Centrality dependence of cumulants of net-charge distributions at FAIR energy

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One of the main objectives of the Compressed Baryonic Matter (CBM) experiment scheduled to be held at the Facility for Anti-proton and Ion Research (FAIR), is to investigate the properties of an extended QCD matter at high baryo-chemical potential and at moderate/low temperature [1]. It would be worthwhile to examine how the known observables behave as indicators of phase transition in a baryon rich environment expected at FAIR energies. One observable that can be related to such transition, is the event-to-event (e-to-e) fluctuations of conserved quantities like net-charge, net-baryon number and net-strangenes. The fluctuation measure of such variables are found to be sensitive to the critical point in the QCD phase diagram. Different moments of the distributions of these conserved quantities, can be connected to the thermodynamic susceptibility and to the correlation length of the matter constituting the intermediate 'fireball' created in high-energy heavy-ion collisions [2]. In this paper we report a simulation study on the centrality dependence of the moments of net-proton (ΔN_p) and net-kaon (ΔN_k) numbers and net-charge ($\Delta N_{\rm ch}$) distributions by using Au+Au collision data at $E_{lab} = 30A$ GeV generated by the UrQMD code [3]. The cumulants (C_q) of a variable N are defined as

$$C_1 = \langle N \rangle\,,\ C_2 = \left\langle (\delta N)^2 \right\rangle,\ C_3 = \left\langle (\delta N)^3 \right\rangle,$$
$$C_4 = \left\langle (\delta N)^4 \right\rangle - 3\left(\left\langle (\delta N)^2 \right\rangle\right)^2 \tag{1}$$

where $\delta N = N - \langle N \rangle$ denotes the deviation of N from its mean value $\langle N \rangle$. The first four moments of any distribution namely the mean (M), the variance (σ^2), the skewness (S) and the kurtosis (κ) are expressed in terms of C_q,

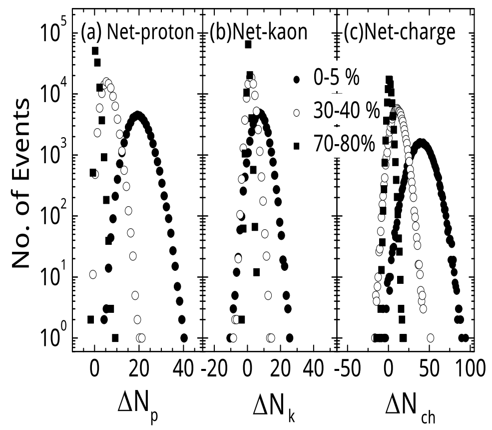

FIG. 1: ΔN_p, ΔN_k & $\Delta N_{\rm ch}$ distributions at three different centralities at midrapidity.

$$M = C_1,\quad \sigma^2 = C_2,$$
$$S = \frac{C_3}{(C_2)^3/2},\ \kappa = \frac{C_4}{(C_2)^2} \tag{2}$$

The products of these moments expressed in terms of the cumulant ratios as,

$$S\,\sigma = \frac{C_3}{C_2},\quad \kappa\,\sigma^2 = \frac{C_4}{C_2} \tag{3}$$

are directly related to the susceptibility ratios, whose variation with centrality and/or particle/energy density can serve the purpose of an indicator to phase transition.

The rapidity (pseudorapidity) and transverse momentum cuts employed in this analysis are same as those of the STAR experiment [4]. In Fig.1 we have plotted the distributions of ΔN_p, ΔN_k and $\Delta N_{\rm ch}$ at three different centrality bins in the midrapidity region. The distributions are not corrected for finite centrality bin width. However, in the subsequent

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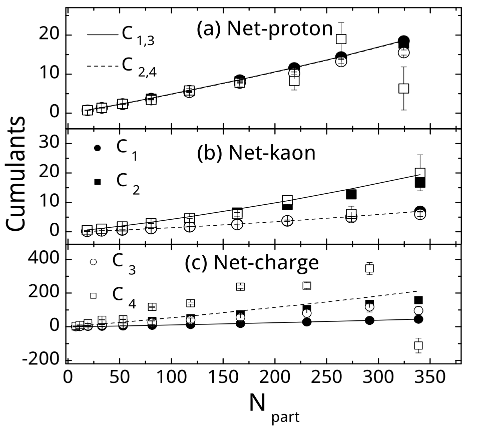

FIG. 2: Various cumulants plotted against N_{part}. Continuous curves represent corresponding Poisson expectations.

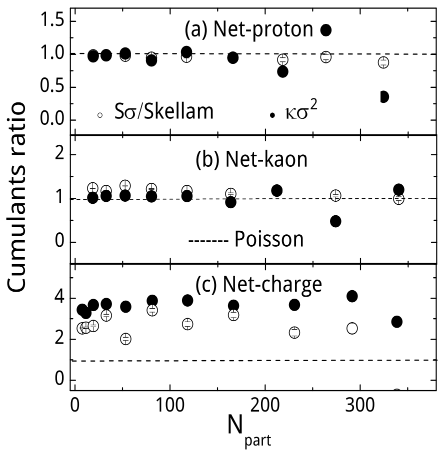

FIG. 3: Cumulant ratios ($S\sigma/(skellam)$ and $\kappa\sigma^2$) plotted against N_{part}.

analysis the C_q and other moments are corrected for finite centrality bin and for autocorrelation effect [2]. The statistical uncertainties are calculated by using the Delta theorem [5]. We observe that the mean value and the width of the ΔN_p and ΔN_k distributions are much larger in central collisions than in the peripheral collisions. Unlike at RHIC energies, the mean value of ΔN_p distribution is quite large at FAIR energy, where the proton number is dominated by baryon stopping in the mid-rapidity region, and the yield of antiproton is quite low. But the same is not true for the ΔN_k distributions, as along with K^+ a good number of K^- are also produced. In order to examine the centrality dependence of the distributions, in Fig.2 we have plotted the variation of C_q as a function of N_{part}. In general we observe a more or less linear trend for all C_q. For protons and kaons the odd (even) order C_q values are grouped together, which is not the case for all charged particles. The separation between these two groups is more prominent in ΔN_k distribution. In comparison with ΔN_p and ΔN_k the absolute values of C_q are quite high for ΔN_{ch}. For a better understanding of the issues we have also incorporated the expectation of the Poisson distribution, which represents an independent emission of particles. To cancel out the volume effect we have plotted the centrality dependence of different C_q ratios/moment-products in Fig.3. The Skellam (Poisson) baseline is calculated from the mean values of particle and antiparticle distributions. The UrQMD simulation results are more or less consistent with the STAR data [6]. For ΔN_{ch} we observe large C_q ratios that are not compatible to Poisson distribution. In summary, we have explored some preliminary results on centrality dependence of C_q of different orders for ΔN_p, ΔN_k and ΔN_{ch} distributions generated by the UrQMD code. At $E_{lab} = 30A$ GeV the results do not require the augmentation of any exotic state. A more involved analysis of other aspects of net charge fluctuation with a much better statistics is perhaps required for this purpose.

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