Applications of Holography in Hot Strongly Coupled Plasmas

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PT FS

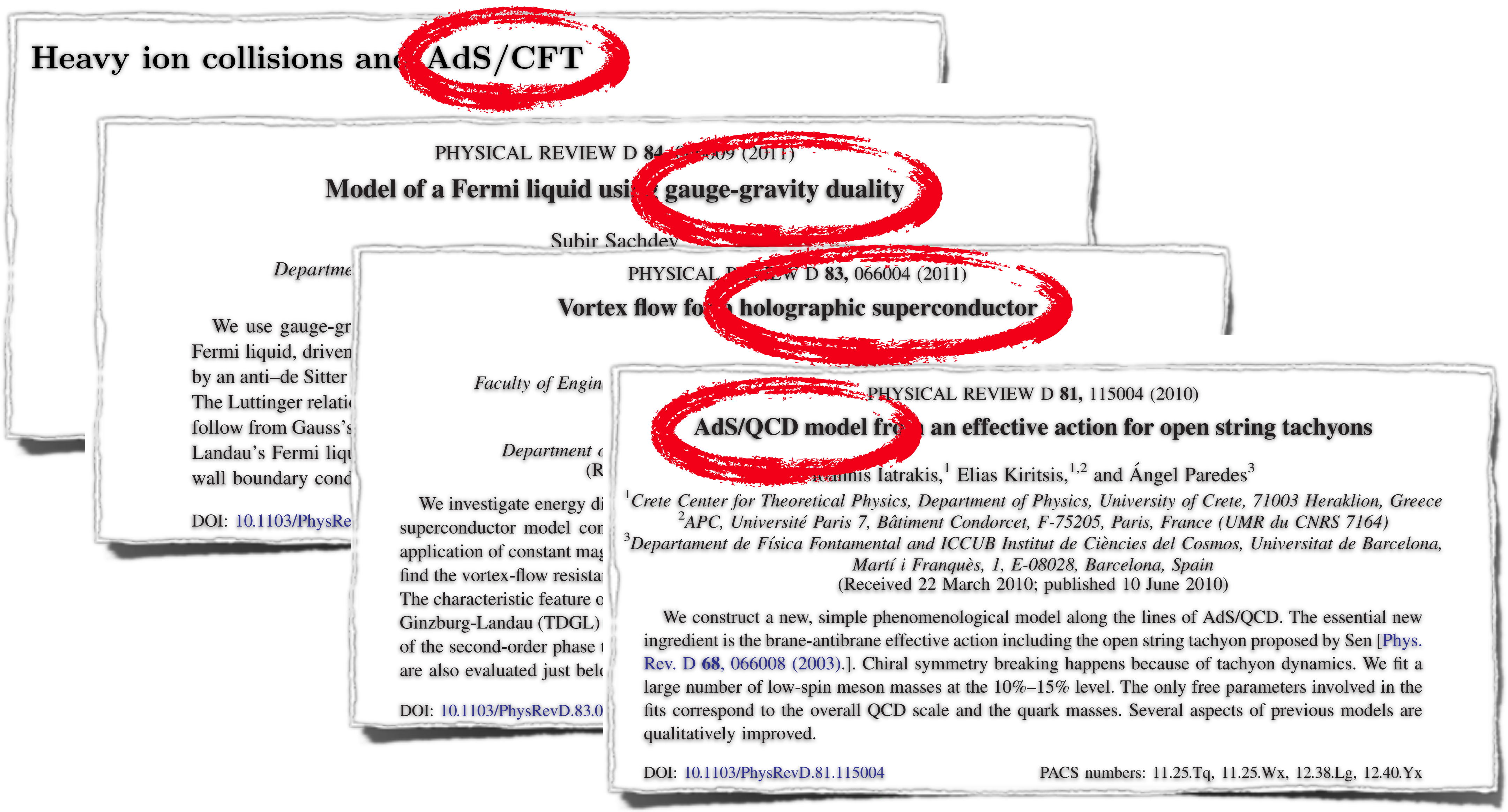
FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

in collaboration with Carlo Ewerz

EMMI - Physics Days 2011
GSI, Darmstadt

GSI, November 07, 2011

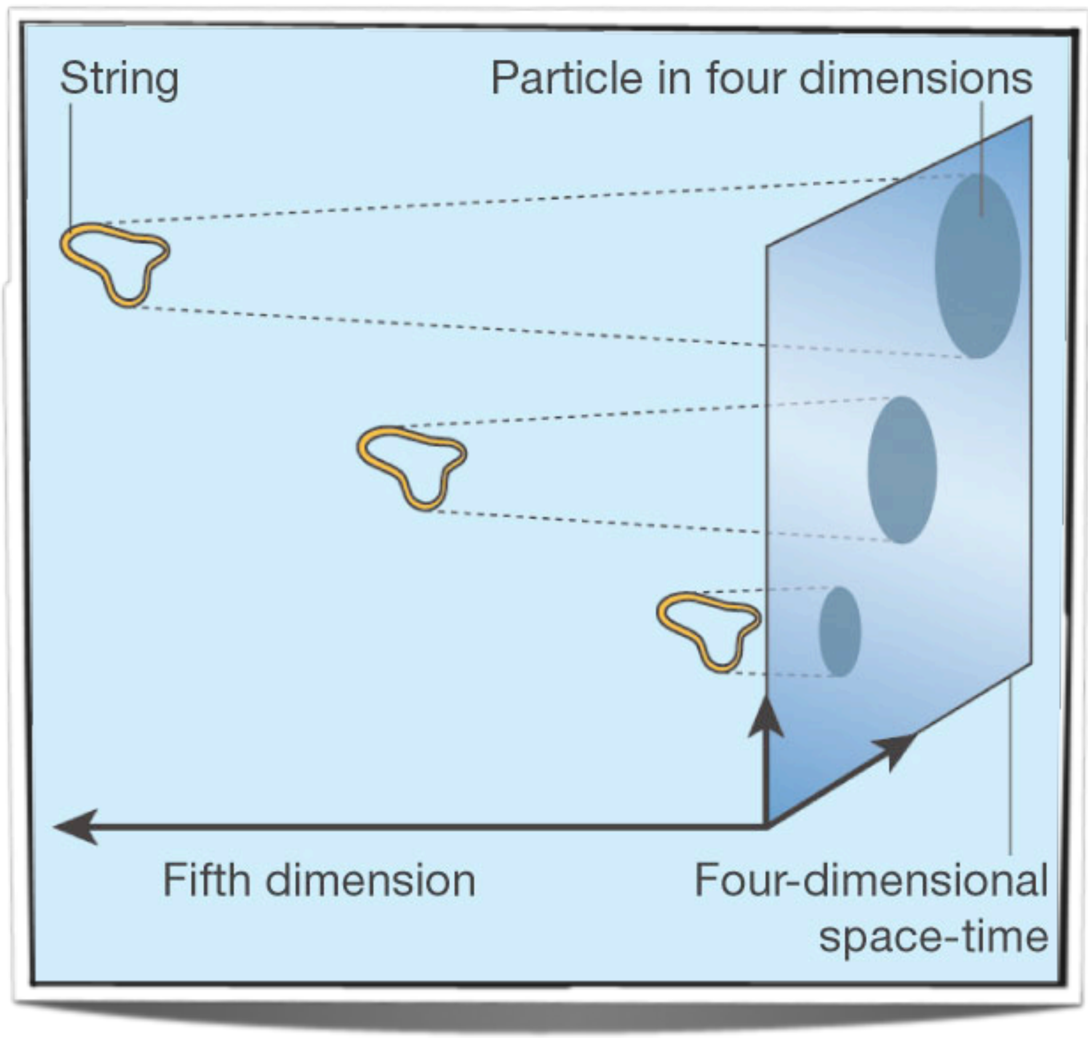
Holography, Gauge/Gravity duals, AdS/CFT correspondence, ...



...many realisations, but one concept.

Holographic Principle

The physics in a (d+1)-dimensional volume can be described by a theory living on the d-dimensional boundary.



Maldacena, 2003

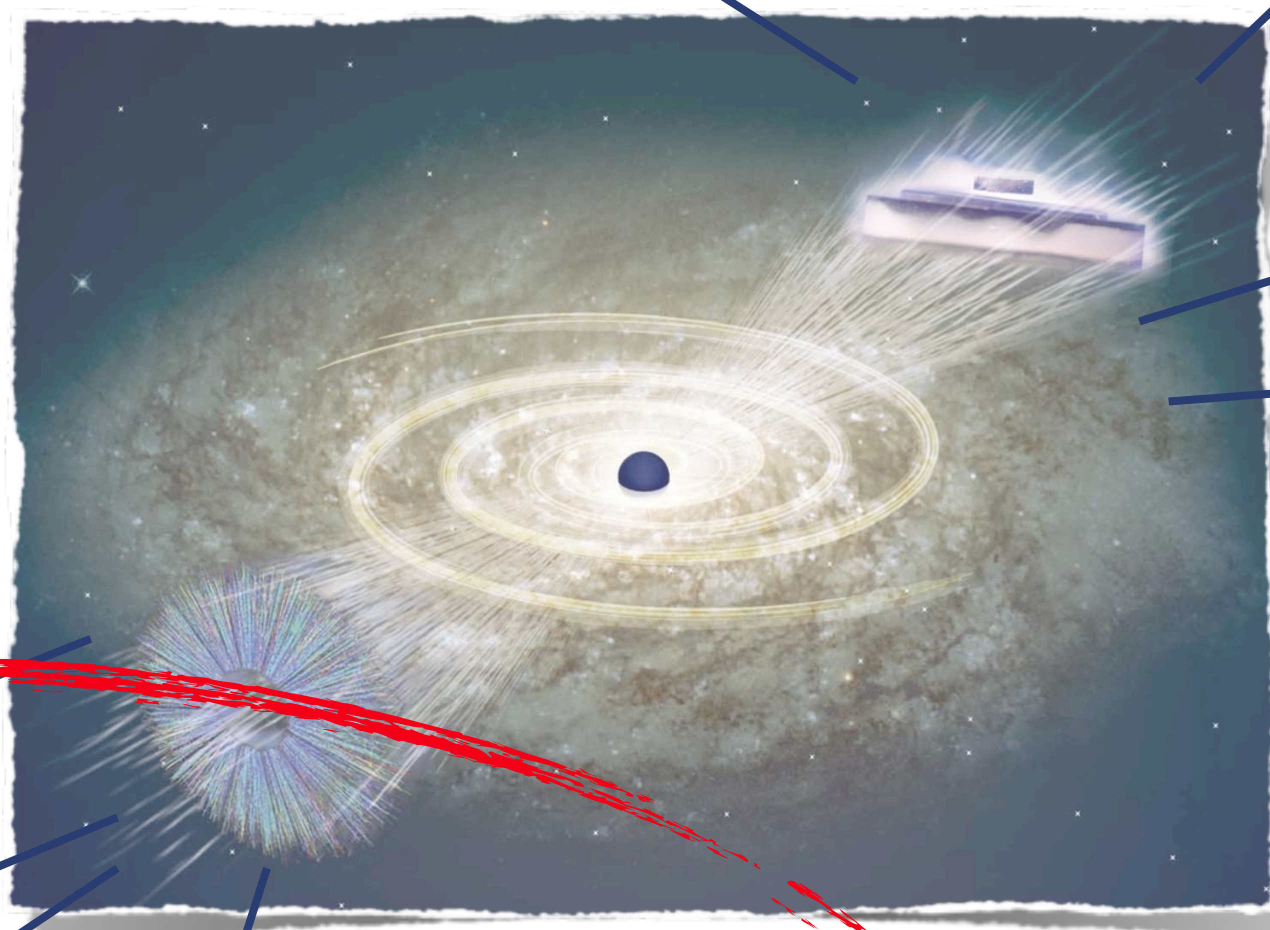
- e.g.: duality between gauge theories in d-dimension and gravity theories (string theories) in higher dimensions.

Practical Realisation of Holography

Holographic Superconductors

Condensed Matter Physics

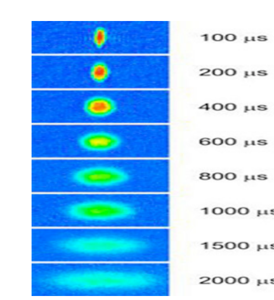
Non-Relativistic AdS/CFT



Non-Fermi liquids
using gauge/gravity duality

Holographic
Neutron Stars

Zaanen, 2007



O'Hara et al., 2002

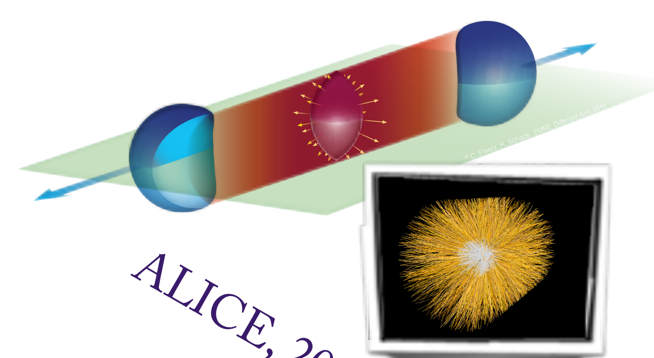
AdS/CFT

AdS/QCD

Fluid/Gravity Correspondence

Gauge/Gravity Dualities

High Energy Physics



ALICE, 2010

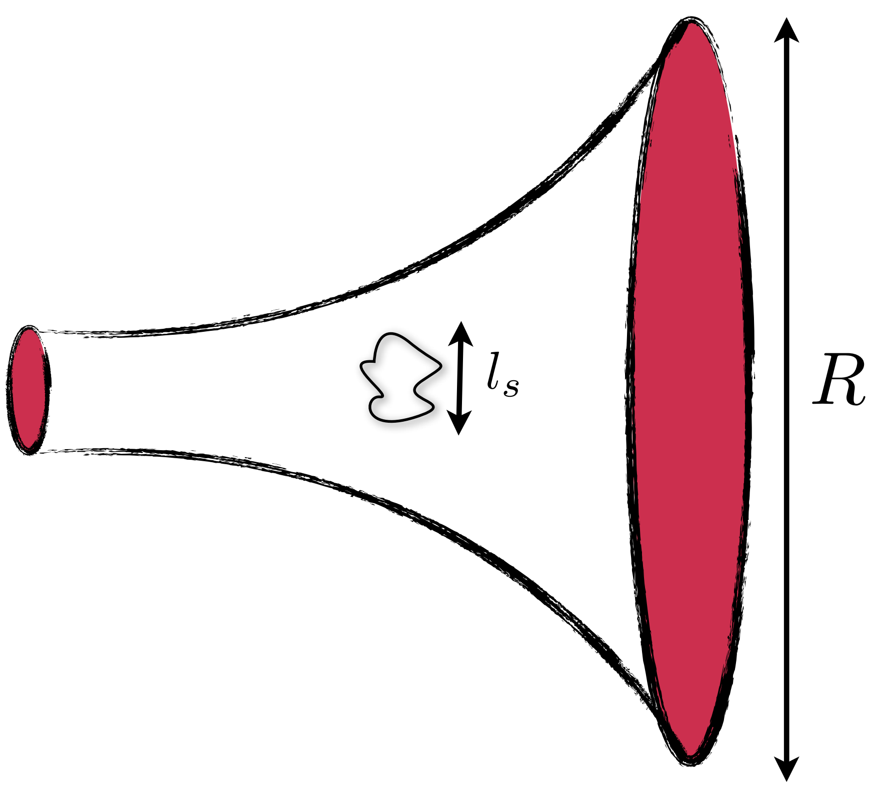
η/s
similar

Gauge/Gravity Duality

$\mathrm{SU}(N_c)\ \mathcal{N}=4\ \mathrm{SYM}$ $\qquad$ $AdS_5 \times S^5$

d-dim. **gauge theory** (without gravity) $\Longleftrightarrow$ d+1-dim. **gravitational theory**

entropy of gauge theory $\propto$ volume $=$ entropy of gravitational theory $\propto$ area



Why is that duality useful?

$$g_{\mathrm{YM}}^2 = 2\pi g_{\mathrm{s}}\,, \quad R^4 = 4\pi g_{\mathrm{s}} N_{\mathrm{c}} l_{\mathrm{s}}^4\,, \quad \lambda = g_{\mathrm{YM}}^2 N_{\mathrm{c}}$$

$$\lambda \text{ fixed}, N_{\mathrm{c}} \longrightarrow \infty : \qquad g_{\mathrm{s}} \sim \lambda / N_{\mathrm{c}}$$

$$\lambda \longrightarrow \infty : \qquad R^4 \sim \lambda\, l_{\mathrm{s}}^4$$

strongly coupled QFT $\longleftrightarrow$ weakly coupled gravity

QCD $\longleftrightarrow$ $\mathcal{N} = 4$ super Yang-Mills

- $\mathcal{N} = 4$ SYM very different from QCD
  - Maximally supersymmetric
  - Conformal theory, coupling is constant
  - No confinement, no chiral symmetry breaking
  - $N_c \to \infty$ for duality

- At finite T, differences are smaller:
  - Above $2T_c$ QCD almost conformal
  - No confinement in QCD above T_c
  - Finite T breaks supersymmetry

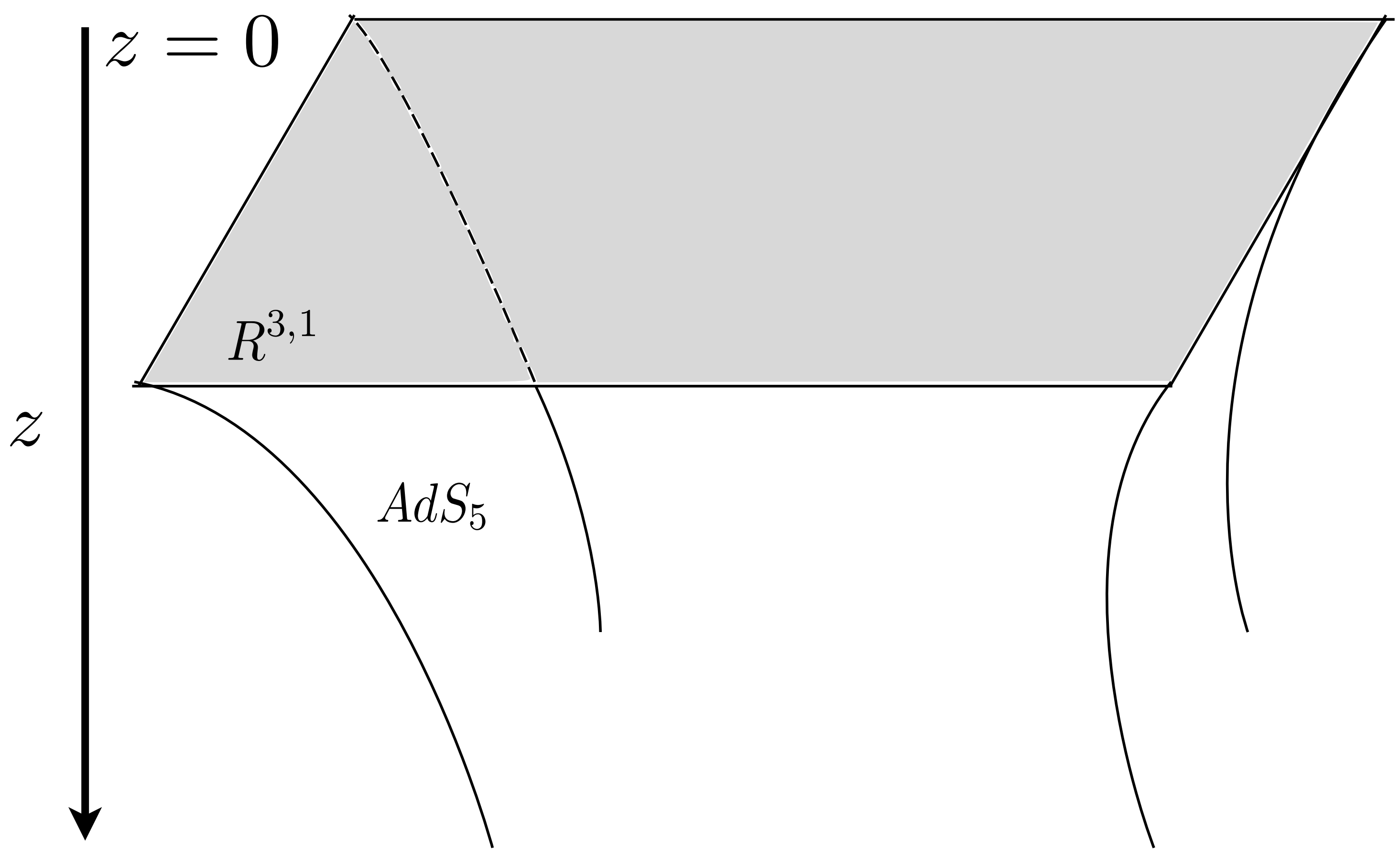
Basic Properties of AdS

- AdS_5 metric:

$$ds^2 = \frac{R^2}{z^2}\Big(-dt^2 + d\vec{x}^2 + dz^2\Big) \text{ with } R \text{ being the AdS curvature}$$

- Solution to 5D Einstein-Hilbert action:

$$S = \frac{1}{16\pi G}\int d^5x\,\sqrt{-g}(\mathcal{R} - 2\Lambda)$$

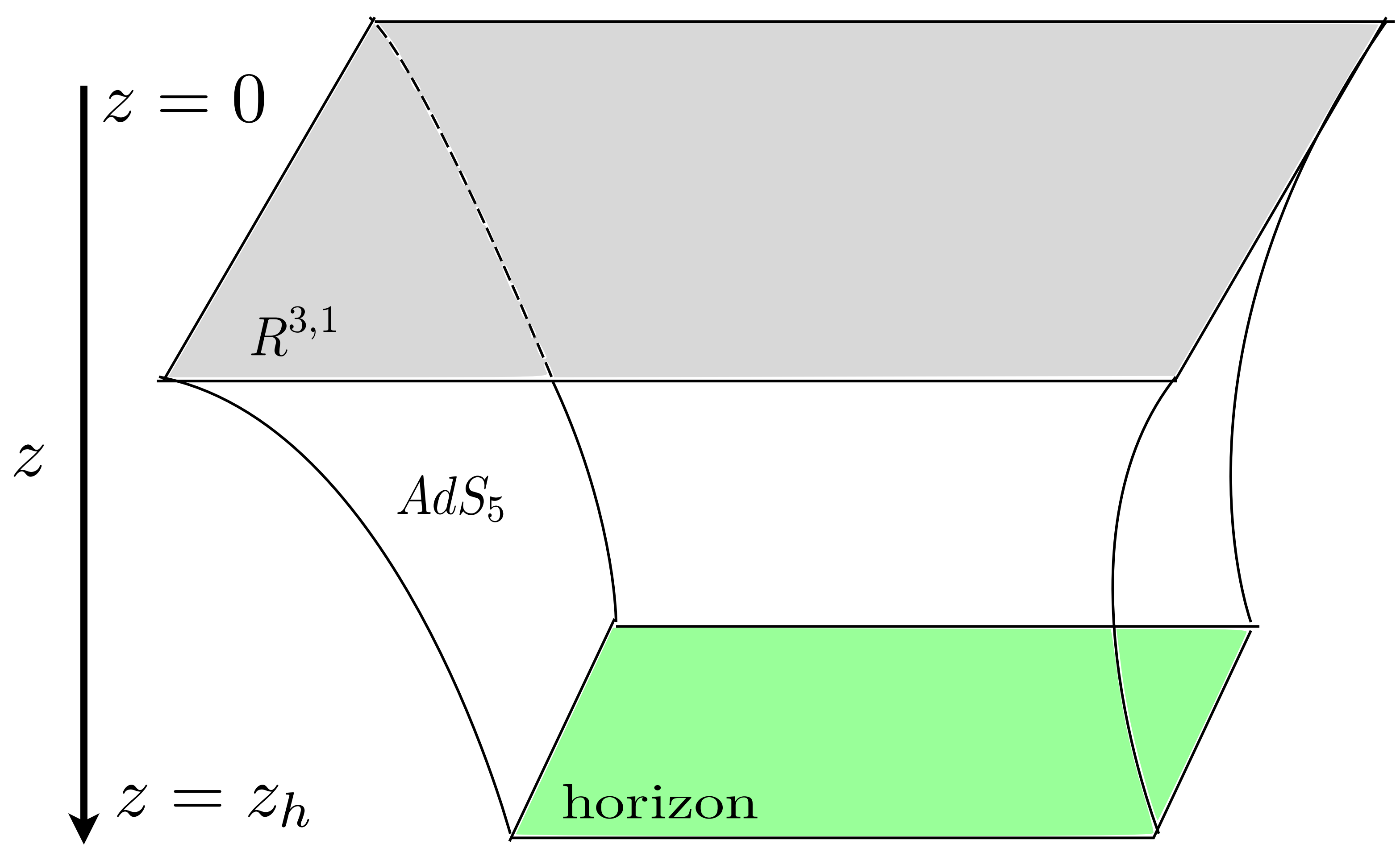


Basic Properties of AdS

- AdS_5 black hole metric:

$$ds^2 = \frac{R^2}{z^2}\left(-h\,dt^2 + d\vec{x}^2 + \frac{dz^2}{h}\right) \text{ with } h = 1 - \frac{z^4}{z_h^4} \text{ and } T = \frac{1}{\pi\, z_h}$$

- Solves the same e. o. m.:



Metric models at finite temperature

- AdS_5 BH metric at finite temperature:

$$ds^2 = \frac{R^2}{z^2}\left(-h\,dt^2 + d\vec{x}^2 + \frac{dz^2}{h}\right) \text{with} \quad h = 1 - \frac{z^4}{z_h^4} \quad \text{and} \quad T = \frac{1}{\pi\, z_h}$$

- SW_T model:

Kajantie, Tahkokallio, Yee

$$ds^2 = \frac{R^2}{z^2}\, e^{cz^2}\left(-hdt^2 - d\vec{x}^2 - \frac{dz^2}{h}\right)$$

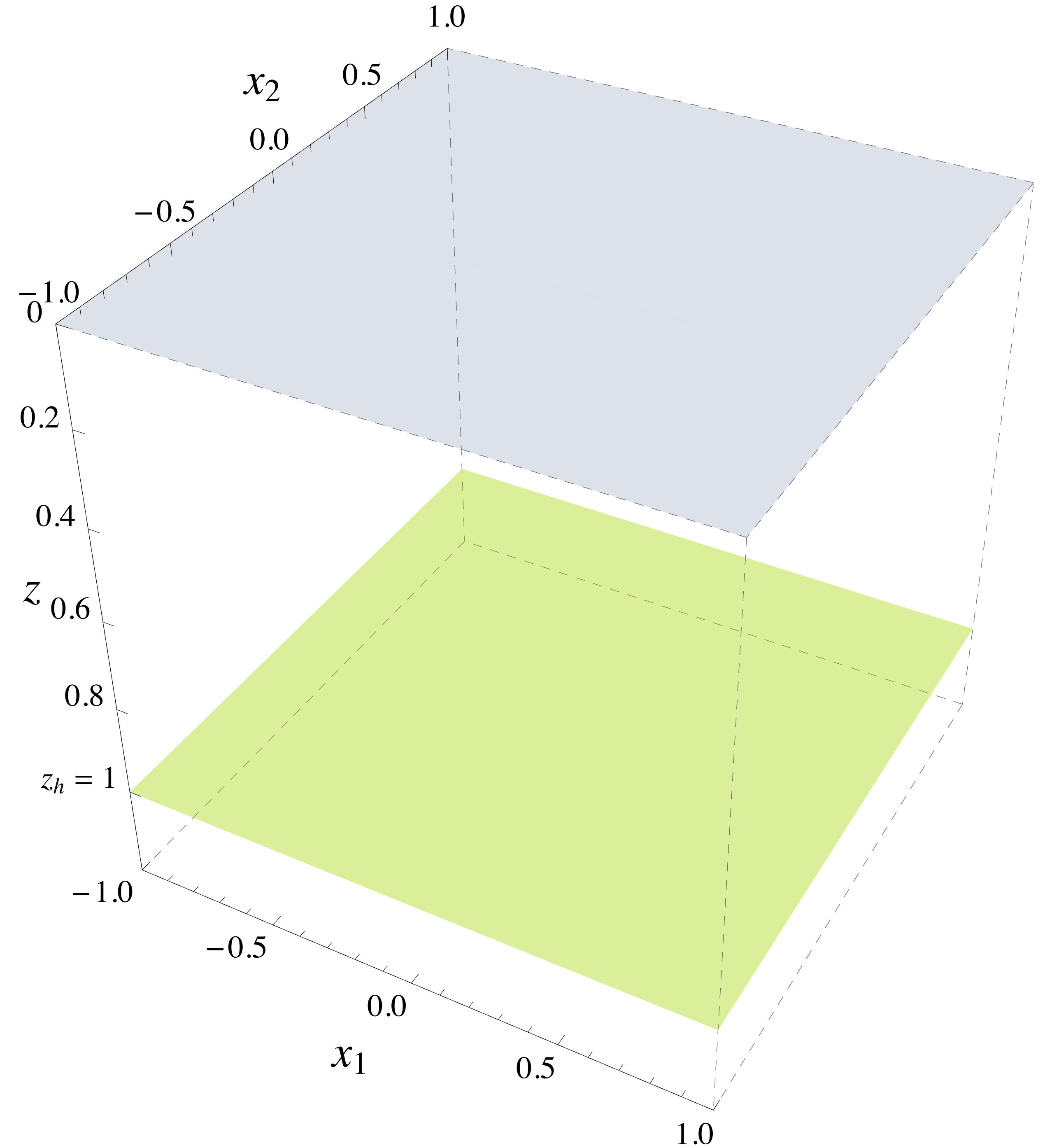
- 2-parameter model:

DeWolfe, Rosen; Gubser

$$ds^2 = e^{2A(\Phi)}\left(-h(\Phi)\,dt^2 + d\vec{x}^2\right) + \frac{e^{2B(\Phi)}}{h(\Phi)} d\Phi^2$$

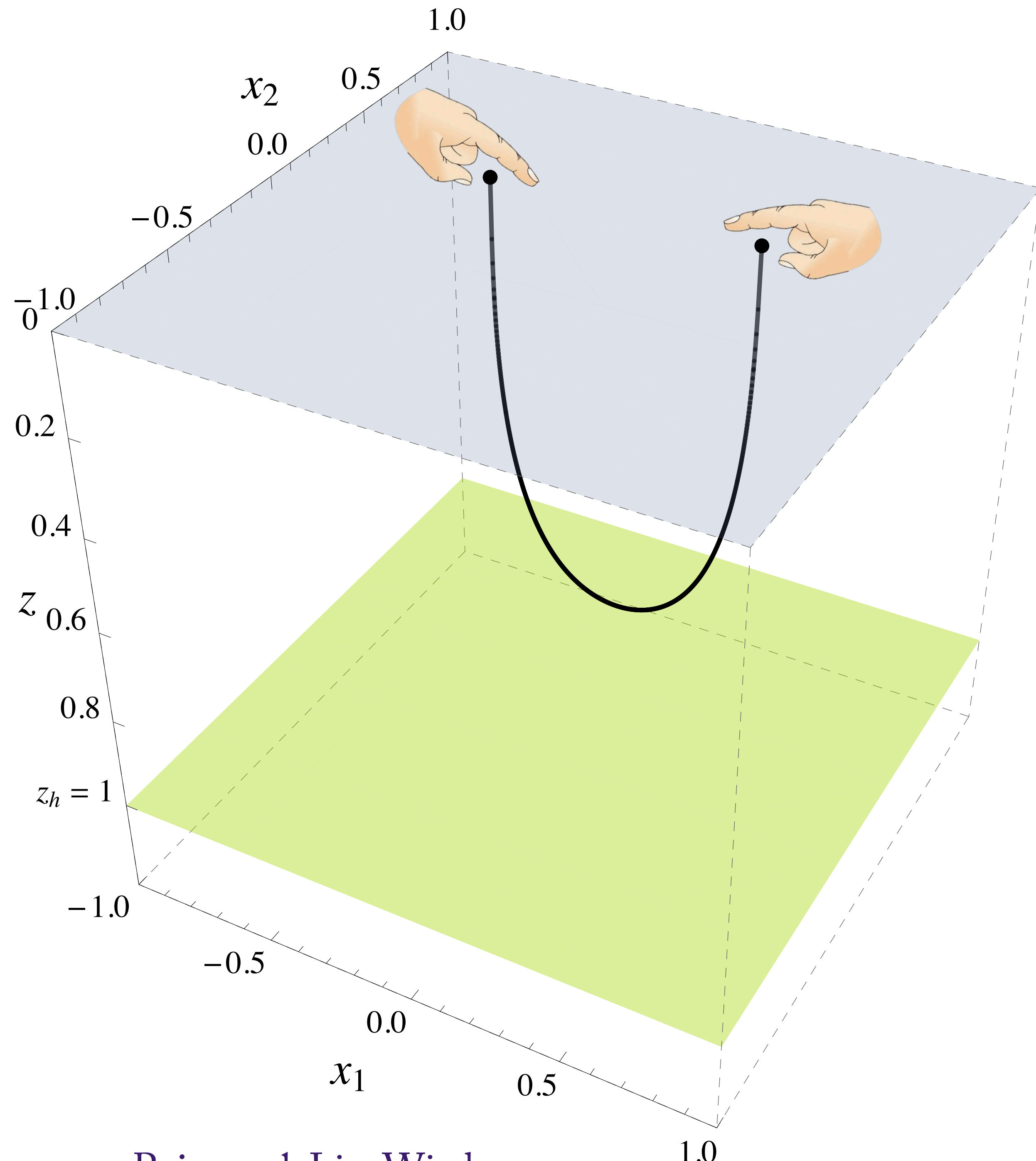
is a solution to equations of motion.

Screening distance in hot moving plasmas



Rajagopal, Liu, Wiedemann

Screening distance in hot moving plasmas



Rajagopal, Liu, Wiedemann

Nambu-Goto action:

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

with $g_{\alpha\beta} = G_{\mu\nu}\partial_\alpha x^\mu \partial_\beta x^\nu$

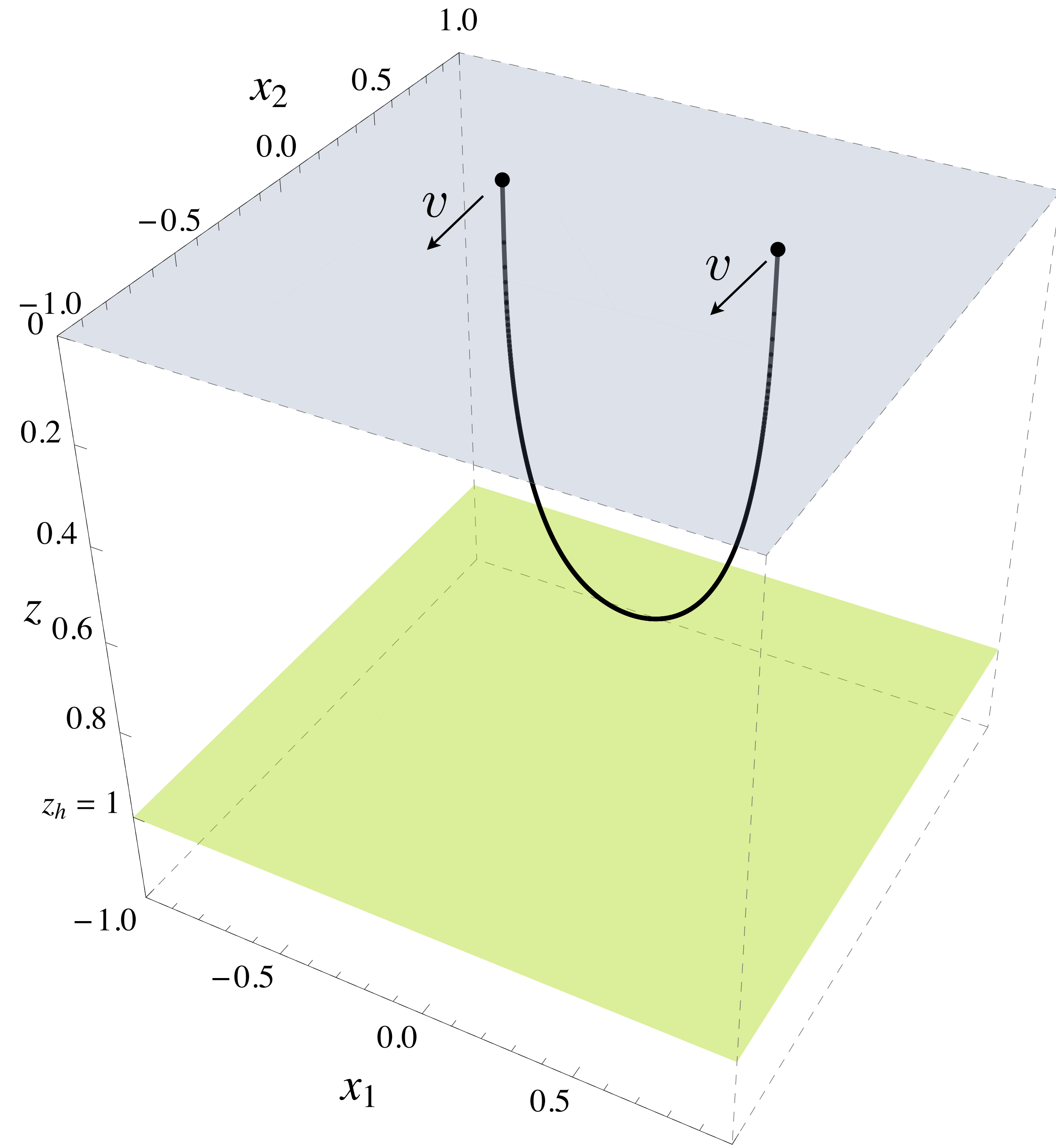
Screening distance in hot moving plasmas

- Static $q\bar{q}$- pair in a hot moving plasma "wind" blowing in x_2-direction
- velocity $v = \tanh \eta$
- orientation angle θ

Nambu-Goto action:

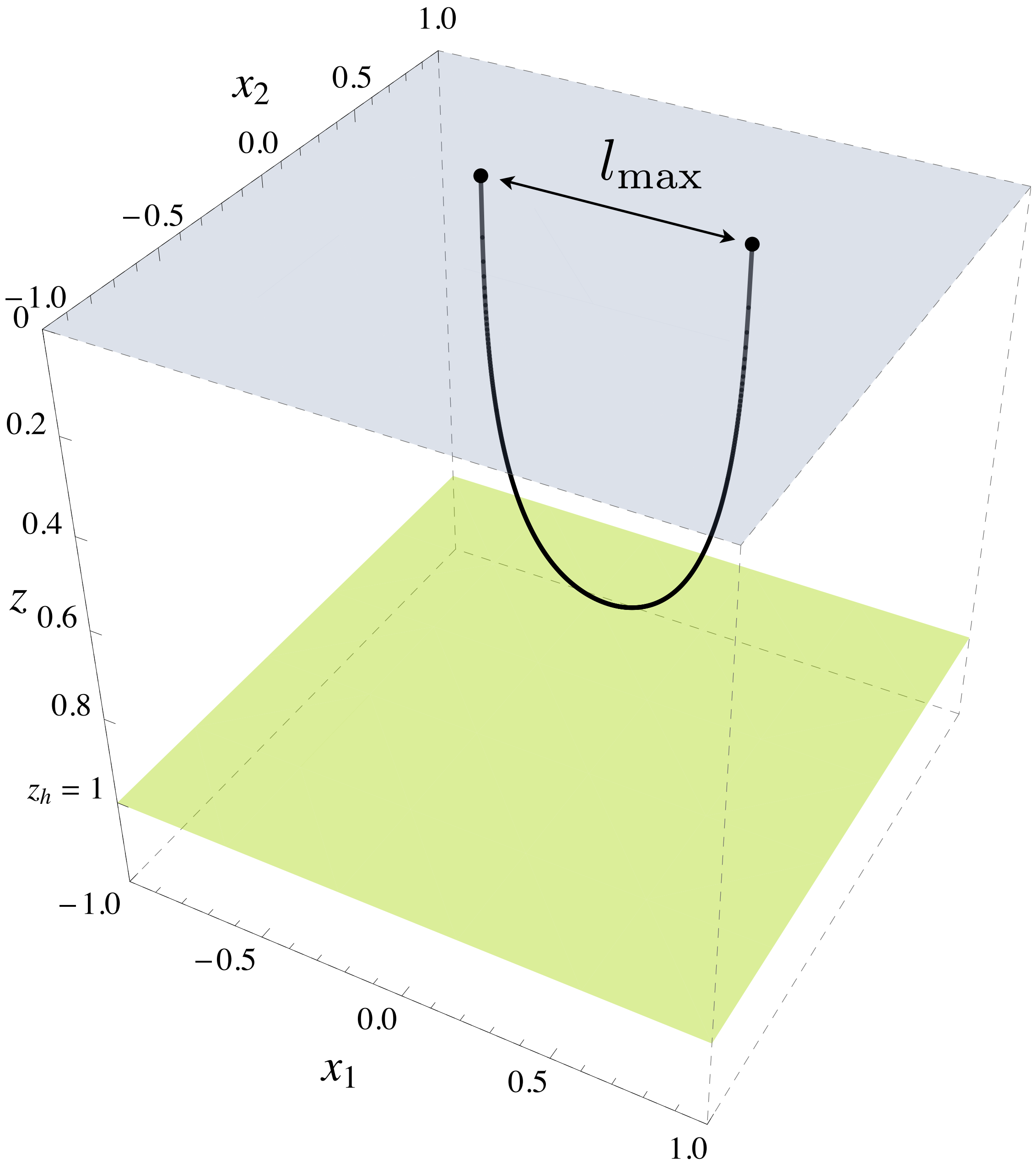
$$S = \frac{1}{2\pi\alpha'} \int d\sigma d\tau \sqrt{- \det g_{\alpha\beta}}$$

with $g_{\alpha\beta} = G_{\mu\nu} \partial_\alpha x^\mu \partial_\beta x^\nu$



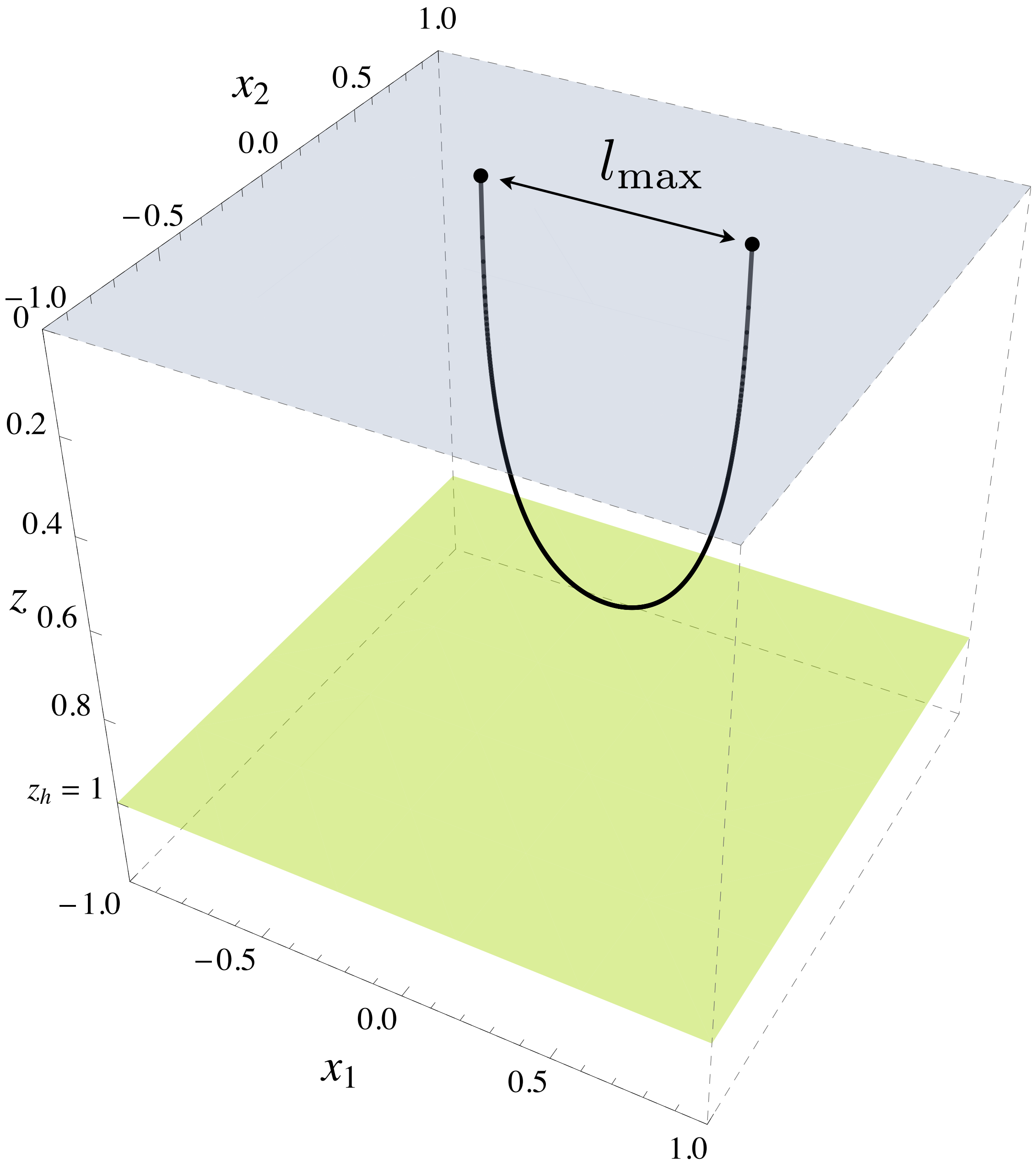
Rajagopal, Liu, Wiedemann

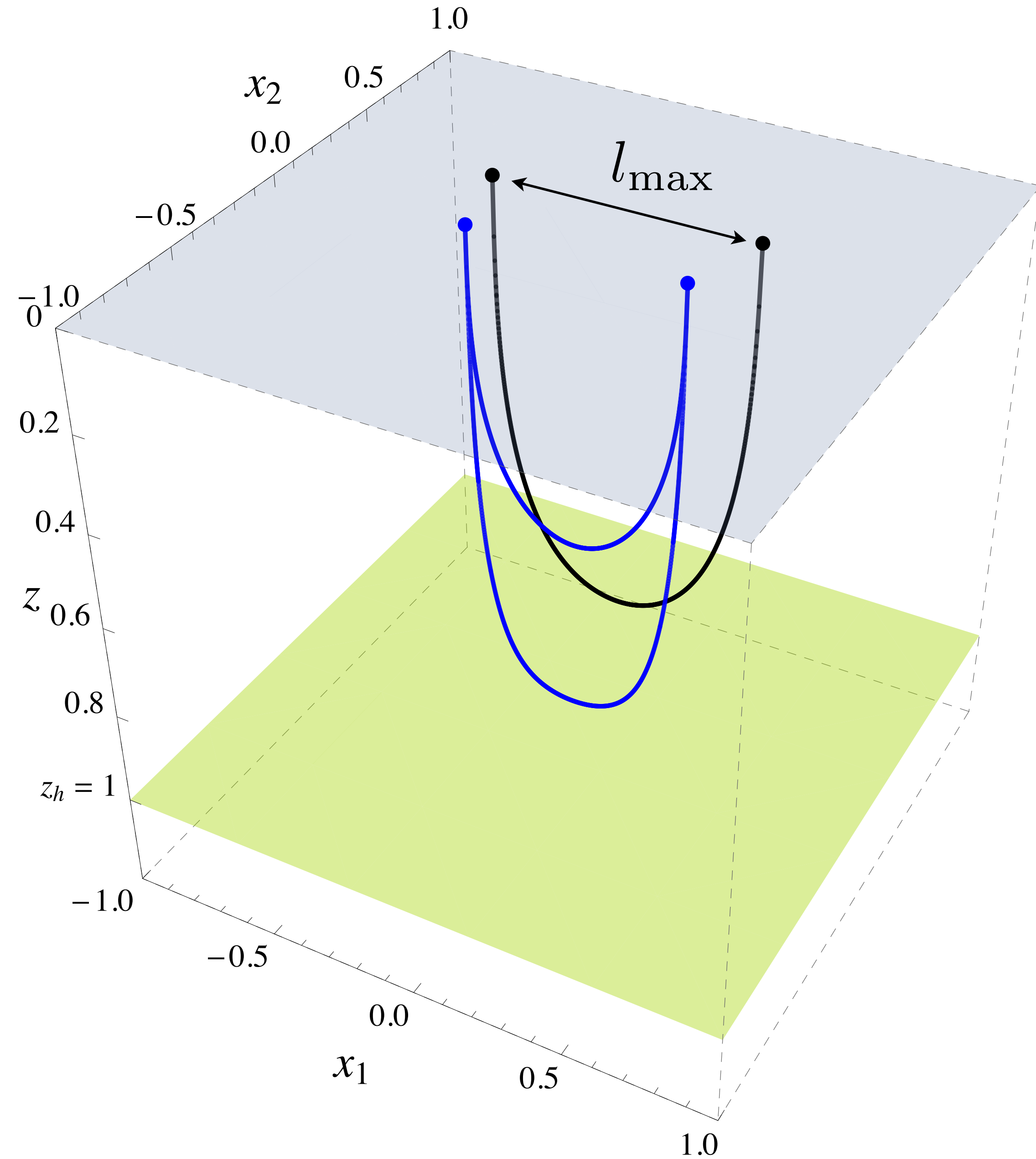
Configuration of the strings



- The string configuration coming closer to the horizon is unstable.

Configuration of the strings

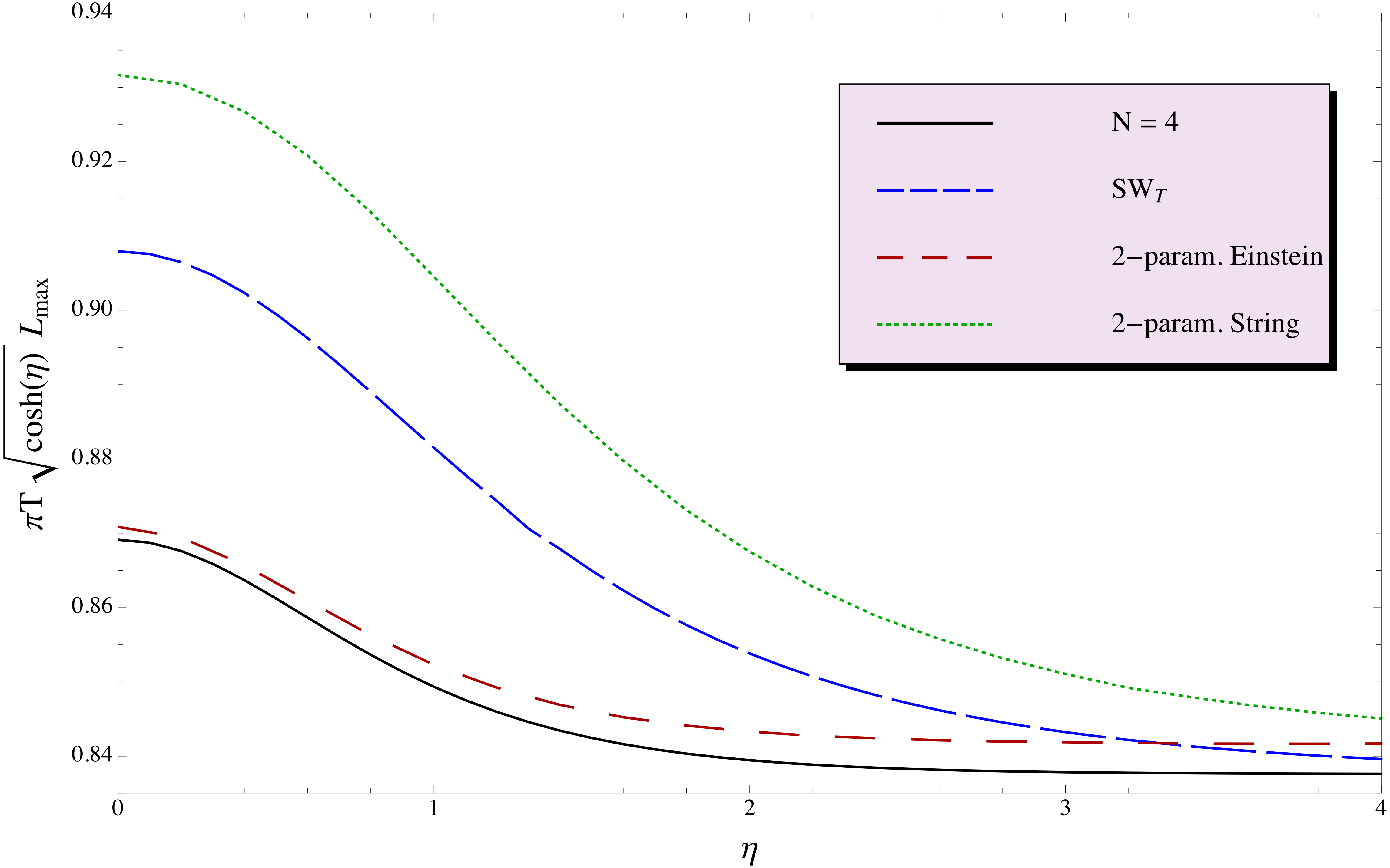




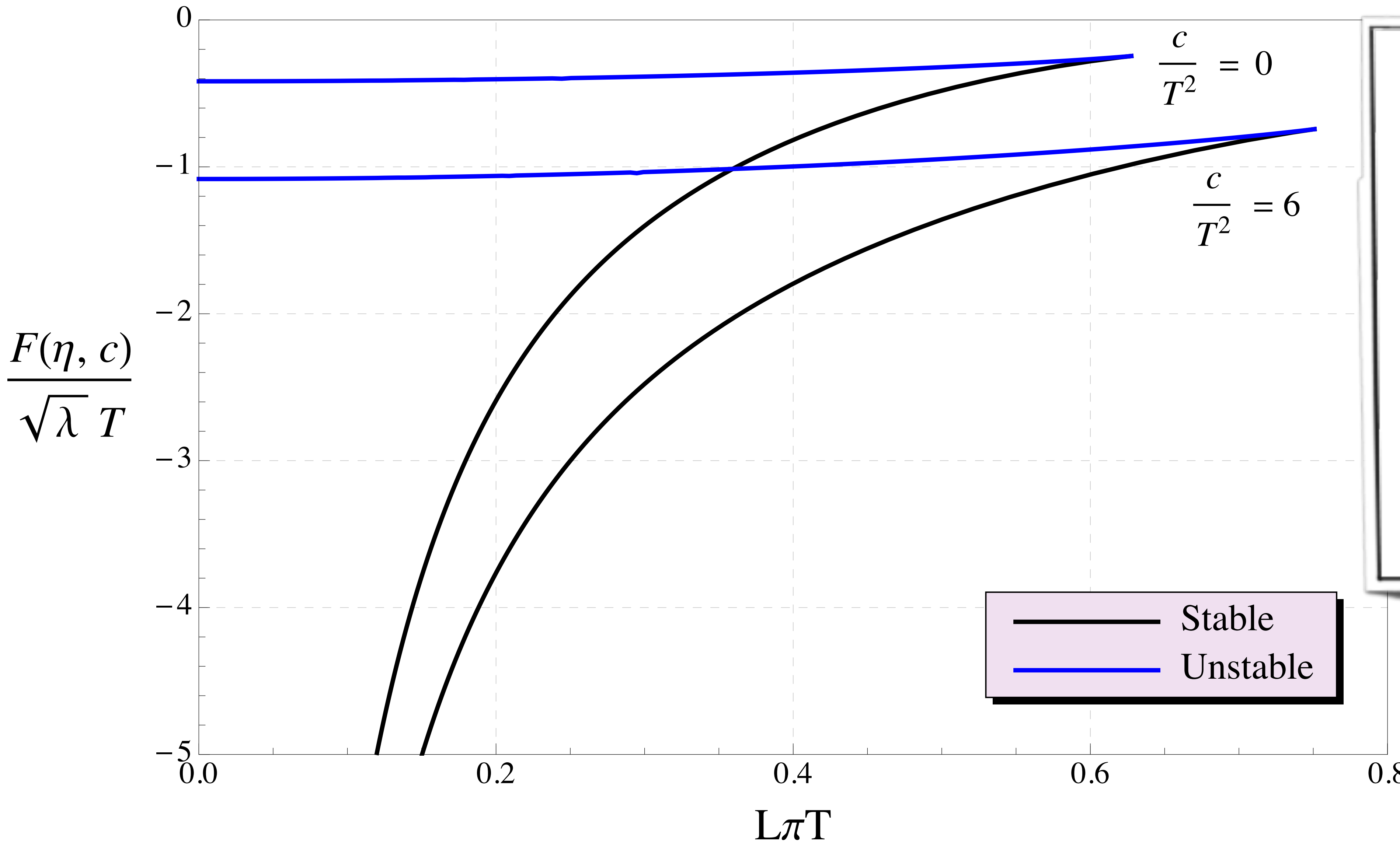
- The string configuration coming closer to the horizon is unstable.

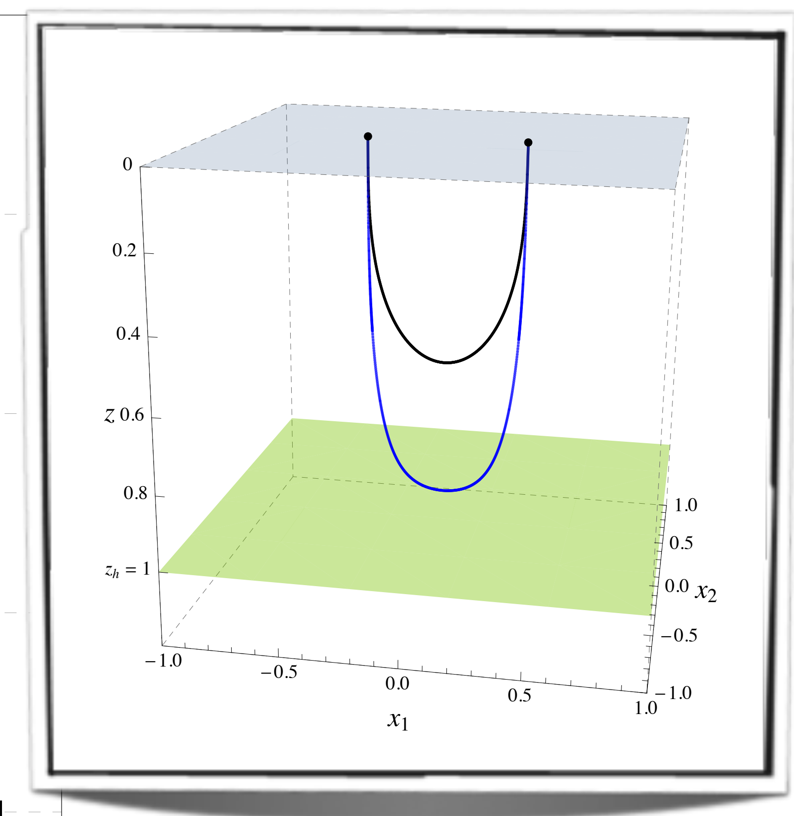
Screening distance bound

- $L_{\max}$ is minimal for $\mathcal{N} = 4$.



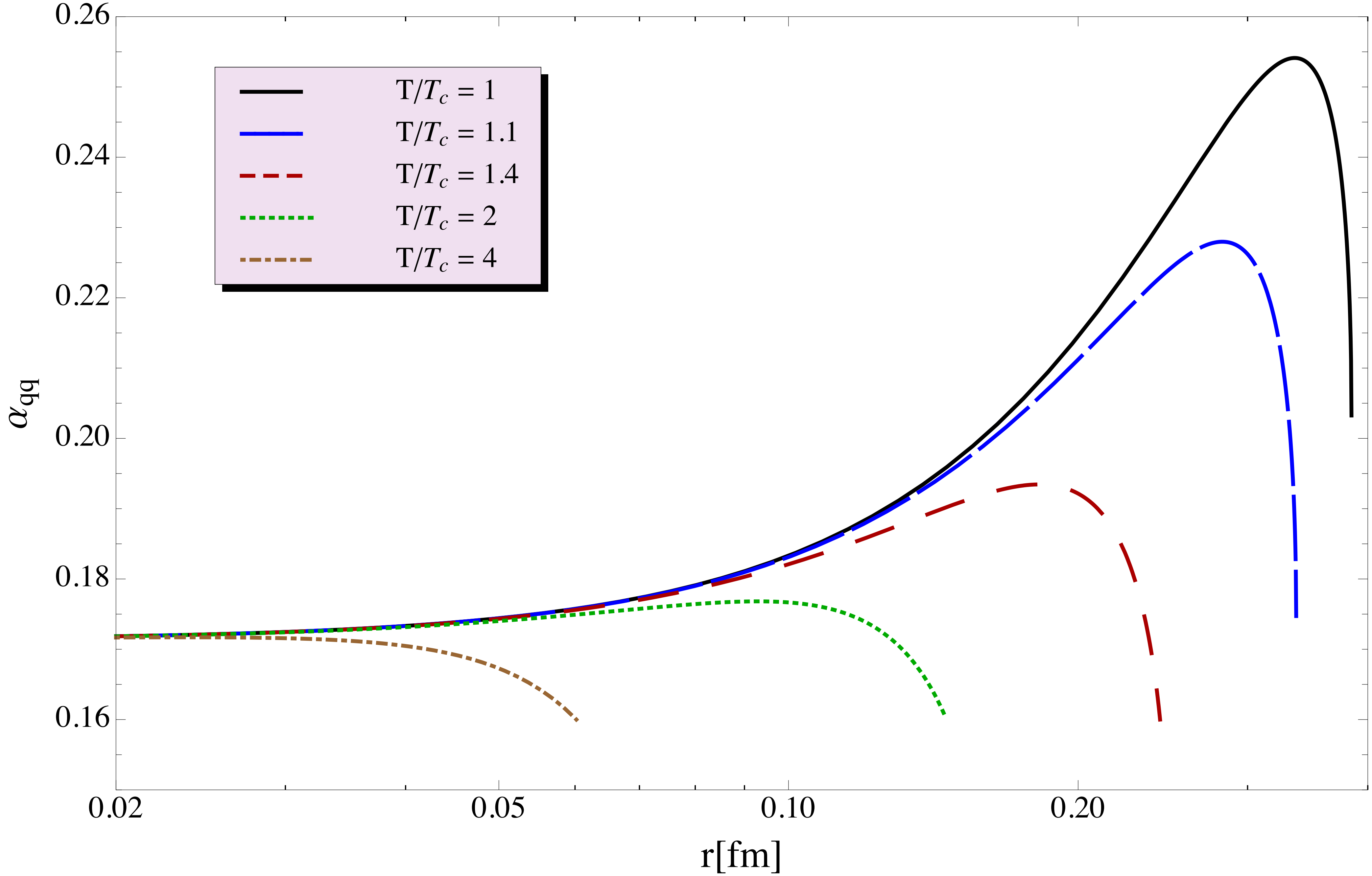
$Q\bar{Q}$ -free energy: results





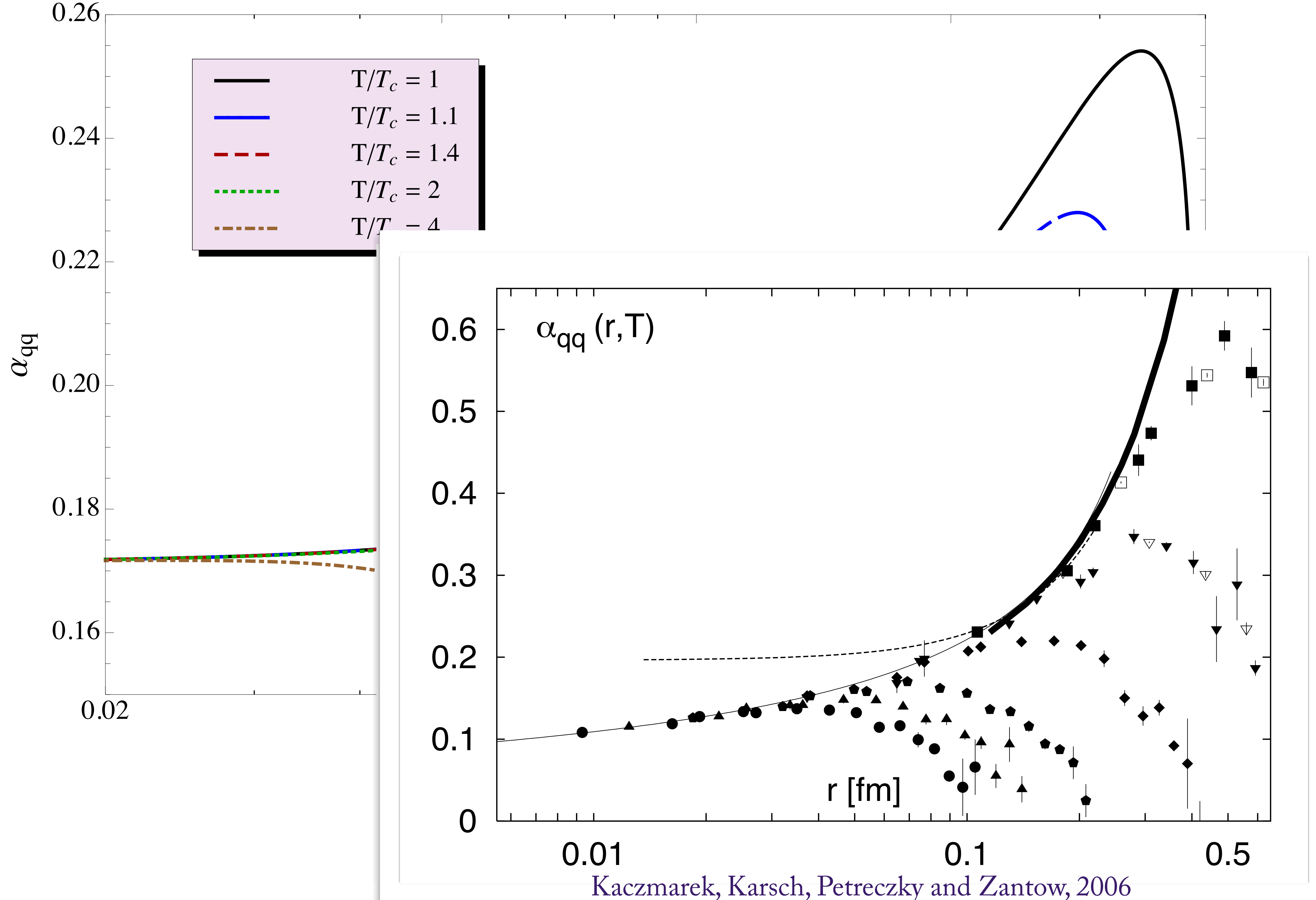
- Free energy of $q\bar{q}$-pair at finite rapidity $\eta = 1$.
- Unstable configurations are weaker bounded.

Running Coupling from Free Energy



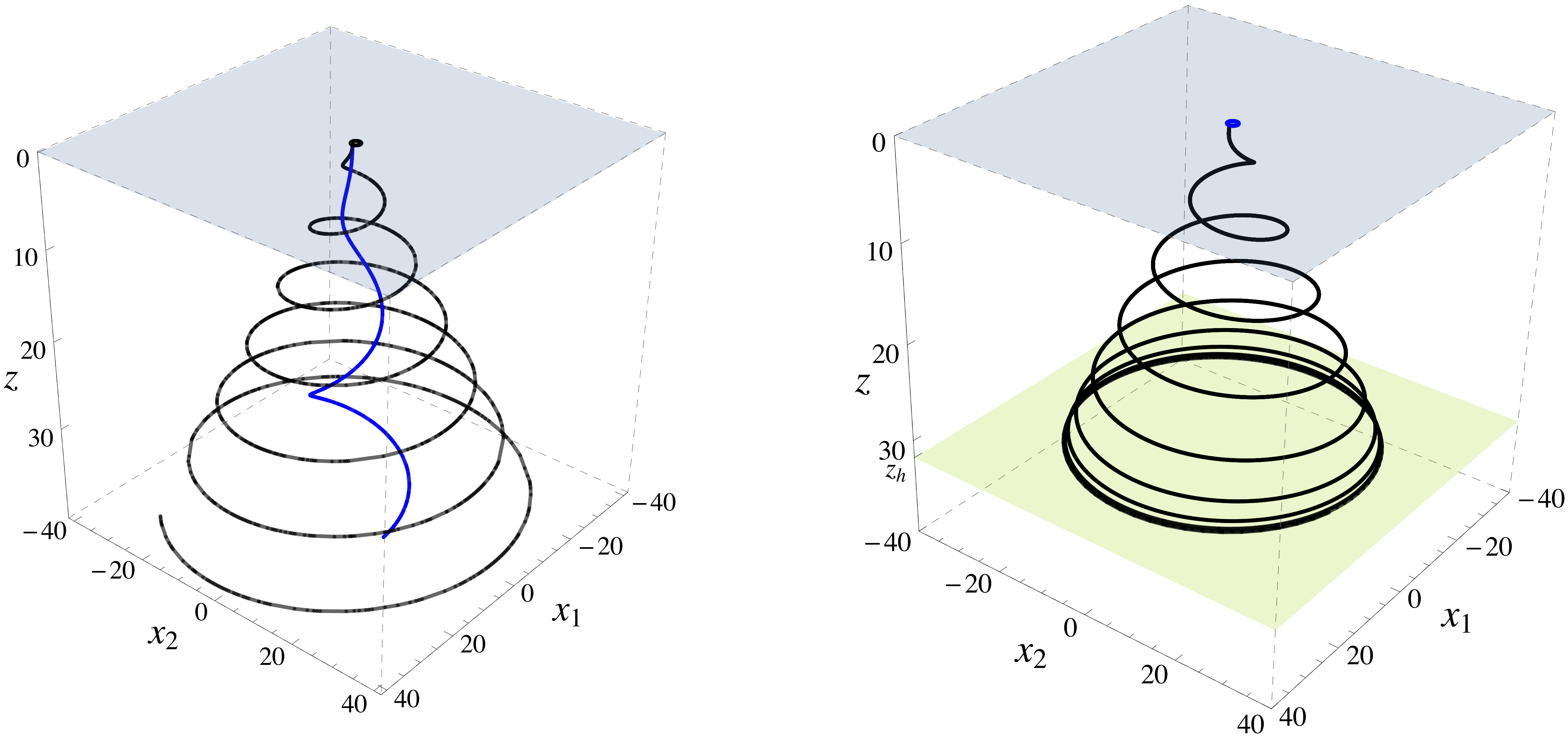
- Coupling α_{qq} is defined as $\alpha_{qq} = \dfrac{3r^2}{4}\dfrac{dF(r,T)}{dr}$ in QCD.
- Many possibilities by rescaling the parameters.

Running Coupling from Free Energy



Kaczmarek, Karsch, Petreczky and Zantow, 2006

Rotating Quark at Finite Temperature



- Is energy loss due to synchrotron radiation or due to drag dominant?
- What happens in deformed models?
  - dE/dt is very *robust*.

Rotating Quark in Deformed Metric Models

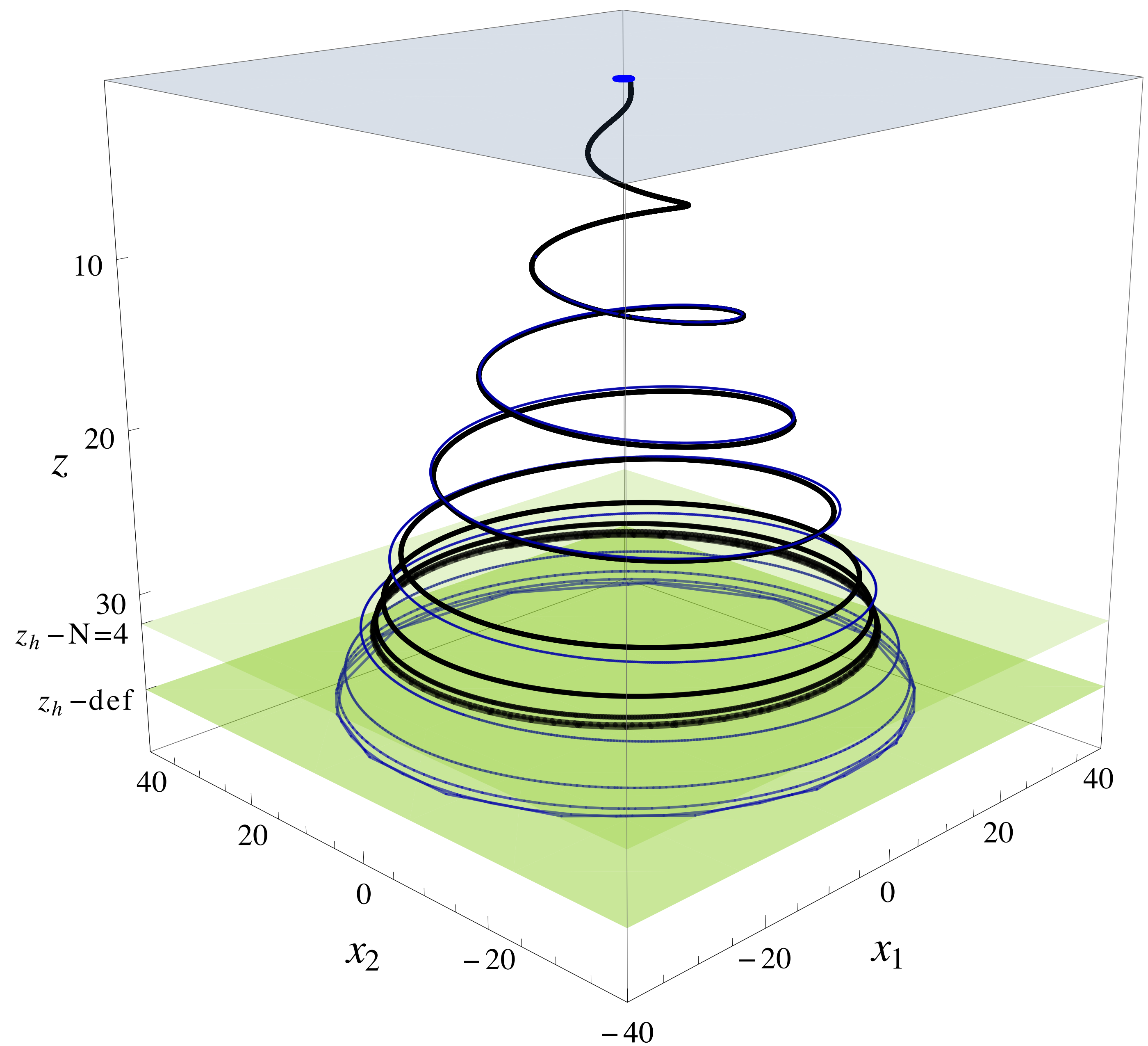
- Is $\omega \ll \pi T, \; R_0 \ll 1/\omega$

  then $\left.\dfrac{dE}{dt}\right|_{\mathrm{RotQ}} \approx \left.\dfrac{dE}{dt}\right|_{\mathrm{Drag}}$

- Is $\omega \gg \pi T, \; R_0\, \omega = v \approx 1$

  then $\left.\dfrac{dE}{dt}\right|_{\mathrm{RotQ}} \approx \left.\dfrac{dE}{dt}\right|_{\mathrm{VacRad}}$

  Vacuum radiation of conformal $\mathcal{N} = 4$



$T = 0.01, \; \omega = 0.7, \; R_0 = 1, \; \phi = \phi_{\mathrm{max}}$

- Vacuum radiation is independent of the deformation ϕ.
- Universal scaling in the crossover regime.

Conclusions

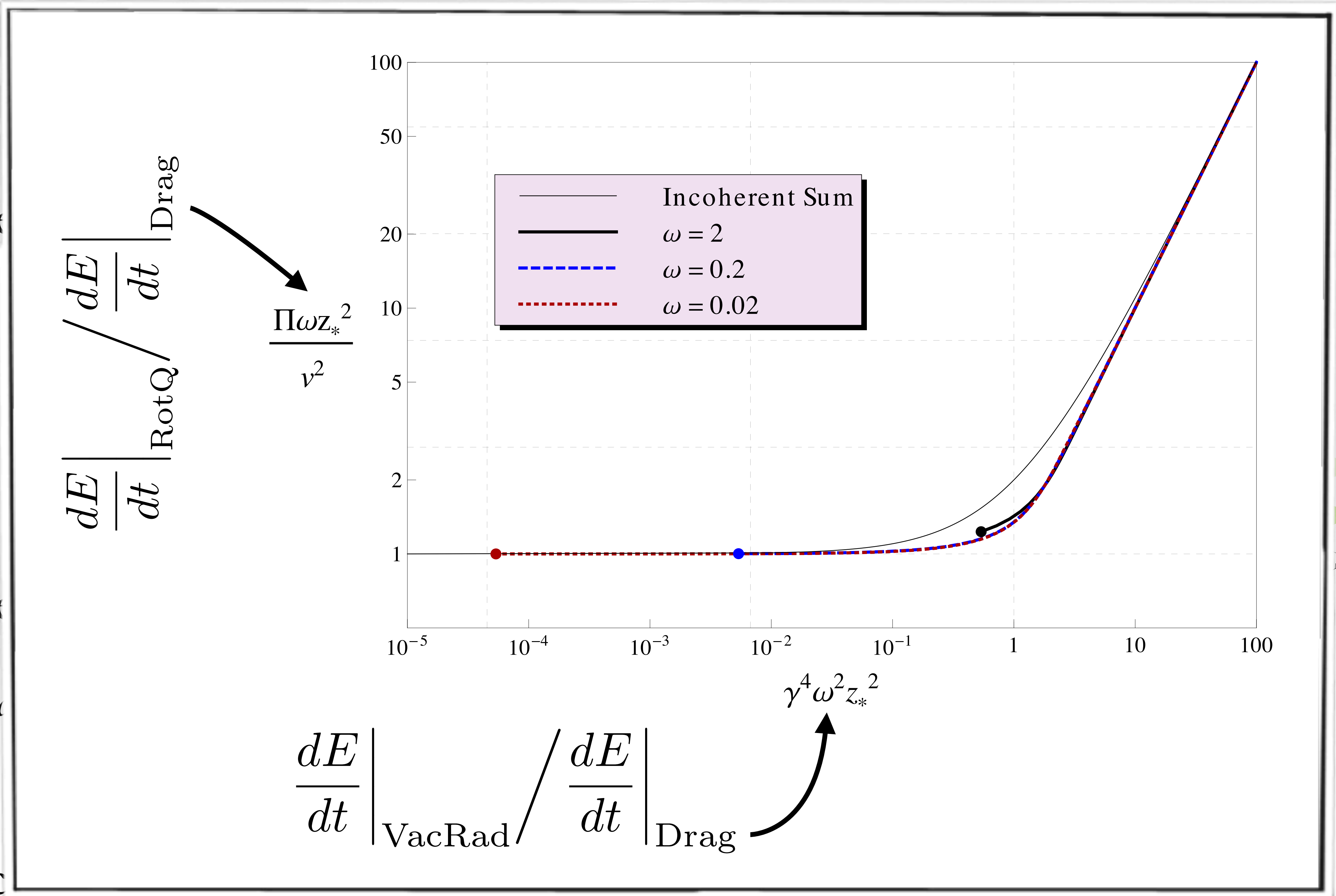
- Although being a conjecture the AdS/CFT correspondence as a realisation of the *Holographic principle* is a very powerful tool for qualitative and quantitative analysis, e.g.:
    - *Robustness* and *Universality* of the screening distance.
    - Running coupling of $q\bar{q}$ - pairs resembles Lattice QCD data.
    - *Robustness* of the energy loss of rotating quarks in deformed models.
- Many other more sophisticated models (e.g. including D3/D7 branes) available that nicely reproduce many QCD features.

Thank you for your attention!

Rotating Quark in Deformed Metric Models

- Is

the



- Is

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- Universal scaling in the crossover regime.