Susceptibilities of conserved quantities in relativistic heavy-ion collisions at RHIC

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Introduction

The major motivations of heavy-ion collisions at ultra-relativistic energies is to study the formation of new form of matter, called quark-gluon plasma (QGP) and study its basic properties. Susceptibilities of conserved quantities, such as electric charge, baryon number and strangeness are sensitive to the onset of quantum chromodynamics (QCD) phase transition, and provide information on the mater produce in heavy ion collisions. In this work, we have used the Ultra-relativistic Quantum Molecular Dynamics (UrQMD) and the hadron resonance gas (HRG) models to analyize the 2nd order susceptibilities of conserved charges. In experiments, one needs to understand and correct for detector acceptance, efficiency and limited particle identification in order to interpret the results and compare with theoritical calculations. The transverse momentum cutoff dependence of suitably normalized susceptibilities are proposed as useful observables to probe the properties of the nedium at freezout.

Observables and Formalism

The susceptibilities of the conserved quantities of the strongly interacting matter in thermal and chemical equilibrium can be computed within the grand canonical ensemble (GCE) from partial derivatives of pressure (P) with respect to the chemical potentials,

$$\chi^{ijk}_{BQS} = \frac{\partial^{i+j+k}((\frac{T}{V}\ln Z)/T^4)}{\partial^i(\mu_B/T)\partial^j(\mu_Q/T)\partial^k(\mu_S/T)} \quad (1)$$

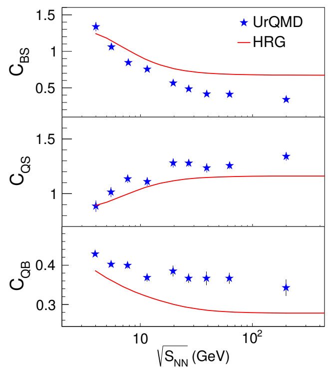

FIG. 1: Beam energy dependence of ratios C_{XY} for central (0-5%) Au+Au collisions using UrQMD and HRG models.

HRG model includes all hadrons and resonances from the Particle Data Book, the partition function (Z) is written as:

$$\begin{aligned}\ln\ Z &= \sum_i \ln Z_i \\ &= VT^3 \sum_i \frac{g_i}{2\pi^2}\left(\frac{m_i}{T}\right)^2 \sum_{l=1}^{\infty}(-a)^{l+1}\, l^{-2} \\ &\quad K_2\left(lm_i/T\right)\exp[l\left(B_i\mu_B + Q_i\mu_Q + S_i\mu_S\right)/T].\end{aligned} \quad (2)$$

From experimental point of view it is strightforward to compute these susceptibilities from differnt order central moments of conserned quantities:

$$\chi^{11}_{XY} = \frac{1}{VT^3}\mathrm{M}^{11}_{\mathrm{XY}}. \quad (3)$$

Using this relations, the ratio (C_{XY}) between diaginal to offdiagonal susceptibilits [1] which expected to sensitive at phase transition are presented as a function of beam energy.

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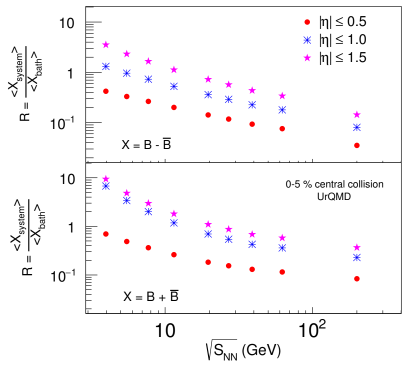

FIG. 2: The ratios of net baryon (top panel) and total baryon (bottom panel) numbers within the system to the bath for central Au+Au collisions are plotted as a function of collision energy.

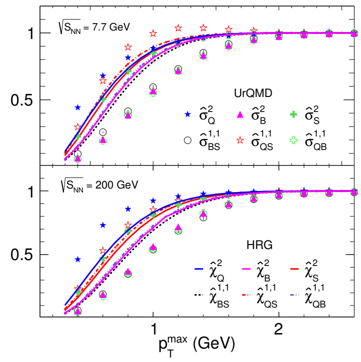

FIG. 3: The $p_{T\,\mathrm{max}}$ dependence of all second order susceptibilities normalised by their values for $p_{T\,\mathrm{max}}$ value and $\eta_{\mathrm{max}} = 0.5$ for central Au+Au collisions.

Results

The results [2] of C_{QB}, C_{QS} and C_{BS} as a function of collision energy are shown in Fig. 1. Ideally, in order to observe grand canonical fluctuations, the ratio $\mathcal{R}$ of the total conserved charge carried by the system to that by the bath should be much smaller than unity ($\mathcal{R} << 1$). On the other hand, for large enough acceptance it is possible that the system size becomes comparable with that of the bath giving rise to non-thermal fluctuations due to global charge conservation. Another factor that adds to the above complication is the fact that baryon stopping is not constant across $\sqrt{s_{NN}}$, resulting in completely different distributions of conserved charges in η for different $\sqrt{s_{NN}}$, as demonstrated n Fig. 2. We find that for high $\sqrt{s_{NN}}$, $\mathcal{R}$ is signifacantly less than unity but for lower energies it does not holds. Thus, a fixed η window across all beam energies does not corresponds to same system to bath effective volume ratio for all $\sqrt{s_{NN}}$ [3].

Acceptance dependence on p_T window has been studied by studying the normalised 2^{nd} order susceptibilities by their value at highest p_T, as shown in Fig 3. It is interesting to observed a clear conserved charge ordering in these normalised susceptibilities. In HRG setup, it is easy to understand that such mass ordering arises masses of hadrons that contribute to the different susceptibilities.

Summary

(1) We have studied the ratio of 2nd order diagonal to off-diagonal susceptibilities as a function of $\sqrt{s_{NN}}$, corresponding to FAIR and RHIC energies.
(2) $|\eta_{\mathrm{max}}| \leq 1$ acceptance is studied for study grand canonical fluctuations for all $\sqrt{s_{NN}} >$ 10 GeV.
(3) Suitably normalised susceptibilities show a conserved charge ordering in the p_T acceptance in HRG as well as in UrQMD. An experimental observation of such ordering will confirm the presence of the hadronic medium at the time of freeze-out of the susceptibilities.

Acknowledgments

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References

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