Charmonium dissociation temperatures in lattice QCD with a finite volume technique

Takashi Umeda

for the WHOT-QCD Collaboration

筑波大学
University of Tsukuba

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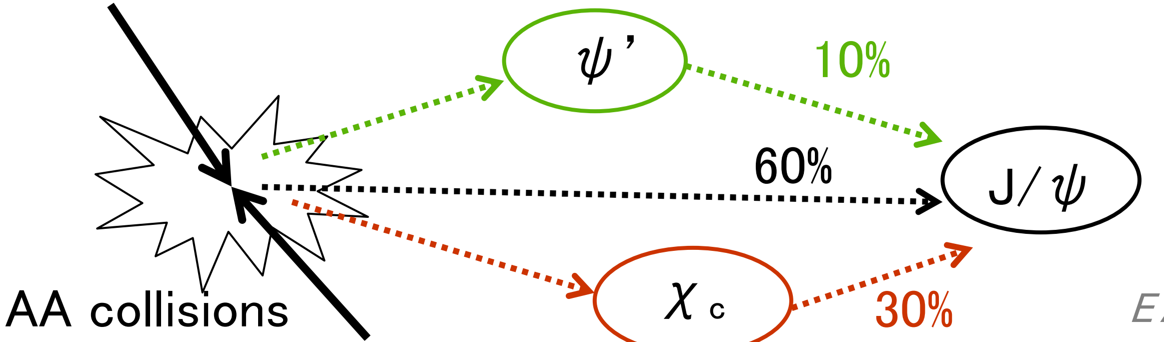
Introduction

Charmonium dissociation temperatures, T_{dis}, play important role in discussion on J/ψ suppression scenarios

Recently, Sequential J/ψ suppression scenario is often discussed



E705 Collaboration, PRL70, 383, (1993).

We investigate T_{dis} for J/ψ, ψ(2S), χ_c etc...
using Finite Temperature Lattice QCD simulations

Current status on T_{dis}

- Lattice QCD studies (by MEM analysis) suggest
  - J/ψ state may survive up to T=1.5Tc or higher
  - χ_c states may dissolve just above Tc
    e.g. A.Jakovac et al. (2007)
  - no results on excited states, ψ'
- The 2nd statement may be misleading (!)
  small change even in P-wave state
  up to 1.4Tc w/o the constant mode
- On the other hand, the potential model studies
  suggest charmonium dissociation may also
  provide small change in the correlators
  e.g. A.Mocsy et al. (2007)

Therefore we would like to investigate T_{dis}
using new approaches with Lattice QCD

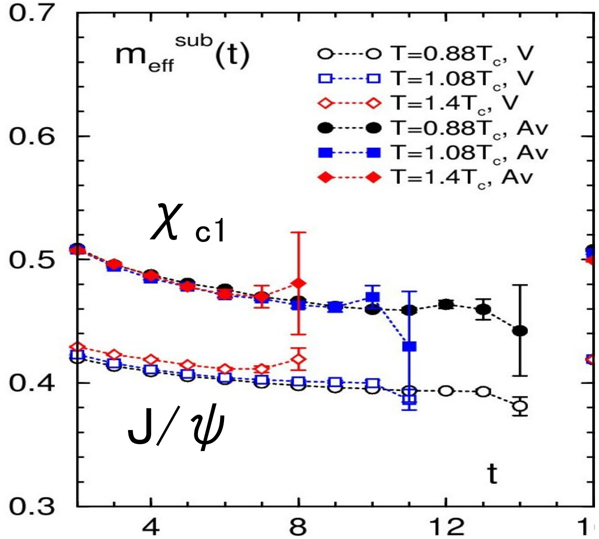


Fig: Temp. dependence of $M_{eff}(t)$ for J/ψ, χ_{c1} w/o constant mode.
T.Umeda (2007)

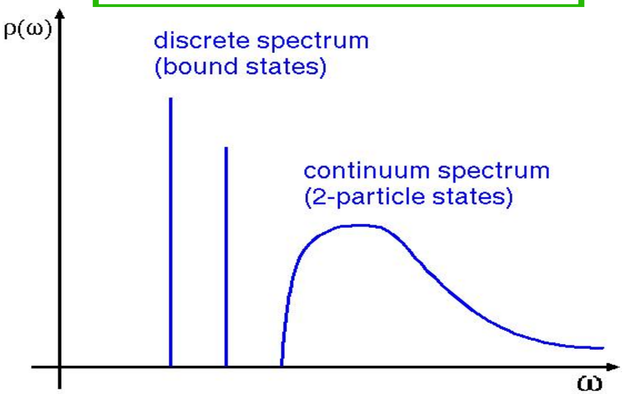
Spectral functions in finite volume

Lattice QCD simulations are performed in a finite volume

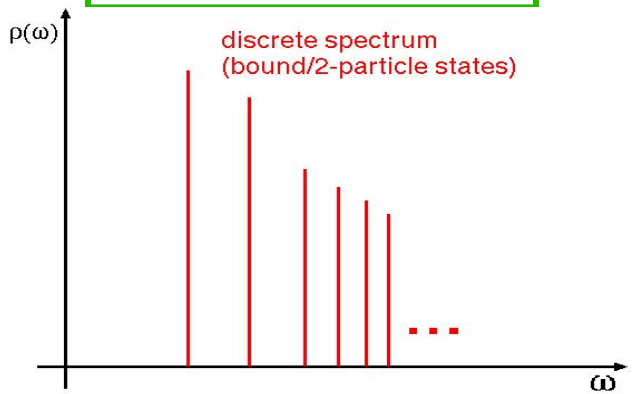
In a finite volume of $(La)^3$, momenta are discretized

$$\vec{p}a = 2\vec{n}\pi/L \quad (n_i = 0, 1, 2, \cdots) \quad \text{for the periodic BC}$$

infinite volume case



finite volume case

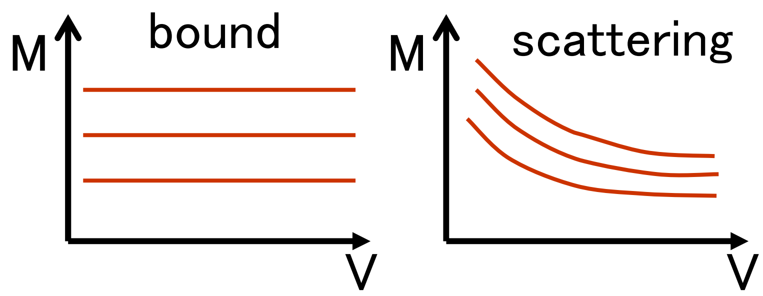


In a finite volume, discrete spectra does not always indicate bound states !

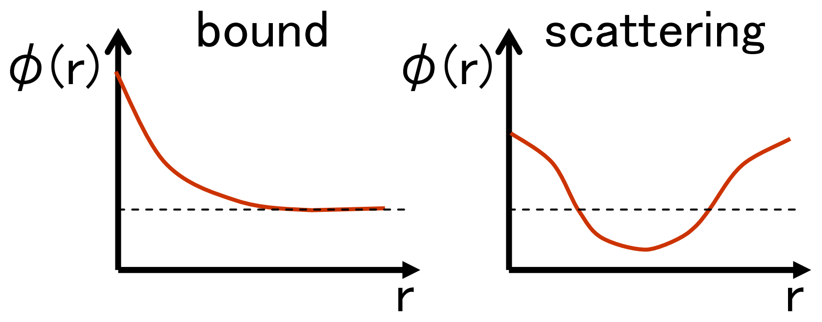
bound state or scattering state ?

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

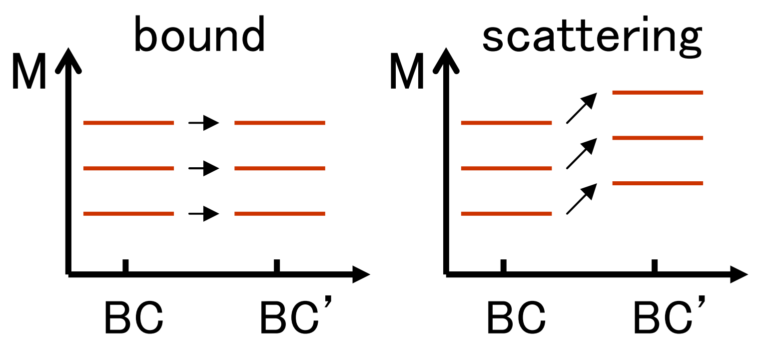
■ Volume dependence



■ Wave function



■ Boundary Condition (B.C.) dep.



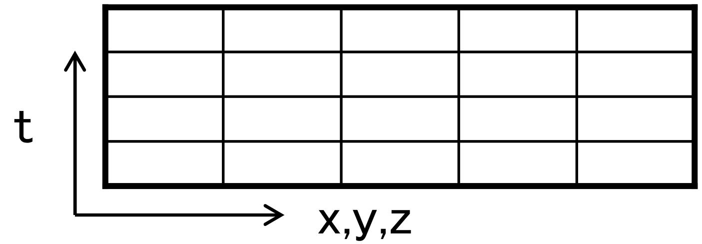
We will demonstrate these Tests using Finite Temp. Lattice QCD

Lattice setup

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

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

  anisotropy : $a_s/a_t = 4$

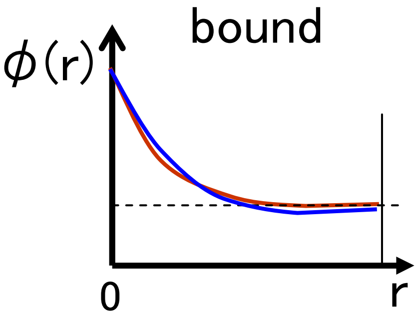


- Quark mass

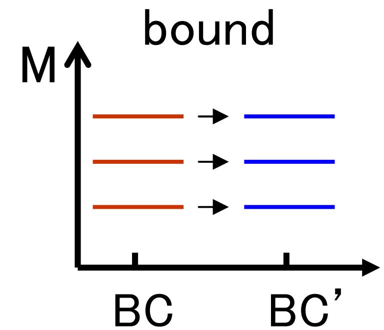
  charm quark (tuned with J/ψ mass)
- Variational analysis with 6 x 6 correlation matrix

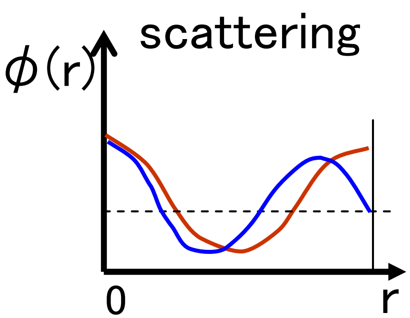
N_t	32	26	20	16	12
T/T_c	0.88	1.08	1.40	1.75	2.33
# of conf.					
$V=16^3$	300	300	300	300	300
$V=20^3$	300	300	300	300	300
$V=32^3$	—	—	—	—	100

(1) B.C. dependence

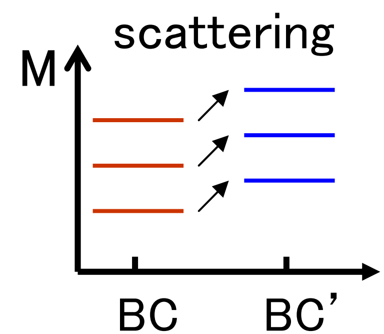


The wave functions are localized,
their energies are insensitive to B.C.





The momenta depends on BC,
the scattering state energies
are sensitive to B.C.



The idea has been originally applied for the charmonium study in H. Iida et al., PRD74, 074502 (2006).

Test with free quarks

The free quarks make the trivial scattering states

→ testing our method (6 x 6 variational analysis)

We prepare 3 types of B.C. for charm quarks

(1) Periodic B.C. $\vec{b} = (\ \ 1,\ \ 1,\ \ 1)$

(2) Anti-Periodic B.C. $\vec{b} = (-1, -1, -1)$

(3) Hybrid B.C. $\vec{b} = (-1,\ \ 1,\ \ 1)$

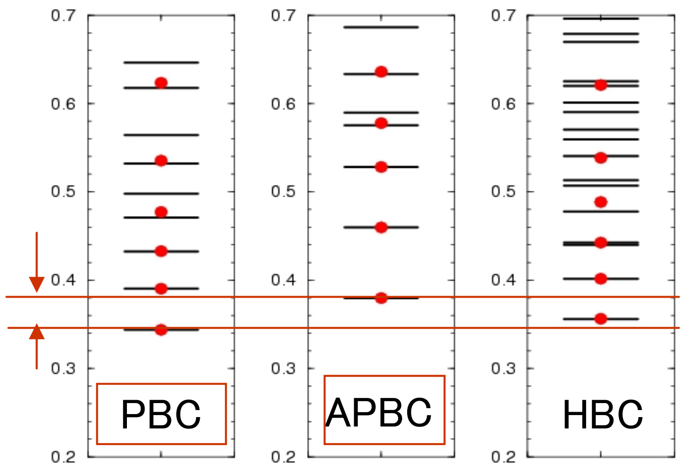
$$q(x_i + L_i) = b_i q(x_i)$$

$b_i = 1$: periodic

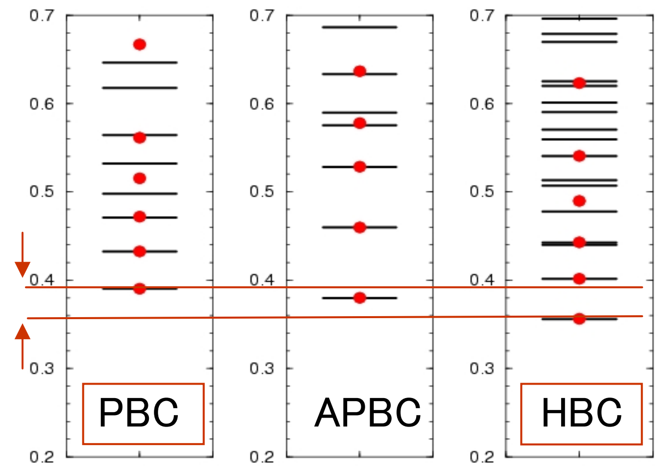
$b_i = -1$: anti-periodic

(free quarks with L/a=20, ma=0.17)

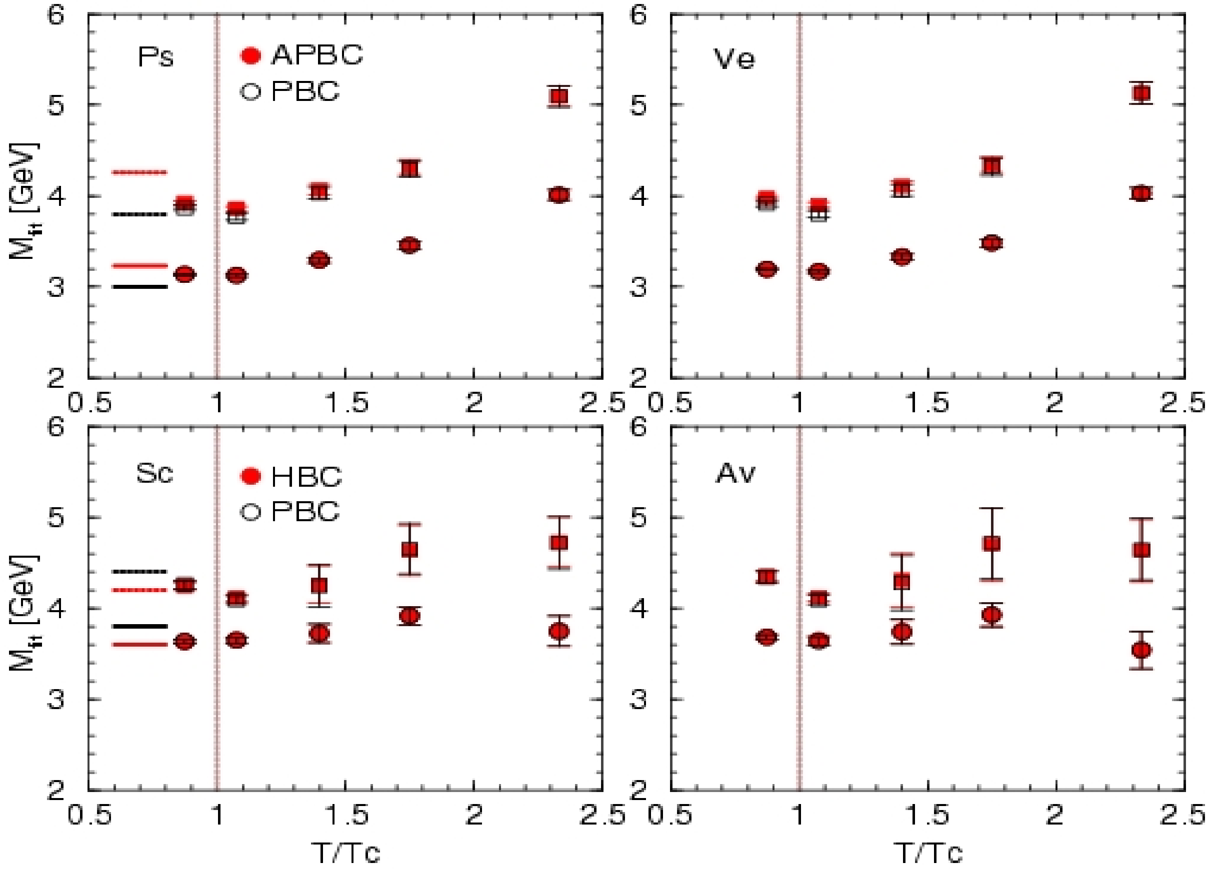
Ps & Ve



Sc & Av



Quenched QCD results



Lowest states
in each channel
Ps : η_c
Ve : J/ψ
Sc : χ_{c0}
Av : χ_{c1}

- No significant differences in the different B.C.
- Lowest energies increase as T increases (thermal quark mass ?)

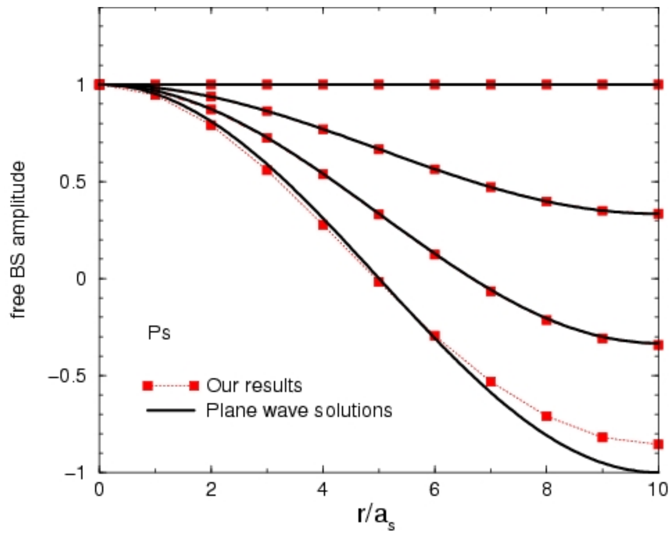
(2) Wave function

Temperature dependence of
"Wave function" (Bethe–Salpeter amplitude)

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

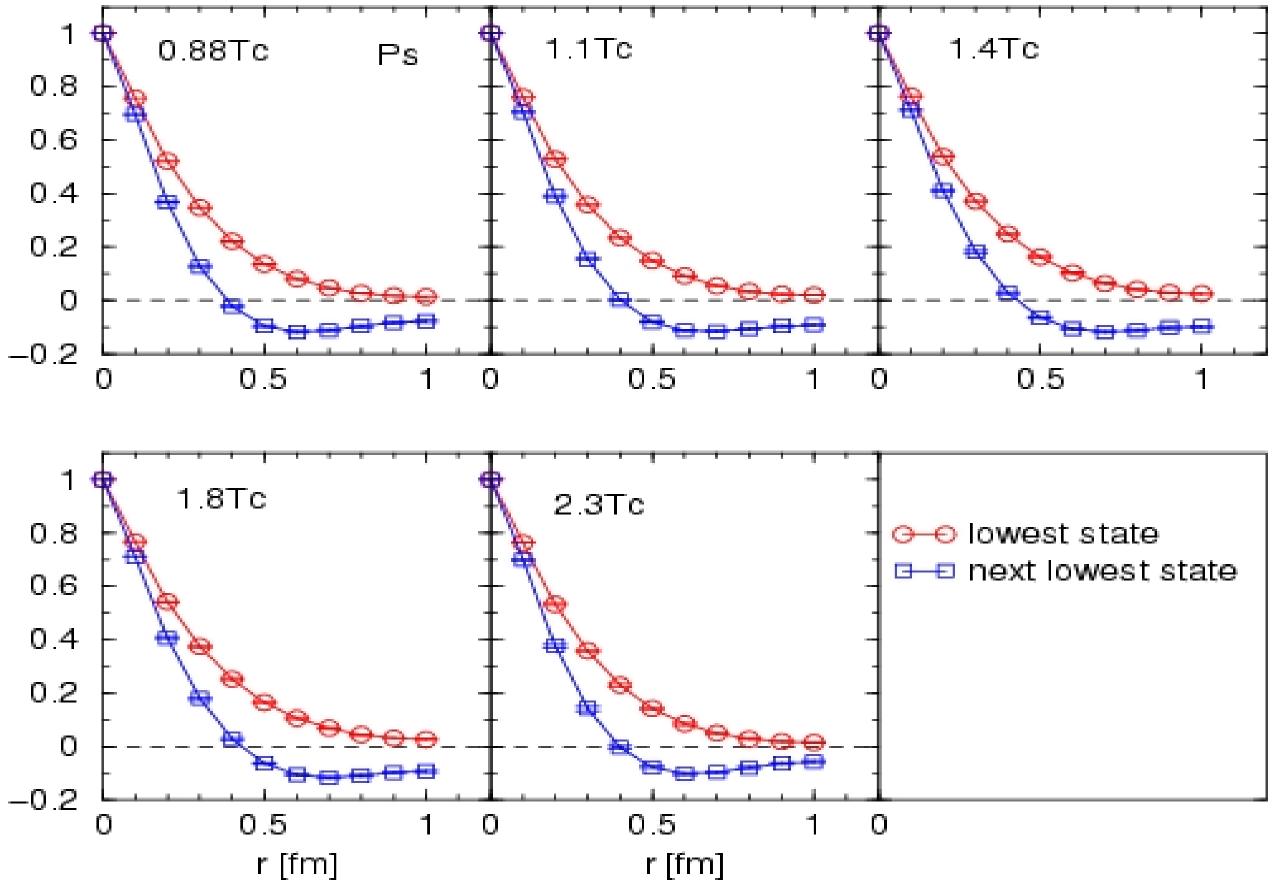
(!) In this talk only S–wave state results will be presented.

Test with free quarks (Ls/a=20, ma=0.17)



- Free quarks make Plane waves with an allowed momentum in a box
- The wave function is constructed with eigen functions of 6 x 6 correlators
- Our method well reproduces the Plane wave solutions (!)

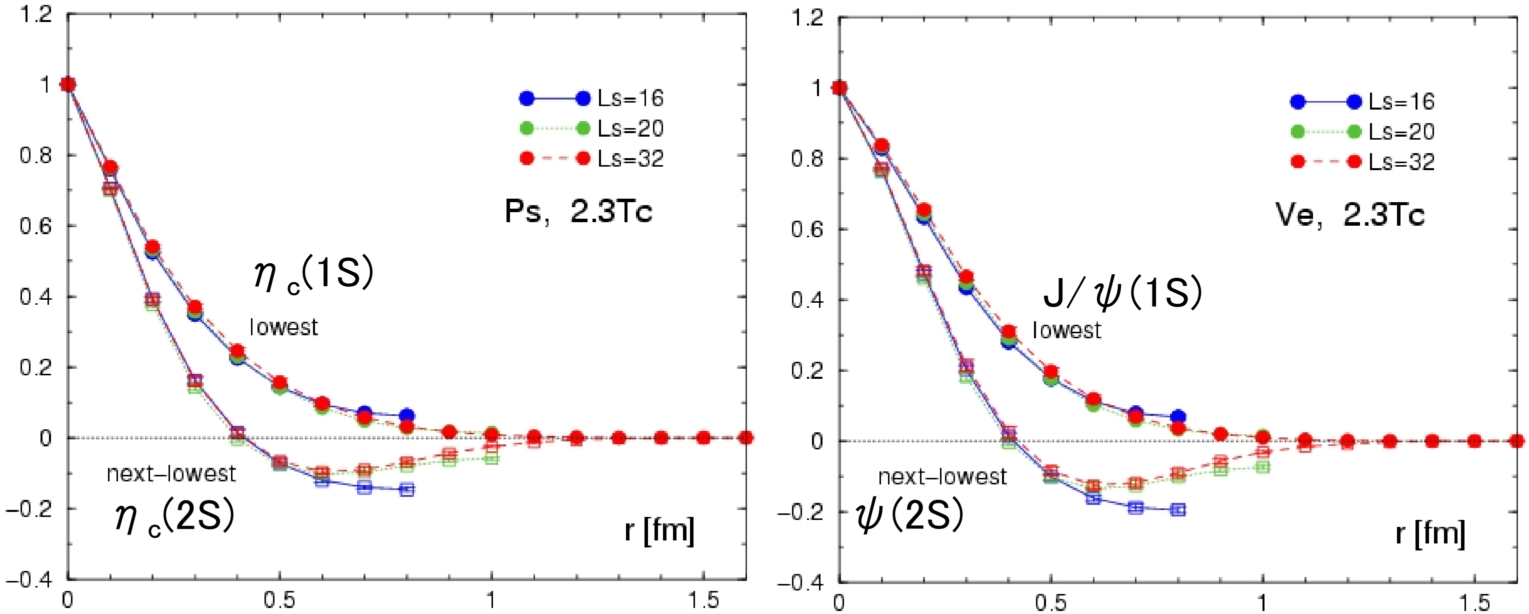
(2) Wave function



- No indication of scattering state up to 2.3Tc (!)
- Ve results show the same behavior as the Ps results

(3) Volume dependence of WF

Volume dependence at T=2.3Tc



- Clear signals for 1S and 2S bound states even at T=2.3Tc (!)
- V = (2 fm)^3 is fairly large for 1S and 2S charmonium

Summary

We investigated T_{dis} of charmonia from Lattice QCD
using the finite volume technique

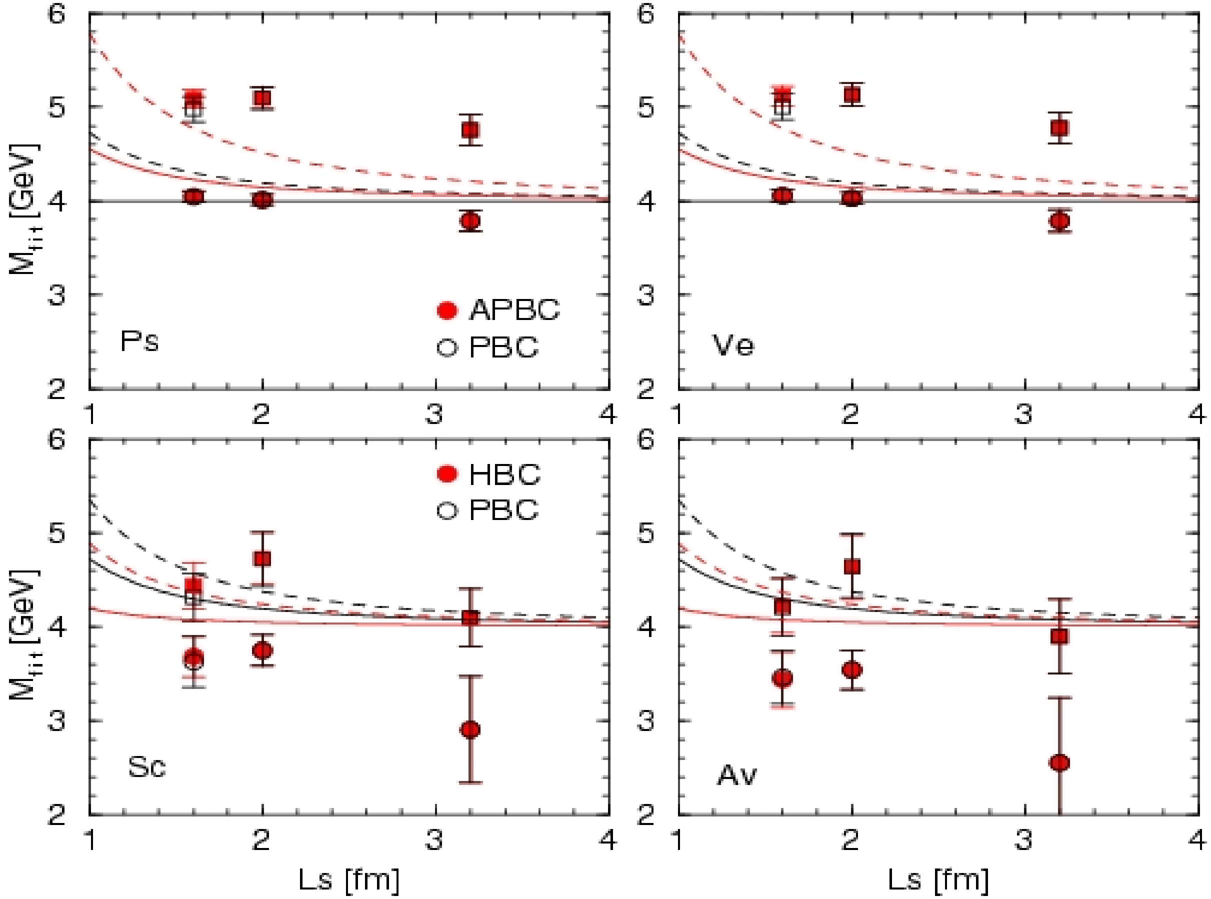
- boundary condition dependence of charmonium spectra
- Temp. dependence of charmonium wave functions
- Volume dependence of wave functions at T=2.3Tc

→ We can find no evidence for scattering state
of charm quarks up to T = 2.3 Tc

Future plan

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

Volume dependence at T=2.3Tc



Expected volume dep. in free quark case

lowest on PBC

next-lowest on PBC

lowest on APBC (HBC)

next-lowest on APBC (HBC)

- Unlike the trivial scattering state (free quarks) behavior
- No good quality results in P-wave states