Study of constant mode in charmonium correlators at finite temperature

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[hep-lat/0701005]

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Introduction

J/ψ suppression is one of the most promising probe
to find the QGP formation in HIC experiment.

Lattice QCD studies of charmonium spectral function
suggest the survival of J/ψ state above T_c ($1.5T_c$?)

- Indirect (sequential) J/ψ suppression

total yield of J/ψ =
direct production of J/ψ (60%)
+ decay from higher states, ψ' & χ_c (40%)

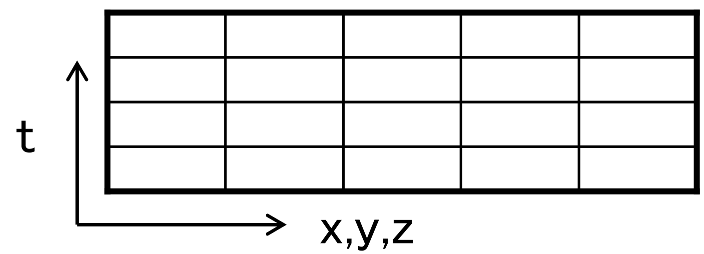
L. Antoniazzi et al. (E705 Collab.), PRL70, 383, (1993).

→ A part of the J/ψ suppression may be observed
at $T_{dis.}(\psi'$ or $\chi_c)$ when $T_{dis.}(\psi'$ or $\chi_c) < T_{dis.}(J/\psi)$

Lattice QCD results

Lattice setup

- Quenched approximation (no dynamical quark effect)
- Anisotropic lattices (tadpole imp. Clover quark + plaq. gauge)
  - lattice size : $20^3 \times N_t$
  - lattice spacing : $1/a_s$ = 2.03(1) GeV,
  - anisotropy : $a_s/a_t = 4$



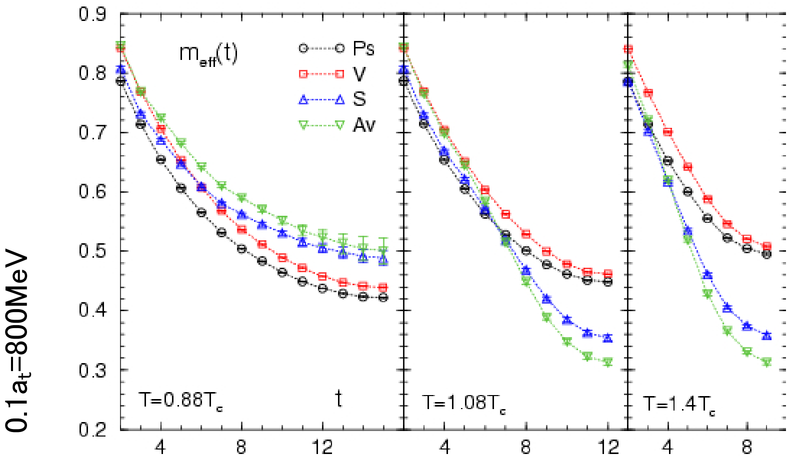
- Quark mass
  - charm quark (tuned with J/ψ mass)
- r_s=1 to reduce cutoff effects in higher energy states

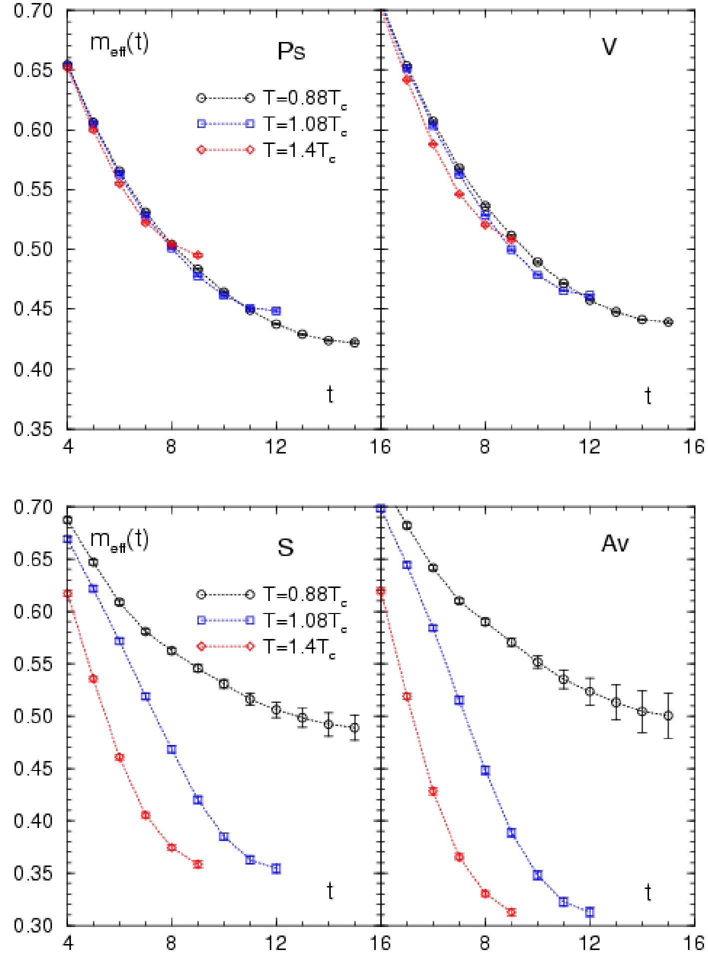
F. Karsch et al., PRD68, 014504 (2003).

N_T	160	32	26	20
T/T_c	~ 0	0.88	1.08	1.4
# of conf.	60	300	300	300

equilib. is 20K sweeps
each config. is separated by 500 sweeps

Quenched QCD at T>0



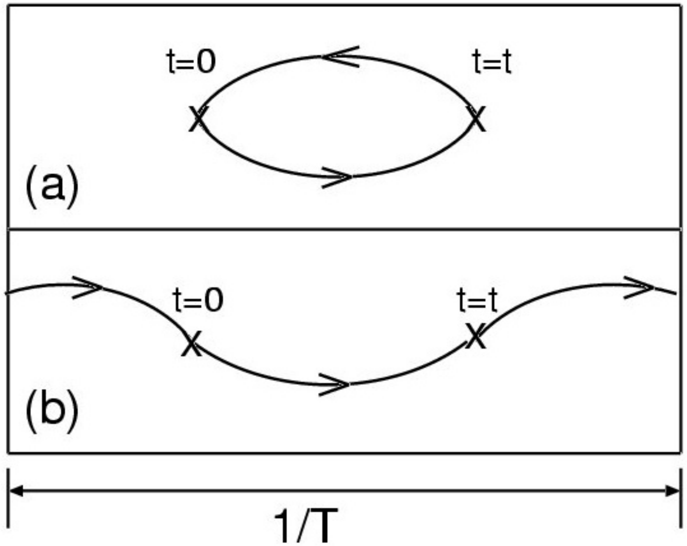


- small change in S−wave states
  → survival of J/ψ & η_c at T>T_c
- drastic change in P−wave states
  → dissociation of χ_c just above Tc (?)

S. Datta et al.,
PRD69, 094507 (2004). etc...

A constant mode

Now we consider the meson correlator with p=0 & $m_{q1}=m_{q2}$



$\exp(-m_q t) \times \exp(-m_q t)$
$= \exp(-2 m_q t)$

m_q is quark mass
or single quark energy

$\exp(-m_q t) \times \exp(-m_q (L_t - t))$
$= \exp(-m_q L_t)$

L_t = temporal extent

- in imaginary time formalism
  $L_t = 1/\mathrm{Temp.}$
  gauge field : periodic b.c.
  quark field : anti-periodic b.c.
- in confined phase: m_q is infinite

→ the effect appears only in deconfined phase

Pentaquark (KN state):
two pion state:
→ Dirichlet b.c.
c.f. T.T.Takahashi et al., PRD71, 114509 (2005).

Physical interpretation

Spectral function at high temp. limit

$$\rho_\Gamma(\omega) = \Theta(\omega^2 - 4m_q^2)\frac{N_c}{8\pi\omega}\sqrt{\omega^2 - 4m_q^2}[1 - 2n_F(\omega/2)]$$
$$\times[\omega^2(a_H^{(1)} - a_H^{(2)}) + 4m^2(a_H^{(2)} - a_H^{(3)})]$$
$$+2\pi\omega\delta(\omega)N_c[(a_H^{(1)} + a_H^{(2)})I_1 + (a_H^{(2)} - a_H^{(3)})I_2]$$

F. Karsch et al., PRD68, 014504 (2003).
G. Aarts et al., NPB726, 93 (2005).

	Γ	$a_H^{(1)} + a_H^{(2)}$	$a_H^{(2)} - a_H^{(3)}$
Ps	γ_5	0	0
V	γ_i	2	2
S	1	0	-2
Av	$\gamma_i\gamma_5$	2	-4

constant mode remains in the continuum & infinite volume

The constant term is related to some transport coefficients.

From Kubo–formula, for example, a derivative of the SPF in the V channel is related to the electrical conductivity σ.

$$\sigma = \frac{1}{6}\frac{\partial}{\partial\omega}\rho_V(\omega)\Big|_{\omega=0}$$

Without constant mode

Our motivation is to study
whether bound state peaks exist or not in QGP phase

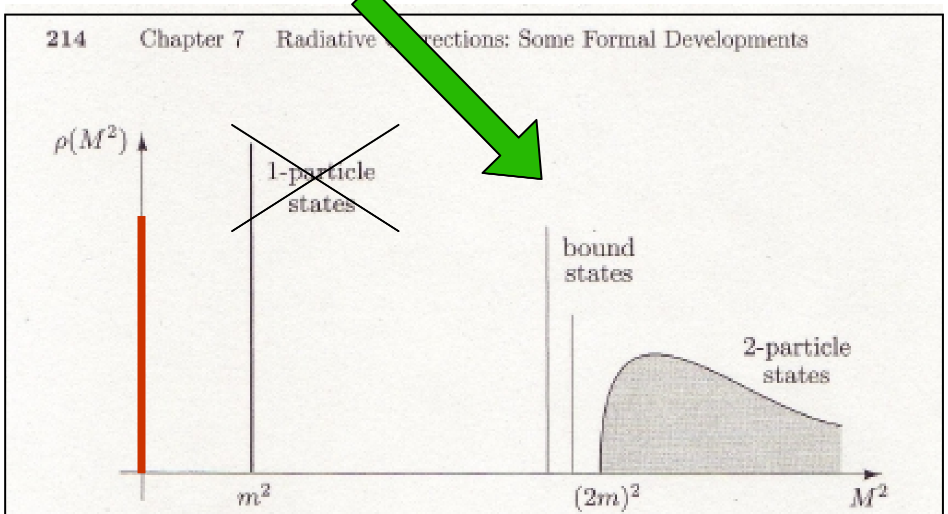


Figure 7.2. The spectral function $\rho(M^2)$ for a typical interacting field theory. The one-particle states contribute a delta function at m^2 (the square of the particle's mass). Multiparticle states have a continuous spectrum beginning at $(2m)^2$. There may also be bound states.

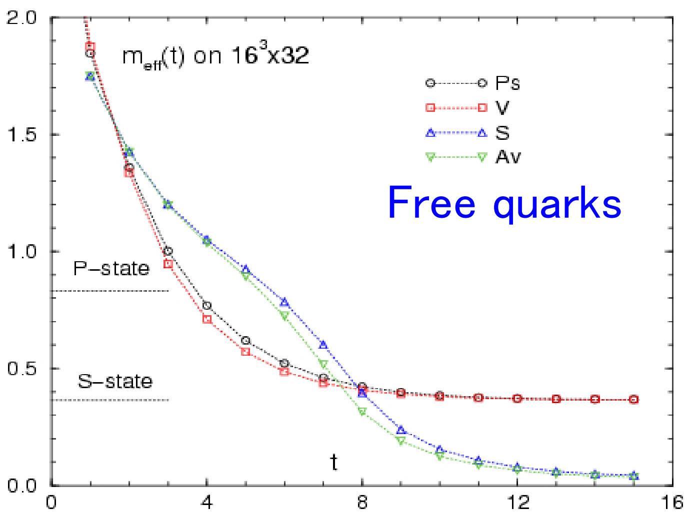
from "An Introduction to Quantum Field Theory"
Michael E. Peskin, Perseus books (1995)

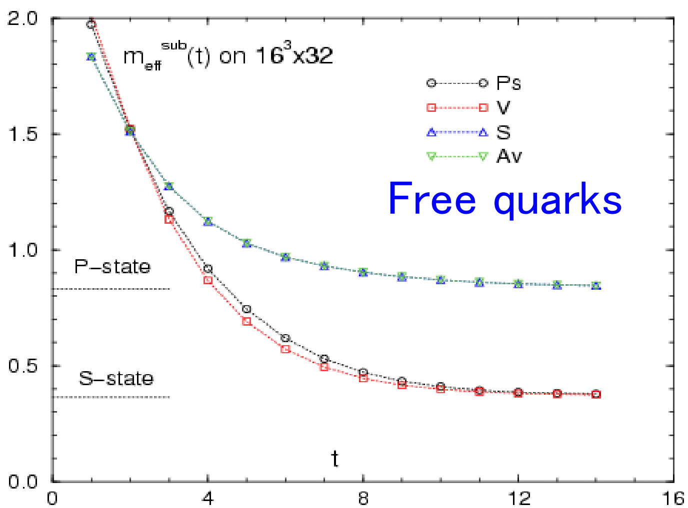
Removing the constant mode

An analysis to avoid the constant mode

Midpoint subtracted correlator

$$\bar{C}(t) = C(t) - C(N_t/2) \quad \Rightarrow \quad \frac{\bar{C}(t)}{\bar{C}(t+1)} = \frac{\sinh^2\left[\frac{1}{2}m_{eff}^{sub}(t)(N_t/2 - t)\right]}{\sinh^2\left[\frac{1}{2}m_{eff}^{sub}(t)(N_t/2 - t - 1)\right]}$$

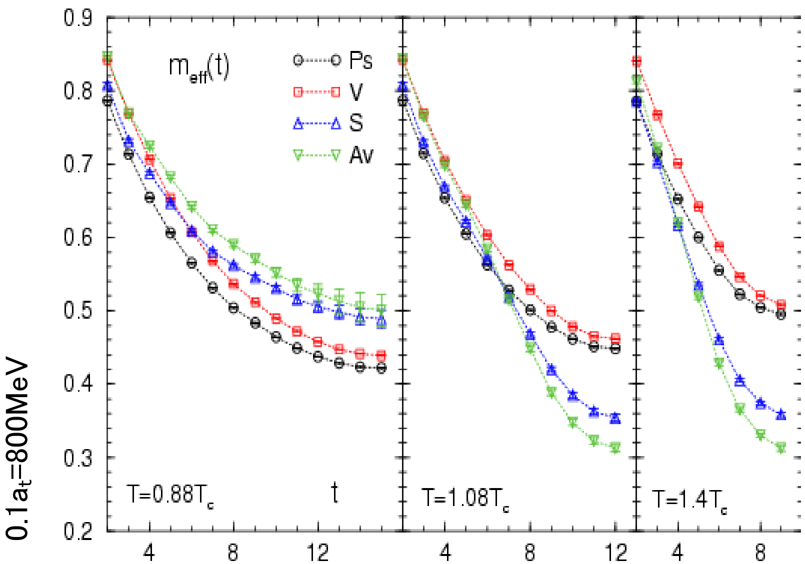




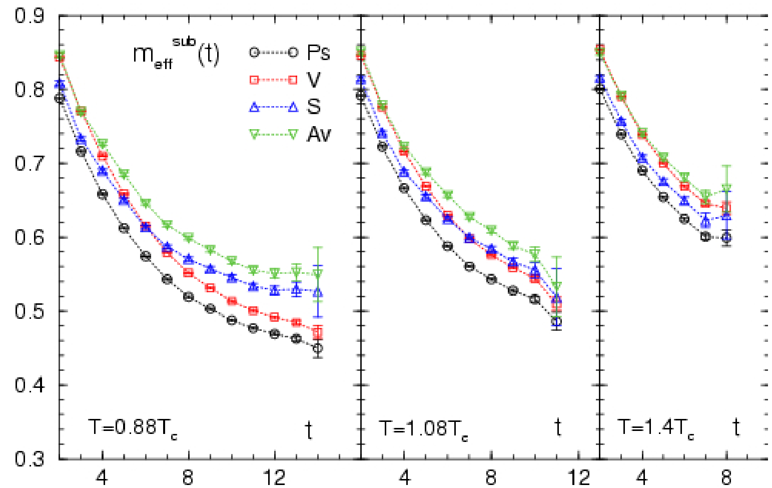
Midpoint subtraction analysis

$$\bar{C}(t) = C(t) - C(N_t/2) \qquad \frac{\bar{C}(t)}{\bar{C}(t+1)} = \frac{\sinh^2\left[\frac{1}{2}m_{eff}^{sub}(t)(N_t/2 - t)\right]}{\sinh^2\left[\frac{1}{2}m_{eff}^{sub}(t)(N_t/2 - t - 1)\right]}$$

usual effective masses at T>0



subtracted effective mass

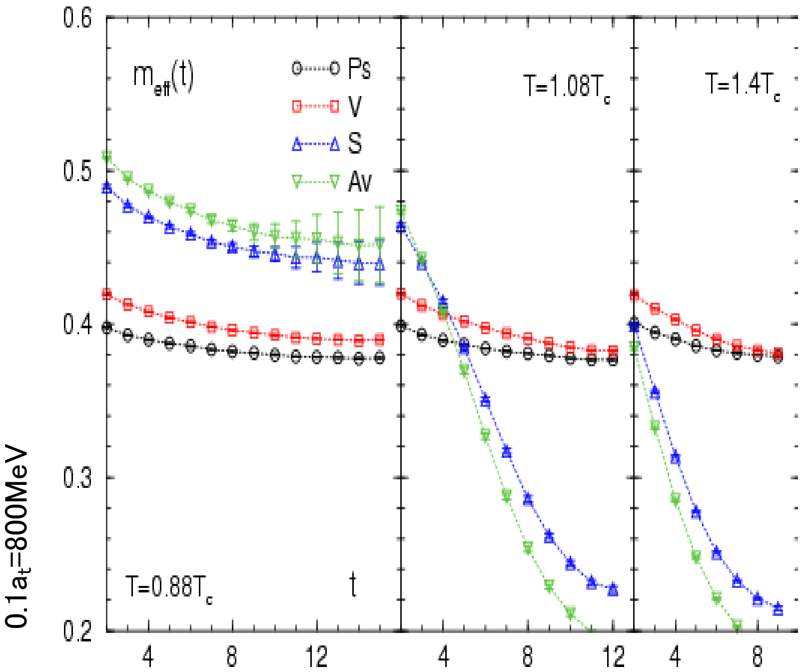


the drastic change in P-wave states disappears in $m_{eff}^{sub}(t)$

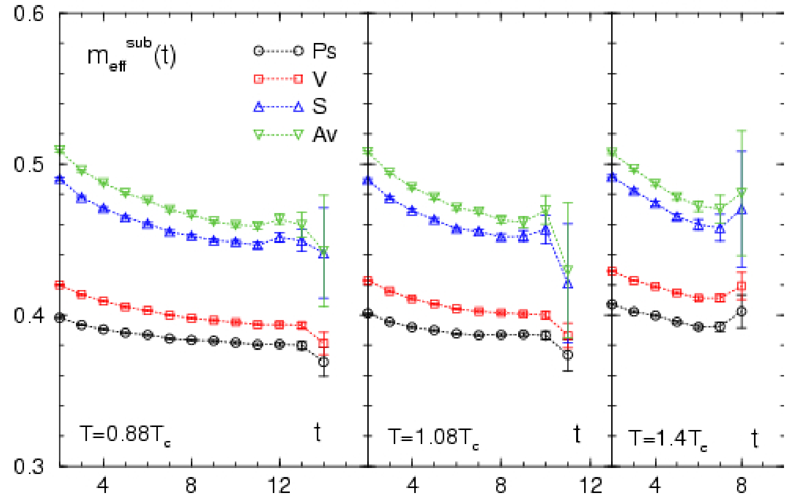
→ the change is due to the constant mode

Results with extended op.

usual effective mass



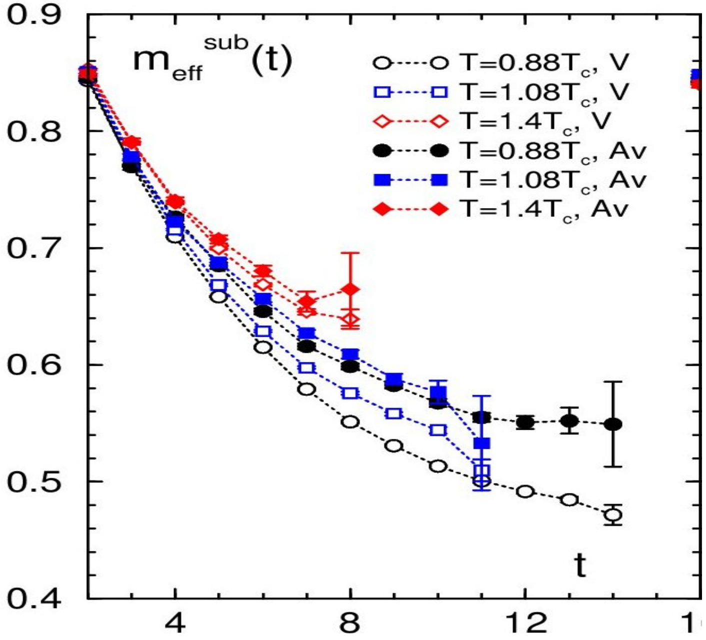
subtracted effective mass



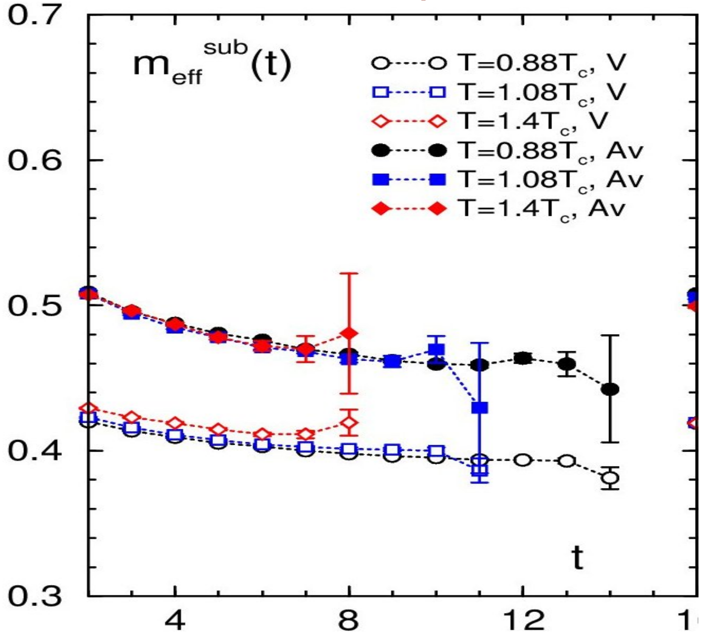
- extended op. enhances overlap with ground state & const. mode
- small constant effect is visible in V channel
- no large change above T_c in $m_{eff}^{sub}(t)$

Discussion

point operators



extended operators



The drastic change of P−wave states is due to the const. contribution.

→ The changes in SPFs should be small(except for ω=0 peak).

Conclusion

- There is the constant mode in charmonium correlators above T_c
- The drastic change in χ_c states is due to the constant mode

➔ the survival of χ_c states above T_c, at least $T=1.4T_c$.

The result may affect the scenario of J/ψ suppression.

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- The drastic change in χ_c states is due to the constant mode

➔ the survival of χ_c states above T_c, at least $T=1.4T_c$.

The result may affect the scenario of J/ψ suppression.

In the MEM analysis,
one has to check consistency of the results
using, e.g., midpoint subtracted correlators.

$$\bar{C}(t) = C(t) - C(N_t/2)$$

$$\bar{C}(t) = \int_0^\infty d\omega \rho_\Gamma(\omega) K^{sub}(\omega,t),$$

$$K^{sub}(\omega,t) = \frac{\sinh^2(\frac{\omega}{2}(N_t/2 - t))}{\sinh(\omega N_t/2)}$$

MEM analysis fails ?

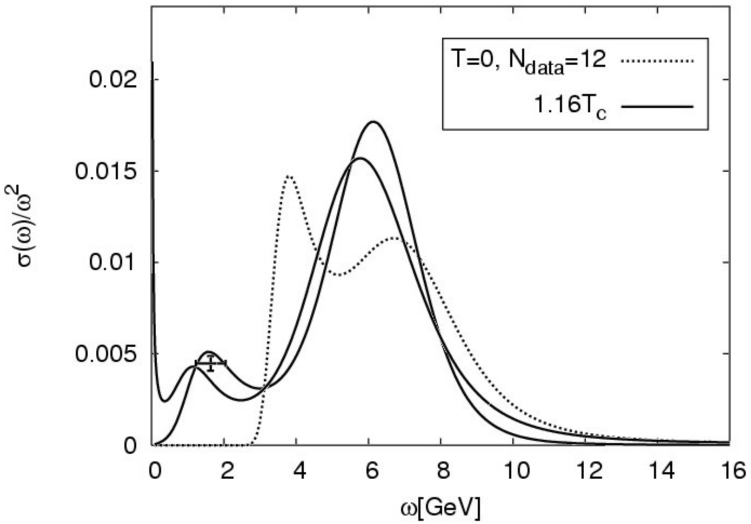
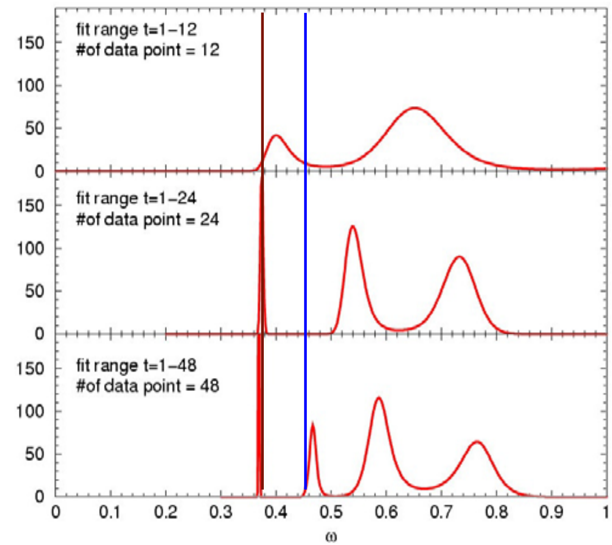


FIG. 19: The scalar spectral function for $\beta = 6.1$ at $T = 1.16T_c$ and at zero temperature reconstructed using $N_{data} = 12$. At finite temperature two default models $m(\omega) = 0.01$ and $m(\omega) = 0.038\omega^2$ have been used.

A.Jakovac et al., PRD75, 014506 (2007).
(also S. Datta et al., PRD69, 094507 (2004).)

MEM test using T=0 data



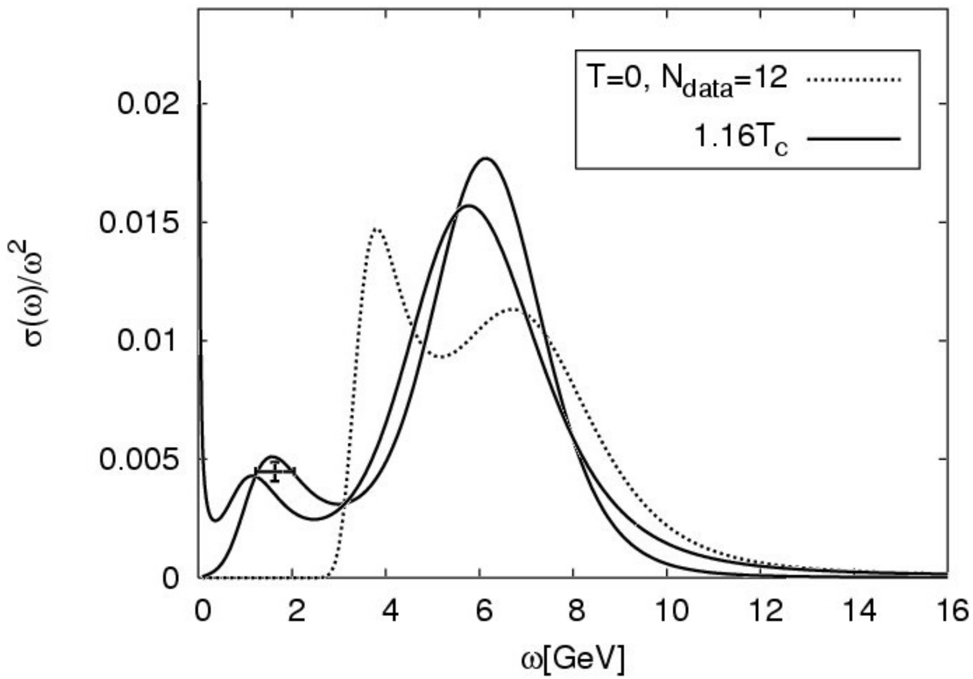
data for T/T_c=1.2

data for T/T_c=0.6

data for T/T_c=0

MEM sometimes fails
when (# or quality) of data point
is not sufficient.

Introduction



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