Finite temperature hadron physics on the lattice

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for QCD-TARO Collaboration

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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)

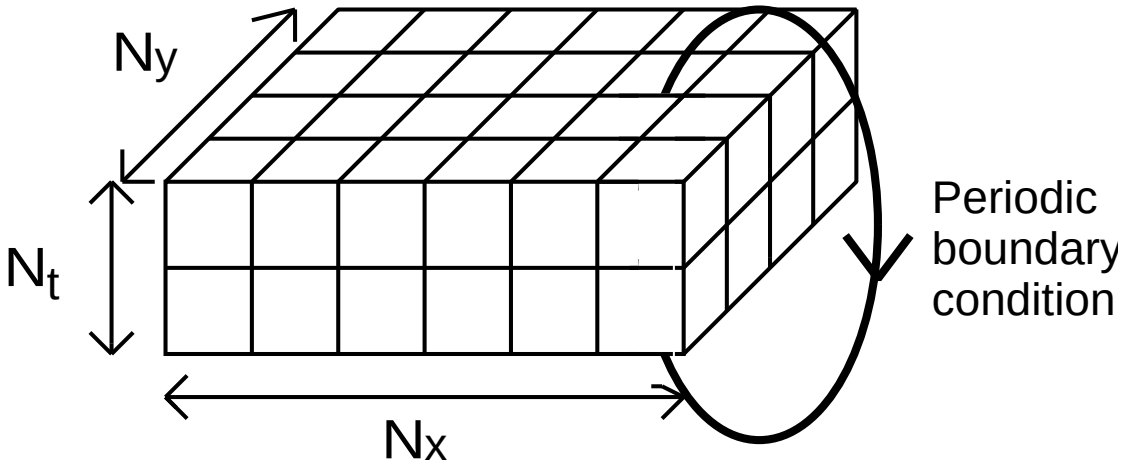
with exact local gauge invariance

$\Downarrow$

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

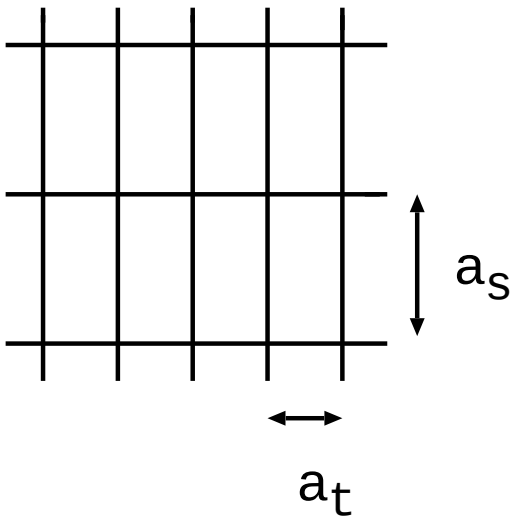
Need detailed information

in temporal(temperature) direction

$\rightarrow$ Anisotropic Lattice

Karsch ('82)

Burgers, Karsch, Nakamura and Stamatescu ('88)



anisotropy ξ

$\xi = a_s / a_t$

$\xi_F = m_s / m_t \; (= \xi)$

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 : $12^3 \times N_t$
  $N_t = 72$ ($T \simeq 0$) : $T = 1/N_t a_t$
  20 ($T \simeq 0.93 T_c$)
  16 ($T \simeq 1.15 T_c$)
  12 ($T \simeq 1.5 T_c$)
- 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

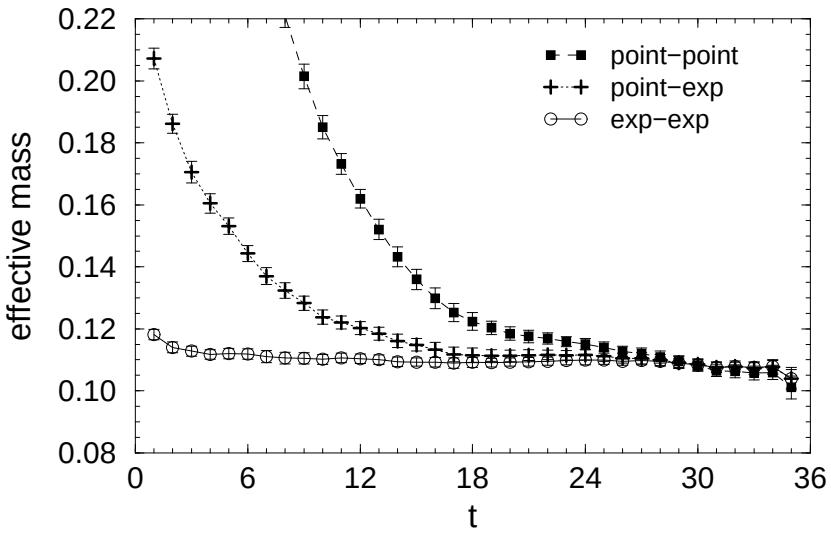
$$m_q \sim 0.17\ GeV (m_{Ps} \sim 0.81\ GeV)$$
$$0.12\ GeV (\quad 0.68\ GeV)$$
$$0.10\ GeV (\quad 0.61\ GeV)$$

Effective mass

Effective mass : m_{eff}

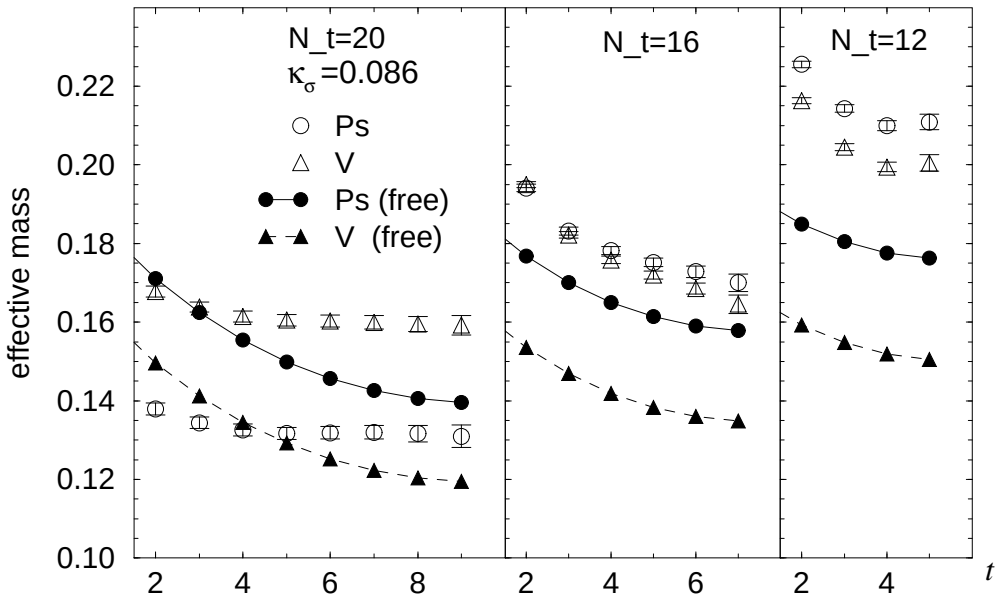
$$\frac{G_M(\vec{x}=0,t)}{G_M(\vec{x}=0,t+1)} = \frac{\cosh\left[m_{\text{eff}}(N_t/2-t)\right]}{\cosh\left[m_{\text{eff}}(N_t/2-t-1)\right]}$$

- Source dependence

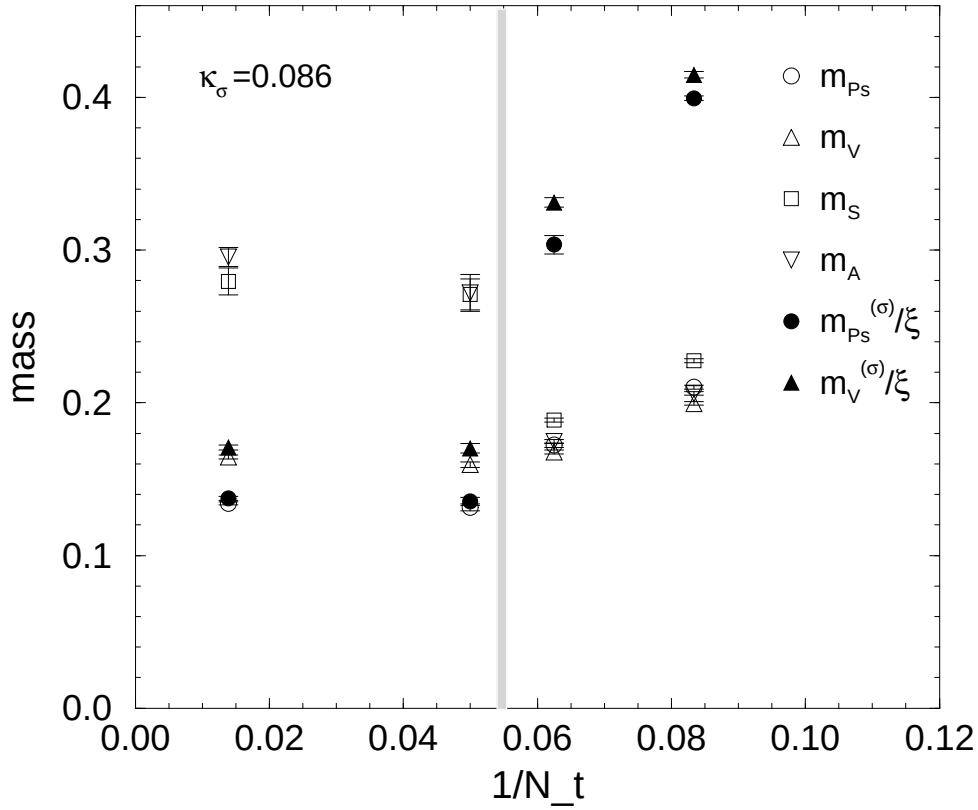


$\Longrightarrow$ We adopt the exp-exp source

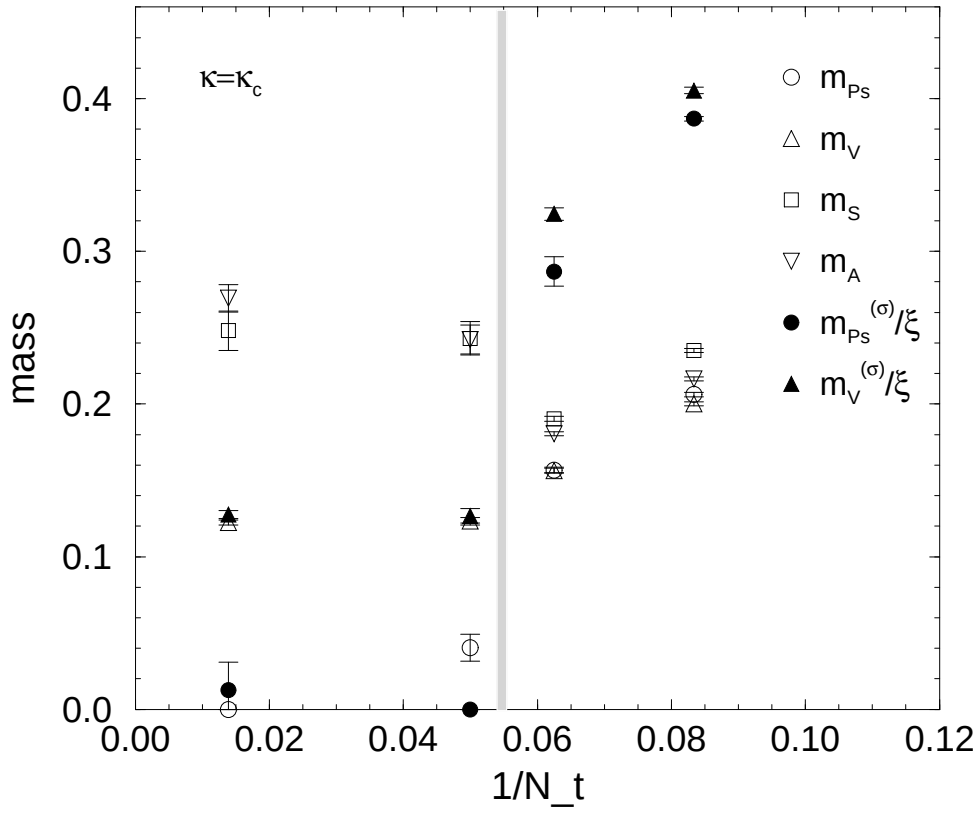
- effective mass at $T > 0$



Temperature dependence of mass



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

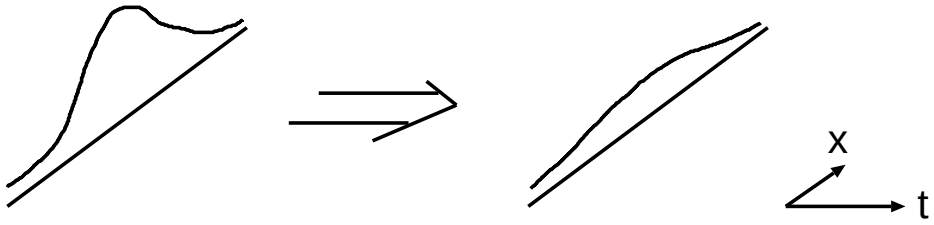


$\kappa = \kappa_c$
$(m_q \to 0 \text{ limit})$

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.

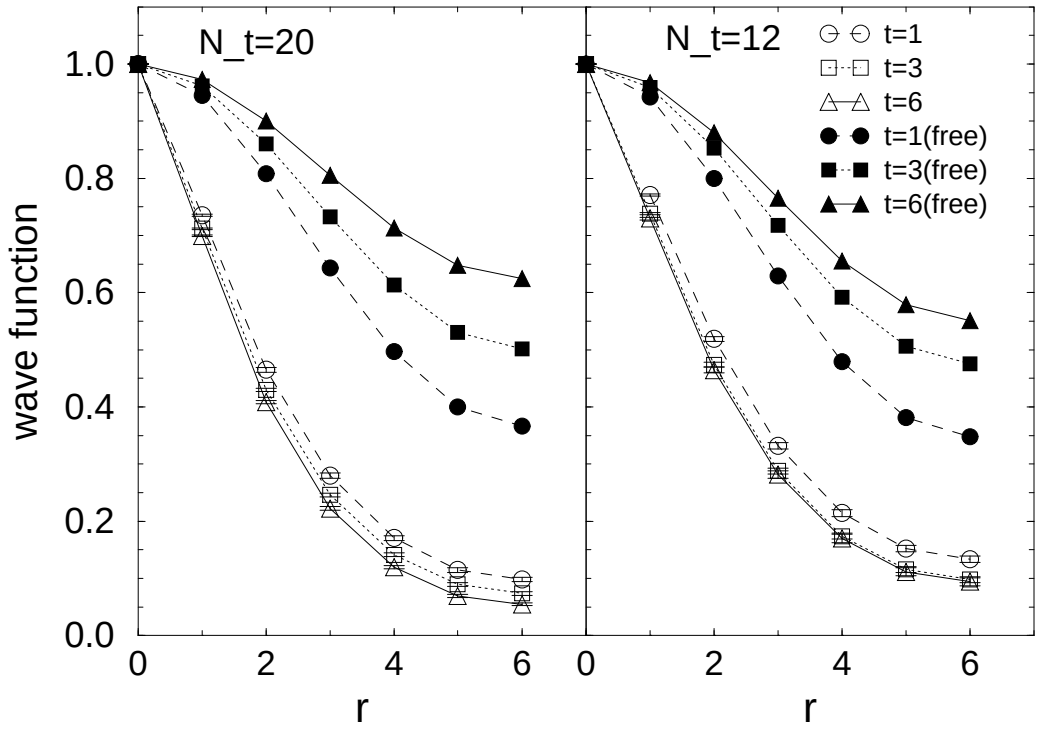


In this case, $\phi_\Gamma(r,t) = w_\Gamma(r,t)/w_\Gamma(r=0,t)$

(normalized at spatial origin)

increase as t.

Ps, exp-exp source

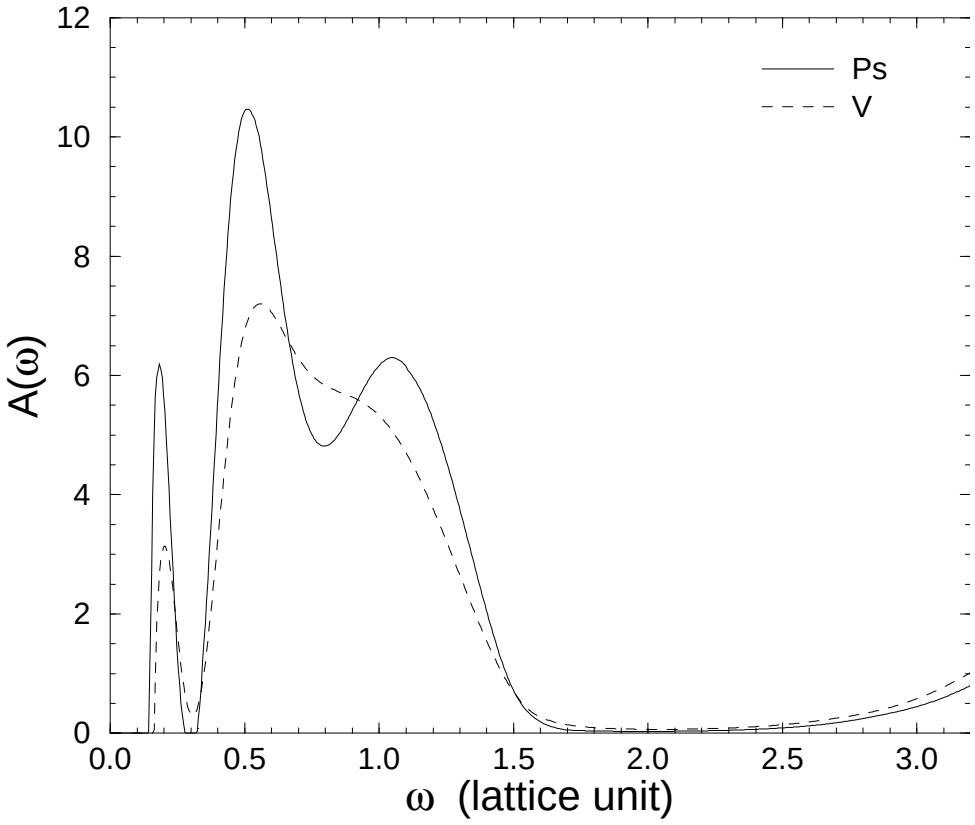


Spectral function

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

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

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 : $m_V \sim 3.1GeV$

Effective mass at $T > 0$

— Heavy quark field—

- parameter

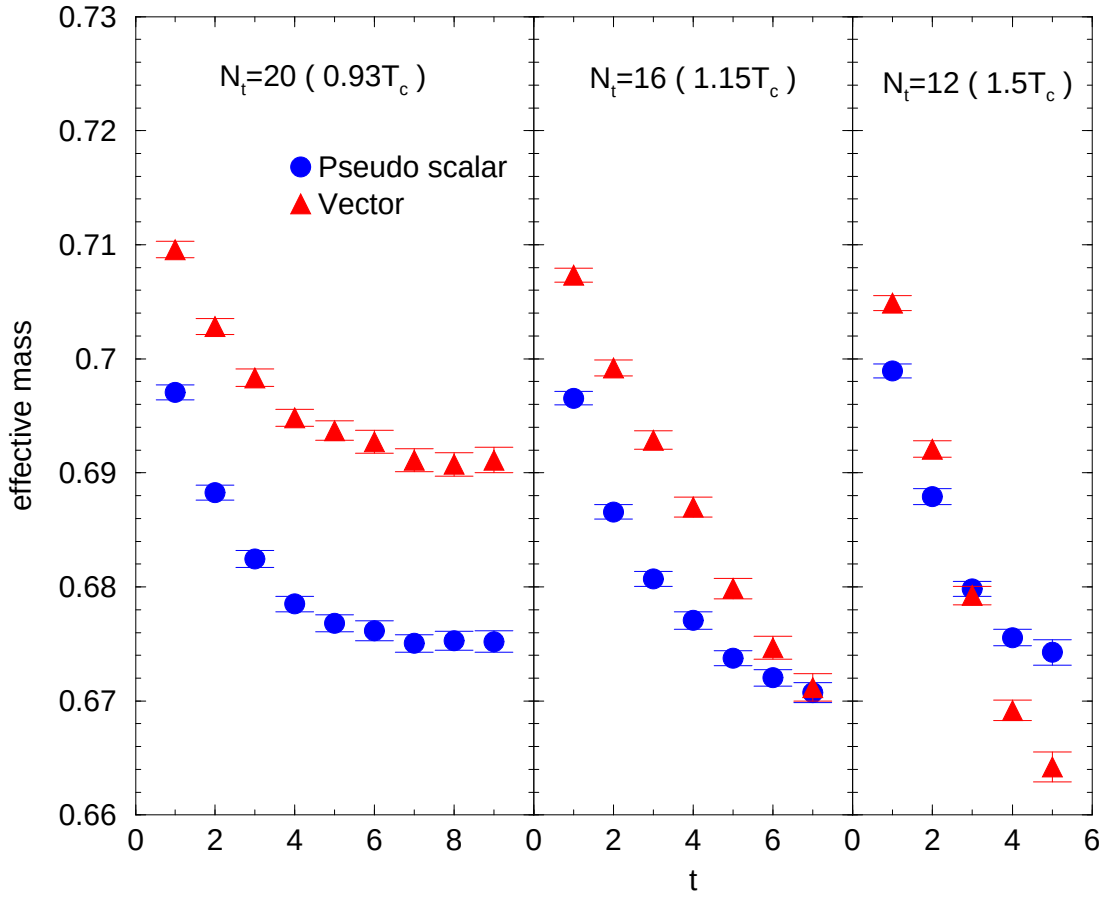
  $1/\kappa = 9.690, \quad \gamma_F = 3.67$

- 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

    $\Rightarrow$ 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.