# Higher moments of net-charge multiplicity distributions in $Au + Au$ collisions in PHENIX experiment at RHIC

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The phenomenology of Quantum Chromodynamics (QCD) at finite temperature (T) and baryon number density is one of the least explored regimes of the theory. QCD predicts a phase transition from hadron gas (HG) phase to quark gluon plasma (QGP) phase at high temperature and/or baryon density, although the exact nature is still not established. However, various QCD based models indicate that at large net-baryon chemical potential ($\mu_B$) and lower T the transition from HG phase to the QGP phase is of first order. On the other hand, lattice QCD calculation with physical quark masses suggests that the phase transition at high T and lower $\mu_B$ could be a simple cross over. It further suggests that the first order phase transition line should end somewhere at finite $\mu_B$ and that point will be a critical point (CP).

Experimentally such a system of strong interactions can be created by colliding two nuclei at high energy. The variation of T and $\mu_B$ can be made available by varying the center of mass energy ($\sqrt{s_{NN}}$). Hence through relativistic heavy-ion collisions we can explore a two dimensional phase diagram, T versus $\mu_B$, of strong interactions.

Recently, it has been proposed that the higher moments of conserved quantities, such as net-baryon, net-charge and net-strangeness distributions are related to their corresponding thermodynamic susceptibility. As an example the third order charge susceptibility is $\chi^3_{(Q)} = \langle(\delta N_Q)^3\rangle\rangle/VT^3 \sim S$. Further, model calculations demonstrate that these susceptibilities and hence the higher moments are sensitive to the correlation length ($\zeta$), as $\langle(\delta N_Q)^3\rangle\rangle \propto \zeta^{4.5}$, which is expected to diverge at the QCD critical point. Therefore, any non-monotonic behavior of the experimentally measured higher moments with $\sqrt{s_{NN}}$ may lead to the location of QCD critical point, if it exists. Since the volume of the system is hard to determine experimentally and to avoid the volume fluctuations, the ratios of susceptibilities, such as $\frac{\chi^4_Q}{\chi^2_Q}$ and $\frac{\chi^3_Q}{\chi^2_Q}$ are used to compare with the experimental data as $\kappa\sigma^2 = \frac{\chi^4_Q}{\chi^2_Q}$.

Currently there is no systematic way of locating this point from first principle as model and lattice calculations face many challenges at finite $\mu_B$. Therefore, several experimental programs besides RHIC have been planned to perform heavy ion collision experiments to locate the QCD critical point.

This thesis attempts a systematic study of higher moments of net-charge multiplicity distributions in Au+Au collisions measured by PHENIX detector from $\sqrt{s_{NN}}$7.7 GeV to 200 GeV. Further, the statistical thermal model based conserved number fluctuation and the importance of detector efficiency is studied for higher moments. The thesis is organized in the following chapters:

**Chapter 1** gives an introduction of QCD phase diagram and QCD critical point. Also, an overview of present and future experimental facilities to explore the QCD phase diagram are discussed. Particular emphasis is given to Beam Energy Scan (BES) program at RHIC, as the data analyzed in this thesis is a part of this program at PHENIX.

**Chapter 2** briefly describes the Relativistic Heavy Ion Collider (RHIC), the experimental facility, dedicated to study the heavy ion collisions at Brookhaven National Laboratory (BNL), USA. Further, the PHENIX experiment and it's detector subsystems are intro-

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duced. More emphasis is given to the set of detectors used in this analysis.

Electron pairs or di-leptons in general are unique probe to study the hot and dense matter formed in relativistic heavy ion collisions at RHIC. But to reduce the background created by $e^+e^-$ pairs from Dalitz decay and $\gamma$ conversions, a Hadron Blind Detector (HBD) was proposed in PHENIX for electron identification in high-density hadron environment. Here, we also discuss the operational principle and performance studies of HBD carried out with p+p collisions at RHIC [1].

In **Chapter 3**, the moments and cumulants of the multiplicity distributions and their relations are discussed. Further, their connection to the thermodynamic susceptibilities of conserved numbers like net-charge($\Delta Q$), net-baryon($\Delta B$) and net-strangeness ($\Delta S$) is shown. Also, the method of calculating correlated errors and the efficiency corrections to the cumulants are described.

**Chapter 4** presents the details how the real data collected by PHENIX are being used for the analysis. Afterwords, centrality bin width effect, transverse momentum ($p_T$) dependence, acceptance ($\eta$ and $\phi$) dependence, track matching effects, effect of tracking efficiency, effect of collision vertex selection on various moments are studied. Besides, the effect of resonance decay on various moments with the help of **P**HENIX **I**ntegrated **S**imulation **A**nalysis (PISA) is analyzed to estimate the systematic errors.

**Chapter 5** contains the higher moment results of net charge($\Delta Q$) distributions and their product ($\frac{\sigma^2}{M}$, S$\sigma$ and $\kappa\sigma^2$) measured by PHENIX detector at RHIC. In this chapter the recent results of higher moments of net-charge multiplicity distributions for Au+Au collisions at $\sqrt{s_{NN}}$ varying from 7.7 GeV to 200 GeV measured by PHENIX detector are shown. The energy and centrality dependence of the higher moments and their products are also shown for the net-charge multiplicity distributions. The results are compared with the values obtained from different heavy-ion collision models [2].

In **Chapter 6**, net-baryon, net-charge and net-strangeness number fluctuations in high energy heavy-ion collisions are discussed within the framework of a Hadron Resonance Gas (HRG) model. HRG is a statistical-thermal model in which hadrons and resonances are treated as non-interacting and point-like particles in the present work. Resonances are included in the model to incorporate the attractive interactions among hadrons. We emphasize the importance of considering the actual experimental acceptances in terms of kinematics ($\eta$ and $p_T$), the detected charge state, effect of collective motion of particles in the system and the resonance decay contributions before comparisons are made to the theoretical calculations [3].

**Chapter 7** describes the importance of finite detector efficiency on higher moments. Further, it discusses a Bayesian method to obtain the event-by-event true distributions of net-charge from the corresponding measured distributions which are subjected to detector effects like finite particle counting efficiencies [4].

**Chapter 8** provides the summary and conclusions drawn from this thesis work and some future insights are also provided in this area of research.

## Acknowledgments

I acknowledges the financial support from CSIR, DST and UGC at various stage of my PhD program. Also, I am thankful to Prof. B. K. Singh (supervisor), Prof. C. P. Singh (co-supervisor), Prof. A. K. Mohanty (external supervisor), Prof. I. Tserruya, Prof. B. Mohanty, Dr. D. K. Mishra and Dr. P. K. Netrakanti for their kind support and encouragement.

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