Fluctuations along freeze-out in heavy ion collisions in the presence of rotation

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Introduction

The quest to map the phase diagram of QCD matter is facilitated jointly by theory and experiments. Heavy ion collisions at facilities like RHIC and LHC serve to unravel the properties of strongly interacting matter not only under high temperatures (T) and baryon chemical potentials (μ_B), but also for finite rotation, parameterized by angular velocity (ω) specially important in the case of peripheral collisions.

The quark-hadron phase transition is of a crossover type at small values of μ_B as established by lattice QCD but is expected to become first order at higher values of μ_B as predicted by various effective model calculations. Thus the existence of a critical point is likely at the onset of the discontinuous first-order transition.

The critical point's presence would lead to long range correlations and result in big fluctuations in various thermodynamic quantities. These may be accessed from the even-by-event fluctuations analyses of hadron quantum numbers or conserved charges obtained from heavy ion collision data if large critical fluctuations survive in remnant form until the onset of freeze-out [1, 2]. A theoretical baseline for the products of moments of different conserved charge distributions that are accessible experimentally can be computed by exploiting their link to susceptibilities that are amenable to QCD based calculations. This approach will be extended in this article to the situation where rotation exist.

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HRG model including rotation

The Hadron Resonance Gas (HRG) model [3], in which the QCD is modelled as a non-interacting gas of hadrons, has been extensively used alongside ab initio lattice QCD treatments and both are found to be mutually consistent in their overlap region of validity. In the currently studied scenario, a parallel global rotation have been incorporated in standard HRG model and the free energy density expression $f_i^{B/M}$ for baryons and mesons, given by [4]

$$f_i^{B/M} = \mp \frac{T}{8\pi^2} \sum_{l=-\infty}^{\infty} \int dk_r^2 \int dk_z \sum_{\nu=l}^{l+2S_i} J_\nu^2(k_r r) \ln(1 \pm e^{-(E_i-\mu_i)/T}),$$

in which the energy spectrum is just offset by an effective chemical potential term induced by the rotation:

$$E_i = \sqrt{k_r^2 + k_z^2 + m_i^2} - (l + S_i)\omega. \quad (1)$$

Susceptibilities and correlations can be calculated by taking derivatives of the pressure $p = -f$ in the following way [5]

$$\chi_{xy}^{jk} = \frac{\partial^{j+k}(\Sigma_i p_i/T^4)}{\partial(\mu_x/T)^j \partial(\mu_y/T)^k}, \quad (2)$$

and their ratios yield the products of moments, for example, $S\sigma = \chi^{(3)}/\chi^{(2)}$ and $\kappa\sigma^2 = \chi^{(4)}/\chi^{(2)}$, where σ, S and κ are the standard deviation, skewness and kurtosis respectively. The link between the experimentally measurable moments and the theoretically calculable susceptibilities is established and it is to be utilized to provide the baseline prediction from our modified HRG model.

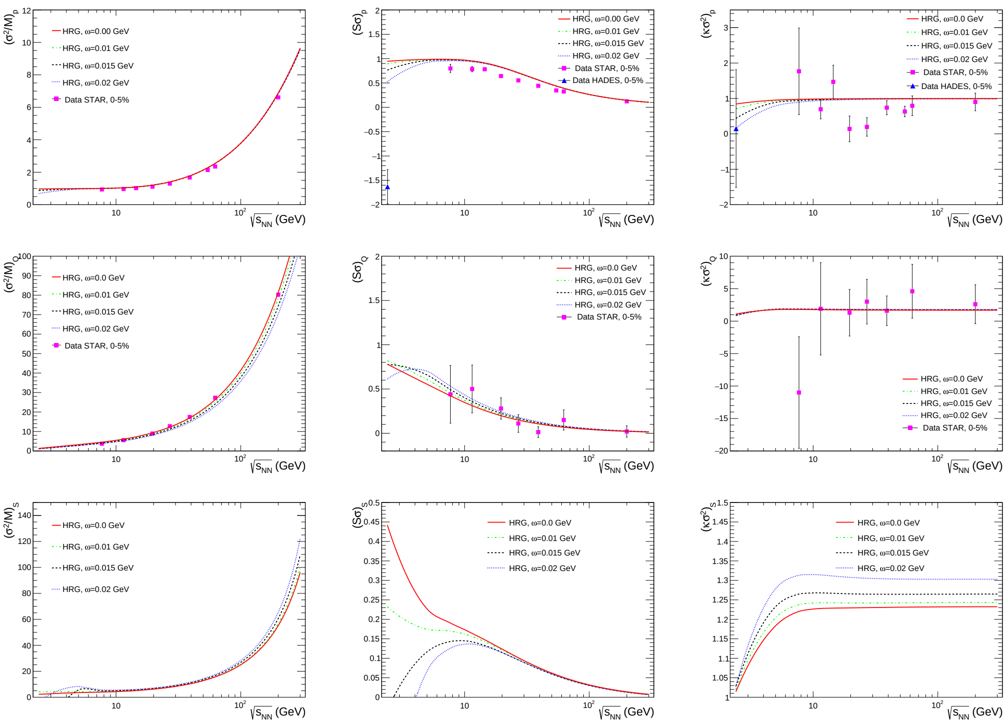

FIG. 1: Products of moments of net-proton, net-charge and net-kaon as functions of the centre-of-mass energy for different angular velocity ω.

Results and Discussion

The products of the moments of conserved charges relevant for our system are plotted in Figure 1 to show their beam energy dependence. The general trend of all the quantities plotted seem to obey the expected behaviour as reported elsewhere. The variations caused due to the inclusion of rotation are shown in the adjoining figure. For central collisions multiplicities of identified hadrons can be well fitted for certain parametrizations of T and μ's with $\sqrt{s}$ and this has been obtained from the literature to qualitatively check for the effects of finite rotation on net proton, charge and strangeness distributions. Since the corresponding parametrization with rotational influence is not directly available as the data is limited exclusively to central collisions, we here juxtapose the data points only for an approximate reference instead of a direct comparison with peripheral collisions data. The latter may be used in the future for a more direct comparison.

References

[1] Friman et al. Eur. Phys. J. C71, 1694 (2011).
[2] Garg et al., Phys. Lett. B 726, 691 (2013).
[3] P. Braun-Munzinger et al., Phys. Lett. B 344, 43 (1995).
[4] Fujimoto et al. Phys. Lett. B 816 (2021) 136184.
[5] Bhattacharyya et al., EPL 115, 62003 (2016).