Medium effects on the quarkonia states above critical temperature

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Introduction

- Study of the properties of heavy quarkonia above deconfinement temperature is of extreme interest for current experiments at RHIC and PANDA[1].
- Because of larger quark mass the heavy quarkonia can survive and remain in bound state above the deconfinement temperature T_c. The binding energy analysis has become important for such studies based on either potential models [2] or by Lattice methods[3].
- The topics of interest include survival probabilities as bound state at some temperature in QGP and in medium transport properties of heavy and light quarks.
- The lattice results of quarkonia correlator studies predicts existence of $1S$ charmonium states upto $1.6T_c$ and of $1P$ states (χ_{c0} and χ_{c1}) states upto $1.1T_c$.

[1] PhysRevD.76.094513, PPNP.65.209, [2] PhysRevD.73.074007, [3] PhysRevD.69.094507, PhysRevD.86.014509, LAT.2005.153

Euclidean correlators and spectral functions

The imaginary time Euclidean correlation functions of meson currents $G(\tau, T)$ are reliably calculated on the lattice

$$G(\tau, T) = \int d\omega \sigma(\omega, T) K(\tau, \omega, T) \tag{1}$$

Where, $\sigma(\omega, T)$ is the zero temperature spectral function and $K(\tau, \omega, T)$ is the kernel of integration and can be written as,

$$K(\tau, \omega, t) = \frac{cosh(\omega(\tau - \frac{1}{2T}))}{sinh(\frac{\omega}{2T})} \tag{2}$$

The spectral function can be written as[1],

$$\sigma(\omega) = \sum_i 2M_i F_i^2 \delta(\omega^2 - M_i^2) + \frac{3}{8\pi^2}\omega^2 \theta(\omega^2 - s_0) f(\omega, s_0) \tag{3}$$

[1] RevModPhys.65.1

The first term in spectral function arises from the pole contributions from the bound states, and the second term is the perturbative continuum above some threshold s_0 and computed here as [1],.

$$f(\omega, s_0) = \left(a_H + b_H \frac{s_0^2}{\omega^2}\right) \sqrt{1 - \frac{s_0^2}{\omega^2}} \tag{4}$$

Table: The coefficients (a_H, b_H) in different mesonic channel[2]

System	a_H	b_H
scalar	-1	1
pseudoscalar	1	0
vector	2	1
axial-vector	-2	3

[1] PhysRevD.73.074007, [2] PhysLettB.497.249

To see the temperature effect on the spectral function and to compare with the lattice QCD results one usually computes the ratio of this correlators to the reconstructred one $G(\tau, T)/G_{recon}(\tau, T)$, where $G_{recon}(\tau, T)$ is given by,

$$G_{recon}(\tau, T) = \int_0^\infty d\omega\sigma(\omega, T = 0)K(\tau, \omega, T) \tag{5}$$

The remaining parameters M_i and wave function dependant decay constants F_i are deduced from the potential model adopted for the present study.

Extraction of spin average mass (M_i) and decay constants (F_i)

For the description of the quarkonia states we consider temperature dependant screened potential of the form

$$V(r,T) = -\frac{\alpha}{r} e^{-\mu(T)r} + \frac{\sigma}{A\mu(T)} (1 - e^{-A\mu(T)r^{\nu}}) \qquad (6)$$

$$\begin{aligned}
\alpha &= CouplingConstant \\
\sigma &= StringTension \\
\nu &= PotentialStrength \\
\mu &= ScreeningParameter
\end{aligned}$$

In the absence of the medium effect (at zero temperature) the potential reduces to the form

$$V(r) = -\frac{\alpha}{r} + \sigma r^{\nu} \qquad (7)$$

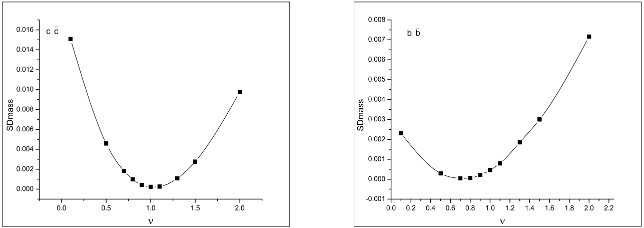


Figure: rms deviation in zero temperature mass for quarkonia states[1] (a) for charmonium states (b) for bottomonium states

[1]NuclPhysA.848.299

$$V(r,T) = -\frac{\alpha}{r}e^{-\mu(T)r} + \frac{\sigma}{A\mu(T)}(1 - e^{-A\mu(T)r^{\nu}}) \qquad (8)$$

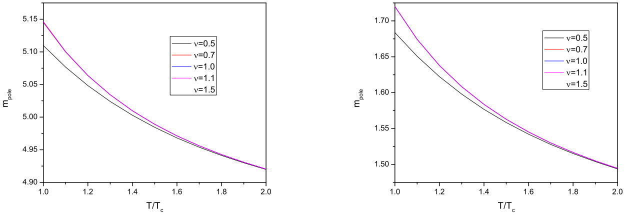


Figure: The pole quark mass for screened coulomb potential at different potential exponent (a) for $b\bar{b}$ system (b) for $c\bar{c}$ system

For computing the mass difference between different spin degenerate mesonic states, we consider the spin dependent part of the usual one gluon exchange potential (OGEP) as

$$V_{SD}(r) = V_{SS}(r)\left[S(S+1)-\frac{3}{2}\right]+V_{LS}(r)\left(\vec{L}\cdot\vec{S}\right)+ V_T(r)\left[S(S+1)-\frac{3(\vec{S}\cdot\vec{r})(\vec{S}\cdot\vec{r})}{r^2}\right] \tag{9}$$

The Coefficients V_{SS}, V_{LS} and V_T are computed as

$$V_{LS}(r)=\frac{1}{2\ m_1 m_2\ r}\left(3\frac{dV_V}{dr}-\frac{dV_S}{dr}\right) \tag{10}$$

$$V_T(r)=\frac{1}{6\ m_1 m_2}\left(3\frac{d^2V_V}{dr^2}-\frac{1}{r}\frac{dV_V}{dr}\right) \tag{11}$$

$$V_{SS}(r)=\frac{16\ \pi\alpha_s}{9\ m_1 m_2}\delta^{(3)}(\vec{r}) \tag{12}$$

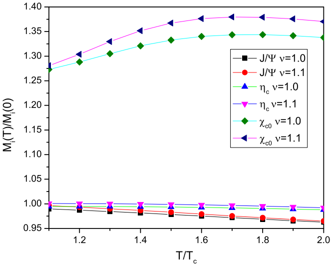
At the leading order in the coupling and inverse mass, the decay constant can be related to the wave function at the origin for the S states, i.e. the pseudoscalar and vector channel as [1],

$$
\begin{aligned}
F_{PS}^2 &= \frac{3}{2\pi}|R_n(0)|^2 \\
F_V^2 &= \frac{9}{2\pi}|R_n(0)|^2 \\
F_S^2 &= -\frac{27}{2\pi m^2}|R_n'(0)|^2 \qquad (13)
\end{aligned}
$$

The spin average masses and the wave functions are obtained by solving the Schroedinger equation numerically using the screened potential.

[1] PhysRevD.51.1125

Results



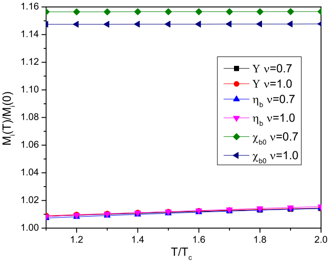


Figure: Ratio of the mass at given temperature to the zero temperature mass for different quarkonium states at different potential exponent ν (a) for charmonium (b) for bottomonium.

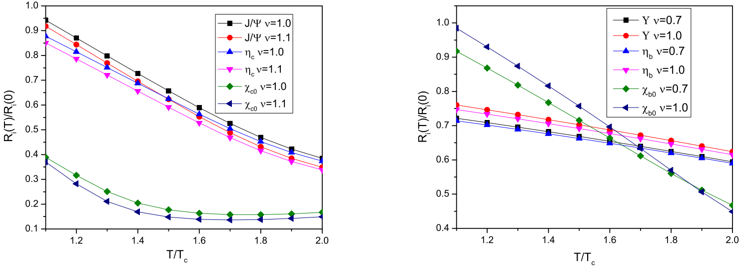


Figure: Ratio of the wave function at zero separation at given temperature $R_i(T)$ to the zero temperature wave function $R_i(0)$ for different quarkonium states at different potential exponent ν (a) for charmonium (b) for bottomonium.

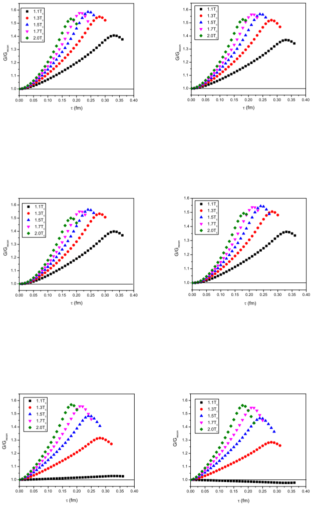


Figure: G/G_{recon} for PS(1S), V(1S) and S(1P) charmonium state

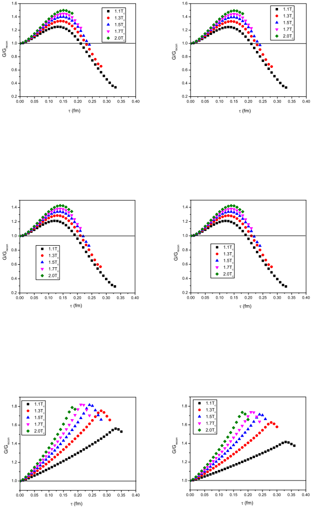
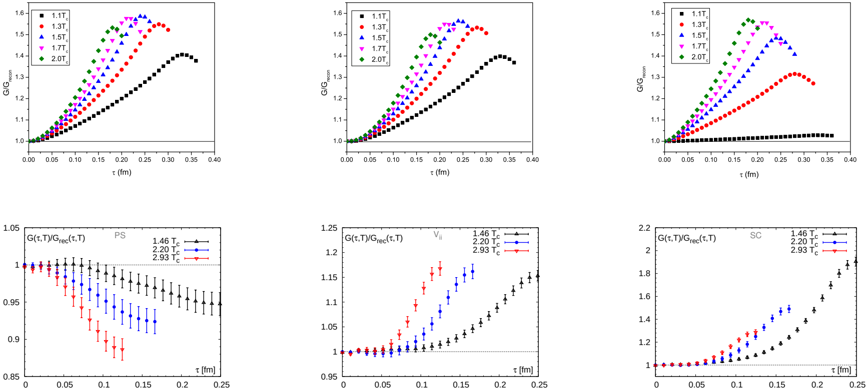


Figure: G/G_{recon} for PS(1S), V(1S) and S(1P) bottomonium state



$G\,/\,G_{recon}$ for PS (1S), V(1S) and SC(1P) $c\bar{c}$ states above for $\nu = 1.0$ and below lattice calculation from

arXiv:1204.4945

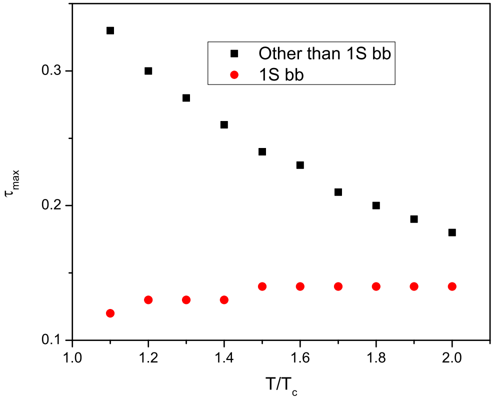


Figure: τ_{max} vs. T/T_c for all quarkonia states

Conclusion I

- The correlators show constant behaviour with respect to potential exponent ν.
- Variation in G/G_{recon} from unity represents dissolution of the quarkonium states into medium at higher temperature above T_c
- τ for maximum occurance of G/G_{recon}, τ_{max} represents the temperature for the maximum correlation of the quarkonia states. In our study, τ_{max} found to be exponentially decreasing with the temperature in the case of quarkonia states (except for $b\bar{b}(1S)$ case).

Conclusion II

- The values of G/G_{recon} below 1 corresponds to value of G to be lower than G_{recon}. This means the survival probability of the state to be lower than in the zero mode case or dissociation of the quarkonium state. Considering the time for $G/G_{recon} = 1$ related with the temperature T as, $\tau = 1/T$ we predict the dissociation temperature of η_c, J/ψ and χ_{c0} to be around $1.2T_c$ while η_b and Υ states can survive upto $3.0T_c$.

[1] PhysRevD.73.074007

Thank You