Effect of kinematic acceptance on conserved number fluctuations

P. Garg[1],* D. K. Mishra[2], P. K. Netrakanti[2],
A. K. Mohanty[2], B. Mohanty[3], and B. K. Singh[1]
[1] *Department of Physics, Banaras Hindu University, Varanasi-221005, INDIAN*
[2] *Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA and*
[3] *School of Physical Sciences, National Institute of Science Education and Research, Bhubaneswar 751005, INDIA*

Introduction

Studying the moments of distribution for conserved quantities like net-baryon, net-charge and net-strangeness number for systems undergoing strong interactions as in high energy heavy-ion collisions, have recently provided rich physics insights. The product of moments of the conserved number distributions are measured experimentally and can be linked to susceptibilities (χ) computed in Quantum Chromodynamic (QCD) based calculations as, $S\sigma = \chi^{(3)}/\chi^{(2)}$ and $\kappa\sigma^2 = \chi^{(4)}/\chi^{(2)}$, where σ, S and κ are the standard deviation, skewness and kurtosis, respectively of the measured conserved number distribution, $\chi^{(n)}$ are the n^{th} order theoretically calculated susceptibilities associated with these conserved numbers[3]. Such a connection between theory and heavy-ion collision experiment has led to furthering our understanding about the freeze-out conditions, details of the quark-hadron transition and plays a crucial role for the search of possible QCD critical point in the QCD phase diagram. Computing these quantities within the framework of a hadron resonance gas (HRG) model [2] provides such a reference for both experimental data and QCD based calculations. The experimental measurements have limitations due to the finite kinematic acceptance and can detect only certain species of the produced particles. In the present work, we demonstrate the effect of the above experimental limitations on the physics observables $\chi^{(3)}/\chi^{(2)}$ and $\chi^{(4)}/\chi^{(2)}$ using HRG model [1].

*Electronic address: prakhar@rcf.rhic.bnl.gov

In grand canonical ensemble framework, the n^{th} order generalized susceptibility can be expressed as

$$\chi_x^{(n)} = \frac{X^n}{VT^3}\int d^3p \sum_{k=0}^{\infty} (\pm 1)^k (k+1)^n \quad (1)$$
$$exp\left\{\frac{-(k+1)E}{T}\right\} exp\left\{\frac{(k+1)\mu}{T}\right\},$$

where + and − are for meson and baryon, respectively, T is the temperature, V is the volume of the system and μ is the chemical potential of a particle. The factor X represents either B, Q or S of the i^{th} particle depending on whether the computed χ_x represents baryon or electric charge or strangeness susceptibility. The volume element (d^3p) and energy (E) can be written as $d^3p = p_T m_T \cosh\eta dp_T d\eta d\phi$ and $E = m_T \cosh\eta$, where $m_T = \sqrt{p_T^2 + m^2}$, here η, p_T and ϕ represents the rapidity, transverse momenta and azimuthal angle of a particle, respectively. The experimental acceptances can be incorporated by considering the appropriate integration ranges in η, p_T, ϕ and charge states by considering the values of $|X|$. The total generalized susceptibilities will then be the sum of the contribution from baryons and mesons as, $\chi_x^{(n)} = \sum \chi_{x,baryon}^{(n)} + \sum \chi_{x,meson}^{(n)}$.

Results and Discussions

Figure 1 shows the variation of $\chi_x^{(3)}/\chi_x^{(2)}$ and $\chi_x^{(4)}/\chi_x^{(2)}$ as a function of $\sqrt{s_{\rm NN}}$ for various p_T acceptances. It is observed that $\chi_x^{(3)}/\chi_x^{(2)}$ and $\chi_x^{(4)}/\chi_x^{(2)}$ have a clear p_T acceptance dependence at all beam energies for net-charge (Fig. 1 (c) and (d)) and net-strangeness (Fig. 1

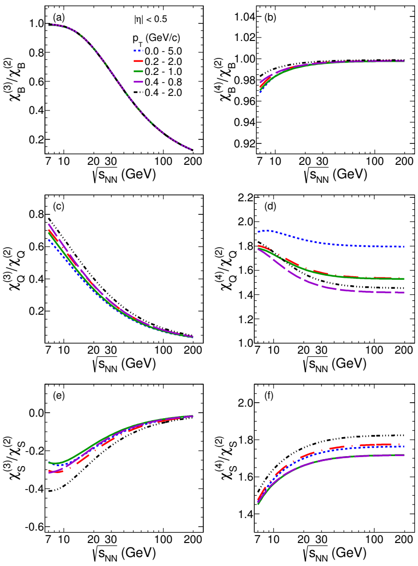

FIG. 1: (Color online) The p_T acceptance dependence of $\chi_x^{(3)}/\chi_x^{(2)}$ and $\chi_x^{(4)}/\chi_x^{(2)}$ for different $\sqrt{s_{\rm NN}}$. Where x stands for either B, Q and S.

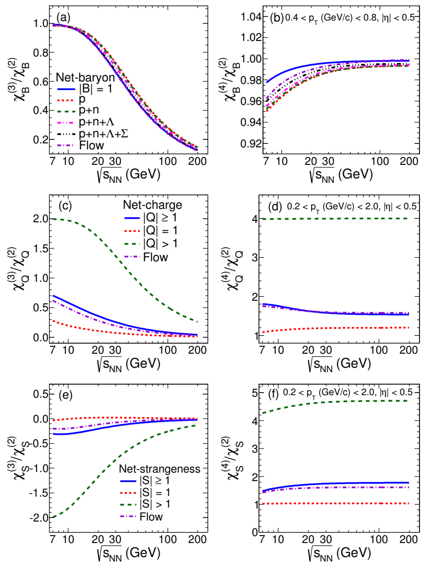

FIG. 2: (Color online) The variation of $\chi_x^{(3)}/\chi_x^{(2)}$ and $\chi_x^{(4)}/\chi_x^{(2)}$, where x stands for B, Q and S as a function of $\sqrt{s_{\rm NN}}$.

(e) and (f)). However the p_T acceptance dependences for net-baryon (Fig. 1 (a) and (b)) is substantially weaker. Hence the p_T acceptance study also emphasizes the need to consider the actual experimental acceptance for model comparisons in fluctuation measures.

Figure 2 shows the variation of $\chi_x^{(3)}/\chi_x^{(2)}$ and $\chi_x^{(4)}/\chi_x^{(2)}$ as a function of $\sqrt{s_{\rm NN}}$ for various types of baryons (Fig. 2 (a) and (b)), values of electric charge states, $|Q| = 1$ and $|Q| > 1$ (Fig. 2 (c) and (d)), and values of strangeness number, $|S| = 1$ and $|S| > 1$ (Fig. 2 (e) and (f)). We find a strong dependence on the $\chi_Q^{(3)}/\chi_Q^{(2)}$ and $\chi_Q^{(4)}/\chi_Q^{(2)}$ on charge state ($|Q| =$ 1 or $|Q| > 1$), both differing from the case of inclusion of all charge states. Same is the situation for net-strangeness. Figure 2 also shows the effect of flow (longitudinal + transverse) on the ratios of susceptibilities as a function of collision energy [4].

In summary, we have studied the importance of considering experimental acceptances of different kinds on observables like n^{th} order susceptibilities $\chi_x^{(n)}$, associated with conserved quantities using HRG model. It is important to consider these effects before experimental measurements are compared to theoretical calculations. We observe finite kinematic acceptances in η and p_T have a strong effect on the $\chi_Q^{(n)}$ and $\chi_S^{(n)}$ values and on their charge states too. However, the effect of flow is small on the ratios of susceptibilities and the improvements can be done by using the radial dependent transverse flow velocities. We find that the dependence on acceptance and resonance decays are stronger for both net-charge and net-strangeness compared to that of net-baryons.

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