Finite temperature hadron physics on the lattice

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for QCD-TARO Collaboration

Contents

The QCD-TARO Collaboration

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Physical goals:

- ○ Finite Temperature QCD
- ○ Finite Chemical Potential
- ○ MCRG and Improved Actions

Introduction

Finite temperature hadron properties:

- What happens on hadrons
  or what new effect above T_c ?
- Change of masses and width near T_c

Example of effective theory:

NJL model analysis

c.f. Hatsuda and Kunihiro, Phys. Rep. 247 (1994) 221

○ Chiral restoration
○ parity partner degeneracy
○ Above T_c : Soft modes

Lattice QCD

Discretization of space-time (Euclidean space)

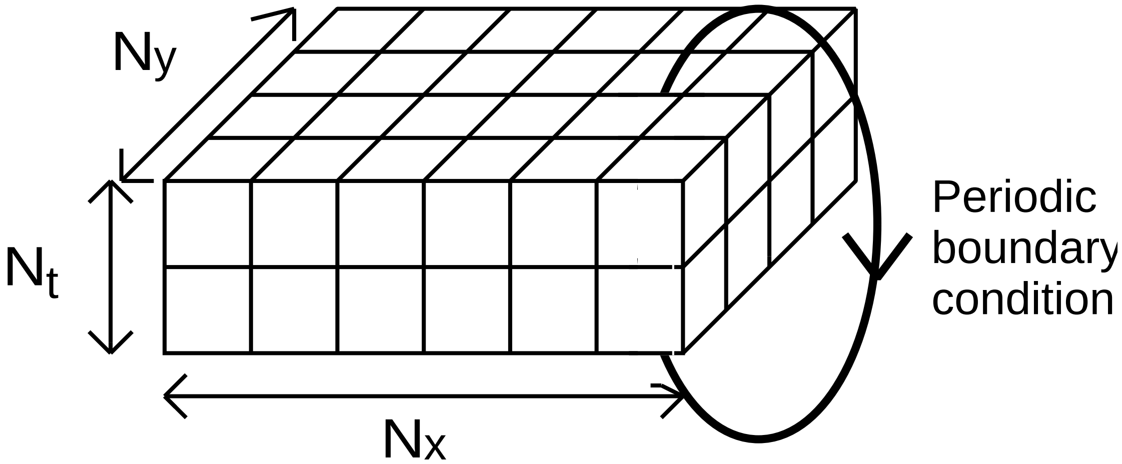
with exact local gauge invariance

$\Downarrow$

Path integral formalism has a well-defined meaning

$\Rightarrow$ Monte Carlo Method

Finite Temperature lattice QCD



$$T = \frac{1}{N_t a} \qquad (\, a \text{ : lattice spacing} \,)$$

Our Approach

Temporal correlator ;

$\Longrightarrow$ Pole mass (mass of temporal direction)

$\Updownarrow$

Screening mass (mass of spatial direction)

$\Longrightarrow$ Wave function

Is there bound state at $T > T_c$?

How can we show that ?

$\Longrightarrow$ Spectral function

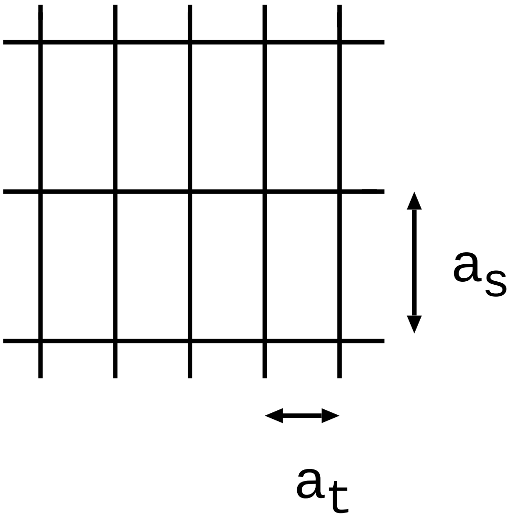
Need detailed information

in temporal(temperature) direction

$\rightarrow$ Anisotropic Lattice

Karsch ('82)

Burgers, Karsch, Nakamura and Stamatescu ('88)



anisotropy ξ

$$\xi = {}^{a_s}/_{a_t}$$

$$\xi_F = {}^{m_s}/_{m_t} \, (\underset{\uparrow}{=} \xi)$$

calibration

(I) Meson with light quark

- Temperature dependence of mass
  (Pole mass vs Screening mass)
- Hadronic bound state above T_c (?)
- Spectral function

Simulation parameters

Gauge field:

$\beta = 5.68$, $\gamma = 4.0$, quenched, 60conf.

○ lattice size : $12^3 \times N_t$

$$\begin{aligned} N_t = 72 &\ (T \simeq 0) \quad : T = 1/N_t a_t \\ 20 &\ (T \simeq 0.93 T_c) \\ 16 &\ (T \simeq 1.15 T_c) \\ 12 &\ (T \simeq 1.5 T_c) \end{aligned}$$

○ Anisotropy : $\xi \equiv a_s/a_t = 5.3(1)$

Engels, Karsch and Scheideler (1997), Klassen (1998)

○ Cutoff : $a_s^{-1} = 0.85(3)$ GeV, $a_t^{-1} = 4.5(2)$ GeV
from heavy quark potential

Quark field : Anisotropic Wilson action

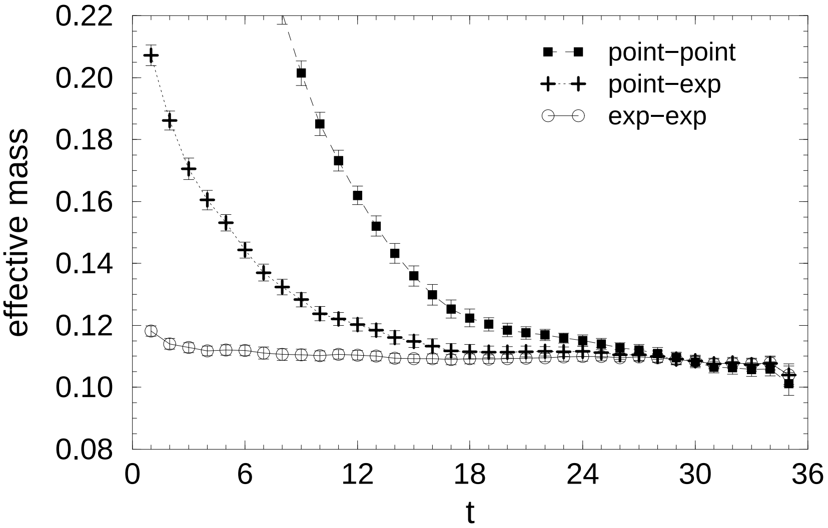
$$\begin{aligned} m_q \sim\ & 0.17\ GeV (m_{Ps} \sim 0.81\ GeV) \\ & 0.12\ GeV (\qquad\ \ 0.68\ GeV) \\ & 0.10\ GeV (\qquad\ \ 0.61\ GeV) \end{aligned}$$

Effective mass

Effective mass : m_{eff}

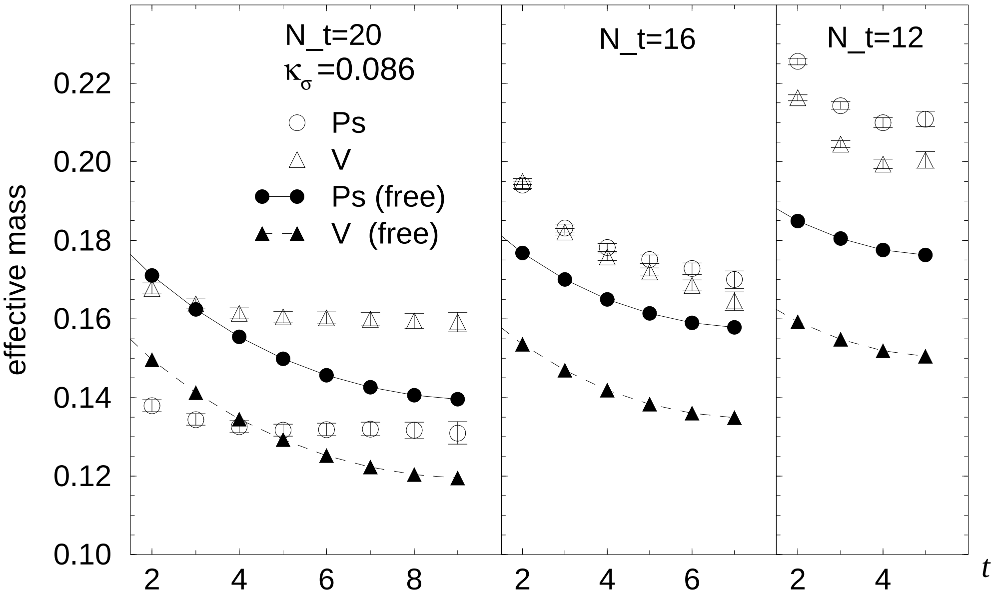
$$\frac{G_M(\vec{x}=0,t)}{G_M(\vec{x}=0,t+1)} = \frac{\cosh\left[m_{\text{eff}}(N_t/2-t)\right]}{\cosh\left[m_{\text{eff}}(N_t/2-t-1)\right]}$$

- Source dependence

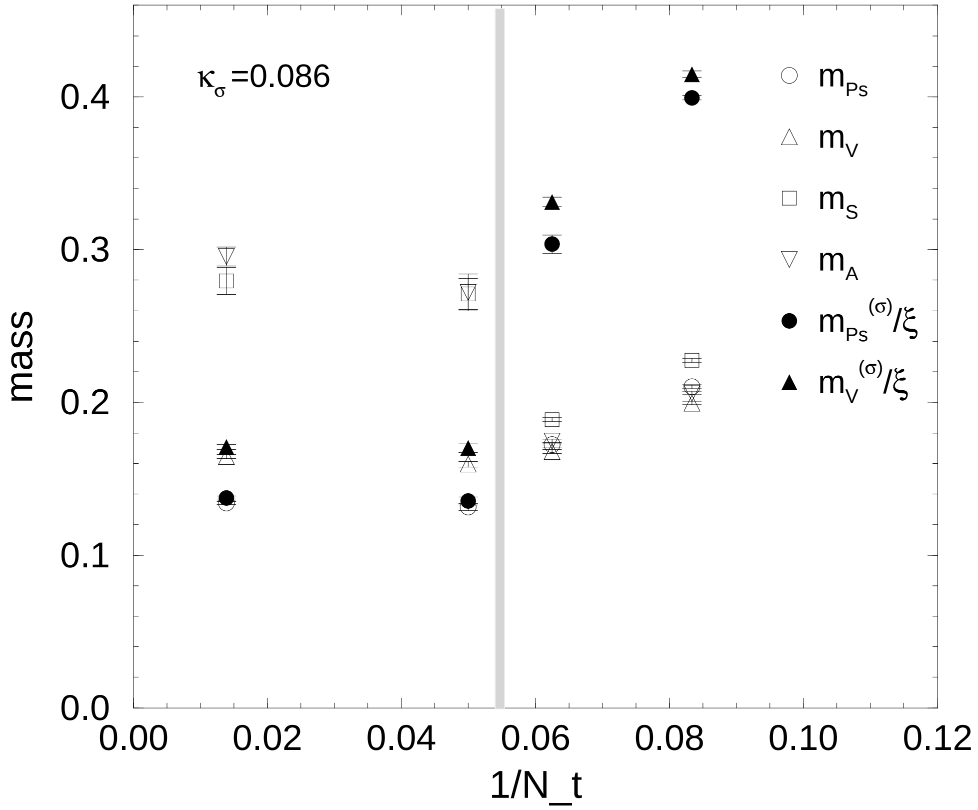


$\Longrightarrow$We adopt the exp-exp source

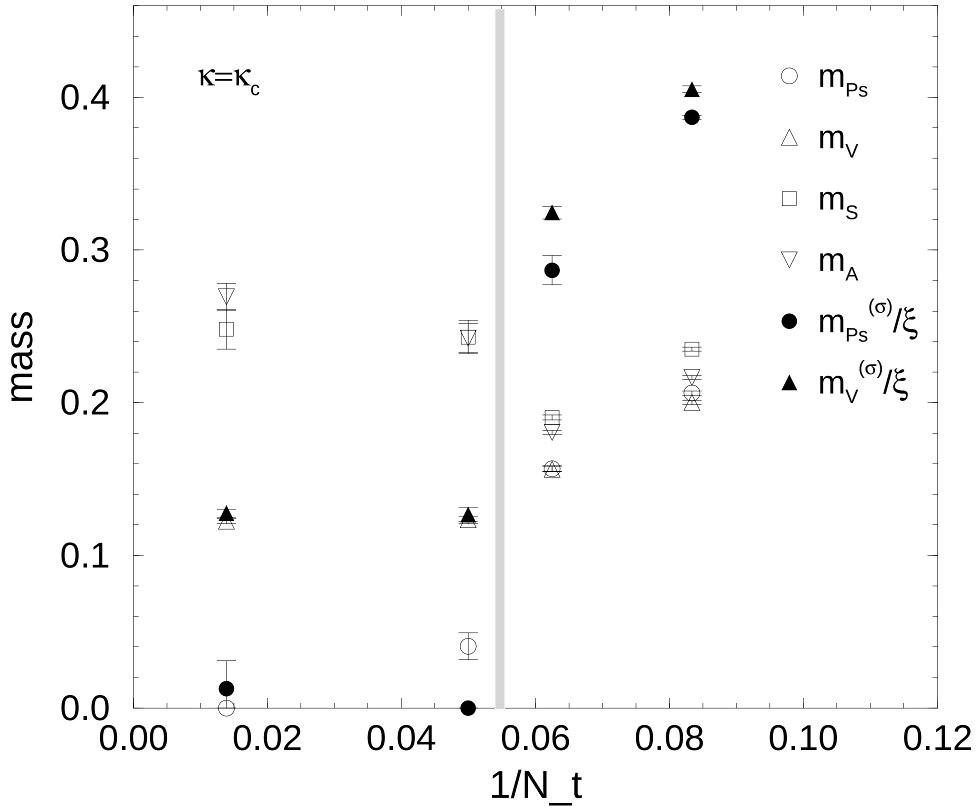
- effective mass at $T > 0$



Temperature dependence of mass



$$\kappa_s = 0.086$$
$$(m_q \sim 0.10\text{GeV})$$

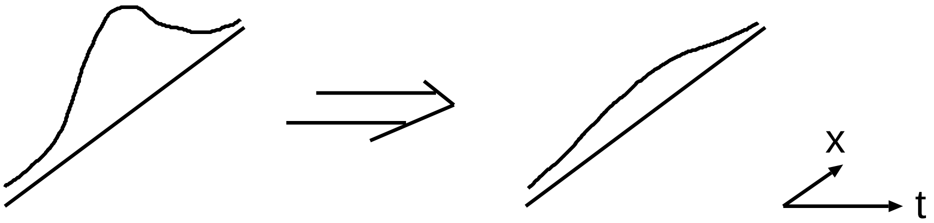


$$\kappa = \kappa_c$$
$$(m_q \to 0 \text{ limit})$$

t-dependence of the wave function

$$w_\Gamma(r,t) = \sum_{\vec{x}} \langle \bar{q}(\vec{x}+\vec{r},t)\Gamma q(\vec{x},t) O^\dagger(0) \rangle$$

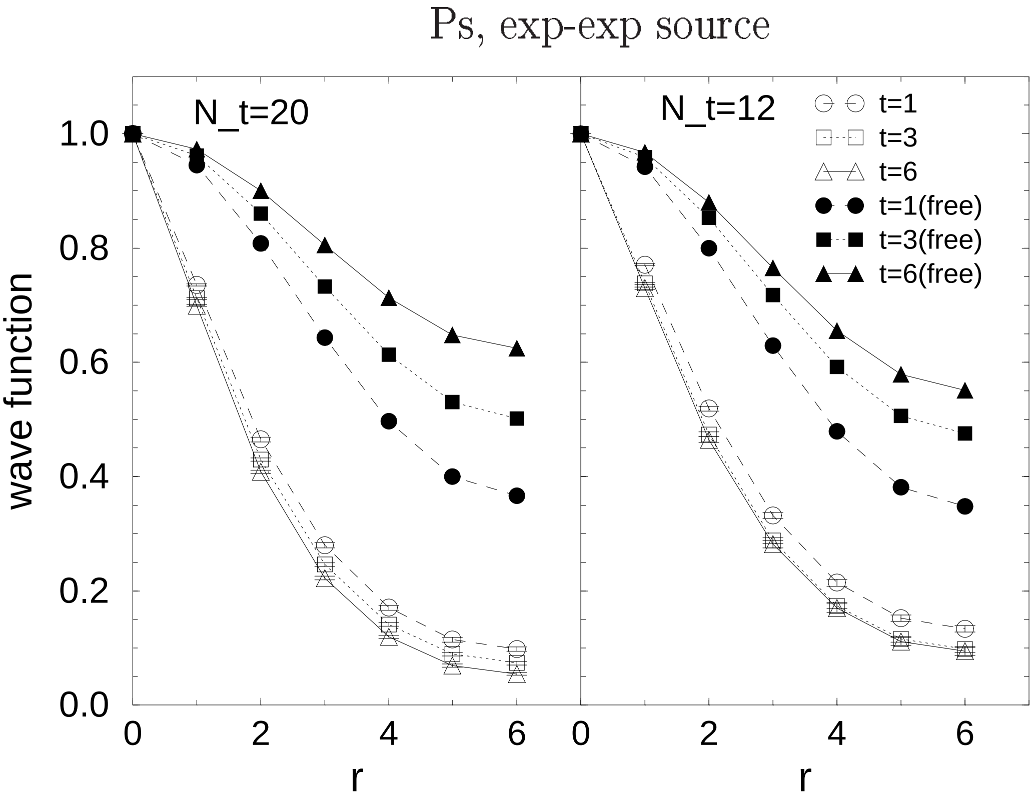
If there is no bound state (like free quark case), wave function becomes broader as t.



In this case, $\phi_\Gamma(r,t) = w_\Gamma(r,t)/w_\Gamma(r=0,t)$

(normalized at spatial origin)

increase as t.



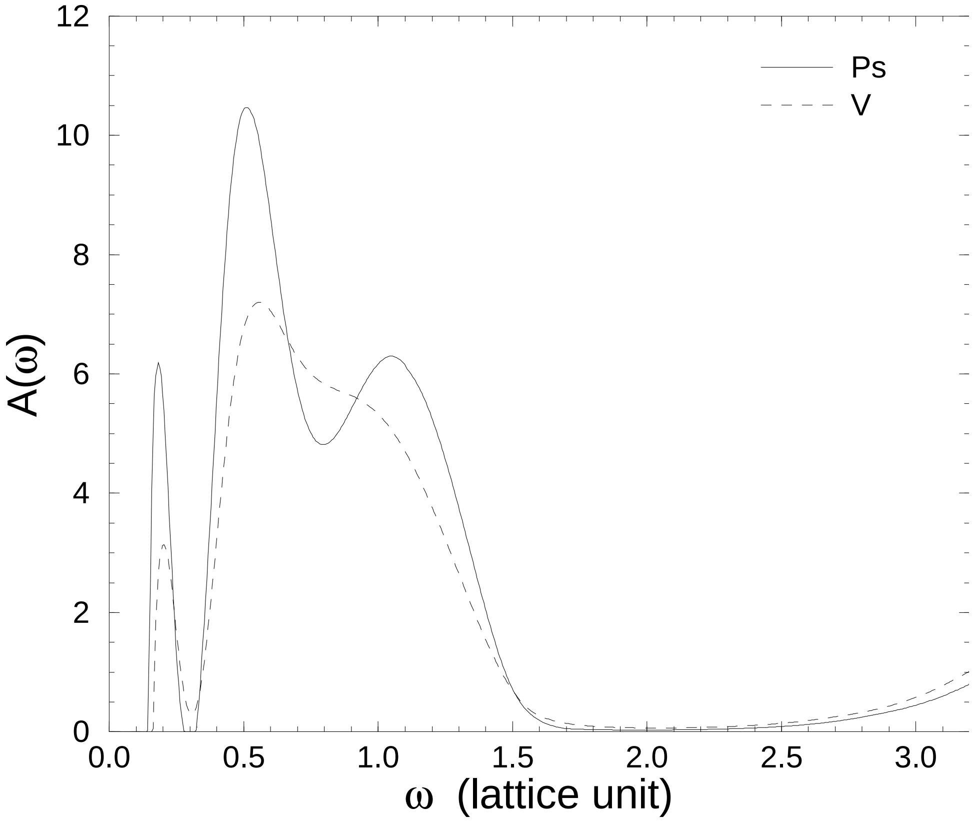
Spectral function

The two point correlation function of meson : $C(t)$

$$C(t) = \int K(t;\omega)A(\omega)d\omega$$

$$K(t;\omega) = e^{-\omega t} + e^{-\omega(N_t - t)}$$

$A(\omega)$: spectral function



Summary and Conclusion (I)

- Effective mass
  - – Significant change above T_c
- Wave functions
  - – Narrower than free $q - \bar{q}$ even at $N_t = 16, 12$. Still prefer to stay together.
- Spatial-mass (screening mass)
  vs temporal-mass (pole mass)
  - – Grows above T_c.
  - – Stronger growing of spatial-masses.
  - – Consistent with NJL model analysis.

(II) Meson with heavy quark

(Problem)

Spatial lattice spacing is coarse

$(a_s^{-1} \sim 0.85\mathrm{GeV})$

Charmonium mass $\sim$ a few GeV

$\Downarrow$

○ Heavy quark action :Fermilab action

($O(a)$ improved (Clover action))

$\Longrightarrow$ Heavy quarkonium physics

Clover action : Sheikholeslami,Wohlert('85)

Fermilab action : El-Khadra,Kronfeld,Mackenzie('97)

We study the Charmonium at $T \geq 0$

- mass shift near T_c

  T.Hashimoto et al,('86)
- J/ψ suppression above T_c

  T.Matsui and H.Satz,('86)

Simulation parameters

On the same configuration as (I) (see p.5)

Target meson mass is J/ψ mass : $m_V \sim 3.1 GeV$

Effective mass at $T > 0$

— Heavy quark field—

- parameter

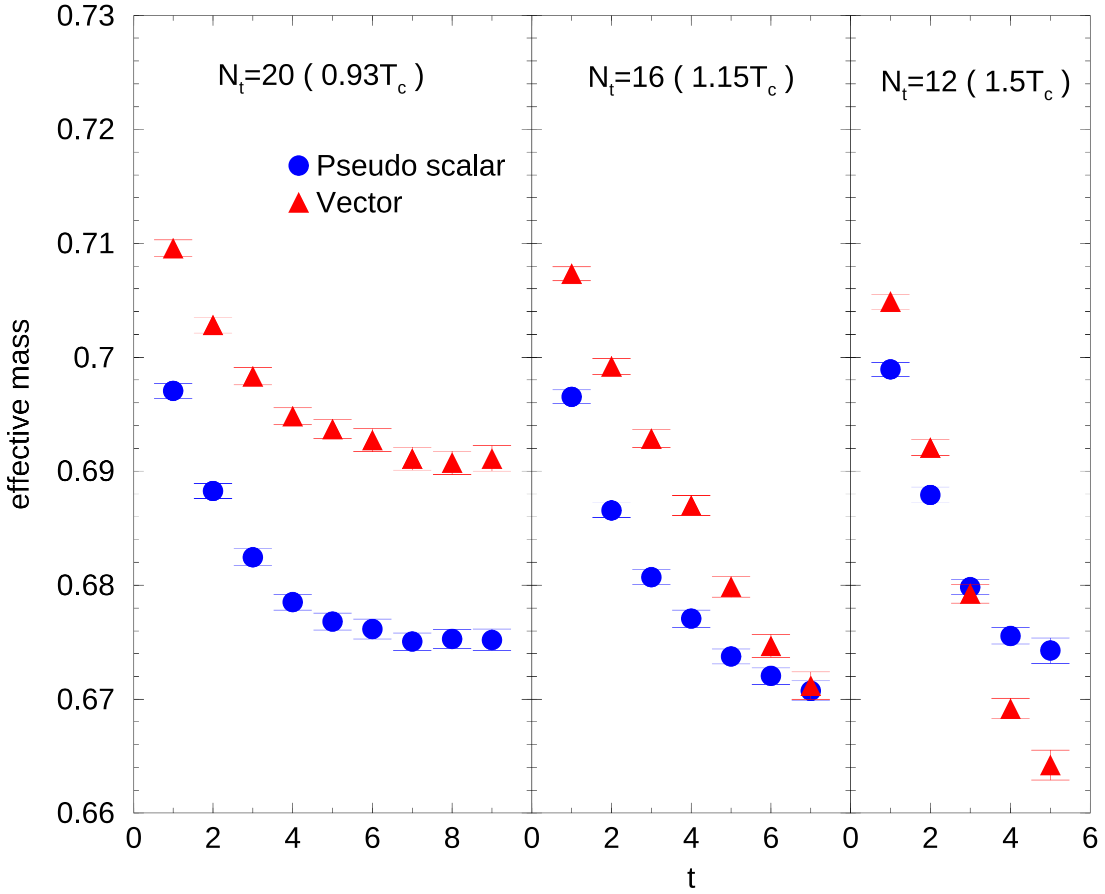
  $$1/\kappa = 9.690, \quad \gamma_F = 3.67$$

- results at $T = 0$

  $$m_{Ps} = 3.04(14)\text{GeV}, \quad m_V = 3.10(14)\text{GeV}$$

- Finite Temperature

effective mass at $T > 0$



Summary and Conclusion (II)

(1) We use the anisotropic Fermilab action for heavy quark system.

(2) Meson correlator

- No significant change at $N_t = 20$
- Significant change at $N_t = 16, 12$

The Temperature dependence is different from that of light mesons .
Especially behavior of vector meson change.

Out look

- ◦ Precise determination of mass shift
  - variational analysis
  - Spectral function
  - Fine lattice

    ⇒ Now under progress

    Lattice size : $16^2 \times 24 \times N_t$

    $N_t = 96$ (at $T \sim 0$)

    $\beta = 4.56$ (Symanzik action (tree))

    Anisotropy : $\xi \sim 4.0$

    Cutoff : $a_s^{-1} \sim 1.6$ GeV ($a_s \sim 0.12$ fm)

- ◦ More detailed analysis of Heavy quarkonium : $J/\psi, \cdots$

- ◦ Other channels : baryons etc.

- ◦ Relation with topological quantities.

- ◦ With dynamical quarks.