HOLOGRAPHIC PICTURE OF HEAVY VECTOR MESONS IN A FINITE DENSITY PLASMA*

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We present the results of a holographic model for heavy vector mesons inside a plasma at finite temperature and density. The spectral function shows a nice description of the dissociation of the mesons in the medium, corresponding to the decrease in the height of the peaks as the temperature and (or) the density increase. We consider the case of bottomonium states at finite temperature and also the case of charmonium dissociation at zero temperature but finite chemical potential.

1. Introduction

Understanding heavy meson dissociation inside a thermal medium can be a helpful tool for studying the properties of the quark–gluon plasma formed in heavy-ion collisions [1] (see also [2]). A holographic description of the dissociation of charmonium and bottomonium states in a plasma at finite temperature but zero density appeared recently in Ref. [3]. This work is an extension to the case of a finite density medium of the model presented in Refs. [4,5].

The holographic model of Ref. [4] is an alternative version of the soft wall model that is consistent with the observation that decay constants of hadronic resonances decrease with radial excitation level. This property is not reproduced in the hard wall AdS/QCD model that appeared in Refs. [6–8], or in the original soft wall model [9].

One can understand the importance of having a consistent description of the decay constants by noticing that at zero temperature, the two-point function of hadronic currents has a spectral decomposition in terms of masses

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and decay constants of the states

$$\Pi(p^2) = \sum_{n=1}^{\infty} \frac{f_n^2}{(-p^2) - m_n^2 + i\epsilon}.$$ (1)

At finite temperature, the particle content of a theory is described by the spectral function. The quasi-particle states appear as peaks that decrease as the temperature or the density of the medium increase. The zero temperature and density limit of the spectral function corresponds to the imaginary part of Eq. (1). It is a sum of Dirac delta functions with coefficients proportional to the square of the decay constants. So, it is important to consider a model consistent with the behavior of zero temperature decay constants in order to find a reliable picture of the finite temperature case.

2. Highlights of the holographic model

Heavy vector mesons are described by a vector field $V_m = (V_\mu, V_z)$ ($\mu = 0, 1, 2, 3$), assumed to be dual of the gauge theory current $J^\mu = \bar{q}\gamma^\mu q$. The action is

$$I = \int d^4x dz \sqrt{-g} \, e^{-\Phi(z)} \left\{ -\frac{1}{4g_5^2} F_{mn} F^{mn} \right\},$$ (2)

where $F_{mn} = \partial_m V_n - \partial_n V_m$ and $\Phi = k^2 z^2$ is the soft wall background, with the parameter k playing the role of an IR, or mass, energy scale. The space is a charged black hole

$$ds^2 = \frac{R^2}{z^2} \left(-f(z) dt^2 + \frac{dz^2}{f(z)} + d\vec{x} \cdot d\vec{x} \right),$$ (3)

with

$$f(z) = 1 - \frac{z^4}{z_h^4} - q^2 z_h^2 z^4 + q^2 z^6.$$ (4)

The parameter q is the charge of the black hole and z_h is the position of the horizon, defined by the condition $f(z_h) = 0$. They are related by

$$\mu = q z_h^2.$$ (5)

The gauge theory correlators are calculated at a finite position $z = z_0$. The inverse of the position is an UV energy parameter. More details can be found in Ref. [3].

3. Results

The spectral function of bottomonium can be calculated using the membrane paradigm [10], for more details, see Ref. [3]. For the model parameters, we use the values obtained in Ref. [4] from the fit of the experimental data at zero temperature and chemical potential for bottomonium and charmonium

$$1/z_0 = 12.5 \text{ GeV}\,; \qquad k_b = 3.4 \text{ GeV}\,; \qquad k_c = 1.2 \text{ GeV}\,. \qquad (6)$$

The critical confinement/deconfinement temperature of this model — with ultraviolet cutoff — was estimated for the case of zero chemical potential in Ref. [5] as $T_c = 191$ MeV.

In figure 1, we show the spectral function for the temperature $T = 220$ MeV for six different values of the chemical potential from $\mu = 0$ to $\mu = 500$ MeV. On the first panel, one can see the peaks corresponding to

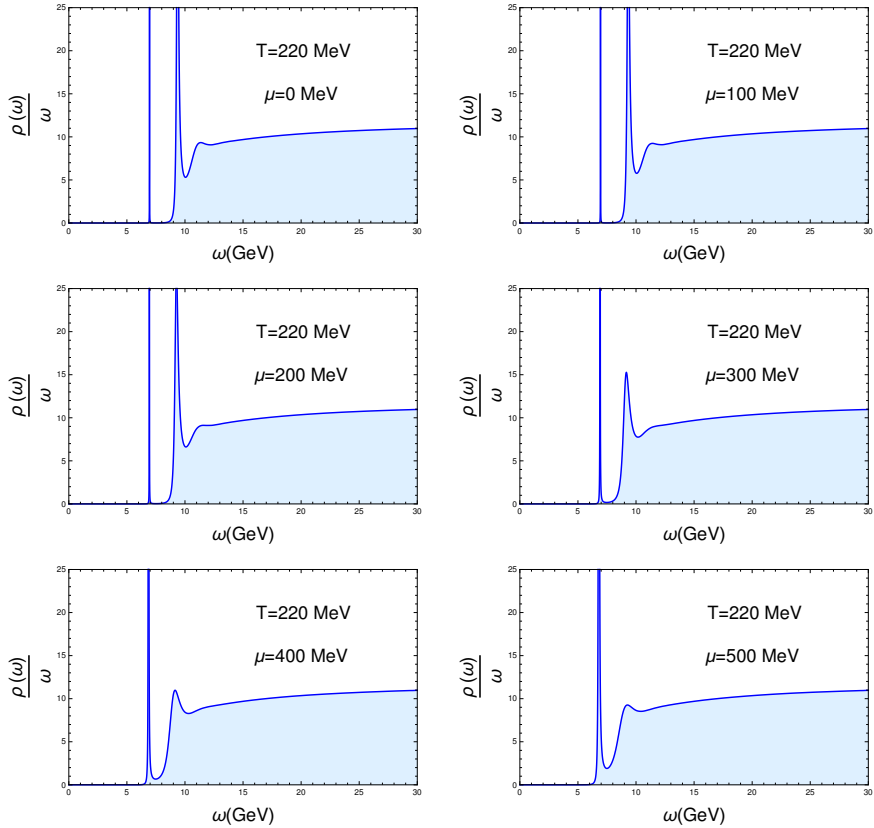Fig. 1. Spectral functions for bottomonium states with temperature $T = 220$ MeV at 6 representative values of μ.

the $1S$ and $2S$ states and a very small peak corresponding to the $3S$ state. Then, raising the value of μ, the second peak dissociates, while the first one develops a larger width.

Then in figure 2, we show the case of $T = 260$ MeV where one sees a clear reduction of the second quasi-particle peak associated with the $2S$ state at $\mu = 0$. Increasing μ, one sees that this state is completely dissociated in the medium at $\mu = 500$ MeV.
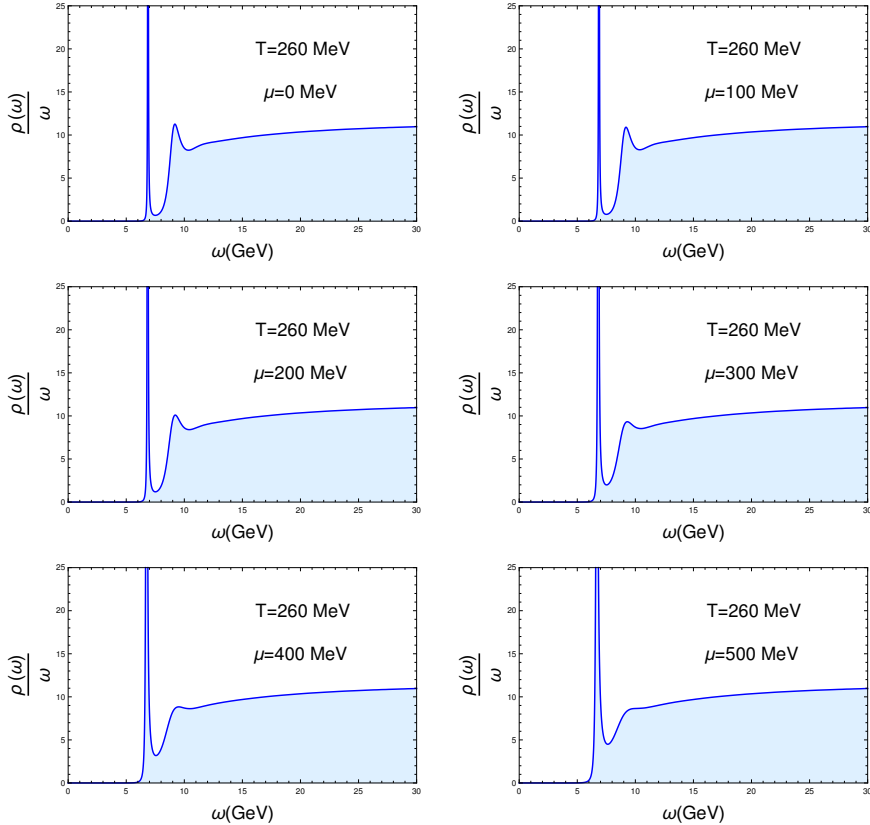

Fig. 2. Spectral functions for bottomonium states with temperature $T = 260$ MeV at 6 representative values of μ.

One can also use this holographic model to look at the particular case of zero temperature and finite chemical potential. In figure 3, we present the results for charmonium from $\mu = 200$ to $\mu = 600$ MeV with temperature

$T = 0$ fixed. One can see that at $\mu = 200$, there are four peaks. Then with increasing μ the quasi-particle peak is decreasing, and the dissociation of the $1S$ state happens at $\mu = 600$ MeV.
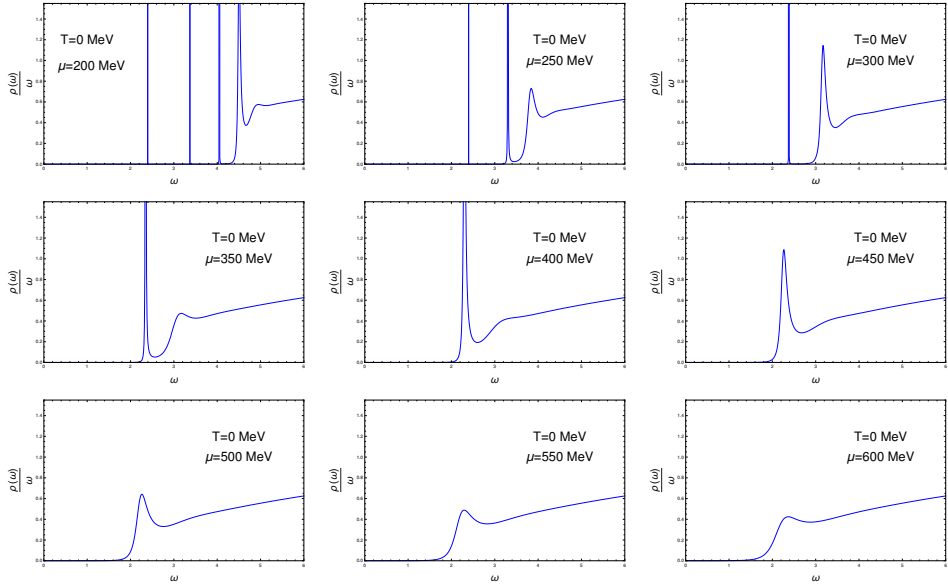

Fig. 3. Spectral functions for charmonium states with vanishing temperature at 8 representative values of μ.

4. Conclusions

A nice picture for the dissociation of bottomonium states emerged in Ref. [3] from the extension of the model of references [4,5] to finite chemical potential and temperature. The obtained plots show the bottomonium dissociation as a function of density and temperature. It was also shown that it is possible to analyse the spectral function at zero temperature and finite density.

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