A constant mode in charmonium correlators in finite temperature lattice QCD

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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 $T_{dis.}(\psi' \text{ or } \chi_c)$ when $T_{dis.}(\psi' \text{ or } \chi_c) < T_{dis.}(J/\psi)$

χ_c states on the lattice

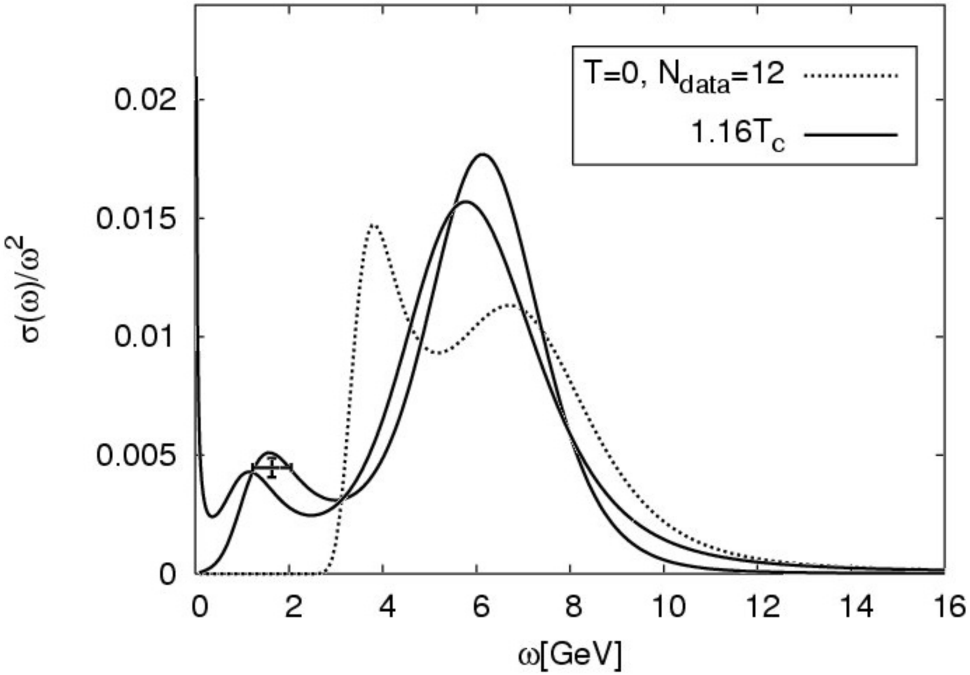


FIG. 19: The scalar spectral function for $\beta = 6.1$ at $T = 1.16T_c$ and at zero temperature reconstructed using $N_{data} = 12$. At finite temperature two default models $m(\omega) = 0.01$ and $m(\omega) = 0.038\omega^2$ have been used.

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

A.Jakovac et al., PRD75, 014506 (2007).

Quenched QCD at T>0

Lattice setup

anisotropic lattices : $20^3 \times N_t$

$1/a_s = 2.03(1)$ GeV, $a_s/a_t = 4$

Clover quark action with tadpole imp. on anisotropic lattice

H. Matsufuru et al., PRD64, 114503 (2001).

r_s=1 to reduce cutoff effects in higher energy states

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

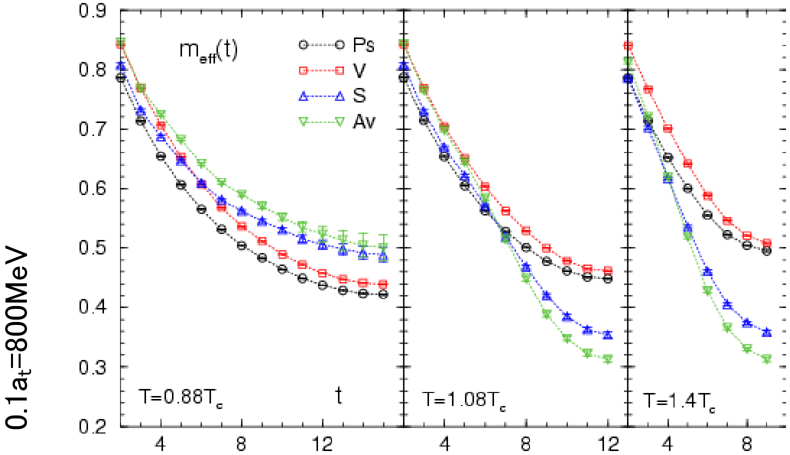
quark mass is tuned with $M_{J/\psi}$(= 3097MeV)

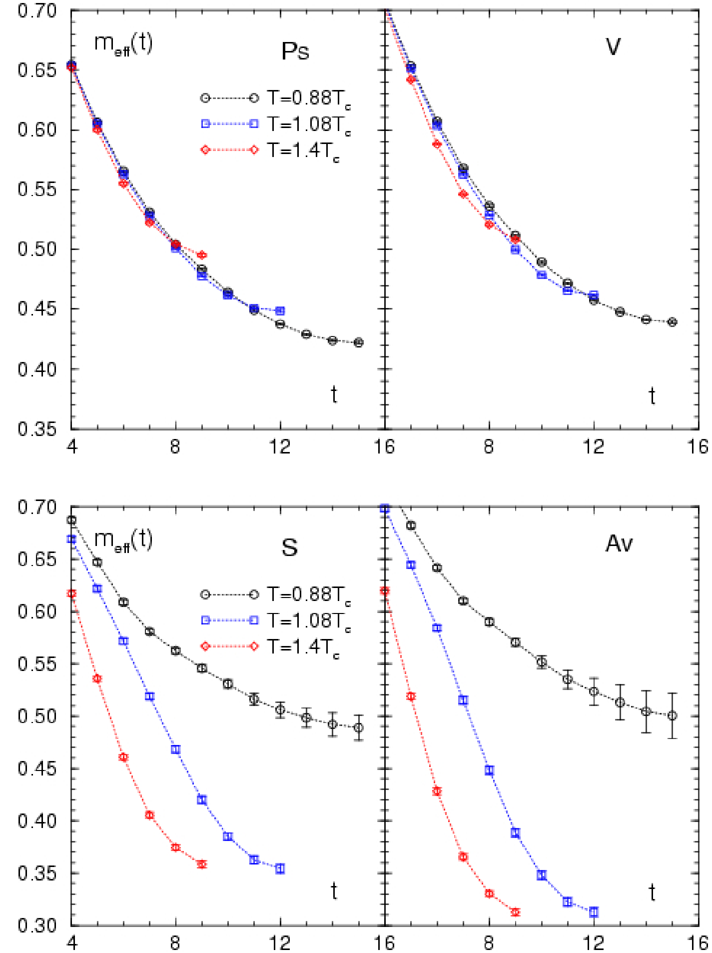
N_T	160	32	26	20
T/T_c	~ 0	0.88	1.08	1.4
# of conf.	60	300	300	300

equilib. is 20K sweeps

each config. is separated by 500 sweeps

Quenched QCD at T>0



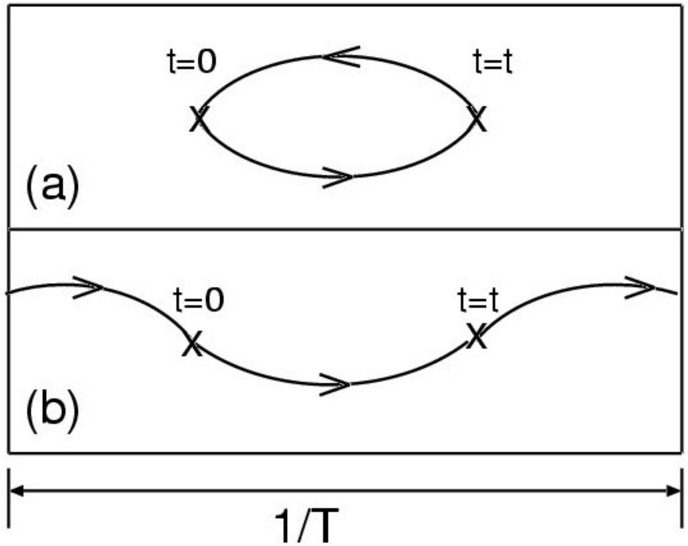


- small change in S−wave states
  → survival of J/ψ & η_c at T>T$_c$
- drastic change in P−wave states
  → dissociation of χ_c just above Tc (?)

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

A constant mode

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



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

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
  $L_t = 1/\text{Temp.}$
  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.

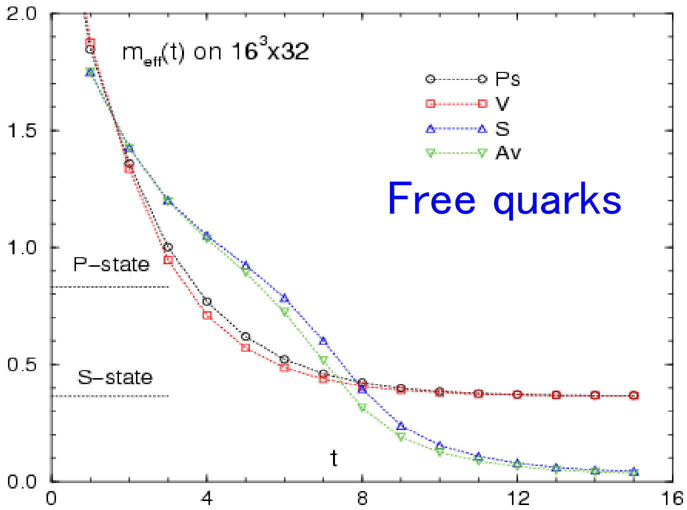
$$\sigma = \frac{1}{6}\frac{\partial}{\partial\omega}\rho_V(\omega)\Big|_{\omega=0}$$

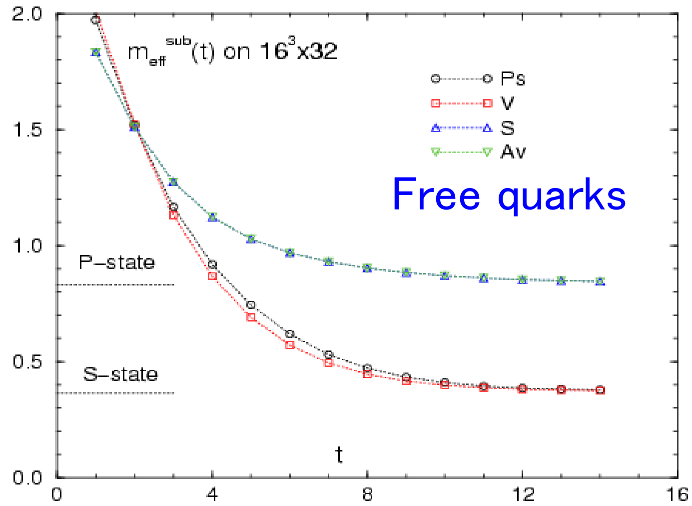
Removing the constant mode

An analysis to avoid the constant mode

Midpoint subtracted correlator

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

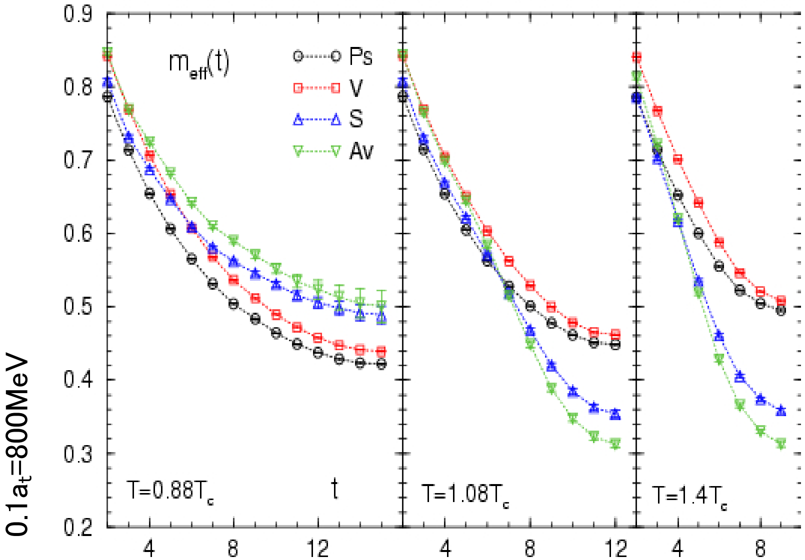




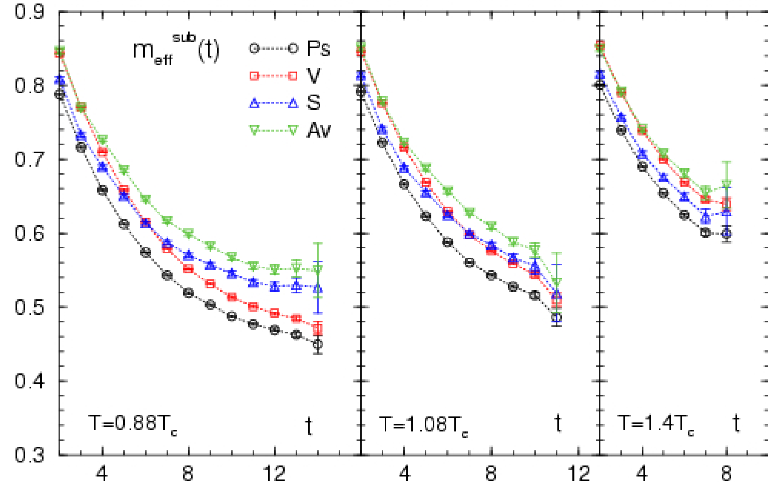
Midpoint subtraction analysis

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

usual effective masses at T>0



subtracted effective mass

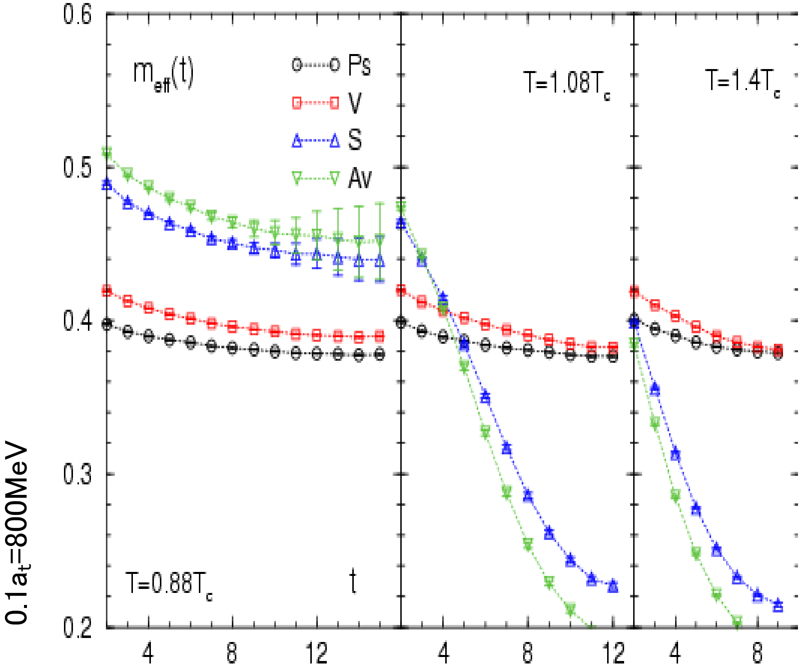


the drastic change in P−wave states disappears in $m_{eff}^{sub}(t)$

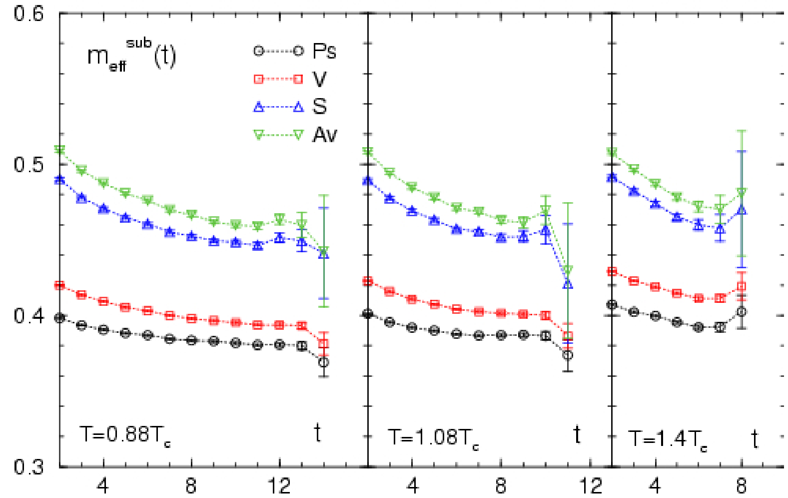
→ the change is due to the constant mode

Results with extended op.

usual effective mass

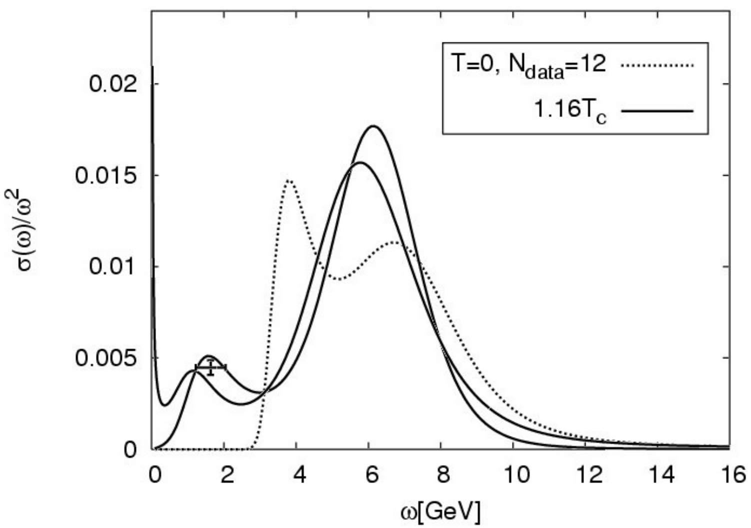


subtracted effective mass



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

MEM analysis fails ?



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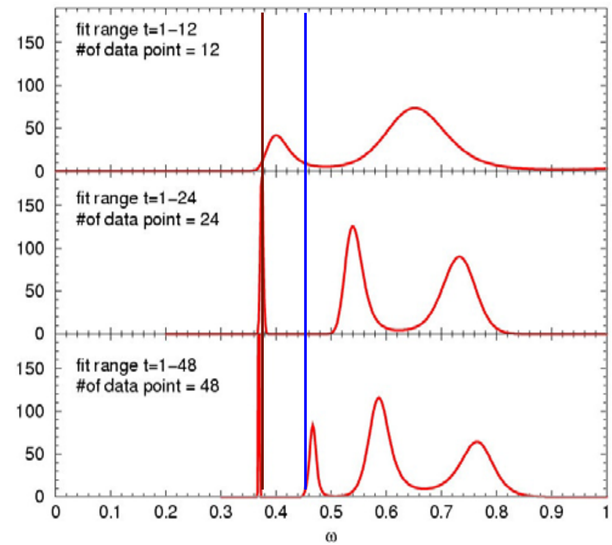
A.Jakovac et al., PRD75, 014506 (2007).
(also S. Datta et al., PRD69, 094507 (2004).)

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.

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.

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

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

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

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