Mapping QGP interaction through its temperature dependent degeneracy factor

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Present work has attempted to map interaction picture of quark gluon plasma (QGP) in terms of its temperature dependent degeneracy factor. From standard statistical mechanical description, entropy density s of massless QGP can be obtained as

$$s = \left[g_g + (g_u + g_s)\left(\frac{7}{8}\right)\right]\frac{4\pi^2}{90}T^3 \approx 20.8\ T^3 \ , \tag{1}$$

which is popularly known as Stephan-Boltzmann (SB) limits. According to lattice Quantum Chromo Dynamics (LQCD) calculation [1, 2], the numerical values of s for QGP

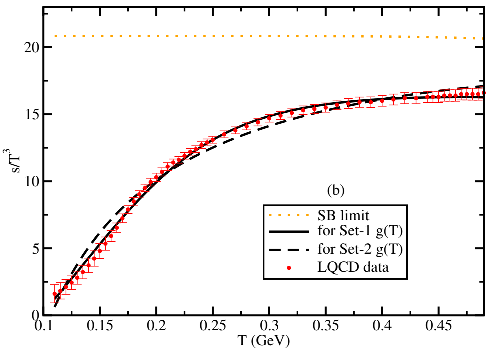

FIG. 1: LQCD data of s/T^3 from Refs. [1, 2] shown by red circles with error bars, straight horizontal (brown) dotted line indicates SB limits of s/T^3. LQCD data has been matched by using two sets of temperature dependent degeneracy factor $g(T)$.

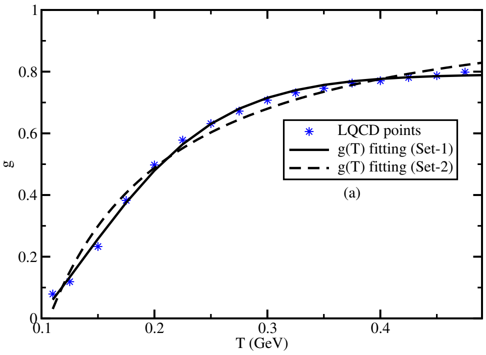

FIG. 2: Temperature dependence degeneracy factors $g(T)$ parametrization curves - Set-1 (solid line), Set-2 (dash line) and LQCD extracted points (stars).

remain always lower than its SB limits. In Fig. (1), red circles present the LQCD data of s/T^3 from Refs. [1, 2] and brown dotted line indicates its SB limit. It is the interaction of the system, for which s is reduced from its SB or non-interaction limit. By assuming appropriate temperature dependent degeneracy factors of quarks and gluons, one can construct LQCD data points for $s(T)$. For this purpose, we have considered a temperature dependent factor $g(T)$, attached with $g_{q,s,g}$ in Eq. (1) and then match the LQCD data of $s(T)$ [1, 2]. We get a parametrized expression:

$$g(T) = a_0 - \frac{a_1}{e^{a_2(T-a_3)} + a_4} \ , \tag{2}$$

where $a_0 = 0.793$, $a_1 = 0.687$, $a_2 = 16.284$, $a_3 = 0.170$, $a_4 = 0.560$. The above set of parameters (say set-1) provide better matching to LQCD data but it is not satisfying the ex-

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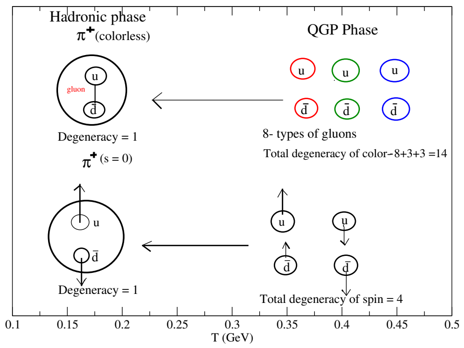

FIG. 3: A schematic diagram shows two phases - QGP and hadronic matter, which carry different number of color (upper part) and spin (lower part) degeneracy factors.

pectation of reaching SB limit of s at $T \to \infty$. To fulfill the condition, we have restricted $a_0 = 1$, and get the another parametrized function:

$$g(T) = 1 - \frac{b_0}{e^{b_1(T-b_2)} + b_3} , \quad (3)$$

where $b_0 = 0.793$, $b_1 = 0.687$, $b_2 = 0.170$, $b_3 = 16.284$, which can be called set-2.

Fig. 2 shows two set of $g(T)$ (dash and solid lines) and LQCD data points (stars) [1, 2]. Their corresponding values of s/T^3 is plotted in Fig. (1). So effectively total degeneracy factor of QGP $g_u+g_s+g_g = 52$ will be suppressed for considering $g(T) * g_{u,s,g}$, and around $T = 0.200$ GeV, $g(T) \approx 0.5$, which means effective degeneracy factor become $0.5 \times 52 = 26$. In hadronic temperature range, around $T \approx 0.120$ GeV, $g(T) \approx 0.13$ will provide effective degeneracy factor $0.13 \times 52 = 7$, which is exactly hadronic degeneracy factor $g_\pi + g_K = 7$. So in this way, we might roughly map QCD interaction picture via shrinking of degeneracy factor of quarks and gluons with lowering the temperature. This fact can be compared with the fact of temperature dependent degree of freedom for di-atomic or n-atomic molecule. At low temperature degrees of freedoms of di-atomic or n-atomic molecules is $3 \times 2 - 1$ or $3 \times n - k$ because of its 1 or k number of atomic bondings, which can be broken at high temperature and degrees of freedom enhanced as

$$3 \times 2 - 1 = 5 \ \to \ 3 \times 2 = 6$$
$$\text{or,}$$
$$3 \times n - k \ \to \ 3 \times n \ . \quad (4)$$

According to equipartition theorem of thermodynamics, internal energy of di-atomic or n-atomic molecular system will be proportional to its degrees of freedom, hence internal energy (other thermodynamical quantities) will also be increased with increasing temperature. To visualize the similar kind of temperature dependence of degeneracy factor for QGP system, we have drawn a schematic diagram in Fig. (3). We have sketched two different number of color degeneracy factors for high T QGP phase and low T hadrinic phase in the upper part of Fig. (3), while same for spin degeneracy factors is drawn in lower part of Fig. (3). In QGP phase, one can identify 8 color gluons, 3 color u and 3 color $\bar{d}$, which can form a color-less π^+ state in low T hadronic phase. This reduction of $8 + 3 + 3 = 14$ color states to one color-less states may be considered one of the possibility however, collective reduction from $g = 52$ at $T \to \infty$ to $g \approx 7$ at $T = 0.120$ GeV is occurring through interaction. Hence, through temperature dependent degeneracy factor, this interaction is attempted to map in present work [3].

References

[1] S. Borsanyi et. al., *Full result for the QCD equation of state with 2+1 flavors*, Phys. Lett. **B 370** (2014) 99, arXiv:1309.5258 [hep-lat].

[2] A. Bazavov et al. *Equation of state in (2+1)-flavor QCD*, Phys. Rev. D 90, 094503 (2014)

[3] S. Satapathy, S. Paul, A. Anand, R. Kumar, S. Ghosh, *From Non-interacting to Interacting Picture of Thermodynamics and Transport Coefficients for Quark Gluon Plasma*, arXiv:1908.04330 [hep-ph]