MEM Analysis of the Thermal Glueball from SU(3) Lattice QCD

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Near the critical temperature T_c, one expects various onsets of the deconfinement transition in the QCD vacuum such as the reduction of the string tension and the partial chiral restoration. As a consequence, some hadrons are expected to exhibit the pole-mass reduction near T_c, as suggested by effective-model studies[1, 2, 3, 4]. Indeed, these changes are considered as important precritical phenomena of the QCD phase transition in RHIC experiments, and corresponding lattice QCD calculations were attempted at the quenched level recently[5, 6, 7, 8]. In this paper, we consider 0^{++} glueball, whose pole-mass reduction is suggested by an effective model based on the dual Meissner picture of color confinement[4].

In general, to study the pole mass of a hadron in lattice QCD, one first constructs a temporal correlator as $G(\tau) = \langle \phi(\tau)\phi(0)\rangle$, and then resorts to its spectral representation as

$$G(\tau) = \int_0^\infty d\omega K(\tau,\omega)A(\omega), \tag{1}$$

where

$$K(\tau,\omega) \equiv \frac{\cosh(\omega(\beta/2-\tau))}{\sinh(\beta\omega/2)}, \tag{2}$$

$\beta \equiv 1/T$, and $A(\omega)$ is the spectral function with its spatial momentum projected to zero, i.e., $A(\omega) \equiv A(\omega, \vec{p} = \vec{0})$. Each peak position of $A(\omega)$ corresponds to a pole mass of a hadron at $T > 0$. Usually, to extract $A(\omega)$ from $G(\tau)$, one adopts an Ansatz to perform a fit analysis. The most popular Ansatz is the delta function, which is justified as long as the peak is sufficiently narrow. At $T > 0$, even a bound state may acquire a thermal width through the interaction with the heat bath, which can be considered with an advanced Breit-Wigner Ansatz[8]. Although the latter is rigid at low temperature, the shape of the spectral function may become complicated near and beyond T_c. In this case, it may be less trivial to figure out a proper Ansatz. Hence, it is desirable to perform the maximum entropy analysis of the glueball correlator at finite temperature[9], because it provides us with a numerical procedure to reconstruct $A(\omega)$ directly from lattice QCD Monte Carlo results[10, 11].

The glueballs are known to give only negligibly weak contributions to the ordinary plaquette-plaquette correlator. To overcome this, we adopt a spatially extended glueball operator generated by the smearing method with a ρ of suitable size[8]. Note that the smearing method has a shortcoming, that is, it may create an unphysical bump in the spectral function. However, since the actual low-lying glueball is a definite bound state in quenched QCD below T_c, the problem of unphysical bump is not serious. This is because the pole position in the complex ω plane is unaffected by a particular choice of the operators[8].

We reconstruct $A(\omega)$ for the smeared glueball correlator normalized as $G(\tau = 0) = 1$. We adopt the Shannon-Jaynes entropy as

$$S \equiv \int_0^\infty \left[A(\omega) - m(\omega) - A(\omega)\log\left(\frac{A(\omega)}{m(\omega)}\right)\right], \tag{3}$$

where $m(\omega)$ is real and positive, referred to as the default model function. $m(\omega)$ is required to reproduce the asymptotic behavior of $A(\omega)$ as $\omega \to \infty$. We adopt the $O(\alpha_S^0)$ perturbative expression as

$$m(\omega) = N\omega^4 \exp\left\{-(\omega\rho)^2/4\right\}, \tag{4}$$

where the normalization factor N is determined to mimic $G(\tau = 0) = 1$, i.e.,

$$1 = \int_0^\infty d\omega K(\tau = 0, \omega) m(\omega). \tag{5}$$

In Fig.1, we show the reconstructed spectral functions of the lowest 0^{++} glueball at $T = 130, 253$, and 275 MeV. We use 5,500 to 9,900 gauge configurations generated by Wilson action with $\beta_{\rm lat} = 6.25$ and the renormalized anisotropy $\xi \equiv a_s/a_t = 4$. The critical temperature is estimated as $T_c \simeq 280$ MeV from Polyakov loop susceptibility. Since the error bar estimated by following Ref.[11] turns out to be unreasonably small, we do not show it to avoid unnecessary confusion. For a reasonable estimate, the jackknife error estimator should be used. In Fig.1, we see the tendency that the peak becomes broader with increasing temperature below T_c, which is consistent with the Breit-Wigner analysis of the thermal glueball correlator[8].

Acknowledgements: The lattice-QCD Monte Carlo calculations have been performed on NEC-SX5 supercomputer at Osaka University.

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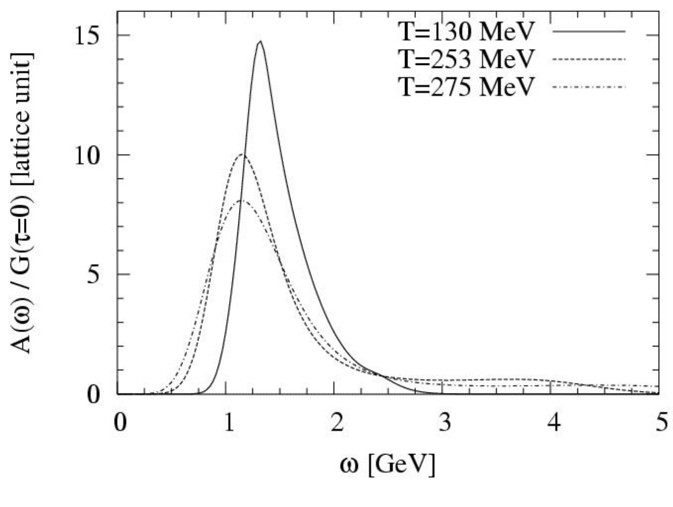

Figure 1: Reconstructed spectral functions of the lowest 0^{++} glueball at $T = 130, 253$, and 275 MeV.