Holographic Picture of Heavy Meson Melting

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Outline

Motivation

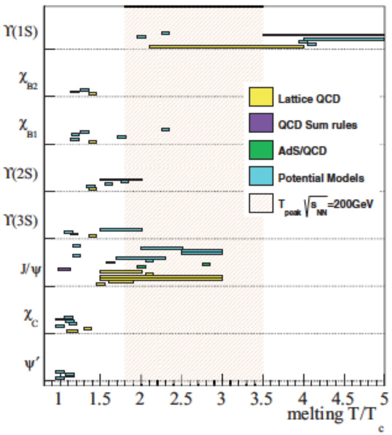

Figure 1: From Adare et. al., 2015.

There is no holographic approximation to the melting picture of charmonium and bottomonium states.

Zero temperature model

Holographic Model

Let us consider the following holographic setup (N. R. F. Braga, M.A. Martin Contreras and S. Diles, Physics Letters B, 763:203 207, 2016.):

$$I = -\frac{1}{4g_5^2}\int d^5x\,\sqrt{-g}\,e^{-\kappa^2 z^2}F_{mn}F^{mn}, \tag{1}$$

where the κ scale is a confining parameter. It is related to the Regge slope for the mesonic spectrum trajectory. The field strength is defined as $F_{mn} = \partial_m A_n - \partial_n A_m$, with $A_m(z, x)$ a $U(1)$ field. The coupling g_5 is defined as

$$\frac{1}{g_5^2} = \frac{N_c\,N_f}{12\pi^2\,R} \tag{2}$$

The geometry background is defined by the Poincare Patch coordinates

$$dS^2 = \frac{R^2}{z^2}\left(dz^2 + \eta_{\mu\nu}dx^\mu dx^\nu\right)\,\Theta\left(z - z_0\right). \tag{3}$$

We will put our holographic boundary at a wall located at $z = z_0$, introducing a new scale.

Our goal is to construct the holographic 2-point function related to heavy vector quarkonium physics:

$$\Pi\left(\tilde{q}^2\right) = -\frac{R\,e^{\kappa^2 z_0^2}}{2\,g_5^2}\frac{U\left(1-\tilde{q}^2, 1, \kappa^2 z_0^2\right)}{U\left(-\tilde{q}^2, 0, \kappa^2 z_0^2\right)}. \tag{4}$$

where $U\left(a, b, z\right)$ is the Tricomi function. The mass spectrum is associated to the poles and the decay constants to the residues in the 2-point function. In order to do this calculation we need the compute the zeroes of the denominator

$$U\left(-\frac{q^2}{4\kappa^2}, 0, \kappa^2 z_0^2\right) = 0, \tag{5}$$

where the zeroes of the Tricomi function are defined as $\chi_n = -q_n^2/4\kappa^2$. The physical masses are given by the on-shell mass condition $q_n^2 = m_n^2$. Then, the mass spectrum is given by

$$m_n^2 = 4a^2\,\chi\left(\kappa, z_0\right). \tag{6}$$

The decay constants, given in terms of the residues R_n, can be determined as follows

$$f_n^2 = 4\kappa^2\,R_n\left(\kappa,\, z_0\right). \tag{7}$$

Results

Holographic Results

Parameter fixing: κ is flavor dependent and it is related to the Regge slope of the trajectory. z_0 is flavor independent and deals with the nature of strong interaction in the meson (Braga, Martin, Diles, 2016).

$c\bar{c}$	κ (MeV)	z_0(GeV^{-1})	m_n (MeV)	f_n (MeV)
1S	1200	0.08	2410.6 (22%)	258.9 (38%)
2S			3408.7 (7%)	251.7 (15%)
3S			4174.3 (3%)	245.9 (31%)
4$S*$			4819.5 (9%)	241.0 (50%)
$b\bar{b}$	κ (MeV)	z_0 (GeV^{-1})	m_n (MeV)	f_n (MeV)
1S	3400	0.08	7011.4 (26%)	628.1 (19%)
2S			9883.1 (1%)	574.5 (15%)
3S			12077.6 (17%)	539.1 (25%)
4S			13923.0 (32%)	512.9 (51%)

Table 1: Results for the $c\bar{c}$ and $b\bar{b}$ vector meson states, reported in (Braga, Martin, Diles. Phys. Lett. B, 763:203 207, 2016.).

Some comments

- Numerical results exposed here are in agreement with non-holographic approaches, as the one followed in **(S. S. Gershtein et. al., 2006)**, or fits done using Schroedinger-like **(R. K. F. Chand, 2013.)** or Cornell-like potentials **(Gunnar S. Bali, 2001)**.
- Notice that our results, sixteen observed quantities fitted holographically, are generated in a three-dimensional parameter space. This is an enormous advantage in order to extend the predictivity and universality of the model to other different spin states, as for examples scalar resonances and glueballs.
- Other holographic extensions based on the soft wall model have a high dimensional parameter space almost equal to the number of observables (i.e. **H. R. Grigoryan, P. M. Hohler and M. A. Stephanov, 2010.**), limiting the model to fit a single meson state.

Finite Temperature

Holographic Setup

On the gravity side, the thermal field theory that describes the vector mesons is identified with the Euclidean AdS Schwarzschild background (N. R. F. Braga, M. A. Martin and S. Diles. EPJ C, 76(11):598, 2016)

$$dS^2 = \frac{R^2}{z^2}\left[f(z)\, d\tilde{t}^2 + d\vec{x}^2 + \frac{dz^2}{f(z)}\right]\Theta(z - z_0), \qquad (8)$$

where z_0 is the locus of the boundary. The blackening factor is given by the expression

$$f(z) = 1 - \frac{z^4}{z_h^4}. \qquad (9)$$

At $z = z_h$ there is an event horizon related to the Hawking temperature, that holographically is defined as the temperature of the thermal theory:

$$\beta = \pi z_h \sqrt{f(z_h)} = \frac{1}{T}. \qquad (10)$$

Holographic Vector Mesons at Finite Temperature

Let us consider the action for the soft wall model with extra D–wall defined before

$$I = -\frac{1}{4g_5^2}\int d^5x\,\sqrt{-g}\,e^{-\kappa^2 z^2}\,F_{mn}F^{mn}, \qquad (11)$$

From this action and the background defined above we will obtain the *spectral density* function, which encodes all the quarkonium thermal information.

$$\rho\left(q_0\right) = -\mathbb{Im}\,G_R\left(q_0\right), \qquad (12)$$

where we have fix the vector meson momentum $\vec{q} = 0$ in order to read the masses behavior.
So, we need to calculated first the *thermal retarded Green function* holographically.

Let us do this!

Thermal Green Function from Holography

We will focus on the spacetime components of the field A_m, which will be written in Fourier space as $A_\mu(q_0, z) = v_\mu^0(q_0)\; V(q_0, z)$, with $V(q_0, z)$ is the bulk to boundary propagator (E. Witten, 1999).
This propagator obeys the following e.o.m

$$\partial_z \left[\frac{e^{-\kappa^2 z^2}}{z} f(z)\, \partial_z V(q_0, z) \right] + \frac{e^{-\kappa^2 z^2}}{z\, f(z)} q_0^2\, V(q_0, z) = 0. \quad (13)$$

altogether with the adjoint boundary conditions

$$V(q_0, z_0) = 1 \quad (14)$$

$$V(q_0, z) = F(q_0, z) \left(1 - \frac{z}{z_h}\right)^{-i\, q_0\, z_h/4}, \quad (15)$$

where $F(q_0, z)$ measures the proximity to the black hole, i.e., at $z = z_h$ we have $F(q_0, z_h) = 1$.

With the solutions obtained above we arrive to the retarded thermal Green function

$$G^R(q_0) = -\,i\,\frac{R}{2\,g_5^2}\,\frac{e^{-\kappa^2 z_h^2}}{z_h}\,\frac{q_0}{|F(q_0, z_0)|^2} \tag{16}$$

Thus, the spectral density function is finally written as

$$\rho(q_0) = \frac{R}{2\,g_5^2}\,\frac{e^{-\kappa^2 z_h^2}}{z_h}\,\frac{q_0}{|F(q_0, z_0)|^2}. \tag{17}$$

Now we have to evaluate numerically the spectral function for each heavy vector meson trajectory. We will do this in the next sections. Notice that the g_5 coupling is independent of the temperature, as first approximation, and it is defined in the same way as the zero temperature coupling

Charmonium Results

Charmonium Holographic Picture

$\rho_{c\bar{c}}$ is constructed from the parameter choice done in the table 1. For simplicity, we fixed $\omega = q_0/2\pi T$.

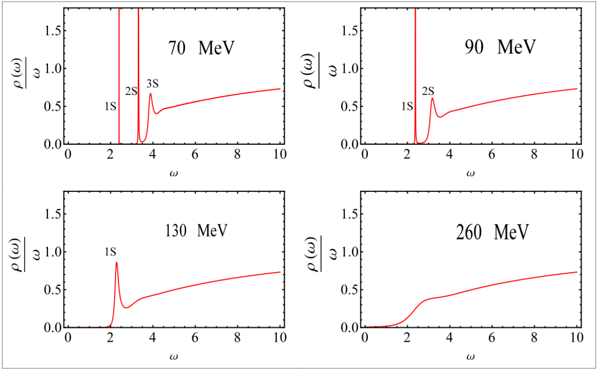

Figure 2: Charmonium melting process starting with a temperature of 70 MeV with three initial states $1S$, $2S$ and $3S$ at left upper panel. Each of the three remaining panels shows the melting temperature of these states (Braga, Martin, and Diles. 2016).

Bottomonium Results

Bottomonium Holographic Picture

$\rho_{b\bar{b}}$ is constructed from the parameter choice done in the table 1.

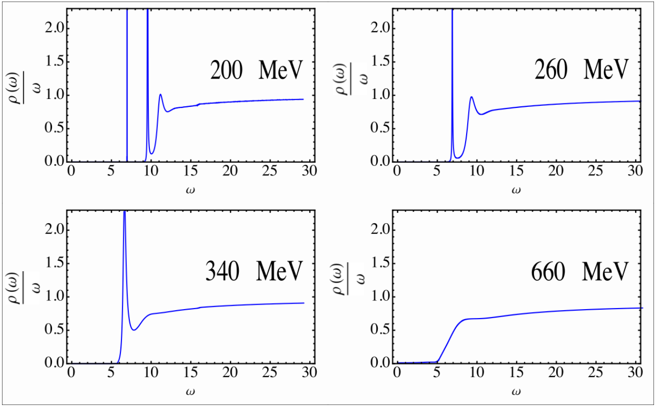

Figure 3: Bottomonium melting process starting at 200 MeV with three states $1S$, $2S$ and $3S$ at left upper panel. Each panel shows the melting temperature for these states (Braga, Martin, and Diles. 2016).

Conclusions

- At low temperature the mass spectrum is organized as $m_n^2 = 4\kappa^2 \chi_n(\kappa, z_0)$.
  - Mass spectrum is discrete with a finite mass gap.
  - The spectral functions are expected to be Delta functions placed at the mass poles
- The melting process is characterized essentially by the temperature.
  - Mass spectrum becomes continuum.
  - Peaks begin to broad, impliying meson destabilization.
  - Meson melting implies that bulk mode state (given by V) are absorbed into the black hole.
  - J/ψ meson melts down at the temperature around to 260 MeV.
  - The melting temperature for the Υ state is near to 600 MeV.
- This holographic model gives a complete melting picture of the vector quarkonium states in terms of 3 parameters.
- This is the first holographic model that does this!

Future work

What is next?

- To understand the universality of this model: scalar mesons, glueballs and baryons.
- To study the universality of the model compared with other holographic approaches.
- To jump to the finite chemical potential realm. (First approximations in this lead can be found in M. A. Martin and J. M. R. Roldan, Photon emission in quark gluon plasma at finite chemical potential. To be published).
- To extend this ideas to top/down approaches recently developed as the AdS bootstrap (M. F. Paulos et. al. 2016).
- To calculate other important quantities as the em form factor.
- To compare with other non-holographic approximations.

Thank you!