Meson Spectroscopy with Clover Action on Anisotropic Lattice

-The QCD-TARO Collaboration-

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Introduction

Motivation

Hadron physics
near QCD phase transition
$\Downarrow$
use finite temperature lattice QCD

Search for

- ◦ Behavior of hadrons at T>0
- ◦ mass shift near T_c

Especially, Charmonium Physics

- ⋄Search for signals of QGP
  - • J/ψ suppression above T_c
  - •mass shift near T_c
  - •existence of bound state above T_c ?
- ⋄Hyperfine Splitting
- ⋄etc...

Our Approach

◦Correlators

•Pole mass (mass of temporal direction)

$\Updownarrow$

•Screening mass(mass of spatial direction)

◦Wave function

Is there bound state at $T > T_c$?

◦Spectral function

More detailed result of hadronic bound state

Difficulties

◦T $\rightarrow$ large, N_t (d.o.f. in t-direction) $\rightarrow$ small

$\Rightarrow$ Anisotropic lattice

(more info. about t-direction)

◦Heavy quarkonium physics and Remove O(a) effect

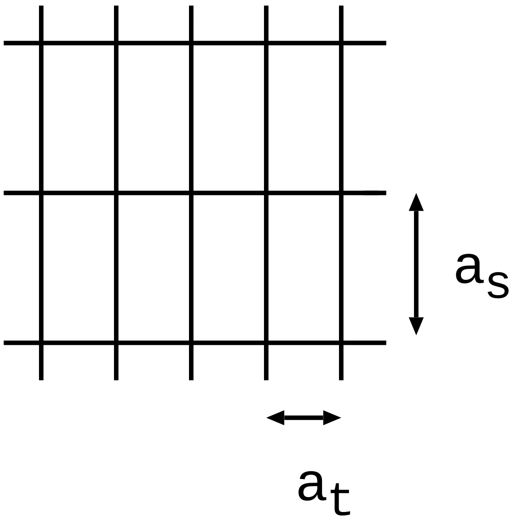
$\Rightarrow$ Fermilab (Clover) action

As effective theory to heavy quarkonium

◦Smear source

Pick up bound state at small τ

Anisotropic Lattice



anisotropy ξ

$\xi = a_s / a_t$

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

calibration

Lattice Actions

Gauge field action:

$$S_G(\beta, \gamma) = \sum_{x,i,j} \frac{\beta}{\gamma} U_{i,j}(x) + \sum_{x,i} \beta\gamma U_{i,4}(x)$$

Heavy quark action:

$$S_F(\kappa_s, \gamma_F) = \sum_x \bar{q}(x) K[U](x,y) q(y)$$

$$K[U](x,y) = 1 - \kappa_s \sum_i [(\xi^{-1} - \gamma_i) T_{+i} + (\xi^{-1} + \gamma_i) T_{-i}]$$

$$- \kappa_t [(1 - \gamma_4) T_{+4} + (1 + \gamma_4) T_{-4}]$$

$$- \kappa_s \frac{1}{2\xi} c_B \vec{\Sigma} \cdot \vec{B} + \kappa_t \frac{1}{2\xi} c_E \vec{\alpha} \cdot \vec{E}$$

$$\kappa_t = \gamma_F \kappa_s$$

Calibration

Find γ_F and κ_s which gives $\xi_F = \xi$

$\circ$Anisotropy of gauge field : ξ

$$\xi = a_s/a_t$$

determined from Wilson loops

$\circ$Anisotropy of quark field : ξ_F

$\diamond$Dispersion Relation

for Heavy quark region

$$\xi_F^2 = \frac{1}{2}\frac{\vec{\hat{P}}^2}{\cosh E(\vec{p}) - \cosh E(0)}$$

$$\hat{P}_i = 2\sin\frac{P_i}{2}, P_i = \frac{2\pi k_i}{N_i}$$

Simulation Parameters

- Quenched lattice
- Lattice Size $12^3 \times N_t$,
  N_t=72(T $\simeq$ 0), 20(T$< T_c$), 16,12(T$> T_c$)

Gauge field:

- $\beta = 5.68$, $\gamma = 4.0$
- ♯conf=60
- Anisotropy:$\xi = a_s/a_t = 5.3(1)$
- Cut-off: a_s^{-1}=0.85(3)GeV,
  a_t^{-1}=4.5(2)GeV

Fermion field:

T=0

Choose κ_s and γ_F with $\xi = \xi_F$

- $m_v \simeq$0.9, 2.0, 2.7, 3.1, 3.5 GeV

T>0

use same κ_s and γ_F

- ♯conf.=60($m_v \simeq$2.0, 2.7, 3.1, 3.5 GeV)
  =20($m_v \simeq$0.9 GeV)

Effective Mass at T>0

◦parameters

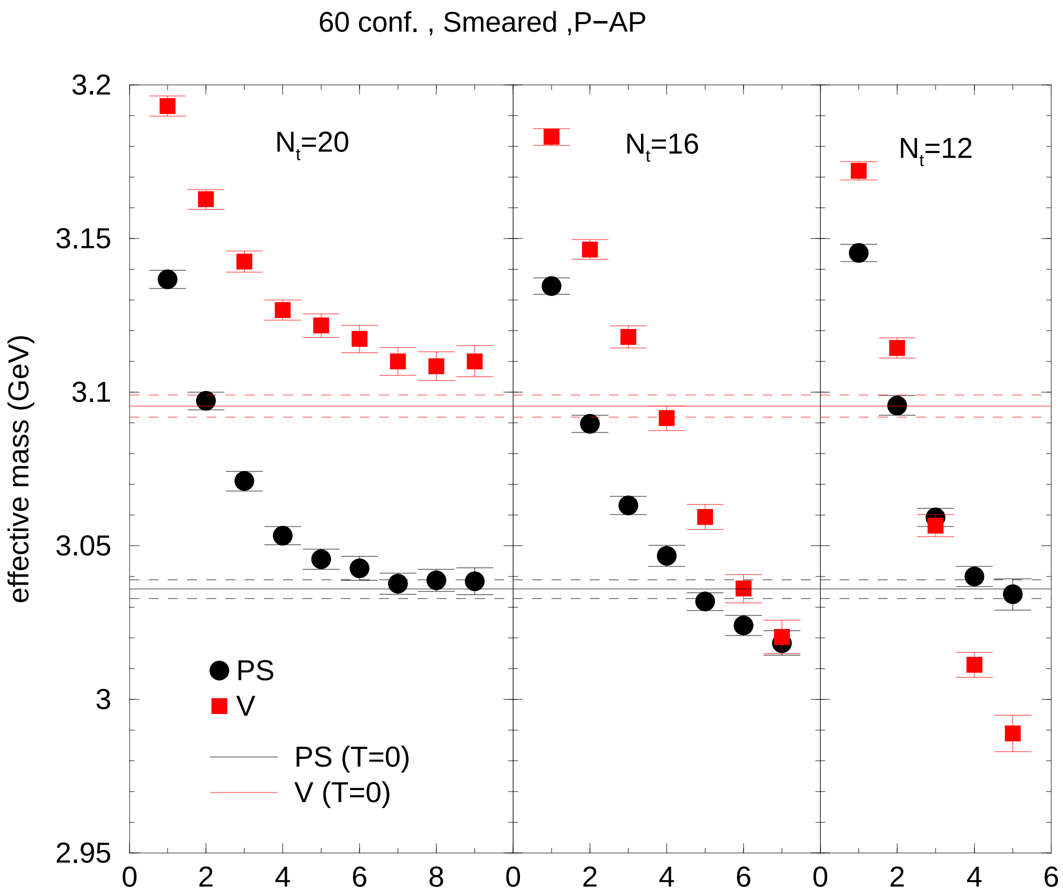
$$\gamma_F = 3.67, \kappa_s = 0.09840, 1/\kappa = 9.69$$

◦♯conf.=60

◦Smeared Source(point-exp source)

◦result at T=0

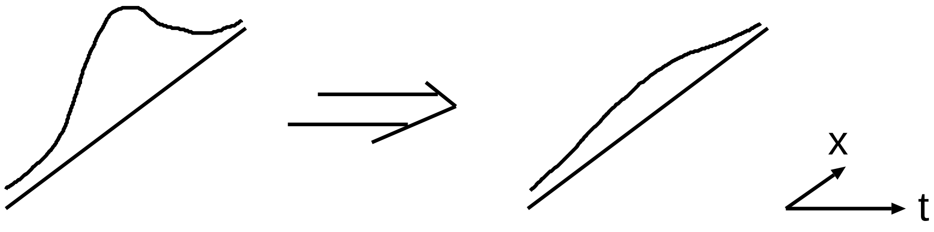
$$m_{ps} = 3.0359(31)\ \text{GeV},$$
$$m_v = 3.0954(36)\ \text{GeV}$$



Wave Function

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

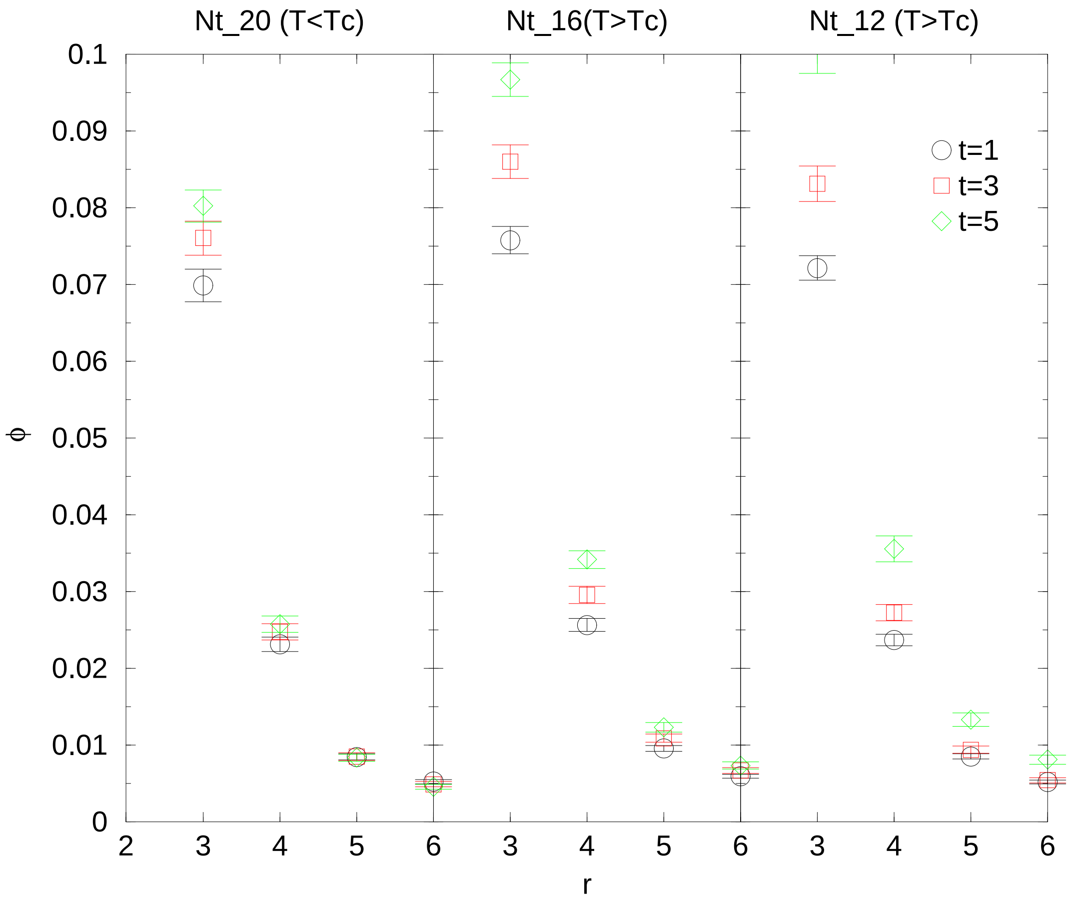
If there is no bound state (like free quark case), wave function becomes broader as t.



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

(normalized at spatial origin)

Vector, point-exp source



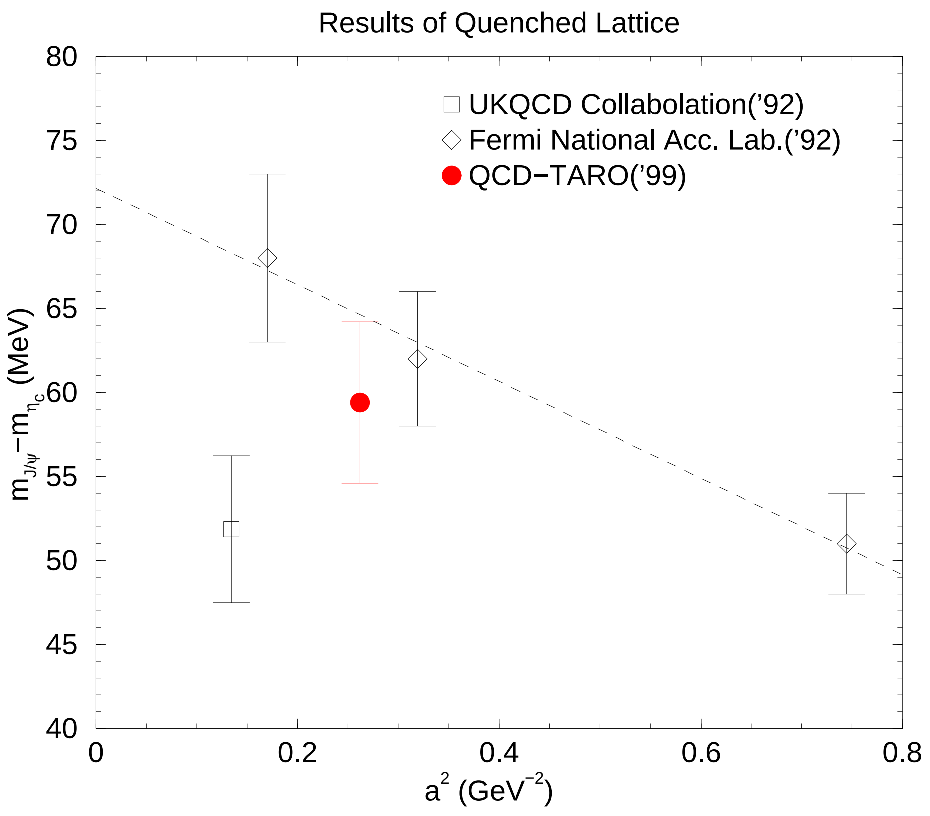
Hyperfine Splitting

from experiment

$$m_{J/\psi} - m_{\eta_c} \simeq 117.1 \text{ Mev}$$

from our results

$$m_{\eta_c} = 3.0359(31) \text{ Gev}$$
$$m_{J/\psi} = 3.0954(36) \text{ Gev}$$
$$m_{J/\psi} - m_{\eta_c} = 59.4(4.8) \text{ Mev}$$



Summary

- ◦Search for charmonium physics
- ◦anisotropic Fermilab action
- ◦Calibration → finished
- ◦Mass Shift
  → Effective mass of Vector channel is rapidly dumped at T> T_c
- ◦ Wave Function
  → Meson correlator doesn't change at T> T_c
- ◦Unclear result whether bound state exist
- ◦Hyperfine Splitting
  → consistent with other papers

Future Plan

More reliable determinaton of mass
→Variational Analisys

→Fine Lattice

Discussion of hadronic bound state
→Spectral Function

Dynamical Quark,etc...