Baseline measures for net-proton distributions in high energy heavy-ion collisions

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Introduction

The STAR experiment at the Relativistic Heavy-Ion Collider facility has reported results for the cumulants and their ratios from the net-proton distributions upto the fourth order cumulants at various collision energies [1]. These measurements were carried to look for the signatures of the possible critical point (CP) in the phase diagram for a system undertaking strong interactions. The results show an intriguing dependence of the cumulant ratios C_3/C_2 and C_4/C_2 as a function of beam energy. The beam energy dependence appears to be non-monotonic in nature. However the experiment also reports that the energy dependence is observed to be consistent with expectation from an approach based on the independent production of proton and anti-protons in the collisions [1]. In this paper we emphasize the need to have a proper baseline for appropriate interpretation of the cumulant measurements and argue that the comparison to independent production approach needs to be done with extreme caution. We demonstrate through our study, if proton and anti-proton distributions are Poisson, Binomial, those obtained from a transport model and from a hadron resonance gas (HRG) Model [2], indicate the higher order cumulant data deviates from them for central 0-5% Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 and 27 GeV. Using HIJING model we show the applicability of the independent production approach at lower beam energies where the anti-proton production is very small is questionable. Further, we have argued that the agreement at the higher beam energies in-spite of significant correlated production of proton and anti-proton ($p/\bar{p} \sim$ 0.77, for 0-5% central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV) in the collisions could be a coincidence due to the acceptance in which measurements have been carried out.

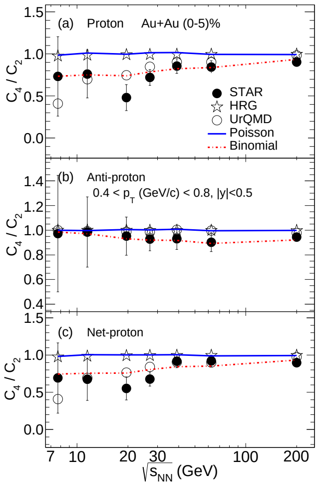

FIG. 1: Ratio of cumulants C_4/C_2 of (a) proton, (b) anti-proton and (c) net-proton multiplicity distribution as a function of beam energy in Au+Au collisions from data, HRG, UrQMD model predictions and from Poisson and Binomial expectations.

Results and discussion

Figure 1 shows the ratio of cumulants C_4/C_2 (solid circle) for proton, anti-proton and net-proton multiplicity distribution from the STAR experimental data as a function of beam energy for 0-5% central Au+Au collisions. Also shown are the Poisson and Bi-

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nomial expectations (curves) which were constructed from measured C_1 and C_2 values of the proton and anti-proton distributions from data. The experimental results are comapred with a transport based model, Ultra Relativistic Quantum Molecular Dynamics (open circle), which is expected to be effective in explaining several bulk observables at lower colliding energies. Thermal model calculations from HRG (open star) including hadrons and its resonances with in the STAR experimental acceptances, shows deviation for proton and net-proton C_4/C_2 and agrees well with the anti-proton data. At $\sqrt{s_{NN}} = 19.6$ GeV, there is a clear deviation of C_4/C_2 for proton distributions between all the baseline measures and experimental data. The C_4/C_2 for anti-proton distribution from data and Binomial expectations agrees well at all collision energies. The C_4/C_2 for net-proton distribution shows the deivation from baseline measures at $\sqrt{s_{NN}} =$ 19.6 GeV which further indicates that this deviation is dominanted by the cumulants for the proton distributions. Figure 2 shows the cumulants of proton, anti-proton and event-by-event (E-by-E) net-proton distribution from HIJING model in Au+Au collisions for 0-5% central collisions as a function of pseudorapidity (η) acceptance. The results are shown for two extreme beam energies (7.7 and 200 GeV) at RHIC for Au+Au collisions. All cumulants increases with η acceptance upto the corresponding beam rapidity and then the values saturates for both $\sqrt{s_{NN}} = 7.7$ and 200 GeV. There is hardly any anti-protons produced at 7.7 GeV collisions, hence the net-proton cumulants are dominated by the corresponding cumulants of the proton distribution. Therefore the IP model expectation very closely follows the net-proton and proton cumulant values. There by confirming our expectation that IP model should not be considered as a baseline for the lower beam energies. In contrast we see interesting η dependence for the Au+Au collisions simulated in HIJING at 200 GeV. A considerable amount of anti-protons are produced and we find the net-proton C_1 and C_3 closely agree with IP expectation for the full η range studied. However we see clear deviation of net-proton C_2 and C_4 from the corresponding IP expectation for $\eta > 0.5$. This study suggests that the agreement between data and corresponding IP result is because of the η acceptance of the measurement and larger acceptance would perhaps have shown the deviations. The deviations are as expected from the breaking of the correlations due to the proton and anti-proton pair production in IP construction at high beam energies.

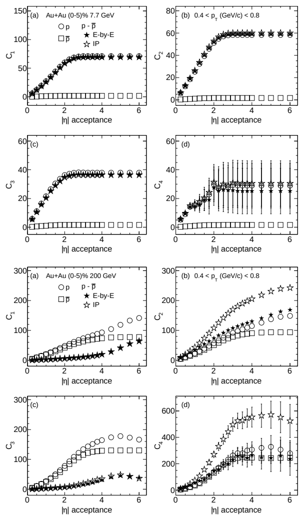

FIG. 2: Cumulants of proton, anti-proton and net-proton (E-by-E) multiplicity distribution as a function of pseudorapidity acceptance in 0-5% central Au+Au collisions from HIJING at $\sqrt{s_{NN}}$ = 7.7 (top panel) and 200 GeV (bottom panel). Also shown is the expectation for net-proton from Independent Production (IP) model. The error bars shown are statistical. The large statistical errors at larger η is due to higher values of σ of the distribution.

References

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