Heavy Quark Correlators Above Deconfinement

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We compare the quarkonia correlators from potential models and from lattice QCD.

Why Interested in Heavy Quark Correlators?

There has been lots of interest in studying the modifications of the heavy quark bound states, ever since in 1986 Matsui and Satz predicted [1] the suppression of the J/ψ peak in the dilepton spectra as signal for deconfinement. The idea was that color screening by the light quarks in the deconfined phase would prevent the binding of a heavy quark and antiquark. Potential model calculations predicted that higher excitations disappear earlier [2], and found that the J/ψ melts at about $1.1T_c$ [3].

The recently available evaluation on the lattice of quarkonia correlators and spectral functions [4–6] presented a surprise: The 1S J/ψ and η_c, survive at least up to $1.5T_c$, with no significant temperature-dependence of their masses [4,5], the 1S η_b is not modified until about $2T_c$ [6], the 1P χ_c^0 and χ_c^1 are dissolved at $1.1T_c$ [5], and the χ_b^0 shows drastic changes already at $1.15T_c$ [6].

While the lattice results do not contradict the idea of sequential dissolution, they are not in agreement with previous potential model calculations. It is questionable though, whether medium modifications of quarkonia can be understood in terms of a temperature dependent potential. Also, even though the extraction of spectral functions from the lattice is very promising, the currently available results are not yet fully reliable. The correlators, however, are accurately determined on the lattice.

Here we present some of our results obtained when investigating heavy quark correlators in potential models with a screened Cornell potential, as well as a potential fitted to the internal energy obtained on the lattice [7,8], and we compare them to the correlators obtained on the lattice.

Potential Models

Potential models intend to understand the modifications at finite temperature of the quarkonia properties using some screened potential to mediate the interaction between the heavy quark and antiquark [9]. A usual screened potential is a finite temperature extension of the zero temperature Cornell potential [10]. We used two, formally very different potentials: One is a phenomenologically motivated screened potential [2]

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

with screening mass $\mu = [0.24 + 0.31 \cdot (T/T_c - 1)]$ GeV, $T_c = 0.270$ GeV, coupling constant $\alpha = 0.471$, and string tension $\sigma = 0.192\text{GeV}^2$. The other is a recently popular [11], yet still questionable identification as potential of the internal energy of a static $q\bar{q}$ pair determined on the lattice. We fit the lattice data on the internal energy from [12] by the Ansatz

$$V(r,T) \;=\; -\frac{\alpha}{r}e^{-\mu(T)r^2} + \sigma(T)re^{-\mu(T)r^2} + C(T)\left(1 - e^{-\mu(T)r^2}\right) . \qquad (2)$$

Solving the Schrödinger equation with these potentials provides the binding energies, the radii, and the wave function of the different bound states. Importantly, the results turn out to be not sensitive to the details of the potential. The masses obtained are in accordance with the lattice, and do not change substantially with temperature, except for the scalar charmonium χ_c^0, whose properties are modified already at $1.1T_c$ [7]. All the wave functions at the origin show a strong drop with increasing temperature [7]. The properties of the pseudoscalar η_c and the vector J/ψ states are identical, since we neglect effects that would arise from the hyperfine splitting.

It is common for all screened potentials that these are finite at infinite separation distances between the quark and antiquark. This determines a threshold for the continuum, $s_0(T) = 2m + \lim_{r\to\infty} V(r,T)$, above which the quark/antiquark can propagate freely. This threshold decreases with increasing temperature.

Assuming thus, that the a heavy quark and antiquark in the deconfined phase interact via a screened potential $V(r,T)$, and propagate freely above the threshold $s_0(T)$, we motivate the following form for the spectral function [7,8]

$$\sigma(\omega,T) = \sum_i 2M_i(T)F_i(T)^2\delta\left(\omega^2 - M_i^2\right) + \frac{3}{8\pi^2}\omega^2\theta\left(\omega - s_0(T)\right) + \chi_s\left(1 - 3\frac{T}{M}\right)\omega\delta(\omega) . \qquad (3)$$

$M_i(T)$ and $F_i(T)$ are the bound state masses and amplitudes. The last term, present only in the vector channel, is due to charge fluctuations and diffusion, with $\chi_s(T)$ the charge susceptibility [8]. For the continuum here we chose a sharp threshold, which needs not be the case [8]. The correlator is now obtained from its spectral representation

$$G(\tau,T) = \int d\omega\sigma(\omega,T)\frac{\cosh\left[\omega\left(\tau - \frac{1}{2T}\right)\right]}{\sinh\left[\frac{\omega}{2T}\right]} . \qquad (4)$$

To make direct comparison with the lattice results, we determine the ratio G/G_{recon}, where G_{recon} is the correlator (4) evaluated with $\sigma(\omega, T = 0)$.

Results and Conclusions

Some results for the correlators are summarized in Figure 1 as obtained on the lattice (left panels) and in our potential model calculations (right panels). For the scalar charmonium (top panel) an increase of the correlator has been detected right above T_c. The increase is enhanced with temperature, despite the fact that the contribution from the χ_c^0 state is negligible. This enhancement is due to the thermal shift of the continuum threshold. The scalar bottomonium correlator also shows an increase (top 2nd panel) right above T_c, even though the χ_b^0 survives until much higher temperatures than the χ_c^0. Thus the continuum seems to be the dominant contribution to the scalar correlator.

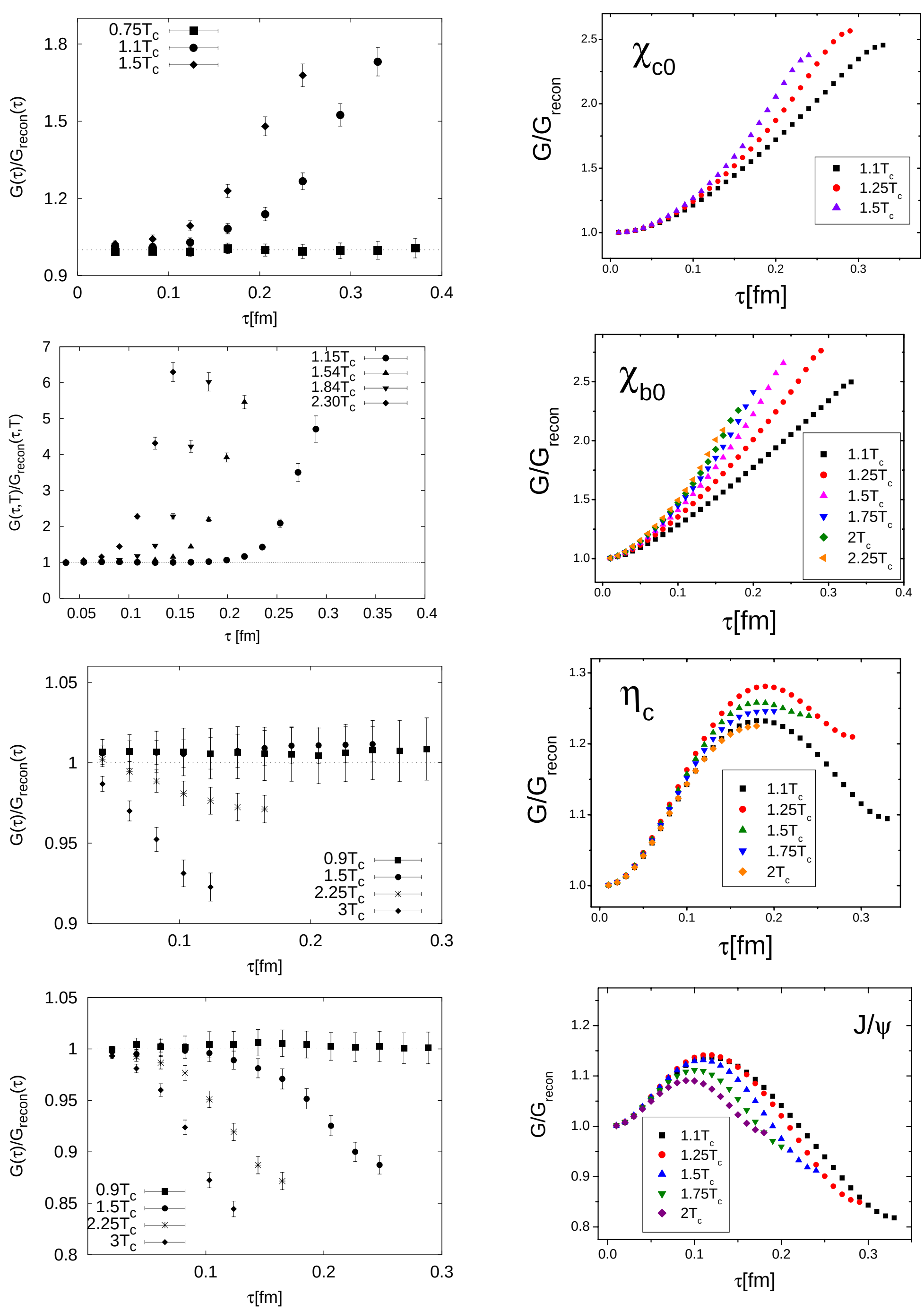

Figure 1. Top to bottom: Ratio of the χ_c^0, χ_b^0, η_c and J/ψ correlator to the reconstructed correlator calculated on the lattice (left panels from [5,6]) and in our model (right panels).

Since in our calculations the pseudoscalar and vector channel correspond to the same 1S state, we would not expect the η_c and the J/ψ correlator to behave differently. The lattice correlator shows no change up until about $3T_c$ for the η_c (2nd bottom left panel), yet a significant decrease for the J/ψ already at $1.5T_c$ at distances > 0.15 fm (c.f. eq. (3) and bottom left panel). We explain this with the effects of diffusion and charge fluctuations that make the J/ψ correlator smaller. Our model calculations show this effect too (bottom two right panels). However, for both the η_c and the J/ψ, the potential model calculations do not reproduce the behavior of the correlator as obtained from the lattice. The identified extra feature is the significant contribution to the correlator from the continuum due to threshold reduction, and manifest in the increase of the correlators at short distances.

The features identified are independent of the form of the potential. The temperature dependence of the correlators show much richer structure than the one seen on the lattice. We are thus led to the question whether some physics is not identified in the lattice correlators due to lattice artifacts, or the physics in the deconfined phase is more subtle than allowing to describe medium effects on heavy quark bound states by potential models. Further investigations of these questions are in progress.

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REFERENCES

1. T. Matsui and H. Satz, Phys. Lett. B **178**, 416 (1986).
2. F. Karsch, M. T. Mehr and H. Satz, Z. Phys. C **37**, 617 (1988).
3. S. Digal, P. Petreczky and H. Satz, Phys. Rev. D **64**, 094015 (2001) [arXiv:hep-ph/0106017].
4. T. Umeda, K. Nomura and H. Matsufuru, Eur. Phys. J. C **39S1**, 9 (2005) [arXiv:hep-lat/0211003]; M. Asakawa and T. Hatsuda, Phys. Rev. Lett. **92**, 012001 (2004) [arXiv:hep-lat/0308034].
5. S. Datta, F. Karsch, P. Petreczky and I. Wetzorke, Phys. Rev. D **69**, 094507 (2004) [arXiv:hep-lat/0312037].
6. K. Petrov, arXiv:hep-lat/0503002; A. Jakovác, P. Petreczky, K. Petrov and A. Velytsky, work in progress.
7. Á. Mócsy and P. Petreczky, Eur. Phys. J. C **43**, 77 (2005) [arXiv:hep-ph/0411262].
8. Á. Mócsy and P. Petreczky, in preparation.
9. N. Brambilla et al, *Quarkonium Physics*, CERN Yellow Report, hep-ph/0412158
10. E. Eichten, K. Gottfried, T. Kinoshita, K. D. Lane and T. M. Yan, Phys. Rev. D **21**, 203 (1980).
11. E. V. Shuryak and I. Zahed, Phys. Rev. C **70**, 021901 (2004) [arXiv:hep-ph/0307267]; Phys. Rev. D **70**, 054507 (2004) [arXiv:hep-ph/0403127]; C. Y. Wong, arXiv:hep-ph/0408020; W. M. Alberico, A. Beraudo, A. De Pace and A. Molinari, arXiv:hep-ph/0507084.
12. O. Kaczmarek, F. Karsch, P. Petreczky and F. Zantow, Nucl. Phys. Proc. Suppl. **129**, 560 (2004) [arXiv:hep-lat/0309121].