Effects of finite volume on Bulk viscosity from PNJL model

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Introduction

A proper understanding of the properties of the quark-gluon plasma formed in ultra-relativistic heavy-ion collisions requires knowledge of the transport coefficients in order to characterize the expansion of the system [1–3]. Bulk viscosity constitutes a very important part of this characterization. Here, we use a QCD-inspired phenomenological model framework, that of PNJL model [4] to quantify the same. However, finite extent of the fireball formed in heavy-ion collisions necessitates such study to incorporate finte spatial size of the system. This will help us to carve a realistic picture of the system's behavior. In this manuscript, we intend to explore the same in a qualitative manner.

Bulk viscosity

Transport coefficients are connected via the Green-Kubo relation [5, 6] to their respective thermal fluctuation or correlation functions. The coefficient of bulk viscosity, ζ in this regard is expressed as [7],

$$\zeta = \frac{1}{2} \lim_{q_0, \vec{q} \to 0} \frac{\int d^4x e^{iq\cdot x} \langle [\mathcal{P}(x), \mathcal{P}(0)] \rangle_\beta}{q_0} \quad (1)$$

We aim to calculate this transport coefficient of quark matter and to notice its qualitative changes due to the finite size consideration of medium. We use Relaxation Time Approximation (RTA) method for this study.

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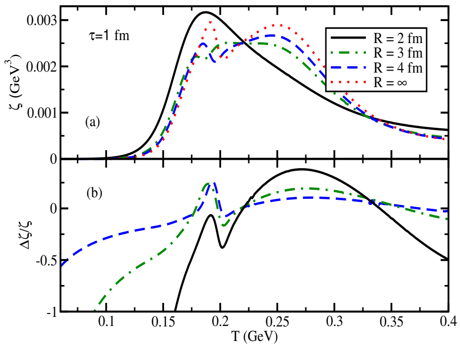

FIG. 1: (a) $\zeta(T)$ for $R = \infty$ (red dotted line), 4 fm (blue dashed line), 3 fm (green dash-dotted line) and 2 fm (black solid line). (b) Difference between finite and infinite matter results for ζ.

Results and discussions

Bulk viscosity ζ, bears special significance because of its relation with conformal symmetry of the system. It contains a conformal breaking term,

$$\left\{ \left(\frac{1}{3} - c_s^2 \right) \vec{k}^2 - c_s^2 \left(M_Q^2 + M_Q T \frac{dM_Q}{dT} \right) \right\}^2 , \quad (2)$$

which vanishes in the limits of $c_s^2 \to 1/3$ and $M_Q \to 0$ [7]. Relating to this fact, our bulk viscosity estimation in PNJL model is trying to measure indirectly the breaking of this conformal symmetric nature of QCD matter in both quark and hadronic domain. In this context, the present investigation has tried to explore the finite system size effect on this breaking of conformal symmetry by studying the R dependence of ζ. For a constant value of relaxation time ($\tau = 1/\Gamma = 1$ fm), we have es-

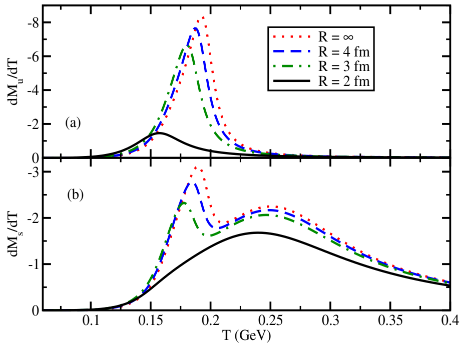

FIG. 2: (a) $\frac{dM_u}{dT}$ and (b) $\frac{dM_s}{dT}$ for for $R = \infty$ (red dotted line), 4 fm (blue dashed line), 3 fm (green dash-dotted line) and 2 fm (black solid line).

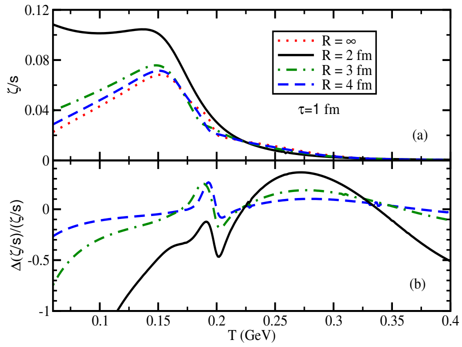

FIG. 3: Same as Fig. (1) for bulk viscosity to entropy density ratio ζ/s.

timated $\zeta(T)$ for different system sizes. The change in ζ is defined as,

$$\frac{\Delta\zeta}{\zeta} = \frac{\zeta(R=\infty) - \zeta(R)}{\zeta(R=\infty)} \,, \qquad (3)$$

The double peak-like structures start diluting as we decrease system sizes and for $R = 2$ fm such nature disappears, indicating some non-trivial contributions from strange sectors [7].

To elucidate, we have to focus on the conformal breaking term, given in Eq. (2) and shown in Fig. (2). We observe that the peak position of $dM_{u,d}/dT$ in Fig. 2(a), which represents the transition temperature (T_c) of chiral phase, shifts towards lower temperature as R decreases. The peak strength of $dM_{u,d}/dT$ also decreases when R decreases. The complex two peak structure comes into picture when we add s quark contribution, which participates partially in chiral phase transition.

Now, normalizing the bulk viscosity by the entropy density, we have plotted ζ/s and $\Delta(\zeta/s)/(\zeta/s)$ for different values of R in Figs. 3(a) and (b) respectively. Though ζ at low temperature limit almost tends to zero but ζ/s at that limit becomes finite because of their comparable magnitudes. Interestingly, the second (mild) peak of ζ almost disappears in ζ/s because $s(T)$ at high T domain is strongly dominant and increases rapidly with respect to $\zeta(T)$. Comparing Figs. 1(b) and 3(b), we notice that the changes of ζ and ζ/s due to finite size are approximately similar.

Summary

The effect of finite size becomes important in terms of conformal symmetry of the system and affects the bulk viscosity. Further study in this direction with quantitative precision is however needed and is in progress.

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