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Nuclear Physics A 947 (2016) 248–259

NUCLEAR PHYSICS A

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

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Received 20 July 2015; received in revised form 11 January 2016; accepted 13 January 2016

Available online 14 January 2016

Abstract

We report a systematic comparison of the recently measured cumulants of the net-proton distributions for 0–5% central Au + Au collisions in the first phase of the Beam Energy Scan (BES) Program at the Relativistic Heavy Collider facility to various kinds of possible baseline measures. These baseline measures correspond to an assumption that the proton and anti-proton distributions follow Poisson statistics, Binomial statistics, obtained from a transport model calculation and from a hadron resonance gas model. The higher order cumulant net-proton data for the center of mass energies ($\sqrt{s_{NN}}$) of 19.6 and 27 GeV are observed to deviate from most of the baseline measures studied. The deviations are predominantly due to the difference in shape of the proton distributions between data and those obtained in the baseline measures. We also present a detailed study on the relevance of the independent production approach as a baseline for comparison with the measurements at various beam energies. Our studies point to the need of either more detailed baseline models for the experimental measurements or a description via QCD calculations in order to extract the exact physics process that leads to deviation of the data from the baselines presented.

Keywords: Relativistic heavy ion collisions; QCD critical point; Higher moments; Net-proton distribution; QCD phase diagram

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http://dx.doi.org/10.1016/j.nuclphysa.2016.01.005
0375-9474/

1. Introduction

The STAR experiment at the Relativistic Heavy-Ion Collider facility has recently reported interesting results on the shape of the net-proton distributions at various collision energies [1]. These measurements are carried out as a part of the first phase of the beam energy scan program to look for the signatures of the possible critical point (CP) in the phase diagram for a systems under influence of strong interactions. The shapes of the net-proton distributions (a proxy for net-baryon distributions) are quantified in terms of the cumulants of the distribution. Measurements upto the fourth order cumulants (C_n, $n = 1, 2, 3$, and 4) have been reported as a function of the colliding beam energy. Varying beam energy of the collision also varies the baryon chemical potential of the system. Thereby allowing experimentally to scan the temperature versus baryon chemical potential phase diagram of strong interactions. The STAR experiments have reported 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 first establish that at the lower colliding energies the beam energy dependence of the net-proton cumulant ratios is dominantly due to the corresponding proton distributions. Very much similar to recently reported, non-monotonic beam energy dependence of the slope of the net-proton directed flow at midrapidity is dominantly due to the corresponding contribution from the measured proton directed flow [2]. 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 that 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 [3]) in the collisions could be a coincidence due to the acceptance in which measurements have been carried out. In addition we point out the role of particle production mechanism and baryon number conservation to such approaches. We have also carried out a very systematic comparison of the four measured cumulants to a variety of baselines measures. These include expectations of whether proton and anti-proton distributions are Poisson, Binomial, those obtained from a transport model and from a hadron resonance gas (HRG) model. All this variety of baselines indicates the higher order cumulant data deviates from them for central 0–5% Au + Au collisions at $\sqrt{s_{NN}} = 19.6$ and 27 GeV.

The paper is organized as follows. Next section deals with the experimental data and sets up the physics problem addressed in the paper. Section 3 compares the cumulants measured in the experiment to the four different baseline measures. Section 4 discusses in detail the independent production approach and finally in section 5 we summarize our findings.

2. Experimental data

Fig. 1 shows the four cumulants of the measured proton, anti-proton and net-proton distributions at midrapidity in 0–5% central Au + Au collisions as a function of center of mass energy. The cumulants of proton distribution in general decreases with increase in beam en-