Measurement of cumulants of net-proton distributions in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV at RHIC

Ashish Pandav for the STAR colloboration*
School of Physical Sciences, National Institute of Science Education and Research, HBNI, Jatni - 752050, Odisha, INDIA

Introduction

The cumulants of event-by-event distributions of conserved quantities for strong interaction such as net-charge, net-baryon and net-strangeness are proposed to be sensitive observables for search of the QCD critical point and the phase transition between quark-gluon plasma and hadronic matter. The cumulants and their ratios are related to the correlation length of the system and the thermodynamic number susceptibilities that are also calculable in various QCD-based models [1]. Cumulants up to the 4^{th} order ($C_n, n \leq 4$) of event-by-event distributions of net charge, net proton and net kaon was measured by the STAR experiment in phase I of Beam Energy Scan (BES) program at RHIC [2]. The cumulant ratios C_3/C_2 and C_4/C_2 of net-proton distribution in the most central (0-5%) gold nuclei collisions show non-monotonic dependence as a function of beam energy [3] which has important implication vis-a-vis the critical point search. Furthermore, the ratio of sixth- to the second-order cumulants (C_6/C_2) can also provide insights into the nature of phase transition. The QCD-based model calculations predicts a negative value of C_6/C_2 of net-baryon distributions for crossover phase transitions if the chemical freeze-out is close enough to the chiral phase transition [4].

Analysis details

New results on the measurement of cumulants up to the 6^{th} order of the event-by-event net-proton distributions for Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV are presented as a function of collision centrality. The protons and antiprotons are selected within the rapidity range $|y| < 0.5$ and within p_T range 0.4 – 2.0 GeV/c. The centrality is determined from the charged particle multiplicity within pseudorapidity range $|\eta| < 1$ excluding the protons and antiprotons to avoid auto-correlation effect. The centrality bin width correction is applied to the measurement of the cumulants and their ratios in order to suppress the volume fluctuation effects [5]. Cumulants are then corrected for the efficiency and acceptance effects of the detector assuming the detector response to be binomial. For estimation of statistical uncertainties on cumulants and their ratios, a resampling method called bootstrap was used. Systematic uncertainties on the C_n's are estimated varying track selection and particle identification criteria.

Results and Discussion

Figure 1 shows the cumulants (up to the 4^{th} order) of net-proton distribution as a function of collision centrality (given by the average number of participant nucleons, <Npart>) for Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV. The cumulants increase with number of participant nucleons. Collision centrality dependence of cumulant ratios, C_2/C_1, C_3/C_2 and C_4/C_2 are shown in Fig. 2. C_2/C_1 decreases with collision centrality. The ratios C_3/C_2 and C_4/C_2 exhibit a weak dependence on collision centrality. The cumulant ratios obtained from UrQMD [6] and HIJING [7] models are also compared to the measurements and are found to only reproduce qualitatively the measured centrality dependence whereas quantitative differences exist. The Skellam baseline for C_4/C_2 which is the expected value if protons and antiprotons follow poisson distributions fails to describe the measured values.

*Electronic address: apandav10@gmail.com

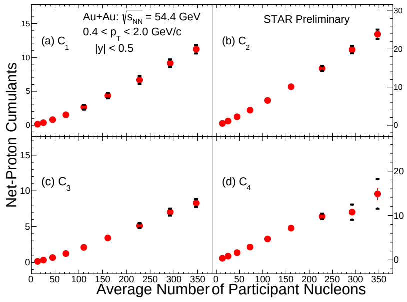

FIG. 1: Cumulants of net-proton distribution up to 4^{th} order as a function of average number of participant nucleons for Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV.

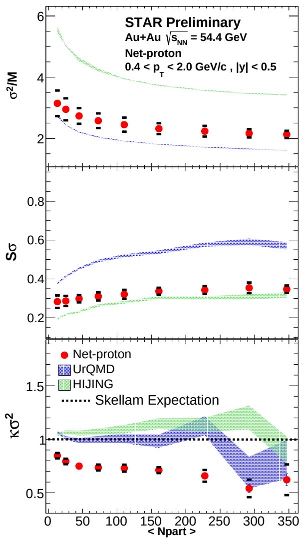

FIG. 2: Ratio of cumulants C_2/C_1, C_3/C_2 and C_4/C_2 of net-proton distribution as a function of average number of participant nucleons (<Npart>) for Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV. Blue and green band are the UrQMD and HIJING expectation respectively.

Figure 3 shows the ratio of the sixth to second order cumulant (C_6/C_2) of net-proton distribution as a function of collision centrality for Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV and $\sqrt{s_{NN}} = 200$ GeV [8]. The value of C_6/C_2 for central collisions (0-40%) at $\sqrt{s_{NN}}$ = 54.4

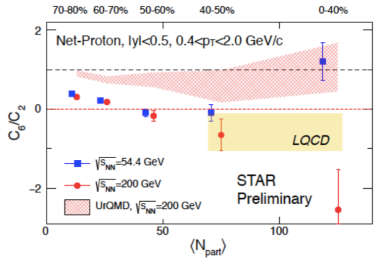

FIG. 3: Cumulant ratio C_6/C_2 of net-proton distribution for Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV (blue) and 200 GeV (red) as a function of collision centrality. Red band is the UrQMD expectation for Au+Au: 200 GeV and yellow band is the Lattice QCD prediction.

GeV shows positive value. This is in contrast to the value of C_6/C_2 obtained at $\sqrt{s_{NN}} = 200$ GeV which has a negative sign in central (0-40%) collisions. The observed negative value of C_6/C_2 could be an evidence of crossover phase transition between hadronic matter and quark-gluon plasma. The UrQMD model expectation for Au+Au at $\sqrt{s_{NN}} = 200$ GeV are found to be positive and consistent with skellam baseline for (0-40%) collision centrality.

Acknowledgments

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