Journal of Physics: Conference Series

Higher moments of net kaon multiplicity distributions at RHIC energies for the search of QCD Critical Point at STAR

To cite this article: Amal Sarkar and the STAR collaboration 2014 *J. Phys.: Conf. Ser.* **509** 012069

Higher moments of net kaon multiplicity distributions at RHIC energies for the search of QCD Critical Point at STAR

Amal Sarkar (for the STAR collaboration)
Indian Institute of Technology Bombay (IITB)
Mumbai, India - 400076

E-mail: amal@rcf.rhic.bnl.gov

Abstract. In this paper we report the measurements of the various moments mean (M), standard deviation (σ), skewness (S) and kurtosis (κ) of the net-Kaon multiplicity distribution at mid rapidity in Au+Au collisions from $\sqrt{s_{NN}}$ =7.7 to 200 GeV in the STAR experiment at RHIC in an effort to locate the critical point in the QCD phase diagram. These moments and their products are related to the thermodynamic susceptibilities of conserved quantities such as net baryon number, net charge, and net strangeness as also to the correlation length of the system. A non-monotonic behaviour of these variables indicate the presence of the critical point. In this work we also present the moment products Sσ and $\kappa\sigma^2$ of net-Kaon multiplicity distribution as a function of collision centrality and energy. The energy and the centrality dependence of higher moments of net-Kaons and their products have been compared with its Poisson expectation and with simulations from AMPT which does not include the critical point. From the measurement at all seven available beam energies, we find no evidence for a critical point in the QCD phase diagram.

1. Introduction

One of the fundamental goals of the heavy-ion collision experiment is to map the QCD phase diagram as a function of temperature and baryon-chemical potential (μ_B) [1]. Finite temperature lattice QCD calculations at baryon chemical potential $\mu_B = 0$ suggest a crossover from a system with hadronic degrees of freedom to a system where the relevant degrees of freedom are quarks and gluons [2]. Several QCD based calculations find the quark-hadron phase transition to be of the first order at large μ_B [3]. The point in the QCD phase plane (T vs μ_B) where the first order phase transition become continuous is called the QCD critical point (CP) [4]. This results in long range correlation and fluctuation at all length scales. Such properties of state open possibilities for distinct experimental signatures which can be used to discover the critical point. Current theoretical calculations are highly uncertain about location of the CP as Lattice calculations at finite μ_B present numerical challenges in computing. The correlation length (ξ) and the magnitude of the fluctuations of the conserved quantities diverge at the critical point [5] but because of the finite size and time effects, ξ takes values in the range of $2-3$fm [6]. Higher non Gaussian moments such as skewness, S ($\propto \xi^{4.5}$), and kurtosis, $\kappa(\propto \xi^7)$ can provide much better handle in location of CP as they are much more sensitive than variance ($\propto \xi^2$) to the correlation length [7]. To cancel out the volume dependence of the higher moments, moment products, such as, S$\sigma(\propto \xi^{2.5})$ and $\kappa\sigma^2(\propto \xi^5)$ are constructed [8]. Lattice calculations and QCD-based models show that moments of net-conserved (baryons (B), strangeness (S) and charge (Q)) distributions are related to its conserved number susceptibilities ($\chi_x = \frac{\langle(\Delta N_x)^2\rangle}{VT}$; where, x represents B, S and Q, & V is the volume) [2,8]. Volume independent moment products Sσ and $\kappa\sigma^2$ are the ratio of third ($\chi_x^{(3)}$) to second $\chi_x^{(2)}$ order and fourth $\chi_x^{(4)}$ to second $\chi_x^{(2)}$ order susceptibilities [2,8]. Close to the critical point, models predict the distributions of the conserved quantities to be non-Gaussian and susceptibilities to diverge causing Sσ and $\kappa\sigma^2$ to deviate from being constants and have large values [7,8]. Experimentally measuring event-by-event all produced conserved quantities is very difficult. However, net proton, kaons and charge can be measured to serve proxy for B, S, & Q. We calculate event-by-event the net-Kaon multiplicity ($\Delta N_K = N_{K^+} - N_{K^-}$) to obtain the net-strangeness distribution. In this paper, we report the measurement of the moments of the net-Kaon multiplicity distributions as a function of baryon chemical potential which was varied from 410 to 20 MeV by changing the $\sqrt{s_{NN}}$ from 7.7, 11.5, 19.6, 27, 39, 62.4 to 200 GeV in Au+Au collisions [9] by the STAR collaboration [10]. Sσ and $\kappa\sigma^2$ have been calculated as a function of collision centrality.

2. Analysis Details

The STAR (Solenoidal Tracker At RHIC) experiment at Brookhaven National Laboratory provides excellent particle identification and large uniform acceptance at mid-rapidity for all the $\sqrt{s_{NN}}$ [9]. Ionization energy loss dE/dx of charged particles in the Time Projection Chamber (TPC) was used to identify charged kaons by comparing it to the theoretical (parameterized) expectation along with a mass square cut from the information of Time-of-Flight (TOF) detector [9]. The analysis was carried out event-by-event with identified positively charged kaons (K^+) and negatively charged kaons (K^-) in full azimuthal coverage for collisions occurring within 30 cm of the TPC center along the beam line. The ΔN_K measurements are carried out within the pseudo-rapidity range $|\eta| < 0.5$ in the range $0.2 < p_T < 1.6$ GeV/c. To reduce the contamination from secondary kaons, we required each $K^+(K^-)$ track to have a minimum p_T of 0.2 GeV/c and a distance of closest approach (DCA) to the primary vertex of less than 1 cm. To suppress the contamination from other particles we use $|n\sigma_{Kaon}| < 2.0$,

$$n\sigma_x = \frac{1}{R}\log\frac{\langle dE/dx\rangle|_{measured}}{\langle dE/dx\rangle|_{expected}} \tag{1}$$

Where, R is the $\langle dE/dx\rangle$ resolution of TPC. For centrality selection we have used uncorrected charged particle multiplicity within $0.5 < |\eta| < 1.0$, to avoid the self-correlation. For each centrality, the average numbers of participants ($\langle N_{part}\rangle$) are obtained by Glauber model calculations. The results are corrected for the finite centrality bin width effects [11].

3. Results

The raw net-Kaon ($\Delta N_K = N_{K^+} - N_{K^-}$) multiplicity distribution which has not been corrected for reconstruction efficiency for various collision centralities (70-80%, 30- 40%, and 0-5%) in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 - 200 GeV at mid-rapidity ($|\eta| < 0.5$), are shown in the Figure 1(a). The mean of net-Kaon (ΔN_K) distribution shifts towards zero with increase in $\sqrt{s_{NN}}$. The four moments (M, σ, S, and κ) of the ΔN_K distributions at various collision energies are plotted as a function of average number of participants $\langle N_{\rm part}\rangle$ in Figure 1(b).The moments are calculated from the ΔN_K distributions after correcting for the finite centrality bin width effects [11]. M shows a linear variation with $\langle N_{\rm part}\rangle$ and increases as $\sqrt{s_{NN}}$ decreases. σ increases with $\langle N_{\rm part}\rangle$ as also with beam energies. S is positive and decreases as $\langle N_{\rm part}\rangle$ increases for a given collision energy. The values also decrease as $\sqrt{s_{NN}}$ increases. This indicates that the distributions become symmetric for more central collision and for higher beam energies. κ

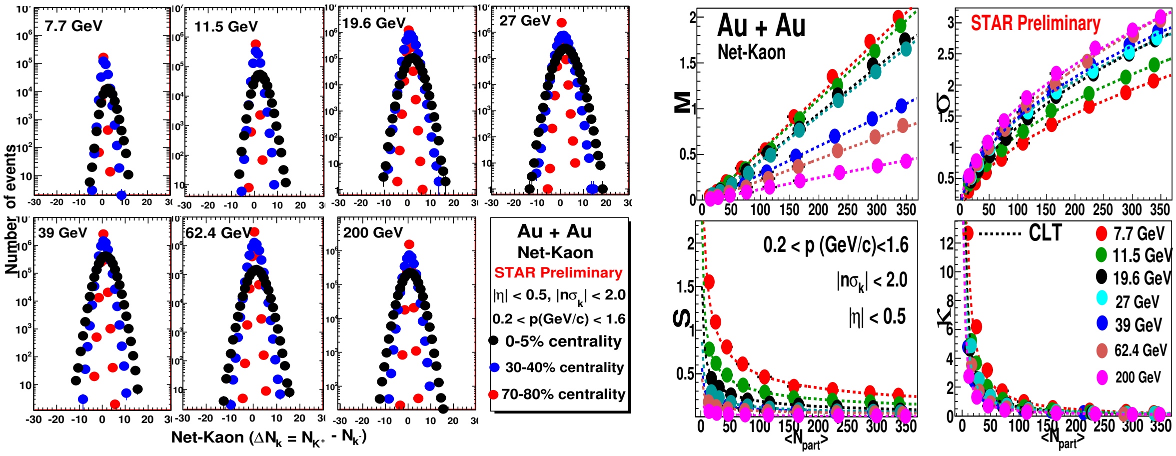

Figure 1. (left panel)ΔN_K multiplicity distribution in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 - 200 GeV for various collision centralities at mid-rapidity ($|\eta| < 0.5$) (right panel) Centrality dependence of moments of ΔN_k distributions for Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 - 200 GeV. The doted lines are the expected values from the central limit theorem. Error bars are statistical.

decreases as $\langle N_{\mathrm{part}} \rangle$ increases, and also decreases as $\sqrt{s_{NN}}$ increases with beam energy. The fitted dotted lines are expected values from the central limit theorem (CLT), which varies as volume′s x, $\sqrt{x}$, $\frac{1}{\sqrt{x}}$ and $\frac{1}{x}$ respectively. Error bars are statistical only, calculated from Delta theorem [12]. All results shown in this paper are not corrected for tracking efficiency. The centrality dependence Sσ and $\kappa\sigma^2$ are shown in Figure 2 and Figure 3 compared with the baseline from Poisson statistics for the seven available beam energies. The Poisson baseline has been calculated from the mean value of the N_{K^+} and N_{K^-} distribution. There is a weak centrality dependence of Sσ value. However, the variation is within 15%. Sσ value is greater than the Poisson baseline for beam energy below 200 GeV. Sσ increases with the decrease in collision energy. Volume independent product $\kappa\sigma^2$ is independent of centrality with in 10%. In

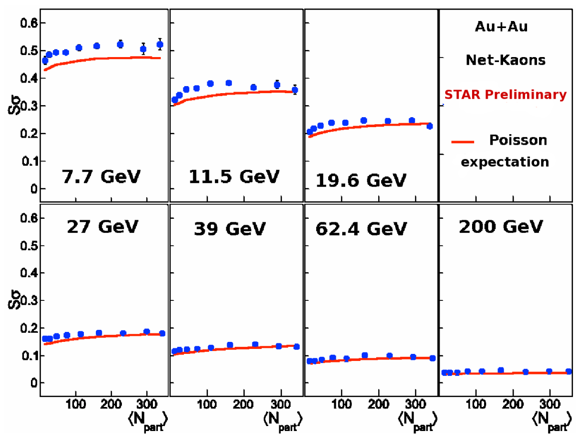

Figure 2. Centrality dependence of Sσ of ΔN_k in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 - 200 GeV compared to its Poisson expectation.

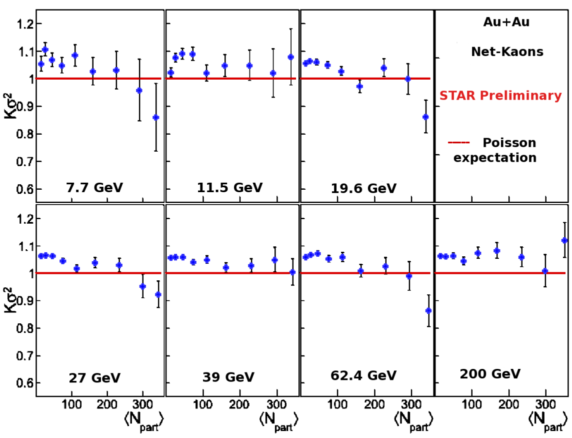

Figure 3. Centrality dependence of $\kappa\sigma^2$ for ΔN_k in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 – 200 GeV compared to its Poisson expectation.

Figure 4 and Figure 5 Sσ and $\kappa\sigma^2$ as a function of energy for the top central 0 – 5% Au+Au collisions are shown. The data as can be seen in the figure matches well with the Poisson baseline as well as with the AMPT model (without CP).

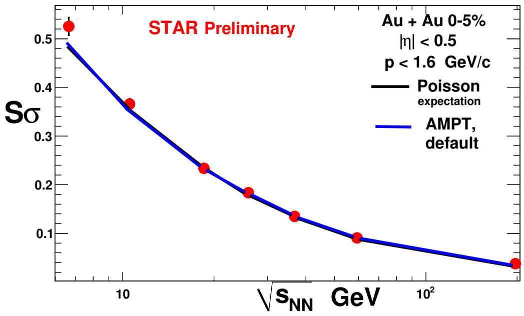

Figure 4. $\sqrt{s_{NN}}$ dependence of Sσ for net-Kaon distributions measured at RHIC for the top central $0-5\%$ Au+Au collisions for available energies. The results are compared to AMPT and with the Poisson expectation.

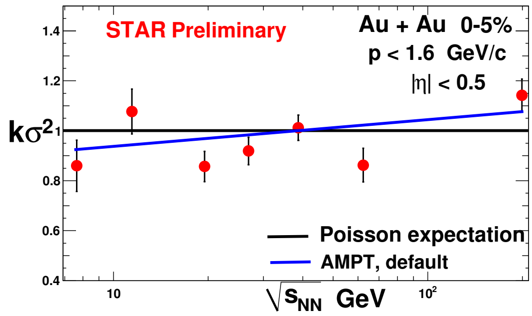

Figure 5. $\sqrt{s_{NN}}$ dependence of $\kappa\sigma^2$ for net-Kaon distributions measured at RHIC for the top central $0-5\%$ Au+Au collisions for available energies. The results are compared to AMPT and with the Poisson expectation.

4. Summary

The first measurements of kurtosis (κ), skewness (S), and variance (σ^2) of net-Kaon multiplicity distributions at mid-rapidity ($|\eta| < 0.5$) in $0.2 < p_T < 1.6$ GeV/c in Au+Au collisions for baryon chemical potentials (μ_B) between 410 and 20 MeV have been shown. The centrality dependence of moments follows the central limit theorem. Sσ and $\kappa\sigma^2$ values have been found to be independent of centrality as a function of $\langle N_{\rm part}\rangle$ for all available collision energies within 15% and are consistent with expectations from AMPT model (which does not have the critical point). No significant enhancement of moment products compared to the Poisson has been observed at measured energies.

References

[1] STAR Collaboration, Adams J *et al* 2005 *Nucl. Phys.* A **757** 102
[2] Aoki Y *et al* 2010 *arXiv:*1007.2613; Cheng M *et al* 2009 *Phys. Rev.* D **79** 074505
[3] Ejiri S 2008 *Phys. Rev.* D **78** 074507; Bowmanand E S and Kapusta J I 2009 *Phys. Rev.* C **79** 015202
[4] Stephanov M A 2004 *Prog. Theor. Phys. Suppl.* **153** 139
[5] STAR Collaboration, Aggarwal M M *et al* 2010 *arXiv:*1007.2613; Stephanov M A 2011 *Phys. Rev. Lett.* **107** 052301
[6] Berdnikov B *et al* 2000 *Phys. Rev.* D **61** 105017
[7] STAR Collaboration, Aggarwal M M *et al* 2010 *Phys. Rev. Lett.* **105** 022302; Stephanov M A 2009 *Phys. Rev. Lett.* **102** 032301
[8] Athanasiou C *et al* 2010 *Phys. Rev. D* **82** 074008; Gupta S 2009 *arXiv:* 0909.4630; Karsch F *et al* 2011 *Phys. Lett.* B **695** pp 136-142
[9] STAR Collaboration, Abelev B I *et al* 2010 *Phys. Rev.* C **81** 024911; STAR Collaboration, Ackermann K H *et al* 2006 *Nucl. Instrum. Meth.* A **558** pp 419-429; STAR Collaboration, Abelev B I *et al* 2006 *Nuclear Physics* A vol 774 pp 956-958
[10] Hatta Y and Stephanov M A 2003 *Phys. Rev. Lett.* **91** 102003
[11] Luo X 2011 *J. Phys.: Conf. Series* **316** 445 012003
[12] Luo X 2012 *J. Phys.* G **39** 025008