Charmonium Systems After the Deconfinement Transition

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J/ψ suppression one of the most discussed signals of deconfinement transition.

The small size of charmonia allow bound states to survive beyond deconfinement, due to the strong Coulomb potential.

However, Screening in quark-gluon plasma $\Longrightarrow$ reduced binding of such systems $\Longrightarrow$ charmonium decay.

Matsui and Satz : Phys. Lett. B178, 416

The bound state will not exist if its radius larger than screening length.
close to the deconfinement transition temperature for J/ψ.
J/ψ suppression as a signal of deconfinement.

NA50 Collab., Phys. Lett. B477, 28 (2000)

Hard gluons needed for breaking J/ψ not available in hadron gas.

D. Kharzeev and H. Satz, Phys. Lett. B 334, 155 (1994)

Calculations using lattice potentials : sequential suppression.
ψ', χ_c dissolve below T_c
J/ψ dissolves by 1.2 T_c

F. Karsch and H. Satz, Z. Phys. C51, 209 (1991)
S. Digal *et al.*, Phys. Rev. D 64, 094015 (2001)
C-Y. Wong, Phys. Rev. C 65, 034902 (2002)

Modifications of the hadron spectrum can be directly studied on lattice by calculating hadronic correlation functions.

Ref: *hep-lat*/0312037
hep-lat/0208012,0309012

On lattice, one measures the Matsubara correlators

$$G_H(\tau, \vec{r}, T) = \langle J_H(\tau, \vec{r}) J_H(0, \vec{0}) \rangle_T$$

where J_H is the suitable hadronic operator

$$J_H = \begin{array}{lll} \bar{c}c & {}^3P_0 & \chi_{c0} \\ \bar{c}\gamma_5 c & {}^1S_0 & \eta_c \\ \bar{c}\gamma_\mu c & {}^3S_1 & J/\psi \\ \bar{c}\gamma_\mu\gamma_5 c & {}^3P_1 & \chi_{c1} \end{array}$$

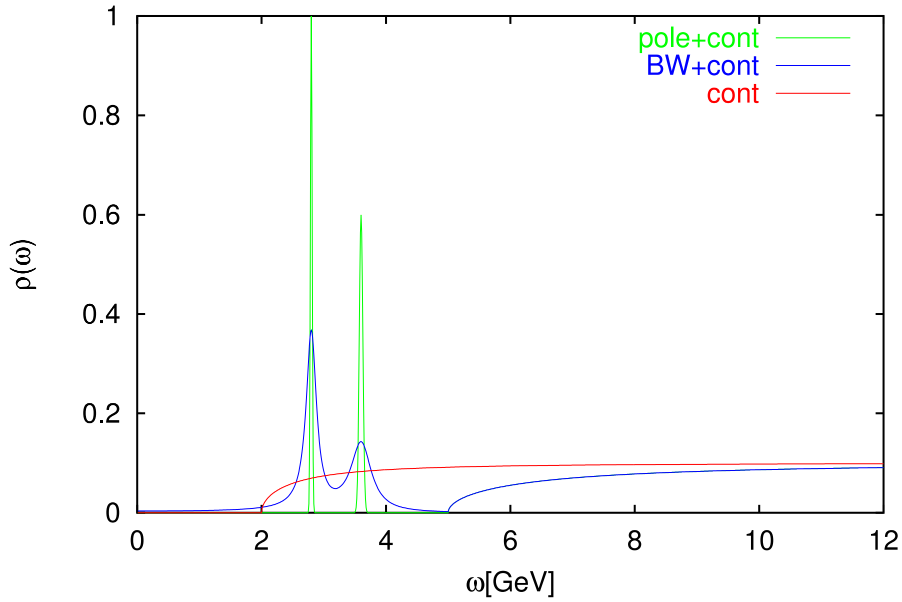
properly renormalized for continuum.

The Fourier transformed correlator $G_H(\tau, \vec{p}, T)$ can be expressed in terms of the spectral function

$$\boxed{G(\tau, \vec{p}, T) = \int_0^\infty d\omega \sigma(\omega, \vec{p}, T) \frac{\cosh(\omega(\tau - 1/(2T)))}{\sinh(\omega/(2T))}}$$

Information about charmonium dissociation can be obtained from the zero-momentum correlation function.

Reduced spectral function $\rho(\omega) = \sigma(\omega, 0)/\omega^2$



How to extract $\rho(\omega)$ from $G(\tau, T)$?

Maximum Entropy Method

Find $\sigma(\omega)$ which maximizes

$$P[\sigma(\omega)|DH] = \exp(-\frac{1}{2}\chi^2 + \alpha S)$$

Prior knowledge supplied through *entropy* term

$$S = \int_0^\infty d\omega[\sigma(\omega) - m(\omega) - \sigma(\omega)\log(\sigma(\omega)/m(\omega))]$$

$m(\omega)$ the solution in absence of data

Successfully used at zero temperature

M. Asakawa *et al.*, Prog. Part. Nucl. Phys. 46, 459 (2001)

Additional problem at finite temperature: small temporal extent and small number of data points

Used to get information about mesonic states and dilepton rate

F. Karsch *et al.*, Phys. Lett. B530, 147 (2002)

Our calculation: Quenched lattices.

No quark loops $\Longrightarrow$ no thermal pions
no thermal quarks

Wilson action $O(a^2)$ error

Nonperturbative (Alpha Coll.) clover action for fermions $O(a^2)$ error

$$\beta = 6.64,\ 7.192 \Longrightarrow a \approx 0.02 \rightarrow 0.04\text{fm}$$

temperature range $0.75T_c \rightarrow 3T_c$

Extent $1 \rightarrow 0.25$ fm $N_\tau = \ 40 \rightarrow 12$

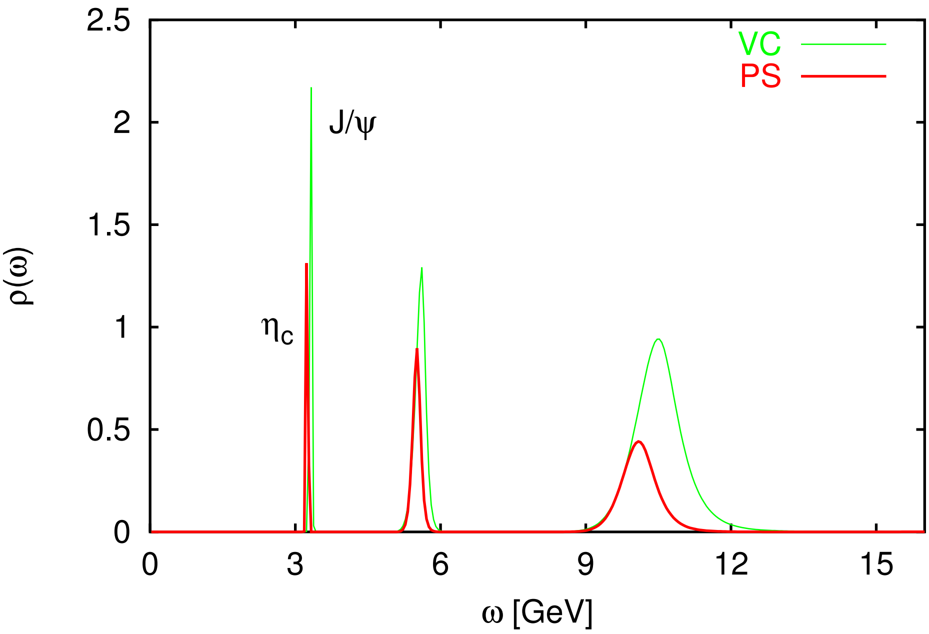
Prior information important for higher temperatures

1S STATES ABOVE T_c

$a \sim 0.041$ fm, $\qquad m_{J/\psi} = 3.14(1)$ GeV

N_τ	24	16	12
T/T_c	0.75	1.12	1.5

Spectral functions at 0.75 T_c

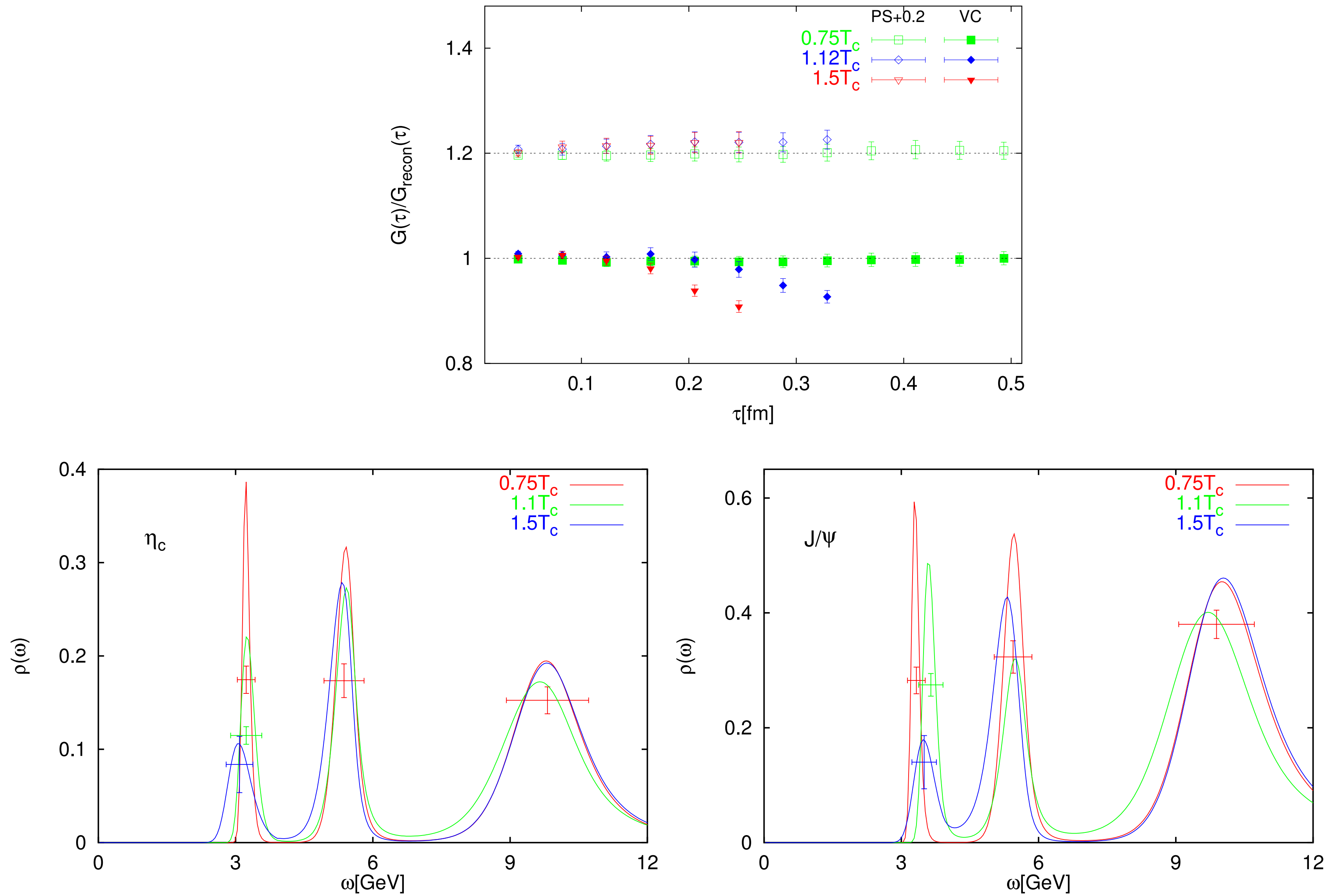


Do they explain the correlators above T_c?

Reconstructed correlators

$$G_{\rm recon}(\tau, T) = \int d\omega \sigma(\omega, 0.75 T_c) K(\omega, \tau, T)$$

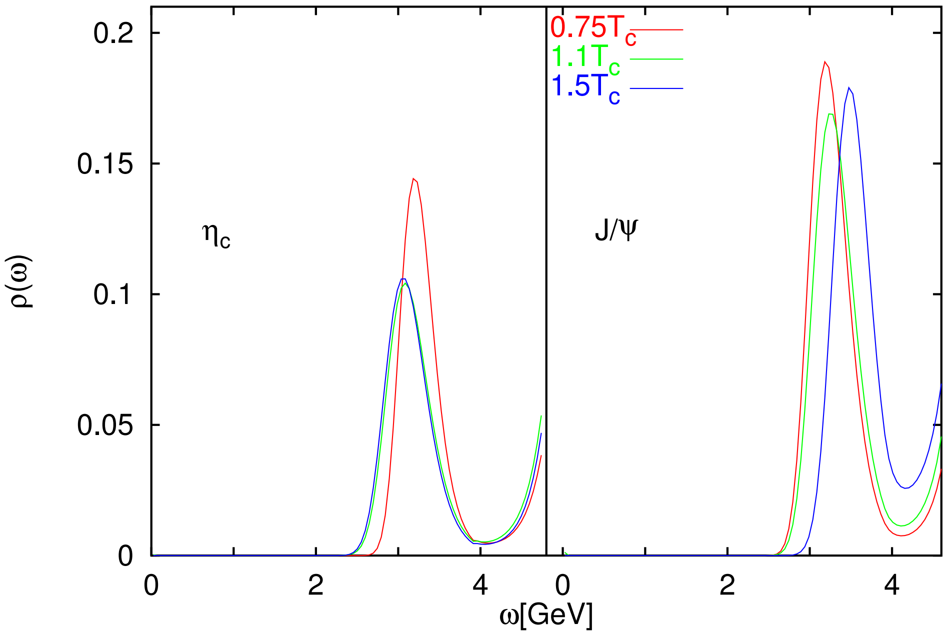
Factors out temperature dependence of kernel.



PS+0.2
VC
0.75T_c
1.12T_c
1.5T_c
G(τ)/G_recon(τ)
τ[fm]
1.4
1.2
1
0.8
0.1
0.2
0.3
0.4
0.5
η_c
ρ(ω)
ω[GeV]
0.75T_c
1.1T_c
1.5T_c
J/Ψ

Effect of the small number of data points?

Use same number of data points
and same physical extent

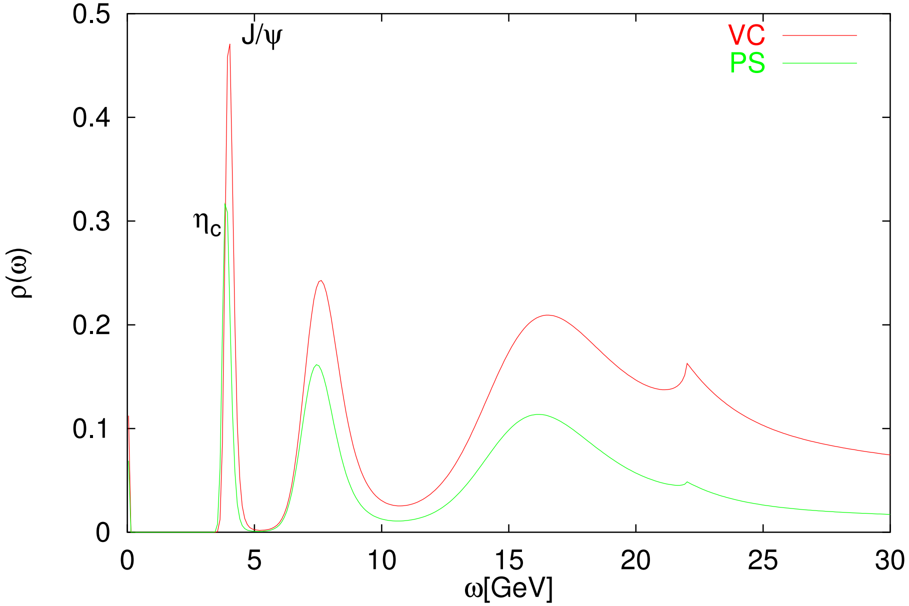


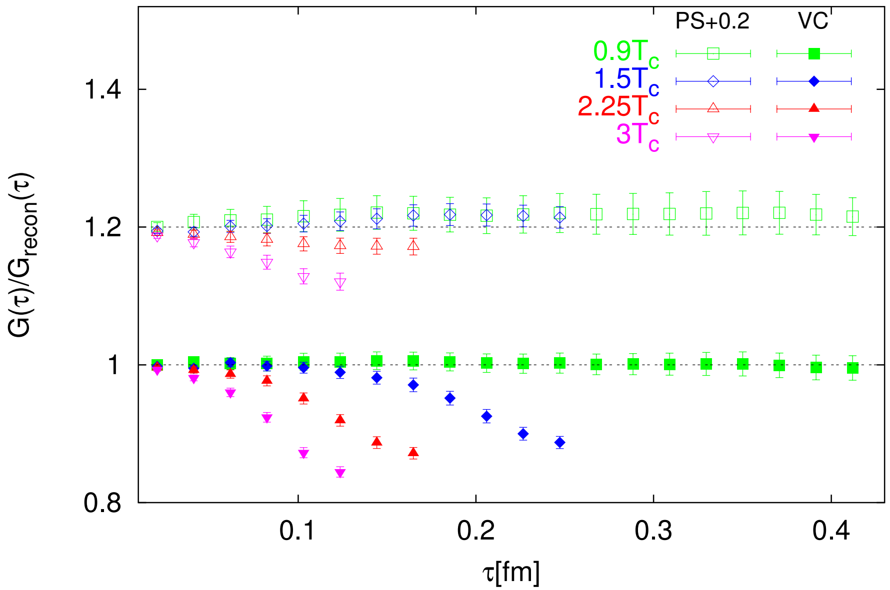
- 1S states survive till 1.5 T_c
- η_c shows practically no change.
- Possible change of property of J/ψ?

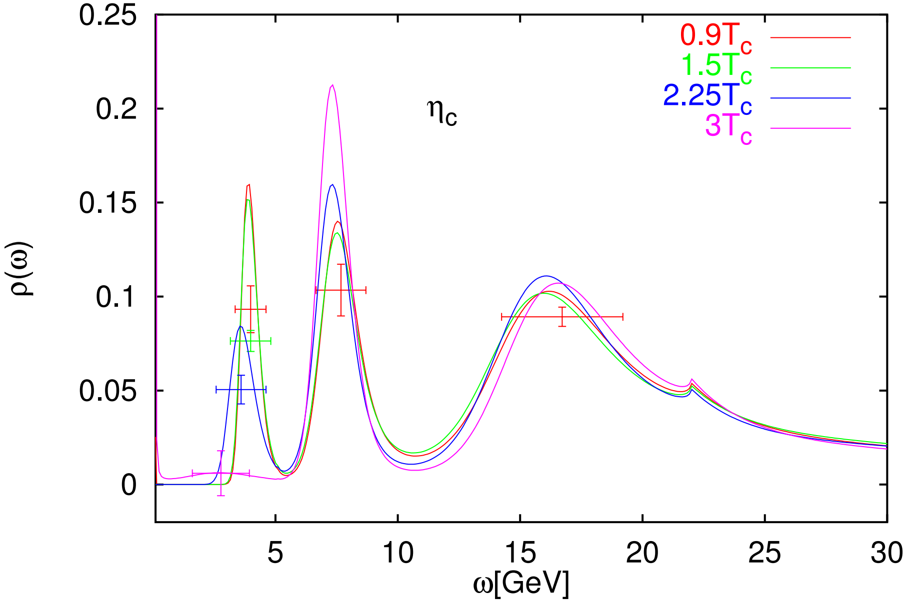
What happens at higher temperatures?

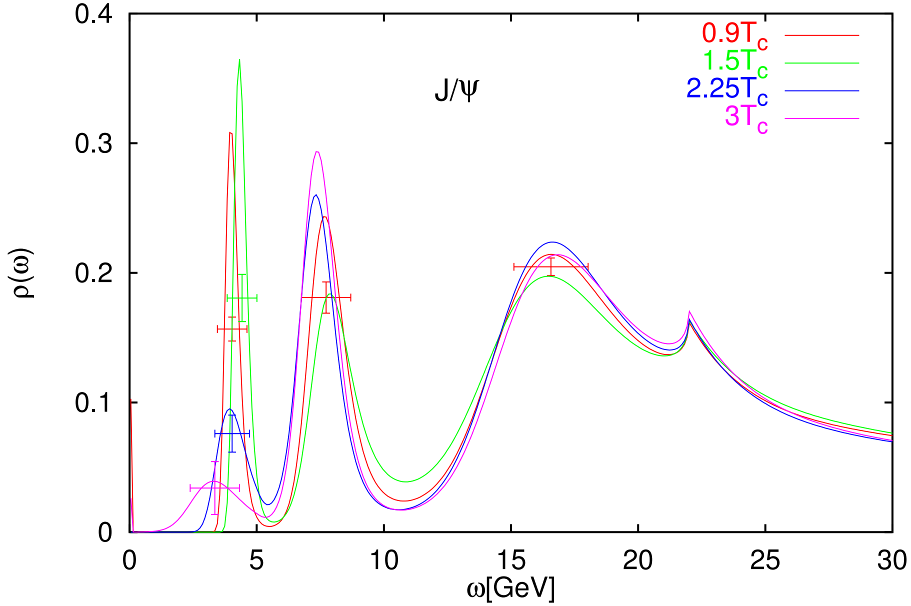
Finer set at β=7.192, $a \sim 0.021$ fm. $\kappa = 0.13114 \rightarrow m_{J/\psi} = 3.78(2)$ GeV

N_τ	40	24	16	12
T/T_c	0.9	1.5	2.25	3







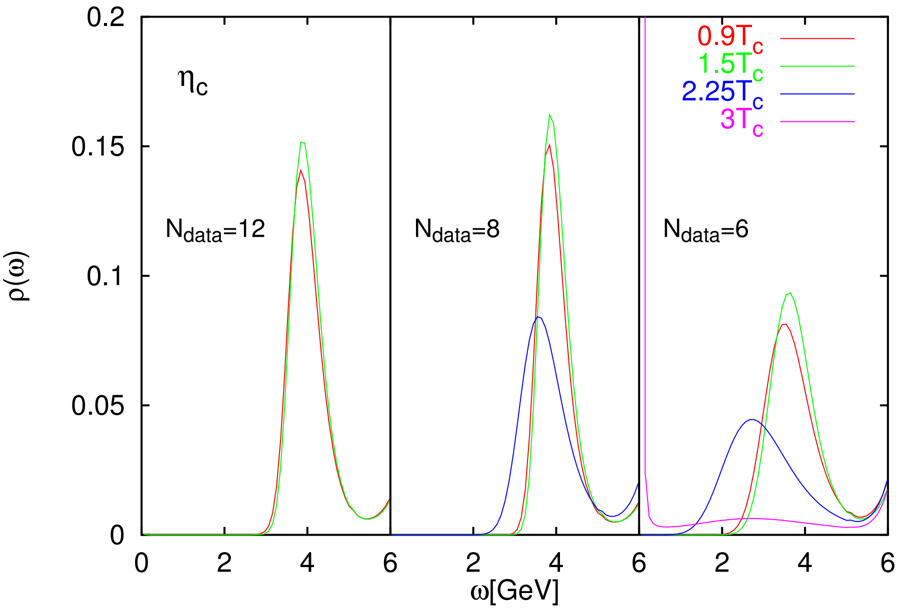


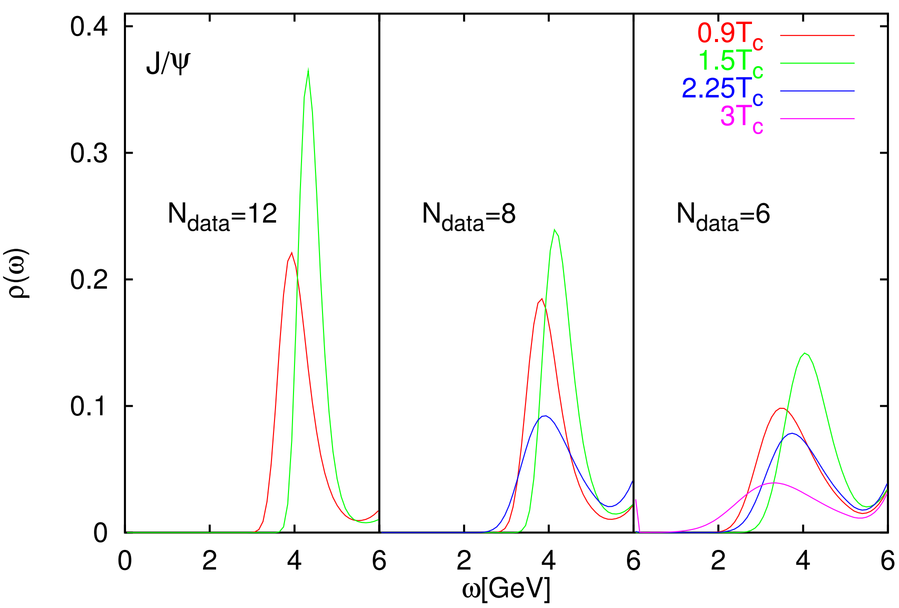
1S States survive upto 2.25 T_c

- η_c shows no change upto 1.5 T_c
- Weakening (and possibly broadening) at 2.25 T_c
- No significant resonance seen at 3 T_c

- J/ψ shows no weakening upto 1.5 T_c *but some changes?*
- Weakening (and possibly broadening) at 2.25 T_c
- No significant resonance seen at 3 T_c

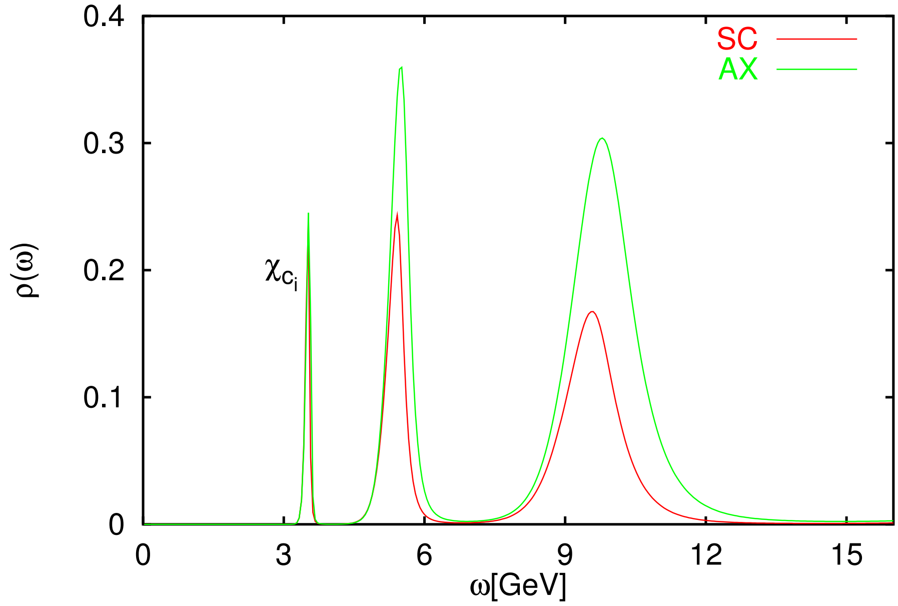
Effect of limited number of data points?

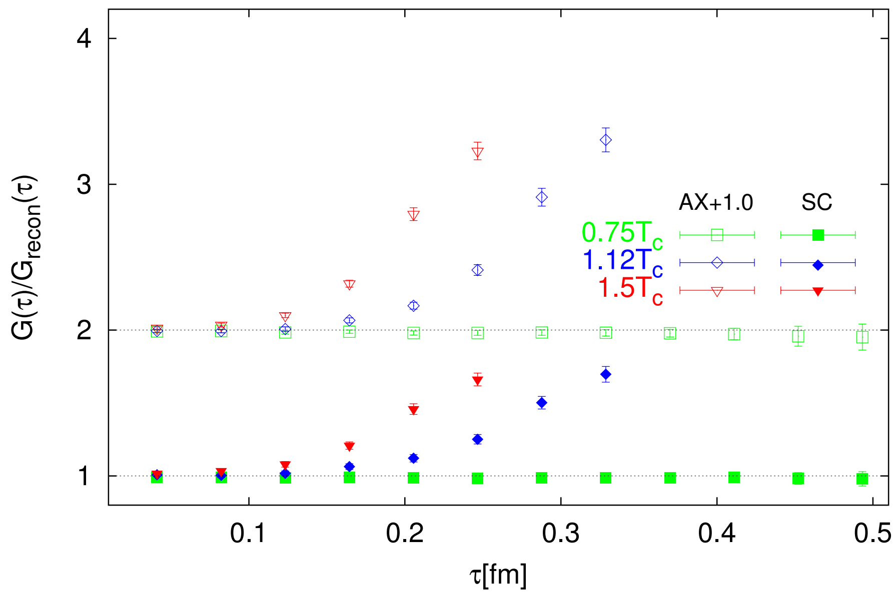


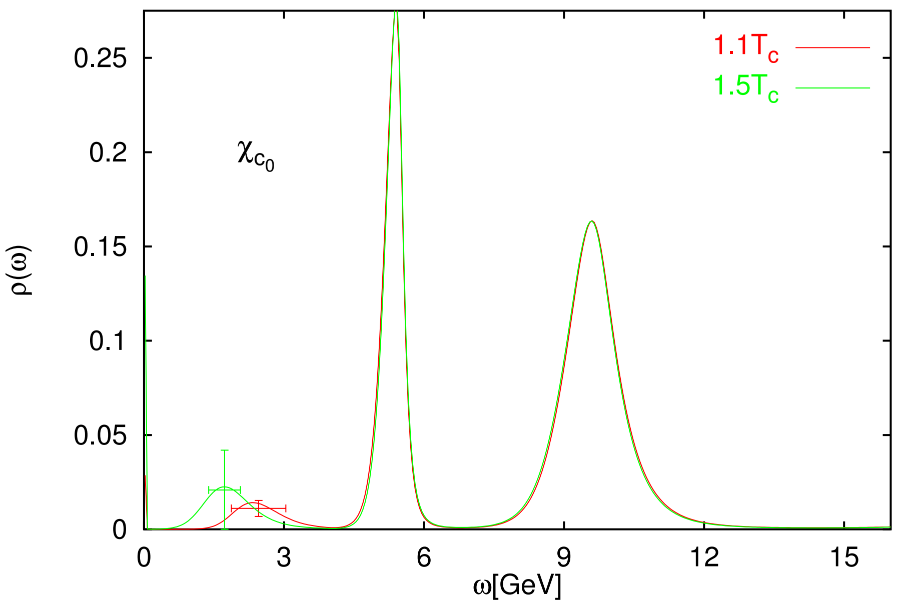


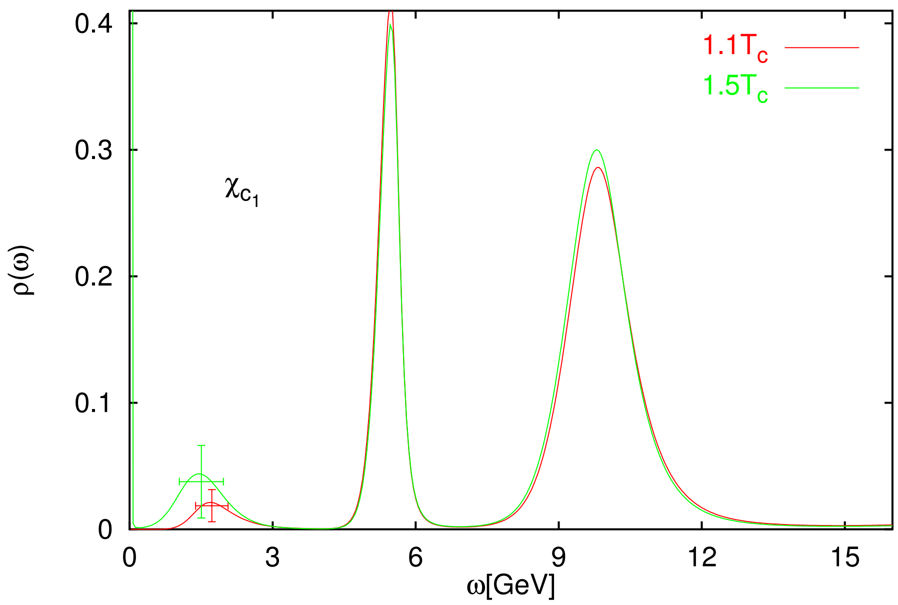
RESULTS FOR THE 1P STATES

$a \sim 0.041$ fm, $m_{J/\psi} = 3.14(1)$ GeV



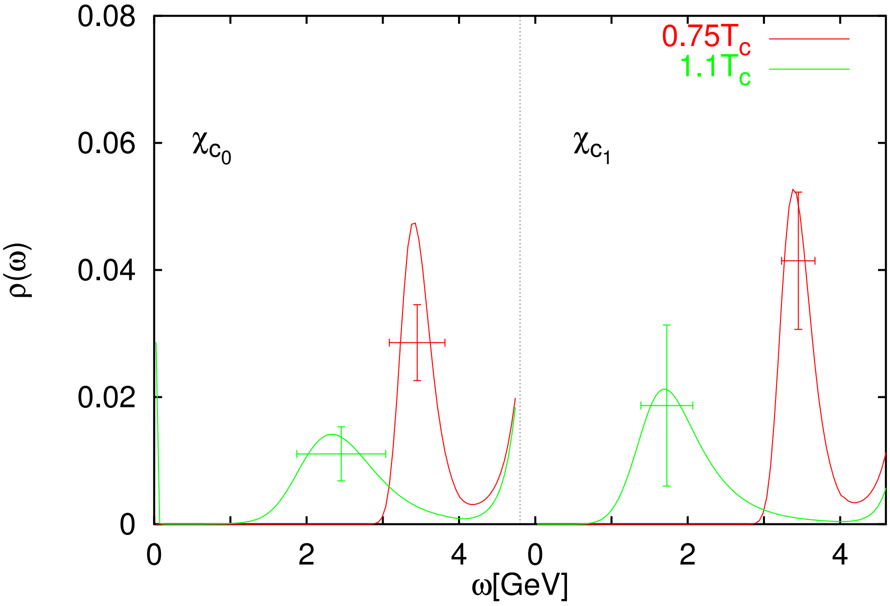






- 1P states undergo serious system modification already at 1.1 T_c
  At T_c?
- The correlator modification will be consistent with the dissolution of the state at T_c
- Spectral function supports the conclusion

Effect of small number of data points?



Summary and Discussion:

- Information about medium modification of charmonia can be obtained from the temporal correlators.
- With suitable prior information about structure of spectral function at high w it is possible to explore the low energy structure of the spectral function.
- $\bar{c}c$ states show no change of behaviour below T_c, at least upto 0.93 T_c. *Effect of quenching?*
- 1P states suffer serious system modifications, possibly dissolution, above T_c
- 1S states remain as bound states till quite high temperatures.
  At least upto 1.5 T_c no significant weakening of the state is seen.
  J/ψ shows some medium effects?
- Above this temperature, medium effects tend to weaken the peak.
  But significant bound state remains till $\gtrsim 2T_c$.
- We do not see any significant resonance at 3 T_c.