Fluctuations of conserved charges in hadronic matter under rotation

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Introduction

One of the major goals of relativistic heavy-ion collisions is to study the QCD matter at high temperature (T) and low baryon density (μ_B). In such collisions a non-zero value of Λ and $\overline{\Lambda}$ polarization which is translated to large angular velocity or vorticity ($\omega \simeq (9 \pm 1) \times 10^{21} s^{-1}$) has been observed [1]. In addition to the temperature, the baryon chemical potential and the magnetic field (B), the vorticity ω also plays as a relevant parameter to characterize the properties of hot and dense matter formed in heavy-ion collisions [2]. In theory ω could be chosen to be comparable to a typical QCD scale, and it would be a quite inspiring question how the QCD phase diagram evolves with increasing ω. In the present work we perform a robust analysis based on the hadron resonance gas (HRG) model to estimate the different thermodynamic quantities such as pressure, entropy density, susceptibilities and their ratios in rotating frames [3, 4]. The HRG model has manifested eminent successes in reproducing the particle abundances in heavy-ion collision experiments. With global rotation, the pressure is inhomogeneous to be balanced with the centrifugal force, from which we can infer the distribution of the angular momentum and also the moment of inertia of hot and dense matter.

To study the HRG model in rotating systems we need to write the pressure in terms of the cylindrical coordinates, (k_r, ℓ, k_z). The pressure has contributions from both mesons (m) and baryons (b) up to an ultraviolet mass scale, Λ:

$$p(T, \mu, \omega; \Lambda) = \sum_{m;\, M_i \leq \Lambda} p_m + \sum_{b;\, M_b \leq \Lambda} p_b \,, \quad (1)$$

The generalized pressure can be written as

$$p_i^{\pm} = \pm \frac{T}{8\pi^2} \sum_{\ell=-\infty}^{\infty} \int dk_r^2 \int dk_z \sum_{\nu=\ell}^{\ell+2S_i} J_\nu^2(k_r r) \times \log\left\{1 \pm \exp[-(\varepsilon_{\ell,i} - \mu_i)/T]\right\} . \quad (2)$$

The '+' and '-' signs are for baryons and mesons respectively. The energy can be written as $\varepsilon_{\ell,i} = \sqrt{k_r^2 + k_z^2 + m_i^2} - (\ell + S_i)\omega$ with S_i and m_i being the spin and the mass of the particle i. We note that the radial integration is with respect to k_r^2 in the above form; that is, $dk_r^2 = 2k_r dk_r$. The rotation effect shifts the energy dispersion relation by the cranking term, i.e., $-J \cdot \omega$, which varies as $(\ell + s_i)\omega$ from $s_i = -S_i$ to $s_i = +S_i$. To simplify the expression we reorganize the sum over s_i and ℓ so that the energy shift can be the same, $-(\ell + S_i)\omega$, to simplify the expression. Then, the spin sum is translated to the sum with respect to ν with the square of the Bessel function $J_\nu^2(k_r r)$ as in Eq. (2). The Bessel function arises from the weight in the Bessel-Fourier expansion. For $\omega \to 0$ limit, we can recover the standard expression for pressure in ideal HRG model.

The fluctuation of conserved charges, such as, baryon number, strangeness and electric charge, are considered to be very sensitive probes of phase transition in strongly interacting matter. Near the critical end point (CEP), the fluctuations are supposed to be large. Susceptibilities provide the measure of the intrinsic statistical fluctuations in a system close to thermal equilibrium system. The

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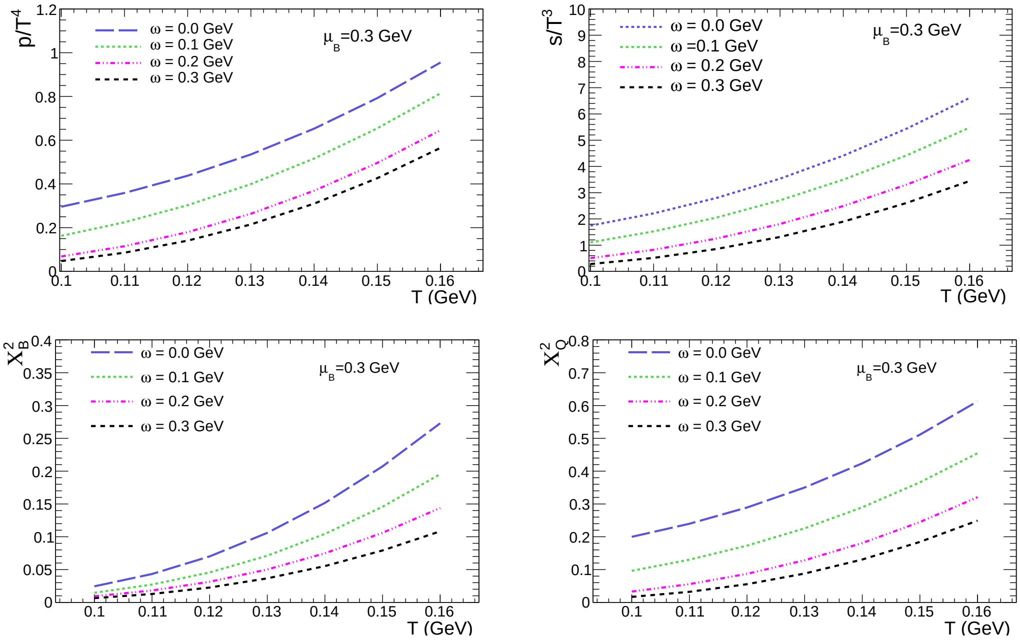

FIG. 1: (upper panel) Thermodynamic variables at μ_B=300 MeV. (left) Pressure, (right) Entropy Density ; (lower panel) Susceptibilities of the hadronic matter estimated using HRG under rotation at different angular velocity ω.

nth-order susceptibility is defined as,

$$\chi_x^n = \frac{1}{VT^3} \frac{\partial^n (\ln Z)}{\partial \left(\frac{\mu_x}{T}\right)^n} \qquad (3)$$

where μ_x is the chemical potential for conserved charge x. In this work we will consider x to be baryon number (B) and electric charge (Q).

Results and discussions

In Fig. 1 (upper panels) we have plotted thermodynamic variables, pressure and entropy density of hadronic matter using HRG model at finite $\mu_B = 300$ MeV, which is close to the CEP value for different values of angular velocity ω. We have also estimated the fluctuation of conserved charges in the presence of rotation which is considered to be an important probe of CEP. Fig. 1, lower panel-left plot shows the baryon number susceptibility of 2nd order (χ_B^2) and lower panel-right plot shows the electric charge susceptibility of 2nd order (χ_Q^2) with temperature estimated with HRG under rotation. It is noted that, at a given temperature, in presence of rotation, susceptibility (χ_B^2 and χ_Q^2) decreases with increasing angular velocity ω and the effect of rotation is found to be quite significant in search of QCD critical point. Combining rotation and magnetic field and study of its effect on phase transition as well as susceptibilities, is under progress.

References

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