Glueball Properties at $T > 0$ from SU(3) Anisotropic Lattice QCD

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Hadrons are relativistic bound states of quarks and gluons. Hence, at nonzero temperature/density even within the confinement phase, we expect that they change their properties as a consequence of the changes of the QCD vacuum such as the reduction of the string tension and the partial chiral restoration. In fact, a number of effective models predict the (pole)mass reductions of various hadrons of more than a few hundred MeV near the critical temperature T_c of the QCD phase transition [1, 2, 3, 4]. Recently, motivated by these studies, quenched anisotropic lattice QCD has been used to measure the pole mass of various hadrons at finite temperature [5, 6, 7], reporting the profound results that, for both the light and heavy $q\bar{q}$-mesons, no significant change has been observed below T_c, while, for the glueball, the significant pole mass reduction of about 300 MeV is observed near T_c. In all of these studies, the narrowness of the bound state peak is assumed. However, since at $T \neq 0$, each bound state peak acquires a non-vanishing thermal width through the interaction with the heatbath, it is desirable to be taken into account. Here, we report the advanced analysis of the thermal 0^{++} glueball based on SU(3) quenched anisotropic lattice QCD taking into account the effect of the thermal width.

Generally, to extract physical observables such as mass and width, we have to resort to the spectral representation of the two-point correlator $G(t) \equiv Z(\beta)^{-1}\mathrm{tr}\left\{e^{-\beta H}\phi(t)\phi(0)\right\}$ as

$$G(t) = \int_{-\infty}^{\infty} \frac{d\omega}{2\pi} \frac{\rho(\omega)}{2\sinh(\beta\omega/2)} \cosh\left(\omega(\beta/2 - t)\right), \tag{1}$$

where H is the QCD Hamiltonian, $Z \equiv \mathrm{tr}(e^{-\beta H})$, $\phi(t) \equiv e^{tH}\phi(0)e^{-tH}$ is the zero-momentum projected glueball operator in the imaginary-time Heisenberg picture, and $\rho(\omega)$ is the spectral function. Appropriate smearing on $\phi(t)$ is understood to maximize the overlap to the glueball state. To extract the physical observables, we parameterize $\rho(\omega)$ and use Eq. (1) to fit $G(t)$ generated by lattice QCD. In Refs. [5,6,7], the narrow-peak ansatz has been adopted, where $\rho(\omega)$ is parameterized as $\rho(\omega) = 2\pi A\left(\delta(\omega - m) - \delta(\omega + m)\right) + \cdots$ with the two fit parameters A and m corresponding to the overlap and the pole mass, respectively.

To respect the thermal width, we recall that $\rho(\omega)$ is the imaginary part of the retarded Green function $G_R(\omega)$, i.e., $\rho(\omega) = -2\mathrm{Im}\left(G_R(\omega)\right)$. At $T = 0$, bound state poles of $G_R(\omega)$ are located on the real ω-axis. With increasing T, they begin to move off the real axis into the complex ω-plane. Thus the influence of each complex pole in $\rho(\omega)$ can be parameterized with a Lorentzian as $\rho(\omega) = 2\pi A\left(\delta_\Gamma(\omega - \omega_0) - \delta_\Gamma(\omega + \omega_0)\right) + \cdots$, where A, ω_0 and Γ are used as fit parameters corresponding to the overlap, the center and the thermal width, respectively. $\delta_\epsilon(x) \equiv \frac{1}{\pi}\mathrm{Im}\left(\frac{1}{x - i\epsilon}\right)$ denotes a smeared delta function. We refer to the corresponding fit function as the Breit-Wigner type.

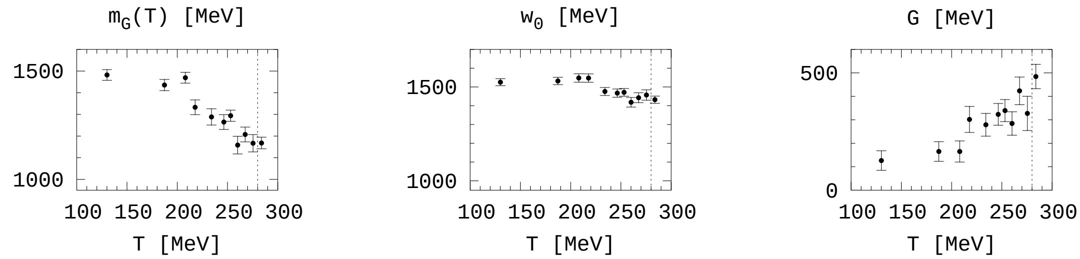

Figure 1: The pole mass $m_{\rm G}(T)$ from the narrow-peak ansatz, the center $\omega_0(T)$ and the thermal width $\Gamma(T)$ from the Breit-Wigner ansatz. The vertical dotted lines indicate the critical temperature $T_c \simeq 280$ MeV. Appropriate smearings are understood.

The numerical results are shown in Fig. 1. We use 5000 to 9900 gauge configurations generated by the Wilson action with $\beta = 6.25$ and the renormalized anisotropy $\xi \equiv a_s/a_t = 4$. Whereas the narrow-peak ansatz indicates the significant pole mass reduction of about 300 MeV, the Breit-Wigner ansatz indicates the significant thermal width broadening of more than 300 MeV with a modest reduction in the peak center. These two analysises thus lead to the two different physical implications. Note that, due to the biased factor "$\sinh(\beta\omega/2)$" in Eq. (1) which enhances the smaller ω region of $\rho(\omega)$, thermal width is effectively seen as the reduced pole mass in the narrow-peak ansatz. Hence, in the case of the glueball, the thermal effect is most probably the thermal width broadening.

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The numerical calculation has been done on NEC–SX5 at RCNP.

References

[1] T. Hatsuda, and T. Kunihiro, Phys. Rev. Lett. **55** (1985) 158.
[2] T. Hashimoto, O. Miyamura, K. Hirose, and T.Kanki, Phys. Rev. Lett. **57** (1986) 2123.
[3] T. Hatsuda Y. Koike, and S. H. Lee, Phys. Rev. **D47** (1993) 1225.
[4] H. Ichie, H. Suganuma, and H. Toki, Phys. Rev. **D52** (1995) 2944.
[5] Ph. de Forcrand et al., QCD-TARO Collab., Phys. Rev. **D63** (2001) 054501.
[6] T. Umeda, R. Katayama, O. Miyamura, and H. Matsufuru, Int. J. Mod. Phys. **A16** (2001) 2215.
[7] N. Ishii, H. Suganuma, and H. Matsufuru, Phys. Rev. **D66** (2002) 014507.
[8] N. Ishii, H. Suganuma, and H. Matsufuru, Phys. Rev. **D66** (2002) 094506.