Cumulant ratios of conserved charges in the UrQMD model

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The Compressed baryonic Matter (CBM) experiment to be held at the Facility for Antiproton and Ion Research (FAIR) is designed to study the physics of dense baryonic matter under extreme thermodynamic conditions [1]. Arguably the simulation study of observables such as the fluctuation measure of conserved quantities like net charge, net baryon and net strangeness will add an extra dimension to the future endeavor to characterize the baryon rich environment. It is found that cumulants of various order and their ratios are directly proportional to the thermodynamic susceptibilities and correlation length of the "fireballs" produced in high-energy nucleus-nucleus (AB) collisions. It has previously been seen that the multiplicity distribution (MD) of charged hadrons can be more suitably described by a negative binomial distribution (NBD) than a Poisson distribution (PD) [2]. In this paper we report a simulation study of the cumulant ratios of the MD of conserved quantities and compare the results with the notional prediction of NBD and PD. Out of a million minimum bias Au+Au events generated at $E_{\rm lab} = 40A$ GeV ($\sqrt{s_{NN}} = 8.77$ GeV) by using the UrQMD code [3], only 0-10% central events are chosen for our analysis. The analysis is performed within the proposed pseudorapidity range ($1.5 \leqslant \eta \leqslant 3.8$) of the CBM detector set up [4]. The statistical uncertainties are calculated by using the Delta theorem [5]. In the subsequent analysis the results are modified for the auto-correlation effect [6]. The first few cumulants $C_{n,N}$ of the distribution of a variable N are defined as,

$$C_{1,N} = \langle N \rangle, \quad C_{2,N} = \left\langle (\delta N)^2 \right\rangle,$$
$$C_{3,N} = \left\langle (\delta N)^3 \right\rangle,$$
$$C_{4,N} = \left\langle (\delta N)^4 \right\rangle - 3\left(\left\langle (\delta N)^2 \right\rangle\right)^2 \qquad (1)$$

Once we have the definition of cumulants, moments of the distribution like the mean value (M), variance (σ^2), skewness (S) and kurtosis

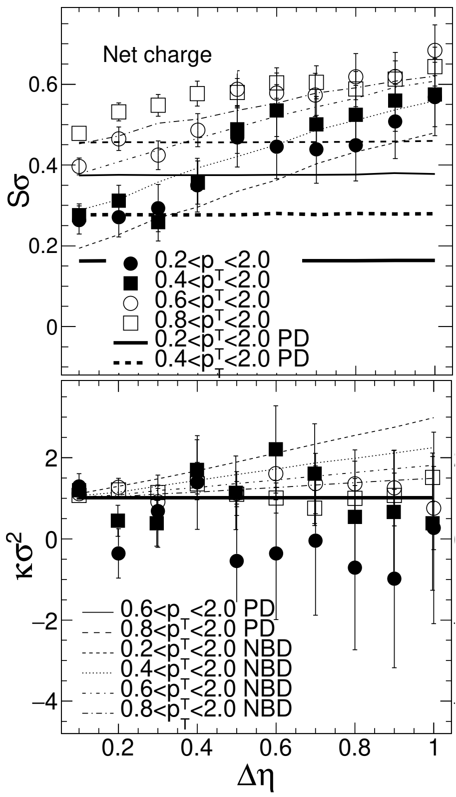

FIG. 1: $\Delta\eta$ dependence of the cumulant ratios of net charge distribution (0-10% centrality).

(κ) are obtained as

$$M = C_{1,N}, \quad \sigma^2 = C_{2,N},$$
$$S = \frac{C_{3,N}}{\left(C_{2,N}\right)^3/2}, \quad \kappa = \frac{C_{4,N}}{\left(C_{2,N}\right)^2} \qquad (2)$$

We use $\delta N = N - \langle N \rangle$ to denote the deviation of N from its mean value $\langle N \rangle$. The cumulant ratios are then constructed to eliminate the trivial volume dependence of the cumulants,

$$S\sigma = \frac{C_{3,N}}{C_{2,N}}, \quad \kappa\sigma^2 = \frac{C_{4,N}}{C_{2,N}} \qquad (3)$$

In FIG.1 we plot the volume independent cumulant ratios for the net-charge distribution as a function of $\Delta\eta$ at different p_T intervals. Corresponding NBD (clan structure)

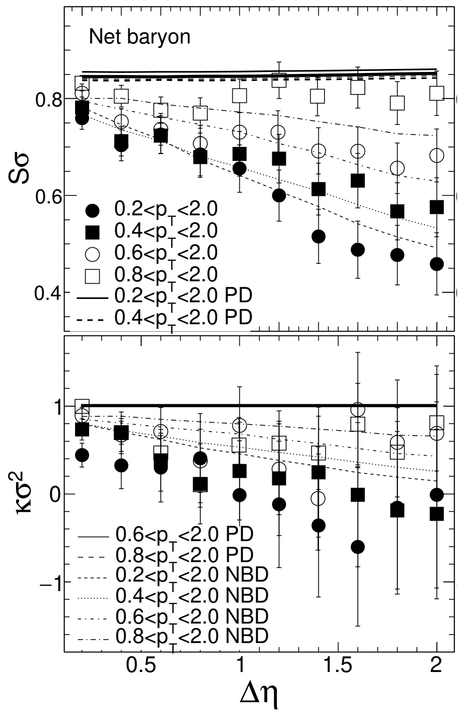

FIG. 2: $\Delta\eta$ dependence of the cumulant ratios of net baryon distribution (0-10% centrality).

and PD (independent emission) predictions are included. The $S\sigma$ values gradually increase with $\Delta\eta$, while the $\kappa\sigma^2$ values, often associated with large statistical errors, fluctuate around $\kappa\sigma^2 = 1$. In FIG.2 the $S\sigma$ and $\kappa\sigma^2$ values are plotted against $\Delta\eta$ for the net baryon number distribution. At FAIR energy the antibaryon yield is quite low and the baryon production is largely influenced by nuclear stopping. With increasing $\Delta\eta$ a decreasing trend in the $S\sigma$ and $\kappa\sigma^2$ values is observed. For both $S\sigma$ and $\kappa\sigma^2$ NBD appears to be a better approximation than the Poisson baseline. In FIG.3 we have plotted $S\sigma$ and $\kappa\sigma^2$ for the net strangeness distribution. While $S\sigma$ shows an increasing trend with increasing $\Delta\eta$, the $\kappa\sigma^2$ values once again fluctuate around $\kappa\sigma^2 = 1$. Deviations from both NBD and PD expectations are observed at large $\Delta\eta$. It is believed that the global charge conservation principle plays an important role that influences the evolution of the cumulants in the η-space. In some cases the acceptance dependence of the C_n ratios is better described by the NBD, which indicates the presence of a clan/cluster structure of particle production. However, no specific indication of any exotic state can be conjectured from the UrQMD results presented in this analysis. To set a reference baseline for the real experiment a more detailed treatment of the simulated data with a larger statistics is perhaps what is needed.

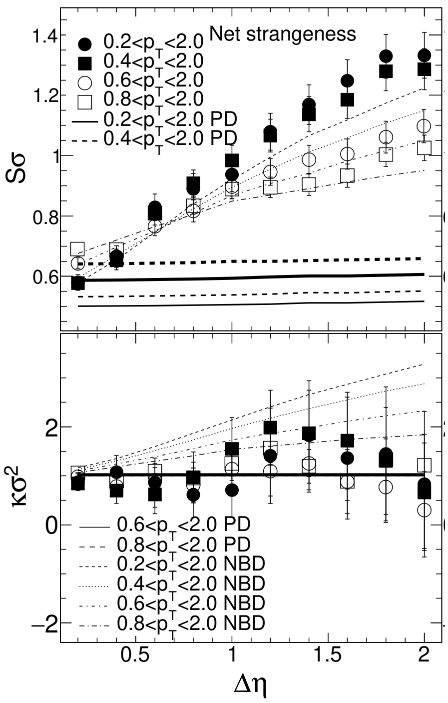

FIG. 3: $\Delta\eta$ dependence of the cumulant ratios of net strangeness distribution (0-10% centrality).

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