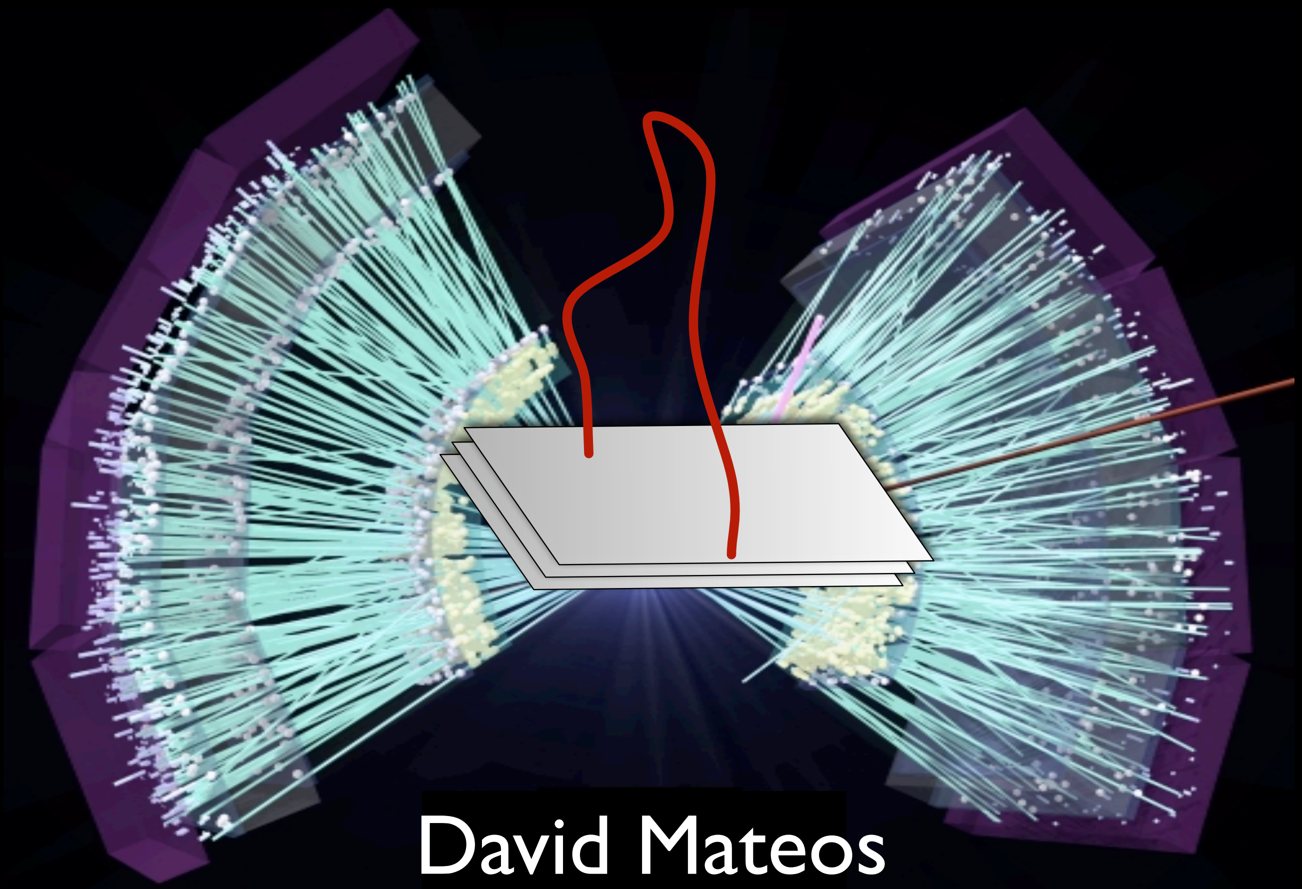
Two Universal String Predictions for Heavy Ion Collisions



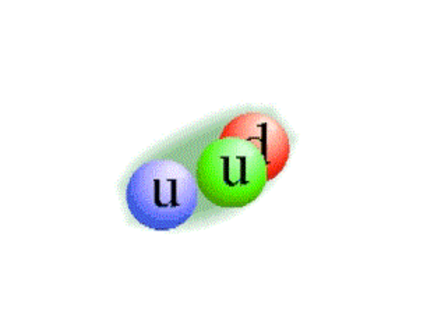
David Mateos
ICREA & University of Barcelona

Plan

- Recap from this morning.
- Phase transitions for mesons.
- Photon emission by sQGP.
- Implications for HIC.
- A new mechanism for quark energy loss.
- Remarks and concluding thoughts.

The QCD challenge

- QCD remains a challenge after 36 years!



The QCD challenge

- QCD remains a challenge after 36 years!
- No analytic and truly systematic methods.
- Lattice is good for static properties, but not for real-time physics...
- ... and for a theorist it is a black box.
- A string reformulation might help.
- Topic of this talk -- with focus on QGP.

The QCD challenge

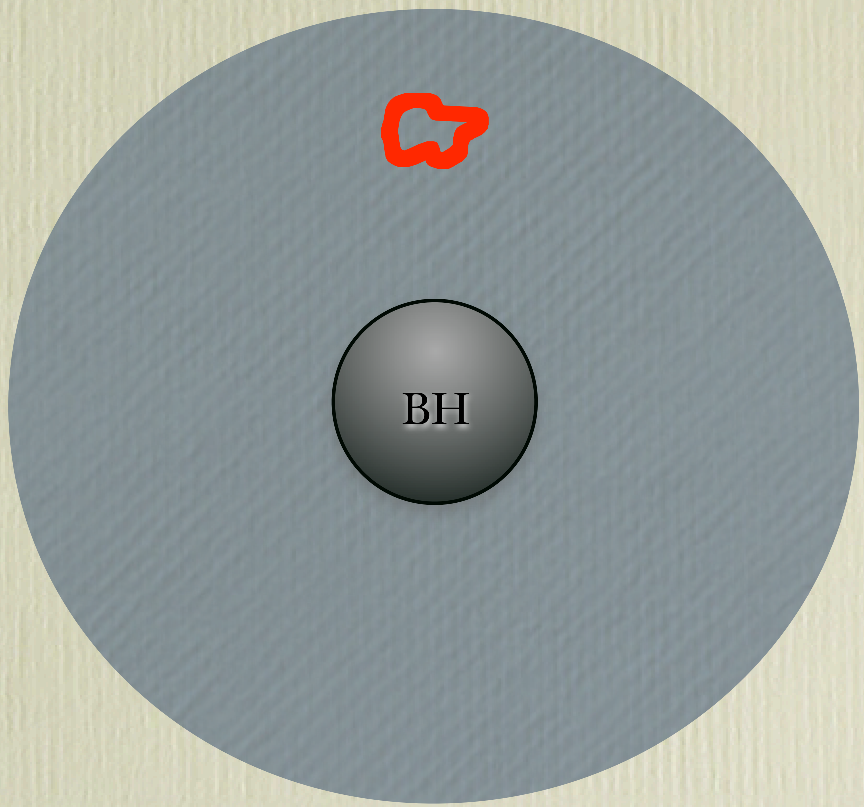
- Problem: Dual of QCD is inaccessible within SUGRA.
- Certain quantitative observables (eg. T=0 spectrum) will require going beyond supergravity.
- However, certain predictions may be universal enough to apply in certain regimes.
- Good example: $\frac{\eta}{s} = \frac{1}{4\pi}$

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

Exploit two universal properties

Deconfined plasma ⟷

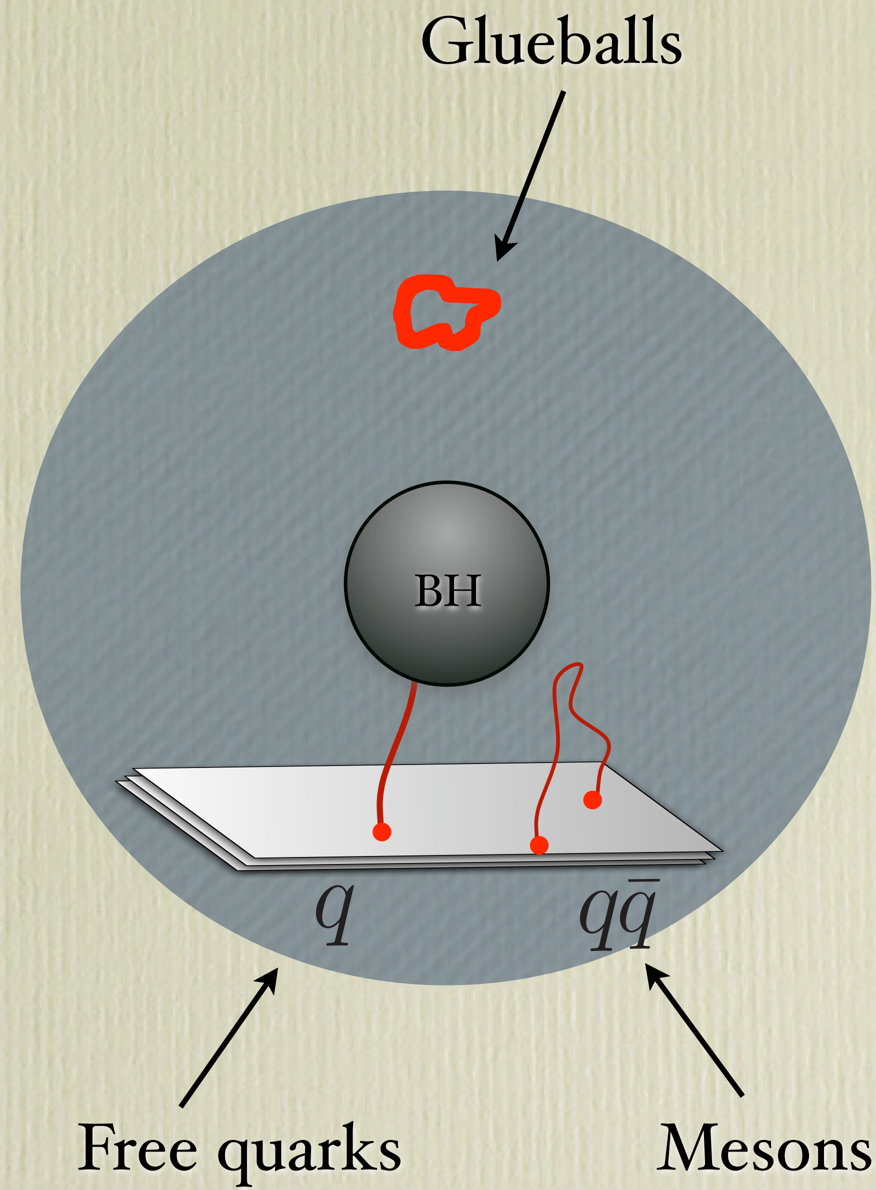
Witten '98



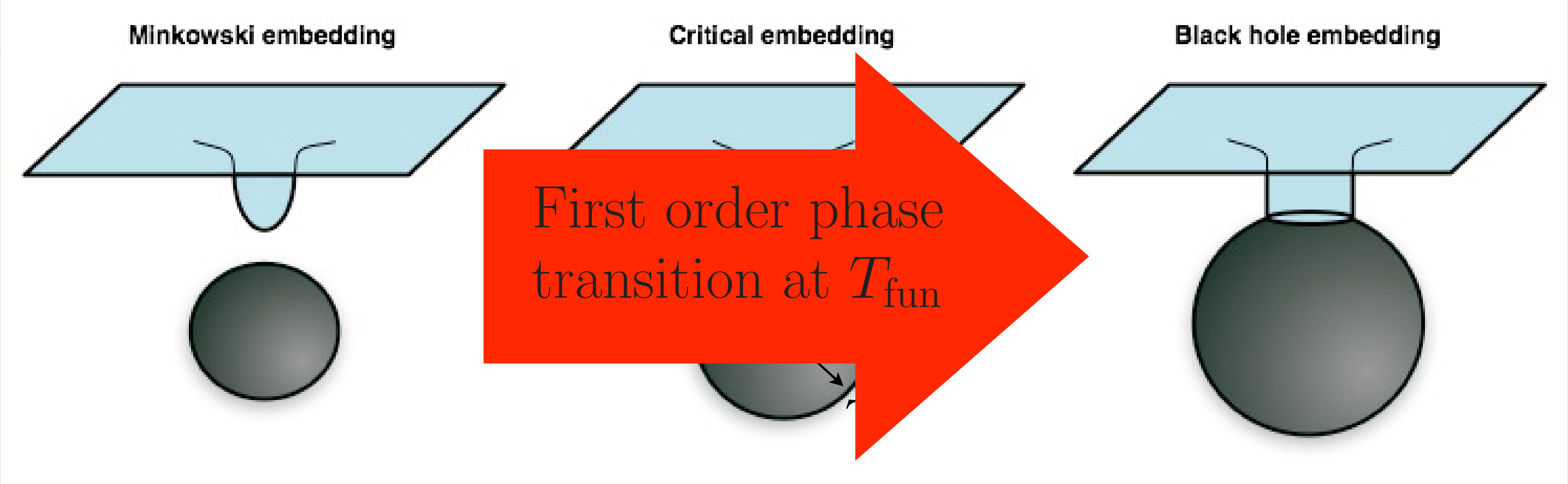
Exploit two universal properties

$N_f \ll N_c$ quark flavours $\longleftrightarrow$

Karch & Randall '01
Karch & Katz '02



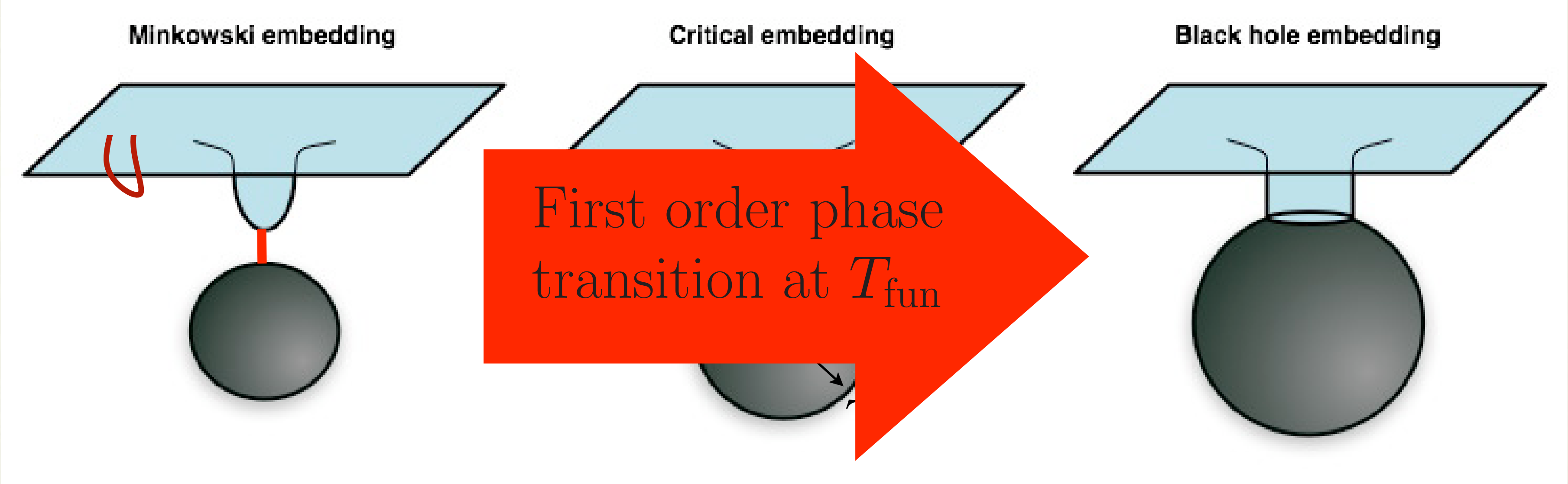
Phase transitions for mesons



(Gluons are deconfined in both phases!)

D.M., Myers & Thomson '06

Babington, Erdmenger, Guralnik & Kirsch '03
Kruczenski, D.M., Myers & Winters '03
Kirsch '04



- Discrete set of mesons with mass gap:

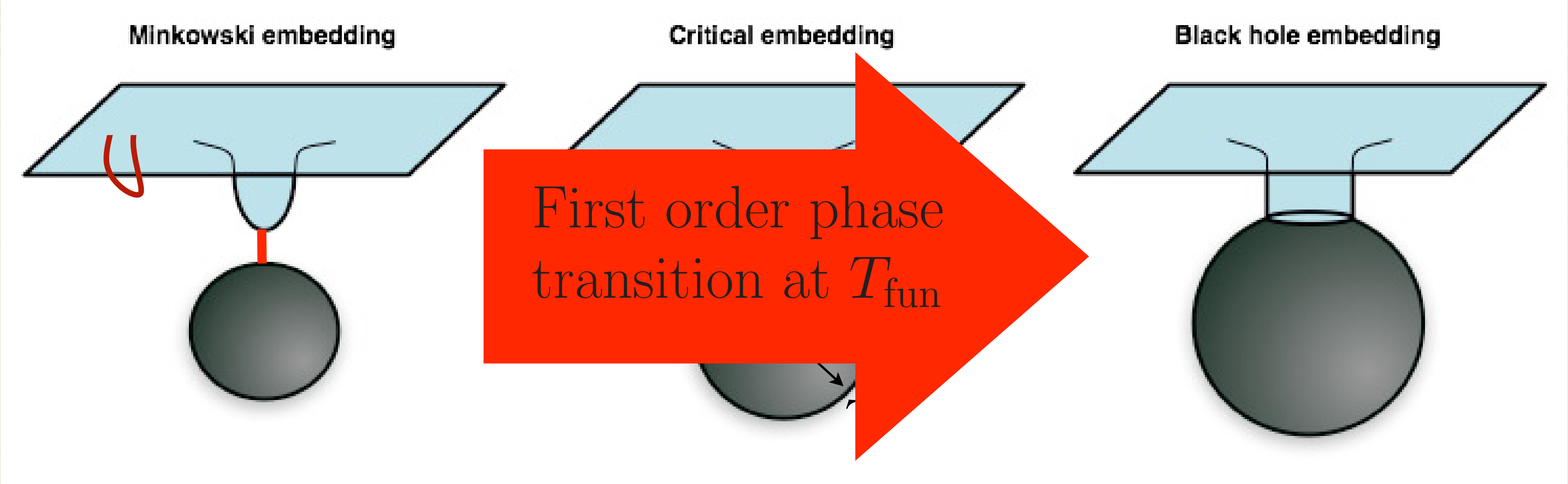
$$M_{\rm mes} \sim \frac{M_{\rm q}}{\sqrt{\lambda}} \sim T_{\rm fun}$$

- Massive quarks.

- Heavy mesons survive deconfinement!

- In good agreement with lattice QCD, eg. for J/Ψ:

$$T_{\rm fun} \sim 1.6\, T_{\rm c} - 2.1 T_{\rm c}$$



- No quasi-particle excitations!

D.M., Myers & Thomson '06
Hoyos-Badajoz, Landsteiner & Montero '06

- Will illustrate this by computing a spectral function of electromagnetic currents, related to photon production:

$$\langle J_\mu^{\text{EM}} J_\mu^{\text{EM}} \rangle$$

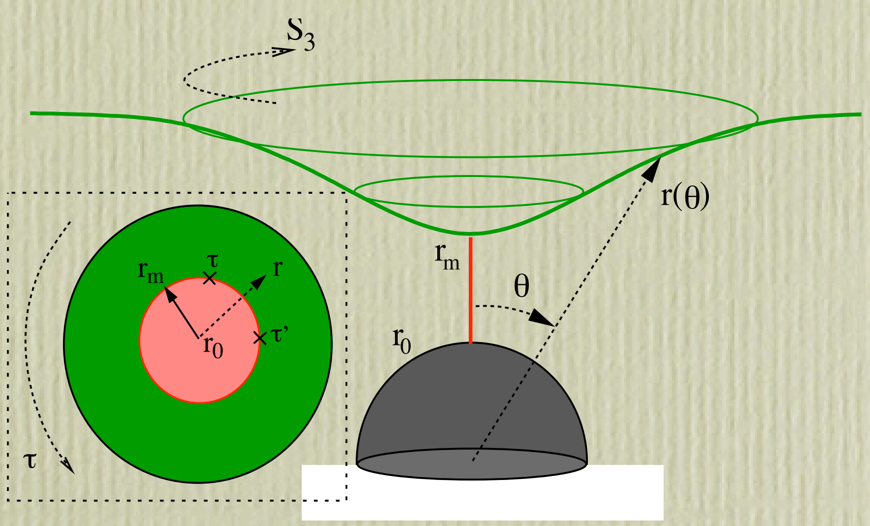
D.M., Patiño-Jaidar '07

Phase transitions for mesons

- Mesons absolutely stable at $N_c \to \infty$, $\lambda \to \infty$, but acquire widths away from this limit.

- Finite coupling: String worldsheet instantons.

Faulkner & Liu '08



$$\Gamma \sim e^{-\sqrt{\lambda}} \sim e^{-M_q/T}$$

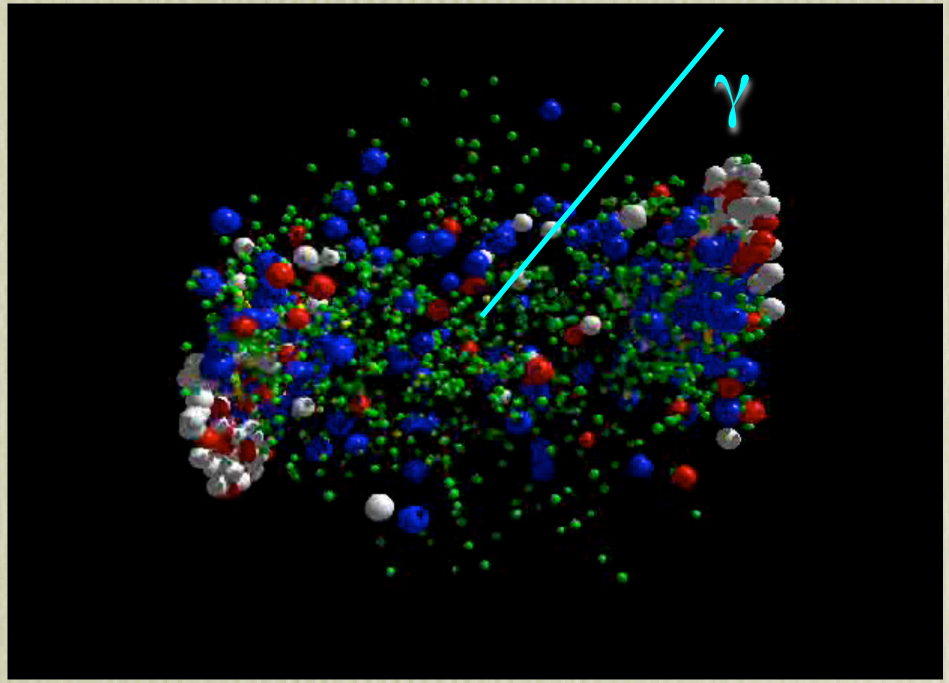
- Finite N: Hawking radiation.

$$\Gamma \sim 1/N_c^2$$

Photon emission by sQGP

Why photons?

- QGP is optically thin → Photons carry valuable information.



- Holographic results for massless matter:

Caron-Huot, Kovtun, Moore, Starinets & Yaffe '06

Parnachev & Sahakian '06

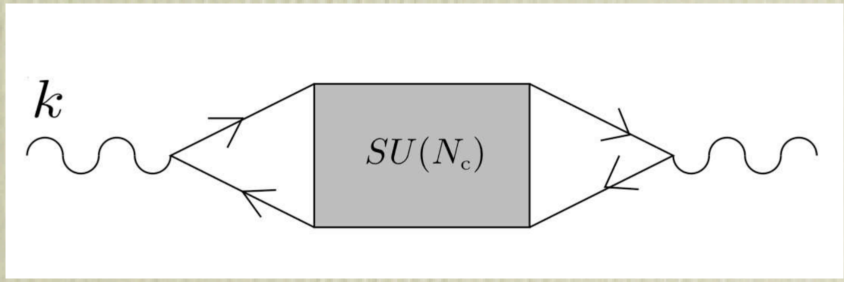
- To leading order in the electromagnetic coupling constant:

$$\frac{d\Gamma}{d^d\mathbf{k}} = \frac{e^2}{(2\pi)^d\, 2|\mathbf{k}|}\,\frac{1}{e^{k^0/T}-1}\,\eta^{\mu\nu}\chi_{\mu\nu}(k)$$

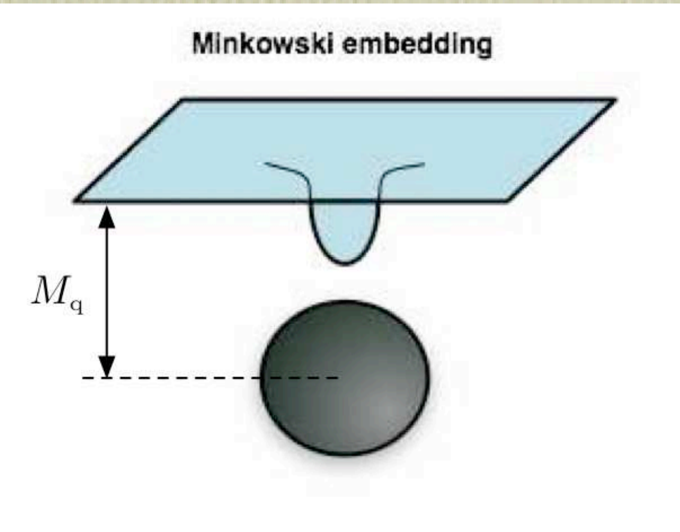
$k=(k^0,\mathbf{k})$, with $k^0=|\mathbf{k}|$, is the photon null momentum

$\chi_{\mu\nu}(k) = -2\,\mathrm{Im}\,G^{\mathrm{R}}_{\mu\nu}(k)$ is the spectral density

$$G^{\mathrm{R}}_{\mu\nu}(k) = -i\int d^{d+1}x\, e^{-ik\cdot x}\,\Theta(x^0)\langle[J^{\mathrm{EM}}_\mu(x), J^{\mathrm{EM}}_\nu(0)]\rangle$$

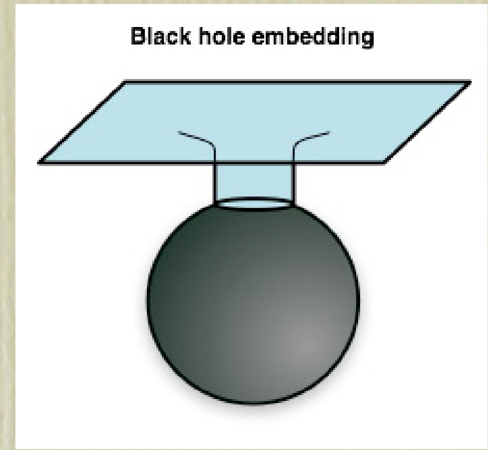


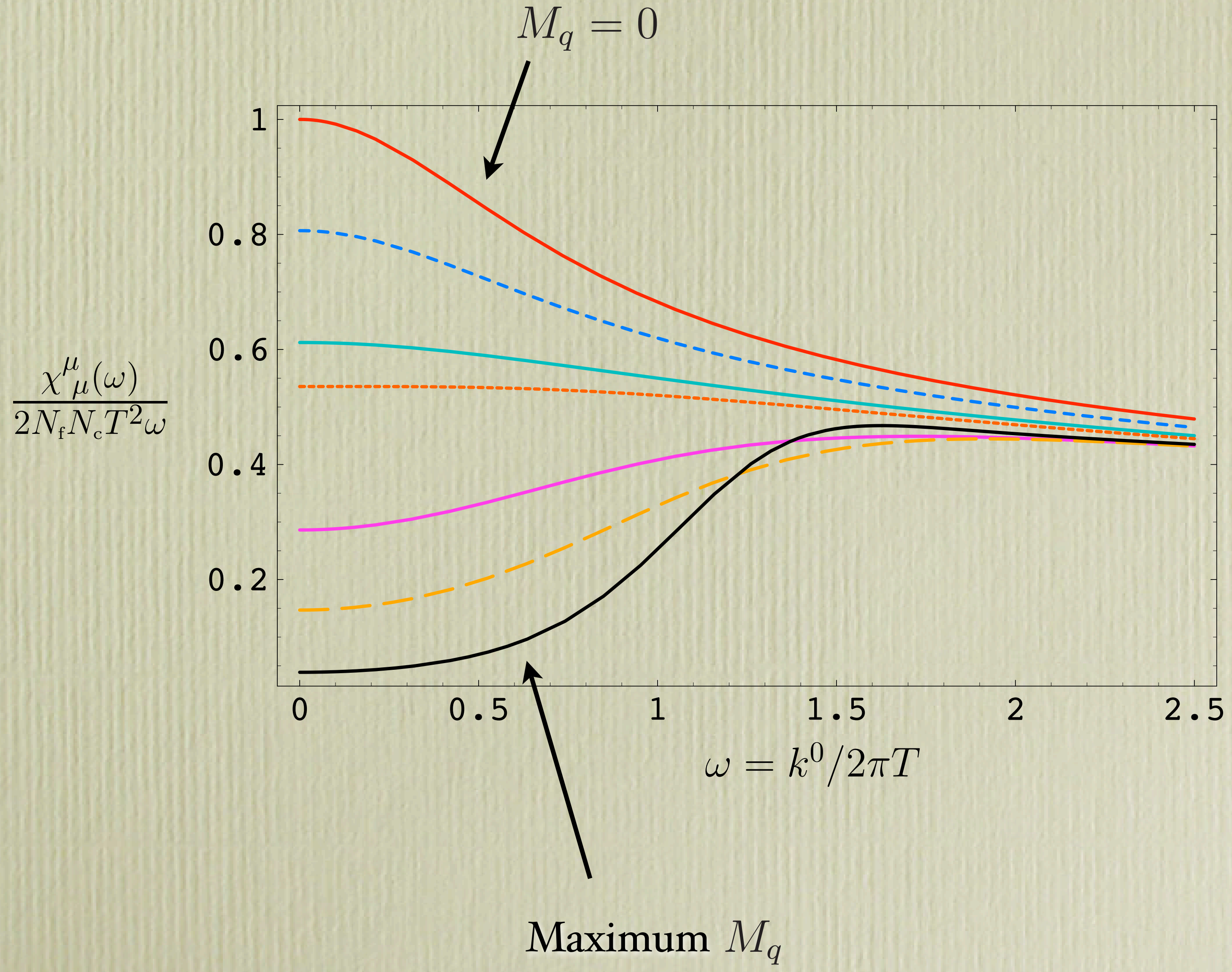
Spectral function for Minkowski



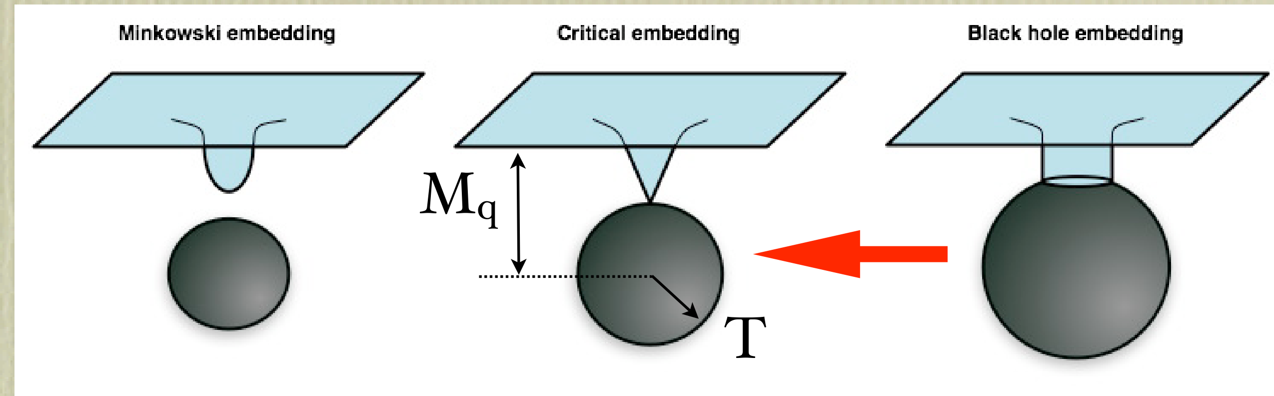
$$\chi = \sum \text{delta functions}$$

Spectral function for BH

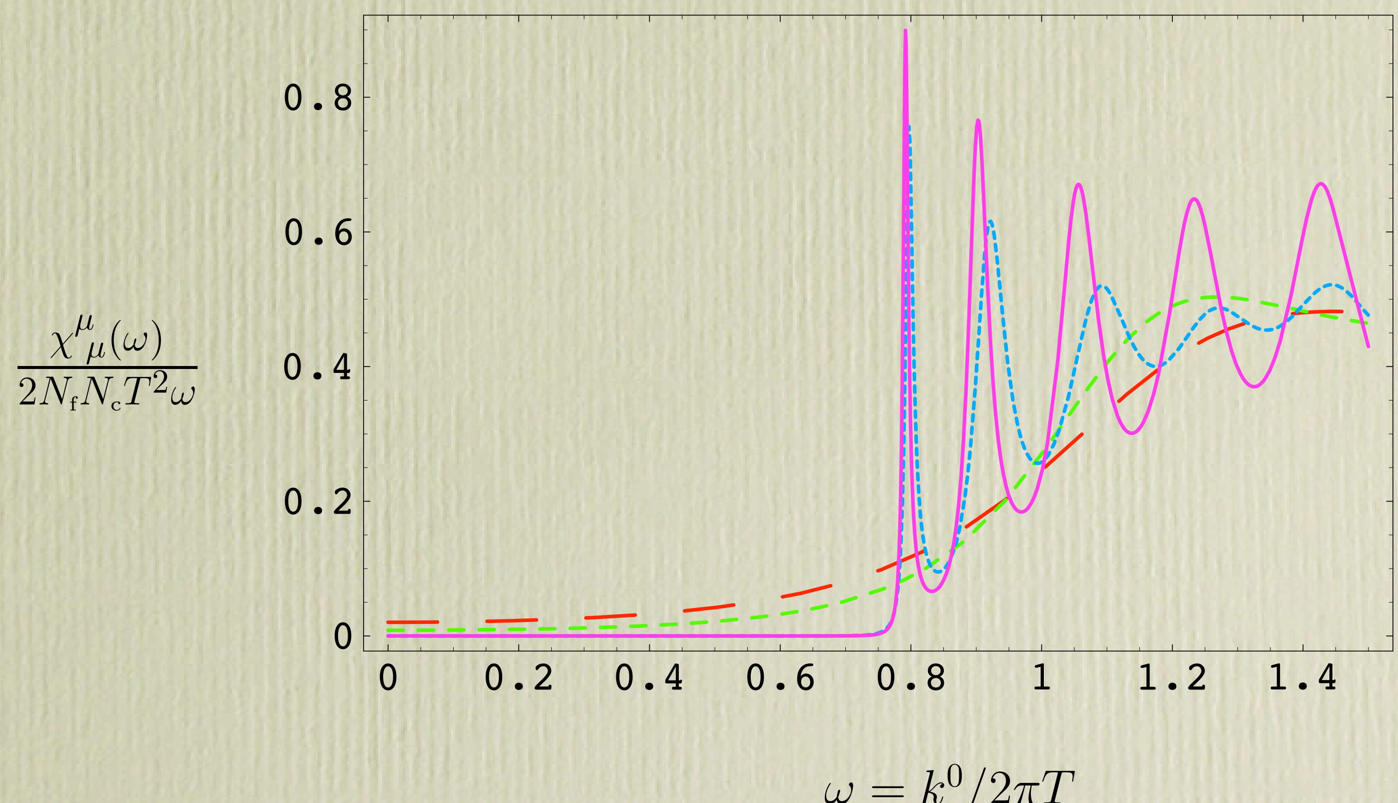




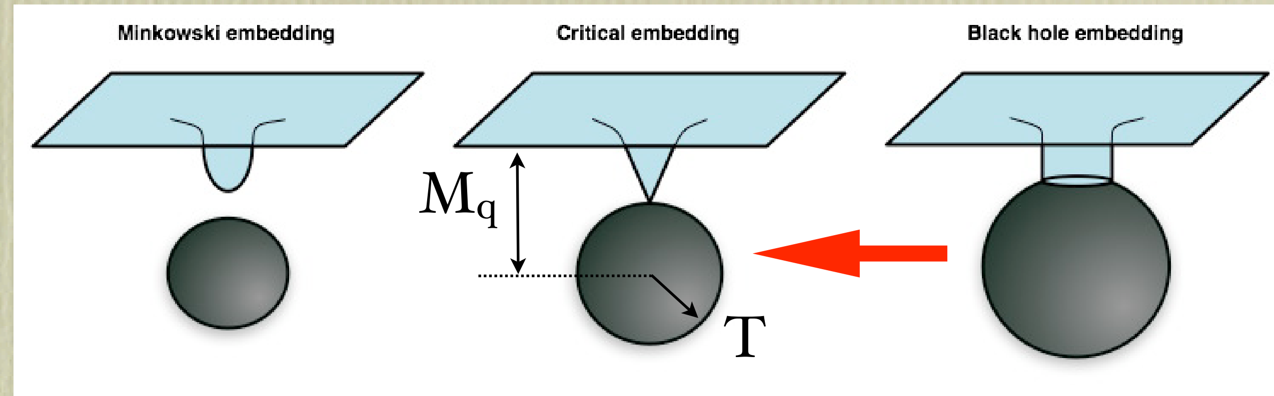
Approaching the critical embedding:



Peaks at null momentum!



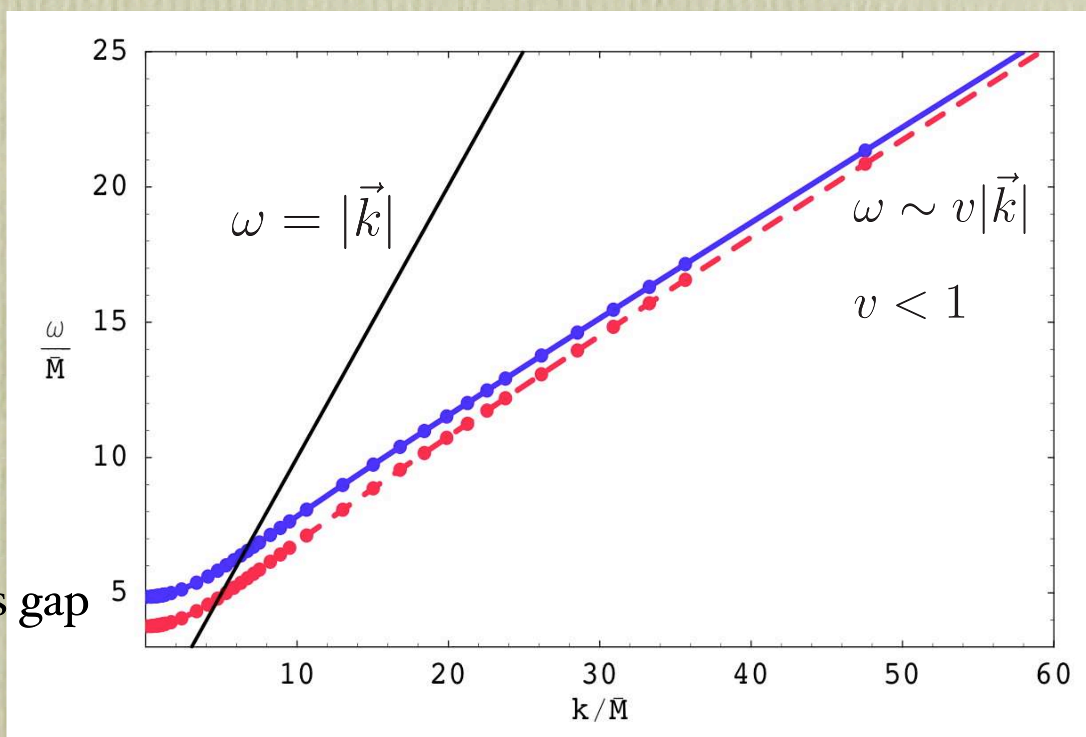
Approaching the critical embedding:



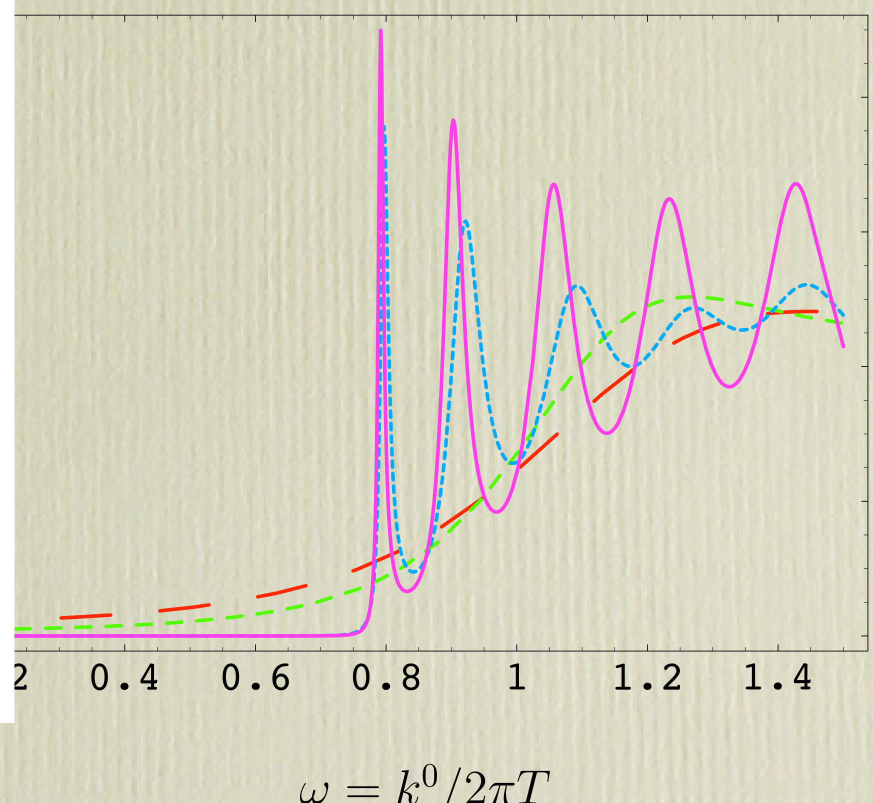
Dispersion relation for mesons

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

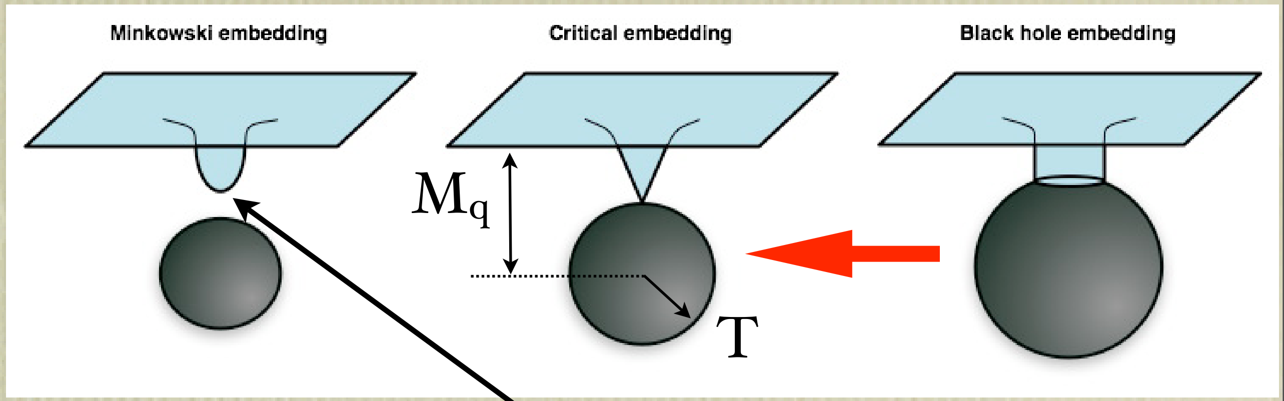
Mass gap



Peaks at null momentum!



Approaching the critical embedding:

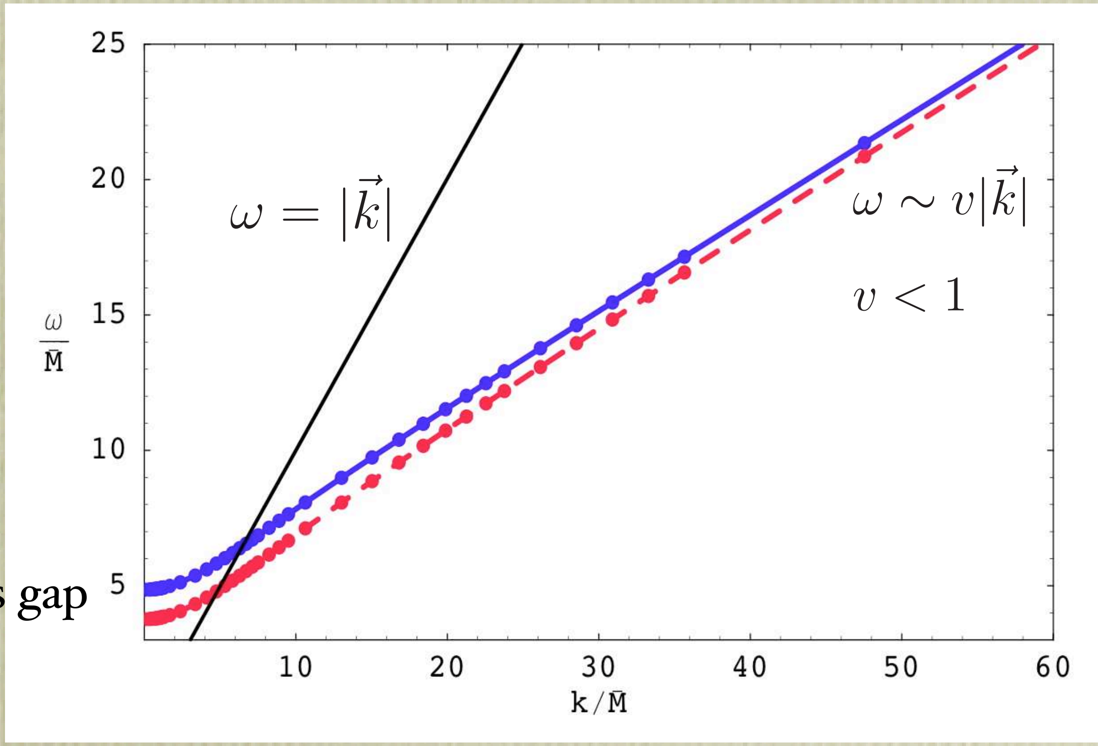


Limiting velocity
=
Local speed of light at the tip

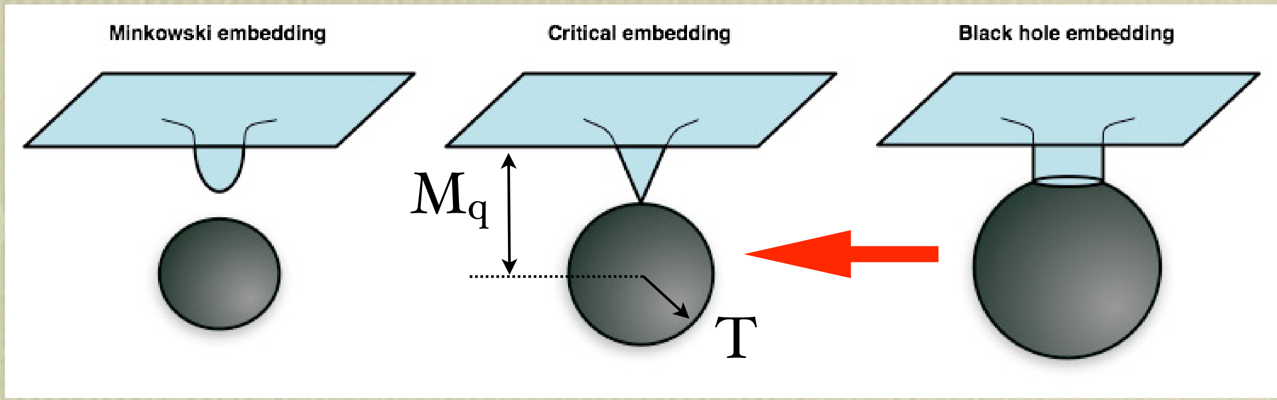
Dispersion relation for mesons

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

Mass gap

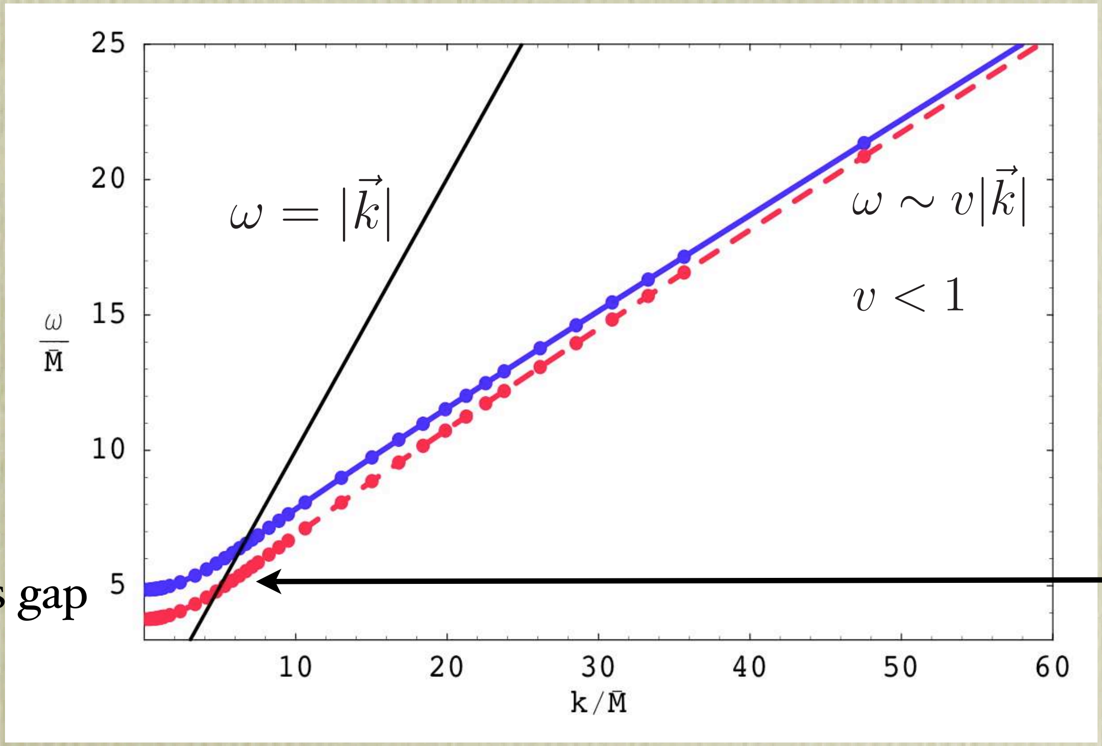


Approaching the critical embedding:

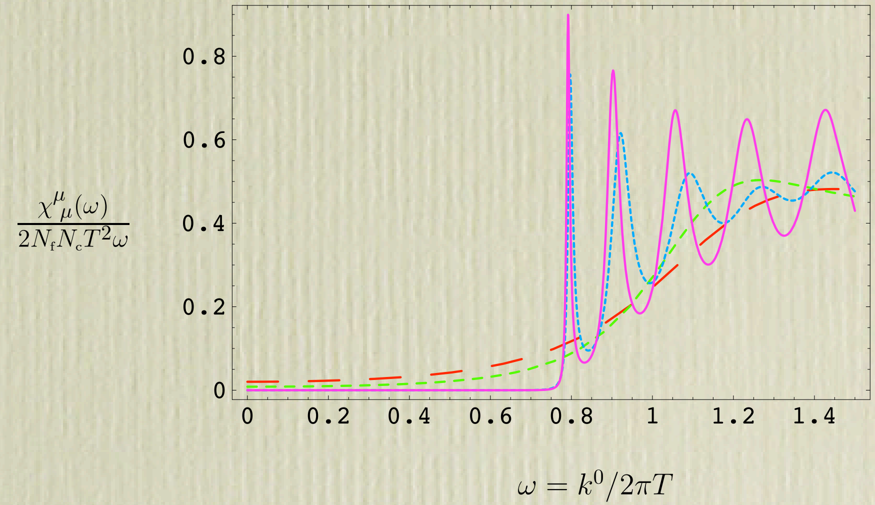


Dispersion relation for mesons

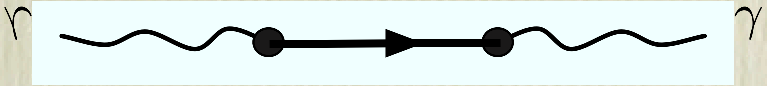
D.M., Myers & Thomson ‘07
Ejaz, Faulkner, Liu, Rajagopal & Wiedemann ‘07



Mass gap



Meson with
null momentum



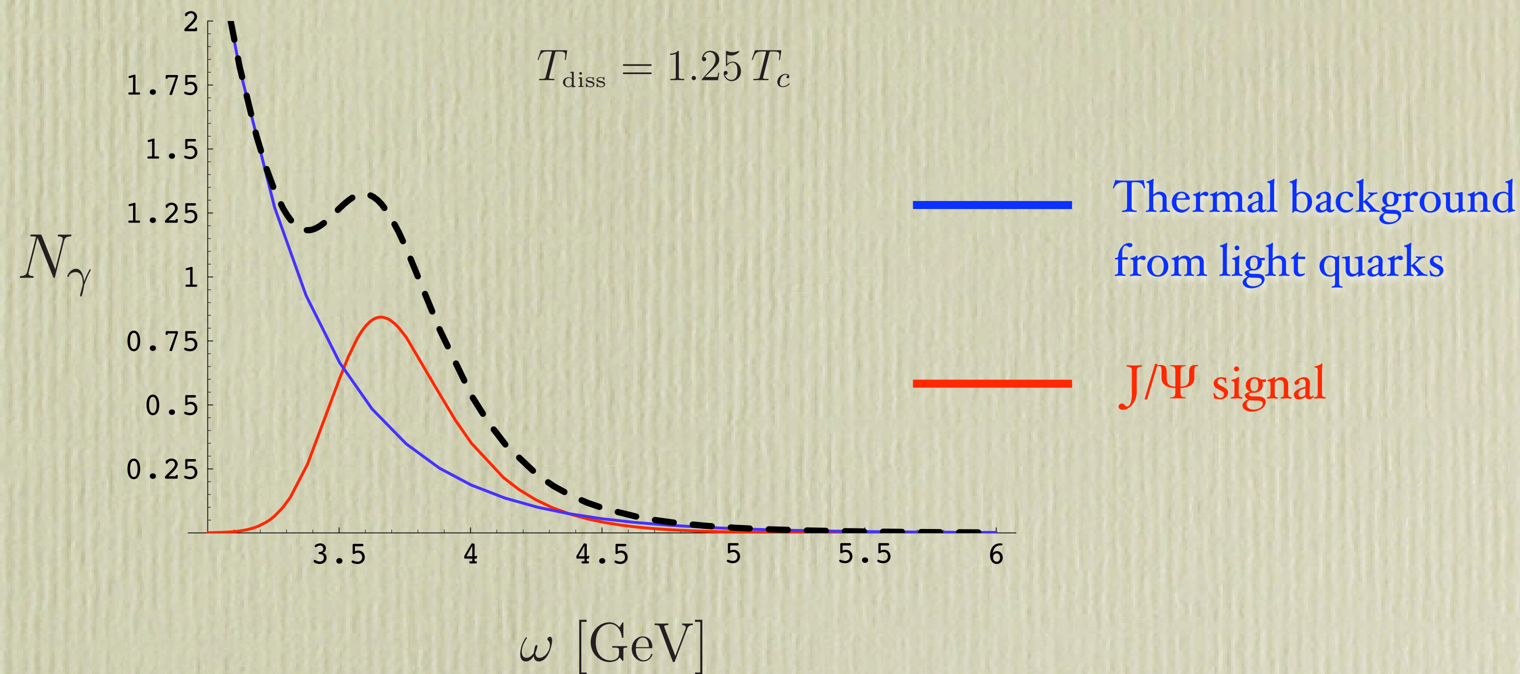
Implications for HIC

Implications for HIC

Casalderey-Solana, D.M. '08

- Comparison with HIC experiments requires model for spacetime evolution of the fireball, number and distribution of J/Ψ's, etc.

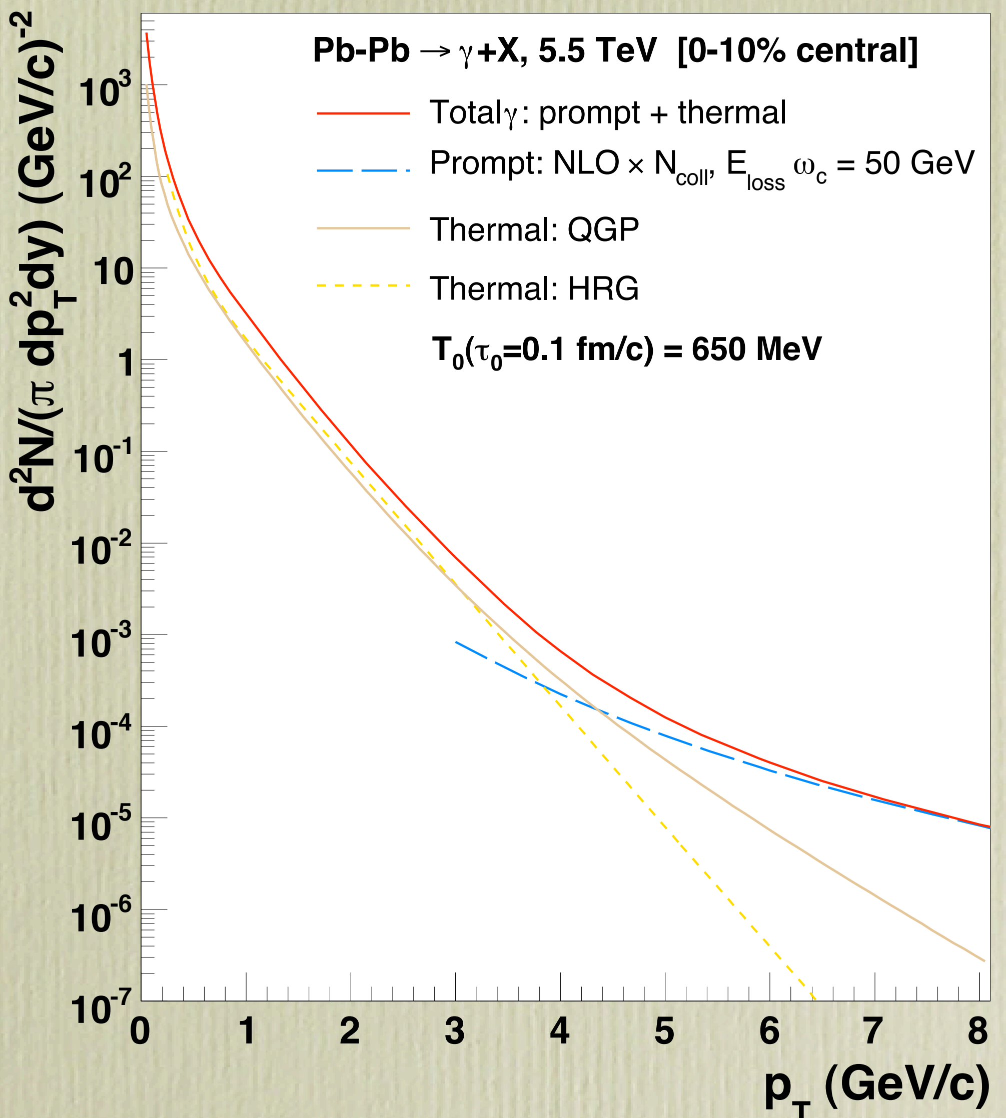
- Simple model yields, for LHC energies:



- Result exponentially sensitive to many parameters.
- Quadratically sensitive to $c\bar{c}$ cross-section
  -- not observable at RHIC.
- Location of the peak between 3-5 GeV.

- Signal is also comparable (or larger) than pQCD background:

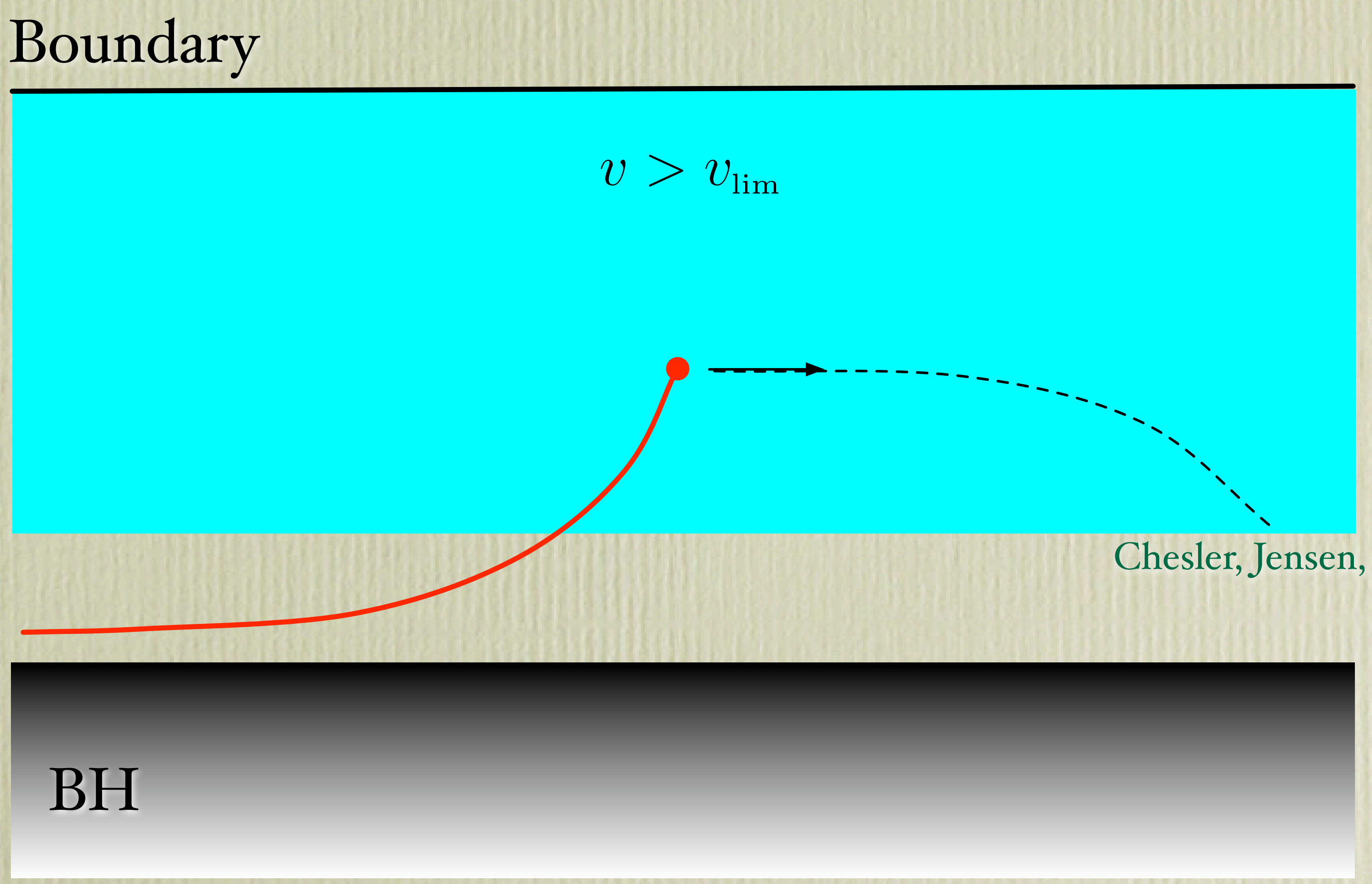
Arleo, d'Enterria and Peressounko '07



A new mechanism for quark energy loss

A new mechanism for quark energy loss

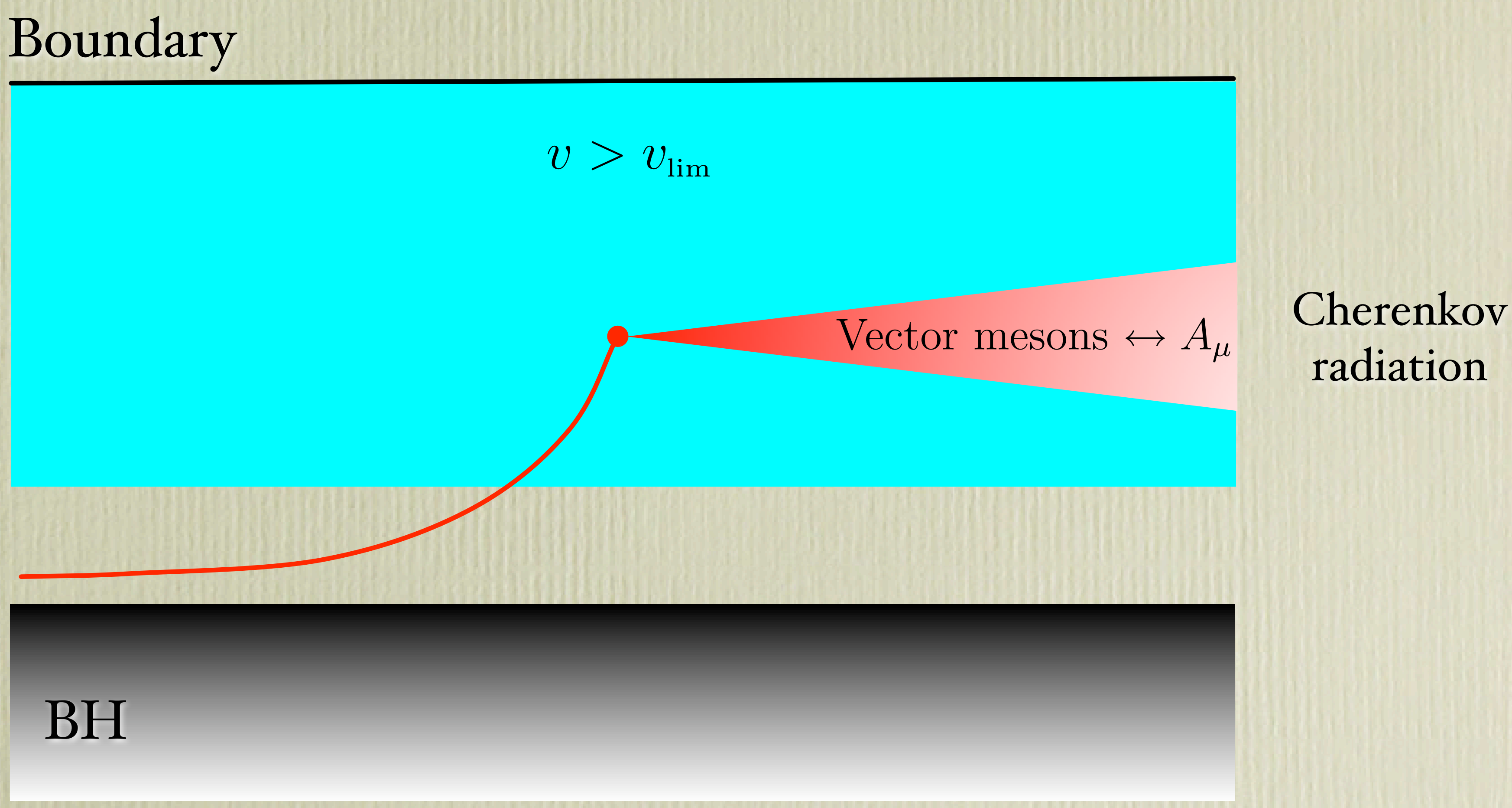
Casalderey-Solana, Fernandez & D.M. (to appear)



Chesler, Jensen, Karch & Yaffe '08

A new mechanism for quark energy loss

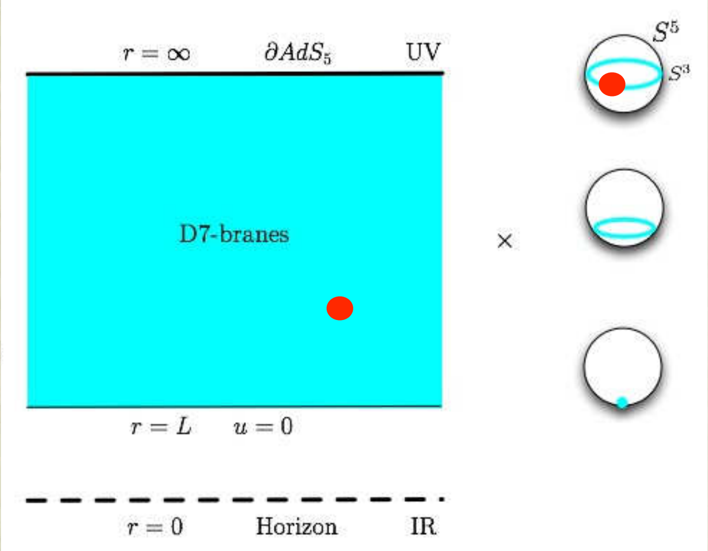
Casalderey-Solana, Fernandez & D.M. (to appear)



Comments

- Will also radiate scalar mesons: $$S \sim -\frac{1}{g_s}\int d^8x\sqrt{-\det(g+F)} - \int d\tau A_\mu \frac{dx^\mu}{d\tau} - \int d\tau \phi_i \frac{dx^i}{d\sigma}$$

- Will also radiate R-charged mesons:

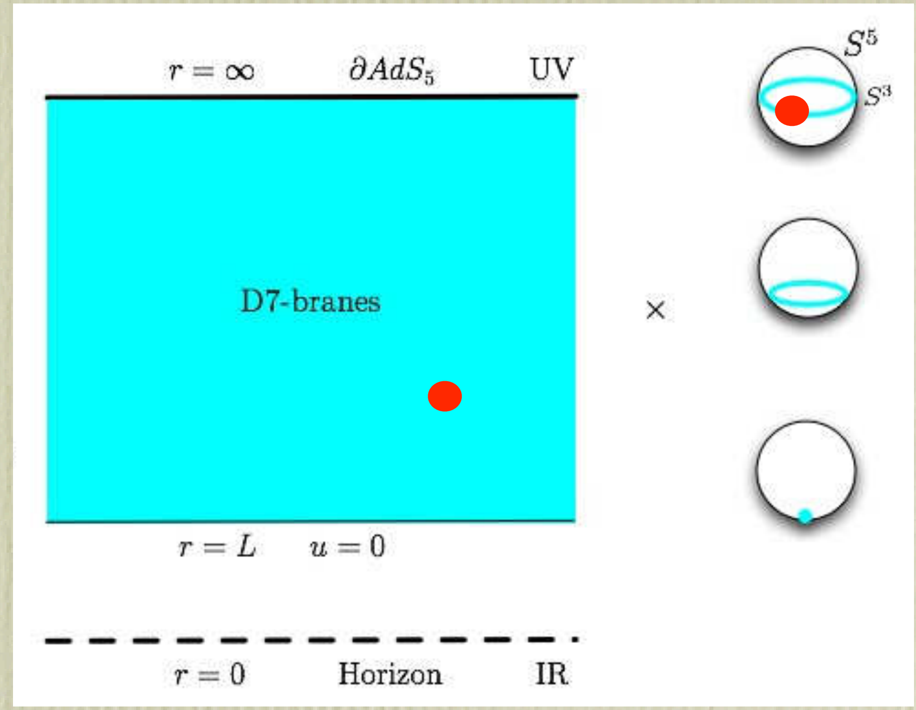


- Energy loss is of order $1/N_c$.

- But exactly calculable and not necessarily subleading for real-world QGP.

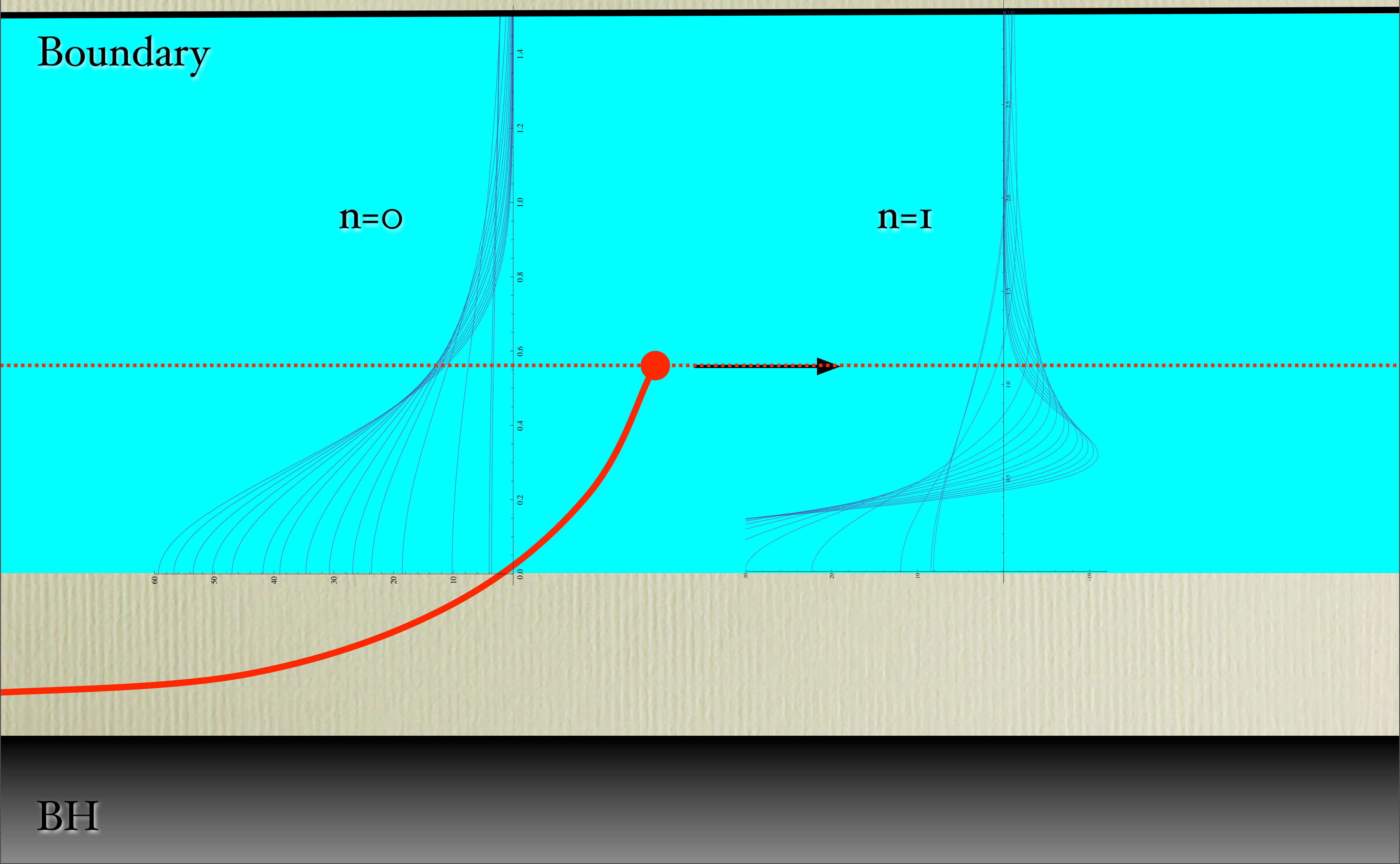
- Characteristic v-dependence.

Preliminary results for D3/D7



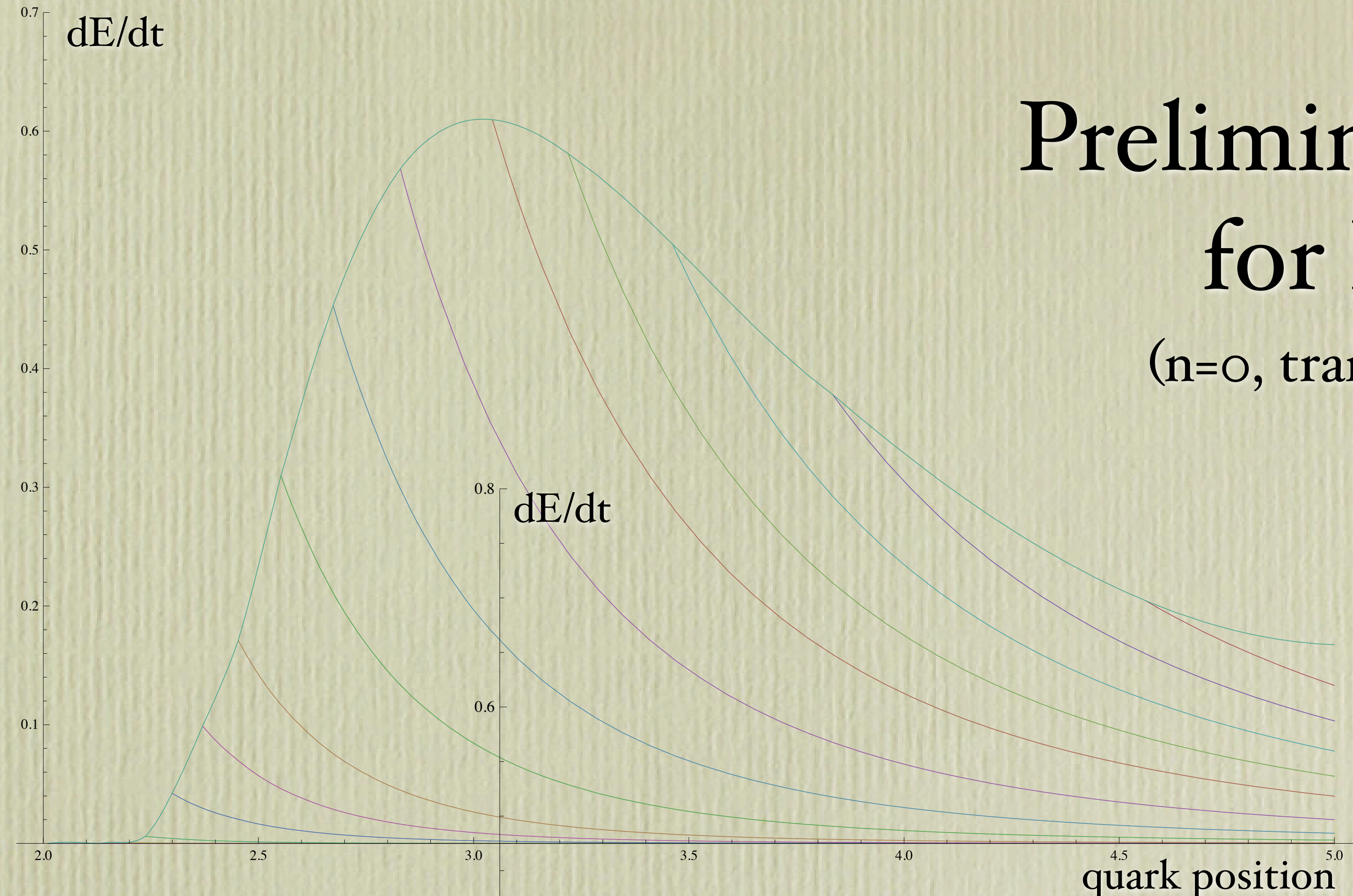
- Focus on sphere zero mode since QCD has no sphere.
- Expand in normalizable modes in radial direction: Infinite tower of **massive** 4D vector mesons.
- Energy loss in longitudinal and transverse modes.

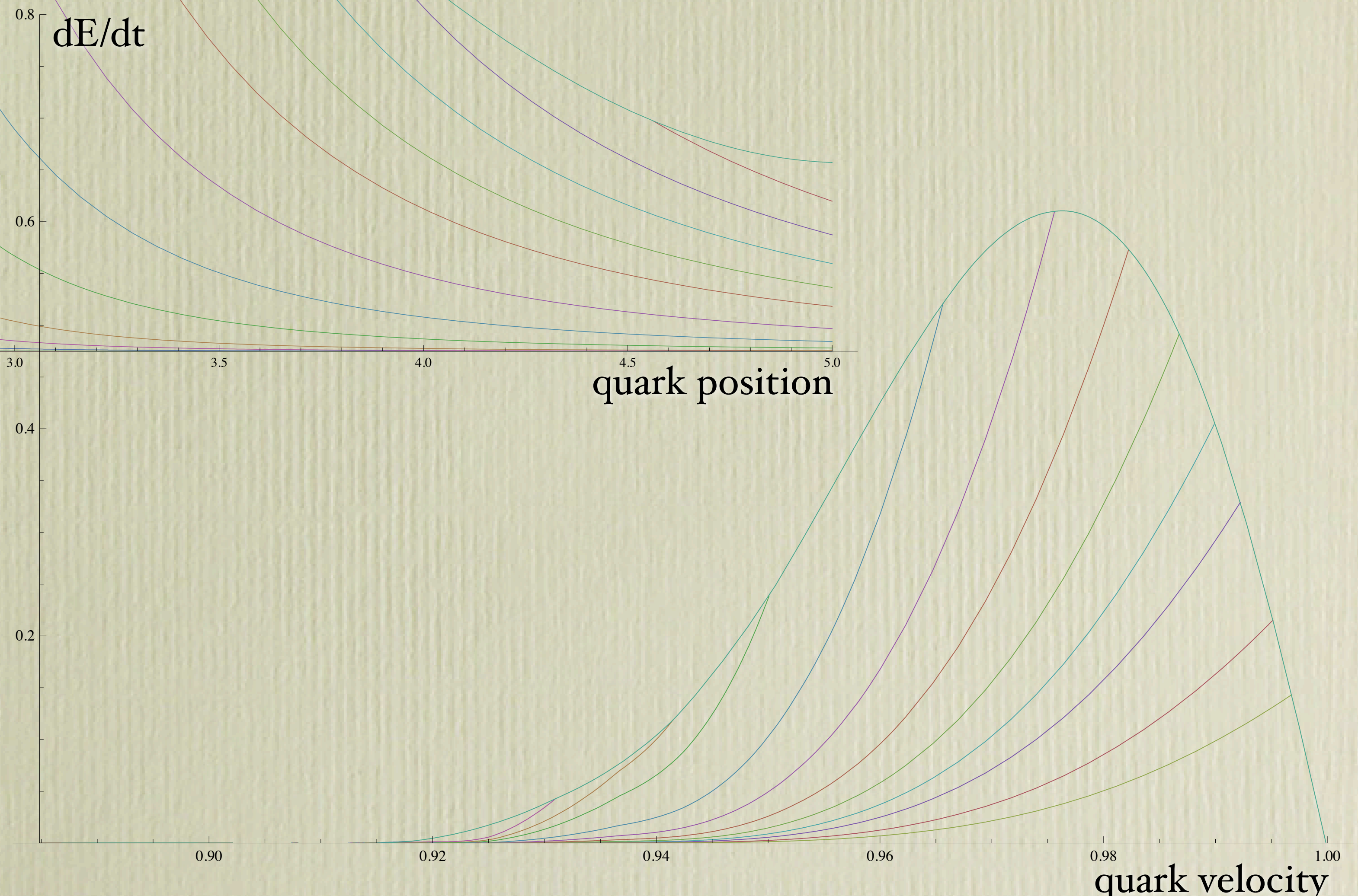
- Coupling to each mode is proportional to meson radial wave function at the location of the quark.



Preliminary results for D3/D7

(n=0, transverse mode)





Remarks

- **Photon peak** and **energy loss** may exist in QCD, irrespectively of whether a string dual exists.

- Depends on only two assumptions:

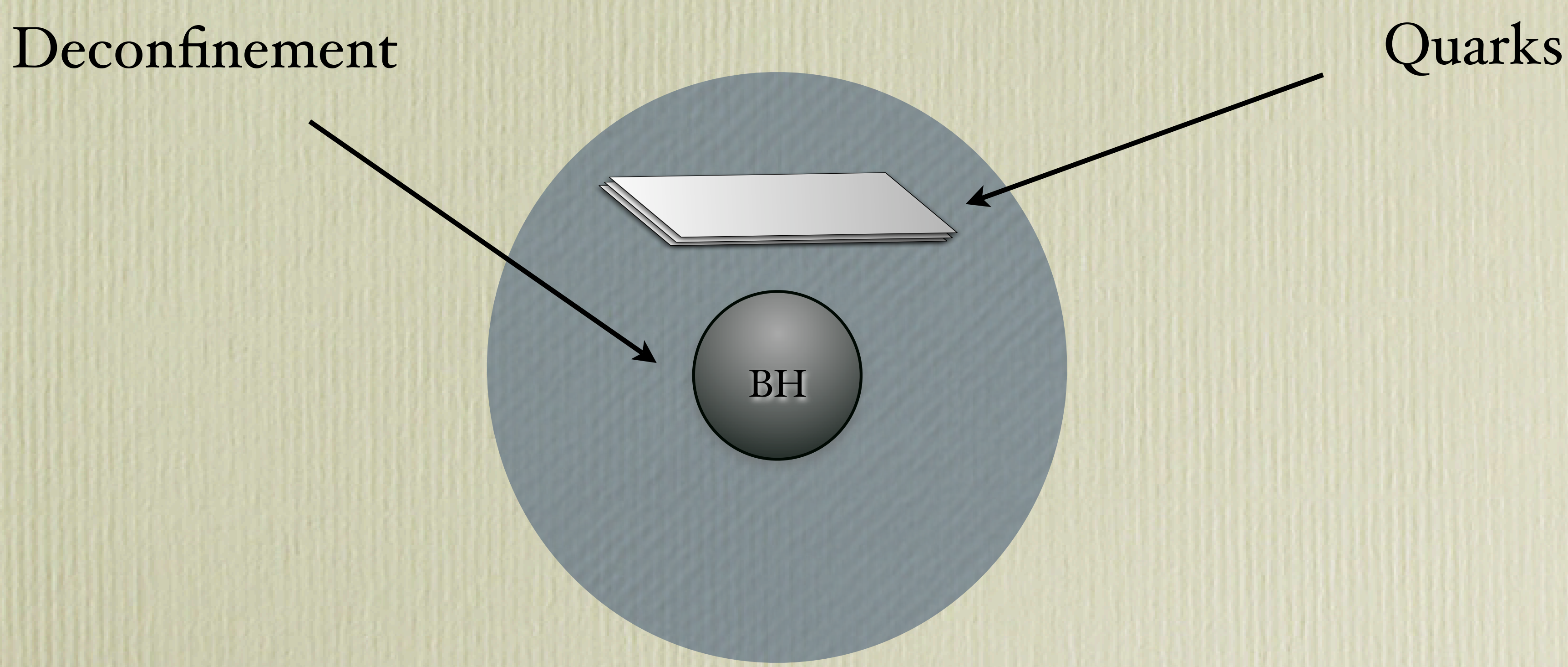
  - Vector mesons (J/ψ, Υ, ...) survive deconfinement.

    Lattice, effective potentials, etc.

  - Their limiting velocity in the QGP is subluminal.

    Heuristically: $$T_{\text{eff}}(v) = \frac{T}{(1-v^2)^{1/4}}$$

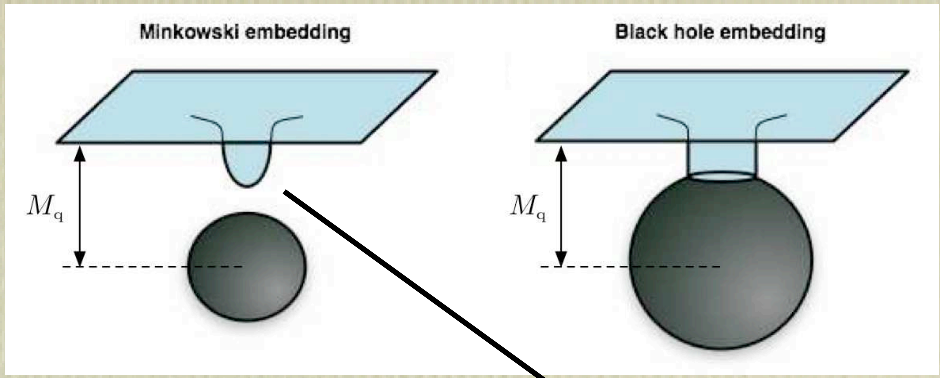
- Verifying in QCD is hard. Reassuring that effect is universal property of all gauge theories with gravity dual:

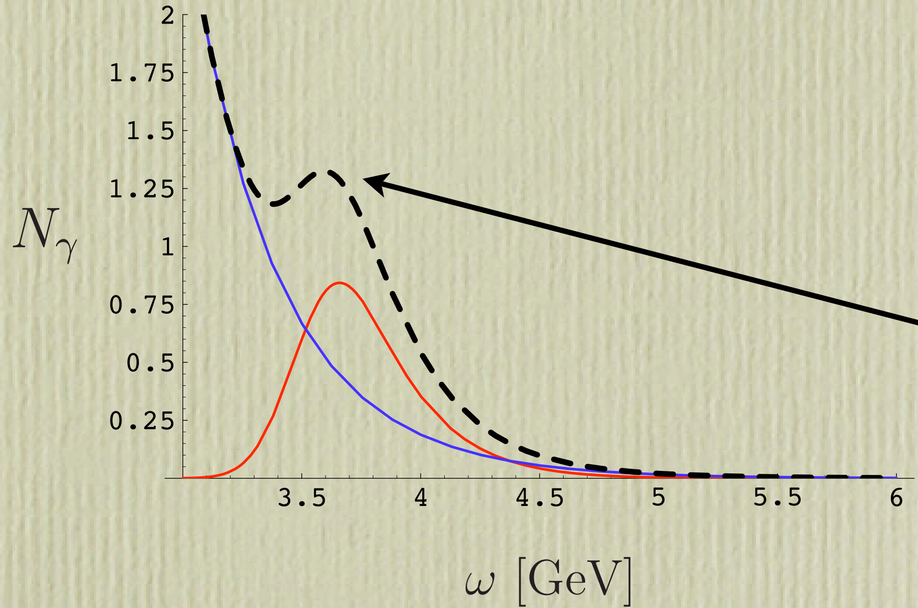


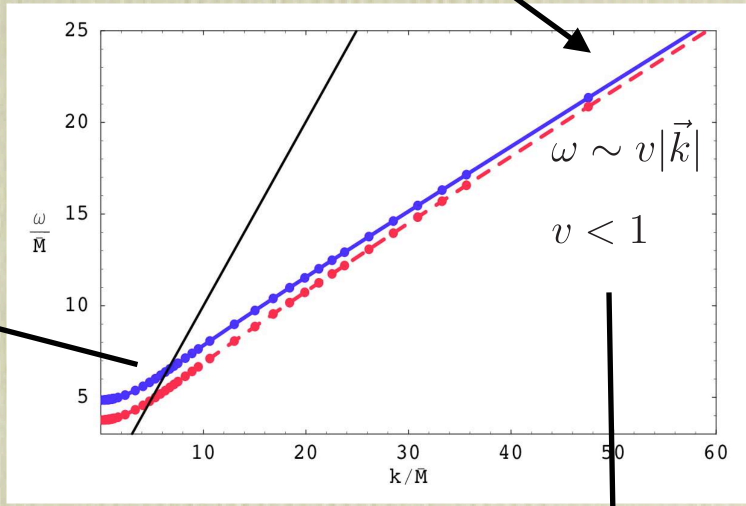
Two phases:

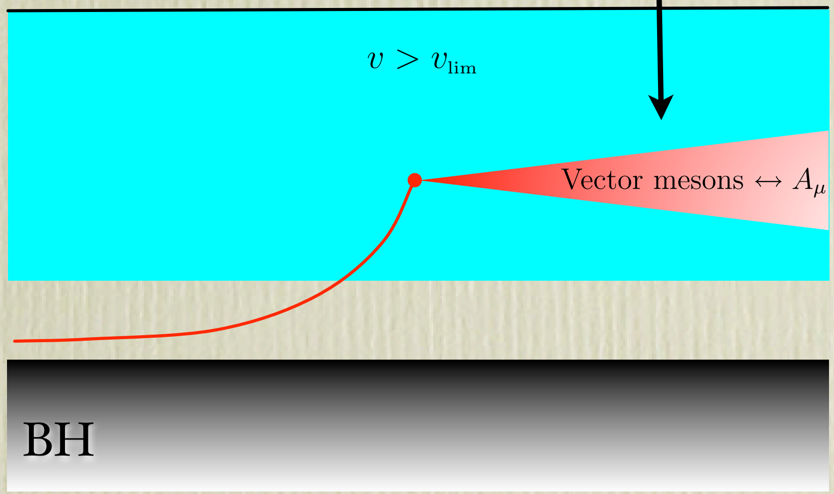
Heavy mesons

survive deconfinement.









Thank you.