T-matrix approach to quarkonium correlation fucntions in the quark-gluon plasma

Daniel Cabrera and Ralf Rapp

Bound states of heavy quarks (charmonium and bottomonium) provide a rich laboratory for spectroscopy in QCD [1]. Potential models have been widely and successfully applied to charmonium and bottomonium spectra in vacuum, and the validity of the approach has received further support from lattice QCD (lQCD). It is therefore promising to extend the potential approach to finite temperatures, *T*. Medium modifications of heavy quarkonia have long been recognized as a valuable probe to characterize properties of the Quark-Gluon Plasma (QGP), such as color screening or deconfinement [2]. A good understanding of quarkonium properties in medium is a prerequisite to utilize them as diagnostic tools for the matter created in high-energy heavy-ion reactions.

Finite-*T* lQCD computations of charmonium spectral functions suggest that low lying S-wave states (η_c, J/Ψ) survive in the QGP up to ~$2T_c$ (T_c: critical temperature) [3,4]. This has been confirmed in potential models based on lQCD heavy-quark free energies implemented into a Schrödinger [5] or Lippmann-Schwinger equation [6]. While the lQCD spectral functions are beset with significant uncertainty, direct (and more accurate) computations are available for the Euclidean correlation function, $G(\tau,T)$ (τ : Euclidean time) which is related to the spectral function, $\sigma(\omega)$~ Im$G(\omega)$, via

$$G(\tau,T) = \int_0^\infty d\omega\, \sigma(\omega,T)\, K(\tau,\omega,T)\,, \qquad (1)$$

with a known temperature kernel, *K*. Rather than performing an inverse integral transform to extract spectral functions from Euclidean lQCD correlators, effective model calculations of spectral functions can be used to straightforwardly compute correlators and constrain them by lQCD results [7,8].

We have employed our earlier developed T-matrix approach [6] for quark-antiquark scattering to calculate charmonium and bottomonium spectral functions based on heavy-quark potentials extracted from lQCD [9]. The T-matrix approach allows for a comprehensive treatment of bound and scattering states which is essential for reliable computations of Euclidean correlators since the latter involve an integration over the entire spectrum (cf. Ref. [8] for calculations using the Schrödinger equation). Our results for S- and P-wave charmonium spectral functions and Euclidean correlation functions are summarized in Figs. 1 and 2. In line with lQCD spectral functions, we confirm that S-wave states survive in the QGP well above T_c, while P-wave (χ_c) states "melt" slightly above T_c. In addition, we find that nonperturbative rescattering effects lead to a large enhancement of strength around and beyond the quark-antiquark threshold, as highlighted by comparing to the perturbative (non-interacting) continuum (dashed line in the left panels of Fig.1, 2). The pertinent Euclidean correlators are calculated from Eq. (1) and normalized to a "reconstructed" correlator following from a schematic $T=0$ spectral function (right panels in Figs. 1, 2). The decreasing trend with *T* for the S-wave correlator, and the enhancement over 1 in the P-wave, qualitatively agree with lQCD results [4], while the magnitude of the S-wave correlator and the T-dependence of the P-wave one are not consistent with lQCD. The plotted ratios are rather sensitive to the reconstructed correlator used for normalization. E.g., when normalizing to the S-wave correlator for $1.5T_c$ (which according to lQCD is consistent with the free one), the agreement improves. The *T*-dependence of the P-wave channel improves when using in-medium *c*-quark masses (as suggested by lQCD), reiterating the importance of threshold effects; finite width effects have little impact. Advanced studies are in progress and will hopefully provide a better understanding of charmonia in the QGP which can then be applied to high energy heavy-ion collisions.

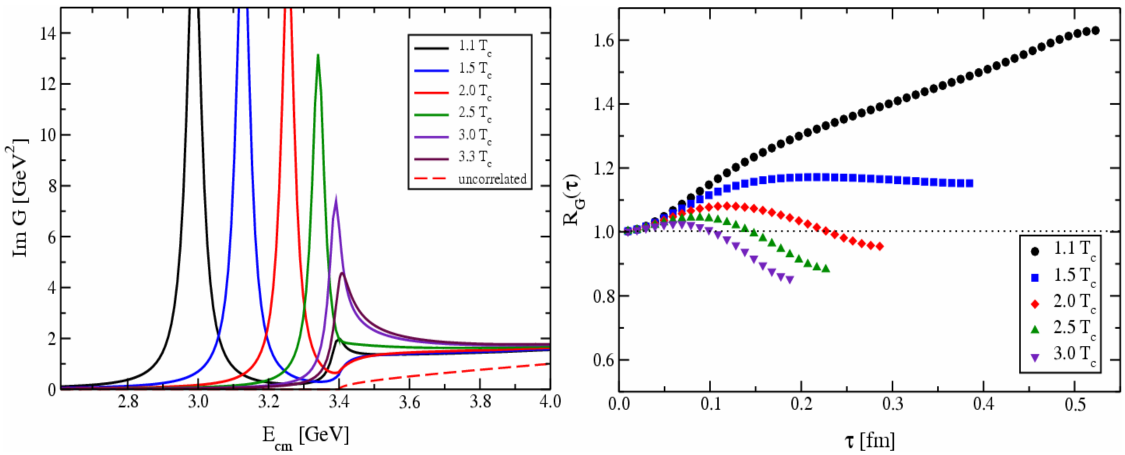

Figure 1. S-wave charmonium spectral function (left) and normalized Euclidean correlation function (right) [9].

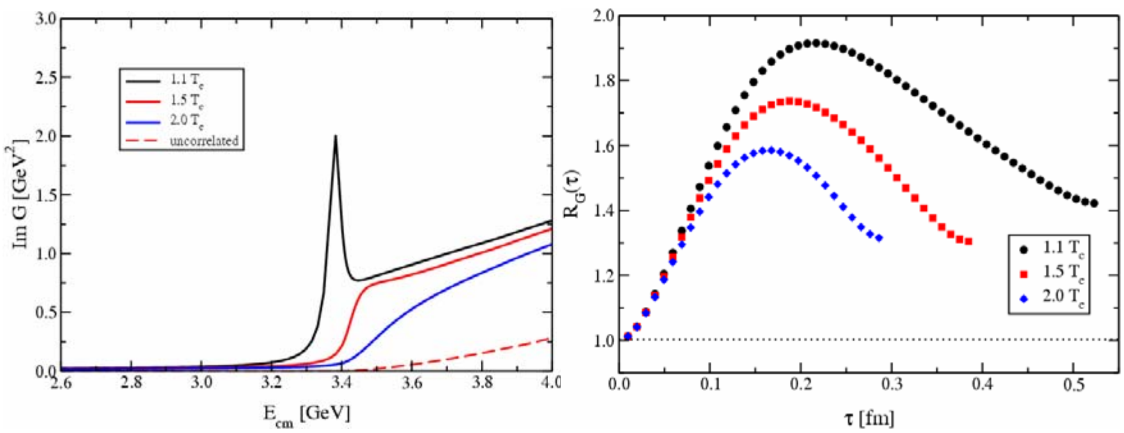

Figure 2. P-wave charmonium spectral function (left) and normalized Euclidean correlation function (right) [9].

[1] N. Brambilla *et al.*, *Heavy Quarkonium Physics*, arXiv:hep-ph/0412158.

[2] T. Matsui and H. Satz, Phys. Lett. **178B**, 416 (1986); R. Rapp and L. Grandchamp, J. Phys. G **30**, S305 (2004).

[3] Y. Asakawa and T. Hatsuda, Phys. Rev. Lett. **92**, 012001 (2004).

[4] S. Datta *et al.*, Phys. Rev. D **69**, 094507 (2004).

[5] E. V. Shuryak and I. Zahed, Phys. Rev. C **70**, 021901 (2004); C.Y. Wong, Phys. Rev. C **72**, 034906 (2005); W.M. Alberico, A. Beraudo, A. de Pace, and A. Molinari, Phys. Rev. D **72**, 114011 (2005).
[6] M. Mannarelli and R. Rapp, Phys. Rev. C **72**, 064905 (2005).
[7] R. Rapp, Eur. J. Phys. A **18**, 459 (2003) [arXiv:nucl-th/0209081].
[8] A. Mocsy and P. Petreczky, Phys. Rev. D **37**, 074007 (2006).
[9] D. Cabrera and R. Rapp, arXiv:hep-ph/0611134; Eur. J. Phys. A **31**, 858 (2007).