Search for Critical End Point at Relativistic heavy-ion collider

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One of the main goal of the high energy heavy-ion collisions is to understand the phase structure of the Quantum Chromodynamic (QCD) phase diagram at finite temperature (T) and baryon chemical potential (μ_B) [1]. Several theoretical models suggest that the QCD phase diagram may contain a first order phase transition line between the hadron gas (HG) phase and strongly coupled Quark-Gluon plasma (QGP) phase which ends at the critical point (CEP) towards high T and lower μ_B. In recent years, experimental programs at Super Proton Synchrotron (SPS) and beam energy scan (BES) program at Relativistic Heavy Ion Collider (RHIC) have drawn much attention aiming to locate the CEP and QGP to HG phase transition. Experimentally, by varying the center-of-mass energies ($\sqrt{s_{NN}}$) of the collision of two heavy nuclei one can control the T and μ_B of the system, hence enables us to scan different sectors of the phase diagram.

Over the past two decades quite a number of such observables have been suggested for clarifying the evolution of the system formed in heavy-ion collisions. These either refer to the signals from the plasma that are supposed to survive the phase transition or to the observables that experience strong fluctuations during the phase transition or close to the critical point. Most commonly measured event-by-event fluctuations in heavy ion collision experiments are particle ratios (K/π, p/π etc.), transverse energy E_T, transverse momentum p_T and particle multiplicity $\langle N\rangle$ fluctuations. Event-by-event fluctuations of various conserved quantities, such as net-baryon number, net-charge, and net-strangeness are proposed as possible signatures of the existence of the CEP. In the thermodynamic limit, the correlation length (ξ) diverges at the CEP. Typically, the variances (σ) of net-baryon, net-charge, and net-strangeness distributions are proportional to ξ as $\sigma^2 = \langle(\delta N)^2\rangle \sim \xi^2$, where N is the multiplicity, $\delta N = N - \mu$ and μ is the mean of the distribution. The magnitude of the ξ is limited by the system size and by finite time effects (critical slowing down), which could be as small as 2 to 3 fm. It has been proposed to measure higher non-Gaussian moments of the fluctuations which are expected to be much more sensitive to the critical point because of the stronger dependence on ξ. The skewness (S) and kurtosis (κ) are related to the third and fourth moments of the distribution as $S = \langle(\delta N)^3\rangle/\sigma^3 \sim \xi^{4.5}$ and $\kappa = \langle(\delta N)^3\rangle/\sigma^4 - 3 \sim \xi^7$.

Experimentally, net-baryon fluctuations are accessible via measuring the net-proton distributions, net-charge fluctuations are accessible by measuring the stable charged particles such as pions, kaons, and protons along with their anti-particles. Similarly, measurement of net-kaon fluctuations act as a proxy for net-strangeness fluctuations,

Figure 1 shows the collision energy dependence of $S\sigma$ and $\kappa\sigma^2$ of net-proton distribution for 0–5% and 70–80% centralities in Au + Au collisions [2]. In the hot and dense medium, the baryon chemical potential μ_B decreases with increasing collision energies, hence Fig. 1 can be interpreted as the μ_B dependence of the moments over the large range of μ_B (20–450 MeV). Deviations are observed for both $S\sigma$ and $\kappa\sigma^2$ from the Skellam and hadron resonance gas model for $\sqrt{s_{NN}} < 39$ GeV. Maximum deviations from Skellam expectation is observed for $\sqrt{s_{NN}} = 19.6$ and 27 GeV.

Figure 2 shows the collision energy dependence of efficiency corrected $S\sigma$ and $\kappa\sigma^2$ of the

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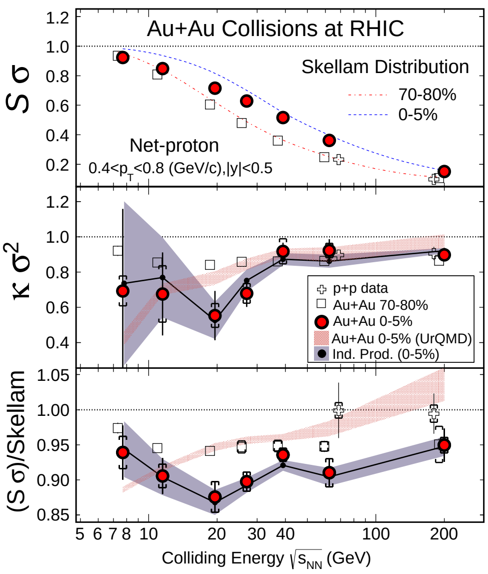

FIG. 1: Collision energy and centrality dependence of efficiency corrected $S\sigma$ and $\kappa\sigma^2$ of net-proton distributions from Au + Au and $p+p$ collisions at RHIC.

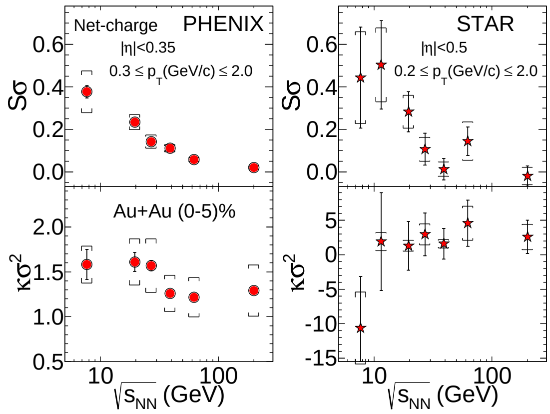

FIG. 2: (Color line)The energy dependence of efficiency corrected $S\sigma$ and $\kappa\sigma^2$ of net-charge distributions for central (0-5%) Au + Au collisions at RHIC.

net-charge distributions for central 0–5% Au + Au collisions measured by two different experiments at RHIC [3, 4]. The $S\sigma$ values from both the experiments decrease with increasing $\sqrt{s_{NN}}$. The $\kappa\sigma^2$ values from PHENIX (left lower panel) remain constant and positive, between $1.0 < \kappa\sigma^2 < 2.0$ at all the collision energies within the statistical and systematic uncertainties. However, there is 25% increase of $\kappa\sigma^2$ values at lower energies below $\sqrt{s_{NN}} = 39$ GeV compared to higher energies. Further, the $\kappa\sigma^2$ values from the STAR experiment are constant at all energies within uncertainties, except for $\sqrt{s_{NN}} = 7.7$ GeV, which shows a negative $\kappa\sigma^2$ value. Product of higher moments can be used to extract the freeze-out parameters (μ_B and T_f) of the QCD phase diagram.

We present some of the experimental results on conserved number fluctuations measured in heavy-ion collisions at RHIC. Deviations are observed in both $S\sigma$ and $\kappa\sigma^2$ for net-proton multiplicity distributions from the Skellam and hadron resonance gas model for $\sqrt{s_{NN}} < 39$ GeV. Higher moments results of the net-electric charge do not observe any significant non monotonic behavior as a function of collision energy. More results and detailed discussion will be presented in the conference. Extraction of the freeze-out parameters using particle ratios and experimentally measured higher moments of net-charge fluctuations combined with the lattice calculations will also be discussed.

References

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