Energy Dependence of High Moments for Net-proton Distributions

X.F. Luo, B. Mohanty, H.G. Ritter, N. Xu

January 23, 2010

This work was supported by the Director, Office of Science, Office of Nuclear Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Energy Dependence of High Moments for Net-proton Distributions

X.F. Luo[1,2]‡, **B. Mohanty**[3], **H.G. Ritter**[1], **N. Xu**[1]
[1]Lawrence Berkeley National Laboratory Berkeley, CA 94720, USA
[2]Department of Modern Physics, University of Science and Technology of China, Heifei, Anhui 230026, China
[3]Variable Energy Cyclotron Center Kolkata 700064, India

Abstract. High moments of multiplicity distributions of conserved quantities are predicted to be sensitive to critical fluctuations. To understand the effect of the non-critical physics backgrounds on the proposed observable, we have studied various moments of net-proton distributions with AMPT, Hijing, Therminator and UrQMD models, in which no QCD critical point physics is implemented. It is found that the centrality evolution of various moments of net-proton distributions can be uniformly described by a superposition of emission sources. In addition, in the absence of critical phenomena, some moment products of net-proton distributions, related to the baryon number susceptibilities in Lattice QCD calculations, are predicted to be constant as a function of the collision centrality. We argue that a non-monotonic dependence of the moment products as a function of the beam energy may be used to locate the QCD critical point.

1. Introduction

Heavy-ion reactions at high energy allow us to study the QCD phase diagram experimentally [1]. At vanishing baryon chemical potential ($\mu_B = 0$), Lattice QCD calculations predict that a cross-over from the hadronic phase to the Quark Gluon Plasma (QGP) phase will occur above a critical temperature. The temperature range for the cross-over has been estimated to be about 170 - 190 MeV [2]. QCD based model calculations indicate that at large μ_B the transition from the hadronic phase to the QGP phase could be of first order with a critical point at the boundary to the cross-over, the QCD Critical Point (QCP) [3]. The location of the QCP or even its existence are not confirmed [4]. The possibility of the existence of the QCP has motivated our interest to search for it with the RHIC beam energy scan program [5]. By decreasing the collision energy down to a center of mass energy of 5 GeV we will be able to vary the baryo-chemical potential from $\mu_B \sim 0$ to μ_B of about 500 MeV.

A characteristic feature of a critical point is the increase and divergence of the correlation length (ξ) and of critical fluctuations. In heavy-ion reactions, finite size

---

‡ E-mail address: xfluo@lbl.gov

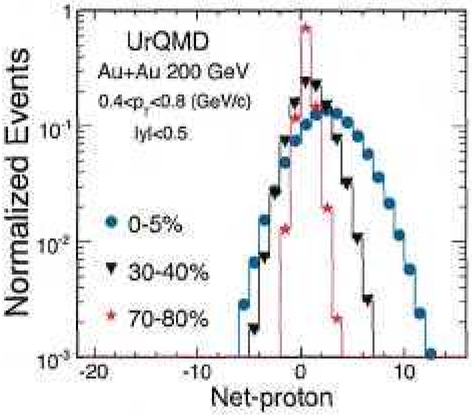

Figure 1: Typical event by event net-proton multiplicity distributions of various centralities for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV calculated by UrQMD model.

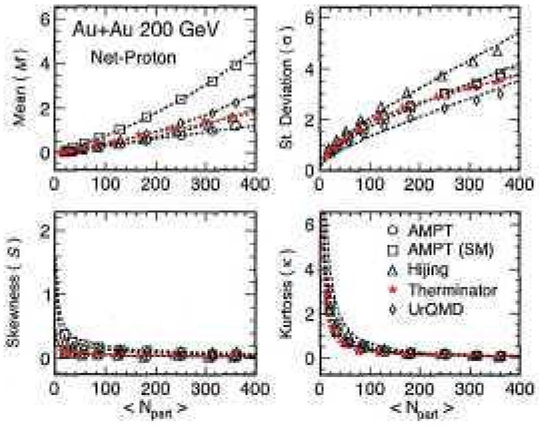

Figure 2: Centrality dependence of various moments of Δp distributions for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV from various models. The dashed lines represent the expectations for statistical emission.

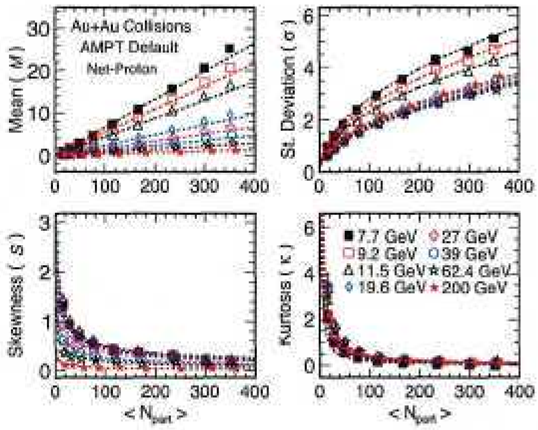

Figure 3: Centrality dependence of various moments of Δp distributions for Au+Au collisions at various energies from the AMPT model. The dashed lines represent the expectations for statistical emission.

models. M and σ show a monotonic increase with $< N_{part} >$ for all of the models, while S and κ decrease monotonically. In Fig. 3, we choose the default AMPT model to evaluate the centrality evolution of the various moments of net-proton distributions for various energies. M shows a linear increase with $< N_{part} >$ and a decrease with $\sqrt{s_{NN}}$. σ increases monotonically with $< N_{part} >$ while it has non-monotonic dependence on $\sqrt{s_{NN}}$. S is positive and decreases with increasing $< N_{part} >$ and $\sqrt{s_{NN}}$. The net-proton distributions become more symmetric for central collision and higher energies. κ decreases with $< N_{part} >$ and is similar for all energies. The dashed lines in Fig. 2 and Fig. 3 are resulting from Equs. (6)-(9) to evaluate the centrality evolution of the various moments. To apply our formulas, we fit the normalized mean value in Equ.(5) with the function $f(<N_{part}>)$. For AMPT String Melting (SM) [11], Hijing [12] and UrQMD [13] models, a 2nd order polynomial, $f(<N_{part}>) = a <N_{part}>^2 + b <N_{part}>$ is applied, while a linear function $f(<N_{part}>) = a* <N_{part}>$ is employed for AMPT default [11] and Therminator [14] models. Once the function $f(<N_{part}>)$ is obtained, the centrality evolution of the other moments is completely determined by Equs. (7)-(9). It is obvious that the centrality evolution of the various moments of net-proton distributions in Fig. 2 and in Fig. 3 can be well described by the dashed lines.

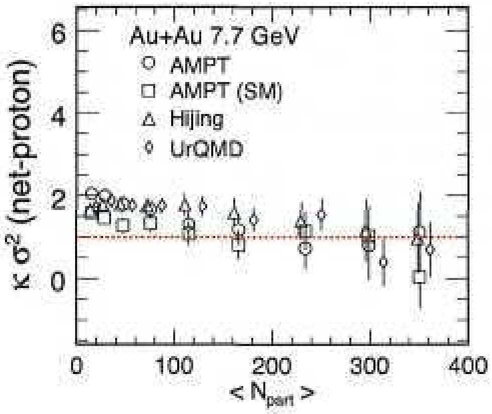

Figure 4: The $\kappa\sigma^2$ of net-proton distributions for Au+Au 7.7 GeV collisions as a function of $<N_{part}>$ from various models.

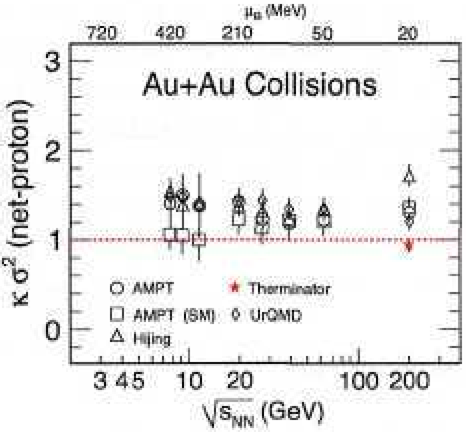

Figure 5: The $\kappa\sigma^2$ of net-proton distributions in Au+Au collisions as a function of $\sqrt{s_{NN}}$ for various models.

The $\kappa\sigma^2$ of the net-proton distributions of Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ GeV as a function of $<N_{part}>$ is shown in Fig. 4 for various models. $\kappa\sigma^2$ is constant with respect to $<N_{part}>$ within the errors, which is consistent with the expectation from the *IIES* assumption. Fig. 5 shows the energy dependence of the $\kappa\sigma^2$ of net-proton distributions for various models. The top of the figure shows the μ_B value corresponding to the various energies. The values shown are averaged within the centrality range studied. The results from various models show no dependence on energy and are close to unity. This suggests that the $\kappa\sigma^2$ of net-proton distributions is not affected very much by the non-QCP physics at different beam energies, such as the change of μ_B [1], and the collective expansion [15]. Note that the result from the pure thermal model, Therminator, is much closer to unity compared to others. Actually, if proton and anti-proton have independent poisson distributions, the difference of protons and anti-protons should distribute as a Skellam distribution [16], for which $\kappa\sigma^2$ is unity. A large deviation from constant as a function of $<N_{part}>$ and collision energy for $\kappa\sigma^2$ may indicate new physics, such as critical fluctuations.

4. Summary and Outlook

Higher moments of the distribution of conserved quantities are predicted to be sensitive to the correlation length at QCP and to be related to the susceptibilities computed in Lattice QCD. Various non-QCP models (AMPT, Hijing, Therminator, UrQMD) have been applied to study the non-QCP physics background effects on the high moments of net-proton distributions. The centrality evolution of the high moments from models can be well described by the scaling derived from the *IIES* assumption and the moment products $S\sigma$, $\kappa\sigma/S$ and $\kappa\sigma^2$ of net-proton distributions are constant with respect to $< N_{part} >$. $\kappa\sigma^2$ is also found to be constant as a function of energy for various models.

Our model study can serve as a background study of the behavior expected from known physics effects for the RHIC beam energy scan, that will span values of μ_B from 100 to about 550 MeV. The presence of a critical point in that region may result in non-gaussian fluctuations and in correlated emission. Then the *IIES* assumption will break down. This is expected to lead to non-monotonic behavior of the observables studied here as a function of collision energy.

Acknowledgments

This work was supported in part by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and National Natural Foundation of China under Grant No. 10835005. BM thanks the Department of Atomic Energy, Government of India for financial support.

References

[1] Adams J *et al.*, 2005 *Nucl. Phys.* A **757** 102; Luo X F *et al.*, 2009 *Physics Letters* B **673** 268; Mohanty B, 2009 *Nucl. Phys.* A **830** 899C.
[2] Aoki Y *et al.*, 2006 *Nature* **443** 675; Cheng M 2006 *Phys. Rev.* D **74** 054507.
[3] Ejiri S, 2008 *Phys. Rev.* D **78** 074507; Bowman, E S, Kapusta J I, 2009 *Phys. Rev.* D **79** 015202.
[4] Stephanov M, 2005 Int. J. Mod. Phys A **20** 4387; Fodor Z *et al.*, 2004 *JHEP* **0404** 50; Gavai R V, Gupta S, 2008 *Phys. Rev.* D **78** 114503; de Forcrand Philippe and Philipsen O. 2002 Nucl. Phys. B **642** 290.
[5] Abelev B. I. et al., arXiv:0909.4131; STAR Internal Note - SN0493, 2009.
[6] Stephanov M A *et al.*, 1999 *Phys. Rev.* D **60** 114028; Berdnikov B and Rajagopal K, 2000 *Phys. Rev.* D **65** 105017.
[7] Stephanov M A, 2009 *Phys. Rev. Lett.* **102** 032301.
[8] Cheng M *et al.*, 2009 *Phys. Rev.* D **79** 074505.
[9] Hatta Y and Stephanov M A, 2003 *Phys. Rev. Lett.* **91** 102003.
[10] Asakawa M, arXiv:0904.2089.
[11] Liu Z W *et al.*, 2005 *Phys. Rev.* C **72** 064901.
[12] Gyulassy M and Wang X N, 1994 *Comput. Phys. Commun.* **83** 307.
[13] Petersen H *et al.*, arXiv:0805.0567.
[14] Kisiel A *et al.*, 2006 *Comput. Phys. Commun.* **174** 669.
[15] Abelev B. I. *et al.* (STAR Collaboration), 2008 *Phys. Rev.* C **77** 54901.
[16] Skellam J G, 1946 *Journal of the Royal Statistical Society* 109 296.