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Drag Force in AdS/QCD Models

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Outline

AdS/CFT in a sentence

A possible definition

AdS/CFT correspondence can be defined as a tool to explore non-perturbative physics using gravity.

...or if you want...

AdS/CFT is the duality that connects a $d+1$–QFT at strong coupling with $d+2$–gravity at weak coupling.

Both are valid *intuitive* definitions.

QGP Generalities

Generalities

E. Shuryak, 2004.
J. Adams et. al. (RHIC), 2005.
S. S. Adler et. al. (RHIC), 2007.

- It is a deconfined state of QCD created in heavy ion collisions, where partons are almost free.
- It behaves as a perfect fluid, i.e., $\frac{S}{V} = \frac{1}{4\pi}$ and $\eta = 0$.
- It is a strongly coupled system.
- It is expected to be formed at $T_c = 175$ MeV, when light mesons melt down.
- Theoretical approaches: lattice QCD, real time methods, bootstrap models, χ-PT, Thermal Loop and other effective lagrangians.

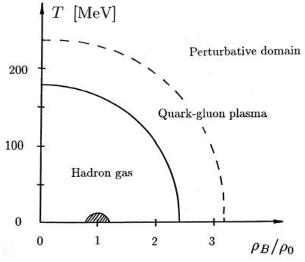


Figure 1: QCD phase diagram

AdS/QCD models

General Idea

AdS/QCD models are a bottom-up approach to introduce confinement into holography by including a form to break softly the conformal invariance.

These approaches have been successful to describe:

At $T = \mu = 0$

- Hadronic spectra
- EM form factors
- Decay constants for heavy mesons
- Structure functions.

Finite T and μ:

- Confinement/Deconfinement phase Transitions.
- Melting of Hadrons at finite T and finite μ
- In-medium (Nuclear) properties
- QCD Thermodynamics

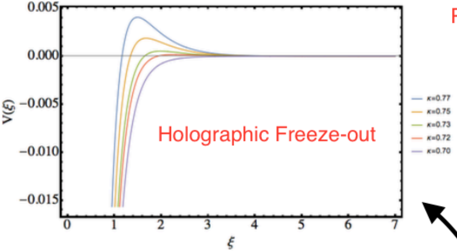
and...QGP?

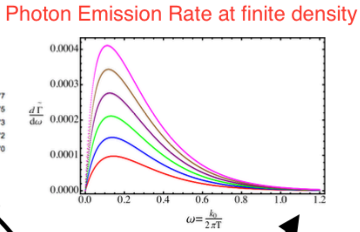
A natural question arises at this point: Could it be possible to describe QGP with AdS/QCD models?

In the case of photon emission, it has been possible to describe the photon emission rate (Y. Y. Bu, 2013).

Thus, it is expected these models could work describing QGP.

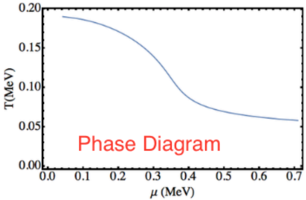
Example: Holographic (toy) model for emitted photons in the fireball





$$dS^2 = \frac{\pi^2 T^2 R^2}{u^2}\left[\frac{du^2}{f(u)} - f(u)\,dt^2 + d\vec{x}\cdot d\vec{x}\right],$$

$$I_{\text{Photons}} = -\frac{1}{4\,g_\gamma^2}\int d^5x\,\sqrt{-g}\,e^{-\Phi(u)}\,F_{mn}\,F^{mn}.$$



Trailing strings as moving quarks

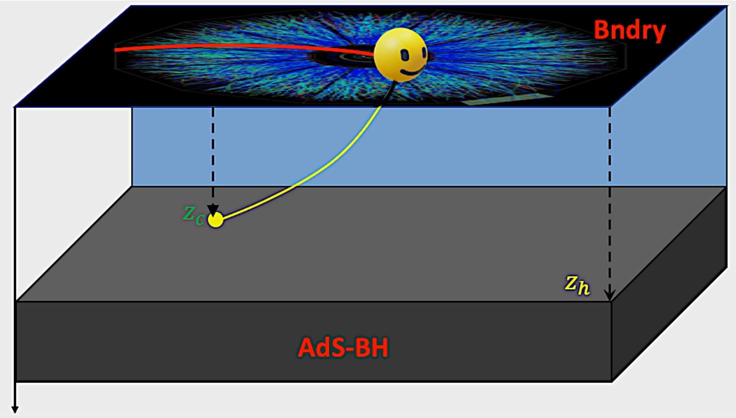


Figure 2: Quark moving across the QGP medium and its holographic description

Holographic Model

For simplicity, we will asume that the quark is moving on the x_1-direction on the boundary with a velocity $v\,\hat{x}_1$.
So, in the static gauge, we can write

$$x_1\,(z) = v\,t + \xi\,(z)$$

Under this gauge choice, the embedding metric γ_{ab} emerges as

$$dS^2 = \frac{R^2}{z^2}\left[-f\left(1-\frac{v^2}{f}\right)dt^2 + \frac{1}{f}\left(1+f\,\xi'^2\right)dz^2 + 2\,v\,\xi'\,dt\,dz\right] = \gamma_{ab}\,d\sigma^a\,d\sigma^b$$

The worldsheet metric is defined by the coordinate choice: $\sigma_a = \{t, z\}$.
From this metric we will obtain an expression for the drag force in the soft wall model context.

Our start point will be the Nambu Goto action defined for the embedding metric given above:

$$
\begin{aligned}
I_{\mathrm{NG}} &= -\frac{1}{2\,\pi\,\alpha'} \int d^2\sigma\, e^{-\Phi(z)} \sqrt{-\det\gamma} \\
&= -\frac{1}{2\,\pi\,\alpha'} \int d^2\sigma\, \frac{e^{2\,B(z)}}{z^2} \sqrt{1-\frac{v^2}{f}+f\,\xi'^2}
\end{aligned}
$$

where $B\,(z) = -\frac{\Phi(z)}{2} + \log\frac{R}{z}$ and $\Phi\,(z) = \kappa^2\,z^2$ is the static dilaton profile. The Drag Force comes from the canonical conjugate momentum $\Pi^{z}_{x_1}$ as follows:

$$
F_{\mathrm{Drag}} = \Pi^{z}_{x_1} = -\frac{1}{2\,\pi\,\alpha'}\frac{e^{2\,B(z)}}{z^2}\frac{\xi'\,f}{\sqrt{1-\frac{v^2}{f}+f\,\xi'^2}} = -\frac{e^{2B(z_c)}}{2\,\pi\,\alpha'\,z_c^2}\sqrt{f\,(z_c)}, \tag{1}
$$

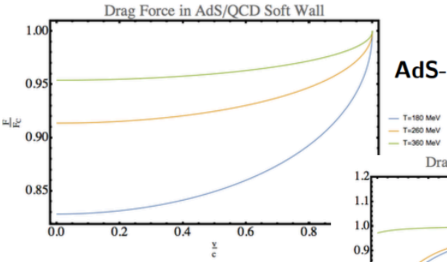
where z_c is critical point that defines the region in the bulk where the string is stretching, and it is defined as $v^2 = f(z_c)$.

Some Remarks

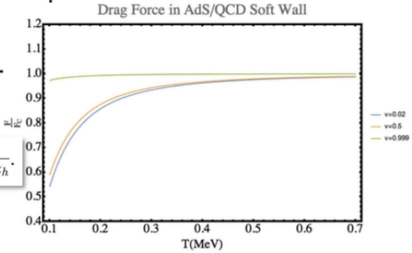
- This z_c defined by the kinematical constrain $f(z_c) = v^2$. i.e. it depends on the thermal conditions for the plasma modeled by the metric.
- z_c can be considered as the "probe" that captures the medium effect on the moving quark since the string end is affected by the BH gravity.

Now, we will focus on two different geometric backgrounds: AdS-Schwartzchild and AdS-Reissner-Nordstrom geometries to see the thermal and chemical potential effects.

AdS-Schwartzschild background



AdS-Schwartzchild Geometry



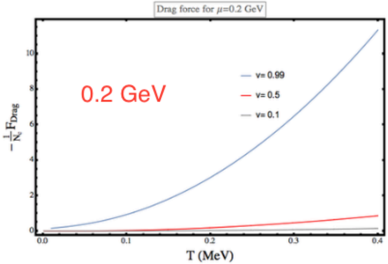
In this case: $f(z) = 1 - \frac{z^4}{z_h^4}$ with $T = \frac{1}{\pi\, z_h}$.

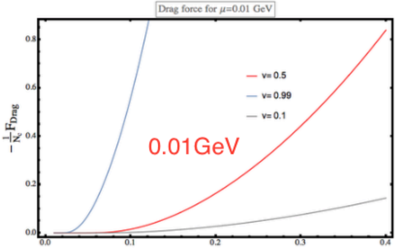
AdS-Reissner Nordstrom background

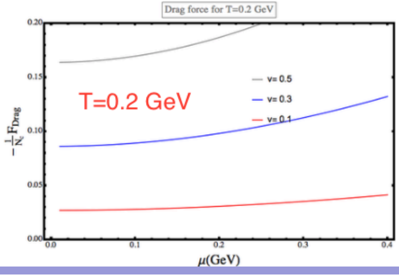
AdS-Reissner-Nordstrom Geometry

In this case: $f(z) = 1 - \left(1 + Q^2\right) \frac{z^4}{z_h^4} + Q^2 \frac{z^6}{z_h^6}$

with $T = \frac{1}{\pi\, z_h}\left(1 - \frac{Q^2}{2}\right)$ and $\mu = \frac{Q}{z_h}$.







Conclusions

- AdS/QCD soft wall model provides a simple framework to study the QGP phenomenology at finite T and finite μ.
- Holographic drag force is enhanced in a dense medium (T. Hirano, 2018).
- Medium properties could be studied by fixing properly the kinematical constrain $f(z_c) = v^2$.

Future work

Things to do next:

- To calculate jet quenching.
- To calculate other thermodynamical quantities as entropy.
- To introduce anisotropies.
- To use other BH backgrounds as the non-commutative ones.

Thank you!