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Fluctuation Evolution in Heavy Ion Collisions at FAIR energy

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Event by event fluctuations of particle multiplicities and of their ratios are considered to be sensitive probes to the exotic phenomena in high energy heavy ion collisions like phase transition or the critical point. A phenomenon of interest might take place at a particular time as per the fulfillment of the required conditions and the observables sensitive to the fluctuations will therefore be non-monotonic at that particular time. Experimentally, fluctuations however are measured only at freeze-out. In this work, using the hybrid version of the UrQMD event generator, we have investigated the propagation of event by event fluctuations of the ratio of particle multiplicities, their ratios and of the ratio of total positive and negative charges in Au+Au collisions at $E_{lab} \leq 90$ AGeV. A commonly used experimental measure ν_{dyn} has been used in this analysis. The hybrid model, i.e., UrQMD with hydrodynamic evolution has been used to study the effect of hydrodynamic evolution on this conventional fluctuation measure. It is observed that the fluctuations as measured by ν_{dyn} get diluted considerably during the evolution till freeze-out. The dominant structures present at the initial stage of evolution get smoothen out. The hydro version of the model with two types of equation of state shows higher fluctuation at lower collision energy as compared to the pure hadronic transport version of the model. The time evolution of the higher order moments of net-proton distributions in a specified coverage showed similar dilution with time.

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1. Introduction

The exploration of the Quantum ChromoDynamics (QCD) phase diagram of strongly interacting matter is a major field of modern high-energy physics. Of particular interest is the transition from hadrons to partonic degrees of freedom which is expected to occur at high temperatures or high baryon densities. These phases play an important role in the early universe and in the core of neutron stars. Heavy ion collisions are used to create new form of matter at high energy/baryonic densities depending upon the incident beam energy. At FAIR energies (10 - 45 AGeV) matter at high baryonic density and moderate temperature is expected to be created. CBM (Compressed Baryonic Matter) experiment at FAIR will search for the critical point, the first order deconfinement phase transition from the hadronic matter to the partonic matter and the equation-of-state of dense baryonic matter.

Observables like fluctuations of conserved quantities (baryon number, electric charge and strangeness) are generally considered to be sensitive indicators of the phase transition and more important to the critical point[1]. Higher moments of distributions of conserved quantities, which measure the deviations from a Gaussian, are argued to have a sensitivity to critical point (CP) fluctuations due to a stronger dependence on correlation length (ξ) [4, 5].

Conserved quantities and their fluctuations are measured at freeze-out by the experiments. For heavy-ion collisions at relatively lower energy, likely to be accessible at FAIR, extreme density region created in the collision might result in large fluctuations of specific quantities as the density also fluctuates event by event. It will be useful to study the propagation of these fluctuations in terms of their survival at freeze-out.

A high density matter undergoing a transition to a partonic state at the highest net-baryon density might undergo rescattering to reach equilibration at a later time. The signal like fluctuation of specific quantities might then undergo evolution to reach the freeze-out stage via equilibration. The main aim of this work is to study this effect.

2. Methodology

We have used UrQMD3.3 version to study the space-time evolution of the fluctuations in Au-Au collisions at Lab energies ranging from 10 GeV/A to 90 GeV/A. The model includes transportation of various degrees of freedom (e.g. baryons and mesons) and the production of new particles via fragmentation of strings made of valence quarks of the original colliding hadrons [7, 8]. In this work, we have studied the evolution of fluctuations at time bins of 0.5 fm/c starting from the time of collision up to 30 fm/c, and the effect of hydrodynamical evolution using 'hadron gas' equation of state. 8 million pure UrQMD transport model events have been used while 0.25 million events in hybrid mode at each energy. Particles of all p_T and in the pseudo-rapidity region of $\pm$ 1 around mid-rapidity have been selected. Particles are said to be finally frozen out and streams freely to the detector at 100 fm/c after the start of the collision. In this model, no explicit implementations have been made for chemical or thermal equilibrium.

For various ratio fluctuation studies, we have used a variable known as ν_{dyn}, that is being used extensively in data analysis which is free from trivial effects like statistical, volume fluctuation and largely independent of the detector acceptance and efficiency. The ν_{dyn} representing dynamical fluctuations, for K/π ratio is written as:

$$\nu_{dyn,K/\pi} = \frac{<N_k(N_k-1)>}{<N_k>^2} + \frac{<N_\pi(N_\pi-1)>}{<N_\pi>^2} - 2\frac{<N_K N_\pi>}{<N_K><N_\pi>} \tag{2.1}$$

where N_K and N_π are the event-wise number of kaons and pions in a given acceptance, respectively. Similar formula can be constructed for Q^+/Q^-.

3. Time Evolution

Fig. 1 (left panel) shows the time evolution of the net-baryon density at three different incident energies. The flat top varies with the incident energy being longer-lived at lower energy. The density reaches a value up to 10 times the nuclear matter density suitable for a transition to a non-hadronic state.

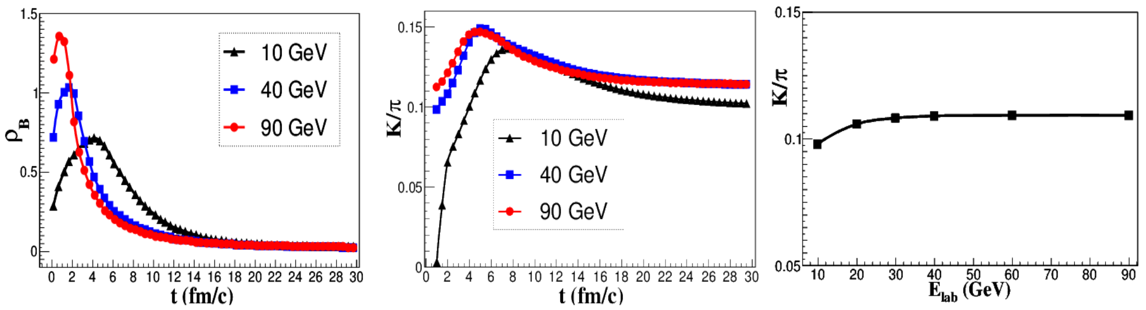

Figure 1: Evolution of baryon density (left panel) and kaon to pion ratio (middle panel) with time elapsed after collision. Beam energy dependence of the ratio of kaon and pion multiplicities at freeze-out (right panel)

As expected from the time required for two nuclei to pass each other, the peak density is achieved faster at higher beam energy. It will therefore be very interesting to study the variation of ratio of kaons and pions and its fluctuation. The individual particle multiplicities show peak struc-

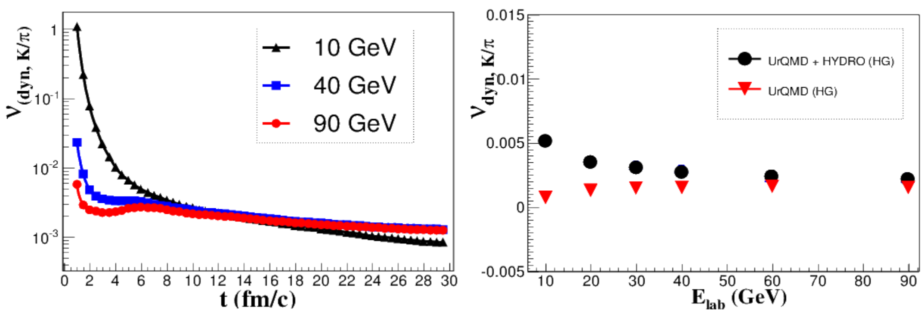

Figure 2: Time evolution of ν_{dyn} of K/π at different collision energies (left panel). Beam energy dependence of ν_{dyn} for K/π with pure transport and with hydro evolution(right panel)

tures at around the highest net-baryon density for koans and pions, the time of complete overlap of two nuclei and subsequently rises towards the finally detected multiplicity. The ratio of total multiplicities of kaon and pion shows a peak around the overlap region saturating at later times as seen in Fig 1 (middle panel). In Fig. 1 (right panel) shows the energy dependence of K/π at freeze-out. The time dependence of the fluctuation measure of the ratios i.e. ν_{dyn} are shown in Fig. 2 (left panel) and Fig. 3 (left panel). As the ν_{dyn} for K/π essentially represents the fluctuation in strangeness production, higher fluctuation at lower beam energy represents the fact that the multiple interaction, the prominent mechanism of production of strangeness at lower energy also leads to larger fluctuations. For the case of Q^+/Q^-, the initial charge conservation have been the cause of the correlated production of oppositely charged particles leading to a negative ν_{dyn} and then the correlation term reduces with the production of more charged particles and it reaches a value close to zero. We have calculated ν_{dyn} with and without hydrodynamic expansion using 'hadron gas'

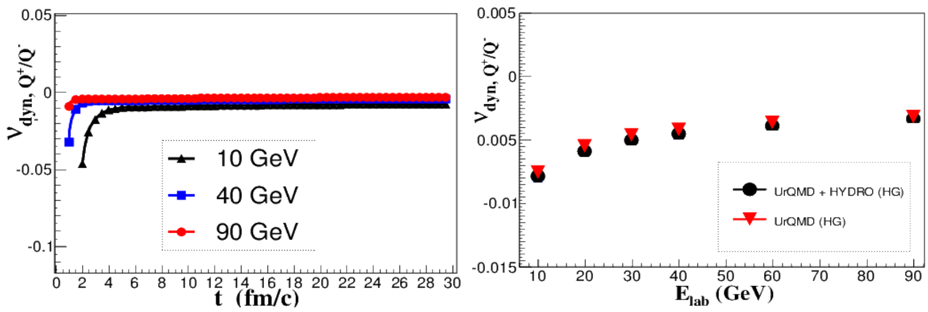

Figure 3: Time evolution of ν_{dyn} of $Q+/Q-$ at different collision energies (left panel). Beam energy dependence of ν_{dyn} for $Q+/Q-$ with pure transport and with hydro evolution (right panel)

equation of state. It is seen from figure 2 (right panel) that at lower collision energies, fluctuation in K/π ratio after hydro expansion is higher as compared to the pure transport results. Whereas, there is almost no effect of hydrodynamic expansion on fluctuation in Q^+/Q^- ratio as shown in figure 3 (right panel).

Recently at RHIC, measurements have been done of the products of moments like $k\sigma^2$ and $S\sigma$ of net-proton multiplicity distributions and results have been compared with the lattice QCD. Near the Critical Point, susceptibilities are expected to diverge, causing these two observables to have non-monotonic variations with N_{part} and/or $\sqrt{S_{NN}}$. For the same study, we extracted the time evolution of the net-proton fluctuation in terms of observables which represent the susceptibilities i.e., Kσ^2 and Sσ, where K, S and σ^2 represent kurtosis, skewness and variance of the distributions. Here we have taken the same coverage and kinematic cuts as that of STAR published results [6], i.e. pseudo-rapidity of 0.5 around mid-rapidity and p_T in the range of 0.4 - 0.8 (GeV/c), for the comparison of the results at freeze-out. It has been shown that these combinations of variables could be compared directly with the lattice simulation results.

Fig. 4 (left panel) and Fig. 5 (left panel) shows the time evolution of Sσ and Kσ^2 for net proton respectively. It is seen that $S\sigma$ is nearly flat with time except initially where it shows structure more prominent at higher energies which then grows to smooth value. Kσ^2 however reduces from higher values with time. It is interesting that the initial energy dependence in Kσ^2 gets washed out at 30 fm/c. Like other fluctuation measures, these two observables as measured at freeze-out is a result of significant dilution. In the study of fluctuation, we look for break from monotonous behavior of the fluctuation measures. It is evident from the present study that the values measured at freeze-out does not contain the structures which might have been present during the evolution. Fig. 4 (right panel) and Fig. 5 (right panel) shows that there is no non-monotonous dependence, as expected from pure transport model without phase transition, with E_{lab} at FAIR-energy when calculated

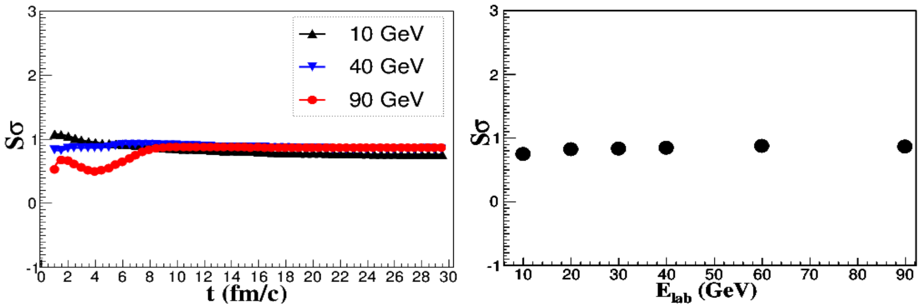

Figure 4: (a) Time evolution of Sσ, and (b) Kσ^2 for net-proton at different collision energies

within the same coverage as of STAR. Even though the energy dependence at detection looks flat, there were structures present at the beginning of the collision.

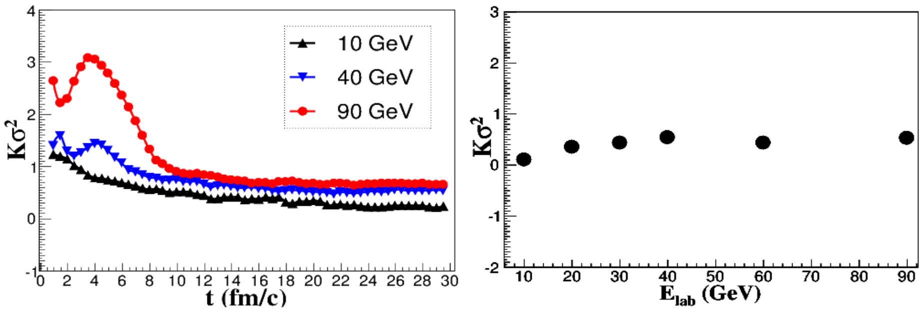

Figure 5: (a) Beam energy dependence of Sσ, and (b) Kσ^2 for net-proton at freeze-out

4. Conclusion

In conclusion we have seen from the transport models that the net baryon density reaches maximum for a short time during the overlap of two nuclei introducing higher fluctuation which gets washes out at freeze-out. Fluctuation reduction is comparatively smaller at lower energies in case of hydrodynamical expansion which makes the measurement at FAIR energies more interesting.

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