Total charge fluctuation in heavy ion collision

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Introduction

Event-by-event fluctuations of positive, negative, total and net charge produced in relativistic nuclear collisions have been of interest to explore phase transition and/or a critical end point (CEP) which is believed to exist somewhere between the hadronic phase and the quark-gluon phase of the QCD phase diagram. The entropy is closely related to the particle multiplicity, and it is expected to be approximately conserved during the evolution of the matter created at the early stage. The entropy fluctuations are not directly observed but can be inferred from the experimentally measured quantities. The final state mean multiplicity is proportional to the entropy of the initial state ($\langle N\rangle \sim S$). The particle multiplicity can be measured on an event-by-event basis, whereas the entropy is defined by averaging the particle multiplicities in the ensemble of events. Thus, the dynamical entropy fluctuations can be measured experimentally by measuring the fluctuations in the mean multiplicity.

For a thermal system formed in heavy ion collisions, the grand canonical ensemble (GCE) is the most appropriate description as only a part of the system around mid-rapidity is measured by experiments. The fluctuations of the energy ($\langle E\rangle$) are identical between CE and GCE, but fluctuations of particles which carry the conserved charge are affected. Since in GCE, the energy and conserved numbers may be exchanged with the rest of the system, therefore, the energy and the conserved numbers may fluctuate. These fluctuations give the properties of the system for example susceptibility is calculated by conserved number fluctuations whereas fluctuations of energy reveals the heat capacity of the system. The CE has been used to describes the system formed in $p + p(\bar{p})$ and $e^+ + e^-$ systems where the particle production is small. This needs to ensure that the quantum number is conserved explicitly in each event. For a system, consists of particles and their corresponding anti-particles, the grand canonical partition function in the Boltzmann approximation can be written as [1]: $Z_{gce}(V,T,\mu) = \prod_j \exp\left(\lambda_{j+}z_j + \lambda_{j-}z_j\right) = \exp\left[2z\cosh\left(\frac{\mu}{T}\right)\right]$ where, $\lambda_{j\pm} = \exp(\pm\mu_j/T)$ correspond the fugacity of j^{th} particle with chemical potential μ_i. The $+ve$ and $-ve$ signs correspond to the particle and anti particle, respectively. $z \equiv \sum_j z_j$ is the single particle partition function. In canonical ensemble, the particles are not allowed to exchange with the system's surrounding, the fugacity is strictly zero which leads to charge conservation constraint $\langle Q\rangle = \langle N_+\rangle - \langle N_-\rangle = 0$ and the partitions function reads as follows: $Z_{ce}(V,T) = I_0(2z)$, where $I_0(2z)$ is the modified Bessel function. Further, the CE partition function can be modified for an explicit charge conservation constrain, i.e. $\sum_j (N_{j+} - N_{j-}) = Q$, for each microscopic state of the system. Using the above partition functions one can derive the other thermodynamic properties of the system after freeze-out.

Results and discussion

Figure 1, shows the ratios of cumulants for total charge multiplicity for different values of partition function (z) in both CE and GCE. The C_2/C_1 calculated in GCE and CE becomes equivalent in the thermodynamic limit (i.e. $z \to \infty$), it is constructive to look for the ratios of higher order fluctuation in two different ensembles. In GCE, the total charge multiplicities are strictly Poissionian, as the

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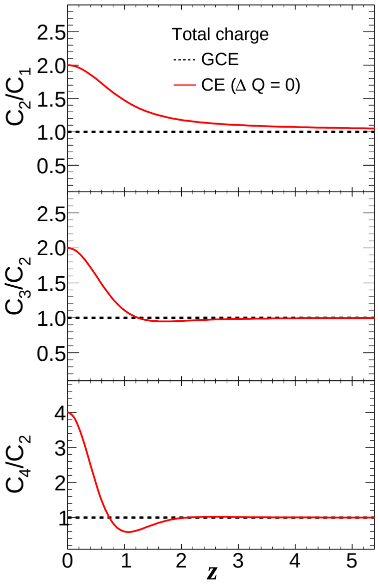

FIG. 1: (Color online) The z dependence of the ratio of cumulants C_2/C_1, C_3/C_2 and C_4/C_2 for total electric charge in GCE (dotted line) and CE (red line) for $\Delta Q = 0$.

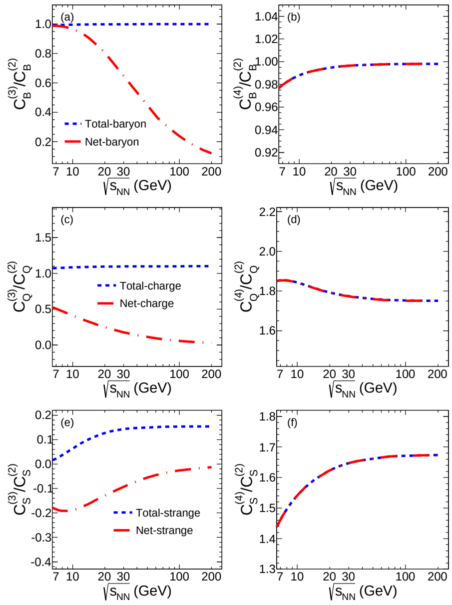

FIG. 2: (Color online) The energy $\sqrt{s_{\rm NN}}$ dependence of $C_x^{(3)}/C_x^{(2)}$ and $C_x^{(4)}/C_x^{(2)}$ ratios for total (dashed) and net (dashed-dotted). Where x stands for either B, Q, and S.

ratios are unity for all z values, while it is not true in case of CE. It can be seen from Fig.1 that C_3/C_2 and C_4/C_2 ratios in CE also approach to GCE values for higher z. The ratios of higher cumulants approach to corresponding GCE values faster than the lower order ratio (C_2/C_1).

Figure 2 shows the C_3/C_2 and C_4/C_2 ratios as a function of $\sqrt{s_{NN}}$ for total charge and net charge. In case of net charge, C_3/C_2 strongly depends on collision energies, whereas for total baryon and total charge, C_3/C_2 ratios for are almost same at all energies. For C_4/C_2, both total charge and net charge are exactly same as a function of $\sqrt{s_{NN}}$ [2]. In case of odd cumulants the apparent difference is because of the contribution from correlation.

In summary, we have calculated the higher order cumulants and their ratios for total baryon, charge and strangeness multiplicity in canonical and grand canonical ensembles. Comparing the ratios of cumulants in CE and GCE for total charge suggests noticeable difference for lower z values. When the number of conserved quanta is small, an explicit treatment of these conserved charges is required, which leads to a canonical description of the system and the fluctuations are significantly different from the grand canonical ensemble. Significant differences are observed for C_3/C_2 ratios as a function of collision energies for the net charge and total charge cases, while C_4/C_2 ratios are same in both the cases. We argue that it would be constructive to look for the fluctuations of total charge distributions measured experimentally for different energies and can be compared with the thermal baseline as discussed in the present work to look for the non-monotonic behavior.

References

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