Understanding medium formation in small systems using heat capacity at the Large Hadron Collider Energies

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1. Introduction

One of the major goals of relativistic heavy ion collisions (RHIC) is to create and characterize Quark-Gluon Plasma (QGP). The characterization of QGP is done by interpreting experimental results using theoretical models e.g., hydrodynamic modelling. The fact that the hydrodynamic modelling of RHIC can explain the nature of momentum space anisotropy of produced particles - is taken as exclusive proof of formation of locally thermalised partonic medium in RHIC. So, it is important to understand how partons of a local region start behaving collectively. Many conclusion regarding QGP is drawn from experimental results, with $p + p$ collisions (assuming that such partonic medium is not formed) as reference. But recently it is observed that small systems formed in high multiplicity $p+p$ collisions show signatures which are observed in heavy ion collisions. The present work is motivated to understand the nature of possible formation of a thermalized medium in small system using heat capacity (C_V). It is the amount of heat energy required to raise the temperature of the system by one unit. It can be measured experimentally by measuring the energy supplied to the system and resultant change in temperature. It gives the measure of how change in temperature changes the entropy of a system ($\Delta S = \int \frac{C_V}{T} dT$). The change in entropy is a good observable for studying the phase transition. In the context of heavy ion collisions, it can be connected to the rapidity (y) distribution ($\frac{dN}{dy} \approx \frac{dS}{dy}$). So, the C_V acts as bridging observables for experimental measurements and theoretical models, where change in entropy can be estimated.

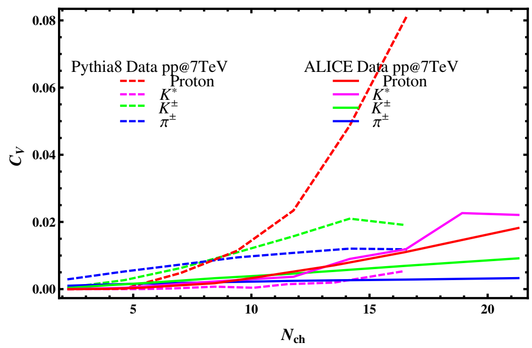

FIG. 1: (Color online) Heat capacity obtained using TB distribution as a function of mid-rapidity multiplicity density for $p+p$ collisions at $\sqrt{s} = 7$ TeV using ALICE data and PYTHIA8 [1].

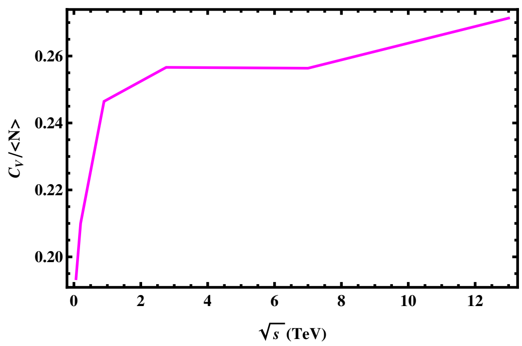

FIG. 2: (Color online) Heat capacity scaled with mean number of particles in the system as a function of collision energy for $p+p$ collisions [1].

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2. Formalism and Results

C_V for a system with vanishing baryonic chemical potential can be written as:

$$C_V = \left(\frac{\partial \epsilon}{\partial T}\right)_V, \quad (1)$$

where V and T stand for volume and temperature respectively.

Tsallis-Boltzmann (TB) distribution function can be used to describe the p_T spectra of identified particles produced in $p+p$ collisions and extract thermodynamical parameters, like T and q (it is a measure of degree of deviation from equilibrium) of the system at the decoupling point. Using T and q extracted from [2], C_V is calculated by using following relation.

$$C_V = \frac{qg}{2\pi^2 T^2}\int_0^\infty dp\ p^2(p^2+m^2) \times [1 + \frac{(q-1)\sqrt{(}p^2+m^2)}{T}]^{\frac{1-2q}{q-1}}, \quad (2)$$

Detailed calculation can be found in our recent paper [1]. From Fig. 1, it is evident that the lighter particles like $\pi^\pm$ and $K^\pm$ tend to show proportionality trends ($C_V \approx \langle N \rangle$), however, the heavier particles like $K^{*0} + \overline{K^{*0}}$ and $p + \overline{p}$ show deviation from above proportionality behaviour. This may be due to the fact that heavier particles decouple from the system earlier in the course of thermalization, whereas, lighter particles may have enough time to interact among themselves before leaving the system, resulting in the onset of their thermal behaviour. Fig. 2 shows $C_V/ < N >$ of charged particles obtained from ALICE data as a function of $\sqrt{s}$. It is observed that $C_V/ < N >$ increases sharply upto $\sqrt{s} = 1.5$ TeV beyond which it increases slowly.

3. Summary

We make the following conclusion based on the present study:

- We have studied how the randomization in QCD matter changes with number of constituents by studying the variation of heat capacity with charged particle multiplicity. It is found that for $N_{ch} > (4-6)$ (mid-rapidity charged particle density), heat capacity saturates for all identified hadrons.

- The importance of multiplicity $N_{ch} > (4-6)$ regarding the question of medium formation in small systems is further prominent in the variation of C_V with collision energies. This may suggest that number of sea quarks and gluons along with valence quarks within the volume of size of proton, which are needed to form the mid-rapidity charged hadron density of (4-6) is sufficient to form a collective medium governed by QCD. The details of the results could be found in Ref. [1].

Acknowledgments

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References

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