Capturing some medium effects in the dilaton to study hadrons in AdS / QCD models

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HADRON 2019, Guilin, China

August 20, 2019

Outline

Introduction

Applicability to hadron physics of Gauge / Gravity ideas. [1]

- N=4 SYM is different to QCD, but we can argue that in some situations both are closer. Ej: Heavy Ion Collisions.
- Gauge / Gravity ideas can be expanded in several directions. This gives us a possibility to get a field theory similar to QCD with gravity dual.
- You can use Gauge / Gravity as a nice frame to built phenomenological models with extra dimensions that reproduce some QCD facts (AdS/QCD models).
- AdS / QCD has been used in a successful way to study hadron physics at zero temperature and density, and also at finite temperature and in a dense medium.

[1] e.g., see J. Erdmenger, N. Evans, I. Kirsch and E. Threlfall, Eur. Phys. J. A **35**, 81 (2008).

Extensions of AdS / CFT to QCD are related at two approaches:

- Top-Down approach.
  You start from a string theory on $AdS_{d+1}xC$, and try to get at low energies a theory similar to QCD in the border.
- Bottom-Up approach.
  Starting from QCD in 4d we try to build a theory with higher dimensions (not necessarily a string theory).

AdS / QCD models belong to the bottom-up approach, and here with Asymptotically AdS metrics with a non-dynamical dilaton, it is possible reproduce some hadronic phenomenology.

In AdS / QCD models we consider

$$S = \int d^{d+1}x \sqrt{g} e^{-\Phi(z)} \left(\mathcal{L}_{Part} + \mathcal{L}_{Int} \right),$$

where for example

- Zero temperature and vacuum: Asymtotically AdS metric and dilaton field.
- Finite temperature and vacuum: AdS black hole metric and dilaton field.
- Zero temperature and dense media: RN AdS black hole metric and dilaton field.

But if we do not forget which metric and dilaton define the background, then could be possible code part of media properties in dilaton field. Recently this idea has started to be explored, e.g.,

- Finite temperature and vacuum:
  - A. V and M. A. Martin Contreras, Nucl. Phys. B **942**, 410 (2019) [arXiv:1808.09096].
  - Gutsche, Lyubovitskij, Schmidt and Trifonov, Phys. Rev. D **99**, no. 5, 054030 (2019) [arXiv:1902.01312]; Phys. Rev. D **99**, no. 11, 114023 (2019) [arXiv:1905.02577].
  - Gutsche, Lyubovitskij and Schmidt, arXiv:1906.08641.
- Zero temperature and dense media:
  A.V and M. A. Martin Contreras, arXiv:1812.00642 [hep-ph].

Melting of scalar hadrons in an AdS/QCD model modified by a thermal dilaton [2]

[2] A. V and M. A. Martin Contreras, Nucl. Phys. B **942**, 410 (2019)

We consider

$$S = \frac{1}{2K} \int d^5x \sqrt{-g}\, e^{-\phi(z)} \mathcal{L},$$

where

$$\mathcal{L} = g^{MN}\, \partial_M \psi\,(x,z)\; \partial_N \psi\,(x,z) + m_5^2 \psi^2\,(x,z).$$

Metric considered is

$$g_{MN} = e^{2\,A(z)}\ \mathrm{diag}\left(-f\,(z)\,,\, 1,\, 1,\, 1,\, \frac{1}{f(z)}\right).$$

The E.O.M. associated with this action is

$$e^{B(z)}\, f\,(z)\; \partial_z \left[e^{-B(z)}\, f\,(z)\; \partial_z \psi\right] - f\,(z)\; e^{2A(z)}\, m_5^2\, \psi + \omega^2\, \psi - f\,(z)\; q^2\, \psi = 0,$$

where $B(z) = \phi(z) - 3A(z)$.

Using the Bogoliubov transformation[3]

$$\psi\,(z) = \sqrt{\frac{e^{B(z)}}{f(z)}}\,u\,(z),$$

it is possible to obtain an equation like

$$u''(z) + U(z)\,u(z) = 0,.$$

where $U(z)$ is the thermal holographic potential given by

$$U(z) = \frac{e^{2\,A(z)}}{f(z)}\,m_5^2 - \frac{B'(z)\,f'(z)}{2\,f(z)} + \frac{f''(z)}{2\,f(z)} - \frac{f'(z)^2}{4\,f(z)^2} - \frac{\omega^2}{f(z)^2} + \frac{B'(z)^2}{4} - \frac{B''(z)}{2}.$$

It is possible consider a Lioville transform also (result are similar but procedure is more elaborated[4]).

[3] M. Fujita, T. Kikuchi, K. Fukushima, T. Misumi and M. Murata, Phys. Rev. D **81**, 065024 (2010) [arXiv:0911.2298 [hep-ph]].

[4] A. V and A. Ibañez, Eur. Phys. J. A **53**, no. 11, 217 (2017) [arXiv:1706.01994 [hep-ph]].

$$U(z) = \frac{e^{2\,A(z)}}{f(z)}\, m_5^2 - \frac{B'(z)\, f'(z)}{2\, f(z)} + \frac{f''(z)}{2\, f(z)} - \frac{f'(z)^2}{4\, f(z)^2} - \frac{\omega^2}{f(z)^2} + \frac{B'(z)^2}{4} - \frac{B''(z)}{2}.$$

we consider

$$A\,(z) = \ln\left(\frac{1}{z}\right), \quad f\,(z) = 1 - (\pi\, T)^4 z^4.$$

and two kind of dilatons

$$\phi_1(z, T) = \kappa^2(1 + \alpha\, T)z^2,$$

Thermal extension of traditional quadratic dilaton[5].

$$\phi_2(z, T) = \kappa_1^2(1 + \alpha\, T)z^2\ \tanh[\kappa_2^2(1 + \alpha\, T)z^2].$$

Thermal extension of dilaton introduced in [[6]].

[5] A. Karch, E. Katz, D. T. Son and M. A. Stephanov, Phys. Rev. D **74**, 015005 (2006).

[6] K. Chelabi, Z. Fang, M. Huang, D. Li and Y. L. Wu, Phys. Rev. D **93**, no. 10, 101901 (2016)

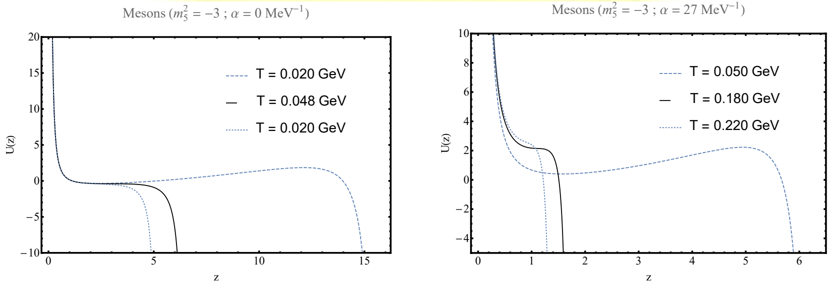

Figure: Plots show the holographic potential calculated using $\phi_1(z)$. On the right side, the traditional case ($\alpha = 0$) is considered. On the left side, we plot potentials considering a thermal quadratic dilaton with $\alpha = 27$ MeV^{-1} (that was fitted to obtain 180 MeV for mesonic melting temperature). In both cases continous line considers melting temperature.

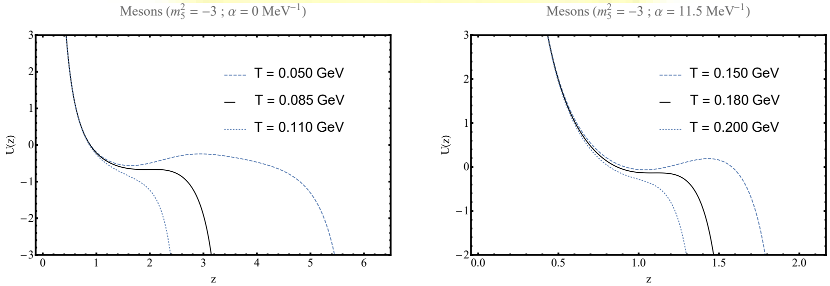

Figure: Plots show the holographic potential calculated using ϕ_2. On the right side, the traditional case ($\alpha = 0$) is considered. On the left side, we plot potentials considering a thermal quadratic dilaton with $\alpha = 11.5$ MeV^{-1}, which was adjusted in order to obtain 180 MeV for mesonic melting temperature. In both cases continous line considers melting temperature.

Final Comments and Conclusions

- We had used the same ideas to calculate properties of nucleons in nuclear medium (Masses and electromagnetic form factors)[7].
- Dilaton field can capture part of the media properties where hadrons are located, then can be considered as a complement to metric at moment to study medium effects in hadrons in this kind of models.
- We plan to use the idea to study other properties and other hadrons in nuclei.

[7] A. Vega and M. A. Martin Contreras, arXiv:1812.00642 [hep-ph].


That's all Folks!