Perspectives of In-Medium Quarkonium Behaviour

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Quarkonia: Probes of Thermal Properties of Media in

$$\Downarrow \qquad\qquad\qquad\qquad \Downarrow$$

Statistical QCD $\stackrel{?}{=}$ **Nuclear Collisions**

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- **Quarkonium Survival in the Quark-Gluon Plasma**
- **Quarkonium Production, Survival, Enhancement in Nuclear Collisions**

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Here address the first:

quarkonia in finite T lattice QCD & in potential studies

• Quarkonium Survival in Finite T Lattice QCD

Determine $Q\bar{Q}$ spectrum $\sigma(\omega, T)$:

quarkonium correlators at fixed quantum numbers i

$$G_i(\tau, T) = \int d\omega \sigma_i(\omega, T) K(\tau, \omega, T)$$

normalize to correlators $G_i^0(\tau, T)$ with $\sigma_i(\omega, T = 0)$, schematically

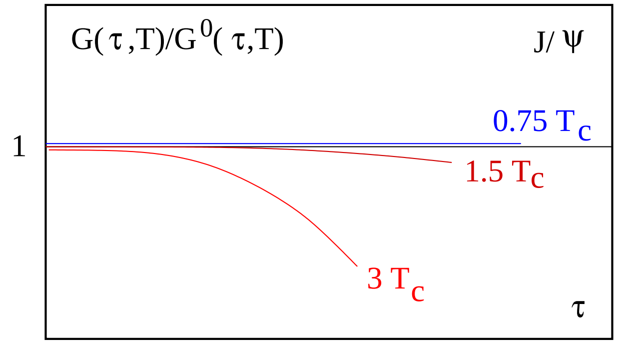
$$\sigma_i(\omega, T = 0) \sim A_i(0)\delta(\omega - M_i) + A_c(\omega, 0)\theta(\omega - \omega_c)$$

sharp resonance plus continuum

resonance weight $\sim$ wave function at origin

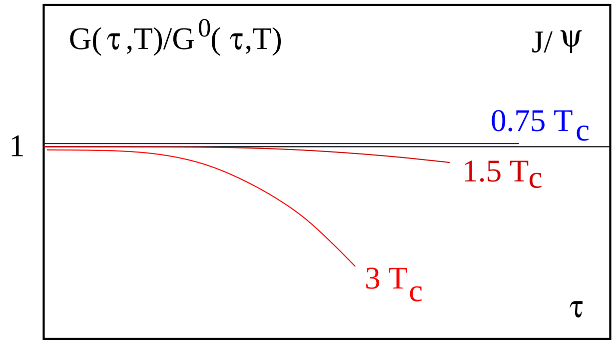
$$A_i(0) \sim |\Phi_i(r = 0, T = 0)|^2$$

calculate correlator ratio for J/ψ:



no change with T up to about 1.5 T_c

calculate correlator ratio for $J/\psi(1S)$:



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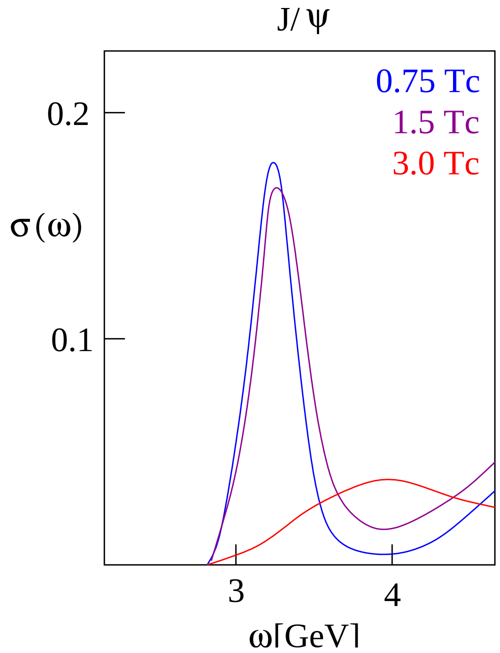
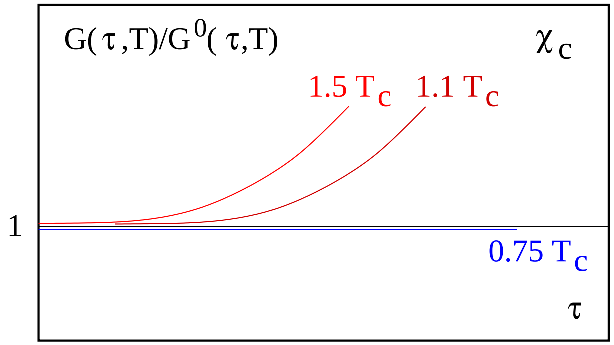


reconstruct $\sigma(\omega, T)$ via MEM:

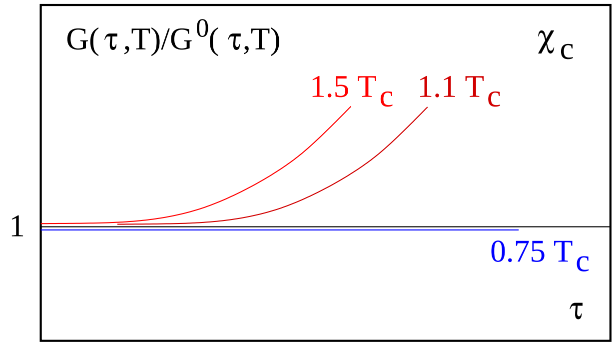
$J/\psi(1S)$ “spectrum” unmodified up to about 1.5 T_c

In contrast, χ_c(1P)



strongly modified at $\sim 1.1\ T_c$

In contrast, $\chi_c(1P)$



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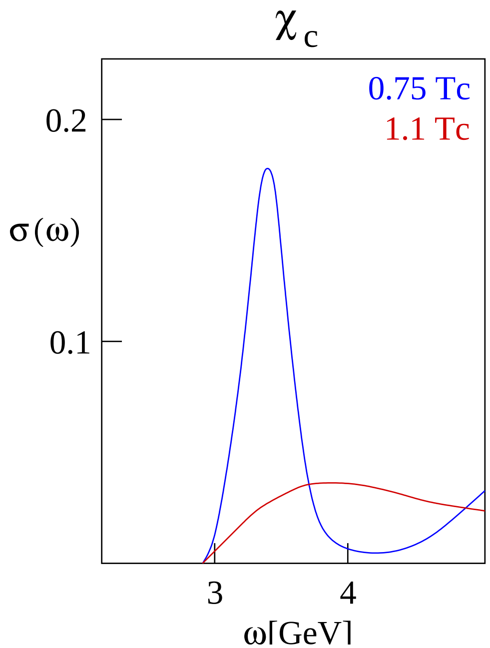
$\chi_c(1P)$ already dissolved
at about $1.1\ T_c$



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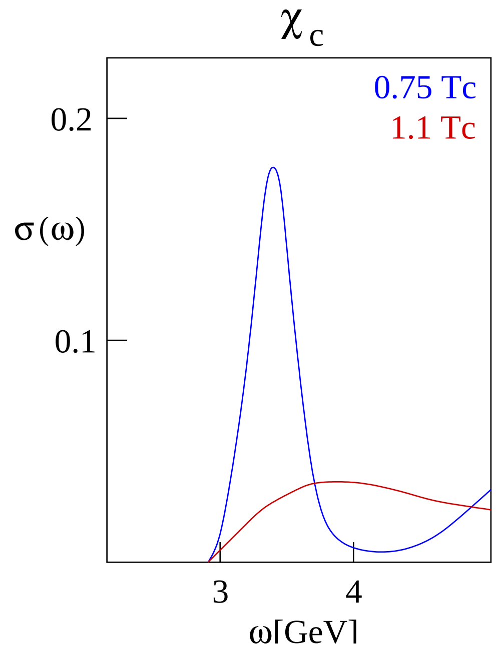

Parenthetic Comment:

Is this really true?

Zero momentum modes? [Umeda]

What do these results imply for J/ψ survival?

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- **one solution to $G_i(\omega,T)/G_i^0(\omega,T) = 1$ is**

$$\boldsymbol{\sigma_i(\omega,T) = \sigma(\omega,0)}$$

temperature-independent spectrum up to some $T_{\rm dis}$

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- another solution to $G_i(\omega, T)/G_i^0(\omega, T) \simeq 1$ is

$$A_i(0)\delta(\omega - M) \quad \to \quad \frac{A_i(T)}{\pi}\frac{\Gamma(T)}{(\omega - M_i)^2 + \Gamma^2(T)}$$

replacing sharp resonance by smeared resonance with lower and wider peak, same overall contribution $A_i(0)$

temperature-dependent wave function at origin,

$$A_i(T) \sim |\Phi_i(T, r = 0)|^2$$

determines width $\Gamma(T)$:

$$\frac{A_i(T)}{\pi} \int d\omega \frac{\Gamma(T)}{(\omega - M_i)^2 + \Gamma^2(T)} = A_i(0)$$

Present lattice data ($G(T) \simeq G^0(T)$) cannot distinguish as long as

– width remains below statistical peak width and

– overall integral remains fixed

$\Rightarrow$ "gradual melting":

$$\text{peak height} \downarrow \quad \leftrightarrow \quad \text{peak width} \uparrow$$

result by construction in accord lattice correlators

- <u>Quarkonium Survival in Potential Models</u>

Define heavy quark potential $V(r,T)$,

solve Schrödinger equation

$$\left\{2m_c - \frac{1}{m_c}\nabla^2 + V(r,T)\right\}\Phi_i(r,T) = M_i(T)\Phi_i(r,T)$$

determine quarkonium wave functions $\Phi_i(r,T)$, radii $\bar{r}_i(T)$, binding energies $\Delta_i(T)$

$\bar{r}_i(T) \to \infty,\ \Delta_i(T) \to 0$: dissociation, defines $T_{\rm diss}$

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Problems & Questions

1. how to specify $V(r,T)$?
2. is $T_{\rm diss} = T_{\rm surv}$(lattice)?
3. do correlators agree with lattice correlators?
4. large radii, small binding energy?

1. Quarkonium Potential

lattice QCD determines the difference $F_1(r,T)$ of colour singlet free energy of system with & without $Q\bar{Q}$ pair

from thermodynamic relation

$$F = U - TS \Rightarrow U = -T^2 \left(\frac{\partial [F/T]}{\partial T}\right)$$

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Possible Potentials:

– $V(r,T) = F_1(r,T)$

[Digal et al. 01, Shuryak et al. 04, Wong 05, Alberico et al. 05, Moczy et al. 07]

– $V(r,T) = U_1(r,T)$

[Wong 05, Alberico et al. 05, Rapp et al. 05, Digal et al. 07]

– linear combination of F_1 and U_1

[Wong 05, Alberico et al. 06]

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2. Dissociation Temperatures

$V(r,T) = F_1(r,T)$:

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$
T_d/T_c	1.2	1	1

$V(r,T) = U_1(r,T)$:

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$
T_d/T_c	2	1.2	1.1

linear combination: in-between

3. Correlators in Potential Models

construct spectral function from ground state resonance, higher resonances, continuum

recall at $T = 0$

$$\sigma_i(\omega, T=0) \sim A_i(0)\delta(\omega - M_i) + A_c(\omega, 0)\theta(\omega - \omega_c)$$

potential models: $A_i(T)$ **decreases strongly with** T
$M_i(T)$ **approximately** T**-independent**

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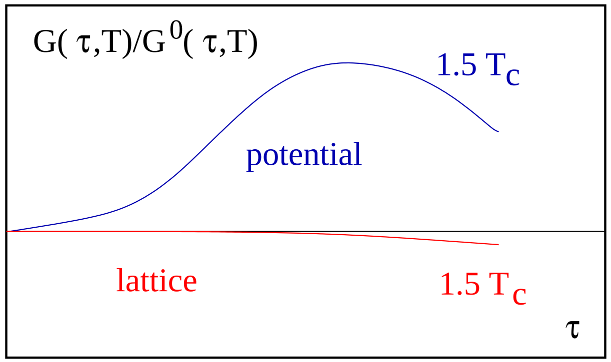
Trial 1: [Mocsy & Petreczky]

$V = U_1$, $\delta(\omega - M_i)$ for ground state resonance, continuum T-independent

$\Rightarrow$ strong disagreement



reason:
ground state resonance reduced in amplitude, but not increased in width

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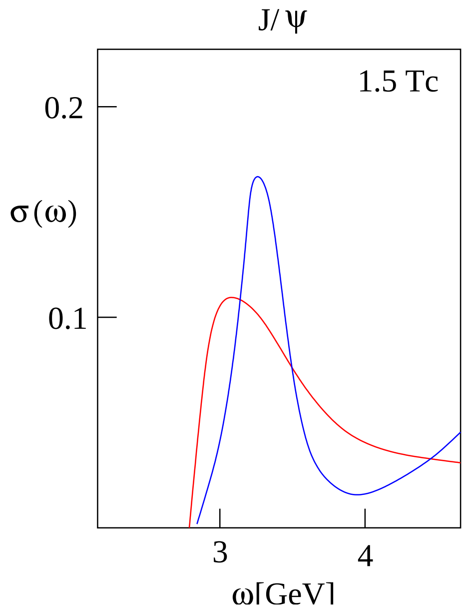
Trial 2: [Mocsy & Petreczky]

$V = F_1$, ground state disappears at $T/T_c = 1.2$, strong continuum above $\sim 2\ m_c$

$\Rightarrow$ "simulates" lattice peak



distinguish: lattice data

– with better peak resolution,
– with better width resolution

Trial 3: -tbd-

$V = U_1$,
correct for polarization energy ($V(r = \infty, T) = 0$),
width $\sim$ amplitude,
continuum threshold decreasing

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"standard model": does it work?

4. Inherent Problem of Potential Models

As $\boldsymbol{T} \longrightarrow \boldsymbol{T}_{\text{diss}}$: $\bar{\boldsymbol{r}}_i(\boldsymbol{T}) \longrightarrow \infty$

$$\boldsymbol{\Delta}_i(\boldsymbol{T}) \longrightarrow \mathbf{0}$$

what about $\bar{\boldsymbol{r}}_i > \mathbf{1}/\boldsymbol{T}_{\text{diss}}$,

$$\boldsymbol{\Delta}_i < \boldsymbol{T}_{\text{diss}}?$$

potential scales vs. medium scales?