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Scaling properties of charged particles generated in Xe-Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV using the AMPT model

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At the critical point a system undergoing phase transition is characterized by large fluctuations in the observables. Fluctuations study is thus one of the important techniques to explore phases of the QCD matter and to search for the critical end point of hadron-quark or quark-hadron phase boundary. Scaling properties of the multiplicity fluctuations of charged hadrons produced in the high energy heavy ion collisions may reveal the features of quark-hadron phase transition and also the particle production mechanism. Scaling exponent obtained from the normalized factorial moments of the number of charged hadrons in the two dimensional (η, ϕ) phase space can quantitatively characterize the system created in these collisions. Within the framework of Ginzburg-Landau (GL) formalism for second order phase transition and for the two-dimensional Ising model simulated for quark-hadron phase transition a universal value of scaling exponent (ν) is obtained as 1.316 ± 0.012. Here we will present observations and results from the analysis performed for the charged particle multiplicity distributions obtained from Xe-Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV with the string melting mode of the AMPT model. Observations, results on the scaling behaviour of the normalized factorial moments and the dependence of the scaling exponent on the transverse momentum bin width will be presented.

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1. Introduction

The main purpose of study of the high energy heavy-ion collisions is to understand the Quantum Chromodynamics (QCD) phase transition diagram and the critical point search. In such interactions, under the conditions of high temperature and energy density, conditions similar to those which existed within a few microseconds just after the Big-Bang could be achieved [1]. Lattice QCD calculations provide a quantitative predictions at $\mu_B = 0$ and find that the transition is a rapid crossover [2]. According to the theoretical considerations deconfinement transition at low temperature T and high baryonic chemical potential μ_B is believed to be of the first order. Thus a critical end point (CEP) is supposed to exist at the end of the first-order transition. However, there exists a sign problem at finite μ_B region in the lattice QCD calculations and large statistical uncertainties in the experimental measurements [3]. So it is difficult both theoritically as well as experimentally to determine the exact location of the CP. At critical point the correlation length of the system diverges (known as Critical opalescence) which results in an increase in density fluctuations of multiplicity distribution of the produced particles [4]. This increase of the density fluctuations at the critical point of QCD phase diagram makes the study of fluctuation more intresting and challenging [5]. The most efficient way to address fluctuations of a system created in a heavy ion collision is to study the fluctuation on event-by-event (E-by-E) basis [6]. The objective of this work is to analyze the generated central Xe-Xe collision event at $\sqrt{s_{\rm NN}}$ = 5.44 TeV using the A Multi-Phase Transport (AMPT) model with String Meting (SM) mode by studying the Normalised Factorial Moments (NFM) as function of decreasing phase space bin size.

2. Methodology

In analogy to the turbulence in fluid, the multilicity fluctuations study in the decreasing phase space bins, reffered as Intermittency is studied in multiparticle production in heavy-ion collisions [7]. In this work we study the scaling behaviour of charged particles spacial distributions in angular phase space distribution using normalised factorial moments (NFM) as proposed in [8]. The (η, ϕ) phase space is divided into a square lattice with $M_\eta \times M_\phi$ bins, where M_η and M_ϕ being the number of bins along η and ϕ respectively. Charged particles generated in the selected η, ϕ and p_T cuts are mapped onto the (η, ϕ) matrix [9]. The formula used for calculating the normalized factorial moments F_q as function of number of bins is defined as,

$$F_q^e(M) = \frac{\frac{1}{N}\sum_{e=1}^{M}\frac{1}{M}\sum_{i=1}^{M} f_q(n_{ie})}{(\frac{1}{N}\sum_{e=1}^{M}\frac{1}{M}\sum_{i=1}^{M} f_1(n_{ie}))^q}. \tag{1}$$

where q is the order of the moment, positive integer ≥ 2 and $n_{ie} \geq$ q is the bin multiplicity. If the system exhibits fluctuations, the Normalised Factorial Moment $F_q(M)$ follow a scaling behaviour

$$F_q(M) \propto M^{\phi_q}. \tag{2}$$

refferred to as *intermittency*. Here ϕ_q is called the intermittency index that characterizes the strength of the intermittency behavior. Eq.(2) is referred here as *M-scaling*. Even if the scaling behaviour in Eq.(2) is not satisfied, to a high degree of accuracy, $F_q(M)$ satisfies the power law behaviour as:

$$F_q(M) \propto F_2(M)^{\beta_q}, \tag{3}$$

such that

$$\beta = (q-1)^{\nu} \tag{4}$$

The Scaling behaviour in Eq.(3) is referred here as *F-scaling* [10]. This behavior has been experimentally verified for optical systems at the threshold of lasing. $\nu = 1.304$ as per GL theory formalism for second order phase transition.

3. A brief introduction of AMPT

A MultiPhase Transport (AMPT) model is a hybrid model based on both the initial partonic and the final hadronic phase. The AMPT model is constructed to describe nuclear collisions with center-of-mass energy ranging from about $\sqrt{s_{NN}}$ = 5 GeV up to 5500 GeV at LHC. This model contains four components namely the initial conditions, parton transport after initialization, hadronization mechanism and hadronic interaction [11]. AMPT exists in two different versions: the AMPT with string melt and the default AMPT version. Around 500K String melting minimum biased Xe-Xe collision events at $\sqrt{s_{NN}}$ = 5.44 TeV are generated. Whereas the analysis is performed for central events with impact parameter $0 \leq b \leq 3.5$ fm. Fig 1(left) shows the pseudorapidity density distribution of the charged particles generated with the AMPT model and are compared with ALICE data points for various centralities and (right) shows the dependence of normalized charged particles density on the number of participants and compared with ALICE data points [12].

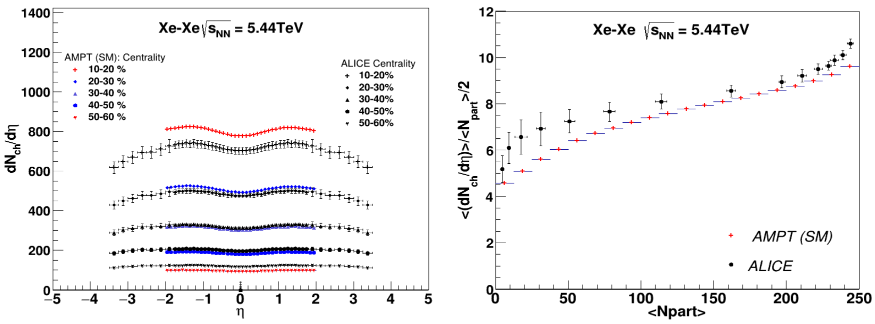

Figure 1: (left) Pseudorapidity density distribution of charged particles for various centralities and (right) charged particle density vs number of participants from the generated events is given and compared with the ALICE data [12] for Xe-Xe collision at $\sqrt{s_{NN}}$ = 5.44 TeV.

4. Observations and Results

The behaviour of the factorial moments $F_q(M)$ are studied for their dependence on M (number of bins) and second order factorial moments $F_2(M)$ in the transverse momentum range of $0.4 \leq$

$p_T \leq 1.0$ GeV/c. From this study, it is observed that $F_q(M)$ is independent of M for q = 2, 3, 4, 5 in the SM mode of the AMPT model. But $F_q(M)$ is observed to show a linear dependence on F_2 for q = 3, 4, 5. Scaling index, ν is determined from the slope for ln β_q against ln(q-1). Fig 2(a) and 2(b) show the *M-scaling* and *F-scaling* behaviour of $F_q(M)$ along with the scaling index value in (c).
Also analysis of the scaling behaviour of F_q is carried in various other p_T bins of various width to

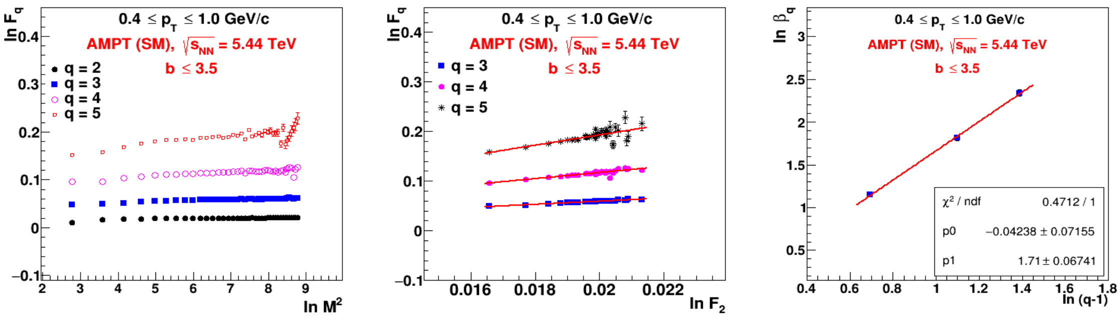

Figure 2: (a) M-scaling behavior of F_q . (b) F-scaling behavior of F_q (c) Log-log plot of β_q versus (q-1), in two dimensional (η, ϕ) phase space in $0.4 \leq p_T \leq 1.0$ GeV/c bin.

study the dependence of scaling exponent on p_T bins and p_T binwidth as studied in [10] . Results from similar analysis from ALICE are also shown for Pb-Pb collision of 2.76 TeV which is close to the theoritically predicted line.

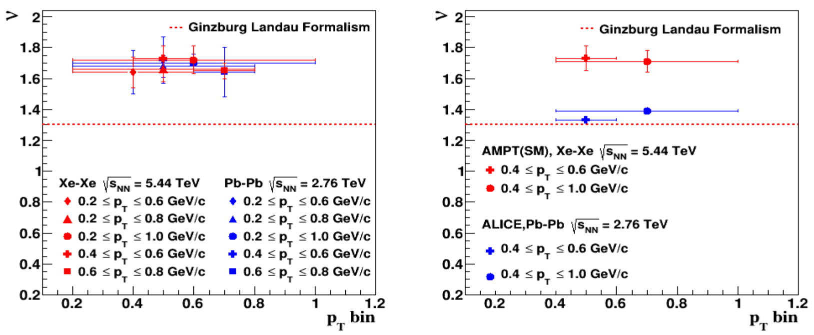

Figure 3: Shows scaling exponent (ν) vs p_T for Xe-Xe at $\sqrt{s_{NN}}$ = 5.44 TeV. ν value obtained for Pb-Pb collision at $\sqrt{s_{NN}}$ = 5.44 TeV from AMPT (SM) model [10] (left panel) and ALICE experiment [13] (right panel) are also given.

5. Summary

Scaling properties of the charged particles generated in the mid rapidity region in Xe-Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV have been studied in the framework of intermittency analysis. A power-law growth of NFM (F_q) with M is observed to be absent at high M values in all the p_T bins. However F-scaling is observed to exist in almost all p_T bin. With no phase transition physics implemented in (SM) AMPT model: Scaling behaviour in line with intermittency is absent and the Scaling exponent is different from value predicted by theory for second order phase transition.

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