Charmonium properties at finite temperature on quenched anisotropic lattices

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Contents

Charmonium properties at T>0 as signals of QGP

- Charmonium spectral function reconstructed from temporal correlators
- Potential model analysis with heavy quark free energies

Introduction

- Charmonium is an important signal for formation of QGP in heavy ion collision experiments.
- Theoretical understanding
  - potential models
    - Mass shift near Tc
      T.Hashimoto et al., Phys. Rev. Lett. 57 (1986) 2123.
    - J/ψ suppression above Tc
      T.Matsui and H.Satz, Phys. Lett. B178 (1986) 416.
  - Lattice QCD
    - Meson correlators
      T.Umeda et al., Int. J. Mod. phys. A16 (2000) 2215.
      $\longrightarrow$ strong spatial correlation at T~1.5Tc

Charmonium spectral function at T>0

- Bielefeld group (light mesons, diquark, charmonium)
  - *F.Karsch et al., Phys. Lett. B530 (2002) 147.*
  - *I.Wotzorke et al., Nucl. Phys. B(PS)106 (2002) 513.*
  - *S.Datta et al., hep-lat/0208012(Lattice02) hep-lat/0312037.*
- Asakawa, Hatsuda and Nakahara (light meson, charmonium)
  - *M..Asakawa et al., hep-lat/0208059(Lattice02).*
  - *M.Asakawa and T.Hatsuda, Phys.Rev.Lett.92 (2004) 012001.*
- Our works (charmonium, light mesons)
  - K.Nomura et al., hep-lat/0209139 (Lattice02).
  - T.Umeda et al., hep-lat/0211003 (Eur.Phys.J.dirC).
  - T.Umeda et al., hep-lat/0309178 (Lattice03).

▶ All study supports an existence of hadronic mode just above Tc

Our approach for spectral function

- Anisotropic lattice
- Analysis procedures
  - Maximum entropy method (MEM)

    Y.Nakahara et al., Phys. Rev. D60 (1999) 091503.
  - Constrained curve fitting

    P.Lepage et al., Nucl. Phys. B(PS)106 (2002) 12.

  We use these two methods in complementary manner
- smearing operators

  enhancement of low frequency modes

  → this may cause artificial peak even in free quark case

  we have to investigate a smearing function dependence

Lattice setup

Anisotropic quenched lattices: $20^3 \times Nt$

- $\xi = a_s / a_t = 4$ *T.R.Klassen, Nucl. Phys. B533 (1998) 557.*
- $a_s^{-1} = 2.030(13)$ GeV (set by hadronic radius r_0)

Quark action:

O(a) improved Wilson action

H.Matufuru et al., Phys. Rev. D64 (2001) 114503.

Temperatures : phase transition occurs at just Nt=28

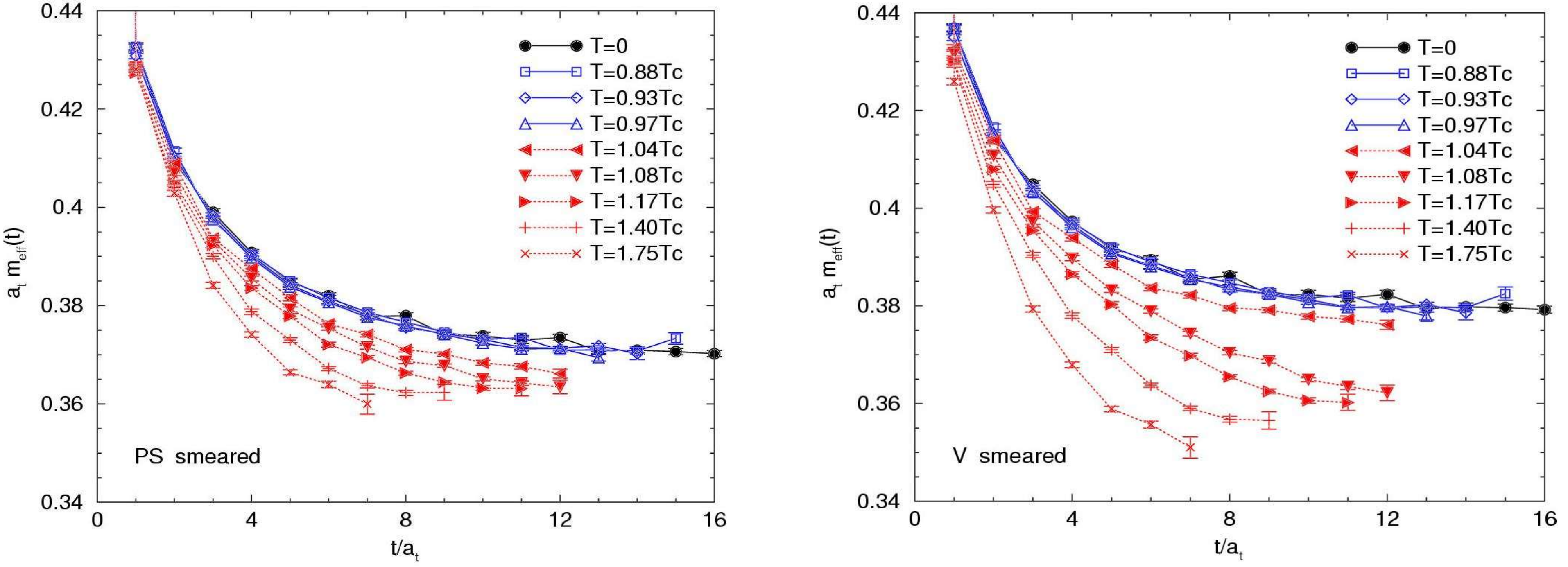
Nt	160	32	30	29	27	26	24	20	16
T/Tc	~0	0.88	0.93	0.97	1.04	1.08	1.17	1.40	1.75

statistics: 1000conf. x 16src. (500conf. for T=0)

Our lattices cover T/Tc=0~1.75 with same lattice cutoff

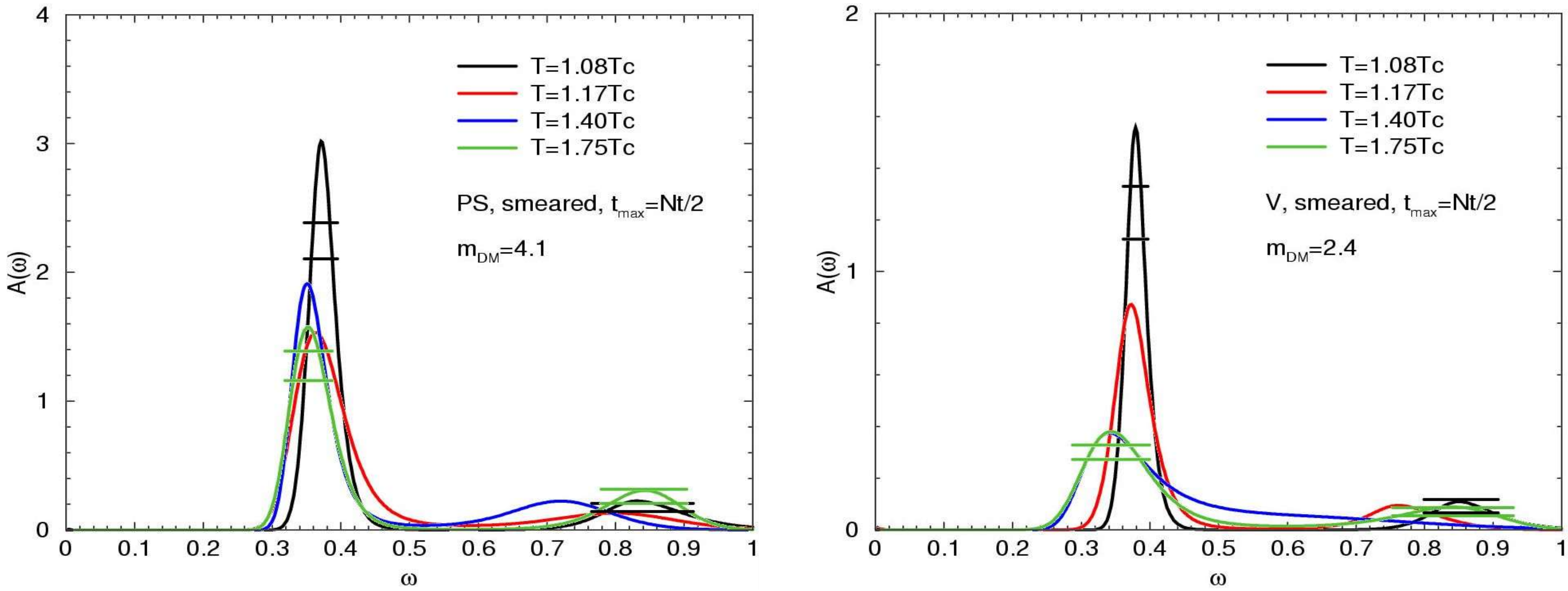
Temporal correlator of charmonium

temperature dependence of effective mass for PS & V channels



- No change of correlators below Tc
- Significant change appears above Tc

Result above Tc

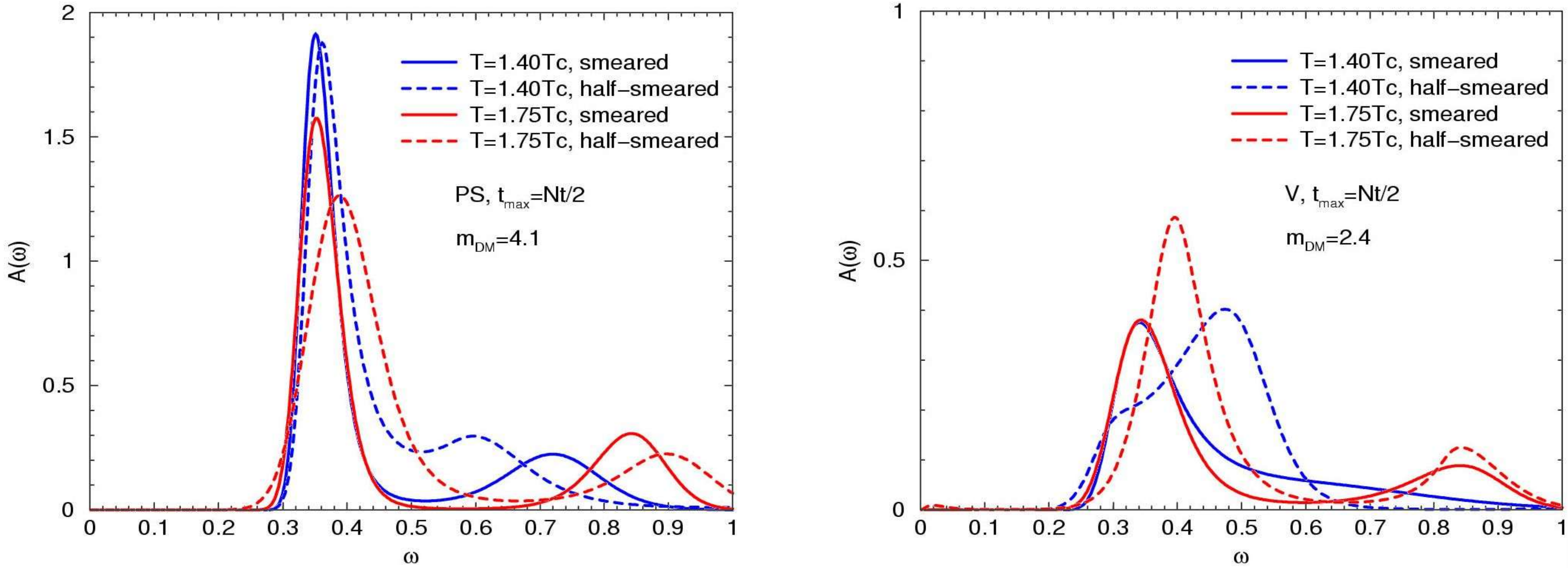


- correlators change gradually as temperature increases
- peak structure suvives above Tc,
- peak positions are similar to the result at T=0
- vector channel shows large change at high T

Result above Tc

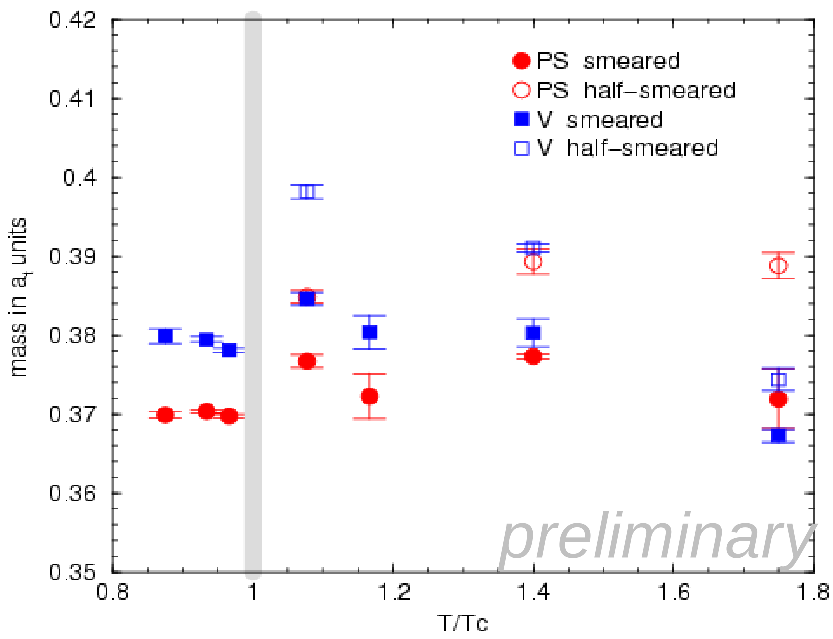
comparison between smeared and half-smeared results

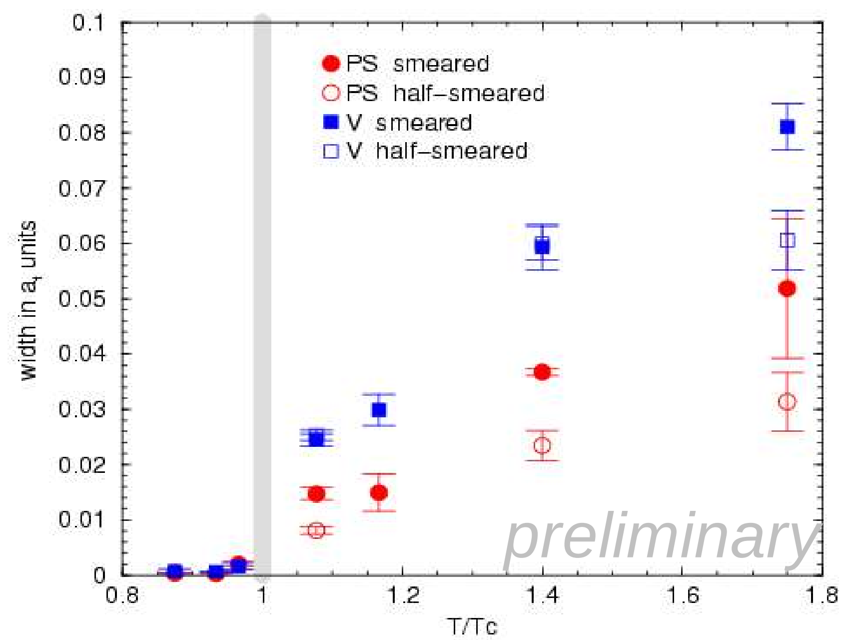
at T/Tc=1.4 and 1.75 (Nt=20 and 16)



- in PS channel at T=1.40Tc
  smeared & half-smeared results have similar peaks
  ==> physical peak exists at T=1.40Tc
- The others show artificial peaks / MEM does not work

Constrained curve fitting analysis





- Constrained curve fit results have large systematic uncertainties due to input parameters as prior knowledge

- small or no mass shift above and below Tc
- wider peak structure above Tc

Heavy quark free energy

These results are inconsistent with some Potential model predictions

What do we use as a “heavy quark potential” ?

c.f. O.Kaczmarek et al., Phys. Lett. B543 (2002) 41.

“Potential” for a system with T, V=const. ➡ (Hermholtz) free energy

The free energy can be extracted from polyakov loop correlations

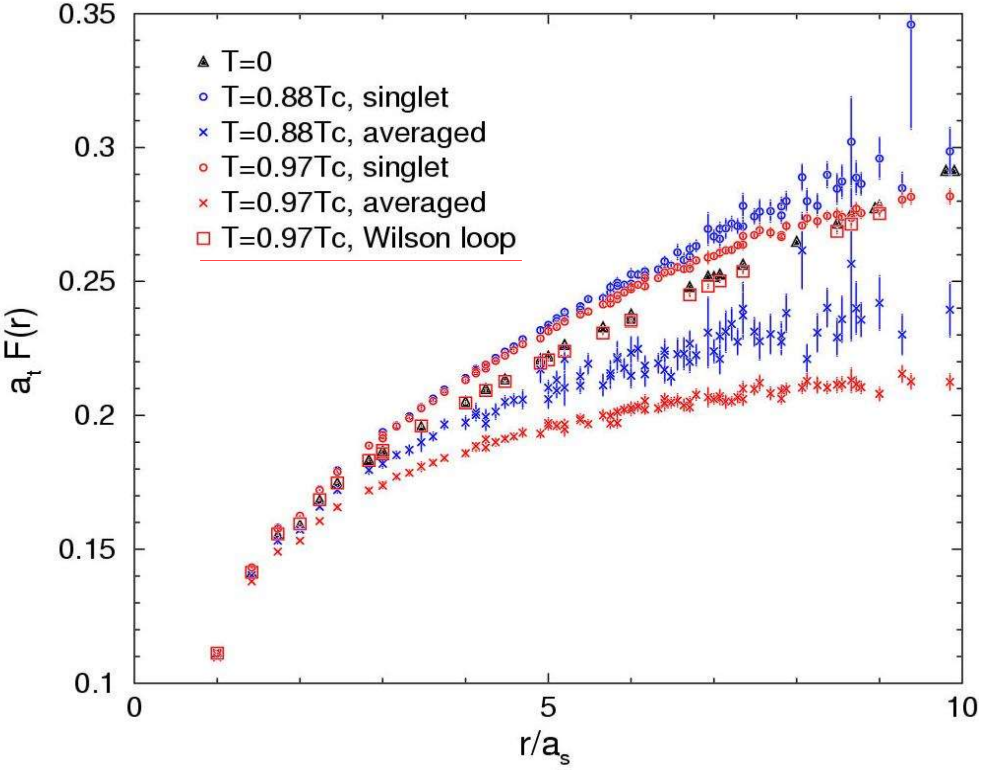
$$\exp\left(-\frac{F_{ave}(\vec{r})}{T}\right) \propto \langle Tr\, L(\vec{r})\, Tr\, L^{\dagger}(\vec{0})\rangle$$ (color averaged)

$$\exp\left(-\frac{F_{sing}(\vec{r})}{T}\right) \propto \langle Tr\, L(\vec{r})\, L^{\dagger}(\vec{0})\rangle$$ (color singlet)

and also from Wilson loop , W(r,t) (same analysis as T=0)

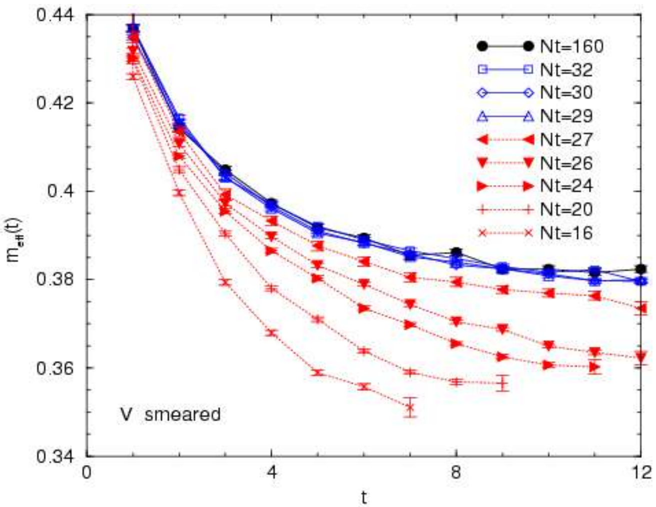
$$\exp\left(-F(\vec{r})\, t\right) \propto \langle W(\vec{r}, t)\rangle$$ (ground state of color singlet potential)

Heavy quark potentials at T<Tc



effective masses at T/Tc = 0~1.75

==> no change below Tc



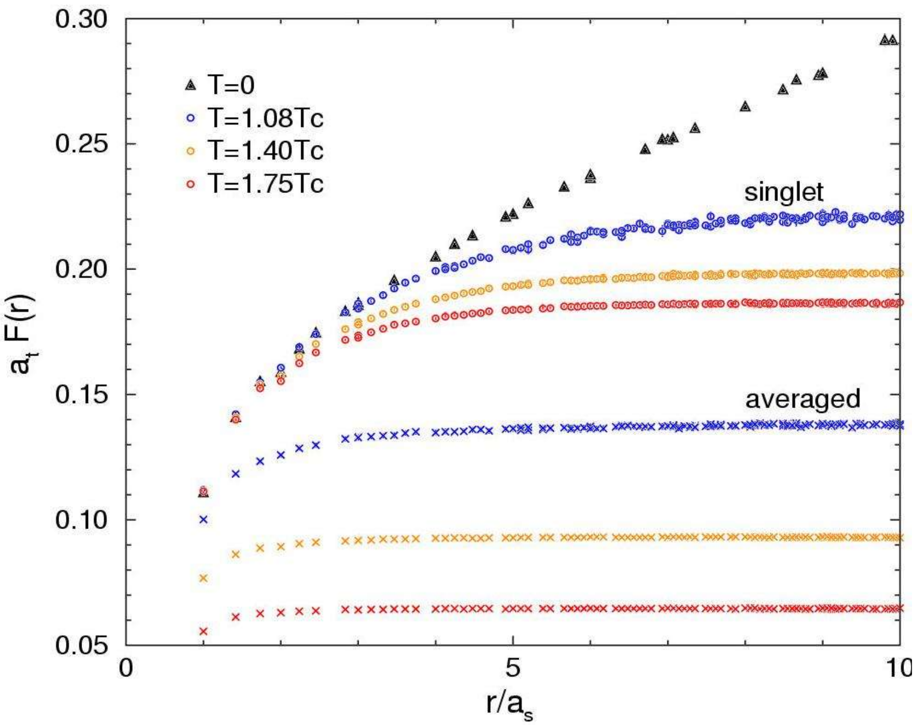
Schrödinger eq. with singlet free energy at T<Tc

==> 50~80MeV larger than T=0

lowest peak of spectral function x thermal averaged singlet potential

O ground state of singlet potential

Heavy quark potentials at T>Tc



Schrödinger eq.

with singlet free energies

(T=1.08Tc) bound state with 170MeV smaller mass than T=0

(T≥1.40Tc) no bound state or too wide wave function

Charmonium bound states survive above Tc

→ roughly consistent with the results of spectral function

But more discussion is needed !

Relation to the QGP signals

- Charmonium mass shift below Tc

==> lowest peak position of charmonium spectral function

no mass shift in our lattice results

- J/psi suppression above Tc

estimation of actual amount of produced J/psi in experiments

is related to mechanism of J/psi production

c.f. P.Crochet, Nucl. Phys. A715 (2003) 359.

==> $c\bar{c}$ pair can bound or not in the deconfinement phase

(*) most of $c\bar{c}$ pairs are produced as color octet pair

c.f. M.Gluck et al., Phys. Rev. D17 (1978) 2324.

Contribution of octet potential may also be important.

Summary

We study charmonium properties

on quenched anisotropic lattices at T/Tc=0.88~1.75

- Reconstruction of spectral functions from temporal correlators
  - below Tc
    no change from T=0
  - above Tc
    peak structure may survive upto T=1.4Tc
    peak width grows as temperature increases
- Potential model with the heavy quark free energy
  - lowest peak of charmonium spectral function
    <==> ground state of color singlet free energy

It is important to discuss the signals of QGP formation
using these data from lattice QCD calculations