Charmonium correlators at finite temperature in quenched lattice QCD

Hideo Matsufuru[1], *Takashi Umeda*[1], *and Kouji Nomura*[2]

[1] *Yukawa Institute for Theoretical Physics, Kyoto University*
[2] *Department of Physics, Hiroshima University*

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Refs.:

T. Umeda, K. Nomura, and H. Matsufuru, hep-lat/0211003
T.Umeda et al., Int. J. Mod. Phys. A16 (2001) 2215

Introduction

Charmonium states at finite temperature:

- Important signal for formation of quark gluon plasma
  in heavy ion collision experiments
- Theoretical understanding
  Based on potential model
  - ◦ Mass shift near T_c
    Hashimoto et al., Phys. Rev. Lett. 57 (1986) 2123
  - ◦ J/ψ suppression above T_c
    Matsui and Satz, Phys. Lett. B178 (1986) 416
  - — No bound state above T_c ?
  - ◦ Bound state may exist near T_c
    Digal et al., Phys. Rev. D 64 (2001) 094015
- Lattice QCD
  - ◦ Quark and antiquark still interact strongly at $T > T_c$
    — behavior different from free quark picture
    QCD-TARO Collab., Phys. Rev. D 63 (2001) 054501
    Umeda et al., Int. J. Mod. Phys. A16 (2001) 2215

In this work, we analyze spectral functions of mesonic correlators in lattice QCD below and above T_c as well as at $T = 0$.

Our approach (1)

Temporal correlators in lattice simulations

$$C(t) = \sum_{\vec{x}} \langle O(\vec{x},t) O^\dagger(0) \rangle \qquad [O(\vec{x},t) : \text{meson operator}]$$

$\Rightarrow$ Spectral function $A(\omega)$

$$C(t) = \int d\omega K(t,\omega) A(\omega) \qquad K(t,\omega) = \frac{e^{-\omega t} + e^{-\omega(N_t - t)}}{1 - e^{-N_t \omega}}$$

□ Anisotropic lattice

$\Rightarrow$ sufficient number of d.o.f.

□ Smearing technique

$\Rightarrow$ low energy part of correlators enhanced

Point correlators are also analyzed at $T = 0$

□ Analysis procedures:

- Maximum entropy method (MEM)

  Nakahara et al., Phys. Rev. D60 (99) 091503

  — without assuming specific form

- χ^2 fit analysis

  — with several ansätze for spectral functions

  $\Rightarrow$ Sum of (relativistic) Breit-Wigner or pole type functions

  Sophisticated form: constrained curve fitting

  Lepage et al., Nucl. Phys. B (PS) 106 (2002) 12

  — add prior knowledge

We use these two methods in complementary manner

Our approach (2)

☐ Criteria for the extraction methods:

- Stability for input parameters or model functions
- Stable result for $T = 0$ correlators with restricted number of d.o.f. (similar to the condition at $T > 0$)

☐ Problem with smeared operators:
Possibility to detect artificial peak
⇒ need check with various smearing functions

Lattice setup

Anisotropic lattices in quenched approximation

- $\xi = a_\sigma/a_\tau = 4$, $a_\sigma^{-1} = 2.030(13)$ GeV
- Size : $20^3 \times N_t$

N_t	T/T_c	$N_{conf} \times N_{source}$
160	~ 0	500×16
32	~ 0.9	1000×16
26	~ 1.1	1000×16

- Quark action: $O(a)$ improved Wilson quark action
  $(\kappa, \gamma_F) = (0.1120, 4.000)$
  → roughly correspond to charm quark mass
  Matsufuru et al., Phys. Rev. D 64 (2001) 114503
- Smearing function: wave function measured at $T = 0$
  We also employ *"half-smeared"* operators

We first examine two analysis methods at $T = 0$ for the point and smeared correlators.

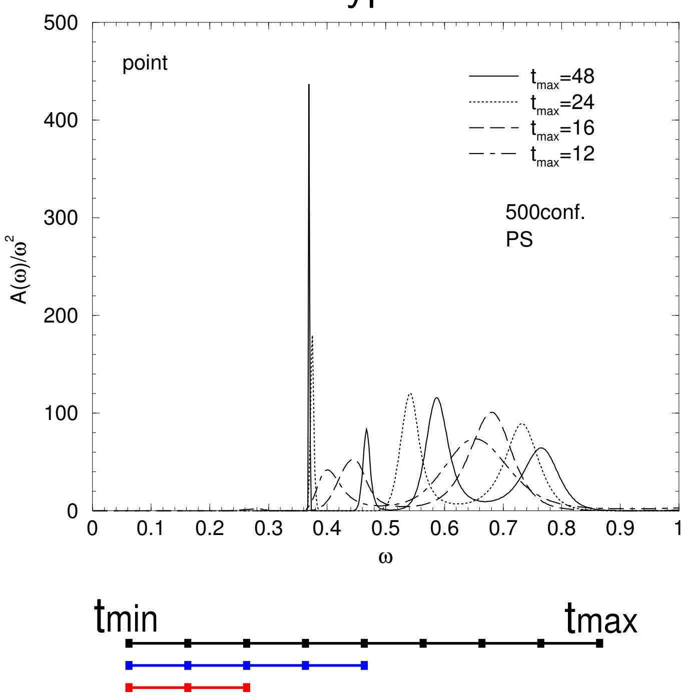
Numerical Results (1): point correlators

□ Point-point correlators

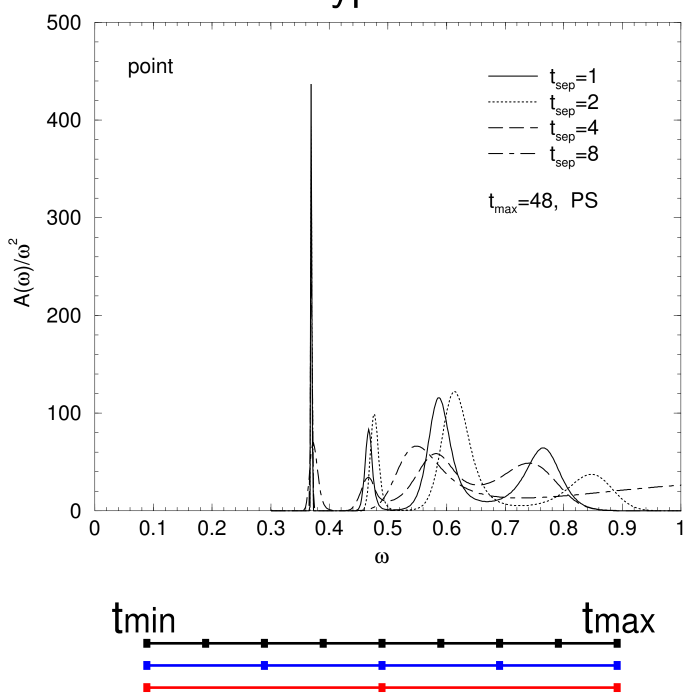
	t_{min}	t_{max}	t_{sep}	N_{DF}
Type-I	1	48	1	48
	1	24	1	24
	1	16	1	16
	1	12	1	12
Type-II	1	48	1	48
	2	48	2	24
	4	48	4	12
	8	48	8	6

Results of MEM:

Type-I



Type-II



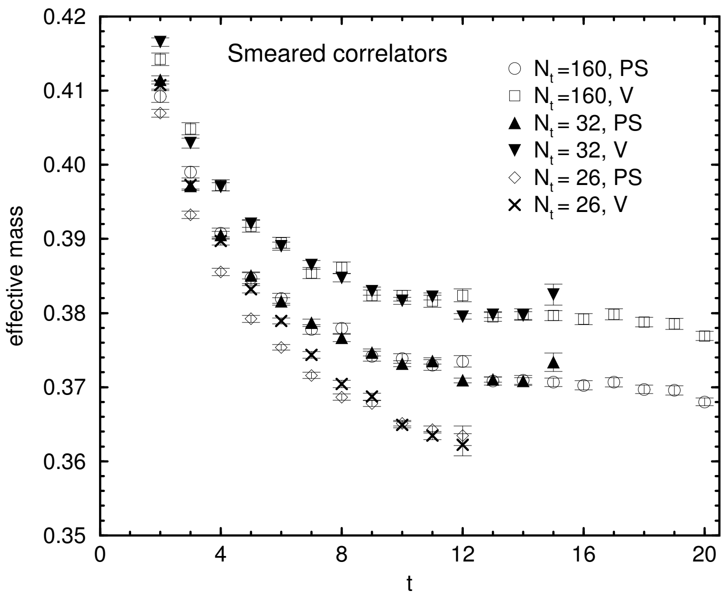
- $t_{max} \simeq 16$ is not acceptable
- $O(10)$ degree of freedom is necessary
- $t_{max}a_\tau$ of $O(1\text{ fm})$ is necessary

$\Longrightarrow$ This requirement cannot be fulfilled at $T > 0$.

In the following, we focus on the low frequency part
(lowest peak) of $\rho(\omega)$.
$\Rightarrow$ Smeared (and half-smeared) correlators

□ Effective mass plot m_{eff} of smeared correlators

$$\frac{C(t)}{C(t+1)} = \frac{\cosh\left[m_{eff}(t)(N_t/2-t)\right]}{\cosh\left[m_{eff}(t)(N_t/2-t-1)\right]}$$



□ Spectrum at $T=0$
— determined by two-pole fit

state	m_{PS}	m_V
ground	0.36856(9)	0.37769(12)
first exc.	0.500(22)	0.479(23)
fit range	17–80	15–80

Numerical Results (3): summary of results

Results for smeared correlators:

◦ χ^2 fit analysis: 2-pole, 1BW, BW+pole(exc.)
◦ Constrained curve fitting: multi-BW (1-4)

In general, constrained curve fitting gives consistent result with standard χ^2 fit

□ At $T = 0$

- In MEM, ground state peak is stable with change of t_{max}
  — For $t_{max} = 12$ ground state peak appears at correct place
- No indication of finite width for ground state, as expected

□ At $T = 0.9T_c$

- MEM and fit analysis give consistent results
- Ground state peaks locate at almost the same places as $T = 0$
- Width from fit is consistent with zero
  No indication of finite width for ground states

□ At $T = 1.1T_c$

- MEM and fit analysis give consistent results
- Smeared and half-smeared correlators give $consistent$ results
- Behavior under change of smearing function is NOT similar to the free quark case

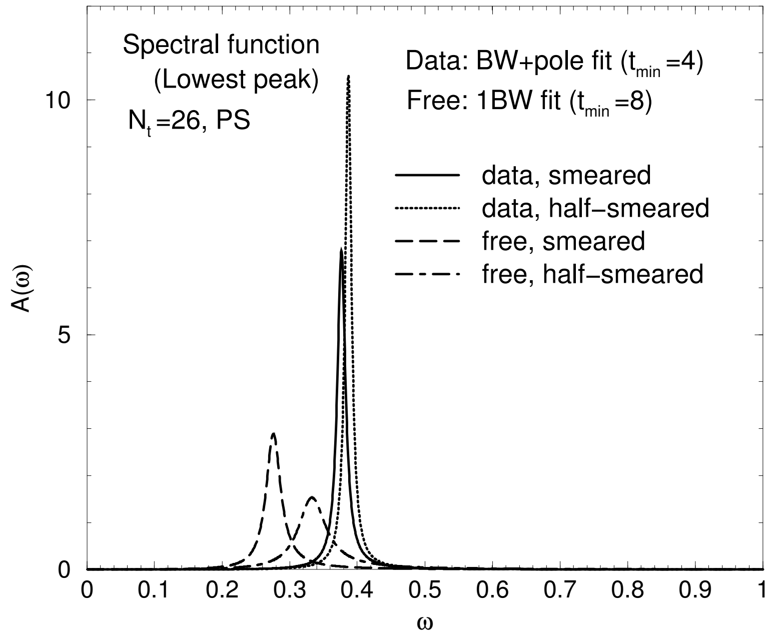
⇒ We conclude that physical peak is observed
— bound-state-like structure

- Finite width is observed ($\Gamma \sim$ 200 MeV)
- Peak positions are almost same as $T < T_c$

Numerical Results (4): result at $T \simeq 1.1T_c$

☐ Spectral function determined by fit
(Only lowest peak is shown.)

Pseudoscalar



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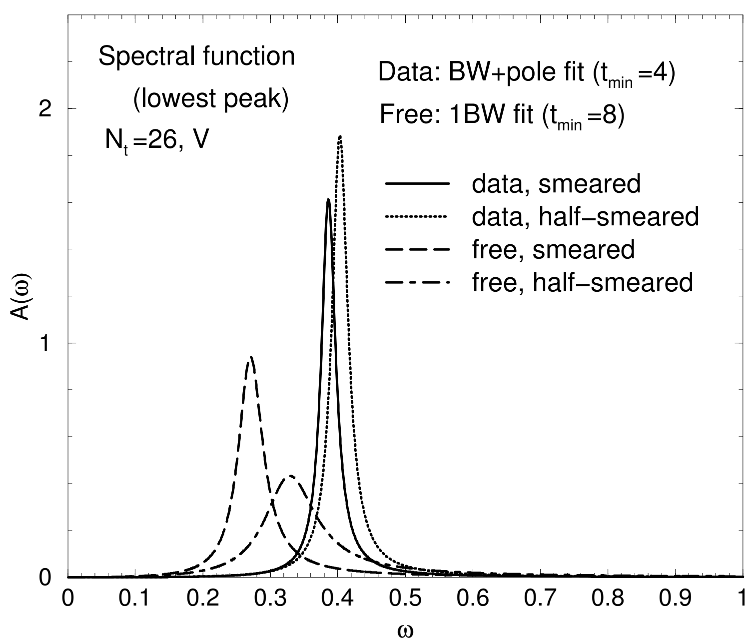


Conclusion and outlook

□ $T \simeq 1.1T_c$

- Spectral function: still strong peak structure at almost
  the same position as $T < T_c$

  ⇒Existence of quasi-stable bound-state-like structure
  Finite width of 100-200 MeV

- Cf. spatial $c\bar{c}$ correlation

  ⇒ Strong spatial correlation between $c\bar{c}$ still at $T \sim 1.5T_c$

□ $T \simeq 0.9T_c$

- No indication of finite width
- No indication of mass shift

□ Procedures:

- MEM (as well as fit analysis) should be applied carefully
- For point correlators, naive application may fail at $T > 0$
- Better to combine with other analysis methods

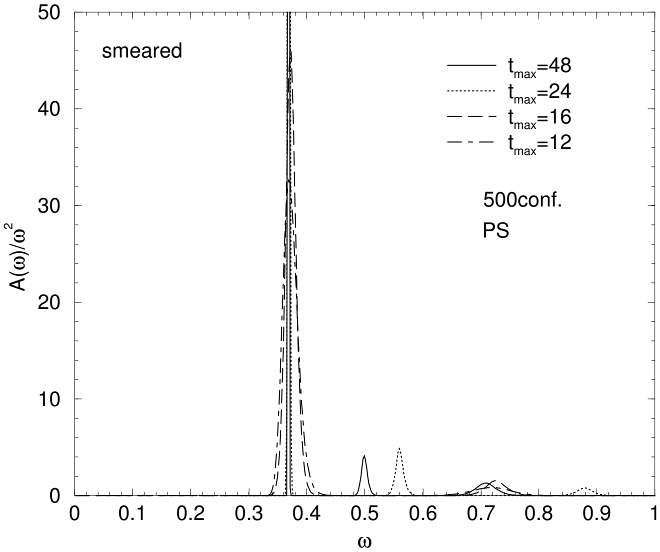
Outlook

◦ Analysis in wider range of temperature
◦ Light quark region
◦ Dynamical quark effects

Appendix: Results at $T = 0$

□ Result of MEM

Pseudoscalar



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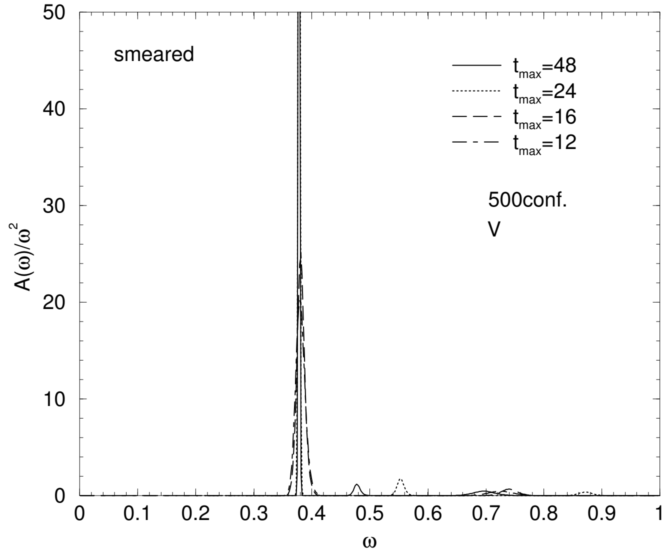
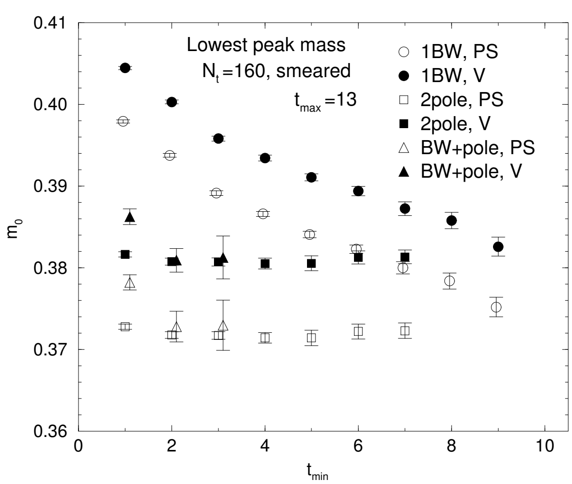


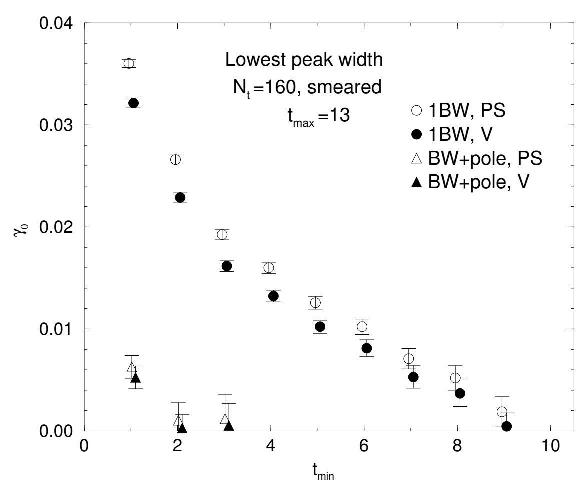
□ Result of Fits

— 2-pole, 1-BW, BW+pole forms

Ground state: mass



width

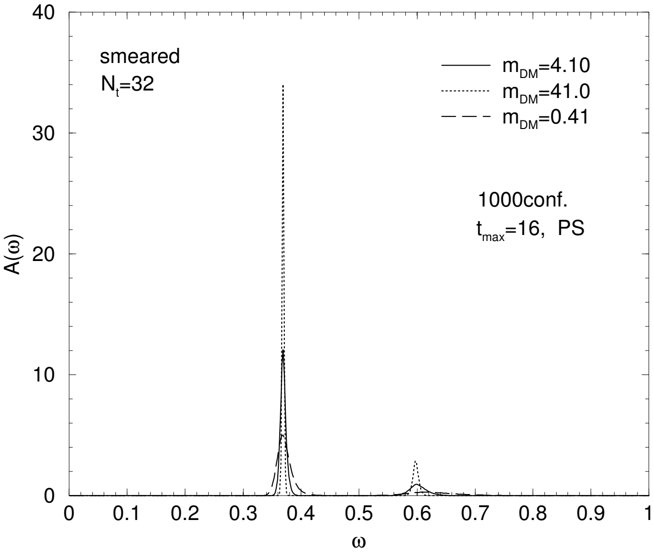


- In MEM, ground state peak is stable with change of t_{max}
- Consistency of methods
- No indication of finite width for ground state, as expected

Appendix: Results at $T = 0.9T_c$

☐ Result of MEM

Pseudoscalar



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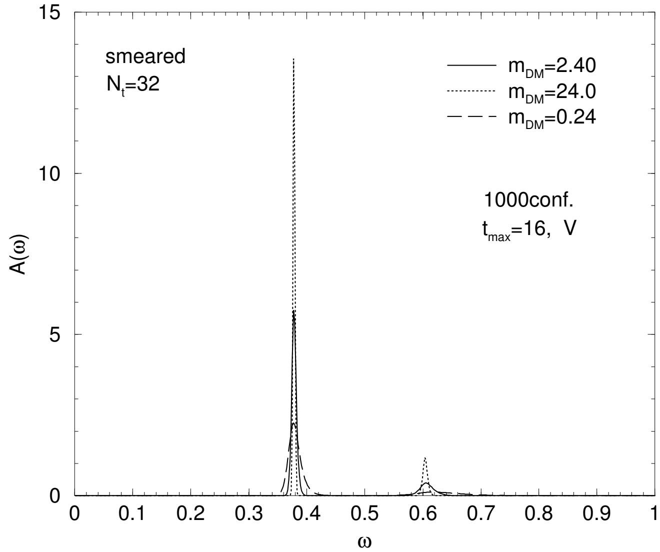
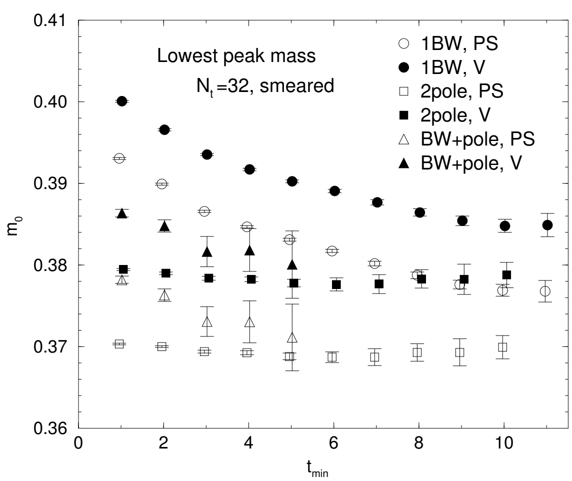


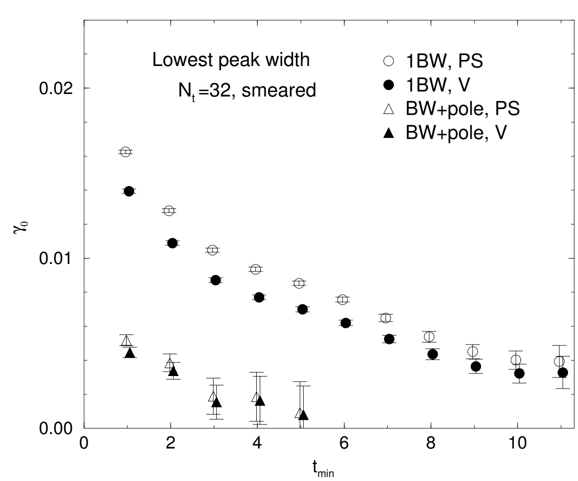
☐ Result of Fits

— 2-pole, 1-BW, BW+pole forms

Ground state: mass



width

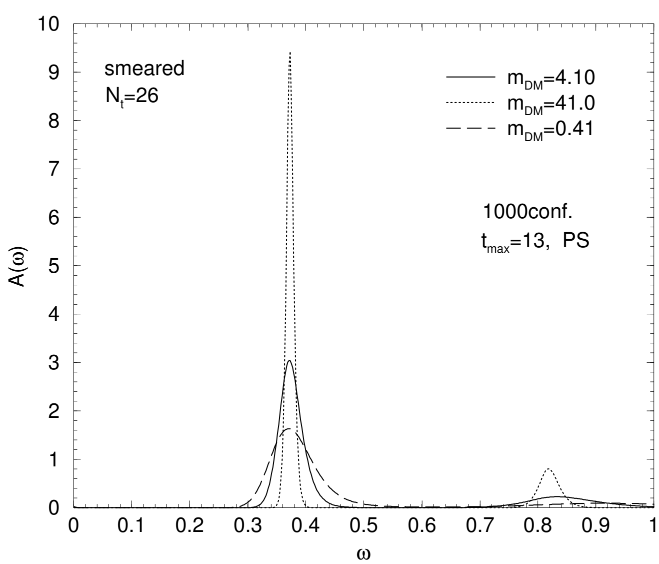


- Ground state peaks locate at almost the same as $T = 0$
- Width from fit is consistent with zero.
  – No indication of finite width for ground state

Appendix: Results at $T = 1.1$

□ Result of MEM

Pseudoscalar



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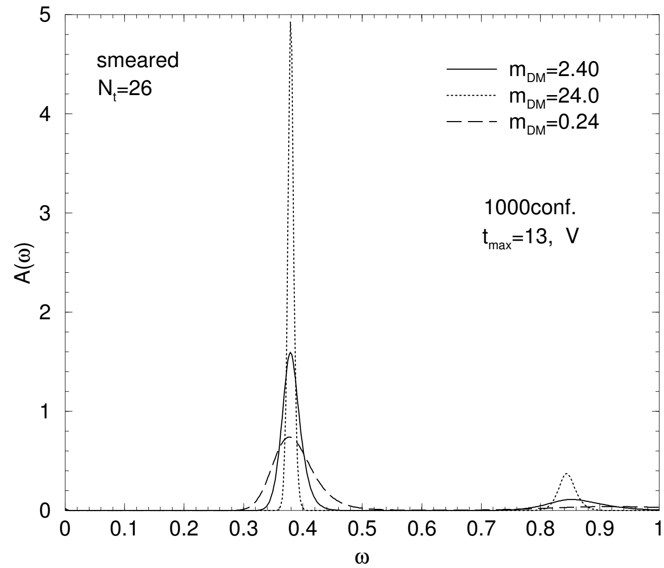
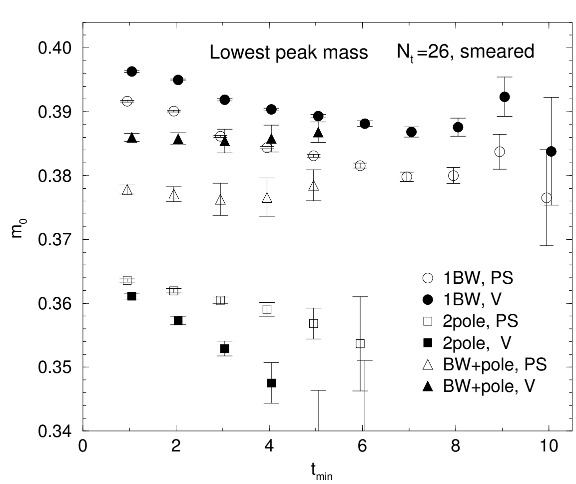


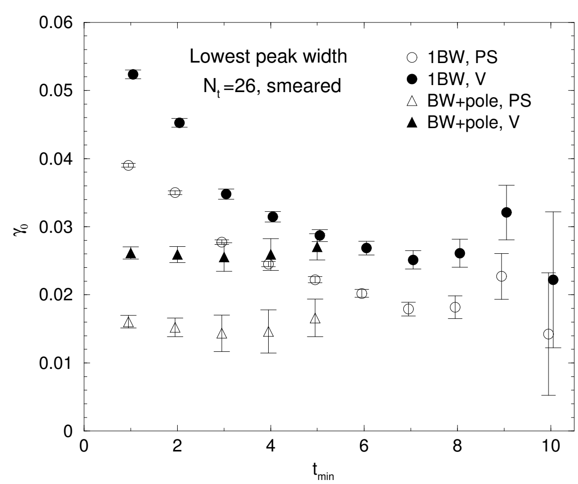
□ Result of Fits

— 2-pole, 1-BW, BW+pole forms

Ground state: mass



width



- There observed hadron-like peak.
- Finite width is observed ($\Gamma \sim$ 200 MeV).
- Peak position is almost same as $T < T_c$.