Correlations of conserved number mixed susceptibilities in a hadron resonance gas model

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Introduction

In recent years, beam energy scan (BES) program carried out at Relativistic Heavy-Ion Collider (RHIC) has drawn much attention with an aim to explore the quantum chromodynamics (QCD) phase diagram at non-zero temperature (T) and baryon chemical potential (μ_B). One of the key observable is related to the event-by-event distribution of conserved charge numbers. It has been suggested that, the ratio of strange to non-strange susceptibilities calculated in lattice QCD can give insight about Quark Gluon Plasma (QGP) phase [1]. The correlation between baryon number (B) and electric charge (Q) (χ_{BQ}) shows a variation with the temperature which are correlated with the changes in relevant degrees of freedom. Similarly correlations of baryons with strangeness (χ_{BS}) and electric charge with strangeness (χ_{QS}) are sensitive to the strangeness degrees of freedom of the system. Hence, observables such as χ_{QS}, χ_{BQ} and χ_{BS} give information about the QCD phase structure [1, 2].

Further, combinations of diagonal and off-diagonal quark number susceptibilities can be used to obtain the fluctuations of conserved charges. Diagonal susceptibilities measure the quark number density to changes in T and μ_B. The off-diagonal susceptibilities in turn can be used to explore the degree of correlation between different charge and baryon numbers that carry different flavors. Higher moments of the distributions are related to the higher power of ξ which makes them more sensitive to CEP effects. Specifically it has been recently suggested to look for mixed pion-proton cumulants as a signature for CEP [3]. The paper suggests to construct five specific mixed pion-proton cumulants from which when non-CEP contributions are subtracted will yield a value of unity if the system experiences critical phenomena. These ratios are claimed to provide strong evidence needed for the discovery of the QCD critical point.

The partition function (Z) in the HRG model include all the degrees of freedom of confined, strongly interacting matter and implicitly contains all the interactions that result in resonance formation. The thermodynamic pressure (P) can be written in the limit of large volume as:

$$P(T,\mu_i,V) = \frac{T}{V} lnZ_i$$
$$= \pm\frac{Tg_i}{2\pi^2}\int d^3k \ln\left\{1 \pm e^{(\mu_i - E)/T}\right\}$$

where m is the mass of the particle with p_T, η and ϕ as the transverse momentum, pseudorapidity and azimuthal angle,respectively. The mixed susceptibilities of the correlated conserved charges can be obtained by taking the derivative of the pressure with respect to different chemical potentials for conserved quantities X and Y,

$$\chi_{xy}^{(n,m)} = \frac{d^{n+m}[P(T,\mu)/T^4]}{d(\mu_x/T)^n d(\mu_y/T)^m} \quad (1)$$

where m and n correspond to the different order of derivatives, x and y are baryon–electric charge, baryon–strangeness or electric charge–strangeness mixed indices and X, Y are combinations of either B, Q or S.

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Results and discussion

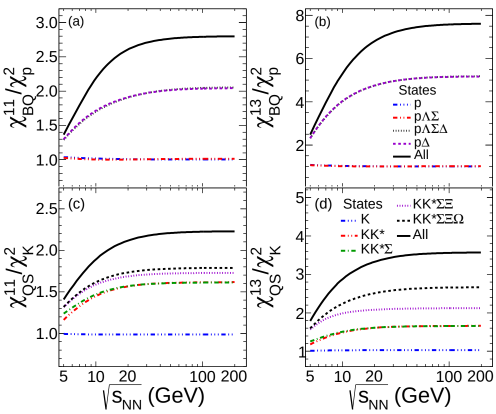

FIG. 1: The variation of $\chi^{11,13}_{BQ}/\chi^2_p$ and $\chi^{11,13}_{QS}/\chi^2_K$ as a function of $\sqrt{s_{NN}}$ within $0.2 \leq p_T$ GeV/$c \leq 2.0$ and $|\eta| \leq 0.5$.

Figure 1 shows the variation of χ^{11}_{BQ}/χ^2_p, χ^{13}_{BQ}/χ^2_p, χ^{11}_{QS}/χ^2_K and χ^{13}_{QS}/χ^2_K ratios as a function of $\sqrt{s_{NN}}$ for various charge states. In case of baryon charge correlations (χ_{BQ}) only charged baryons (anti-baryons) contribute, starting from proton to higher mass charged baryons. For each of the cases, the χ_{BQ} are compared with the inclusion of higher charge states. There is significant difference in χ^{11}_{BQ}/χ^2_p and χ^{13}_{BQ}/χ^2_p after inclusion of higher charge states like Δ^{++}. Baryons with higher electric charge number contribute to the increase of baryon charge correlations and only charged strange particles contribute to the strange electric charge correlations (χ_{QS}). There is a strong dependence of χ^{11}_{QS}/χ^2_K and χ^{13}_{QS}/χ^2_K on the inclusion of higher order strange charged states.

As proposed in [3], we have considered different cumulant ratios of protons and pions as: $(\kappa_{3p}\kappa^{3/2}_{2\pi})/(\kappa_{3\pi}\kappa^{3/2}_{2p})$, $(\kappa_{4p}\kappa^2_{2\pi})/(\kappa_{4\pi}\kappa^2_{2p})$, $(\kappa^3_{4p}\kappa^4_{3\pi})/(\kappa^3_{4\pi}\kappa^4_{3p})$, $\kappa^2_{2p2\pi}/(\kappa_{4\pi}\kappa_{4p})$ and $\kappa^3_{2p1\pi}/(\kappa^2_{3p}\kappa_{3\pi})$. Where, κ_{nx} are the cumulants of different order with $n = 1, 2, 3, 4$ and x being the proton or pion. Figure 2 shows the first three ratios, defined above, as a function $\sqrt{s_{NN}}$, which can be considered as baseline instead of Poisson contribution as baseline.

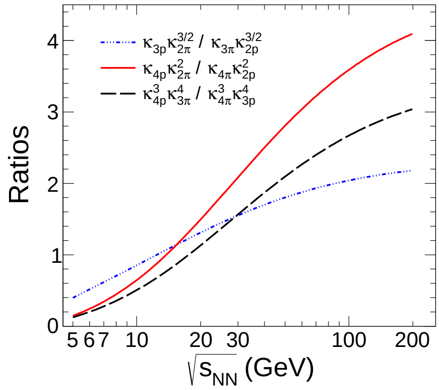

FIG. 2: Various cumulant ratios of proton and pion as a functions

Summary

We have studied the effect of experimental acceptance on the ratios of the mixed susceptibilities using a hadron resonance gas model. We have considered χ^{11}_{BQ}/χ^2_B, χ^{11}_{BQ}/χ^2_Q, χ^{11}_{QS}/χ^2_Q and χ^{11}_{QS}/χ^2_S ratios, which have contributions from charged baryons (anti-baryons) or charged strange particles. We have also provided a HRG based calculation of realistic baseline (non-CEP expectation) for a set of new observables recently proposed for critical fluctuations using the different combinations of cumulant ratios of protons and pions. The results presented in this paper will provide the required baseline for the corresponding measurements in the experiments.

References

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