Fluid property of QGP in presence of magnetic field

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Present work has gone through two parts of investigations. First, it attempts to map interaction of quantum chromo dynamics (QCD) in presence of external magnetic field, described from lattice QCD (LQCD) calculation [2]. Then it explore the fluid property of quark gluon plasma (QGP) in presence of external magnetic field by using the mapped interaction, which depends on temperature T and magnetic field B.

Let us start with quasi-particle expression of entropy density for non-interacting QGP,

$$s = \sum_{i=u,d,s,g} g_i \int_0^\infty \frac{d^3p}{(2\pi)^3} \left(\omega_i + \frac{p^2}{3\omega_i}\right) f_i \ , \qquad (1)$$

where f_i is Fermi-Dirac/Bose-Einstein distribution functions of fermions/bosons (quarks/gluons) and $\omega_i = \sqrt{\vec{p}^2 + m_i^2}$ with $m_{g,u,d,s} = 0,\ 0.005,\ 0.005,\ 0.100$ GeV. The lattice Quantum Chromo Dynamics (LQCD) simulation [2] obtained always lower values of s with respect to Eq. (1), which is approximately $s \approx 20.8\ T^3$, commonly called Stephan-Boltzmann (SB) limit. In this context, we have followed the prescriptions of Chandra and Ravisankar [1], where QCD interaction of quark-hadron phase transition has be mapped via fugacity parameter Z. It has nothing to link with quark or gluon chemical potentials, which are absolutely kept zero. The Z enters in f_i as

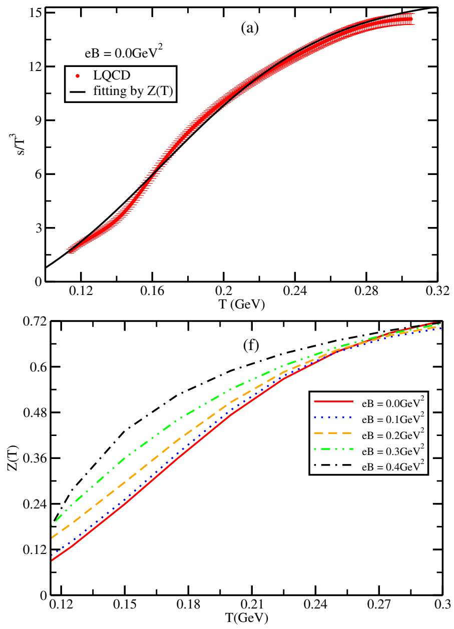

FIG. 1: Fitting curves (black solid line) and LQCD data points (red circles) for normalized entropy density s/T^3 by parameterizing $Z(T)$ at different magnetic field strengths - (a) $eB = 0$, (b) 0.1, (c) 0.2, (d) 0.3 (e) 0.4 GeV^2. Corresponding $Z(T)$ curves are plotted in (b).

$$f_i = \frac{1}{Z^{-1}\exp\left(\beta\omega_i\right) - a_i} \ , \qquad (2)$$

where $a_i = \pm 1$ for fermions/bosons (quarks/gluons) and $Z = 1$, $Z < 1$ represent non-interacting and interacting QGP system respectively. The LQCD data of $s(T)$

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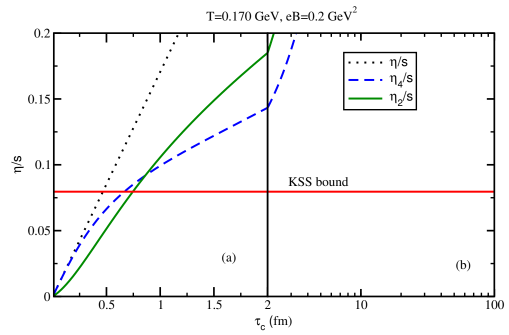

FIG. 2: Collisional relaxation time (τ_c) dependence of shear viscosity to entropy density ratio.

for different eB's are re-drawn red circles in Fig. 1(a). Then, they are fitted (solid black lines) by assuming a temperature dependent fugacity $Z(T)$, which are plotted in Fig. 1(b). So by reducing fugacity with reduction of temperature or/and magnetic field, one can transform a non-interacting to interacting QGP system description and we found a gross $Z(T, B)$ function, which can nicely map the T and B dependent QCD interaction, provided by LQCD [2].

After building the quasi-particle model of interacting QGP in presence of magnetic field, we have estimated normal (η_2) and Hall (η_4) shear viscosity components in presence of magnetic field from the standard relations [4]

$$\eta_{2,4} = \sum_{i=u,d,s,g} \frac{g_i\beta}{15} \int \frac{d^3\vec{p}}{(2\pi)^3} \frac{\vec{p}^4}{\omega_i^2} f_i(1 - a_i f_i) \frac{\tau_c(\tau_c/\tau_B)^{0,1}}{1 + (\frac{\tau_c}{\tau_B})^2} , \quad (3)$$

where $\tau_B = \omega/(eB)$ is appeared as a new time scale due to magnetic field along with the relaxation time τ_c, already existed at $B = 0$. Since gluon g is charge neutral ($e = 0 \Rightarrow \tau_B = \infty$), it will follow without field ($B = 0 \Rightarrow \tau_B = \infty$) expression of η, which can be realized as $\eta = \eta_2(B = 0)$.

Shear viscosity to entropy density ratio measures the fluid nature of the medium. From experimental side, this quantity should be very close to KSS bound $1/(4\pi)$ [3], which is drawn by red solid (horizontal) line in Fig. (2). With the help of Eqs. (3), (1) we have estimated η_2/s (solid line), η_4/s (dash line), $\eta/s = \eta_2(B = 0)/s$ (dotted line), which are plotted against τ_c-axis in Fig. (2). Analyzing Eq. (3), one can recognize $\frac{\eta}{s} \propto \tau_c$ for all quarks and gluons at $B = 0$, while at finite B, u, d, s quarks will acquire anisotropic viscosity components $\frac{\eta_{2,4}}{s} \propto \frac{\tau_c(\tau_c/\tau_B)^{0,1}}{1+(\tau_c/\tau_B)^2}$ but gluon component remain isotropic. Hence, the proportional curve of η/s is slightly bended due to finite B as represented by $\eta_{2,4}/s$ curves. The bending is appeared to be mild as gluon's $\propto \tau_c$ contribution is added with quark's $\propto \frac{\tau_c}{1+(\tau_c/\tau_B)^2}$ contribution. Excluding gluon component, one can see that η_2/s first increases and then decreases with τ_c, where their peak can be seen around $\tau_c \approx \tau_B$. therefore, this η_2/s can cross the KSS line at two times in τ_c-axis. This fact is well explored in Ref. [4]. As normal component η_2 decreases and s increases with B, so η/s decreases more in presence of magnetic field. Hence, Present investigation recognize two sources - magnetic field and interaction, which can push the QGP system towards its nearly perfect fluid nature, quantified by KSS line. A detail investigation on it can be seen in Ref. [5].

References

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