Lattice QCD study of charmonium dissociation temperatures

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JPS meeting, Kinki-Univ., Osaka, Japan , 23 March. 2008

Contents of this talk

Takashi Umeda,
"Constant contribution in meson correlators at finite temperature"
Phys. Rev. D75 094502 (2007) [hep-lat/0701005]

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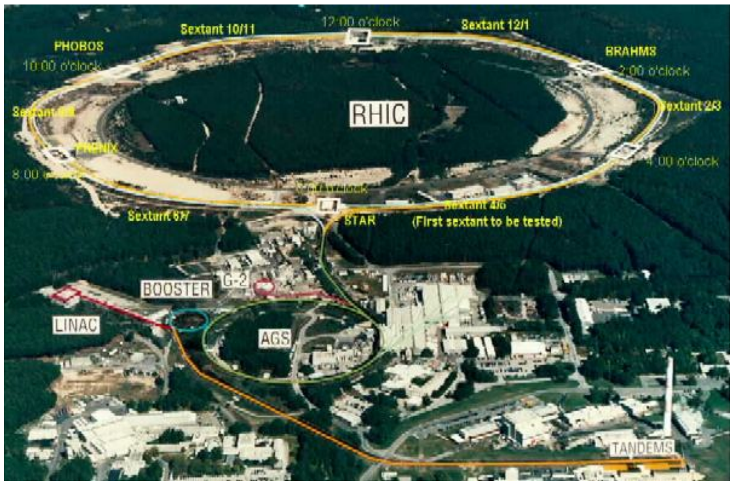
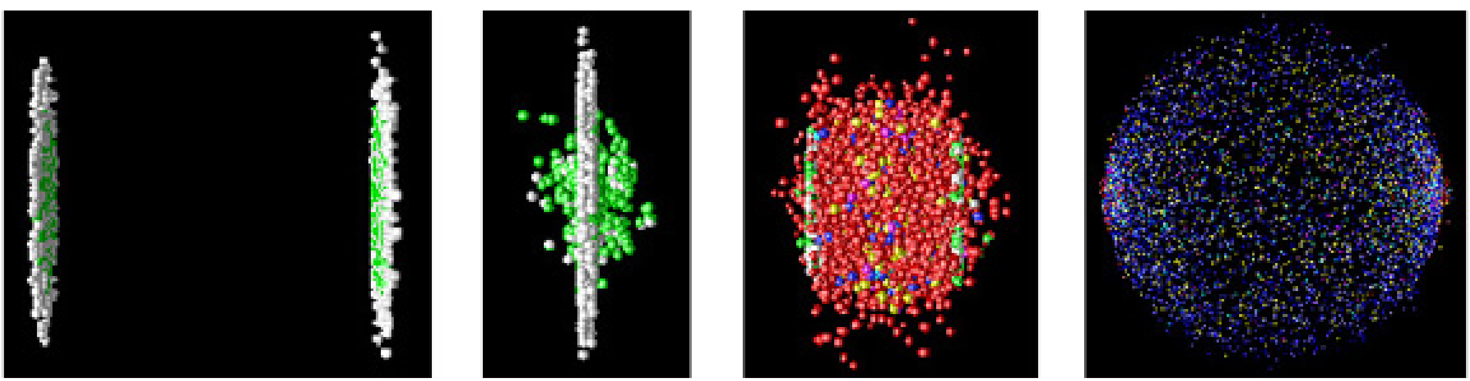
  - -- Quark Gluon Plasma & J/ψ suppression
  - -- Thermal J/ψ on a lattice
- Constant mode in Finite Temp. Field Theory
- Results
- Another approach on this problem
- Summary & future plan

Quark-Gluon Plasma search

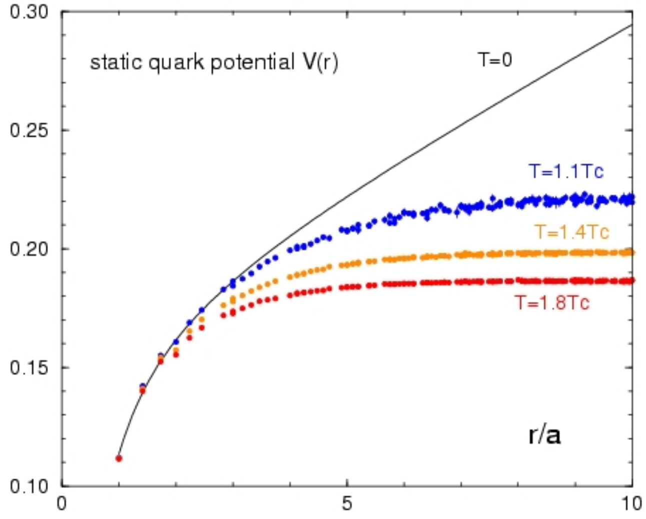


- SPS : CERN (– 2005)
  Super Proton Synchrotron
- RHIC: BNL (2000 –)
  Relativistic Heavy Ion Collider
- LHC : CERN (2009 -)
  Large Hadron Collider



from the Phenix group web-site

J/ψ suppression as a signal of QGP



Confined phase:
linear raising potential
→ bound state of c - c̄

De-confined phase:
Debye screening
→ scattering state of c - c̄

T.Hashimoto et al.('86), Matsui&Satz('86)

Lattice QCD calculations:

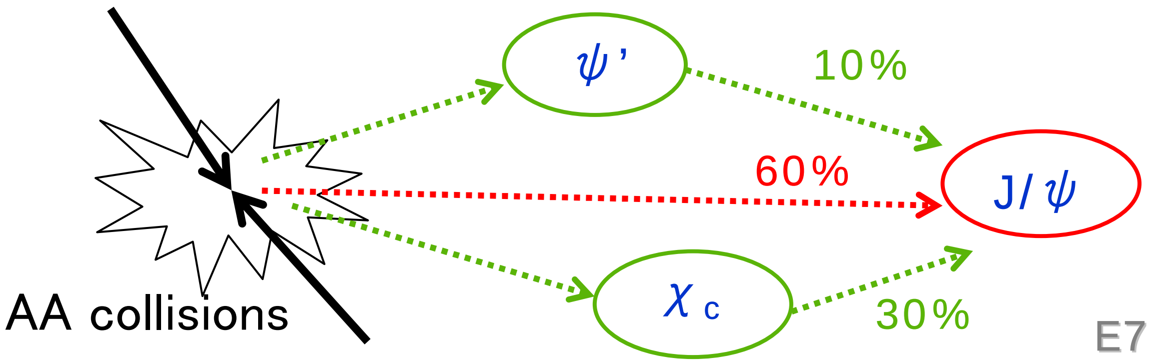
Spectral function by MEM: T.Umeda et al.('02), S.Datta et al.('04), Asakawa&Hatsuda('04), A.Jakovac et al.('07), G.Aatz et al.('06)

Wave func.: T.Umeda et al.('00)

B. C. dep.: H.Iida et al. ('06)

→ all calculations suggest that J/ψ survives till 1.5Tc or higher

Sequential J/ψ suppression scenario



E705 Collab.('93)

J/ψ (1S)	:	$J^{PC} = 1^{--}$	M=3097MeV	(Vector)
ψ (2S)	:	$J^{PC} = 1^{--}$	M=3686MeV	(Vector)
χ_{c0} (1P)	:	$J^{PC} = 0^{++}$	M=3415MeV	(Scalar)
χ_{c1} (1P)	:	$J^{PC} = 1^{++}$	M=3511MeV	(AxialVector)

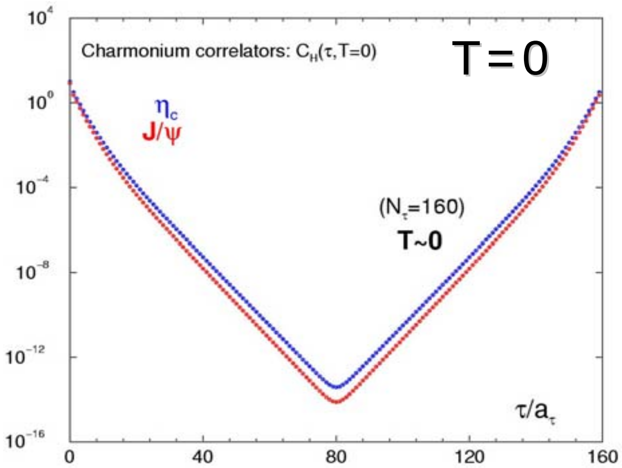
PDG('06)

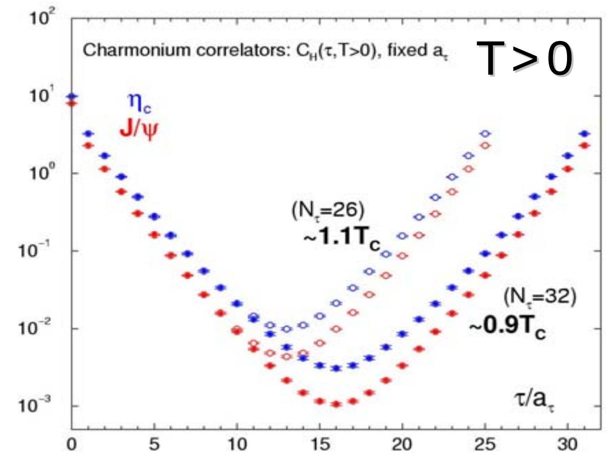
It is important to study dissociation temperatures
for not only J/ψ but also ψ(2S), χ_c's

Spectral function on a lattice

$$C_H(\tau,T) = \sum_{\vec{r}} \langle J_H(\tau,\vec{r}) J_H^\dagger(\tau,\vec{0}) \rangle$$

Thermal Green func.: $C_H(\tau, T)$





$$C_H(\tau,T) = \int_0^\infty d\omega\ \sigma_H(\omega,T)\ \frac{\cosh(\omega(\tau - \frac{1}{2T}))}{\sinh(\frac{\omega}{2T})}$$

Spectral func.: $\sigma_H(w,T)$

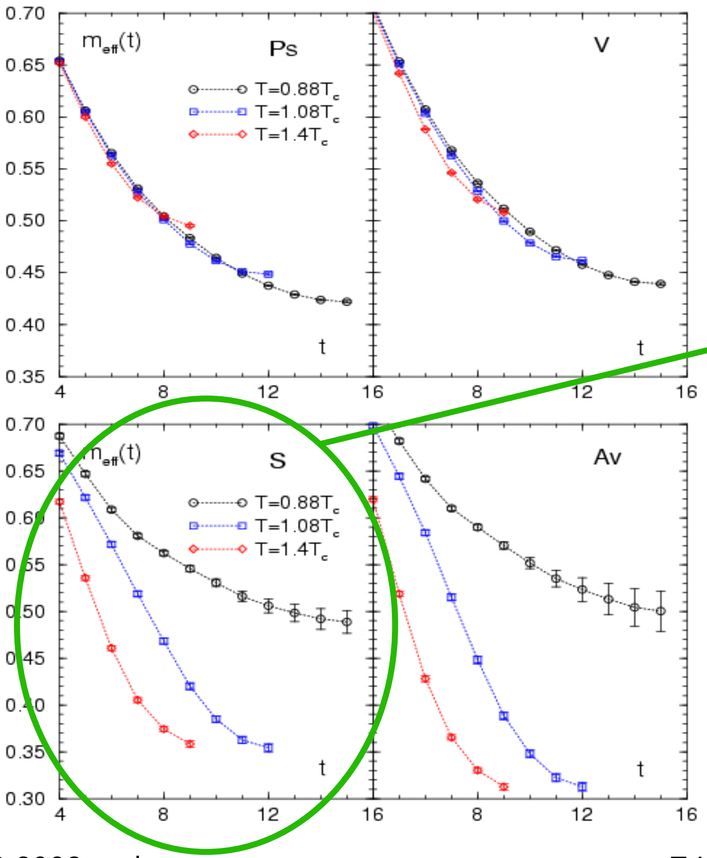
brute force χ^2 analysis fails (ill-posed problem)

→ Bayesian analysis (Maximal Entropy Method)

Output may be arbitrary when data quality is not sufficient

χ_c states dissociate just above Tc ?

$$m_{\text{eff}}(t) = \log\left(\frac{C_H(t,T)}{C_H(t+1,T)}\right)$$



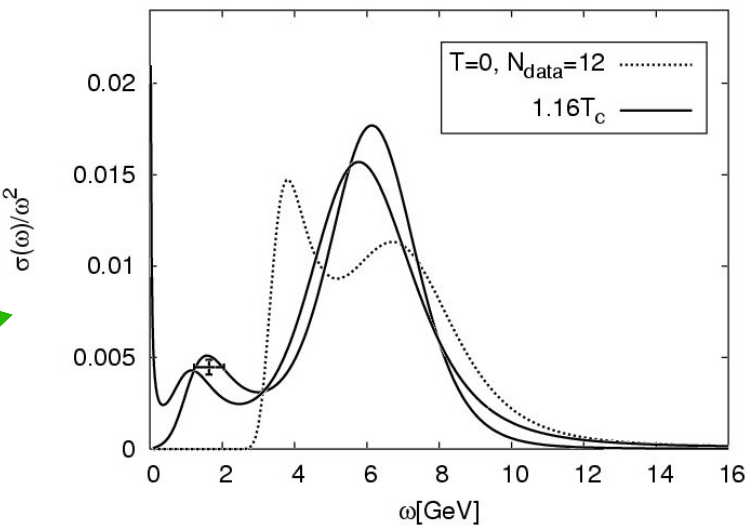
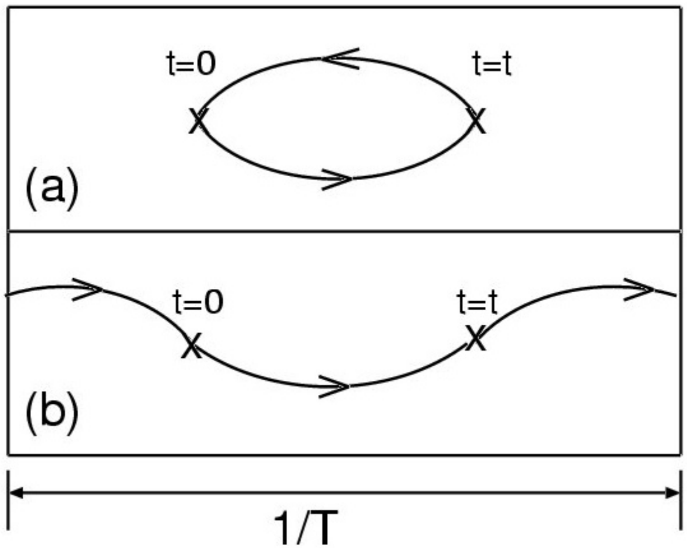


FIG. 19: The scalar spectral function for $\beta = 6.1$ at $T = 1.16T_c$ and at zero temperature reconstructed using $N_{data} = 12$. At finite temperature two default models $m(\omega) = 0.01$ and $m(\omega) = 0.038\omega^2$ have been used.

A.Jakovac et al. ('07).
(also S. Datta et al. ('04).)

Constant mode in meson correlators



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

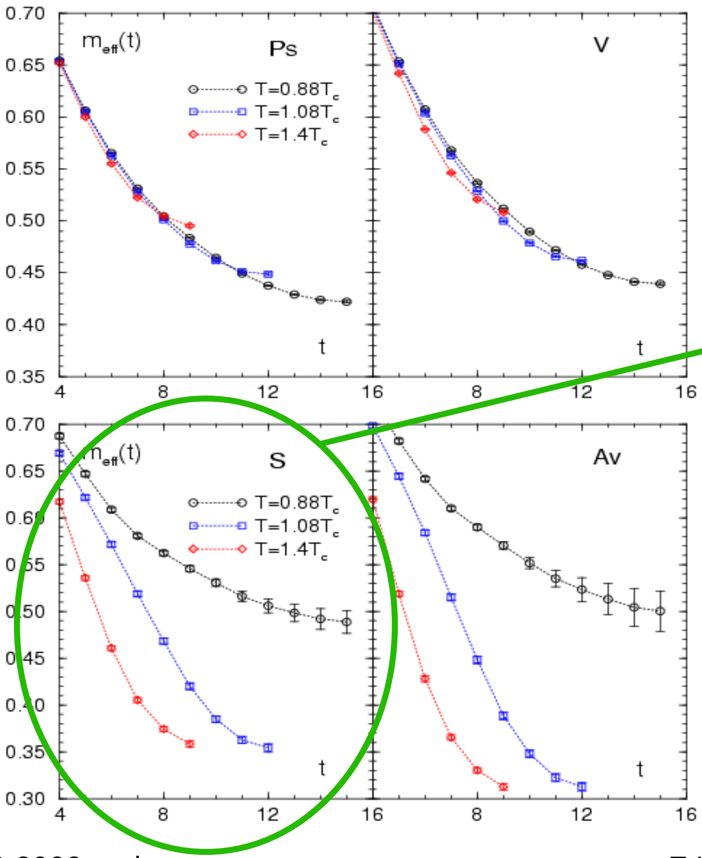
$\exp(-m_q t) \times \exp(-m_q(L_t - t))$
$= \exp(-m_q L_t)$

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

χ_c states dissociate just above Tc ?

$$m_{\text{eff}}(t) = \log\left(\frac{C_H(t,T)}{C_H(t+1,T)}\right)$$



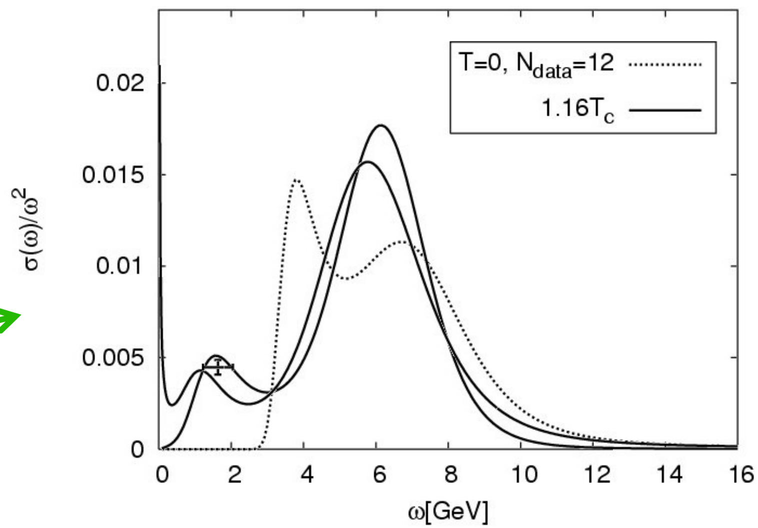


FIG. 19: The scalar spectral function for $\beta = 6.1$ at $T = 1.16T_c$ and at zero temperature reconstructed using $N_{data} = 12$. At finite temperature two default models $m(\omega) = 0.01$ and $m(\omega) = 0.038\omega^2$ have been used.

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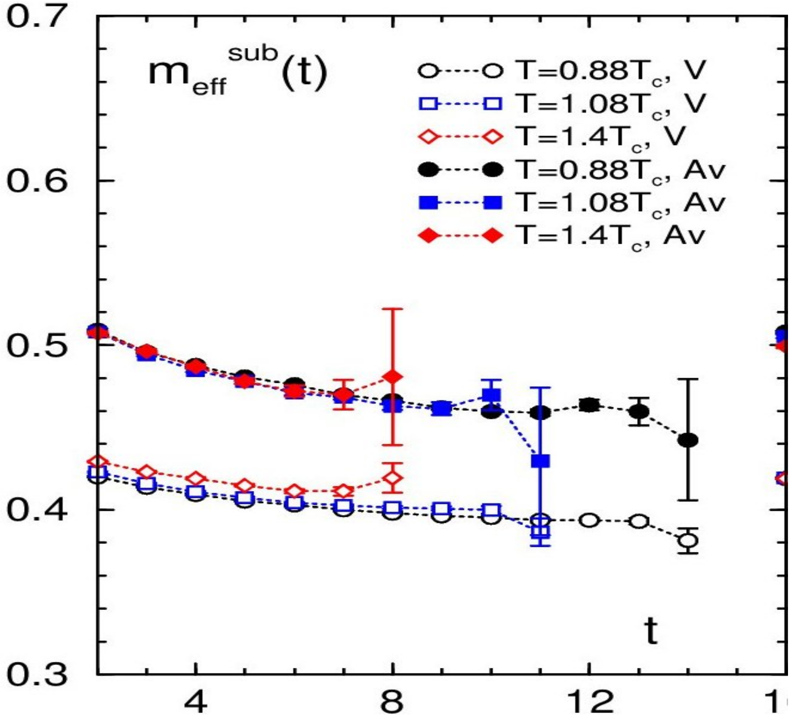
(also S. Datta et al. ('04).)

Midpoint subtraction analysis

Midpoint subtracted correlators

$C_H^{sub}(t,T) = C_H(t,T) - C_H(N_t/2,T)$

→ cut off only constant mode



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

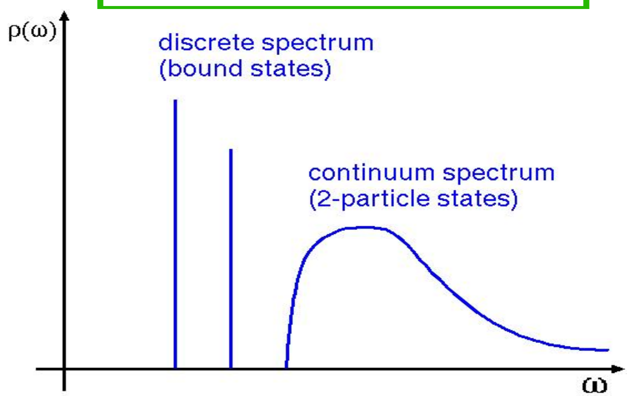
Small changes in SPFs
(except for constant mode effects)
for not only J/psi but also χ_c's

Previous MEM analysis for χ_c states may be misleading

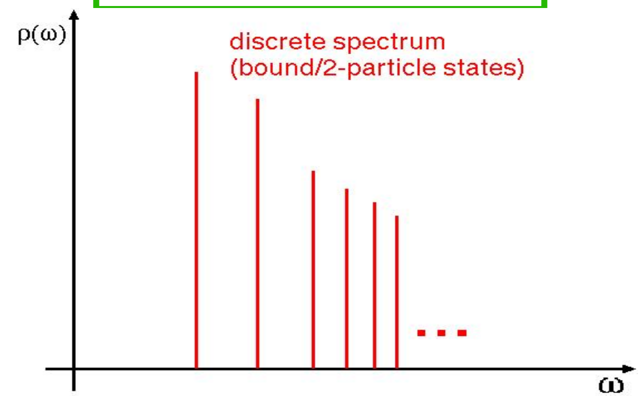
χ_c states may survive up to 1.4Tc (?)

Another approach to study charmonium at T>0

infinite volume case



finite volume case



In a finite volume,
discrete spectra does not always indicate bound states !

In order to study a few lowest states,
the variational analysis is one of the most reliable approaches !

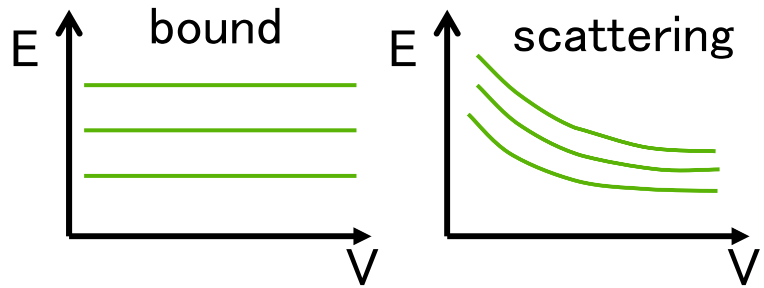
N x N correlation matrix : C(t)

$$C(t)\psi = \lambda(t,t_0)C(t_0)\psi \qquad \lambda_i(t,t_0) = e^{-E_i(t-t_0)}$$

How to identify the states

We know three ways to identify the state in a finite volume

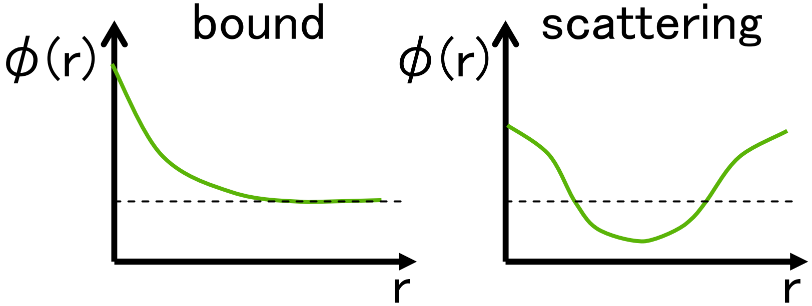
■ Volume dependence



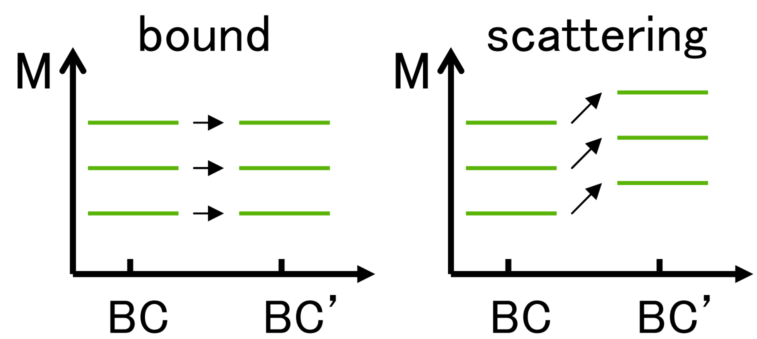
E : energy
V : volume

Φ(r): wave function
r : c - c̄ distance

■ Wave function



■ Boundary Condition (B.C.) dep.



H.Iida et al.('06), N.Ishii et al.('05)

Results of wave functions at T>0

Temp. dependence of "Wave function" (Bethe-Salpeter amplitude)

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

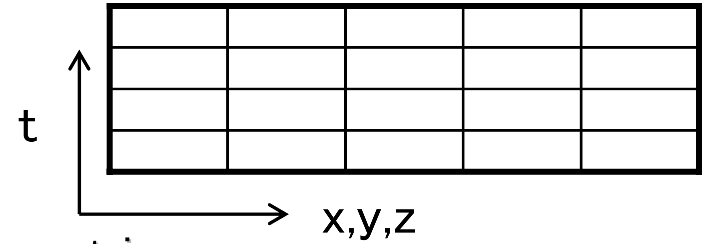
$$\Phi(|\vec{r}|,t) = BS(\vec{r},t)/BS(\vec{0},t)$$

Lattice setup

- Quenched approximation (no dynamical quark effect)
- Anisotropic lattices

  lattice spacing : $a_s = 0.0970(5)$ fm

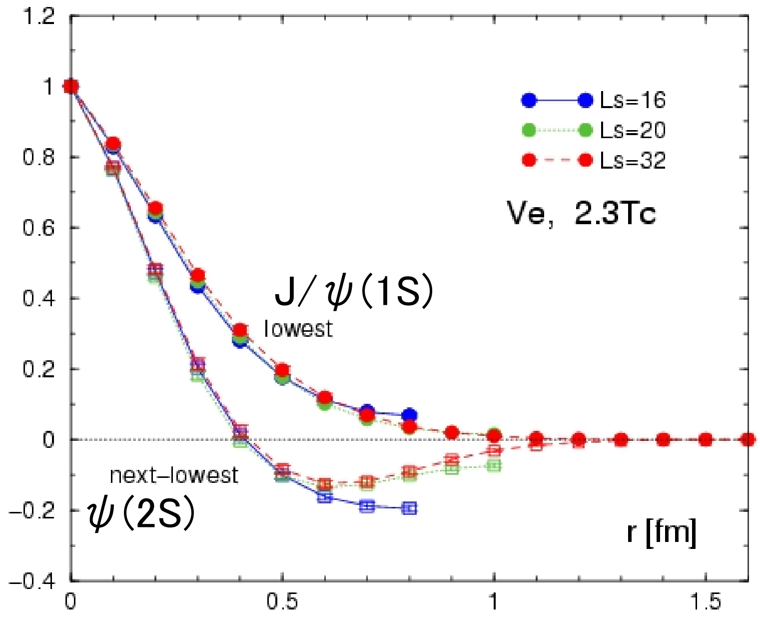
  anisotropy : $a_s/a_t = 4$

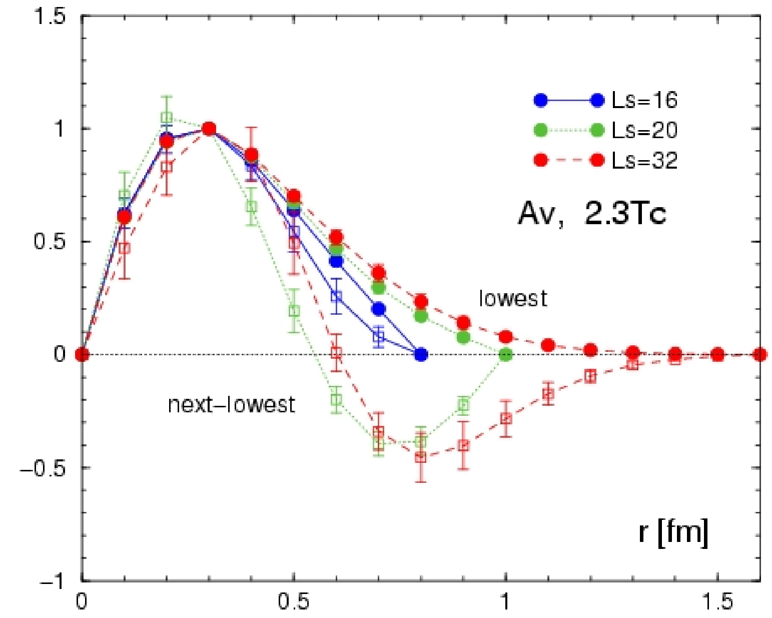


- Variational analysis with 6 x 6 correlation matrix
- T = 0.9Tc – 2.3Tc (Nt = 32 – 16), V = 16^3, 20^3, 32^3

Charmonium wave functions at T=2.3Tc

→ H.Ohno et al. 24aZC AM10:30





- Wave functions are constructed by the variational analysis.
- Clear signals of bound states even at T=2.3Tc (!)
- Large volume is necessary for P-wave states.

Summary and future plan

- There is the constant mode in charmonium correlators above T_c
- The drastic change in χ_c states is due to the constant mode

- Another approach to study charmonium at T>0 with no Bayesian analysis
- No evidence for unbound charm quarks up to T = 2.3 Tc

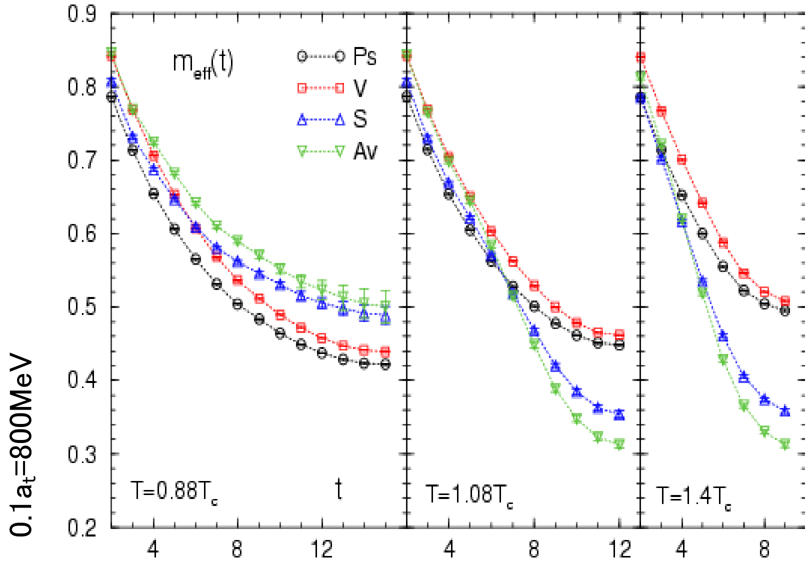
The result may affect the scenario of J/ψ suppression.

Future plan

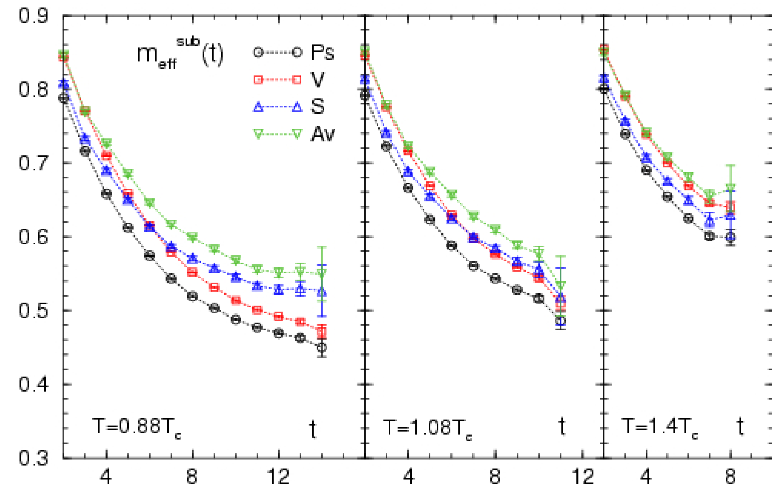
- Discussion on the experimental results of J/ψ suppression
- Full QCD calculations (Nf=2+1 Wilson is now in progress)

Midpoint subtraction analysis

usual effective masses at T>0



subtracted effective mass

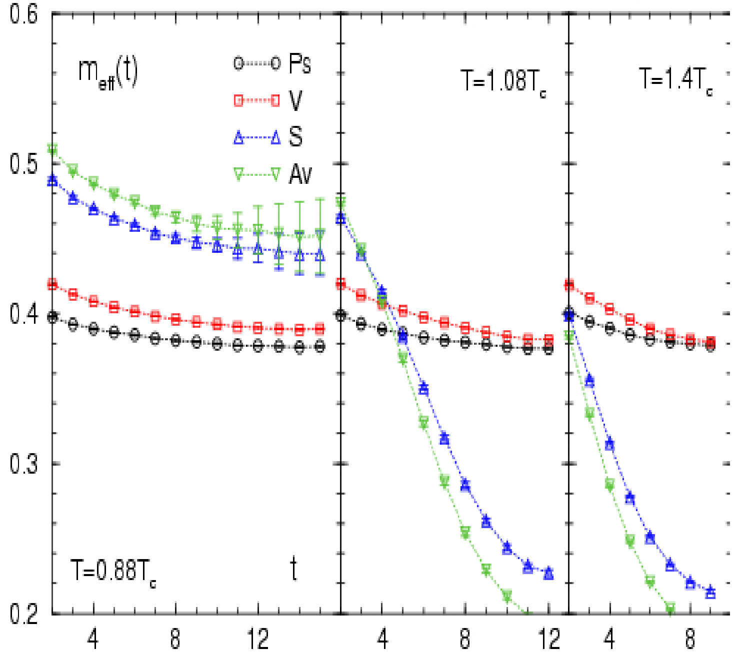


the drastic change in P−wave states disappears in $m_{eff}^{sub}(t)$

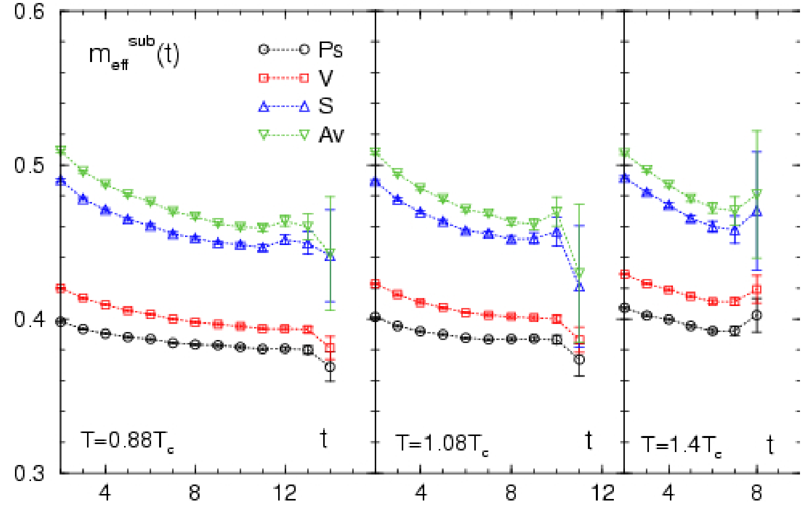
→ the change is due to the constant mode

Midpoint subtraction analysis

usual effective mass



subtracted effective mass



- extended op. enhances overlap with const. mode
- small constant effect is visible in V channel
- no large change above T_c in $m_{eff}^{sub}(t)$