Study of constant mode in charmonium correlators in hot QCD

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Extreme QCD, INFN, Frascati, Italy, 6 August 2007

Introduction

- There is a constant mode in meson correlators at T>0

  T.Umeda Phys.Rev. D75 094502 (2007)

- The constant mode is important

  for the study of charmonium properties at T>0

  → low energy mode strongly affects its correlators

  which is fundamental data of lattice QCD studies

- In the Lattice 2007 symposium,

  the relation between the constant mode

  and (sequential) J/psi suppression is discussed

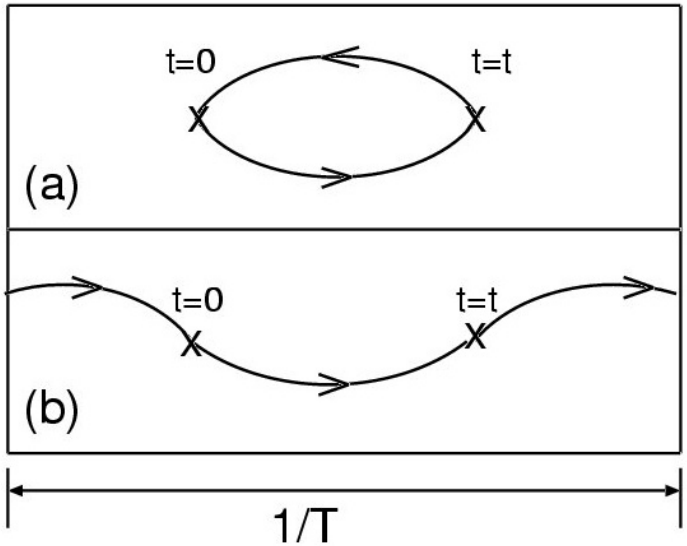
- then in this talk

  I focus on the properties of the constant mode

Contents

- Introduction
- Constant mode in meson correlators at T>0
  - what is the constant mode ?
  - meson correlator with free quarks
  - physical interpretation
  - analysis w/o constant mode
- Quenched QCD calculations at T>0
- Discussion & Conclusion

Constant mode



Pentaquark (KN state):

two pion state:

→ Dirichlet b.c.

c.f. *T.T.Takahashi et al., PRD71, 114509 (2005).*

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

m_q is quark mass
or single quark energy

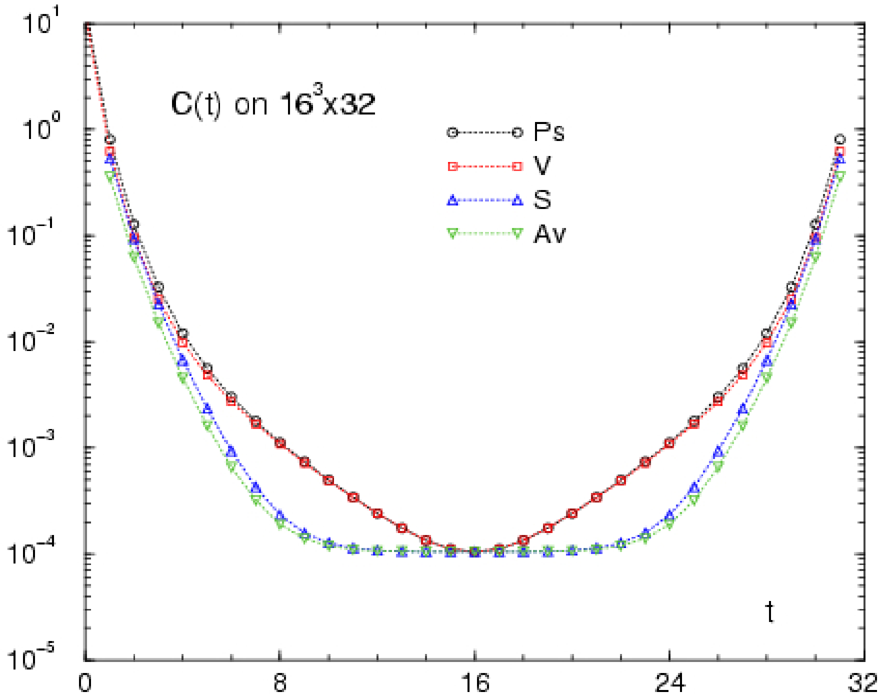
$\exp(-m_q t) \times \exp(-m_q(L_t - t))$
$= \exp(-m_q L_t)$

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

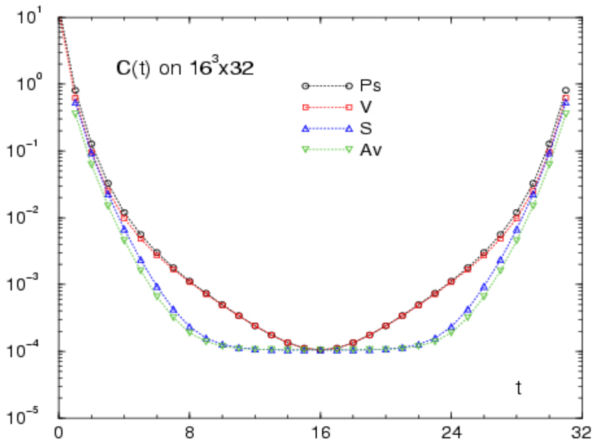
Free quark calculations

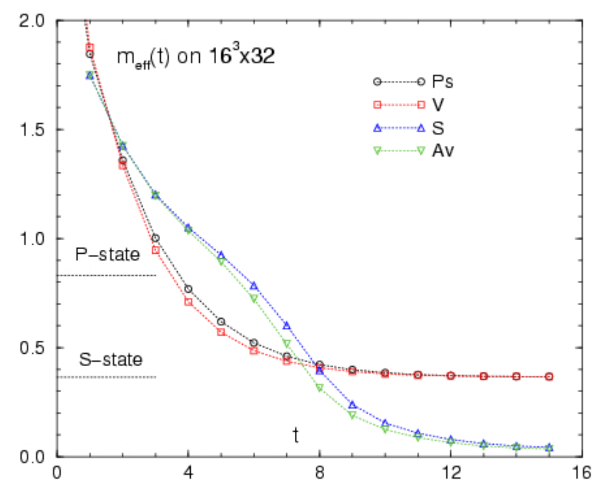


- 16^3 x 32 isotropic lattice
- Wilson quark action with $m_q a = 0.2$

Obvious constant contribution in P–wave states

Free quark calculations





Continuum form of the correlators with P=0

calculated by S. Sasaki

$$C(t) = \sum_{\vec{p}} \frac{4}{\cosh\left(E_p N_t/2\right)} \times$$

$$\begin{cases} \left(E_p^2 \cosh\left[2E_p(t-N_t/2)\right]\right) & \text{for } \Gamma = \gamma_5 \\ \left((E_p^2 - p_i^2)\cosh\left[2E_p(t-N_t/2)\right] + p_i^2\right) & \text{for } \Gamma = \gamma_i \\ -\left(p^2 \cosh\left[2E_p(t-N_t/2)\right] + (E_p^2 - p^2)\right) & \text{for } \Gamma = 1 \\ -\left((p^2 - p_i^2)\cosh\left[2E_p(t-N_t/2)\right] + (E_p^2 - p^2 + p_i^2)\right) & \text{for } \Gamma = \gamma_i\gamma_5 \end{cases}$$

where

E_p : single quark energy with relative mom. p

$$p^2 = \sum_i p_i^2$$

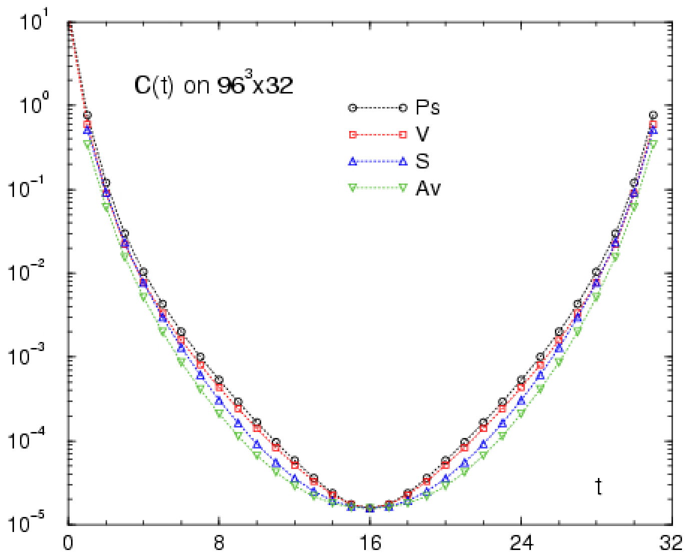
Volume dependence

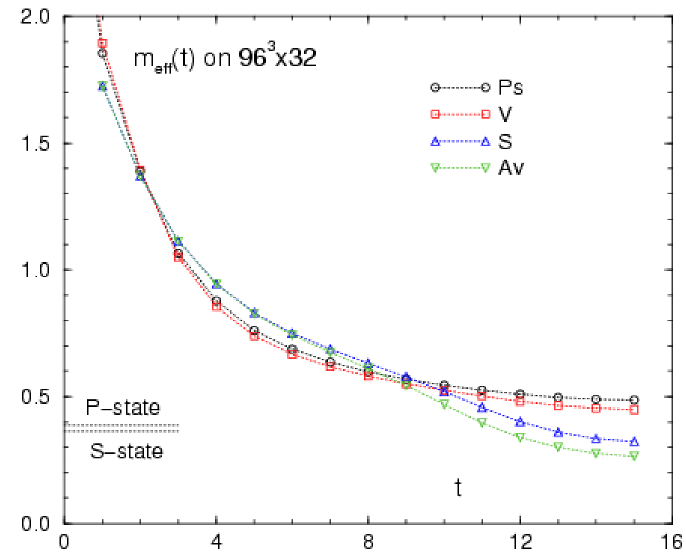
Size of the constant contribution depends on the volume N_s^3

The dependence is negligible at $N_s/N_t \gtrsim 2$

- Results on 96^3 x 32

  ($N_s/N_t=3$ ← similar to T>0 quench QCD calculation)





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

In the study of charmonium dissociation temperatures,
we consider a Temp. dependence of bound state peaks

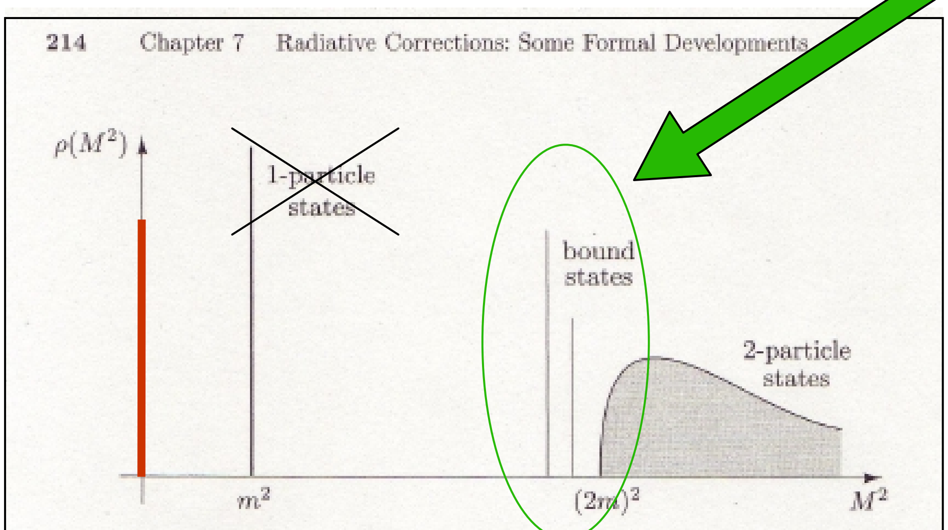


Figure 7.2. The spectral function $\rho(M^2)$ for a typical interacting field theory. The one-particle states contribute a delta function at m^2 (the square of the particle's mass). Multiparticle states have a continuous spectrum beginning at $(2m)^2$. There may also be bound states.

Low energy mode dominates
correlators at large t range

If there is no constant mode
we can easily see the change
of bound states from correlators

Methods to avoid the const. mode
are discussed

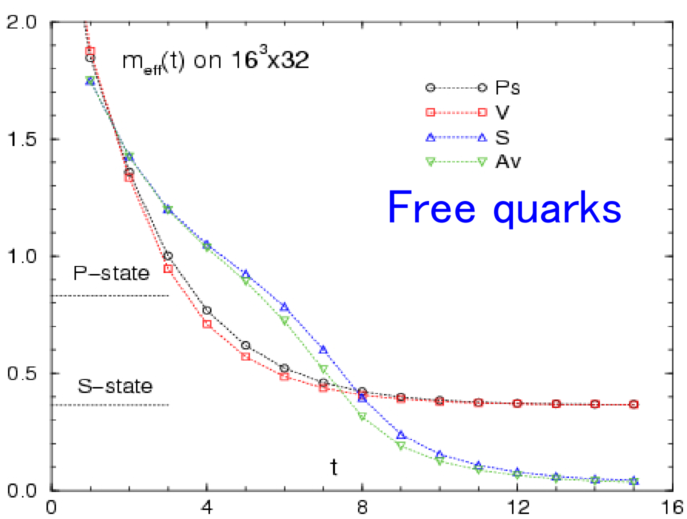
from "An Introduction to Quantum Field Theory"
Michael E. Peskin, Perseus books (1995)

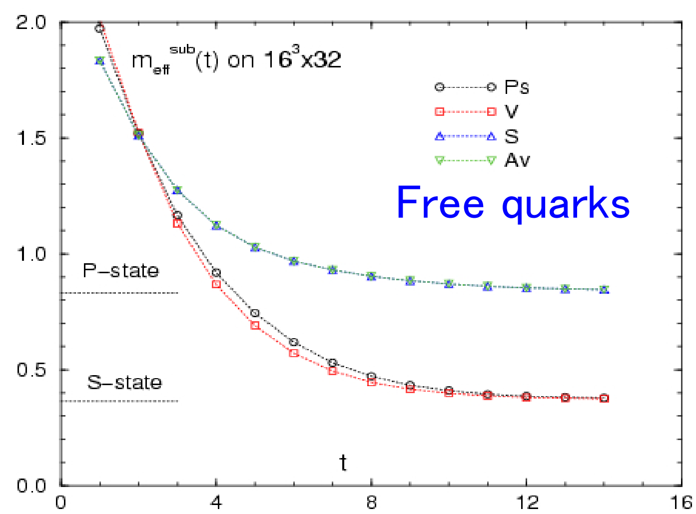
Midpoint subtraction

An analysis to avoid the constant mode

Midpoint subtracted correlator

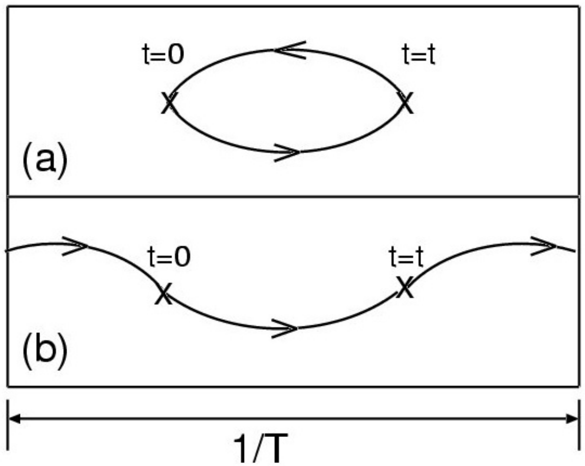
$$\bar{C}(t) = C(t) - C(N_t/2) \quad \Rightarrow \quad \frac{\bar{C}(t)}{\bar{C}(t+1)} = \frac{\sinh^2\left[\frac{1}{2}m_{eff}^{sub}(t)(N_t/2 - t)\right]}{\sinh^2\left[\frac{1}{2}m_{eff}^{sub}(t)(N_t/2 - t - 1)\right]}$$





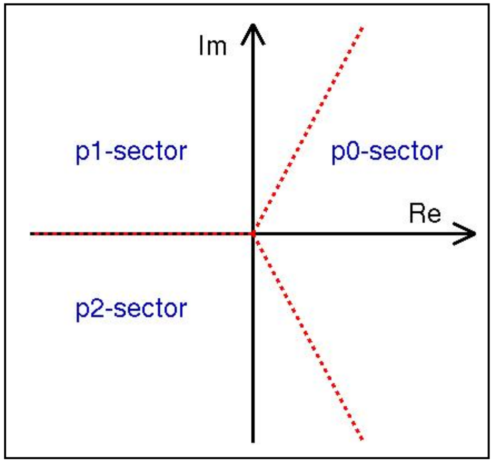
Z_3 symmetrization

Here we consider the Z_3 transformation



Z_3 symmetric

Z_3 asymmetric

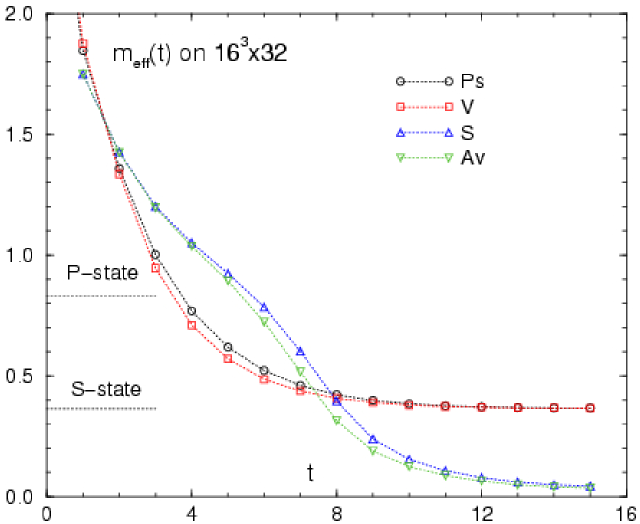


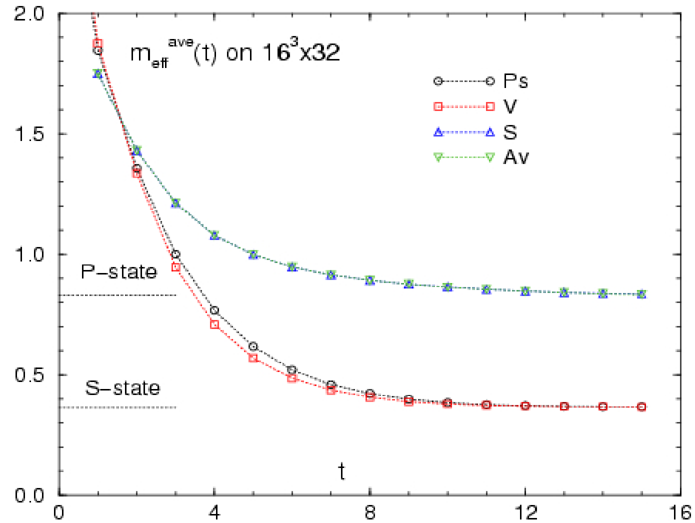
The asymmetry of diag-(b)
is coming from a factor of Re[exp(−i2πn/3)]

$$C^{ave}(t) = \frac{1}{3}\left(C^{p0}(t) + C^{p1}(t) + C^{p2}(t)\right)$$

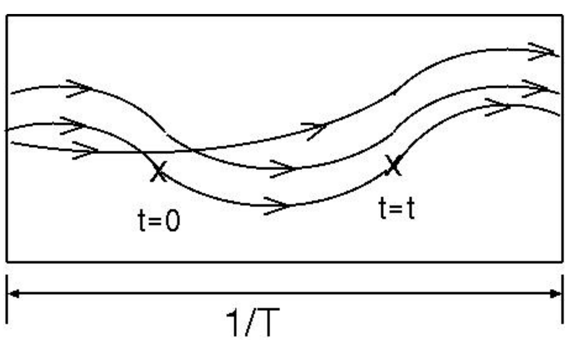
Z_3 asym. terms are removed because $\sum_{n=0}^{2} Re(e^{-i2\pi n/3}) = 0$

Averaged correlators





However, this is not an exact method to avoid the constant contribution.



The 3 times wrapping diagram is also Z_3 symmetric.

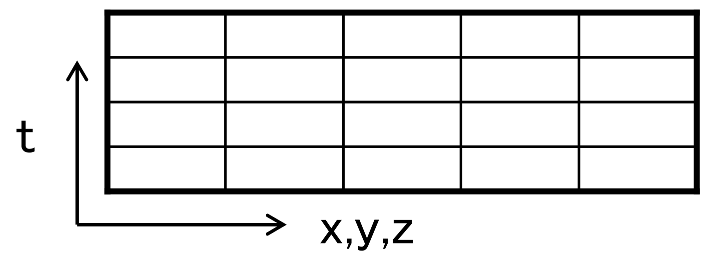
→ the contribution is not canceled.

but, $O(\exp(-m_q N_t)) \gg O(\exp(-3 m_q N_t))$

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 : $a_s/a_t = 4$



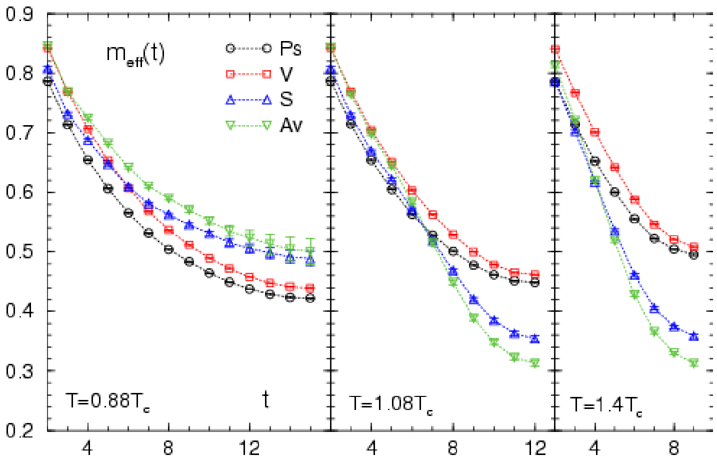
- Quark mass
  - charm quark (tuned with J/ψ mass)
- r_s=1 to reduce cutoff effects in higher energy states

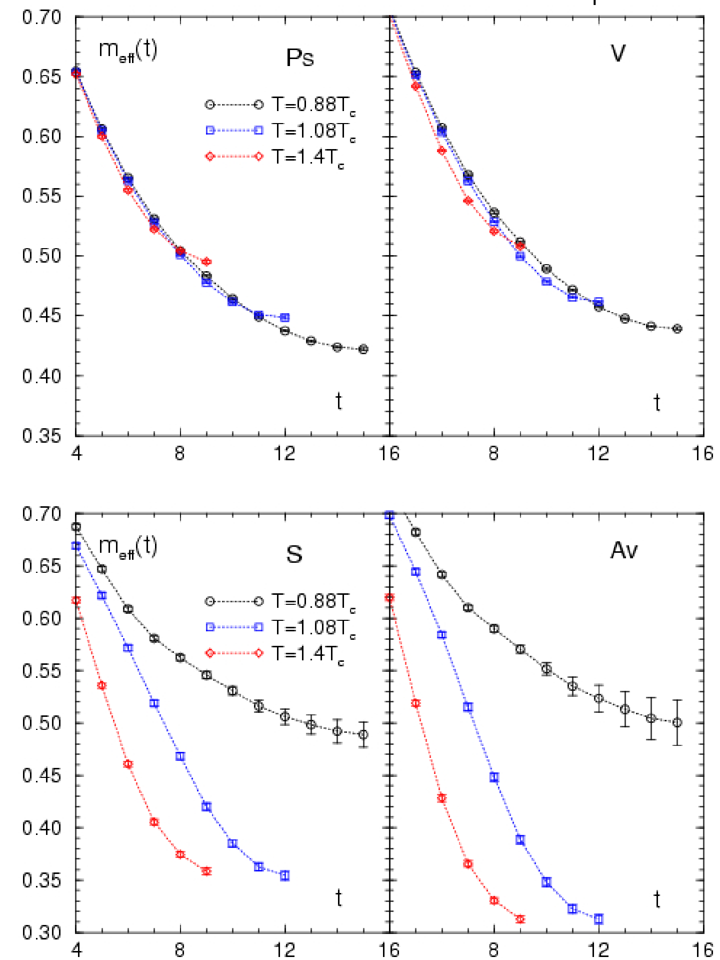
F. Karsch et al., PRD68, 014504 (2003).

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





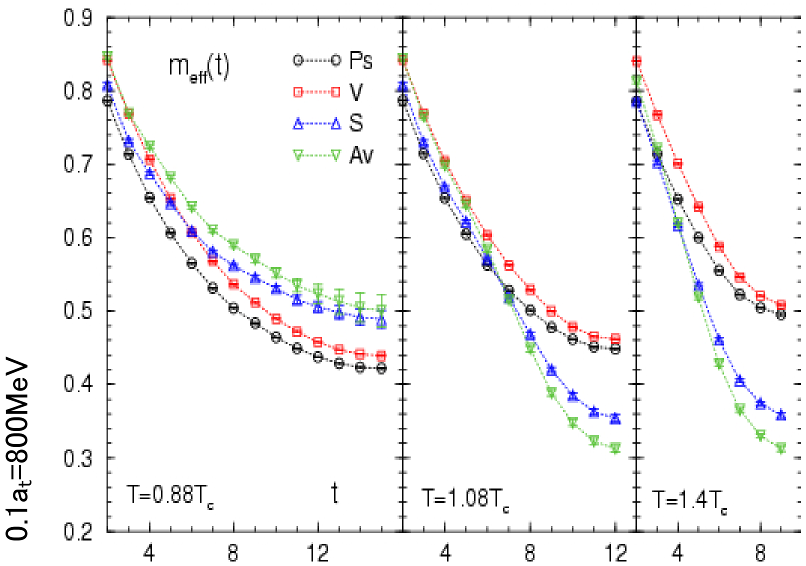
- small change in S−wave states
  → survival of J/ψ & η_c at $T>T_c$
- drastic change in P−wave states
  → dissociation of χ_c just above Tc (?)

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

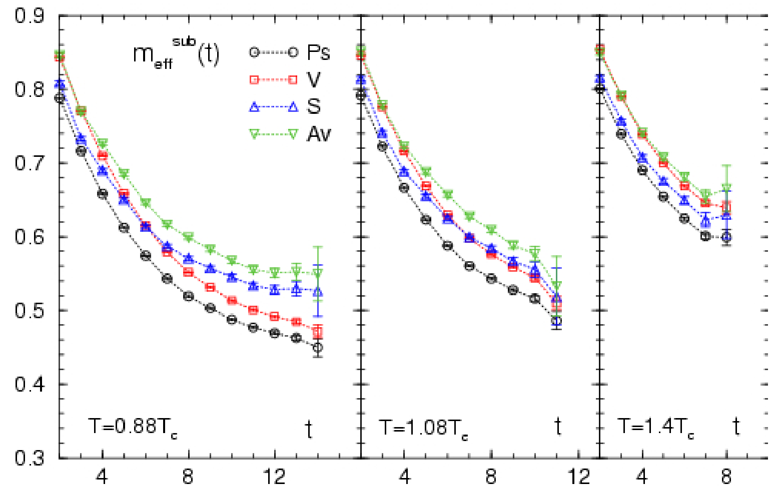
Midpoint subtraction analysis

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

usual effective masses at T>0



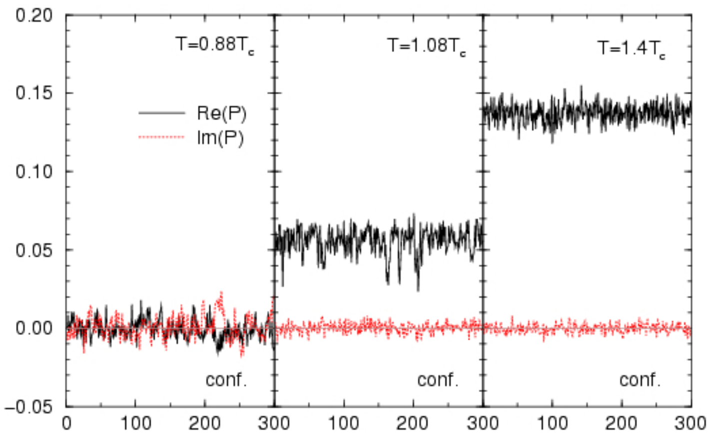
subtracted effective mass



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

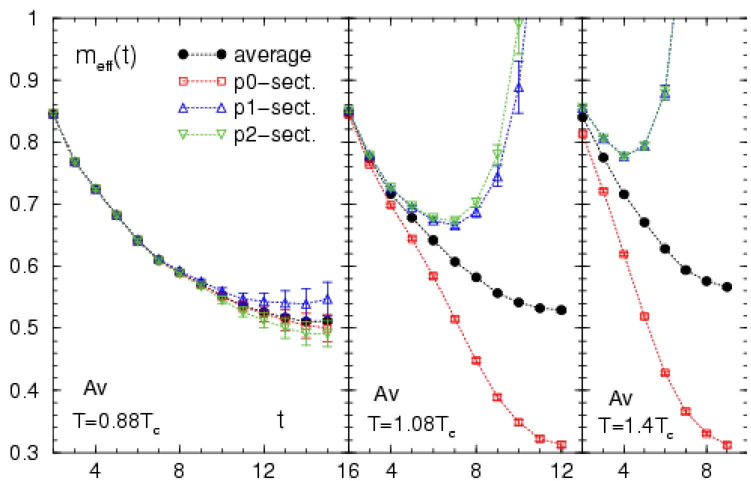
→ the change is due to the constant mode

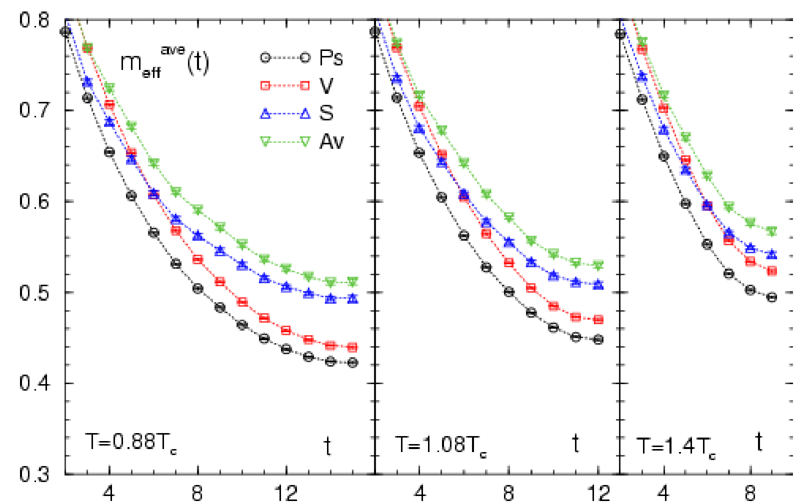
Polyakov loop sector dependence



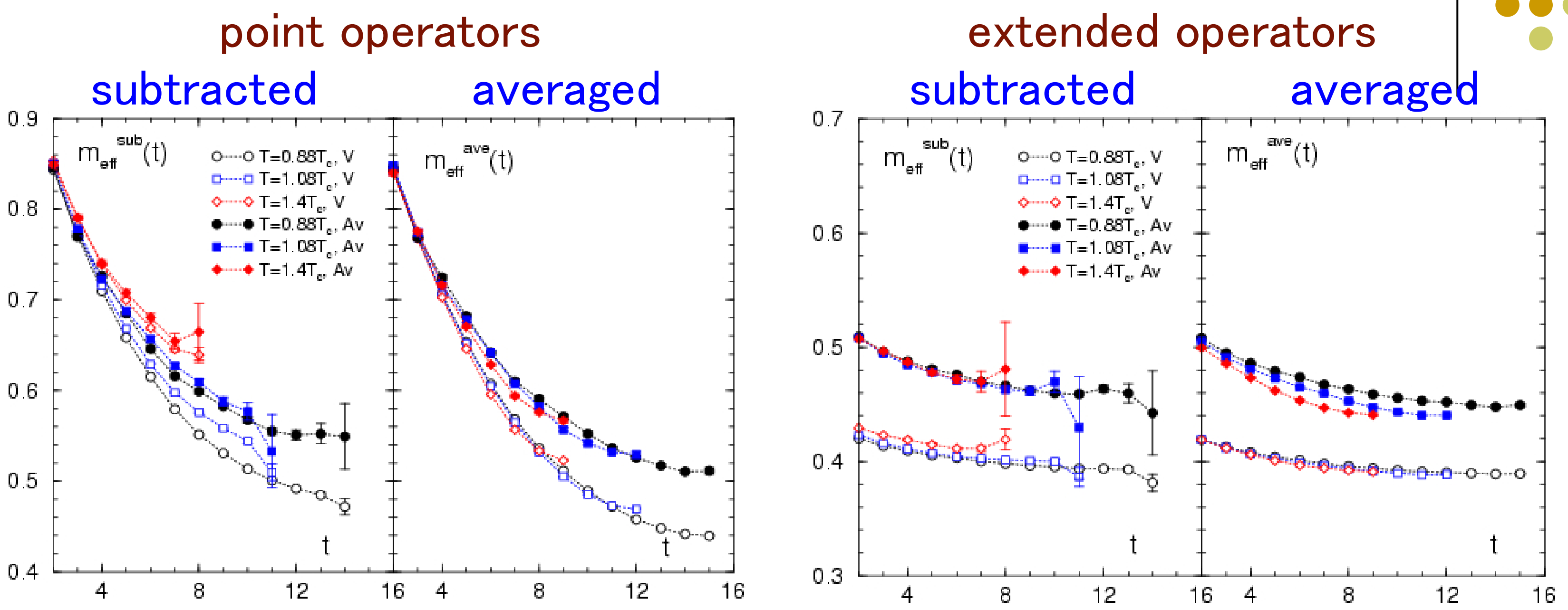
- after Z_3 transformation
  const. → $\mathrm{Re}(\exp(-i2\pi n/3))$*const.
- even below T_c, small const. effect
  enhances the stat. fluctuation.
- drastic change in P-states disappears.

Results for Av channel





Discussion



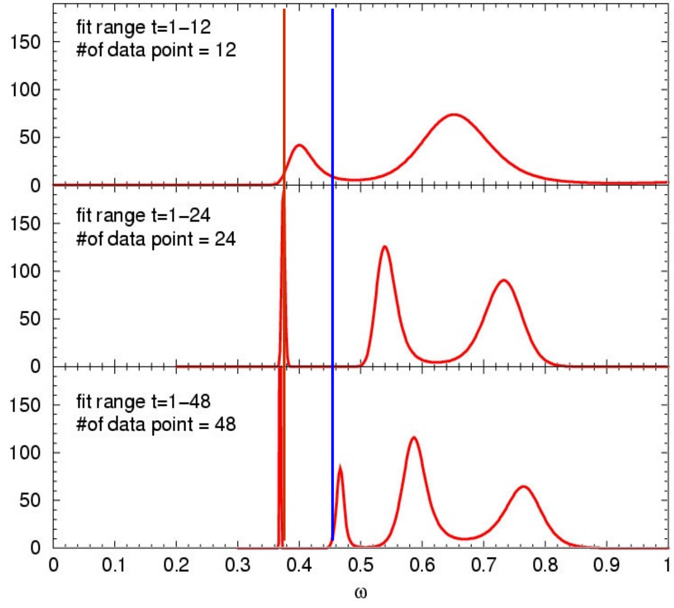
The drastic change of P−wave states is due to the const. contribution.

→ There are small changes in SPFs (except for ω=0).

Why several MEM studies show the dissociation of χ_c states ?

Difficulties in MEM analysis

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 analysis sometimes fails if data quality is not sufficient

Furthermore P–wave states have larger noise than that of S–wave states

MEM w/o the constant mode

In the MEM analysis,

one has to check consistency of the results at $\omega \gg T$
using, e.g., midpoint subtracted correlators.

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

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

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

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.