BEAM ENERGY DEPENDENCE OF EVENT-BY-EVENT HADRON RATIO FLUCTUATIONS FROM Au+Au COLLISIONS AT RHIC*

Jian Tian

for the STAR Collaboration

Nuclear Physics Division, Shanghai Institute of Applied Physics
Chinese Academy of Sciences, Shanghai 201800, China
and
Department of Physics and Astronomy, University of California
Los Angeles, CA 90095, USA

(Received December 5, 2011)

We present measurements of event-by-event fluctuations on hadron multiplicity ratios (K/π, p/π, K/p) in Au+Au collisions at $\sqrt{s_{NN}} = 7.7$, 11.5, 19.6, 39 and 200 GeV using the STAR detector at RHIC. The magnitudes of dynamical fluctuations $\sigma_{\rm dyn}$ for p/π and K/p ratios change smoothly from a larger negative value at $\sqrt{s_{NN}} = 7.7$ GeV to a smaller negative value at 200 GeV while that for the K/π ratios exhibits no significant beam energy dependence. We use a four-event mixing scheme as a reference to evaluate dynamical fluctuations related to pair production $\sigma_{\rm dyn}^{\rm pair}$ for the p/K, K/p, $\bar{p}/p$ and K^-/K^+ ratios at $\sqrt{s_{NN}} = 200$ GeV. We find that these pair-related fluctuations all exhibit a maximum at the mid-central collisions and decrease at the most peripheral and most central collisions.

DOI:10.5506/APhysPolBSupp.5.503
PACS numbers: 25.75.–q, 25.75.Gz

1. Introduction

Experimental results from RHIC (the Relativistic Heavy Ion Collider) indicated that a hot and dense partonic matter has been formed in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [1, 2, 3, 4]. Lattice Quantum ChromoDynamics (QCD) predicted that the transition from partonic to hadronic matter at the small chemical potential region may be a smooth cross over while model calculations predict that at higher density the transition becomes the

* Presented at the Conference "Strangeness in Quark Matter 2011", Kraków, Poland, September 18–24, 2011.

first order [5]. It is expected that a critical point exists in the QCD phase diagram, where the first order phase transition ends. Event-by-event fluctuations in general have been considered as a sensitive probe for nature of the deconfinement and phase transition, especially in search for the critical point (*e.g.* [6]). Recent lattice QCD calculations show a distinct change in baryon and strangeness susceptibilities at the phase transition temperature [7]. The change in susceptibilities may be observed in event-by-event multiplicity ratio fluctuations. In order to study the phase transition and search for the QCD critical point, RHIC started in 2010 an energy scan program, which has taken Au+Au collision data from $\sqrt{s_{NN}} = 200$ GeV down to energies as low as $\sqrt{s_{NN}} = 7.7$ GeV [8].

In these proceedings, we will focus on hadron multiplicity ratio fluctuations from Au+Au collisions at RHIC. Here, we define the event-by-event $K/\pi \equiv \frac{N_{K^+}+N_{K^-}}{N_{\pi^+}+N_{\pi^-}}$, $p/\pi \equiv \frac{N_p+N_{\bar{p}}}{N_{\pi^+}+N_{\pi^-}}$ and $K/p \equiv \frac{N_{K^+}+N_{K^-}}{N_p+N_{\bar{p}}}$. Fluctuations of these hadron multiplicity ratios have already been studied using different data sets and observables by the STAR Collaboration [9, 10, 11].

2. STAR experiment and data setup

All data sets used in this analysis are from Au+Au collisions at $\sqrt{s_{NN}} = 7.7$, 11.5, 39 and 200 GeV from Run 10 and $\sqrt{s_{NN}} = 19.6$ GeV from Run 11. The main tracking detector for charged particles in the STAR experiment is the Time Projection Chamber (TPC) [12]. Particles have been selected within $|\eta| < 1$ and identified using the specific ionization energy loss (dE/dx) in the TPC gas. Tracks within 2σ deviation of the expected particle's Bethe–Bloch curve are identified as pions, kaons and protons, where σ is the resolution on dE/dx measurement. In order to exclude contaminations from pions, particles within 2σ of the expected pion Bethe–Block curve are removed when selecting kaons and protons. We select pions with transverse momentum $p_{\mathrm{T}} > 0.2$ GeV/c and momentum $p < 0.6$ GeV/c, kaons with transverse momentum $p_{\mathrm{T}} > 0.2$ GeV/c and momentum $p < 0.5$ GeV/c, protons with transverse momentum $p_{\mathrm{T}} > 0.4$ GeV/c and momentum $p < 1.0$ GeV/c.

The recently completed Time-of-Flight (TOF) detector [13] is also used in this analysis. Using the Time-of-Flight information of a track from TOF, along with its momentum determined by the TPC, the square of particle's mass can be extracted. Utilizing the TOF allows the pions and kaons identification with extended momentum coverage up to 1.6 GeV/c, protons identification with extended momentum coverage up to 3.0 GeV/c.

In this analysis, a new method by combining TPC and TOF is applied to identify the particles. If a track has matched momentum from TPC and Time of Flight from TOF, the square of mass will be used to identify particles; If the track only has energy loss and momentum information from

TPC, the energy loss will be used to identify particles. This method will ensure the particle identification with the best momentum coverage and purity.

3. Analysis and results

The relative width of observed event-by-event particle ratio distributions, σ_{data} = RMS/mean, may have contributions from statistical, instrumental and dynamical fluctuations, where the dynamical fluctuations is the subject of interest. The statistical and instrumental fluctuations can be evaluated using a mixed event technique. The dynamical fluctuations σ_{dyn} are then estimated by subtracting the relative width of ratio distributions from mixed events with the following formula [14]

$$\sigma_{\text{dyn}} = \text{sign}\left(\sigma^2_{\text{data}} - \sigma^2_{\text{mixed}}\right)\sqrt{\left|\sigma^2_{\text{data}} - \sigma^2_{\text{mixed}}\right|}\,. \tag{3.1}$$

Here, the mixed events are constructed by randomly selecting tracks from multiple events with maximum one track from each event reproducing the multiplicity distribution of the real events. We only mix events with approximately the same multiplicity and vertex position. As a result, the mixed events have on average the same value of particle ratios as the real events, but particle correlations are absent.

The K/π fluctuations characterized by σ_{dyn} for the most central Au+Au collisions from the STAR experiments are shown in figure 1 (a) along with results for the most central Pb+Pb collisions from the NA49 experiments [15]. The same event mixing procedure has been used in these two measurements. The K/π fluctuations characterized by $\sqrt{\nu_{\text{dyn}}}$ [16] from independent analysis of the same STAR data sets [11] are also shown in figure 1 (a). We find these two observables are consistent within statistical errors. The K/π fluctuations at RHIC show no significant energy dependence from $\sqrt{s_{NN}} = 7.7$ to 200 GeV. This energy dependence result is different from the NA49 experiments which reported that fluctuations increase with the decrease of beam energies. We have investigated the dependence of the fluctuations on the detector acceptance within the STAR detector and concluded that the large difference cannot be attributed solely to acceptance. Three model predictions from AMPT [17], HSD [18] and UrQMD [19] using the STAR experimental acceptance are plotted in figure 1.

The p/π fluctuations characterized by σ_{dyn} for the most central Au+Au collisions from the STAR experiments are shown in figure 1 (b) along with results from the NA49 experiments [15]. The dynamical fluctuations from the STAR experiments show a smooth increasing from a larger negative value at $\sqrt{s_{NN}} = 7.7$ GeV to a smaller negative value at 20 GeV. Results from the NA49 experiments have the same magnitude and trend at overlap energies as the STAR data. The STAR measurements of $\sqrt{\nu_{\text{dyn}}}$ from an independent analysis of the same data sets [11] are shown in figure 1 (b) which agree with the measurements of σ_{dyn}.

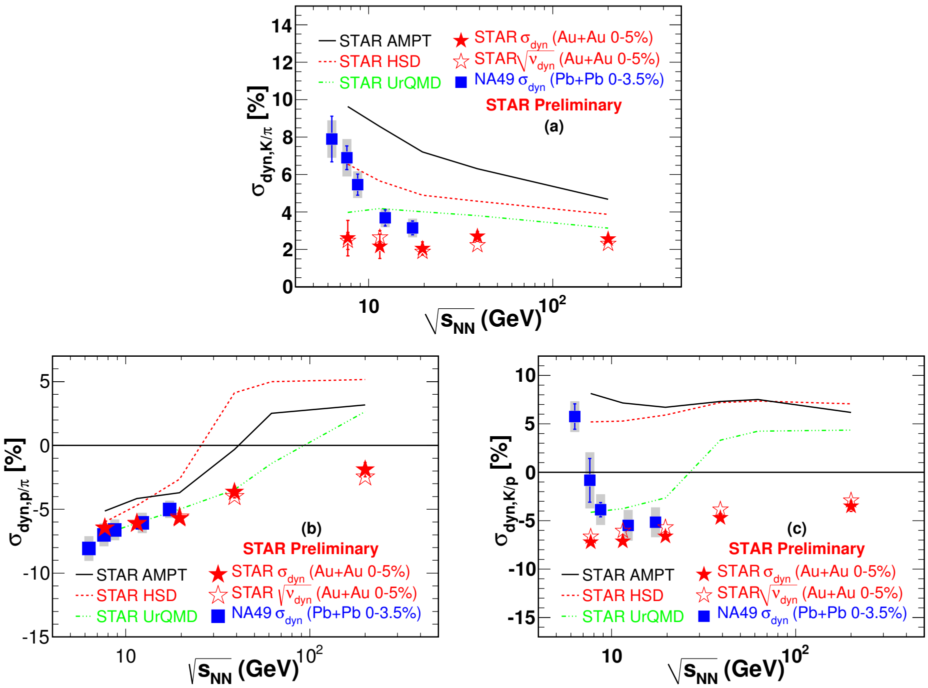

Fig. 1. Measured K/π (a), p/π (b) and K/p (c) fluctuations for central Au+Au collisions at $\sqrt{s_{NN}} = 7.7$, 11.5, 19.6, 39 and 200 GeV from the STAR experiments compared with the central Pb+Pb collisions from the NA49 experiments. Only statistical errors are shown for the STAR data. Model calculations from AMPT, HSD and UrQMD with the STAR experimental acceptance are also shown.

The K/p fluctuations characterized by σ_{dyn} and $\sqrt{\nu_{\mathrm{dyn}}}$ [11] for the most central Au+Au collisions from the STAR experiments are shown in figure 1 (c) along with results from the NA49 experiments [20]. We find the STAR measurements of σ_{dyn} and $\sqrt{\nu_{\mathrm{dyn}}}$ are not exactly the same. The fact that the multiplicity of protons and kaons in each event are both very low, plays an important role in the observed differences. The STAR measurements of K/p dynamical fluctuations show the same trend as p/π fluctuations, which is different from the results reported by the NA49 experiments that fluctuations are positive and increasing with decreasing incident energy.

At $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ beam energy, the net baryon density in the STAR acceptance is small, and most baryon and strangeness quantum numbers are pair produced [21]. We propose to use a 4-event mixing scheme to model single particle statistical and instrumental fluctuations without the presence of pairs. Specifically, we take four independent events and choose p, $\bar{p}$, K^+ and K^- from these four events, respectively. Such a reference would include fluctuations from various origins except correlated fluctuations from the pair production dynamics. We introduce $\sigma_{\rm dyn}^{\rm pair}$, defined by

$$\sigma_{\rm dyn}^{\rm pair} = {\rm sign}\left(\sigma_{\rm data}^2 - \sigma_{4-{\rm mixed}}^2\right)\sqrt{\left|\sigma_{\rm data}^2 - \sigma_{4-{\rm mixed}}^2\right|}\,, \tag{3.2}$$

in an effort to isolate the part of the fluctuations caused by pair production.

The $\sigma_{\rm dyn}^{\rm pair}$ for p/K and K/p multiplicity ratio fluctuations as a function of the number of collision participants $\langle N_{\rm part}\rangle$ from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are shown in figure 2 (a). We find that all the fluctuations are positive and there is a good agreement in $\sigma_{\rm dyn}^{\rm pair}$ values for p/K and K/p. The magnitude of the fluctuations show a maximum at mid-centrality, $\langle N_{\rm part}\rangle \sim 100$–$200$, and decrease for the most peripheral and most central collisions. The $\sigma_{\rm dyn}^{\rm pair}$ for K^-/K^+ and $\bar{p}/p$ as a function of $\langle N_{\rm part}\rangle$ from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are plotted in figure 2 (b). All fluctuations are negative and maximum fluctuations at mid-centrality are observed at the same range as p/K (K/p) fluctuations. This is an indication that the pair production mechanism does indeed have a larger effect on $\sigma_{\rm dyn}^{\rm pair}$ at mid-centrality. The extent of these pair fluctuations on the beam energy and the dynamical formation mechanism is being investigated also.

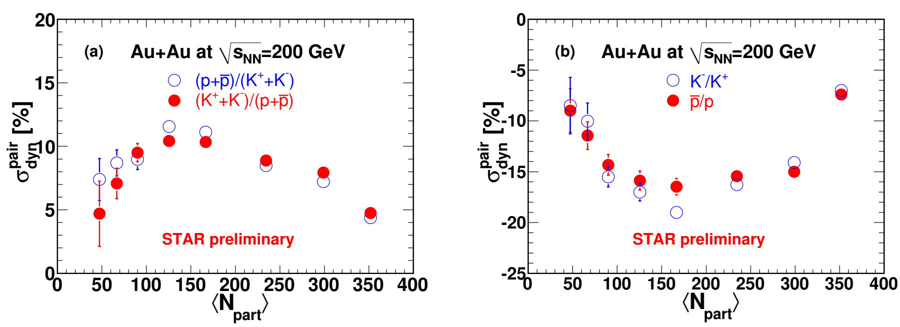

Fig. 2. Event-by-event p/K, K/p (a), K^-/K^+ and $\bar{p}/p$ (b) multiplicity ratio fluctuations $\sigma_{\rm dyn}^{\rm pair}$ as a function of $\langle N_{\rm part}\rangle$ from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Only statistical errors are shown.

4. Summary and outlook

In summary, we presented studies of dynamical fluctuations of the K/π, p/π and K/p ratios on an event-by-event basis from Au+Au collisions at $\sqrt{s_{NN}} = 7.7$, 11.5, 19.6, 39 and 200 GeV with the STAR detector at RHIC.

The K/π dynamical fluctuations at RHIC are positive and show no significant energy dependence from $\sqrt{s_{NN}} = 7.7$ to 200 GeV. Dynamical p/π and K/p fluctuations tend to increase smoothly from a larger negative value at $\sqrt{s_{NN}} = 7.7$ GeV to a smaller negative value at 200 GeV. We use a 4-event mixing scheme to evaluate the dynamical fluctuations related to pair production dynamics. A strong centrality dependence of $\sigma_{\rm dyn}^{\rm pair}$ with a maximum at mid-centrality is observed for the p/K, K/p, K^-/K^+ and $\bar{p}/p$ ratios from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The extension of our fluctuation studies to the 27 GeV data taken in 2011 and to more proposed beam energies below 7.7 GeV will greatly expand our search window for a possible critical point in the QCD phase diagram.

This work was supported in part by the National Natural Science Foundation of China (Grant Nos. 11105206, 11035009), the China Postdoctoral Science Foundation (No. 2011M500643), the China Postdoctoral Special Science Foundation (No. 201104281).

REFERENCES

[1] I. Arsene *et al.* [BRAHMS Collab.], *Nucl. Phys.* **A757**, 1 (2005).
[2] B.B. Back *et al.* [PHOBOS Collab.], *Nucl. Phys.* **A757**, 28 (2005).
[3] J. Adams *et al.* [STAR Collab.], *Nucl. Phys.* **A757**, 102 (2005).
[4] K. Adcox *et al.* [PHENIX Collab.], *Nucl. Phys.* **A757**, 184 (2005).
[5] K. Rajagopal, F. Wilczek, `arXiv:hep-ph/0011333v2`.
[6] H. Heiselberg, *Phys. Rep.* **351**, 161 (2001).
[7] F. Karsch, *PoS* **CPOD07**, 026 (2007).
[8] M.M. Aggarwal *et al.* [STAR Collab.], `arXiv:1007.2613v1[nucl-ex]`.
[9] B.I. Abelev *et al.* [STAR Collab.], *Phys. Rev. Lett.* **103**, 092301 (2009).
[10] J. Tian [STAR Collab.], *J. Phys. G* **37**, 094044 (2010).
[11] T. Tarnowsky [STAR Collab.], *J. Phys. G* **38**, 124054 (2011).
[12] M. Anderson *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A499**, 659 (2003).
[13] W.J. Llope *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A522**, 252 (2004).
[14] S.V. Afanasiev *et al.* [NA49 Collab.], *Phys. Rev. Lett.* **86**, 1965 (2001).
[15] C. Alt *et al.* [NA49 Collab.], *Phys. Rev.* **C79**, 044910 (2009).
[16] C. Pruneau, S. Gavin, S. Voloshin, *Phys. Rev.* **C66**, 044904 (2002).
[17] Z.W. Lin, C.M. Ko, B.A. Li, S. Pal, *Phys. Rev.* **C72**, 064901 (2005).
[18] W. Ehehalt, W. Cassing, *Nucl. Phys.* **A602**, 449 (1996).
[19] S.A. Bass *et al.*, *Prog. Part. Nucl. Phys.* **41**, 255 (1998).
[20] T. Anticic *et al.* [NA49 Collab.], *Phys. Rev.* **C83**, 061902(R) (2011).
[21] B.I. Abelev *et al.* [STAR Collab.], *Phys. Rev.* **C79**, 034909 (2009).