Holographic Picture for Heavy Vector Meson Dissociation in a Plasma

Strong and Electroweak Matter Conference (SEWM), Barcelona 2018.

Nelson Braga
Universidade Federal do Rio de Janeiro, Brazil

Based in:arXiv:1802.02084 (to appear in Phys.Lett.B), Phys.Lett.B 774, 476 (2017); Phys.Lett.B 773, 313 (2017).

Colaborations with:
Luiz F. Ferreira and Alfredo Vega

Motivation:

describe the thermal dissociation of heavy vector mesons inside a quark gluon plasma using holography (AdS/QCD "botton up" model).

In particular: **density** and **magnetic field** effects.

Gauge/String duality at finite temperature.

Witten (1998): finite temperature version of AdS/CFT

Black hole in anti-de Sitter space	$\leftrightarrow$	Gauge Theory at finite temperature

The Hawking temperature of the black hole (B.H) is the temperature of the gauge theory.

Charge of the B.H. ➔ Density of the medium

Einstein-Maxwell action ➔ Magnetic field

D'Hoker and P.Kraus,

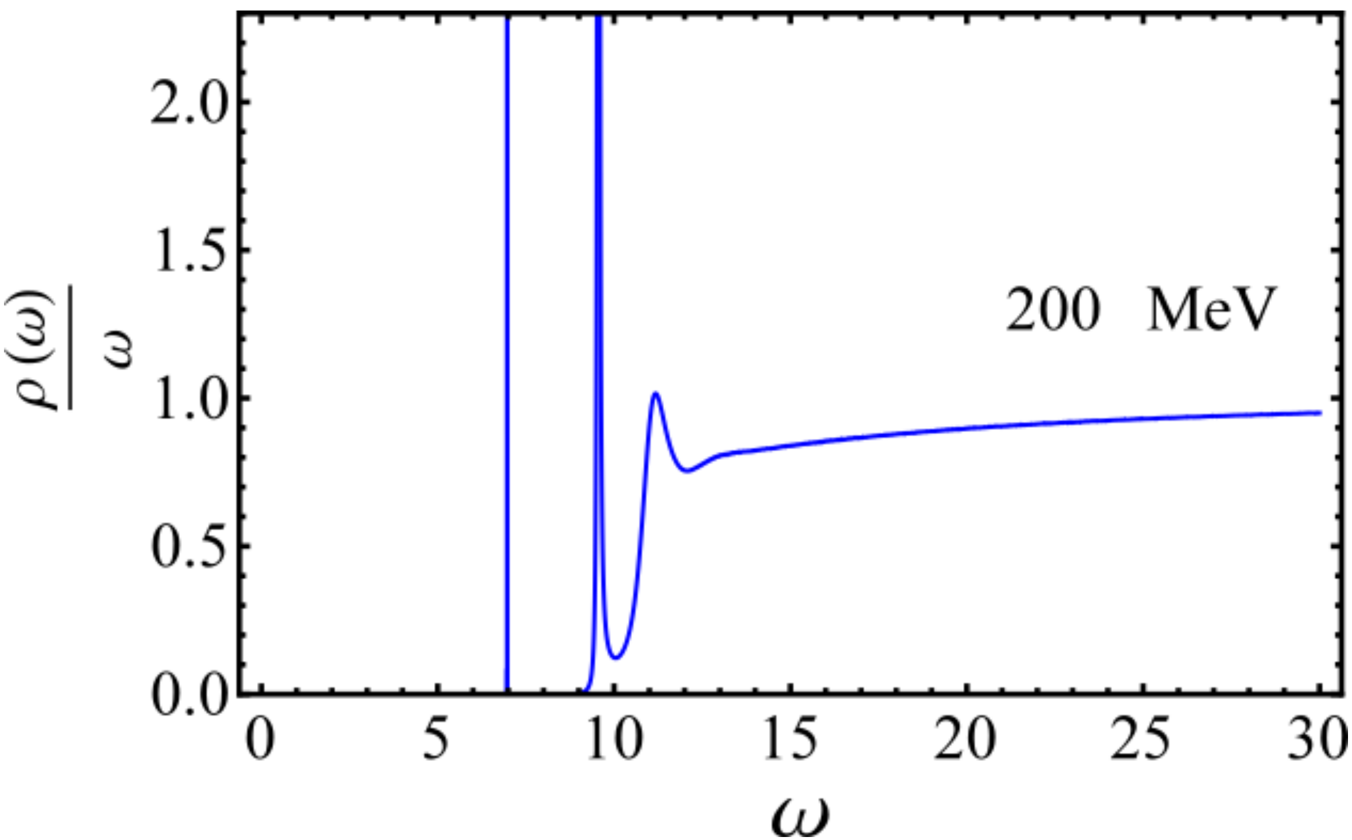
JHEP 0910, 088 (2009);1003, 095 (2010)

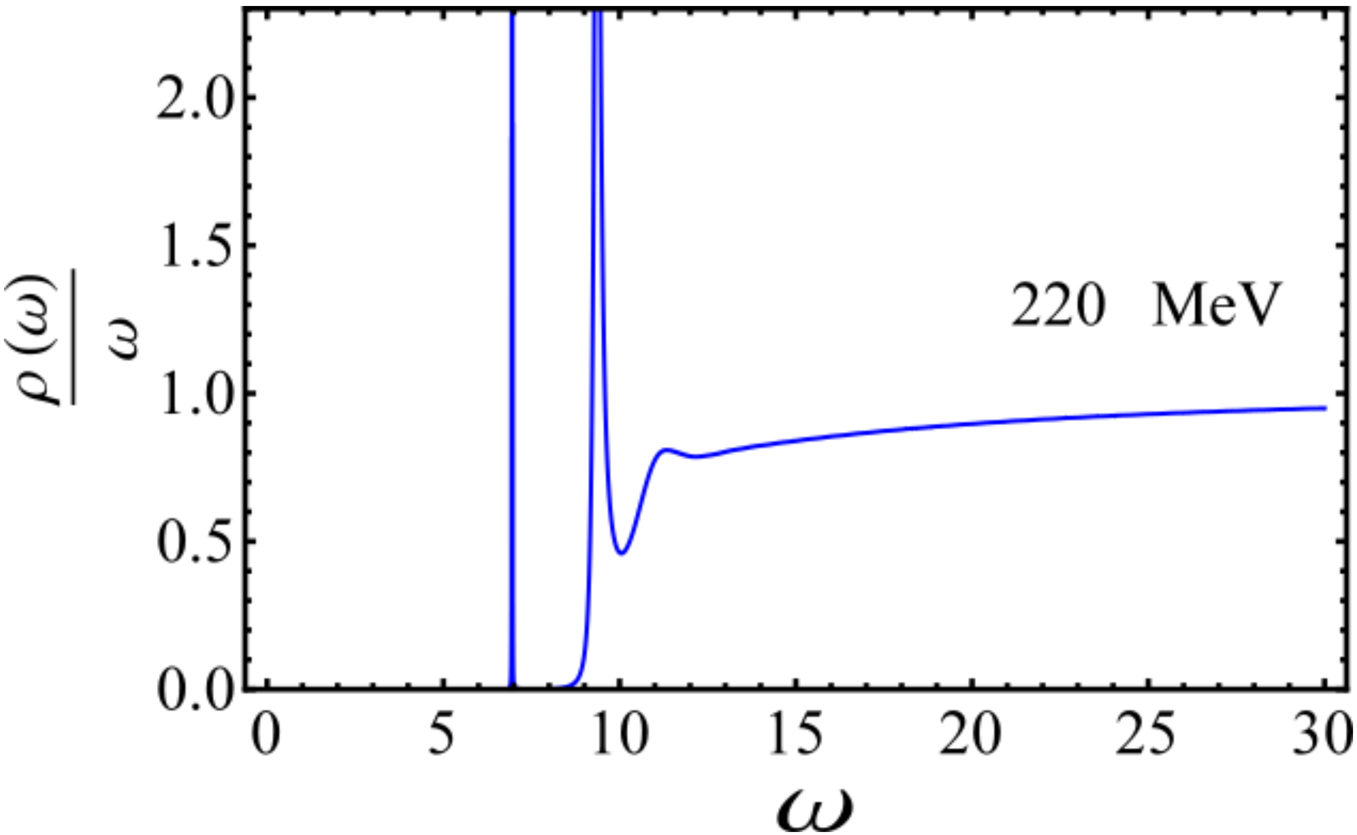
Important

The holographic model must be consistent with masses and **decay constants** for mesons in the vacuum.

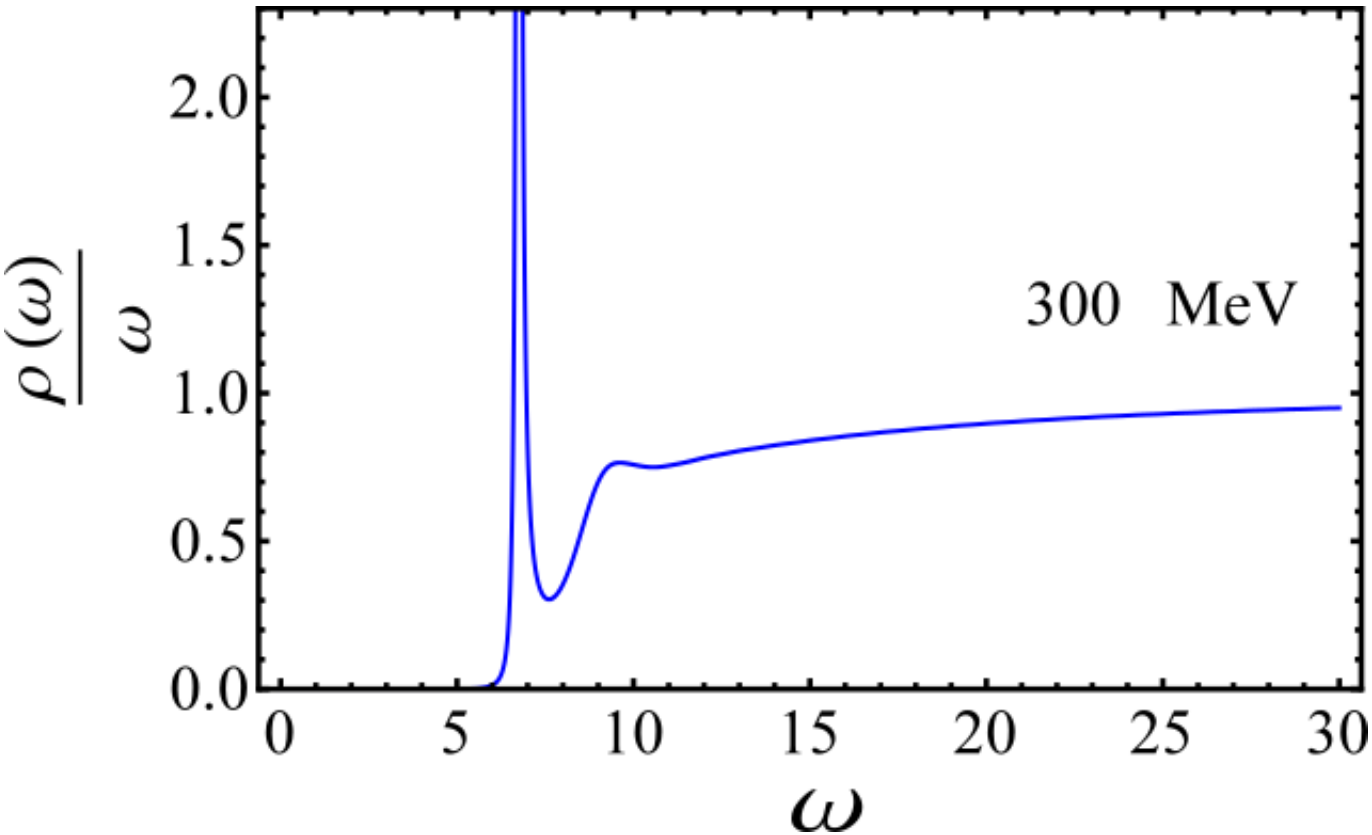
Why do we have to worry about **decay constants** ?

Bottomonium Spectral function

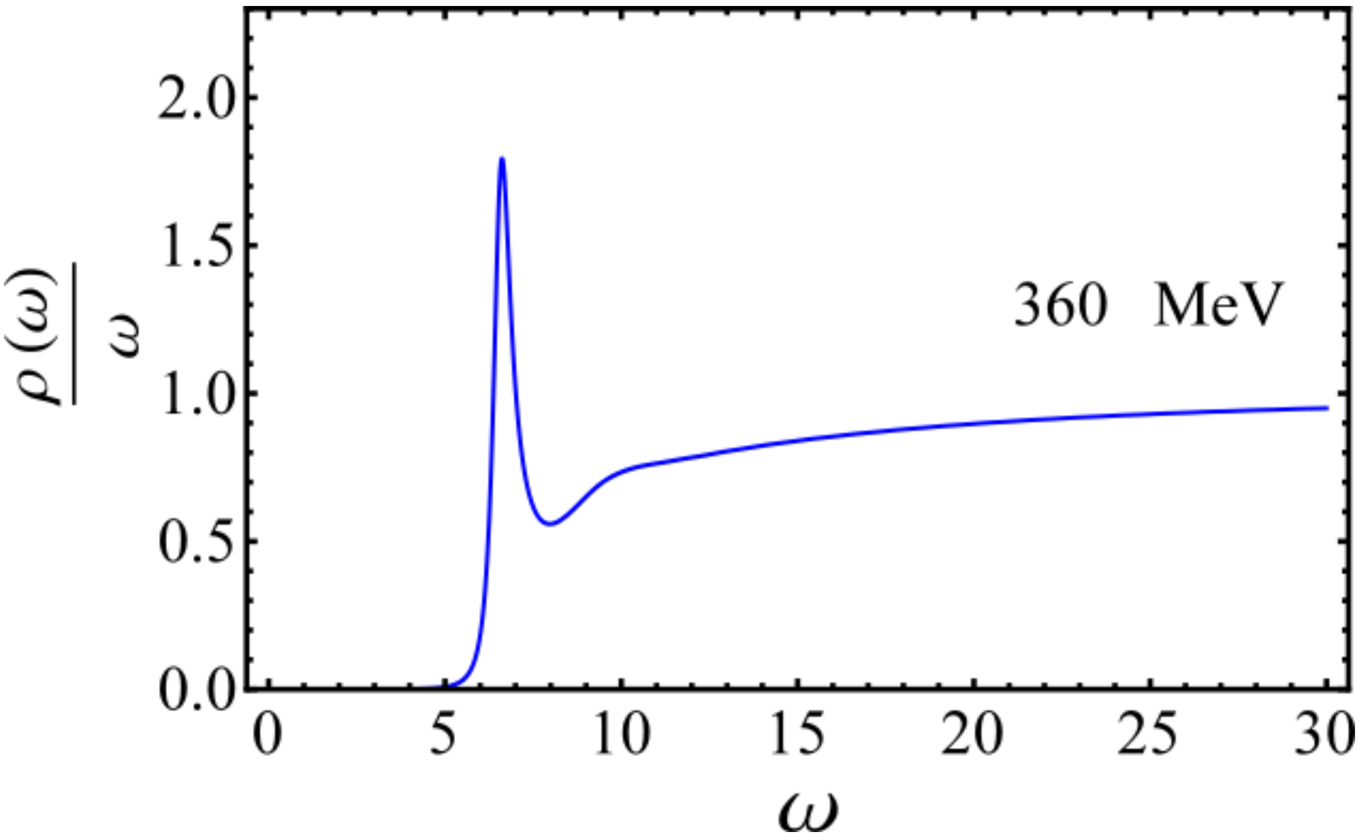




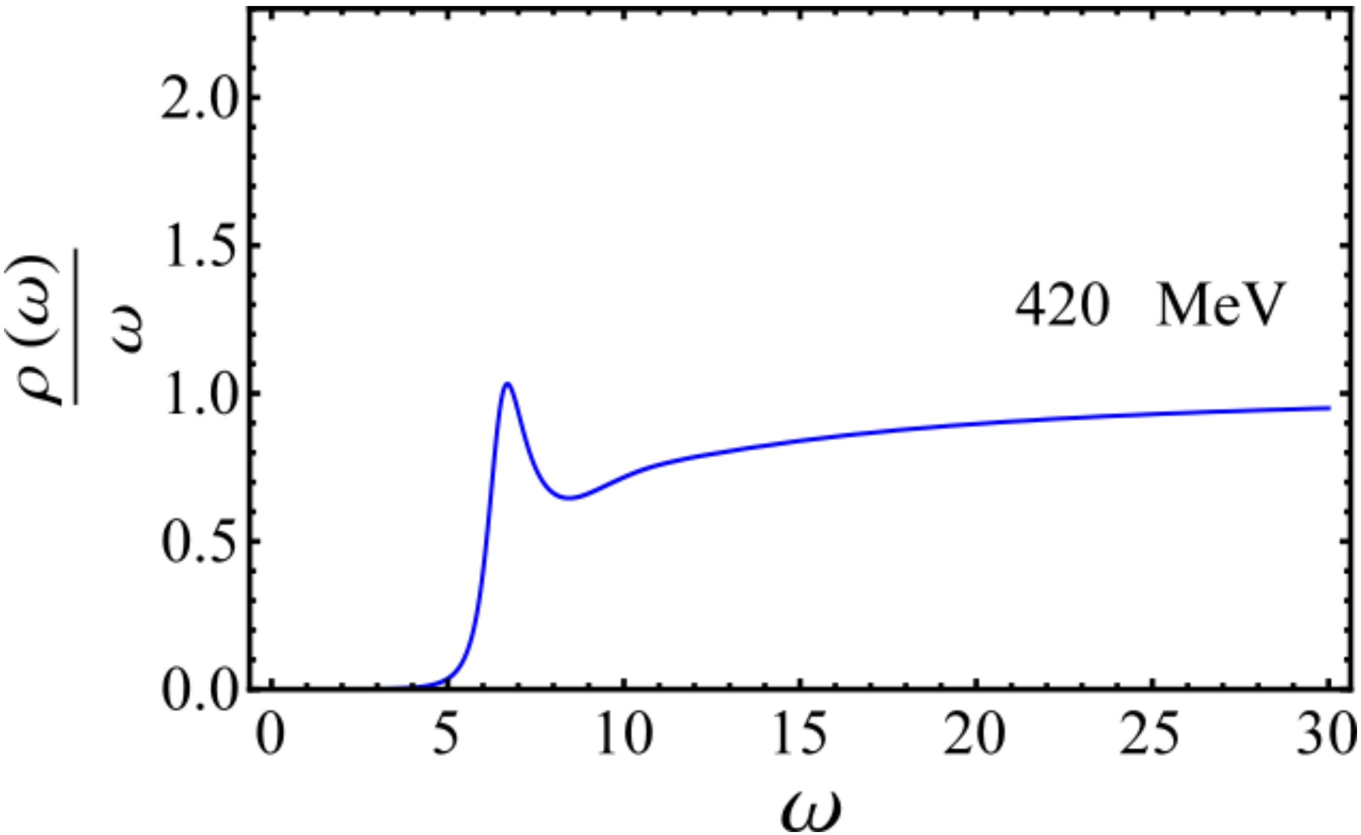
2.0
1.5
1.0
0.5
0.0
$\frac{\rho(\omega)}{\omega}$
220 MeV
0
5
10
15
20
25
30
ω



2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
$\frac{\rho(\omega)}{\omega}$
ω
300 MeV

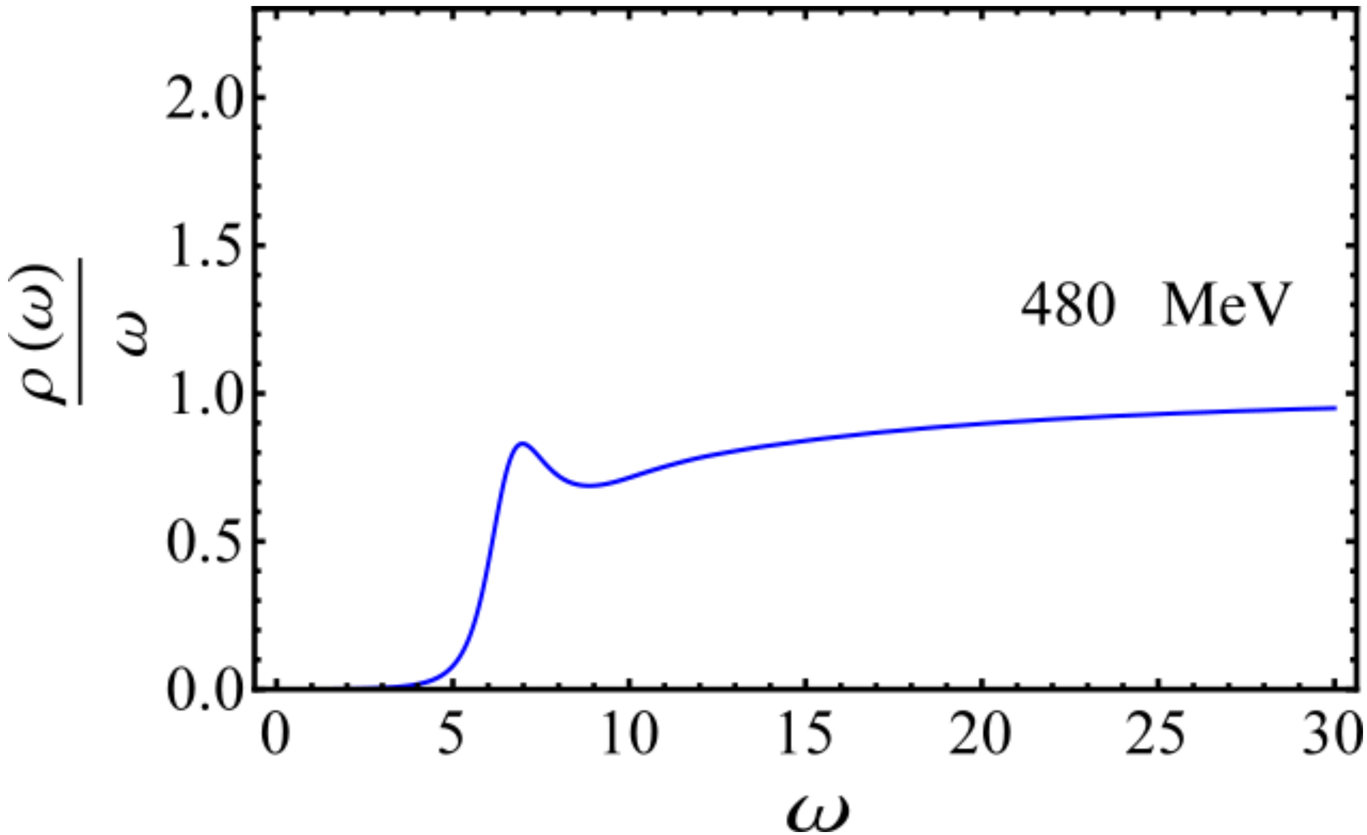


2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
ρ(ω)/ω
ω
360 MeV



$\frac{\rho(\omega)}{\omega}$
2.0
1.5
1.0
0.5
0.0
420 MeV
0
5
10
15
20
25
30
ω

Bottomonium Spectral function



In the limit of T $\rightarrow$ 0

Quasi-states $\rightarrow$ Dirac delta peaks of the meson states

Two point function at zero temperature:

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

Imaginary part: $f_n^2\, \delta(-p^2 - m_n^2)$

Data for $c\bar{c}$ vector mesons

$$J/\psi\,,\ \psi'\,,\ \psi''\,,\ \psi'''$$

Charmonium data			
	Masses (MeV)	$\Gamma_{V\to e^+e^-}$(keV)	Decay constants (MeV)
$1S$	3096.916 ± 0.011	5.547 ± 0.14	416.2 ± 5.3
$2S$	3686.109 ± 0.012	2.359 ± 0.04 c	296.1 ± 2.5
$3S$	4039 ± 1	0.86 ± 0.07	187.1 ± 7.6
$4S$	4421 ± 4	0.58 ± 0.07	160.8 ± 9.7

K. A. Olive *et al.* [Particle Data Group Collaboration], Chin. Phys. C **38**, 090001 (2014).

$$\langle 0|\, J_\mu(0)\, |n\rangle = \epsilon_\mu f_n m_n$$

Relation between decay constant and eletron-positron width

$$f_V^2 = \frac{3m_V\,\Gamma_{V\to e^+e^-}}{4\pi\alpha^2 c_V}$$

Data for $b\bar{b}$ vector mesons

$\Upsilon, \Upsilon', \ldots$

Bottomonium data			
	Masses (MeV)	$\Gamma_{V \to e^+e^-}$ (keV)	Decay constants (MeV)
$1S$	9460.3 ± 0.26	1.340 ± 0.018	715.0 ± 2.4
$2S$	10023.26 ± 0.32	0.612 ± 0.011	497.4 ± 2.2
$3S$	10355.2 ± 0.5	0.443 ± 0.008	430.1 ± 1.9
$4S$	10579.4 ± 1.2	0.272 ± 0.029	340.7 ± 9.1

The decay constants decrease with radial excitation level.

This behavior is not reproduced by the original AdS/QCD models like:

Hard wall, J. Polschinski, M.Strassler, 2002; H. Boschi-Filho, N. B. 2003.

Soft wall, A.Karch, E.Katz, D.T.Son and M.A.Stephanov, 2006.

D4-D8, T. Sakai, S. Sugimoto, 2005.

How can one calculate decay constants and masses from holography?

Correlator of gauge theory currents:

$$\int d^4x\, e^{-ip\cdot x} \langle 0 | \, J_\mu(x) J_\nu(0) \, | 0 \rangle = \left(p^2 \eta_{\mu\nu} - p_\mu p_\nu \right) \sum_{n=1}^{\infty} \frac{f_n^2}{(-p^2) - m_n^2 + i\epsilon}$$

Gauge string duality provides a tool to calculate the lefhand side of this equation.

Gauge string duality: vector fields in anti-de Sitter space work as sources for current correlators.
Model:

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

$$F_{mn} = \partial_m V_n - \partial_n V_m \qquad \phi(z) = k^2 z^2 + Mz + \tanh\left(\frac{1}{Mz} - \frac{k}{\sqrt{\Gamma}}\right)$$

$$\text{charmonium}: \quad k_c = 1.2\,\text{GeV}; \ \sqrt{\Gamma_c} = 0.55\,\text{GeV}; \ M_c = 2.2\,\text{GeV};$$

$$\text{bottomonium}: \quad k_b = 2.45\,\text{GeV}; \ \sqrt{\Gamma_b} = 1.55\,\text{GeV}; \ M_b = 6.2\,\text{GeV}.$$

3 parameters ("related to"): **quark mass, string tension , large mass scale** associated with the mass change in the non hadronic transition: heavy meson ➔ leptons

Holographic (and experimental) Results for Charmonium		
State	Mass (MeV)	Decay constants (MeV)
$1S$	$2943\ (3096.916 \pm 0.011)$	$399\,(416 \pm 5.3)$
$2S$	$3959\ (3686.109 \pm 0.012)$	$255\,(296.1 \pm 2.5)$
$3S$	$4757\ (4039 \pm 1)$	$198\,(187.1 \pm 7.6)$
$4S$	$5426\ (4421 \pm 4)$	$169\,(160.8 \pm 9.7)$

Holographic (and experimental) Results for Bottomonium		
State	Mass (MeV)	Decay constants (MeV)
$1S$	$6905\ (9460.3 \pm 0.26)$	$719\,(715.0 \pm 2.4)$
$2S$	$8871\,(10023.26 \pm 0.32)$	$521\,(497.4 \pm 2.2)$
$3S$	$10442\ (10355.2 \pm 0.5)$	$427\,(430.1 \pm 1.9)$
$4S$	$11772\,(10579.4 \pm 1.2)$	$375\,(340.7 \pm 9.1)$

Finite temperature and density:

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

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

$$T = \frac{|f'(z)|_{(z=z_h)}}{4\pi} = \frac{1}{\pi z_h} - \frac{q^2 z_h^5}{2\pi}$$

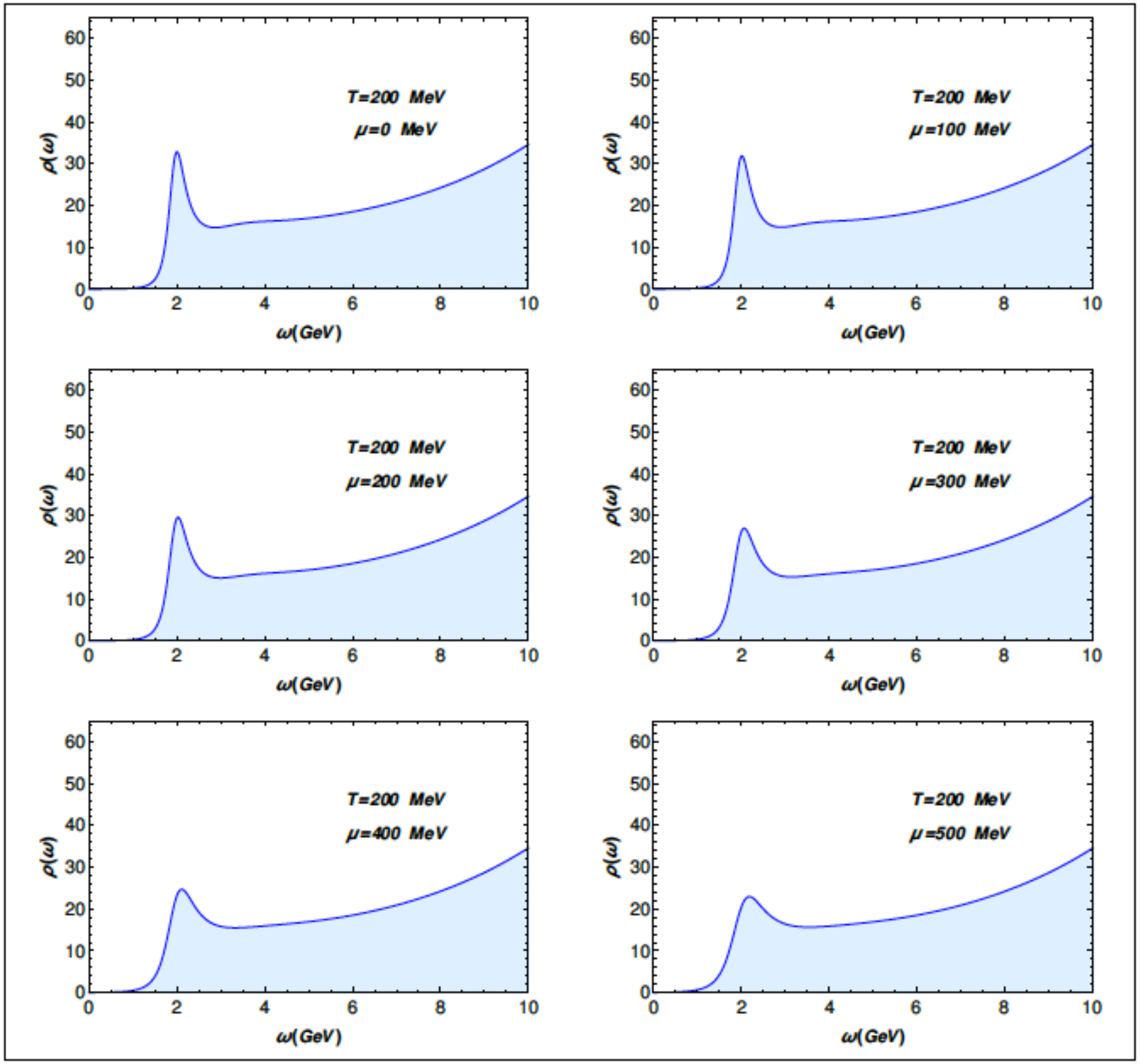
Finite temperature and background B field

$$ds^2 = \frac{R^2}{z^2}\left(-f(z)dt^2 + \frac{dz^2}{f(z)} + (dx_1^2 + dx_2^2)d(z) + dx_3^2 q(z)\right)$$

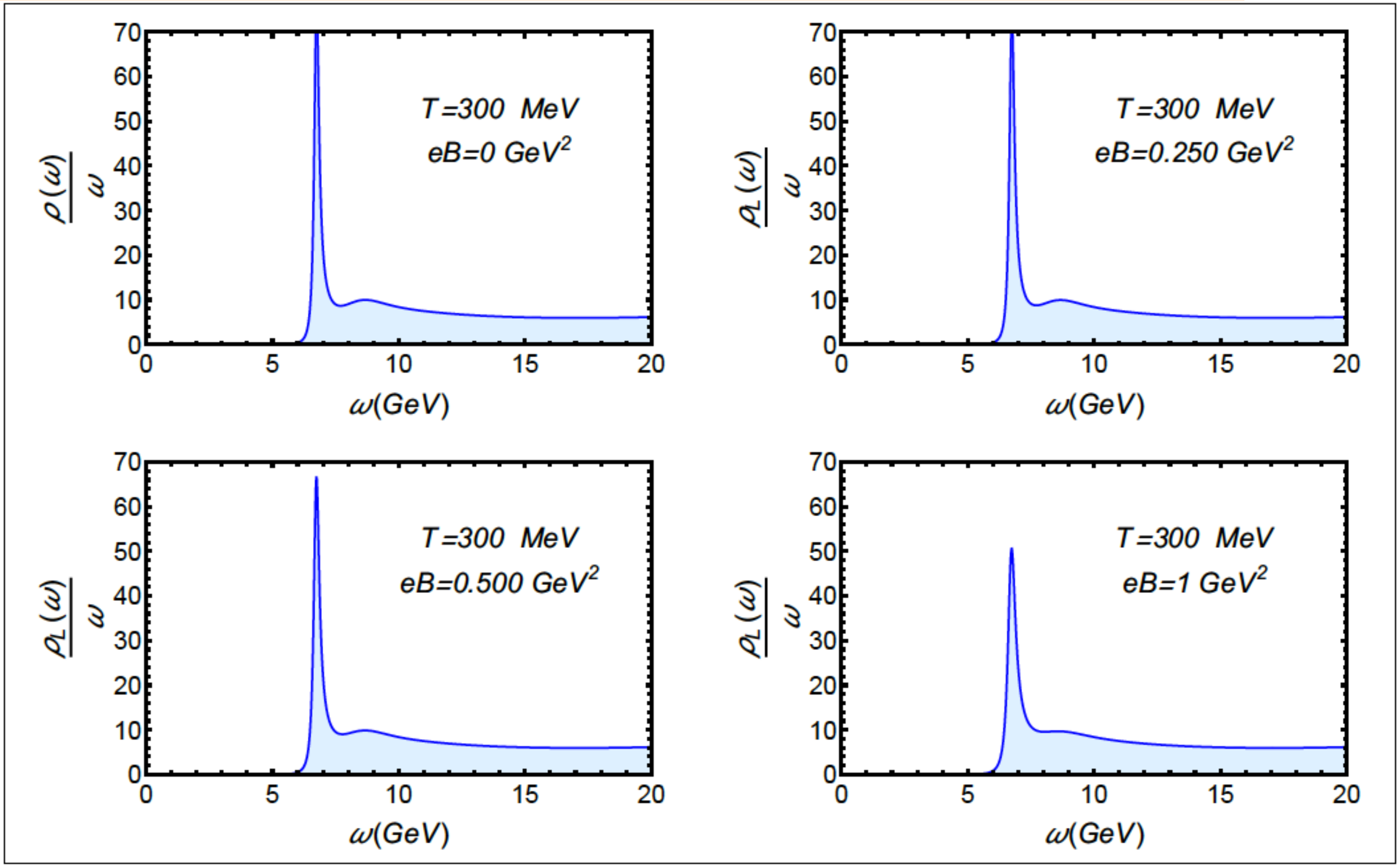
$$f(z) = 1 - \frac{z^4}{z_h^4} + \frac{2}{3}\frac{e^2B^2z^4}{1.6^2}\ln\left(\frac{z}{z_h}\right)$$

d(z) , q(z) = functions of T , B.

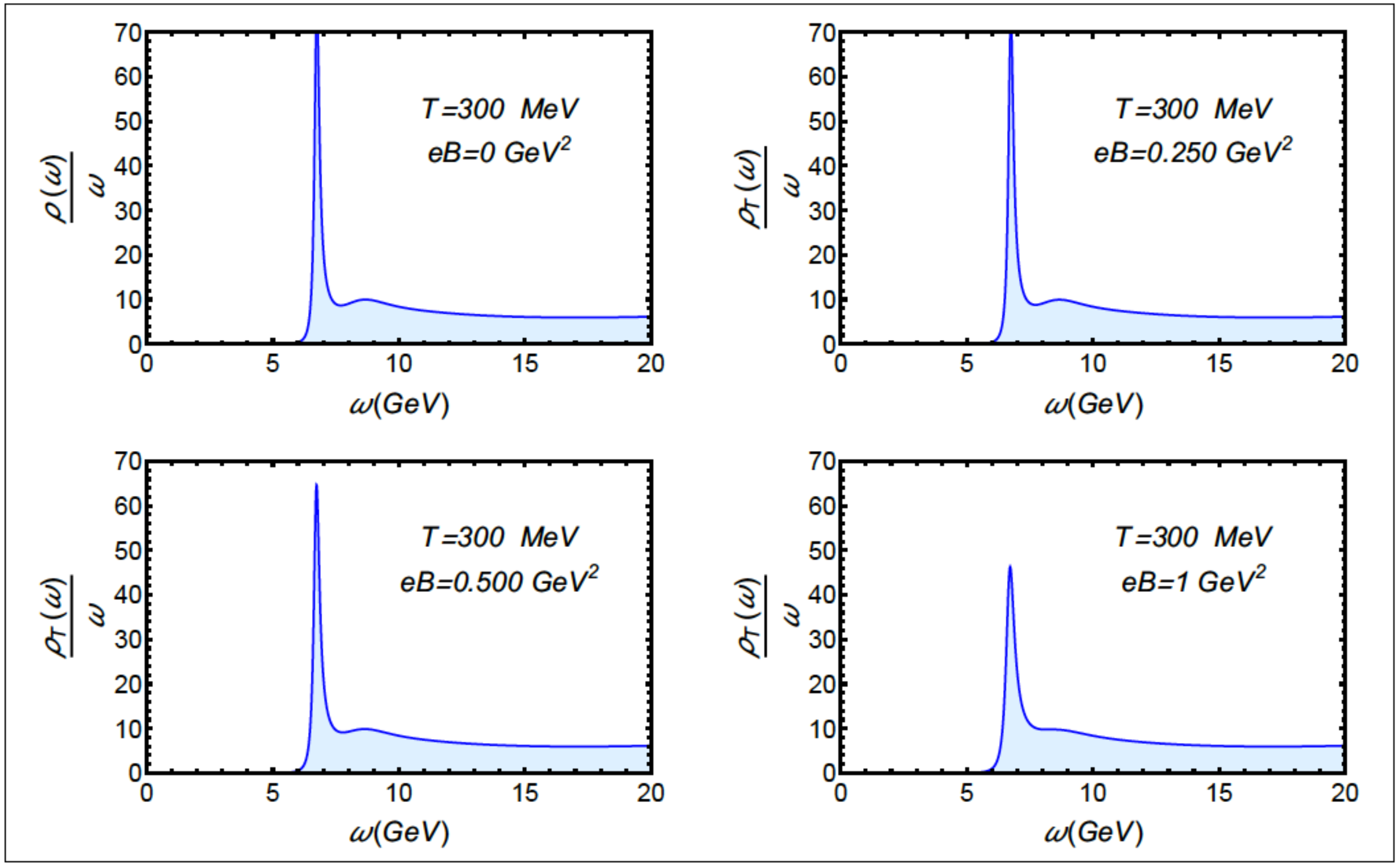
Spectral functions. Density effect in charmonium



Effect of magnetic field in Bottomonium. Magnetic field paralell to polarization



Effect of magnetic field in Bottomonium. Magnetic field perpendicular to polarization



Final remark:

The background geometry represents just the effect of the magnetic field on the plasma.

Magnetic fields could have also a direct effect of the charged constituents of the heavy mesons.
Dudal and Mertens, Phys. Rev. D 91, 086002 (2015)
Phys. Rev. D 97, 054035 (2018).
DBI like action.

Future plan: test the direct effect in this new holographic model.

Thank you !!