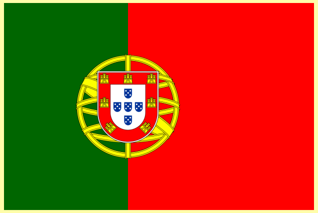
Holographic model for heavy vector mesons

Excited QCD, Sintra , Portugal, 2017.



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Based in arXiv.: 1507.04708, 1604.08296 , 1704.05038

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Motivation:

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

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

First step:

Find a model that provides masses and decay constants for mesons in the vacuum.

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	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

Υ, Υ', ...

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 previous AdS/QCD models.

How can one calculate decay constants and masses from holography?

Correlator of gauge theory currents:

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

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

In order to find the masses and decay constants one has to express the gauge theory correlator as a sum of propagator poles.

Standard way of calculating decay constants using AdS/QCD soft wall model. Vector fields in anti-de Sitter space work as sources for current correlators:

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

$$F_{mn} = \partial_m V_n - \partial_n V_m \qquad \Phi = k^2 z^2$$

$$\langle 0|\, J_\mu(x) J_\nu(y)\, |0\rangle = \frac{\delta}{\delta V^{0\mu}(x)} \frac{\delta}{\delta V^{0\nu}(y)} \exp\left(-I_{onshell}\right)$$

$$I_{on\,shell} = -\frac{1}{2\tilde{g}_5^2} \int d^4x \left[\frac{e^{-k^2 z^2}}{z} V_\mu \partial_z V^\mu \right]_{z\to 0}$$

How do we find poles in this expression?

The field solutions are written as :

$$V_\mu(p,z) = v(p,z) V_\mu^0(p)$$

where the "bulk to boundary propagator" satisfies:

$$v(p, z=0) = 1 \,.$$

and can be written as:

$$v(p,z) = -\left[\frac{e^{-k^2 z'^2} \partial_{z'} G(p, z', z)}{z'} \right]_{z' \to 0}$$

where:

$$G(p,z,z') = \sum_{n=1}^{\infty} \frac{\phi_n(z)\phi_n(z')}{(-p^2) - m_n^2}$$

Here are the propagator poles !

Result for some AdS/QCD models:

Soft wall: decay constants are degenerate
Hard wall model: they increase with excitation level

Alternative➔The correlators are not calculated at the boundary of AdS space but at a finite position ➔ UV scale
Evans, Tedder, 2006
Afonin, 2011,12

Heavy vector mesons: 1507.04708: the decay process depend on an extra energy parameter (Ultraviolet scale). ➔ the decay constants decrease with excitation level.

Two point correlation function:

$$\Pi(p^2) = \frac{1}{2\tilde{g}_5^2}\frac{e^{-k^2 z_0^2}\, U(1 - p^2/4k^2, 1, k^2 z_0^2)}{U(-p^2/4k^2, 0, k^2 z_0^2)}$$

Prescription for masses and decay constants :

$$\lim_{p^2 \to p_n^2} \Pi(p^2) \approx \frac{f_n^2}{(-p^2) + p_n^2}$$

Results for Charmonium states		
	Masses	Decay constants
$1S$	2410	258.8
$2S$	3409	251.7
$3S$	4174	245.9
$4S$	4819	241.0

Results for Bottomonium states		
	Masses	Decay constants
$1S$	7011	627
$2S$	9883	574
$3S$	12077	538
$4S$	13923	512

MeV

Remark

Much better results for masses with a different model, But very bad decay constants !!!!! ArXiv 1511.06373 Parameters here: string tension quark masses.

Charmonium Results	
State	Mass (MeV)
$1S$	3075.5 (0.68%)
$2S$	3664.5 (0.58%)
$3S$	4118.2 (1.20%)
$4S$	4502.5 (1.84%)

Bottomonium Results	
State	Mass (MeV)
$1S$	8662.37 (8.43%)
$2S$	9625.72 (3.96%)
$3S$	10383.5 (0.27%)
$4S$	11033.6 (4.28%)
$5S$	11613.7 (6.94%)
$6S$	12143.2 (10.2%)

Description of the thermal dissociation of charmonium and bottomonium vector states inside a quark gluon plasma.

Gauge/String duality at finite temperature.

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

Black hole in anti-de Sitter space	↔	Gauge Theory at finite temperature

The Hawking temperature of the black hole is the temperature of the gauge theory.

Vector meson currents described by a vector field in a finite temperature soft wall background with UV cutoff:

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

where:

$$F_{mn} = \partial_m V_n - \partial_n V_m \;\; ; \;\; \Phi = k^2 z^2$$

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

$$f(z) = 1 - z^4 / z_h^4$$

On shell action. Note the UV cut off: $1/z_0$

$$I_{on\,shell} = -\frac{1}{2g_5^2}\int d^4x\ [e^{-k^2z^2}\sqrt{-g}\,g^{zz}g^{\mu\nu}V_\mu\partial_z V_\nu]|_{z\to z_0}^{z\to z_h}$$

$$V_\mu(q,z) = v(q,z)V_\mu^0(q)$$

Son, Starinets prescription:

$$I_{on\,shell} = \int d^4q\ [V_\mu^{0*}(q)\mathcal{F}^{\mu\nu}(z,p)V_\nu^0(q)]_{z\to z_0}$$

$$\mathcal{F}^{\mu\nu}(z,q) = \frac{1}{2g_5^2}e^{-k^2z^2}\sqrt{-g}\,g^{zz}g^{\mu\nu}v^*(q,z)\partial_z v(q,z)]$$

Retarded Green's function

$$G_R^{\mu\nu}(q) = \mathcal{F}^{\mu\nu}(z=z_0,q)$$

Thermal spectral function

$$\rho^{\mu\nu}(q) = -\mathcal{I}m\{G_R^{\mu\nu}(q)\}$$

Vector mesons at rest $q^\mu = (\omega, \vec{0})$

Non trivial B.C. ➔ **Incoming wave at the horizon**

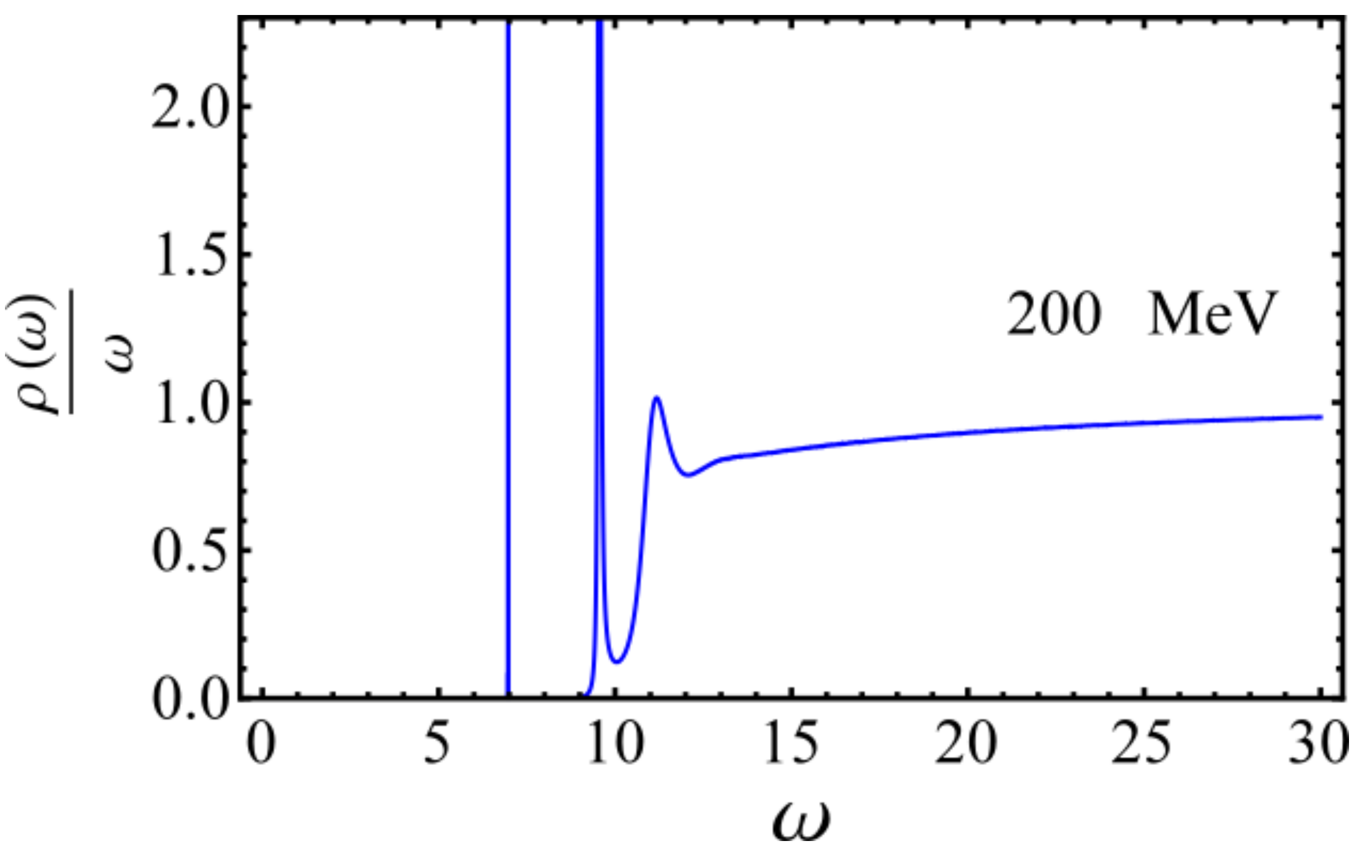
Parameters that provide the best fit for masses and decay constants in the zero temperature case:

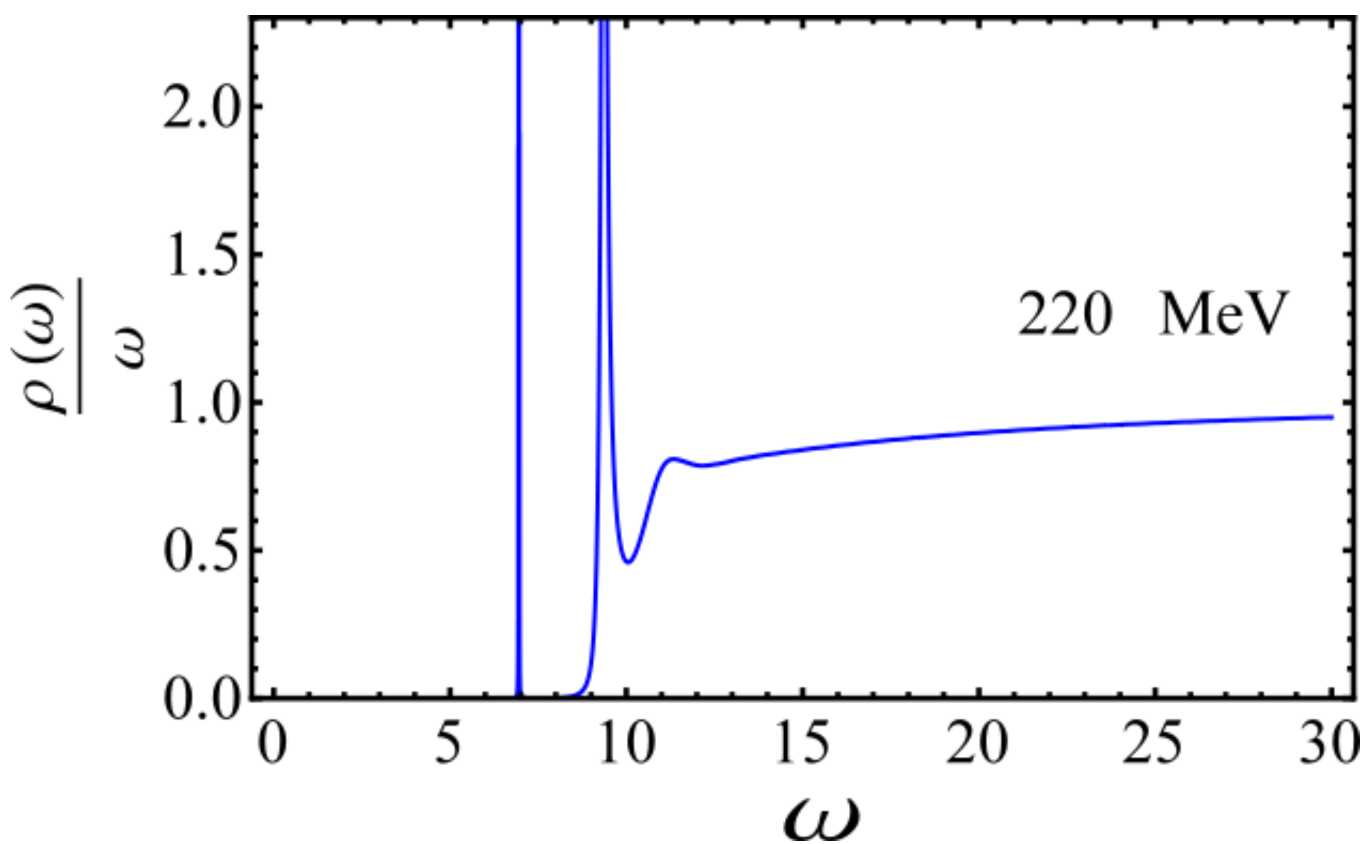
$$k_c = 1.2GeV;\ k_b = 3.4GeV;\ 1/z_0 = 12.5GeV$$

Using these parameters at finite temperature one finds the plots shown in the sequence.See: arXiv **1604.08296**

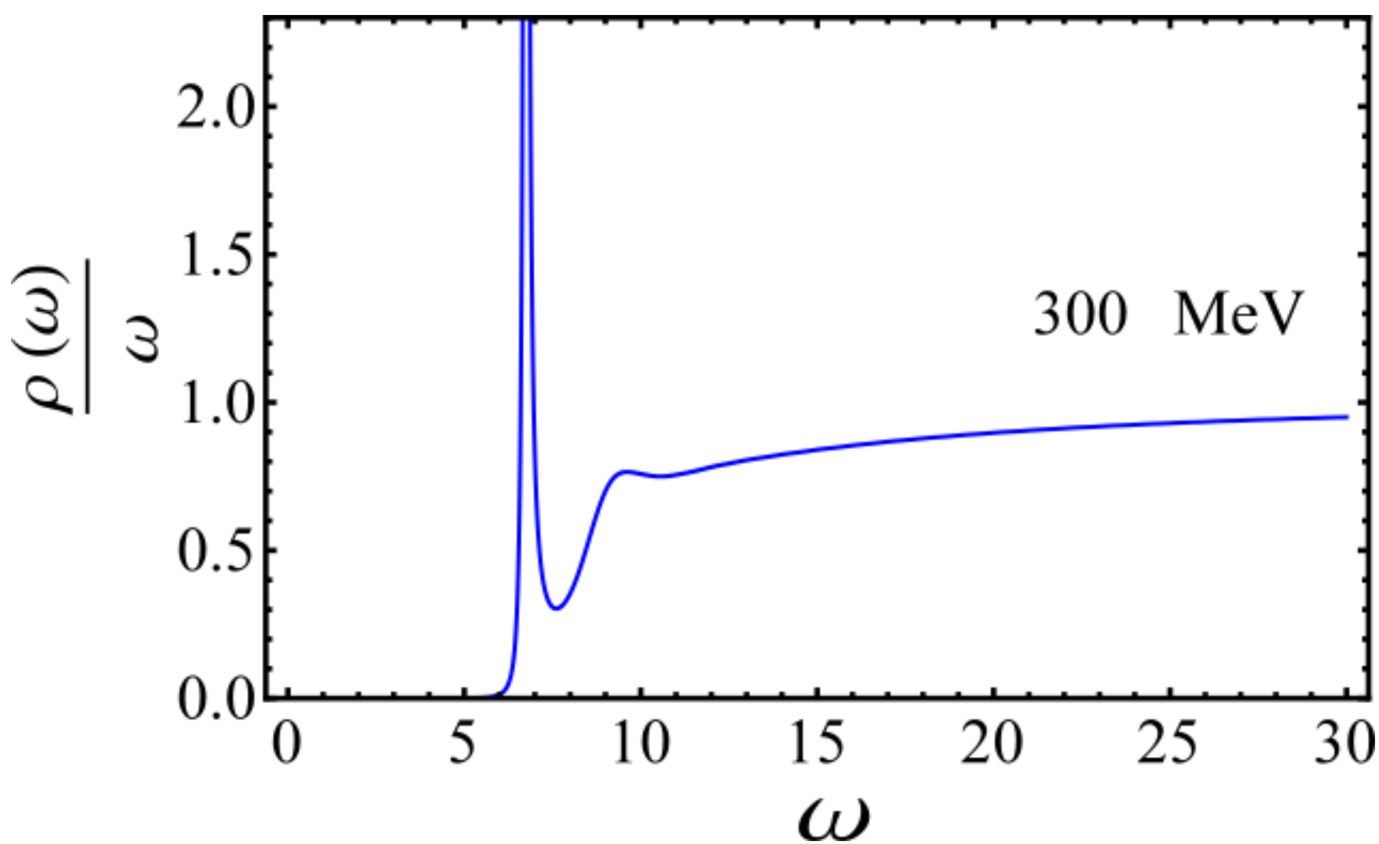
(T_c = 191 MeV)

Bottomonium spectral function.

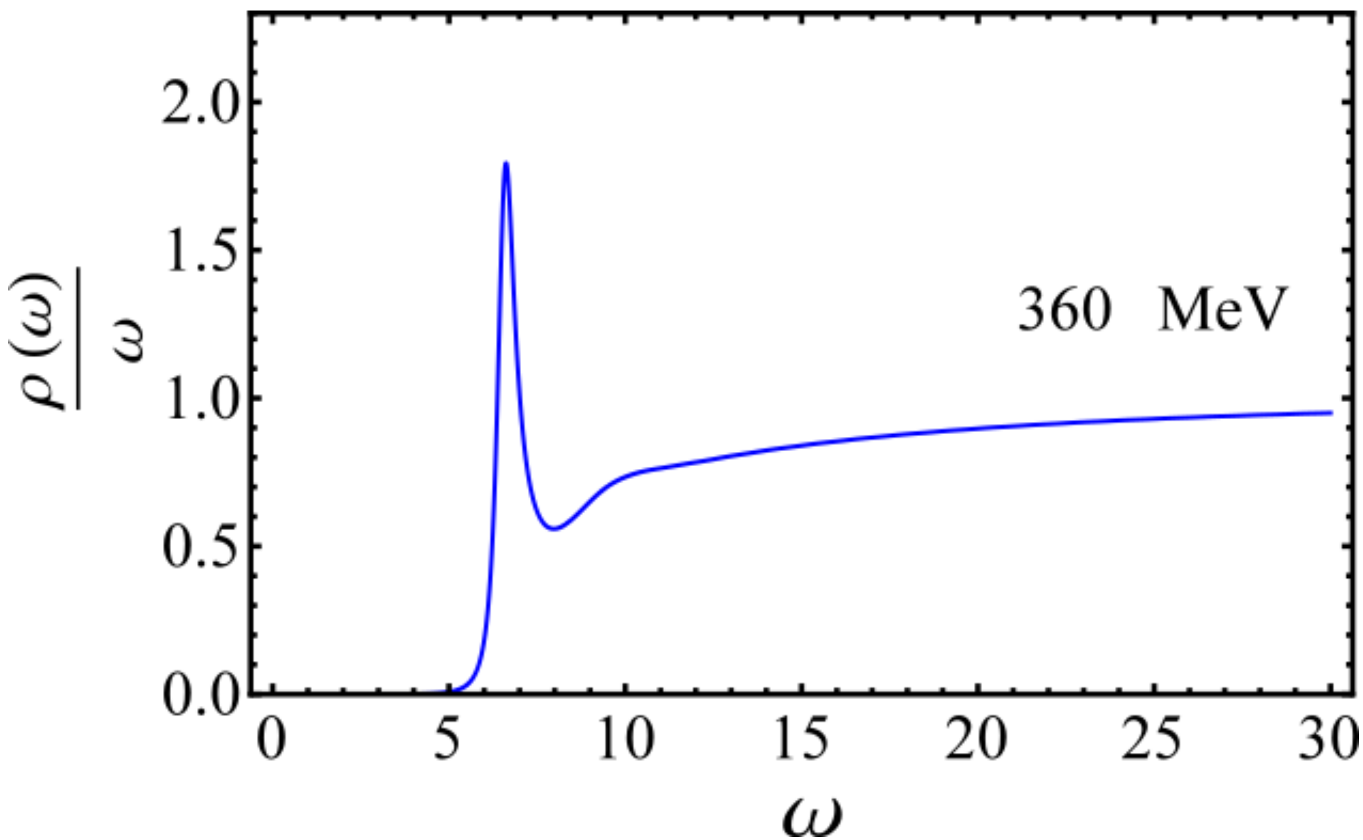




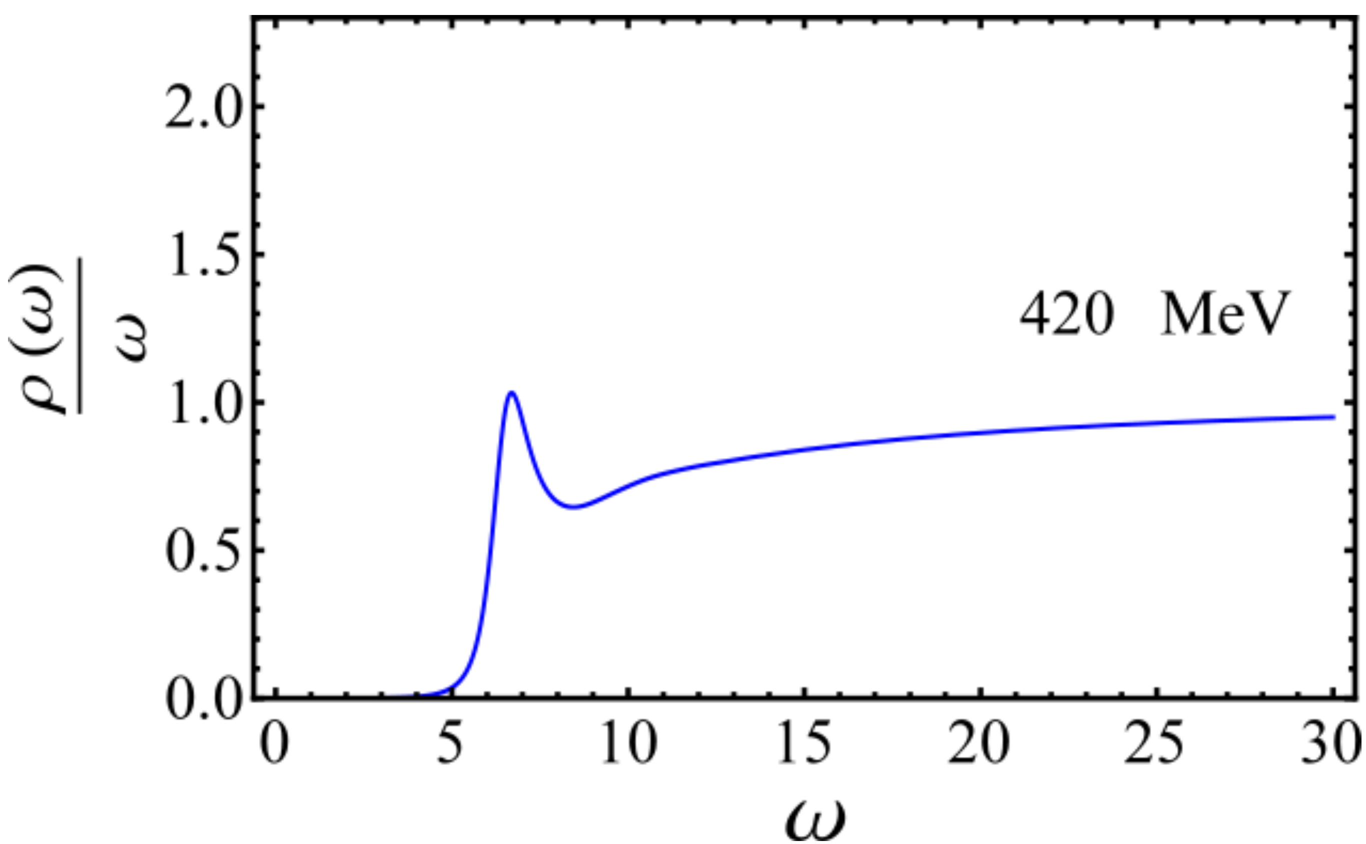
220 MeV
$\frac{\rho(\omega)}{\omega}$
ω
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
25
30



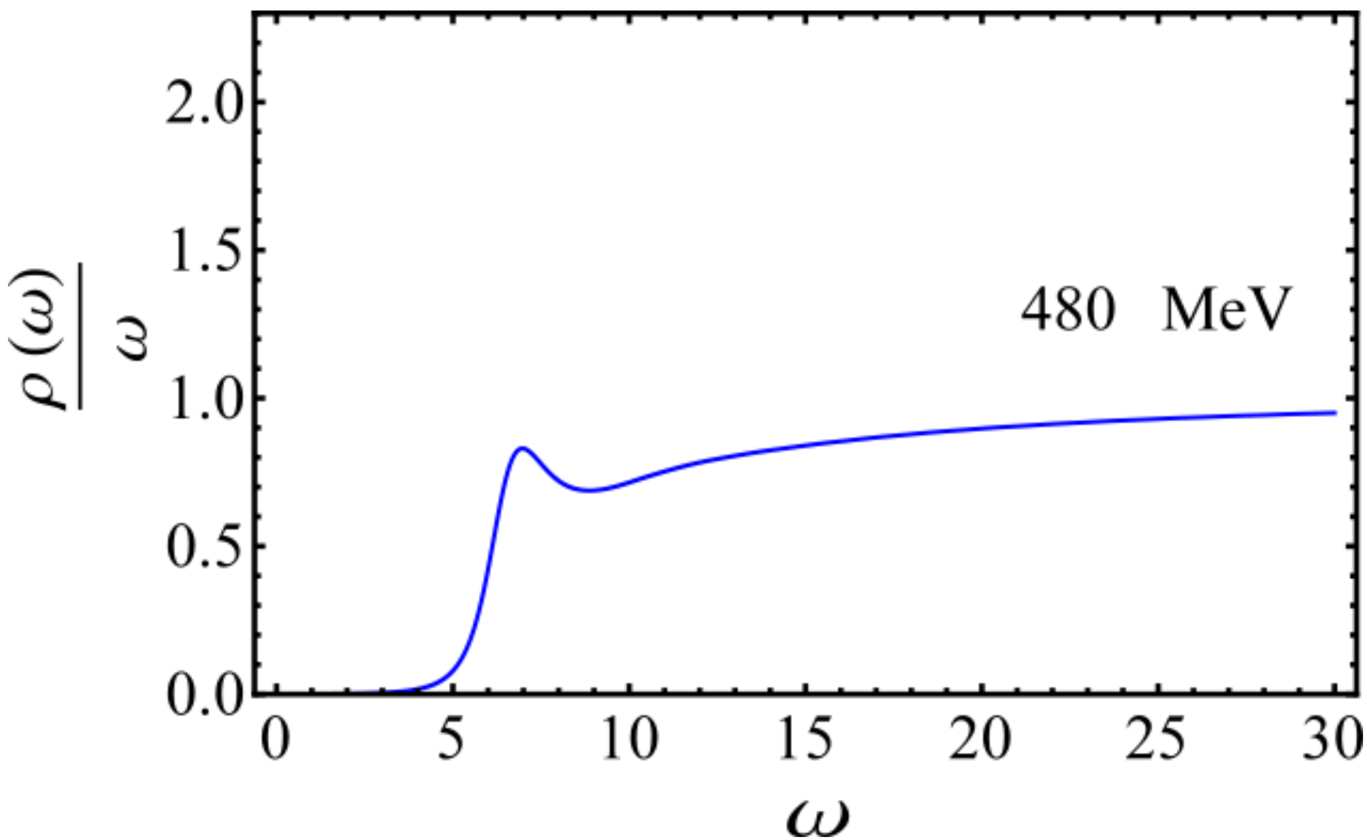
$\frac{\rho(\omega)}{\omega}$
2.0
1.5
1.0
0.5
0.0
300 MeV
0
5
10
15
20
25
30
ω



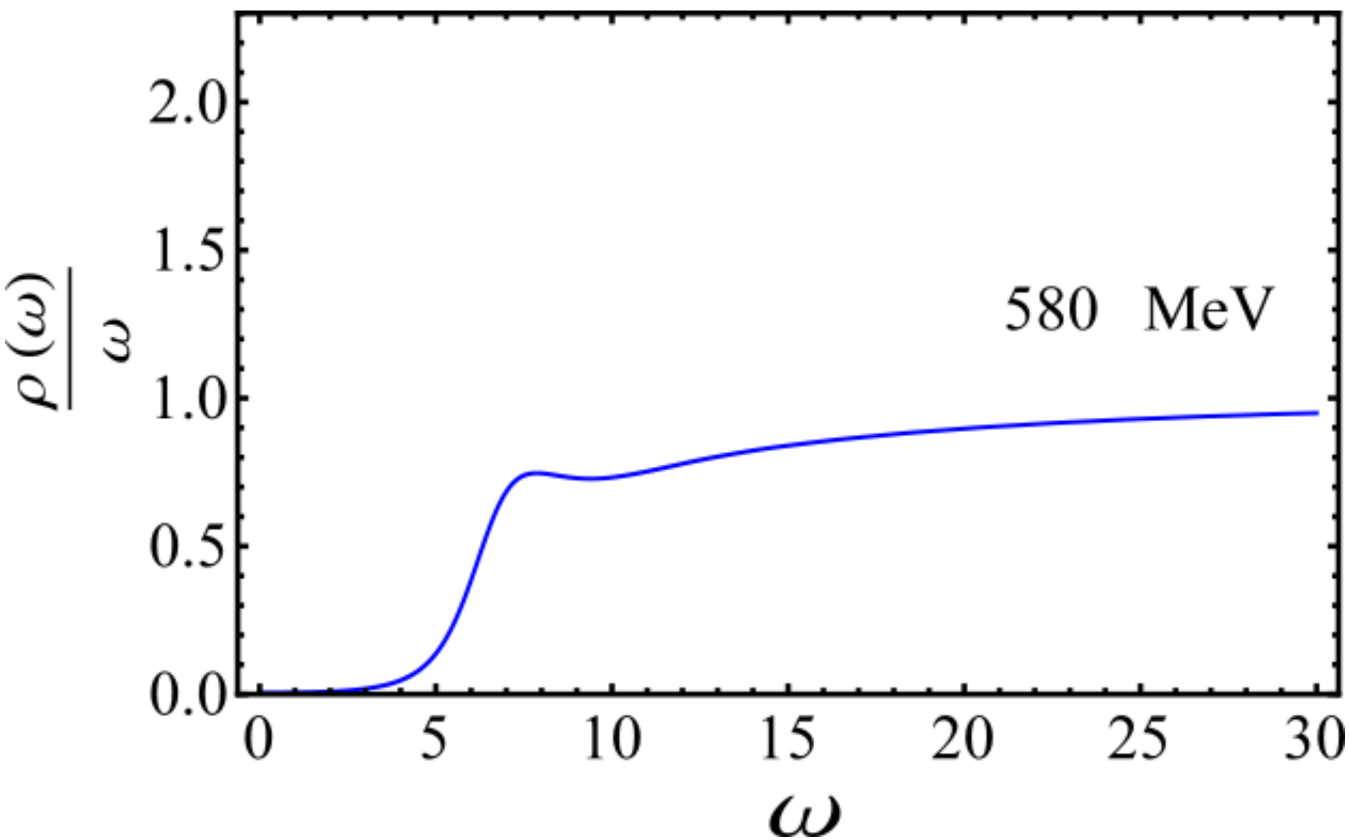
360 MeV
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
ω
ρ(ω)/ω



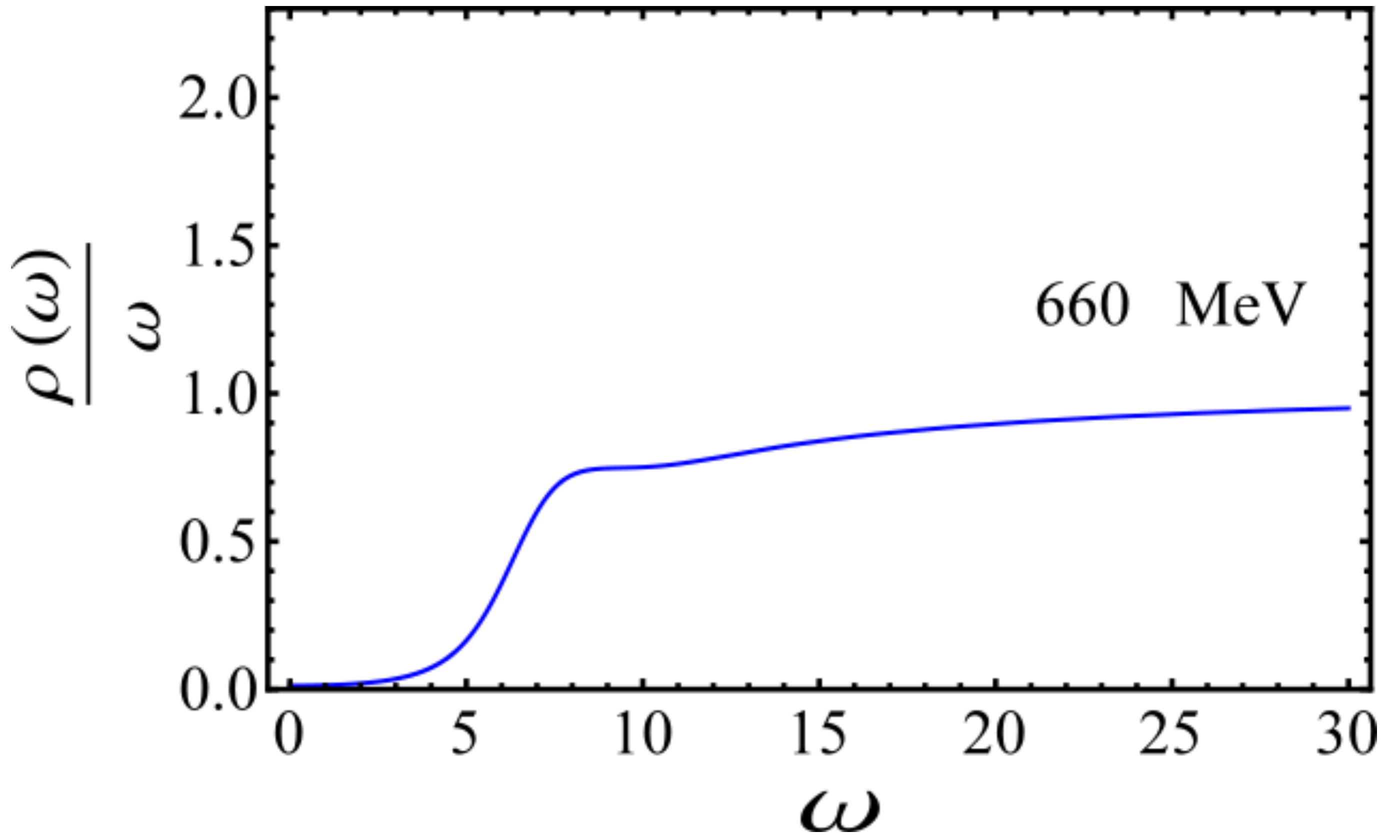
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
ω
ρ(ω)/ω
420 MeV



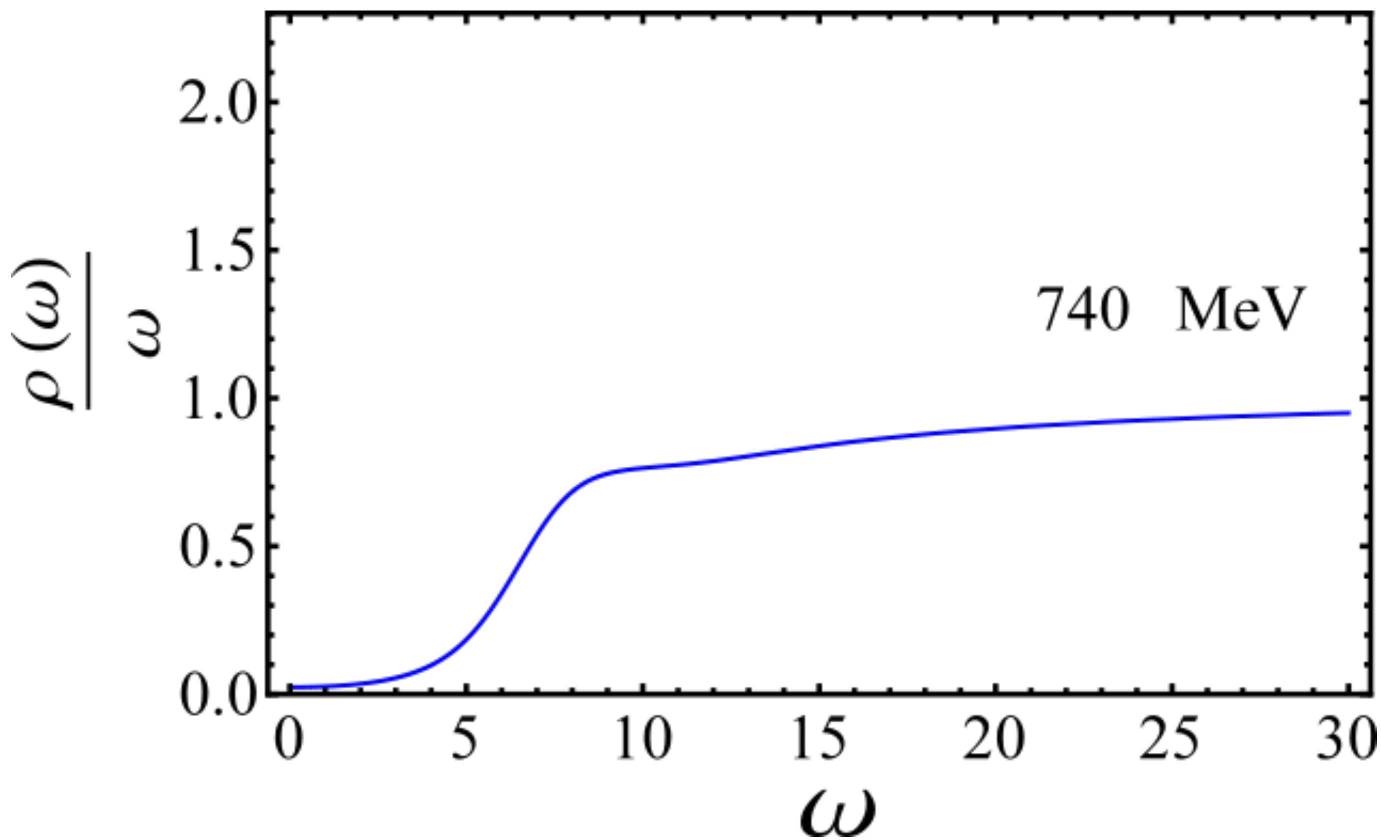
2.0
1.5
1.0
0.5
0.0
$\frac{\rho(\omega)}{\omega}$
480 MeV
0
5
10
15
20
25
30
ω



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

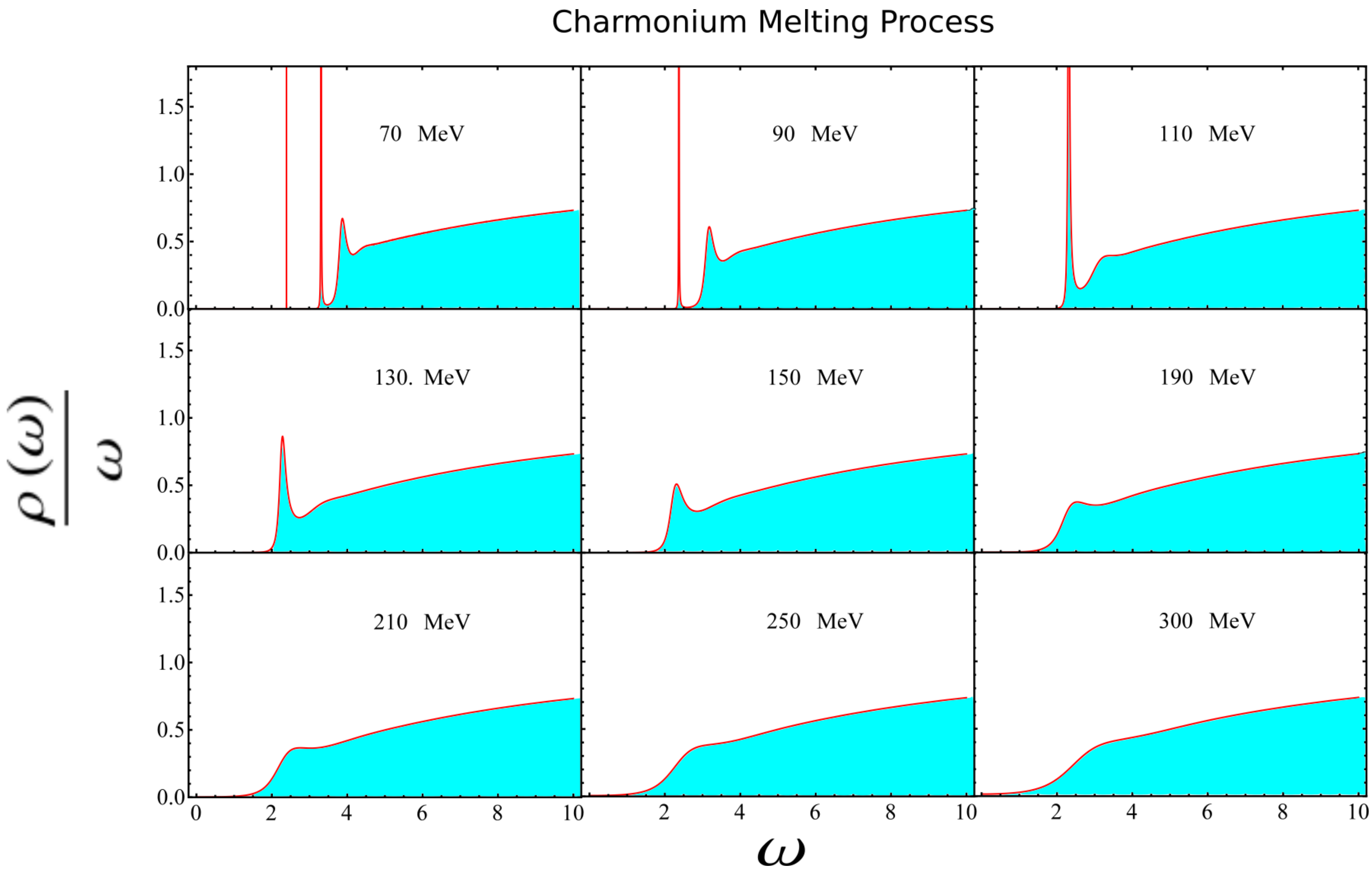


2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
$\frac{\rho(\omega)}{\omega}$
ω
660 MeV



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

Charmonium melting



The heavy vector meson states 1S, 2S, 3S melt at different temperatures.

Bottomonium states melt at higher temperatures than charmonium states.

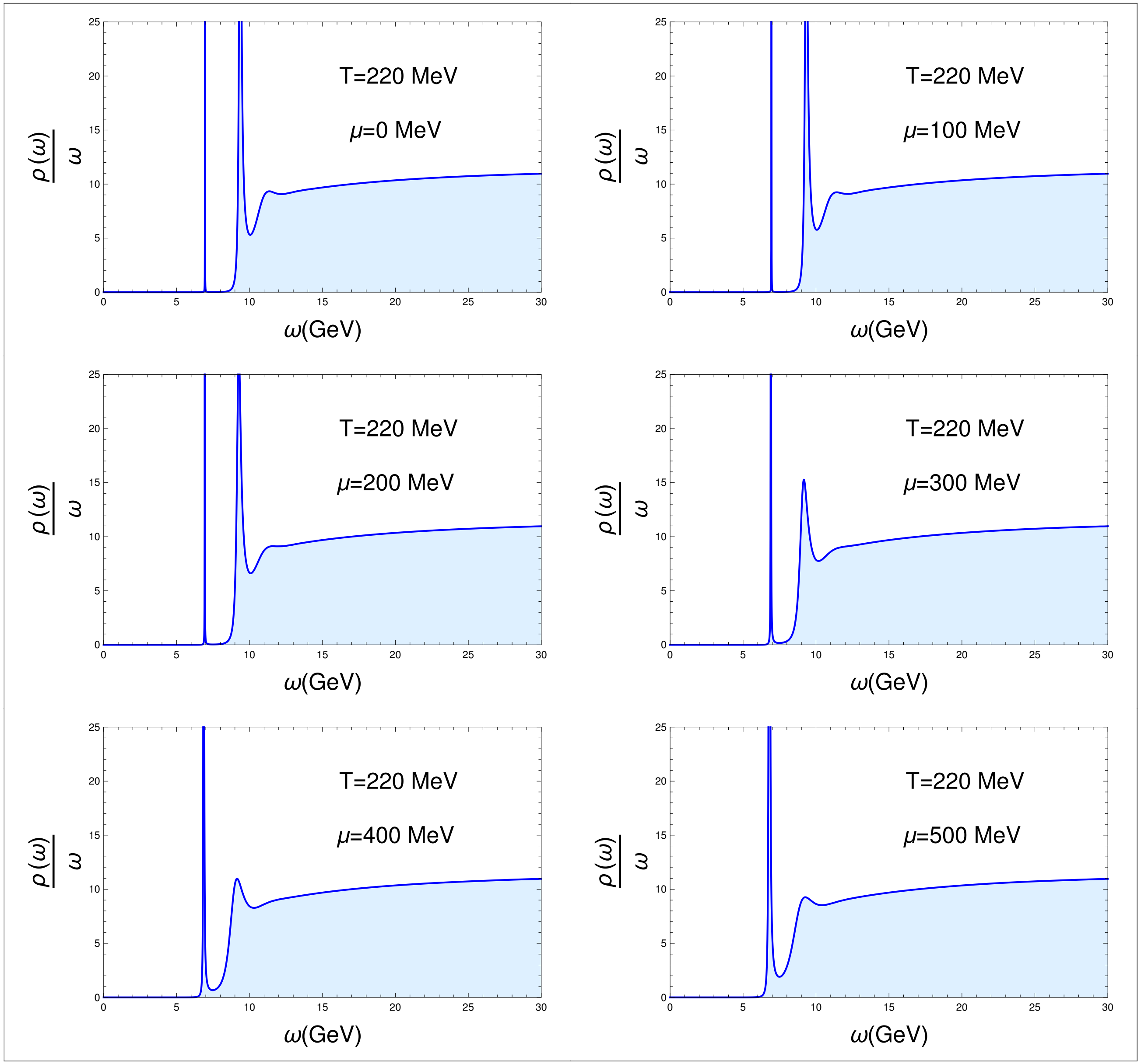
The model separates very clearly the 3 states.

Possibility of investigating the temperature of the plasma.

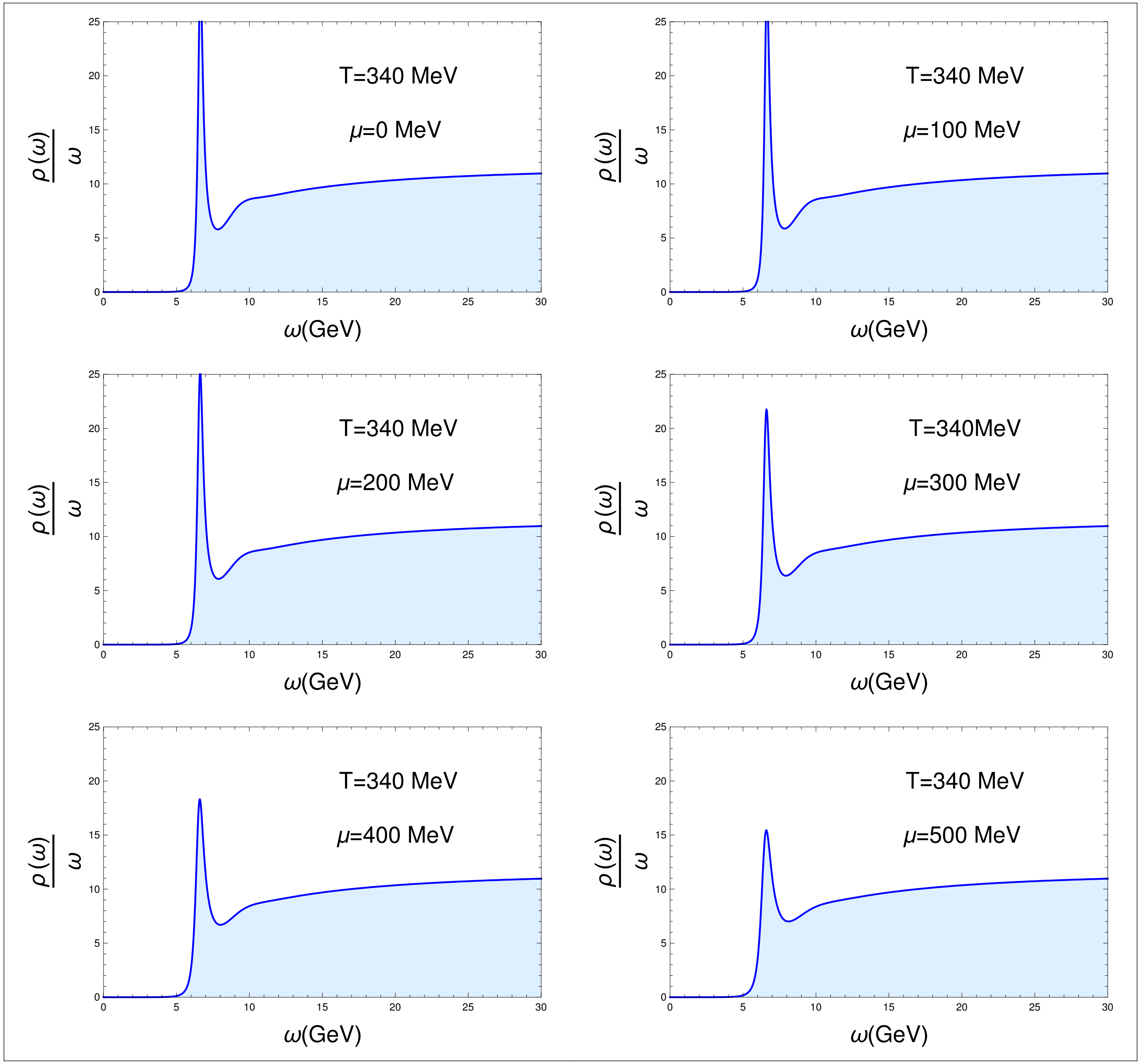
Remark: in lattice simulations the 1S, 2S, 3S states get mixed (same quantum numbers).
So it is not simple (presently) to describe the thermal behavior of the states.

Plasma at finite density (and temperature)

→ Charged Black Hole arXiv. 1704.05038



T=220 MeV
μ=0 MeV
μ=100 MeV
μ=200 MeV
μ=300 MeV
μ=400 MeV
μ=500 MeV
ρ(ω)/ω
ω(GeV)



T=340 MeV
μ=0 MeV
T=340 MeV
μ=100 MeV
T=340 MeV
μ=200 MeV
T=340MeV
μ=300 MeV
T=340 MeV
μ=400 MeV
T=340 MeV
μ=500 MeV
ρ(ω)/ω
ω(GeV)

The intervals of chemical potentials where the peaks dissociate are consistent with QCD expectations.

Thank you !!