BNL-75636-2006-CP

Quarkonia in a Deconfined Gluonic Plasma

S. Datta[1], A. Jakovac[2], F. Karsch[3], P. Petreczky[4]

[1] Brookhaven National Laboratory, Upton, NY 11973 USA
[2] Institute of Physics, BME Budapest, H-1111, Budapest, Hungary
[3] Brookhaven National Laboratory, Upton, NY 11973 USA
[4] Brookhaven National Laboratory, Upton, NY 11973 USA

Presented at the Particles and Nuclei International Conference
(PANIC 05)
Santa Fe, New Mexico, USA
24-28 October 2005

March 2006

Physics Department

Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

DISCLAIMER

Quarkonia in a deconfined gluonic plasma

S. Datta*, A. Jakovác†, F. Karsch*,** and P. Petreczky*

*Brookhaven National Laboratory, Upton, NY 11973, USA
†Institute of Physics, BME Budapest, H-1111 Budapest, Hungary
**Bielefeld University, D-33615 Bielefeld, Germany

Abstract. We discuss lattice results on the properties of finite momentum charmonium states in a gluonic plasma. We also present preliminary results for bottomonium correlators and spectral functions in the plasma. Significant modifications of $\chi_{b_{0,1}}$ states are seen at temperatures of 1.5 T_c.

Keywords: Quark-gluon plasma,quarkonia suppression
PACS: 11.15.Ha, 12.38.Gc, 12.38.Mh, 25.75.-q

Following the suggestion of Matsui and Satz [1] that J/ψ can act as a probe of deconfinement, heavy quarkonia in the context of relativistic heavy ion collisions have been extensively studied both theoretically and experimentally. Early, potential model based studies indicated that all charmonium bound states dissolve by temperatures $\sim$ 1.1 T_c [2]. But direct lattice studies over last few years have concluded that while the excited χ_c states dissolve quite early in the plasma [3], the 1S states $J/\psi, \eta_c$ survive till quite high temperatures [3, 4], at least in a purely gluonic plasma [1]. It has recently been claimed [6] that the observed J/ψ suppression in SPS and in RHIC is consistent with suppression of only the secondary J/ψ from excited state decays, in accordance with the lattice results.

For understanding the mechanism of charmonia dissolution, as well as for phenomenological purposes, it is important also to know the effect of the plasma on a bound state in motion with respect to the plasma rest frame. This problem can be studied directly on lattice, in ways similar to that of the bound states at rest [7]. We look at the momentum-projected Matsubara correlators

$$G(\tau,\vec{p},T) = \sum_{\vec{x}} e^{i\vec{p}.\vec{x}} \, \langle J_H(\tau,\vec{x}) J_H^{\dagger}(0,\vec{0})\rangle_T \tag{1}$$

where J_H is a suitable mesonic operator, $\vec{p}$ the spatial momentum, T is the temperature of the gluonic plasma and the Euclidean time $\tau \in [0, 1/T)$. Through analytic continuation, the Matsubara correlator can be related to the hadronic spectral function by an integral equation:

$$G(\tau,\vec{p},T) = \int_0^\infty d\omega \; \sigma(\omega,\vec{p},T) \, \frac{\cosh(\omega(\tau - 1/2T))}{\sinh(\omega/2T)}. \tag{2}$$

[1] Naively, one would not expect a much earlier dissolution due to dynamical quarks. A recent study in 2-flavor QCD [5] supports this expectation.

The 1S charmonia $\eta_c, J/\psi$ at rest undergo very little significant modification till temperatures of 1.5 T_c. However, the finite momentum correlators $G(\tau,\vec{p},T)$ show significant temperature dependence even earlier. Medium modifications become stronger with increasing momentum. For $p \sim 1$ GeV, significant modifications of the correlator are already seen at 1.1 T_c. The spectral function $\sigma(\omega,\vec{p},T)$, extracted from $G(\tau,\vec{p},T)$, shows a clear peak also at high momenta, but it is significantly modified from the zero temperature peak. Physically this can be understood as follows. A charmonium state moving in the plasma frame "sees" more energetic gluons, leading to an increase in its collisional width. An in-medium change of the energy-momentum dispersion relation is also possible. Due to paucity of space, we refer to Ref. [7] for further discussion of this, and turn here to bottomonia instead.

The Υ_b peak in the dilepton channel will be accessible to both RHIC and LHC, and may produce cleaner setups for plasma-related modifications since normal nuclear modifications for bottomonia are expected to be small. On the other hand, the 1S states Υ_b and η_b are very tightly bound and even the potential model calculations estimated a very high dissolution temperature for them [2]. The behavior of 1P bottomonia is less clear: while the potential models predict a dissolution temperature close to T_c [2], they also suggest a size similar to the 1S charmonia for these states and therefore one may expect a similar dissolution temperature [2]. A recent study [9], on the other hand, has found modifications of χ_b close to T_c, unlike η_b. More than 40% of the total Υ_b seen in hadronic collisions come from decay of excited bottomonia, and an early dissolution or strong modification of χ_b will modify this contribution significantly.

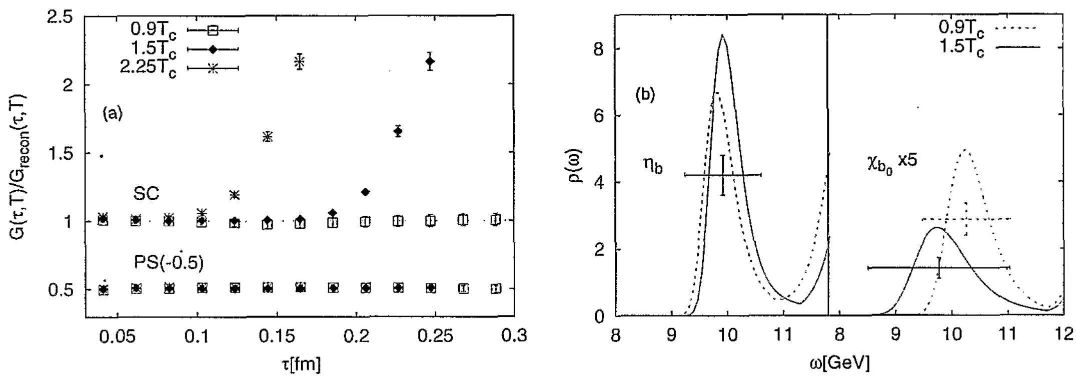

FIGURE 1. (a) $G(\tau,T)/G_{\rm recon}(\tau,T)$ for $\bar{b}\gamma_5 b$ and $\bar{b}b$ at $\vec{p}=0$. (b) Spectral function constructed from $G(\tau,T)$ using maximum entropy method.

We studied bottomonia in gluonic medium following the same methods used for the charmonia study in Ref. [3], and on the finest set of lattices used there. These lattices have a cutoff a^{-1} = 9.72 GeV, which is somewhat coarse for bottomonia [2]. This, therefore, should only be taken as a pilot study. We studied zero momentum

[2] Ref. [9], uses an anisotropic lattice which is slightly finer in time, a_t^{-1} = 10.89 GeV, but considerably coarser in space, a_s^{-1} = 2.72 GeV. It also uses a different action, so the cutoff effects should be different.

projected $\bar{b}\Gamma b$ (point-point) correlators, where $\Gamma = \gamma_5, \gamma_i, 1$ and $\gamma_i\gamma_5$ for $\eta_b, \Upsilon_b, \chi_{b_0}$ and χ_{b_1}, respectively.

We extract $\sigma(\omega,T)$ from $G(\tau,T)$ using the "Maximum Entropy Method" [8], where the inversion of Eq. (2) is turned into a well-defined problem of finding the most probable spectral function given data and prior information for $\sigma(\omega,T)$. Also very useful and robust conclusions of possible change of state with deconfinement can be obtained by comparing the correlators measured above T_c with $G_{\mathrm{recon},T^*}(\tau,T)$, correlators reconstructed from the spectral function obtained at the smallest temperature below T_c (see Ref. [3] for details of our analysis method). If the spectral function is not modified with temperature, $G(\tau,T)/G_{\mathrm{recon},T^*}(\tau,T) = 1$. A comparison of the measured correlators in the pseudoscalar and scalar channels with the reconstructed correlators is shown in Fig. 1(a). $G(\tau,T)$ for the pseudoscalar shows no significant modification for temperatures upto 2.25 T_c, indicating that η_b is essentially unmodified at these temperatures. The scalar correlator, on the other hand, shows large changes at long distances already at 1.5 T_c. The modification pattern in Fig. 1(a) is somewhat different from that seen in scalar charmonia, where the medium effect was seen to have set in at smaller distances and less abruptly.

Figure 1(a) shows qualitatively similar trend as in Ref. [9], but the deviation of the scalar correlator seen by us is much smaller than that seen in Ref.[9]. This could be due to the use of anisotropic lattice in [9]. Figure 1(b) shows a comparison of the ground state peaks at 0.9 T_c and 1.5 T_c for the pseudoscalar (left) and scalar (right) channels. Plotted here is the dimensionless quantity $\rho(\omega,T) = \sigma(\omega,T)/\omega^2$. As expected, the η_b peak shows no significant modification at 1.5 T_c. The χ_{b_0} peak, on the other hand, shows significant deviation, with a possible shift and broadening. The Υ_b and χ_{b_1} show similar trends to η_b and χ_{b_0}, respectively. It will be interesting to further study the modification of the χ_b peak, both in terms of the nature of the modification and its behavior at temperatures closer to T_c.

This manuscript has been authored under contract number DE-AC02-98CH1-886 with the US Department of Energy. Computations were done in NERSC, Berkeley and in NIC, Juelich. A.J. is supported by Hungarian Science Fund OTKA (F043465).

REFERENCES

1. T. Matsui and H. Satz, *Phys. Lett.* **B 178**, 416 (1986).
2. F. Karsch and H. Satz, *Z. Phys.* **C 51**, 209 (1990).
   S. Digal, P. Petreczky and H. Satz, *Phys. Rev.* **D 64**, 094015 (2001).
3. S. Datta *et al.*, *Nucl.Phys.Proc.Suppl.* **119**, 487 (2003); *Phys. Rev.* **D 69**, 094507 (2004).
4. M. Asakawa and T. Hatsuda, *Phys. Rev. Lett.* **92**, 012001 (2004).
   T. Umeda, K. Nomura and H. Matsufuru, *Eur. Phys. J.* **C39S1**, 9 (2005).
   H. Iida et al., *PoS LAT2005*, 184 (2005) (hep-lat/0509129).
5. R. Morrin et al., *PoS LAT2005*, 176 (2005) (hep-lat/0509115).
6. F. Karsch, D. Kharzeev and H. Satz, hep-ph/0512239.
7. S. Datta et al., in: Proc. SEWM 2004 (hep-lat/0409147).
8. M. Asakawa, T. Hatsuda and Y. Nakahara, *Prog. Part. Nucl. Phys.* **46**, 459 (2001).
9. K. Petrov et al., *PoS LAT2005*, 153 (2005) (hep-lat/0509138).