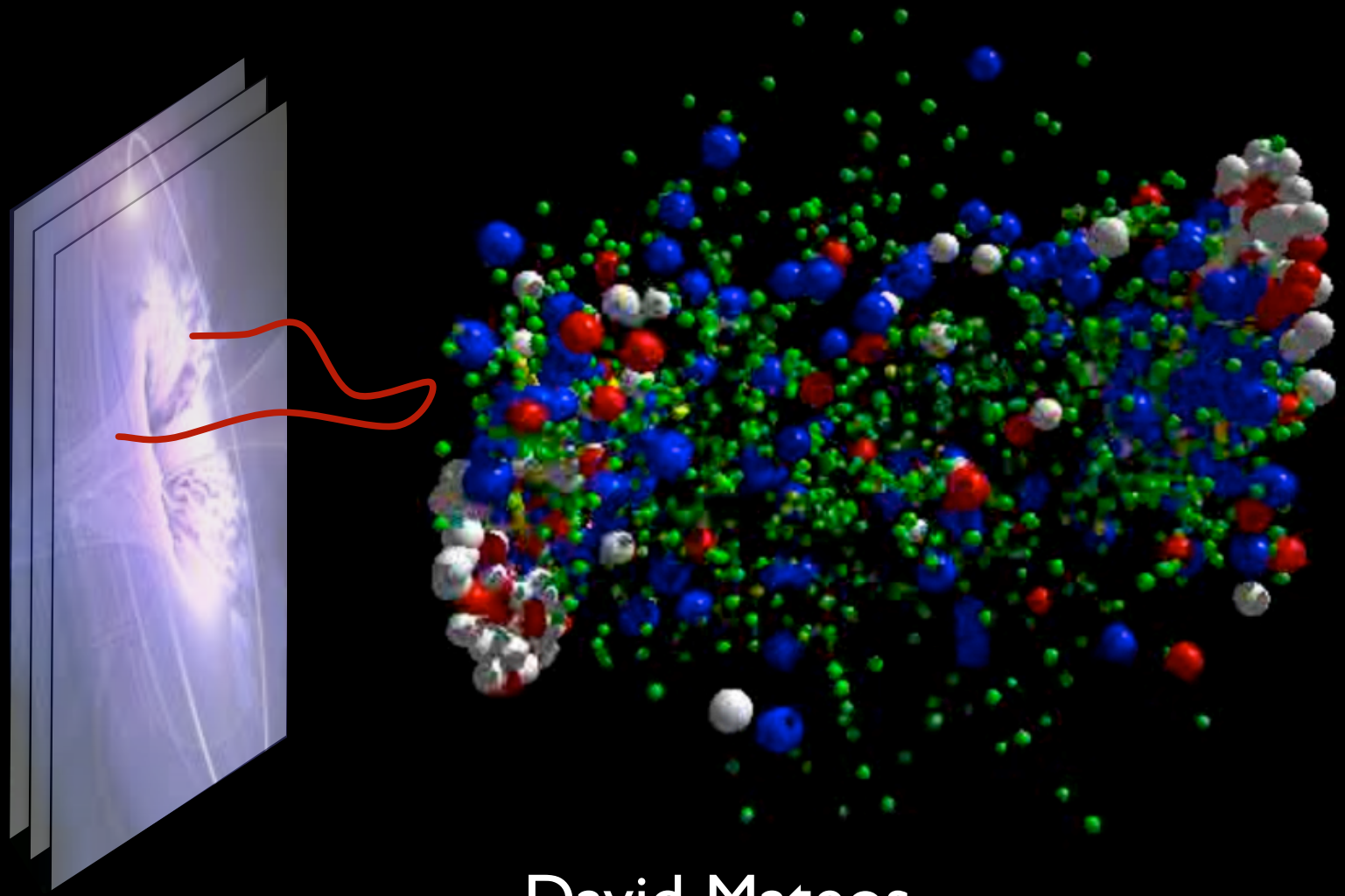
Applying AdS/CFT to Non-Abelian Plasmas



David Mateos
ICREA & University of Barcelona

Plan

- My personal view.
- Illustrate it with a few examples.
  - I apologize in advance for my omissions.

  - For more information see:

Casalderrey-Solana, Liu, D.M., Rajagopal & Wiedemann
arXiv:1101.0618 [hep-th]

The QCD challenge

- QCD remains a challenge after many years.

The QCD challenge

- QCD remains a challenge after many years.

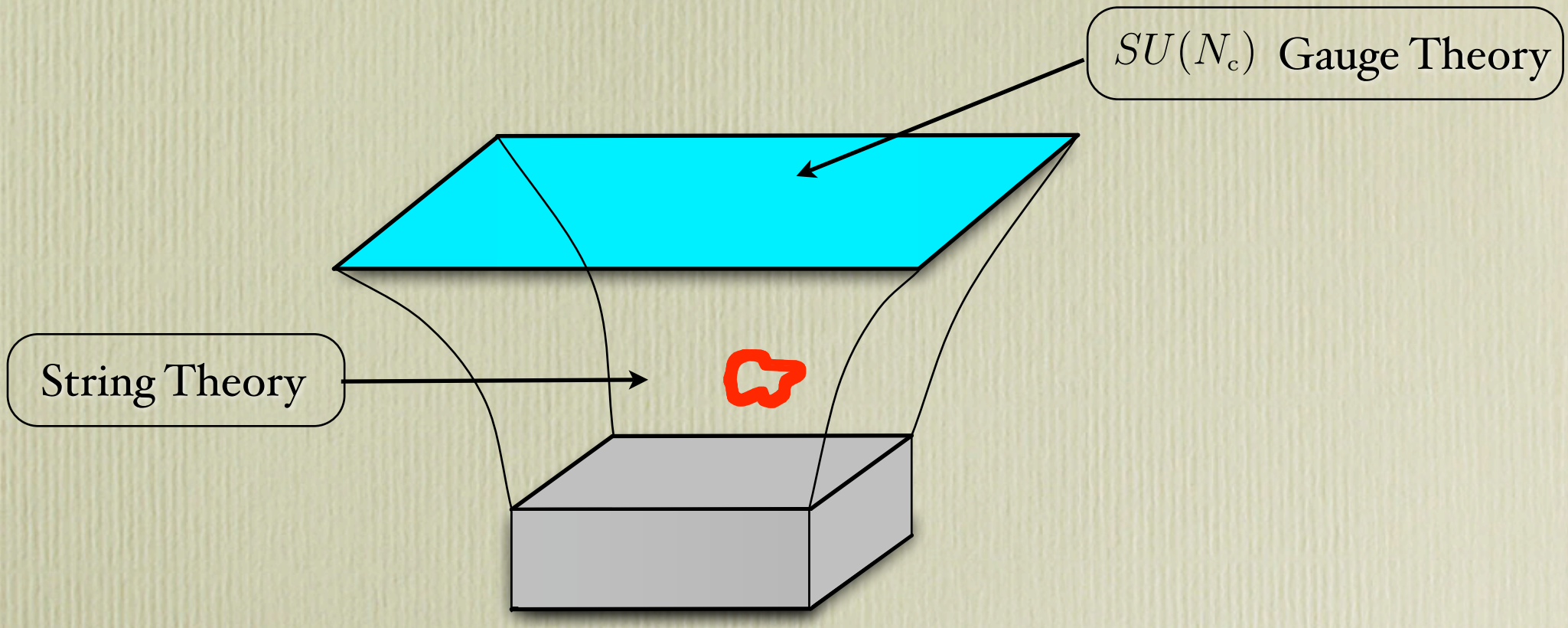
- We have some good tools but they all have limitations. For example:

  - Perturbation theory: Weak coupling.
  - Lattice: Difficult to apply to real-time phenomena.
  - Etc.

The gauge/string duality

(= AdS/CFT correspondence = Holography)

Maldacena '97



- Exact equivalence at *all* energies, N_c and $\lambda = g_{\rm YM}^2 N_c$!

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(= AdS/CFT correspondence = Holography)

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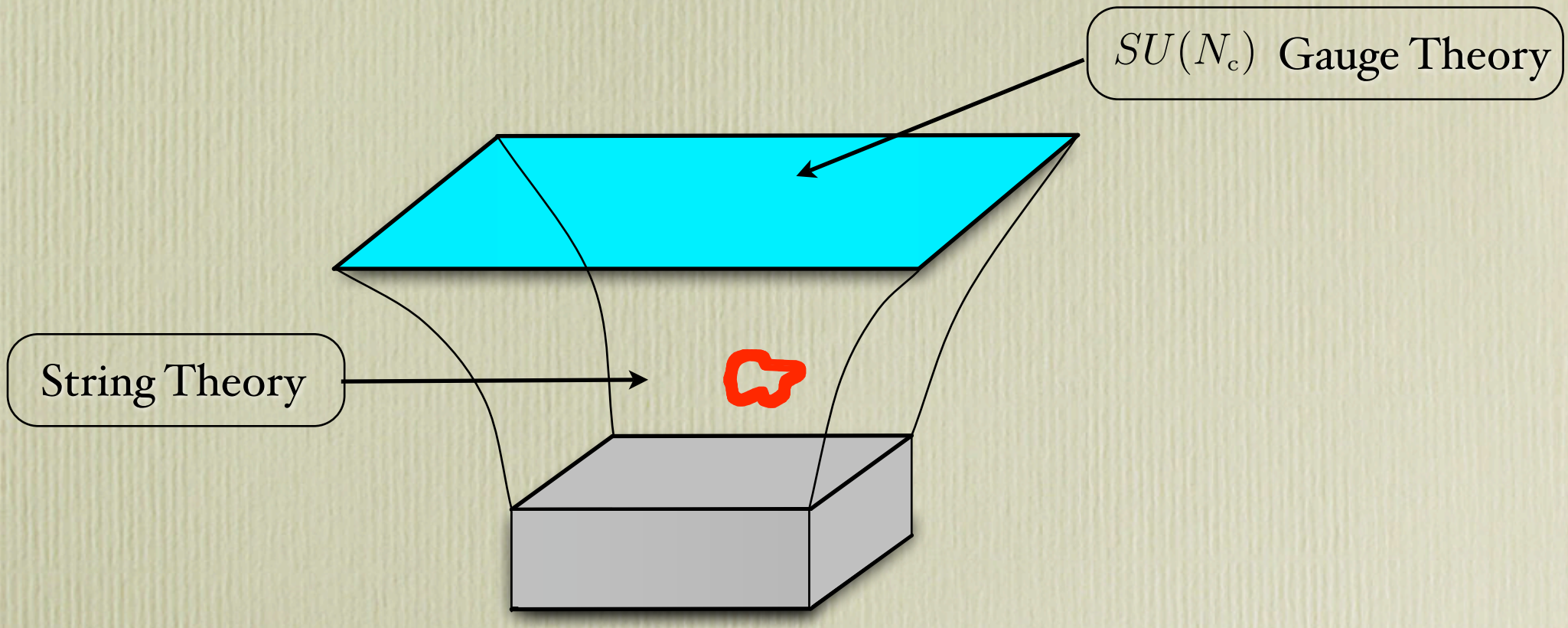


- Exact equivalence at *all* energies, N_c and $\lambda = g_{\rm YM}^2 N_c$!
- *Disclaimer:* Not proven but overwhelming evidence.

From viewpoint of a *theorist*

- Duality is a remarkable development:

Quantum gravity = Ordinary QFT

From viewpoint of a *theorist*

- Duality is a remarkable development:

Quantum gravity = Ordinary QFT

- Unifying framework for diverse (and difficult) fields of physics: QGP, condensed matter, etc.

cf. Rajagopal's talk on Monday

In terms of *applications* to QCD

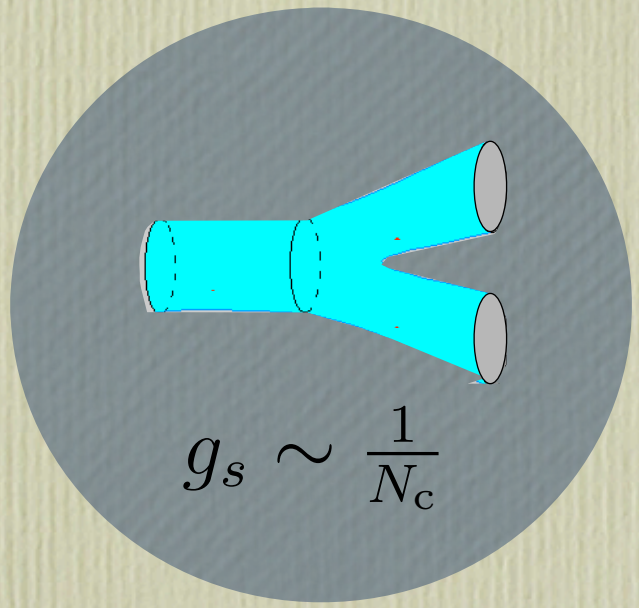
At present the duality has its own limitations

↓

Complementary tool

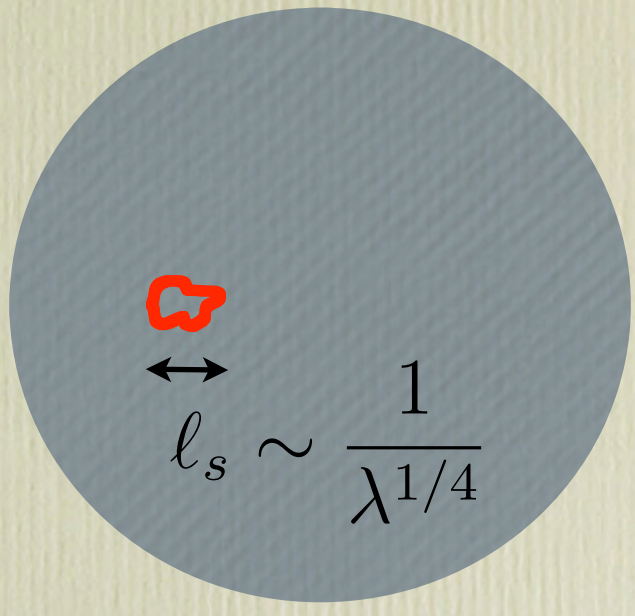
Limitations

$$N_c \to \infty$$



Suppresses quantum corrections.

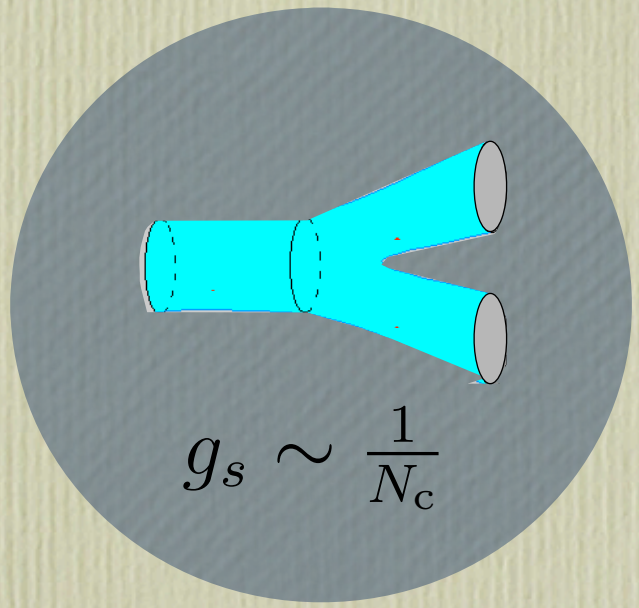
$$\lambda = g_{\rm YM}^2 N_c \to \infty$$



Makes the string tiny.

Limitations

$$N_c \to \infty$$



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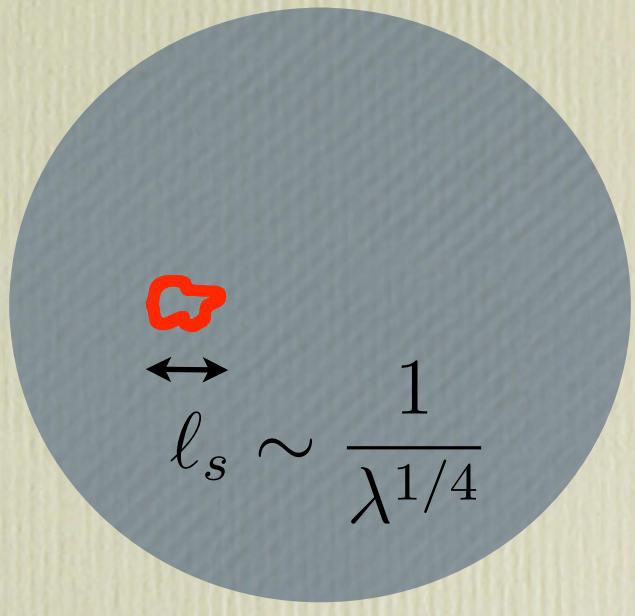

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→ Classical Gravity!

Limitations

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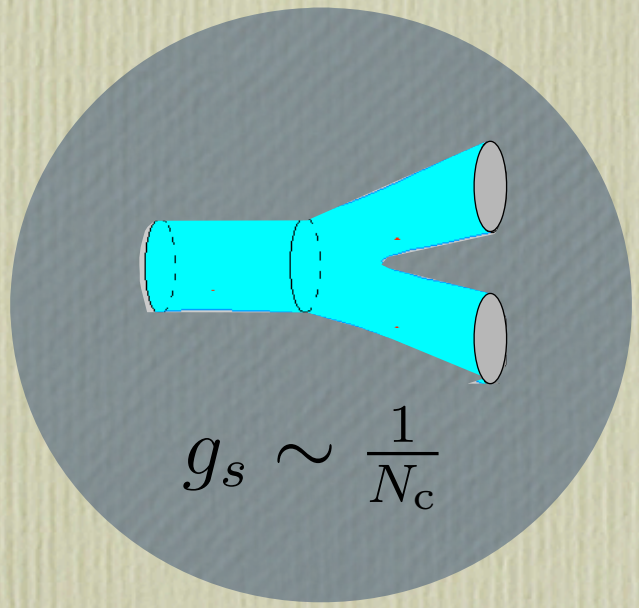

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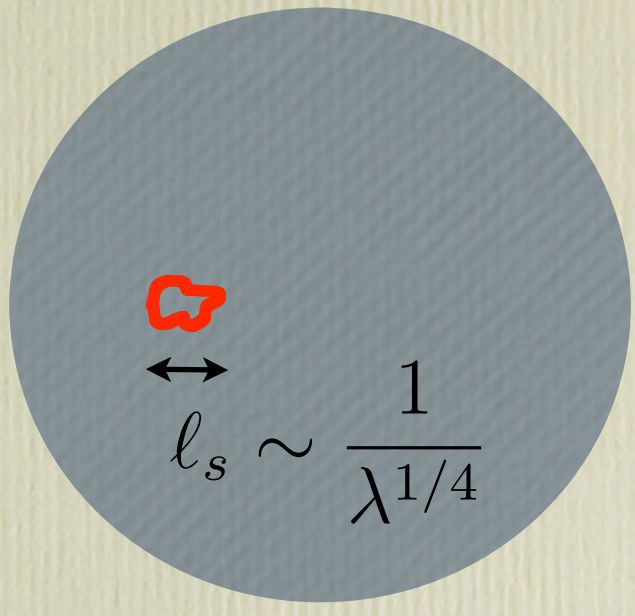


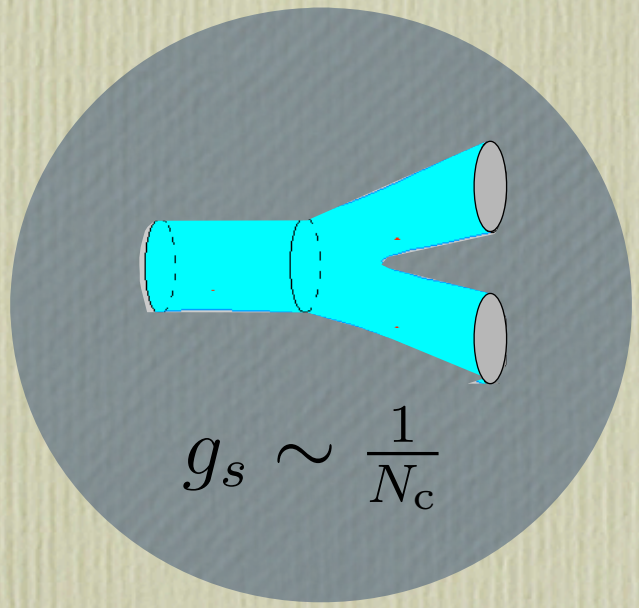
Makes the string tiny.

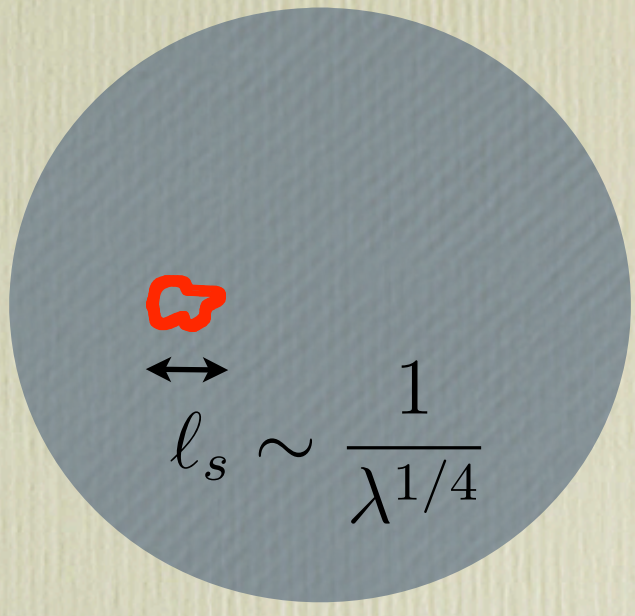
Technical difficulties, *not* fundamental limitations.

Limitations

$N_c \to \infty$

$\lambda = g_{\rm YM}^2 N_c \to \infty$





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Makes the string tiny.

Solving large-N_c would be great progress!

Limitations

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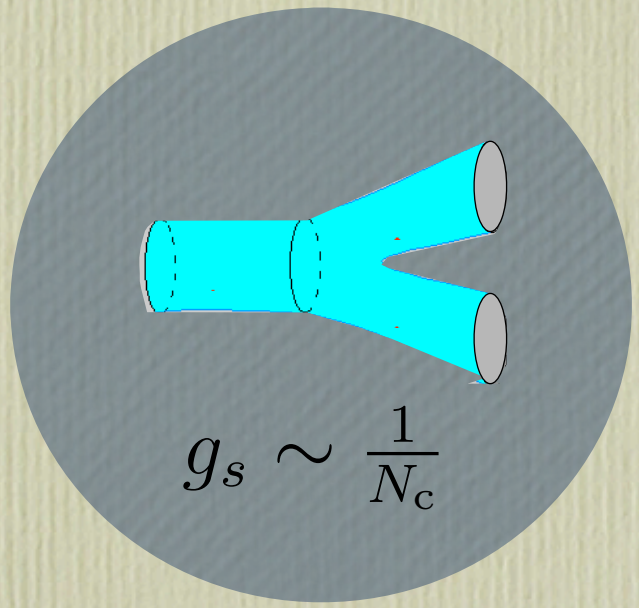

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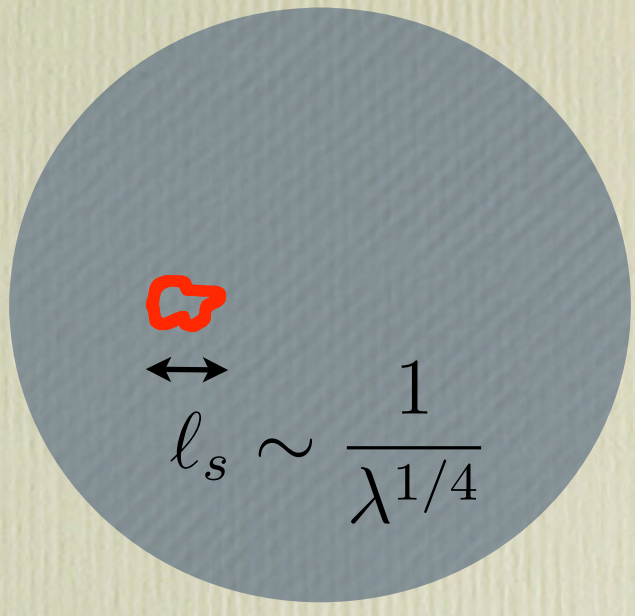
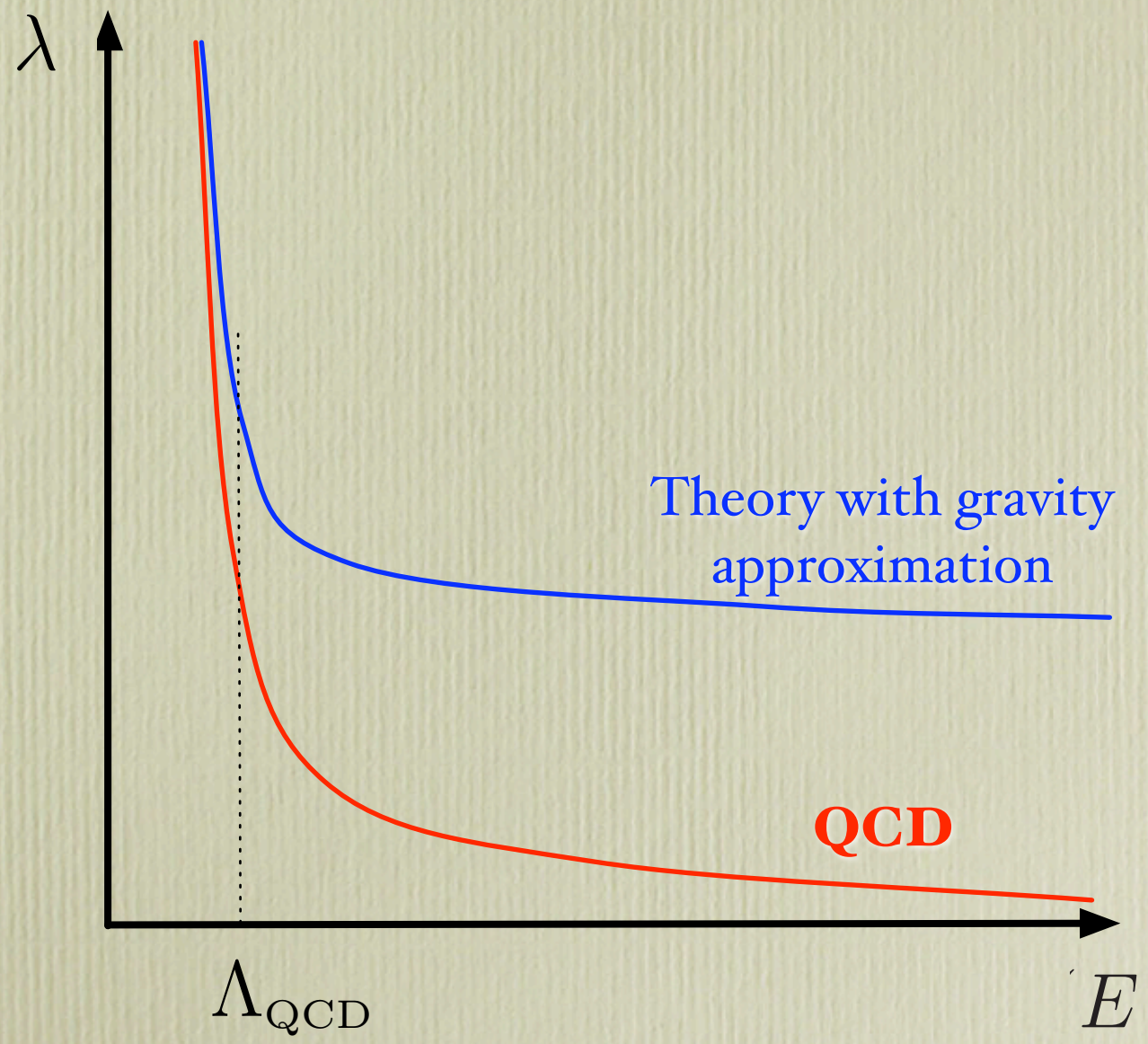


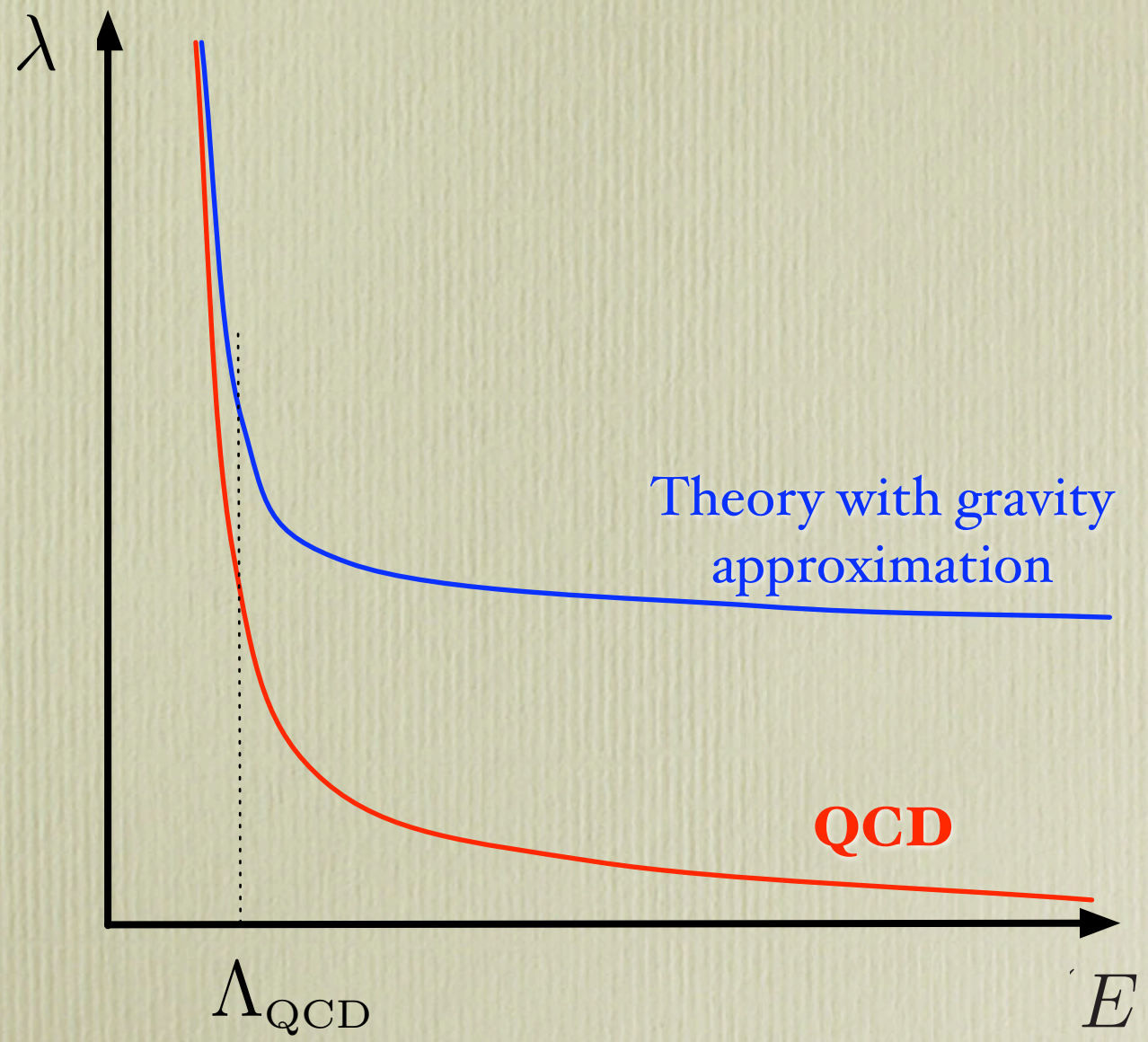
Makes the string tiny.

Strong coupling means *no* asymptotic freedom!

Limitations



Limitations



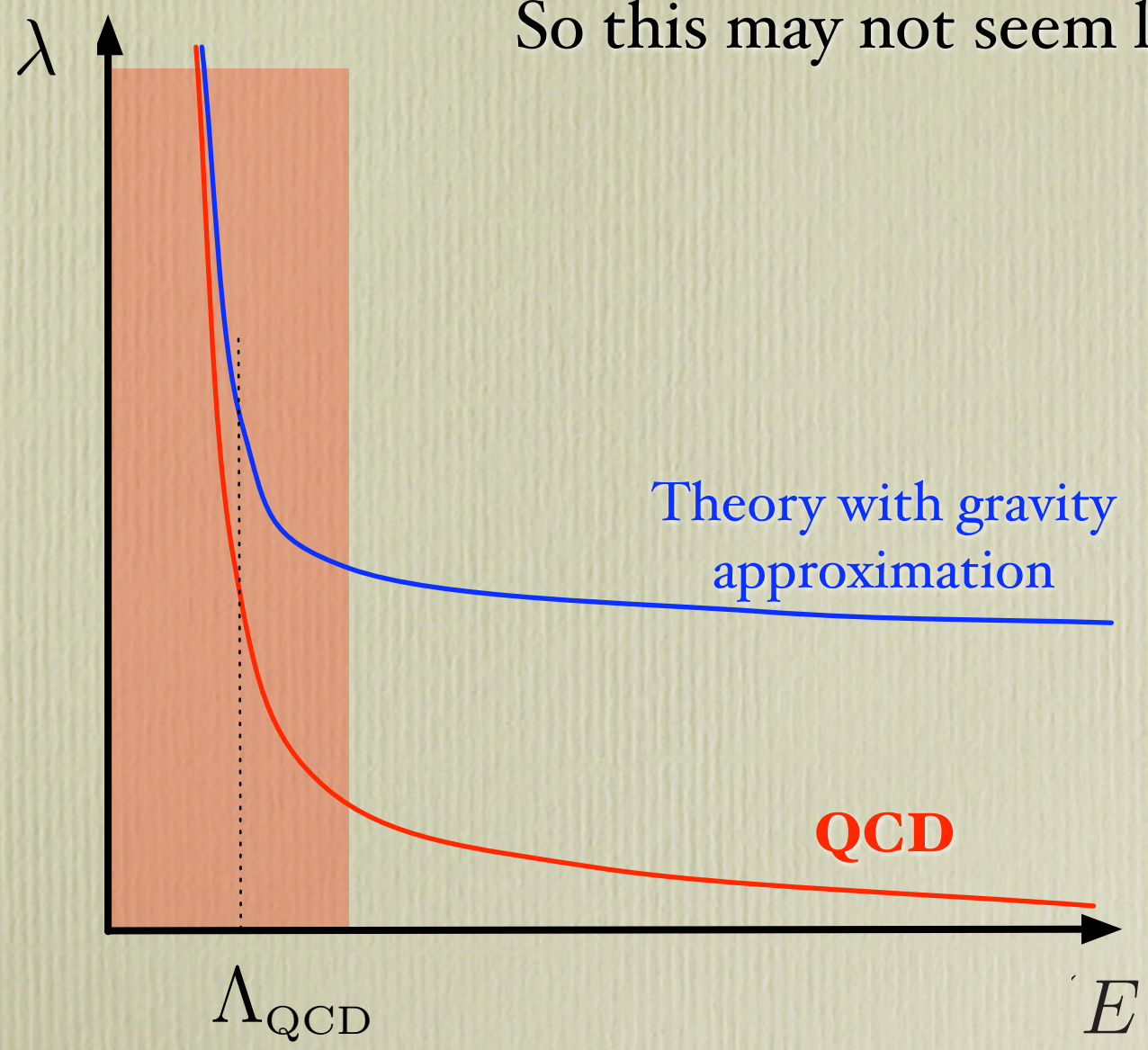
Need not be CFT!

AdS/CFT is a misnomer!

- Confinement.
- SχSB.
- Thermal phase transitions.
- Etc.

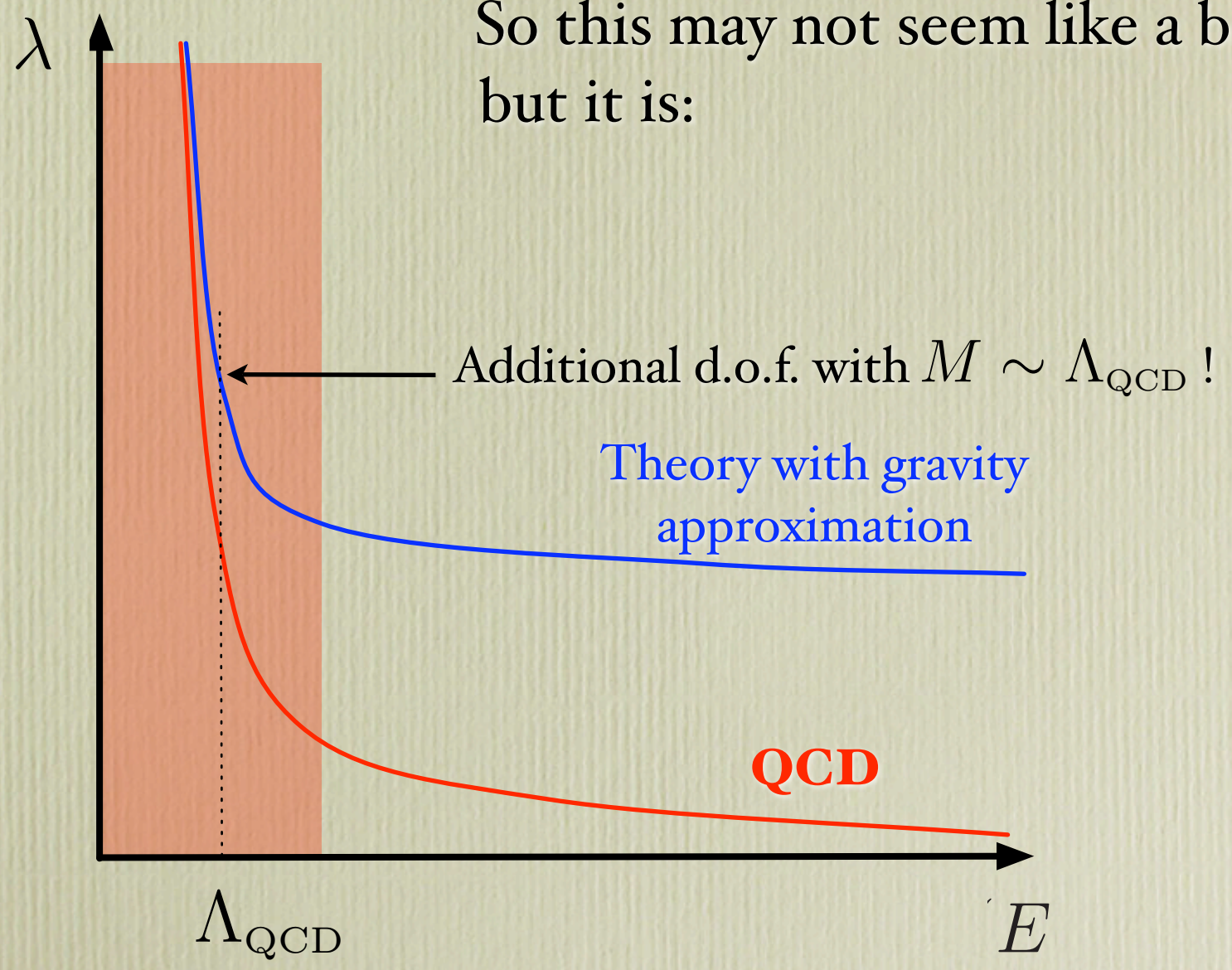
Limitations

So this may not seem like a big deal...



Limitations

So this may not seem like a big deal...
but it is:



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- However, *certain* results may be universal enough to apply to QCD in *certain* regimes:

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  - Qualitative insights.

- This can be very useful!

A good quantitative example

$$\frac{\eta}{s} = \frac{1}{4\pi}$$

Policastro, Son & Starinets '01
Kovtun, Son & Starinets '03

- It is the same for all non-Abelian plasmas with gravity dual in the limit $N_c \to \infty$, $\lambda \to \infty$.
  - Theories in different dimensions.
  - With or without quarks.
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  - Theories in different dimensions.
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  - Etc.
- RHIC & LHC indicate $\frac{1}{4\pi}$ is in the right ballpark.

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- $\frac{1}{4\pi}$ is *not* a lower bound in AdS/CFT!

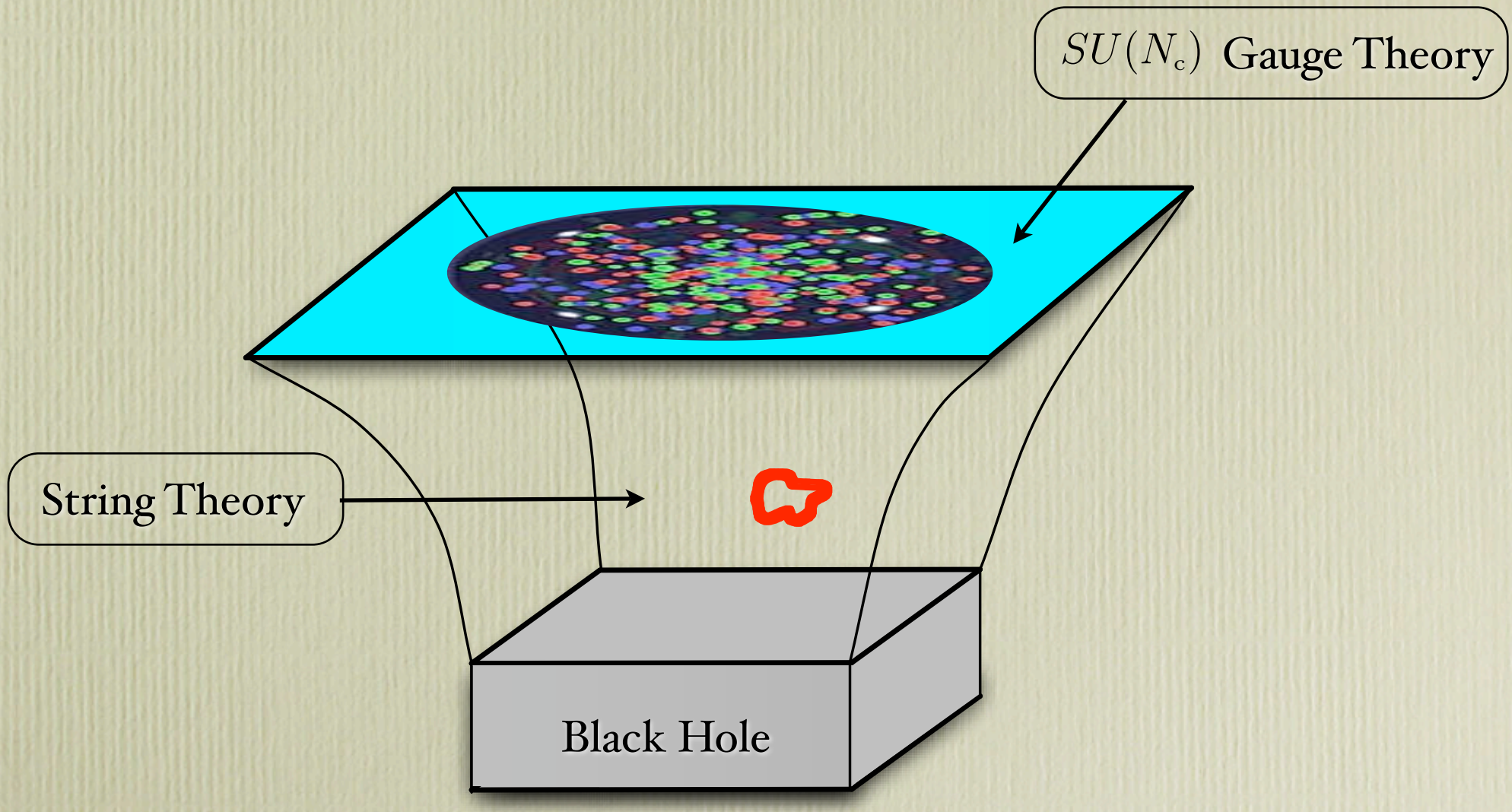
Kats & Petrov '07
Mia, Dasgupta, Gale & Jeon '09
Buchel, Myers & Sinha '09

Strategy

Seek results based on universal features of the duality.

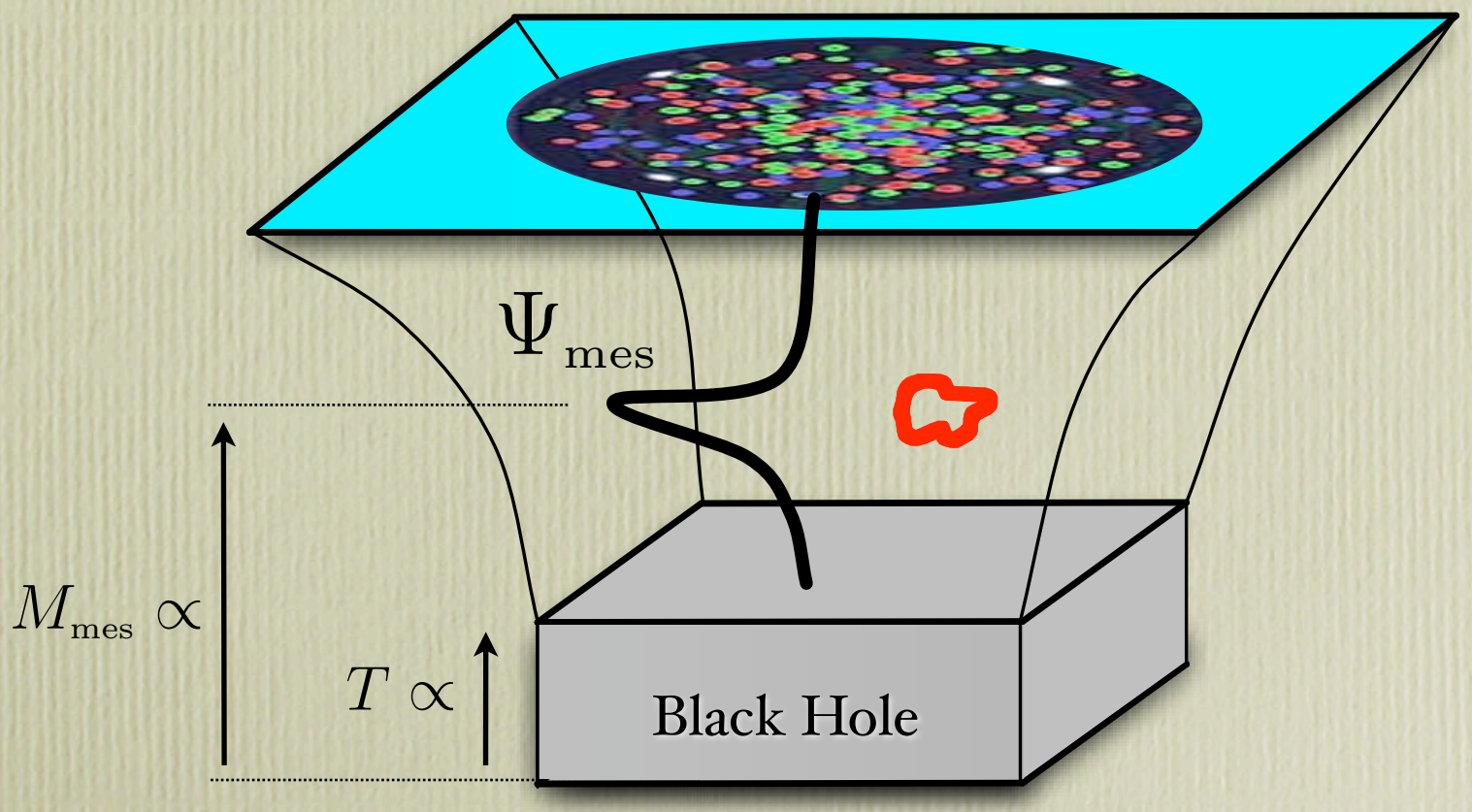
Deconfinement = Black Hole

Witten '98



Heavy quarkonium survives deconf.

D.M., Myers & Thomson ‘ 06
Hoyos-Badajoz, Landsteiner & Montero ’06
Babington, Erdmenger, Guralnik & Kirsch ’03
Kruczenski, D.M., Myers & Winters ’03
Kirsch ‘04



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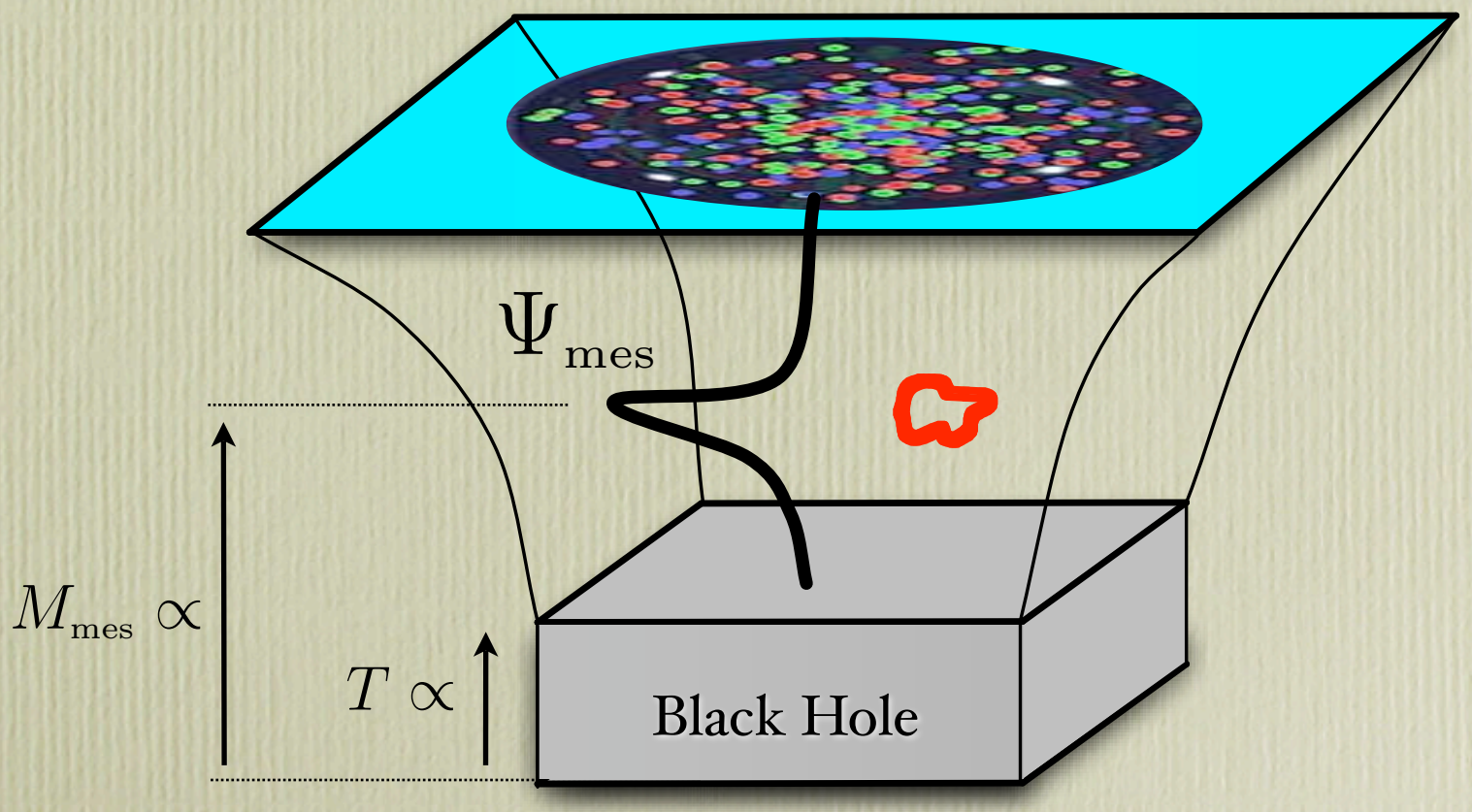
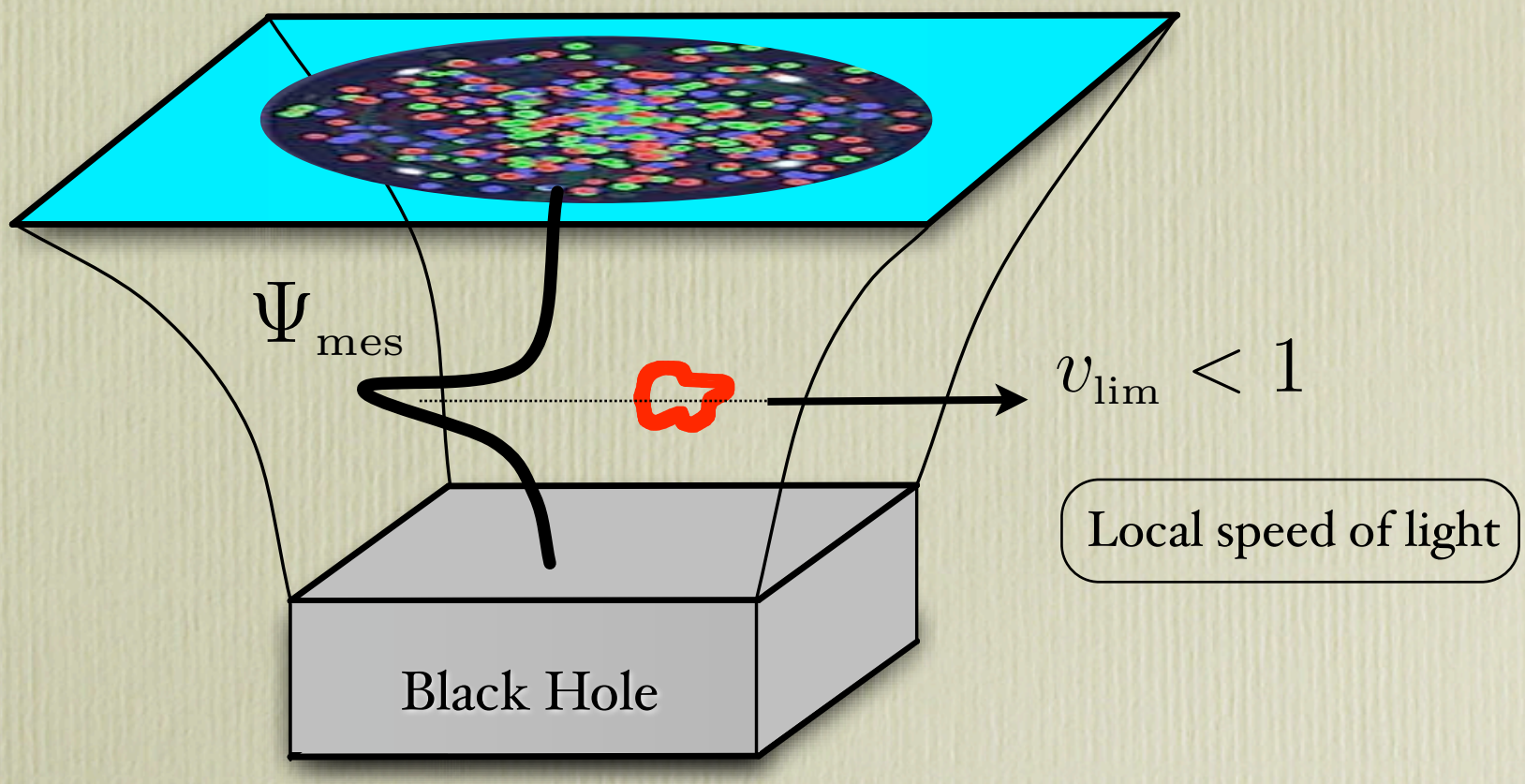


$J/\Psi \rightarrow T_{\rm diss} \sim 1.6 - 2.1 T_{\rm c}$

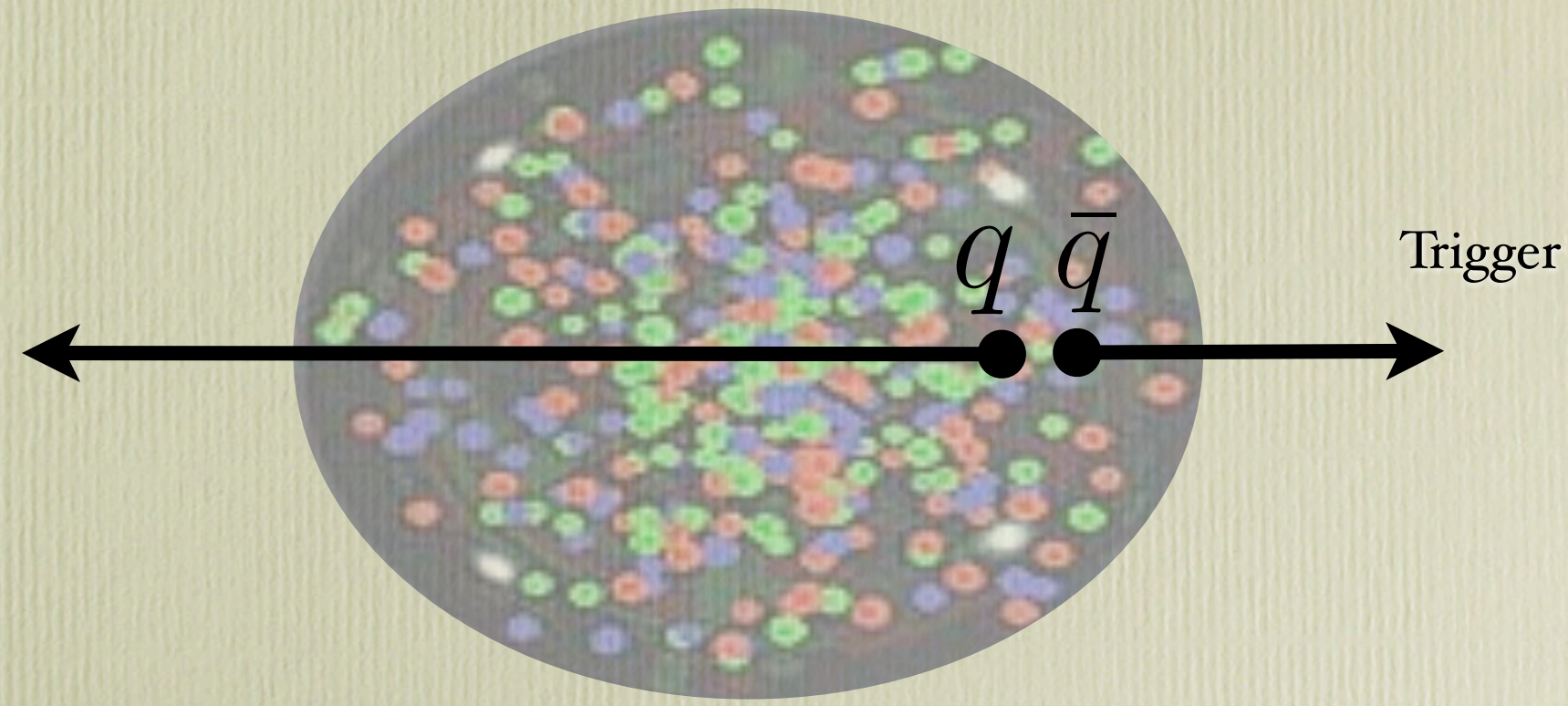
Quarkonium limiting velocity

D.M., Myers & Thomson '07
Ejaz, Faulkner, Liu, Rajagopal & Wiedemann '07



Cherenkov quark energy loss

Casalderrey-Solana, Fernandez & D.M. '10



$$v_q > v_{\rm lim}$$

Cherenkov quark energy loss

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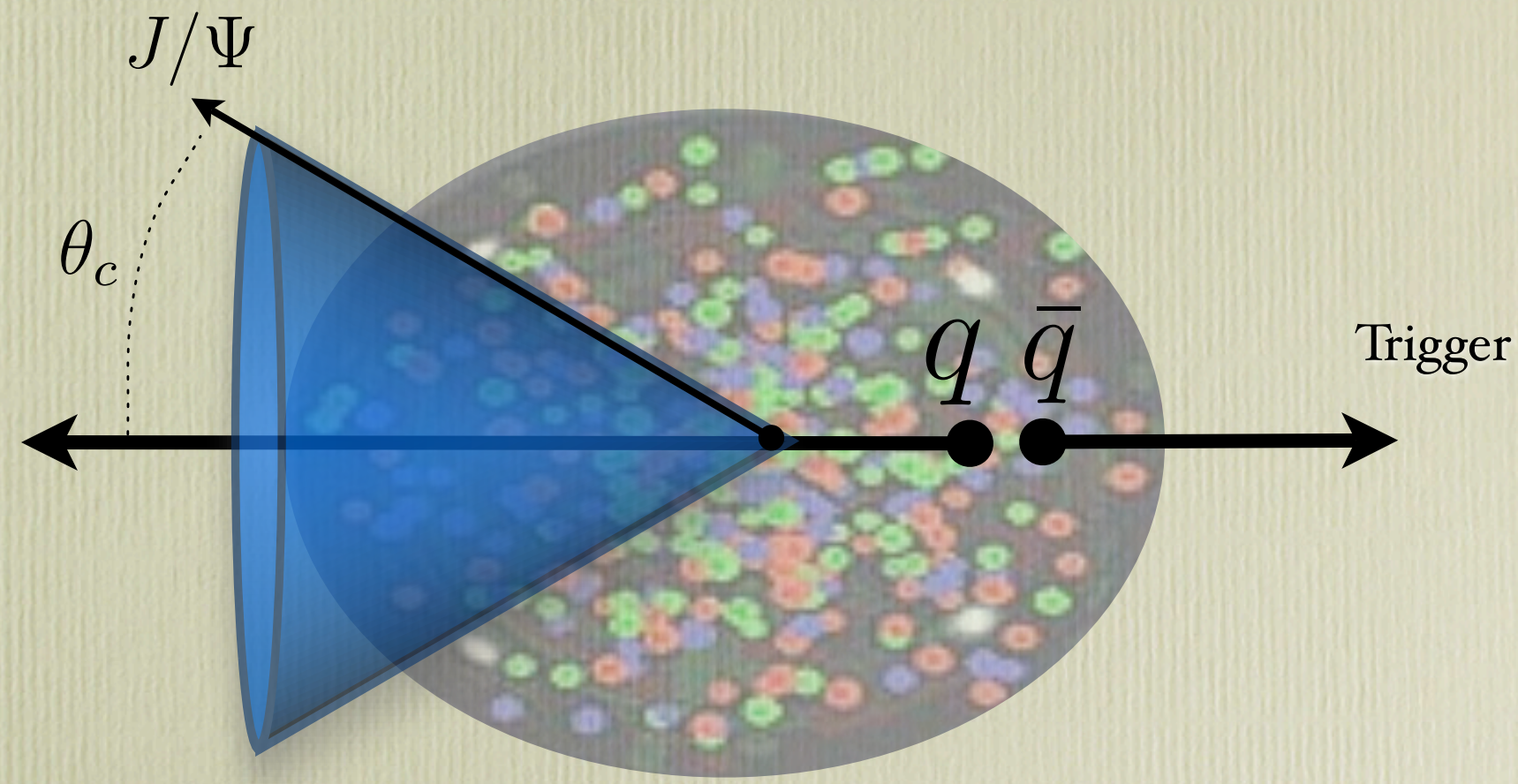
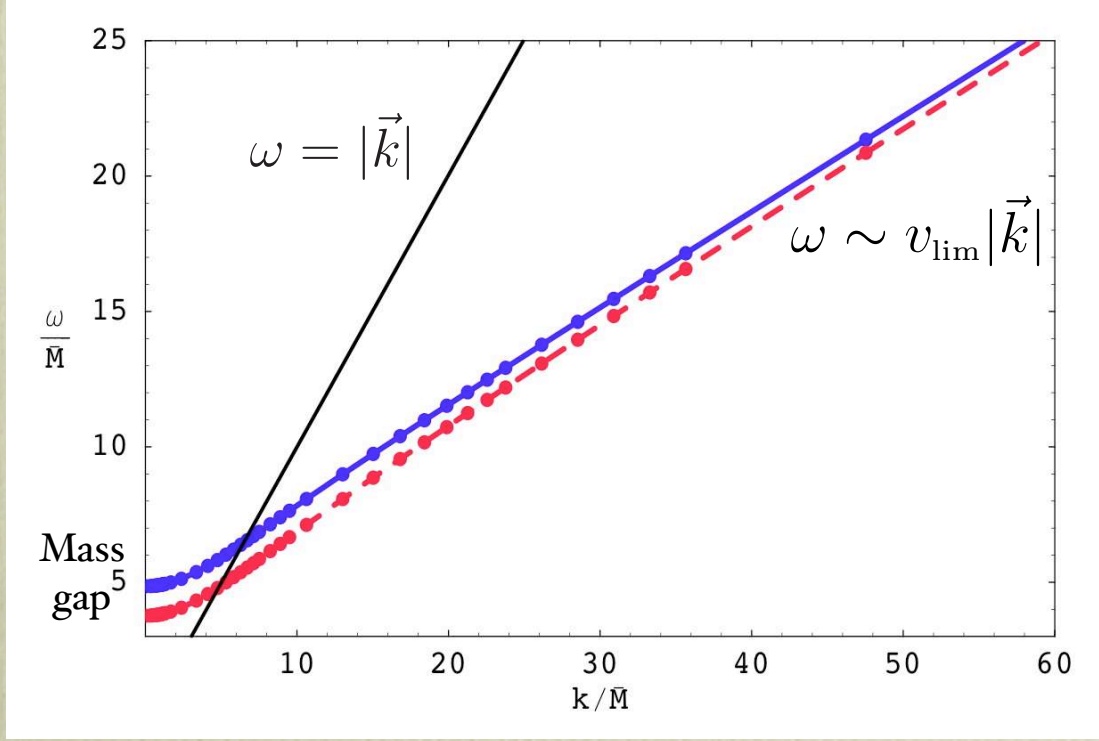


$$\cos\theta_c = \frac{v_{\rm lim}}{v_q} \lesssim 70^0$$

$$\frac{dE}{dx} \approx 2 - 8 \ \mathrm{GeV/fm}$$

Quarkonium dispersion relation

D.M., Myers & Thomson '07
Ejaz, Faulkner, Liu, Rajagopal & Wiedemann '07



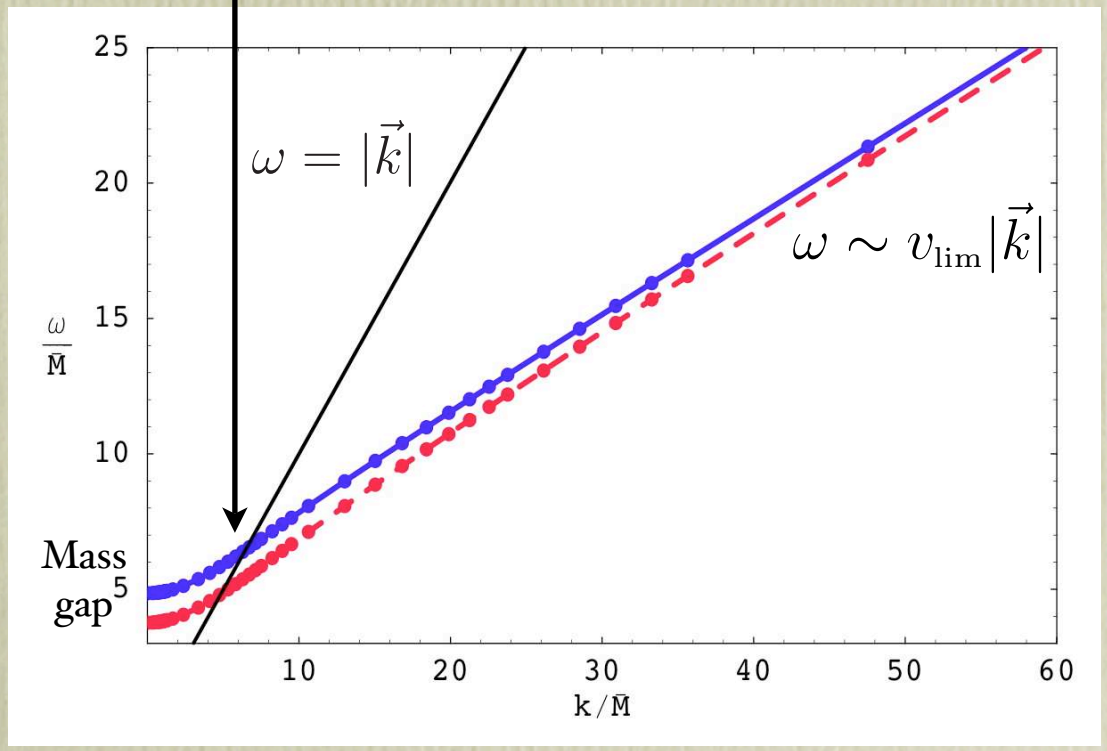
Lattice?

cf. Nanaka's talk on Tuesday

Quarkonium dispersion relation

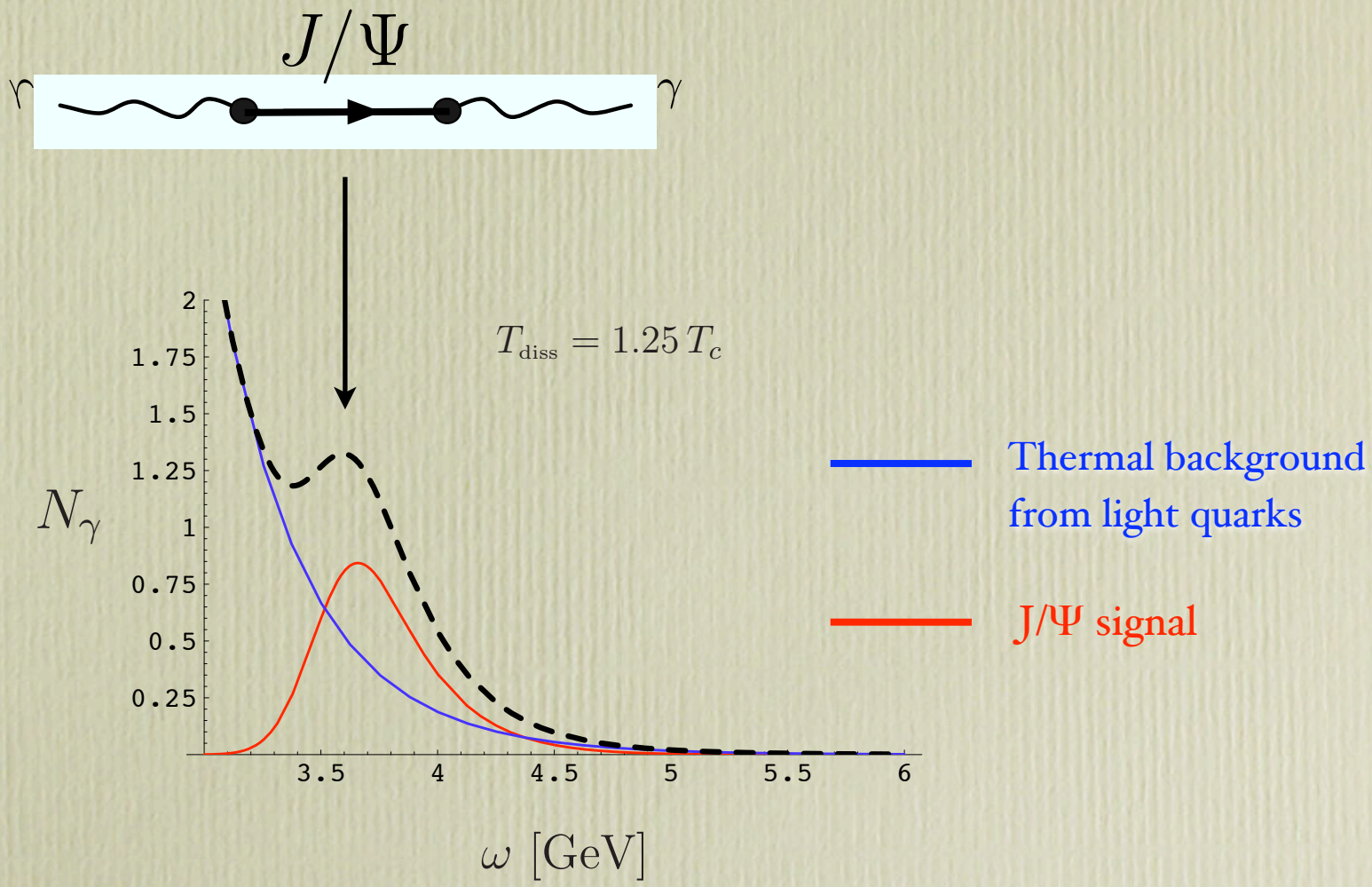
D.M., Myers & Thomson '07
Ejaz, Faulkner, Liu, Rajagopal & Wiedemann '07

Meson with $\omega^2 = k^2$ has same quantum numbers as a photon



Peak in spectrum of thermal photons

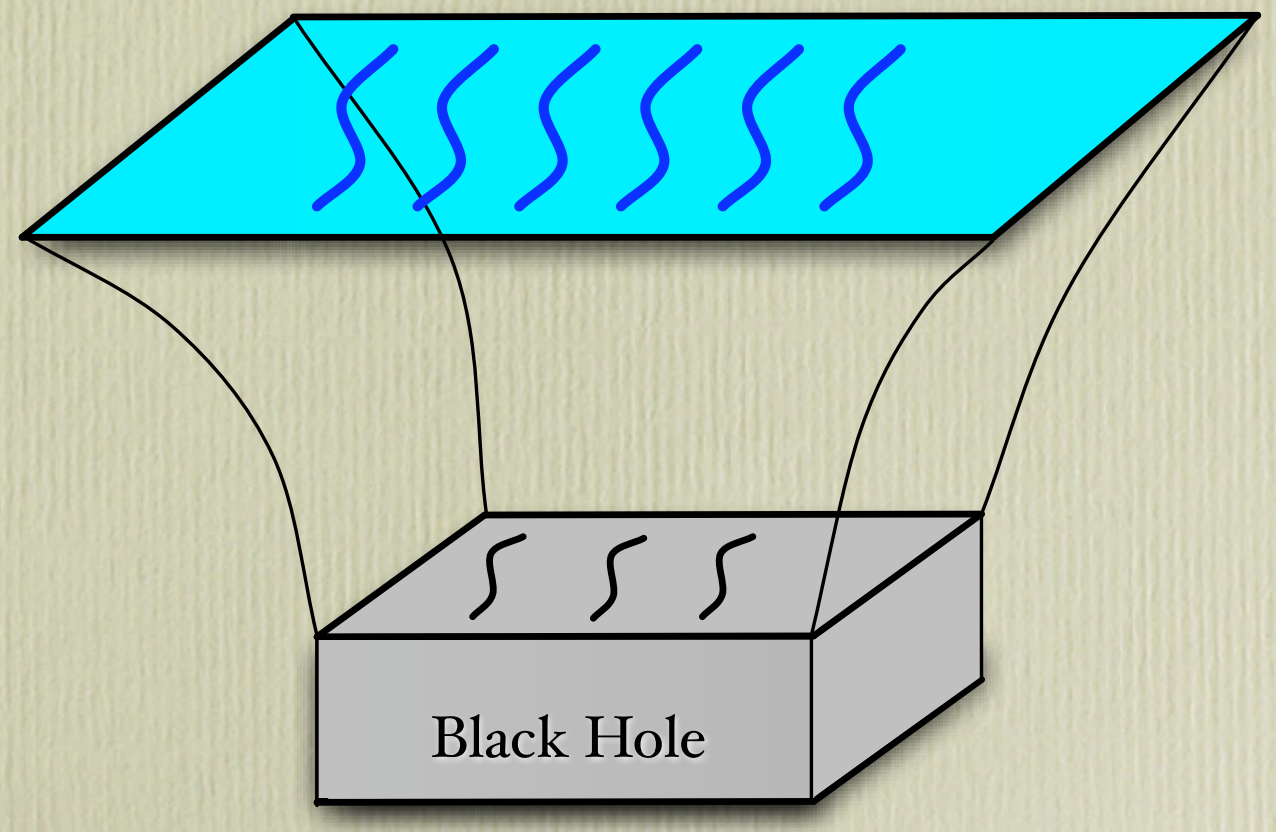
Casalderrey-Solana & D.M. '08



Caution: Peak size is *very* sensitive to in-medium J/Ψ physics!

All-order hydrodynamics from gravity

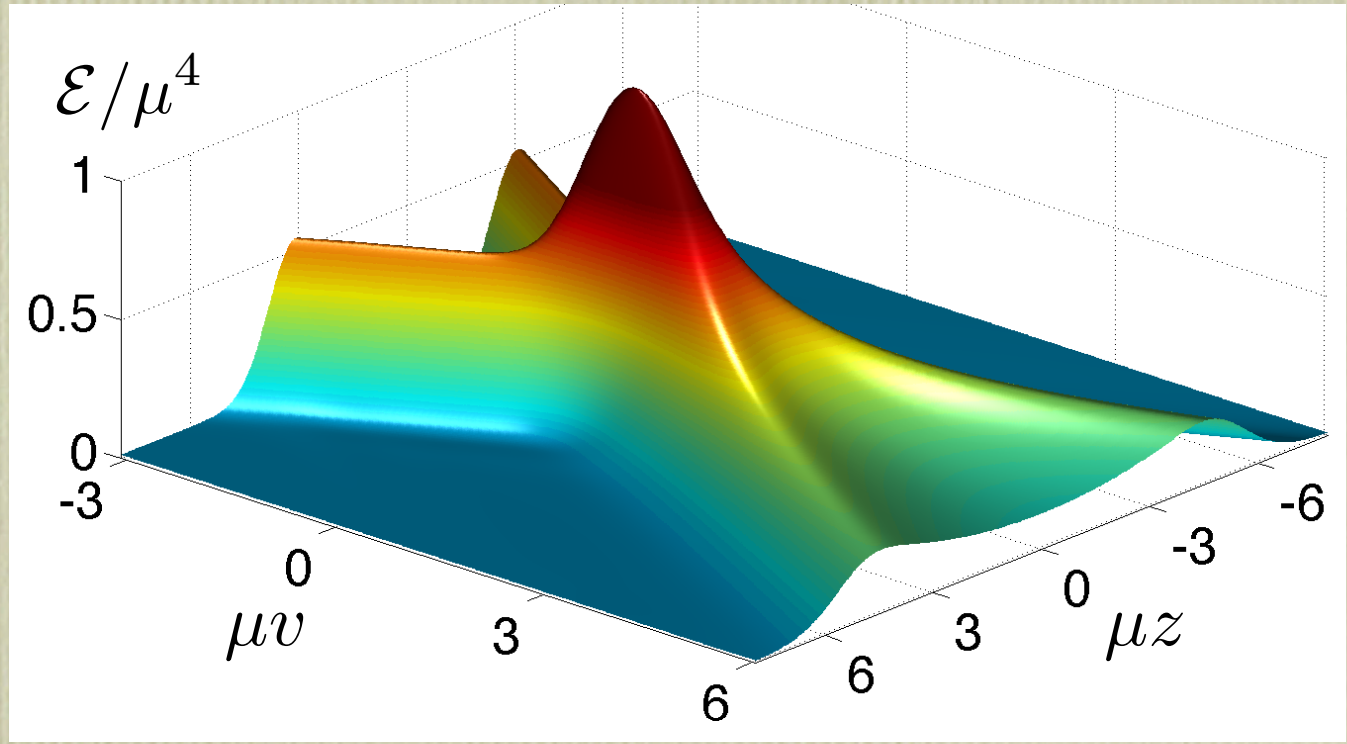
Bhattacharyya, Hubeny, Minwalla & Rangamani '08



Allowed calculation of 2nd order hydro coefficients for N=4 SYM.

Bhattacharyya, Hubeny, Minwalla & Rangamani '08
Baier, Romatschke, Son, Starinets & Stephanov '08

Time dependence & thermalization



Janik, & Peschanski '06
Grumiller & Romatschke '08
Albacete, Kovchegov & Taliotis '09
Kovchegov & Lin '09
Gubser, Pufu & Yarom '09
Lin & Shuryak '09
Beuf, Heller, Janik, & Peschanski '09
Chesler & Yaffe '09
Chesler & Yaffe '10
Balasubramanian et al '11
Caron-Huot, Chesler & Teaney '11

"Just" solve classical GR = PDEs numerically.

Caution: Thermalization may occur via weak-coupling mechanism.

Conclusions

- Gauge/String duality is not a *precision* tool for sQGP, but it provides solvable models.

- Sometimes these may offer valuable insights into problems difficult (or impossible) to analyze by other methods.