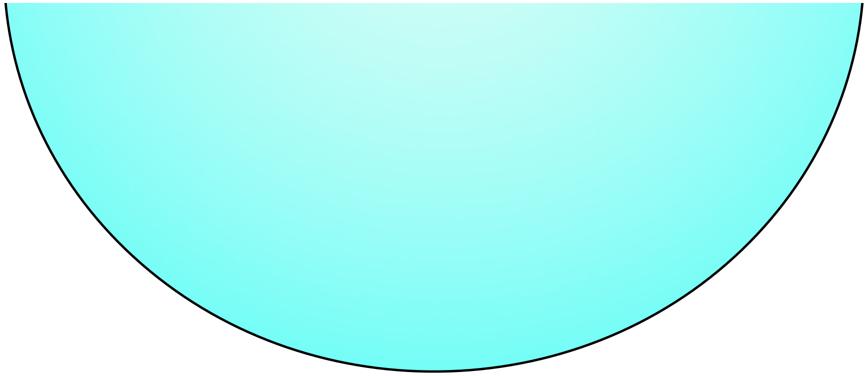
Do not require quantum gravity to probe region close to singularity if we go to high energy scale $r \gg R$

Adding Flavor

Schwarzschild-black string AdS soliton can be lifted to massive IIA or type IIB theory on a 4-sphere

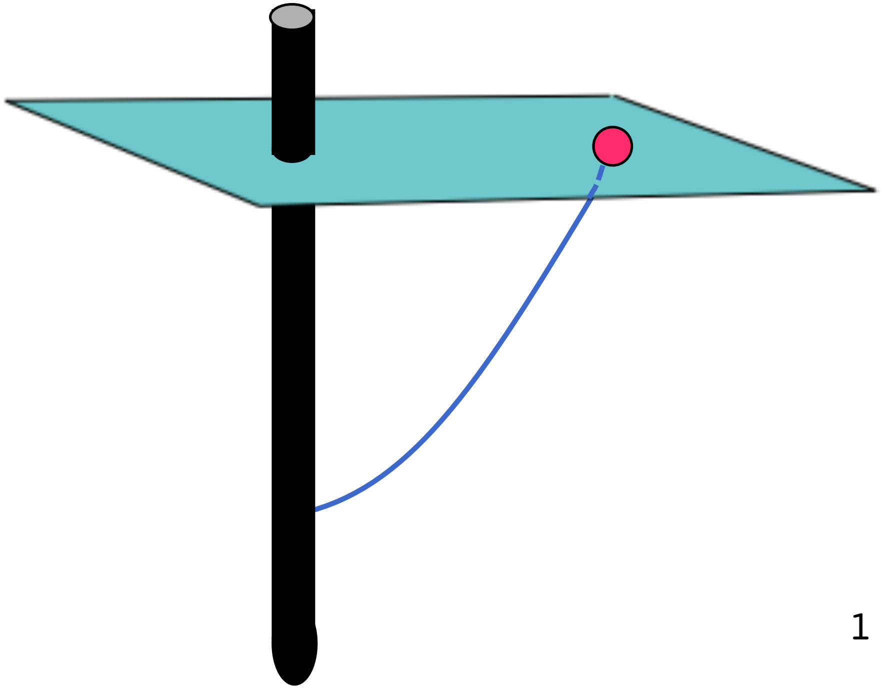
(Cvetic, Lu, Pope 1999)
(Cvetic, Lu, Pope, Vazquez-Poritz 2000)

From the DBI action, we obtain D8-brane solutions which live on 4D spacetime, wrap the 4-sphere and form a curve *r(y)* down to the minimal radius r_0



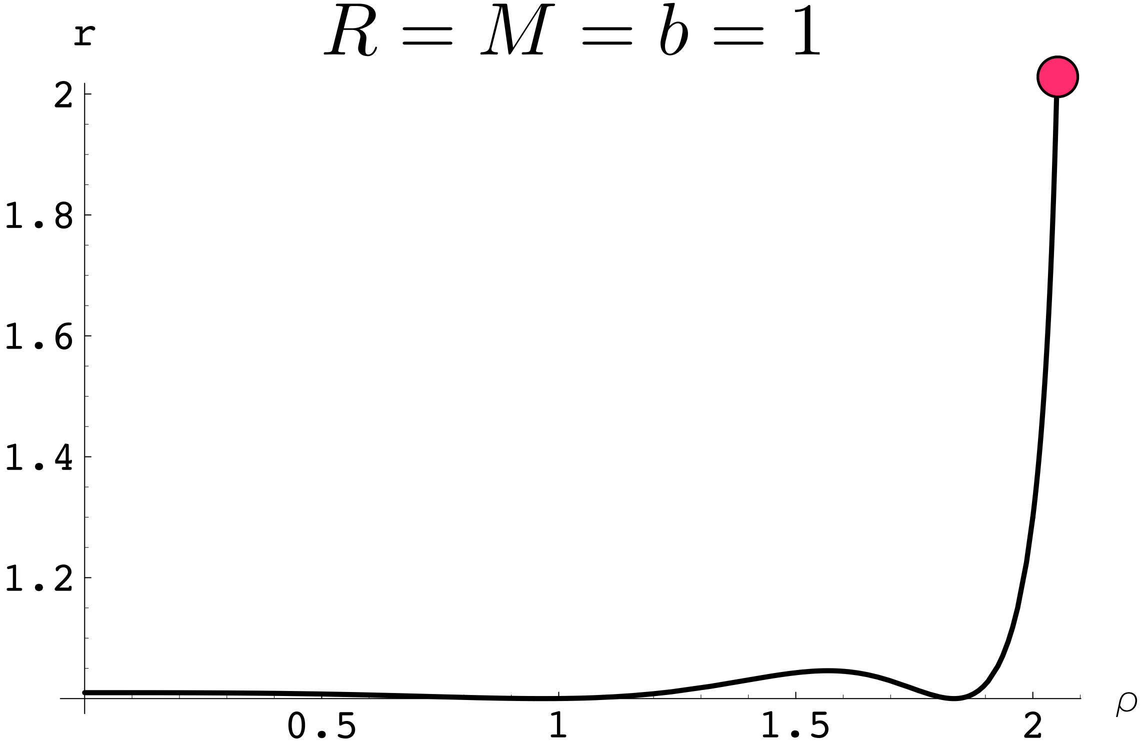
Quark Interacting with a Colorful Black Hole

Schematic depiction

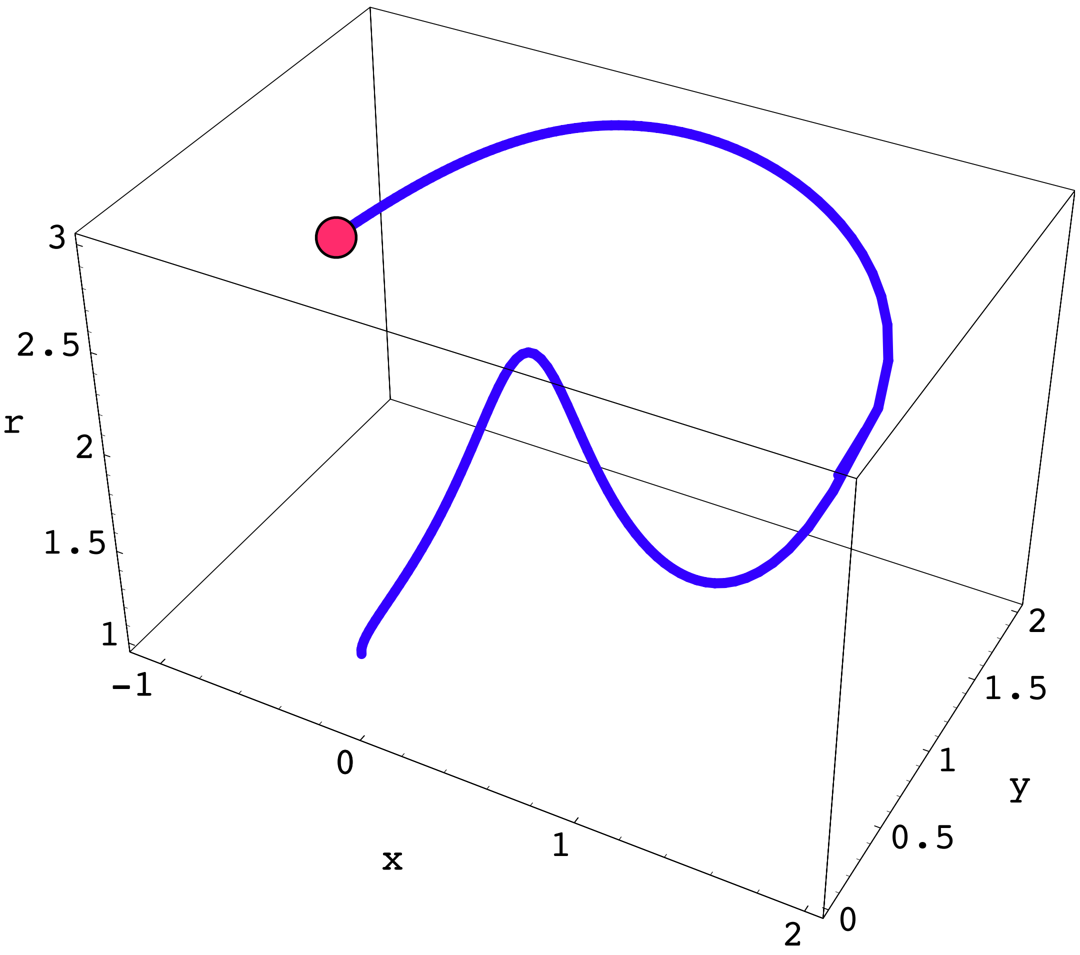


Numerical results

$R = M = b = 1$



Quark Rotating Around the Black Hole

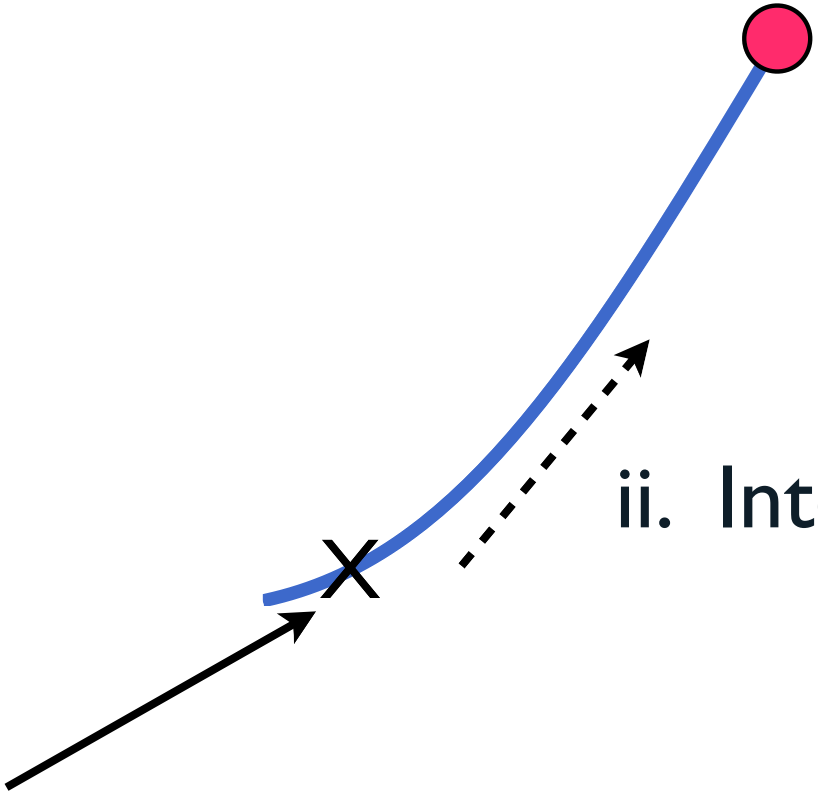


String winds around as quark undergoes circular motion

Studied in absence of black hole

(Athanasiou, Chesler, Liu, Nickel, Rajagopal 2010)

Imposing Boundary Conditions

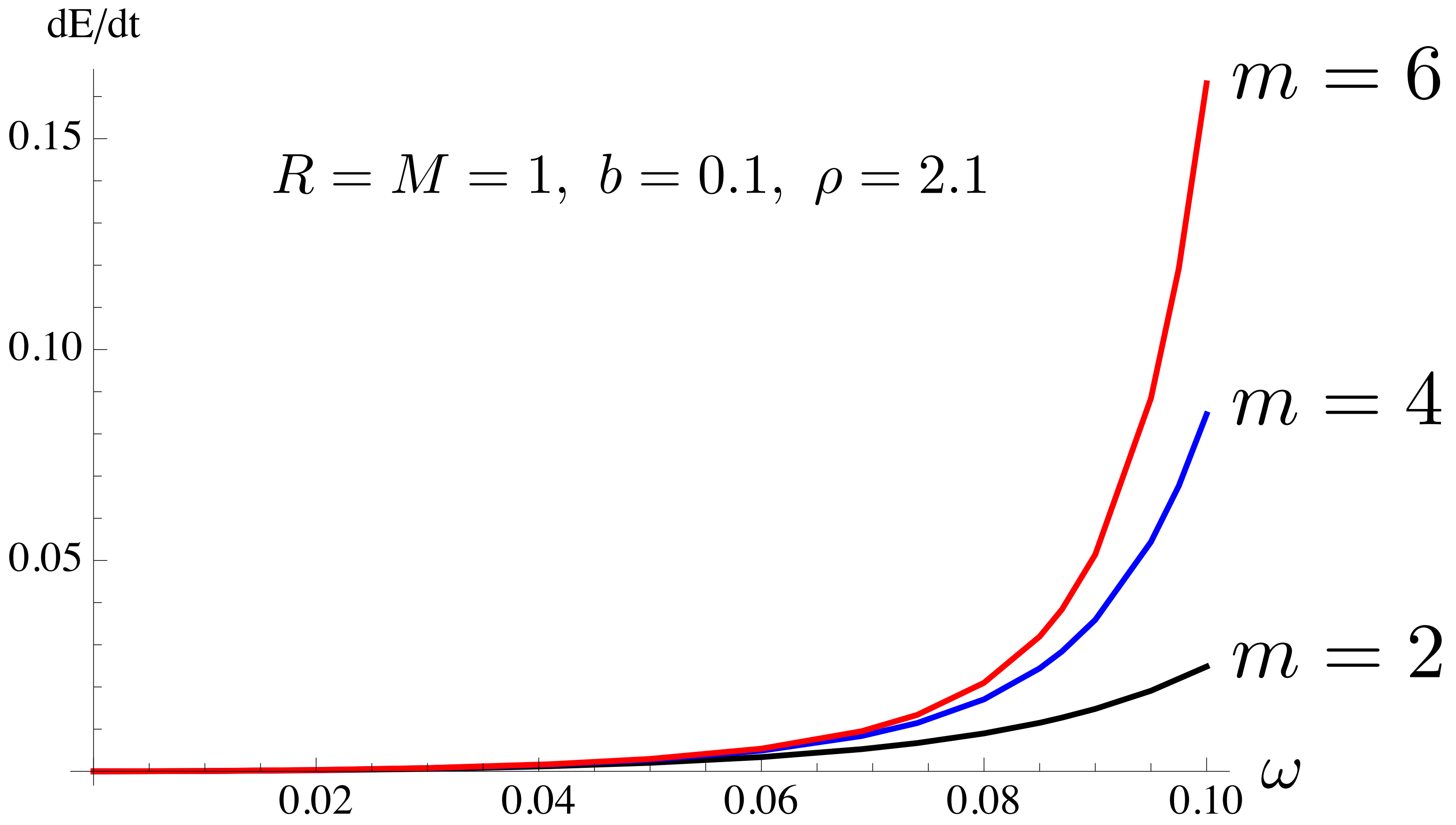


iii. Shooting method enforces boundary condition here

ii. Integrate along the string

i. Critical point where it is enforced that worldsheet remains timelike

Rate of Energy Loss

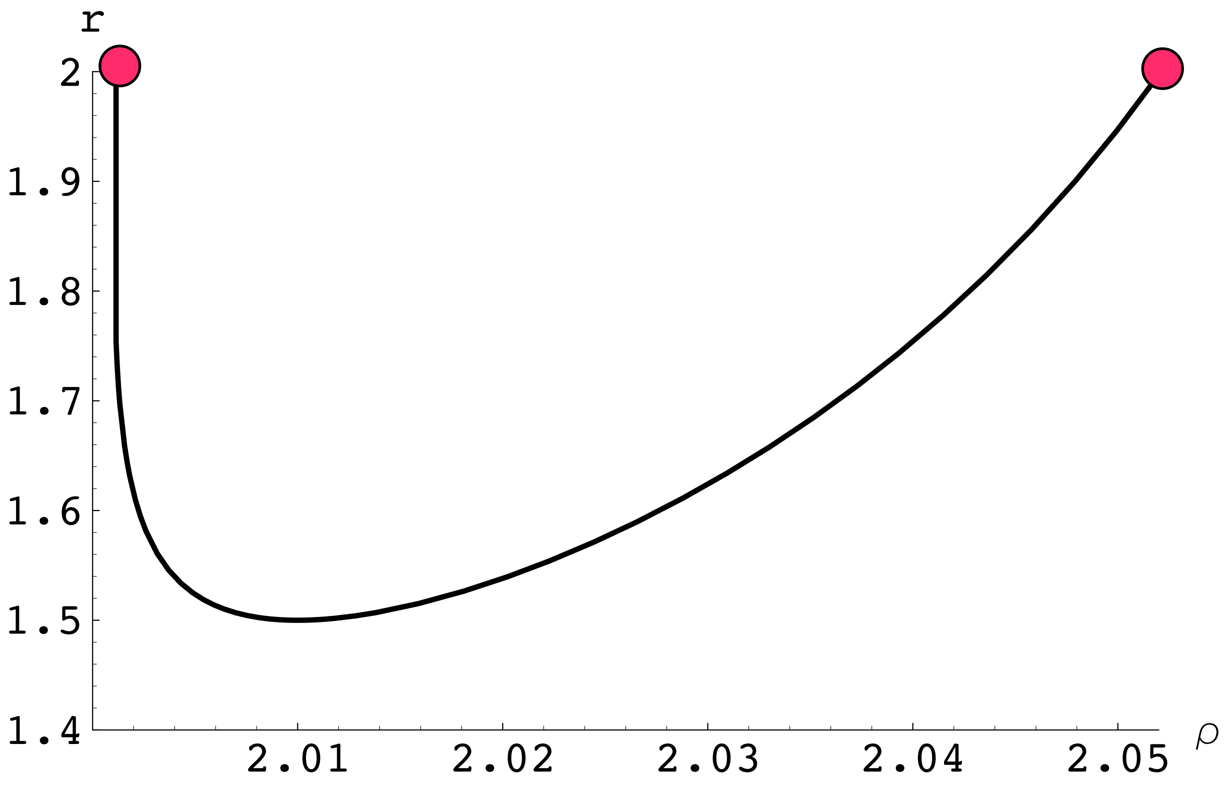


$$\frac{dE}{dt} \approx 0.008v\ e^{(20.65+16.45m-0.25m^2)v-0.89m}$$

Analogous to quark energy loss in strongly-coupled plasma

(Herzog, Karch, Kovtun, Kozcaz, Yaffe 2006)

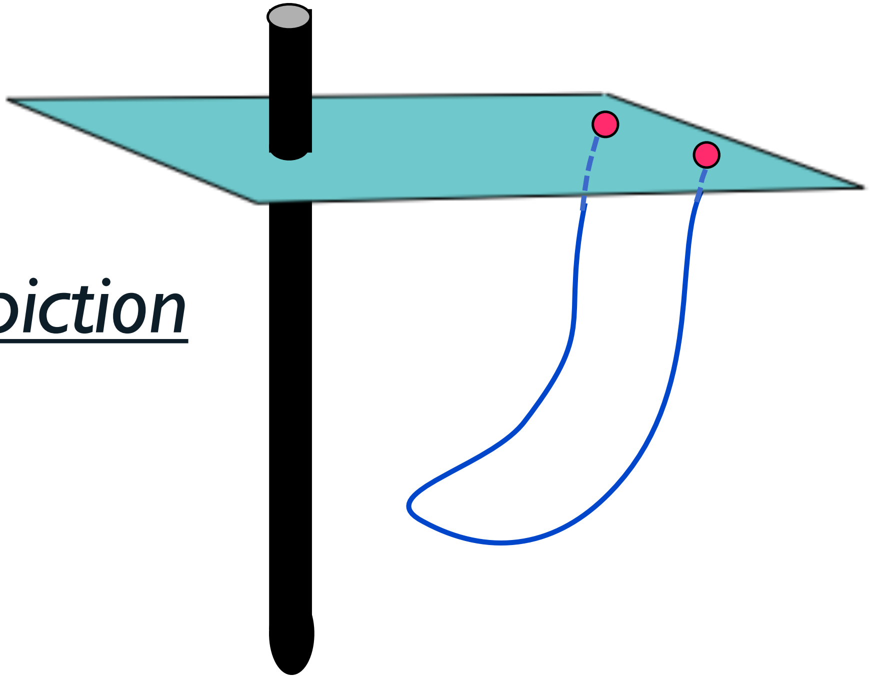
Radially-Separated Quark-Antiquark Pair



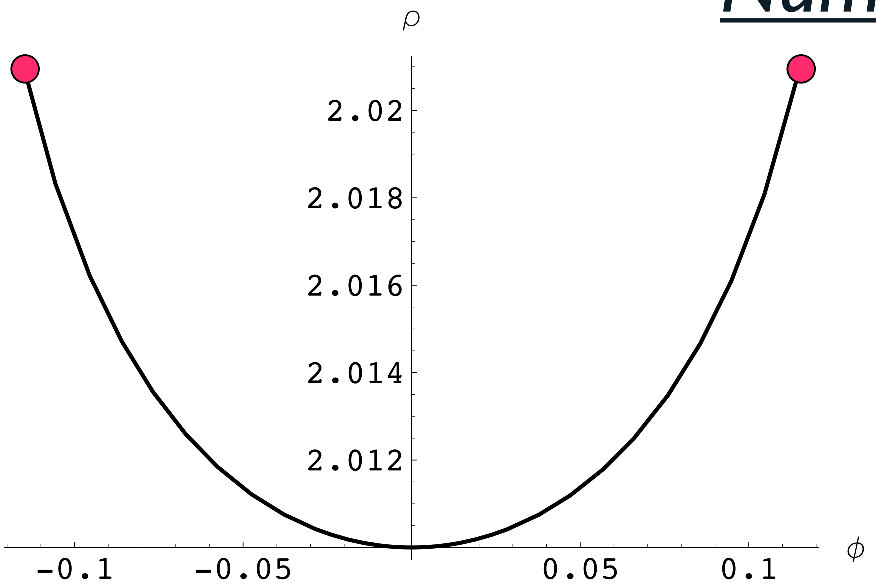
The presence of the black hole modifies the quark-antiquark potential

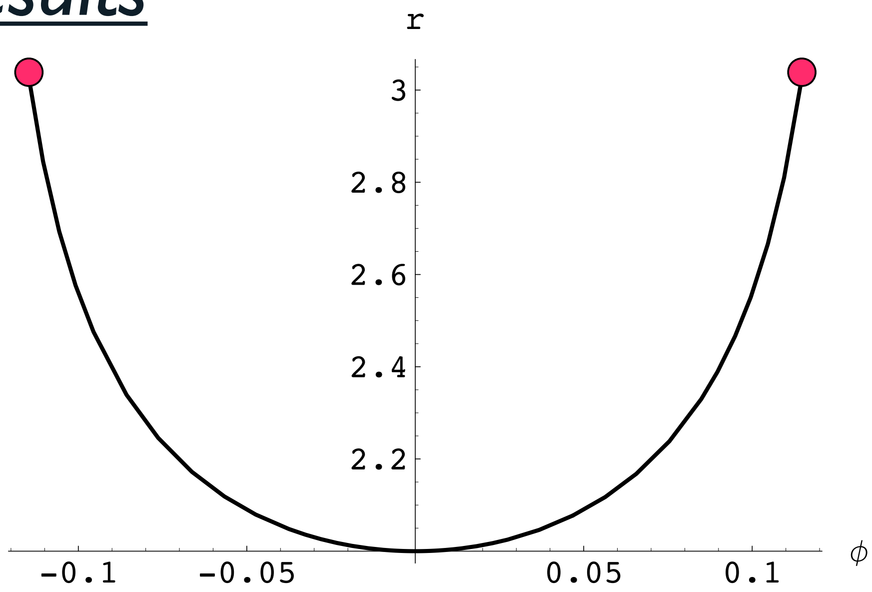
Tangentially-Separated Quark-Antiquark Pair

Schematic depiction



Numerical results

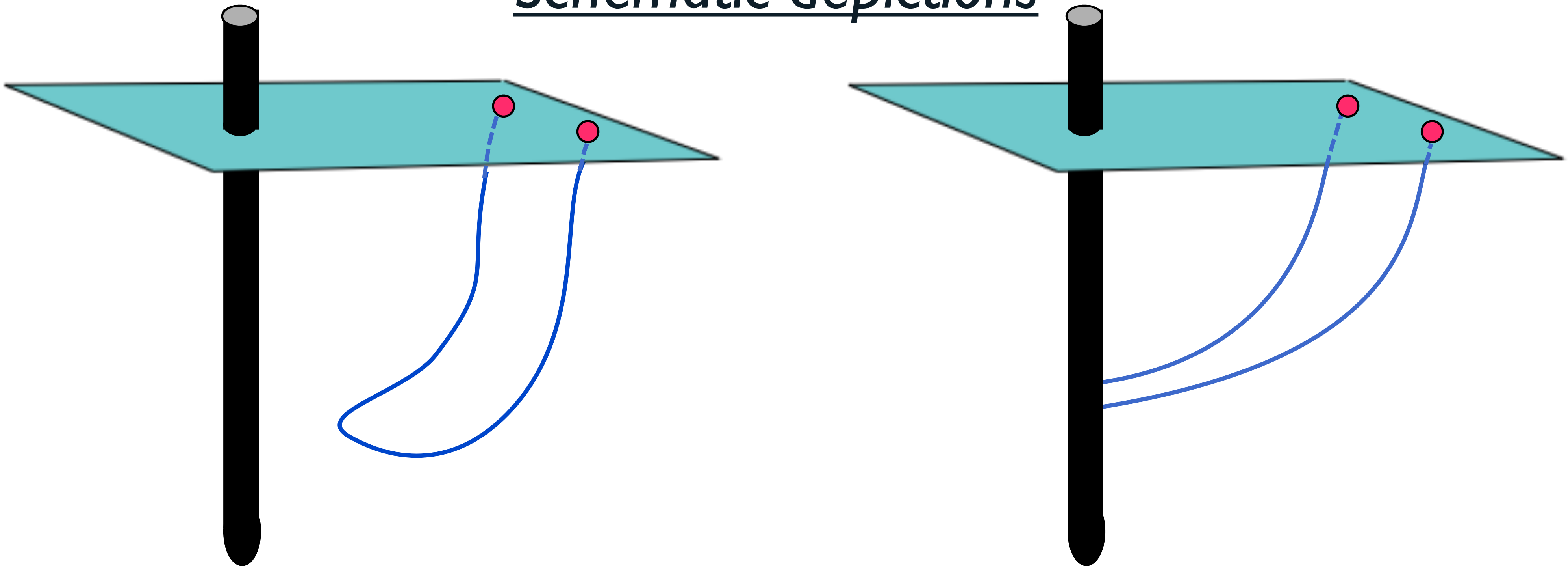




Quark-Antiquark Screening Length

Past a certain distance, the quark-antiquark pair are described by disconnected strings

Schematic depictions



Analogous to screening length in strongly-coupled plasma

(Rey, Theisen, Yee 1998)

(Brandhuber, Itzhaki, Sonnenschein, Yankielowicz 1998)

Conclusions

- Can use AdS/CFT to probe strongly-coupled field theory closer to black hole than expected from 4D gravity perspective

- Shares a number of features with strongly-coupled plasma

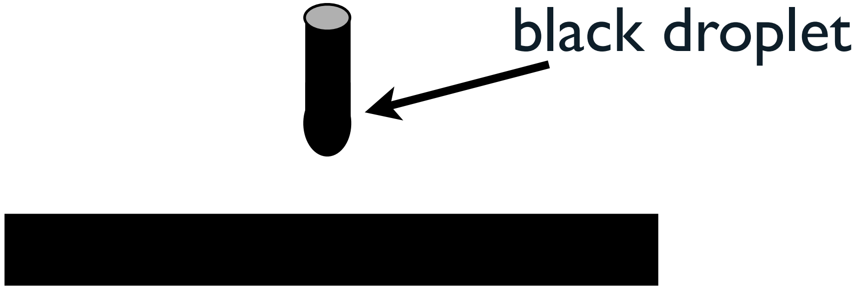
  quark energy loss, quark-antiquark screening

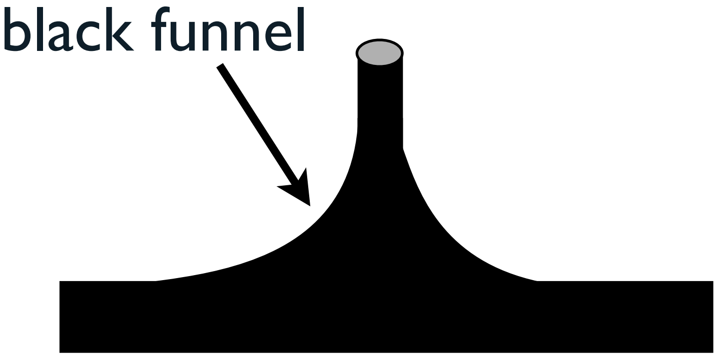
Future Directions

- Use this approach to study black hole radiation

Not much is known about this in the strongly-coupled regime

- Study color-charged black holes in a strongly-coupled plasma





(Hubeny, Marolf, Rangamani 2009)

- Generalize to rotating black hole