Preface

One of the major challenges of present day fundamental research is to connect the science of 'small' with the science of 'Big'. While the standard model of elementary particles based on the principles of local gauge invariance provides us with a solid foundation of the former, the 'Big bang' cosmology based on the principles of general theory of relativity can to a large extent explain the latter. The approaches are quite different and could not so far be brought under a common theoretical framework. It is generally believed that the entire universe, i.e. the spacetime, all matter and radiation came into being through the fragmentation of a very hot and dense primordial 'fireball' created in the Big bang. It is necessary to understand how the universe evolved during those initial moments of its birth. As the baby universe expanded and cooled, it underwent through a number of symmetry breaking processes like, the electroweak symmetry, the color SU(3) gauge symmetry, the chiral symmetry, and the matter–antimatter symmetry. From the time of electroweak decoupling (some pico-seconds) to hadronization (about 10 μsec.) after the Big bang, the universe is believed to be filled up with a color conducting extended state comprising of weakly coupled quarks and gluons, a state popularly known as the quark-gluon plasma (QGP), and a state that can be characterized by using perturbative quantum chromodymanics (QCD). The universe that we live in today is overwhelmingly dominated by matter, which resulted from a very small aberration that took place during those early moments in the form of violation of CP symmetry. As our understanding of the fundamental laws of nature improves, and as newer experimental evidences allow us to modify and/or fine tune the theoretical concepts, we become more capable of looking back into those early evolutionary stages of the universe and unravel its mysteries with greater precision.

Soon after ideas like *asymptotic freedom* and *color confinement* were introduced, it was realized that the QCD vacuum can be heated to such high temperatures that some of the symmetries broken during the evolution of the primordial fireball can be restored, and a QGP-like state can be created even in a terrestrial laboratory when two heavy nuclei collide with each other at high energies, called the 'little bang'. Any such terrestrially created fireball will however not only be much shorter lived ($t \sim 10^{-22}$ sec.) and much smaller in dimension ($r \sim 10$ fm.), but it would also be of much less density and less temperature than the primordial one. It was primarily due to the works of R. Hagedron we later realized that a transition from the QGP to color neutral hadrons can be extended to much lower temperatures ($T \sim$ rest energy of a π-meson), that is far away from the asymptotic freedom and that needs to be treated by invoking non-perturbative QCD. As two nuclei impinge upon each other with high collision energies (say $\sqrt{s} \sim$ TeV), anti-quarks and quarks will be produced with equal abundance, and the valence quarks present in the incoming nuclei will constitute only a small percentage of the total number of particles present in the nuclear/partonic fireball. Under such circumstances we expect an equilibrated state of high temperature and low baryo-chemical potential (μ_B). On the other hand at lower collision energies (say $\sqrt{s} \sim 10$ GeV) the number of valence quarks present in the colliding nuclei will comprise a significant fraction of the total number of new quarks/anti-quarks created, and the intervening state, even though a color conducting one, should correspond to a lower temperature and higher value of μ_B. Such a state may prevail in the core of very compact astrophysical objects like neutron stars.

Over the last forty–fifty years an enormous amount of theoretical and experimental research have been undertaken in the field of high-energy heavy-ion interaction and QGP physics. Experiments have been performed by using various target-projectile combinations over a widely varying collision energies. New experimental facilities are still being created so that we get a complete ($\mu_B - T$) scan of the matter present in the fireball created in the little bang, or equivalently study the entire QCD phase diagram. On the theoretical side several signals that can identify the creation of a QGP-like state are suggested. Analysis of experimental data shows that perhaps the goal to create QGP in a terrestrial laboratory has already been accomplished. However, a complete characterization of such a short lived state extended only over an extremely minuscule of volume, is not an easy task. One has to understand that a high-energy heavy-ion interaction is a very complex dynamical process, where on an average a large number of background particles are produced, and an appropriate signal has to be filtered out only after eliminating a large amount of noise. Many of the theoretical predictions are based on lattice QCD (LQCD) calculations, which works well at high T and $\mu_B \approx 0$. At non-zero μ_B, LQCD has its own problems, a satisfactory solution for which is not yet found. Overall high-energy heavy-ion interaction is an exciting area of physics that needs command over several other areas like, nuclear physics, particle physics, astroparticle physics, theory of relativity, thermodynamics, statistical mechanics, relativistic fluid dynamics etc..

In a high-energy nucleus-nucleus (AB) collision a large number of new particles are produced, most of them are pions, and the phenomenon is known as multiparticle production. Till date the physics of multiparticle production is also not very comprehensively understood. Because of its implicit complexities, the problem needs to be probed from all possible angles. A lot of information related to the dynamics of multiparticle production can be extracted by studying the global properties of high-energy interaction like multiplicity distribution, rapidity distribution, transverse momentum distribution etc., or by studying the local properties like fluctuations in number densities. In the year 1983 an important observation was made by the JACEE collaboration, where unnaturally large fluctuations in produced particle rapidity distributions were found in some cosmic-ray events, that cannot simply be an artifact of statistical coincidence. It has also been shown that the dynamical components of these unusually large particle density values, irrespective of their exact analytical form, abide by a power-law type of scale invariance with decreasing phase space resolution size. This observation lead to a paradigm shift in multiparticle research from studying global properties to studying local variables that are confined within limited regions of phase space. Various speculative proposals, conventional as well as exotic, have so far been put forward to explain this fluctuation phenomenon.

To characterize the particle density fluctuation and cluster formation we need to use suitable statistical tools. In this thesis we have used some of these methods and analyzed nuclear photo-emulsion data on the angular distribution of singly charged particles produced in a fixed target experiment on ^{28}Si-emulsion interaction at an incident energy of 14.5A GeV (Experiment No. E847 performed at the Alternating Gradient Synchrotron at the Brookhaven National Laboratory by the SUNY at Buffalo, USA, group). The experimental results are systematically compared with a Monte-Carlo model simulation based on Ultra-relativistic Quantum Molecular Dynamics (UrQMD). On a few occasions the ^{28}Si-Ag/Br results are also compared with ^{32}S-Ag/Br results at an incident energy of 200A GeV. The thesis starts with a brief introductory discussion on AB interaction at relativistic energy, where some qualitative description of the QGP state and the global scenario of past, present and future experimental facilities are reviewed. Some aspects of multiparticle data analysis techniques have been summarily outlined. In chapter two we briefly discuss the nuclear emulsion technique, the data collection process and the simulation method(s) adopted in the present investigation. The UrQMD model along with a charge reassignment algorithm that mimics the Bose-Einstein correlation as an after burner to the UrQMD output, have been outlined. Gross features of the data are also listed in this chapter. Based on the statistical techniques like intermittency, erraticity and multifractality, we present some results on different multiplicity moments and the scaling relations followed by them respectively, in chapter three, four and five. Each of these techniques deals with fluctuation study of particle densities in limited phase space intervals. In chapter six and seven we present our results, respectively on unusual azimuthal structure formation and wavelet analysis, where corresponding results of ^{32}S-Ag/Br interaction at 200A GeV are also incorporated. We have also performed a collective flow analysis of our ^{28}Si-Ag/Br data and compared them with those of ^{84}Kr-Ag/Br data at an incident energy of 1.52A GeV. However, to follow a convention of our university, in stead of discussing this work in a separate chapter, we have attached the corresponding photocopy of the published paper at the end. We conclude by making some critical observations on the major results of the entire investigation and have tried to identify some prospective areas of further study.

This thesis is based on my research efforts spanned over a period of last five years or so in the field of relativistic AB collision. In addition, at present I am also working on the multifractal characteristics of the time series data of different observables. So far I have eighteen (18) publications to my credit (as an author and/or a co-author), and nine (09) of them that constitutes the body of this thesis are listed below.

1. *Intermittency and erraticity of charged particles produced in ^{28}Si-Ag/Br interaction at 14.5A GeV* – P. Mali, A. Mukhopadhyay and G. Singh, *Can. J. Phys.* **89**, 949 (2011).

2. *Factorial correlator and short-range correlation of charged particles produced in ^{28}Si-Ag/Br interaction at 14.5A GeV* – P. Mali, A. Mukhopadhyay and G. Singh, *Phys. Scr.* **85**, 065202 (2012).

3. *Self-affine two-dimensional intermittency in ^{28}Si-Ag/Br interaction at 14.5A GeV* – P. Mali, A. Mukhopadhyay and G. Singh, *Acta. Phys. Pol.* **B 43**, 463 (2012).

4. *Multifractal analysis of charged particle distribution in ^{28}Si-Ag/Br interaction at 14.5A GeV* – P. Mali, A. Mukhopadhyay and G. Singh, *Fractals*, **20**, 13 (2012).

5. *Wavelet analysis of shower track distribution in high-energy nucleus-nucleus collisions* – P. Mali, S. Sarkar, A. Mukhopadhyay and G. Singh, *Adv. High Ener. Phys.*, **2013**, 759176 (2013).

6. *Azimuthal structure of charged particle emission in ^{28}Si-Ag(Br) interaction at 14.5A GeV and ^{32}S-Ag(Br) interaction at 200A GeV* – P. Mali, A. Mukhopadhyay and G. Singh, *Int. J. Mod. Phys.* **E 23(5)**, 1450027 (2014).

7. *Multifractal detrended fluctuation analysis of phase-space fluctuation in relativistic nuclear collisions* – P. Mali, S. Sarkar, S. Ghosh, A. Mukhopadhyay and G. Singh, *Physica* **A 424**, 25 (2015).

8. *Multifractal detrended moving average analysis of particle density functions in relativistic nuclear collisions* – P. Mali, A. Mukhopadhyay and G. Singh, *Physica* **A** (in press, 2016) DOI: 10.1016/j.physa.2016.01.023

9. *Azimuthal correlation and collective behavior in nucleus-nucleus collisions* – P. Mali, A. Mukhopadhyay, S. Sarkar, G. Singh, *Phys. Atom. Nucl.* **78(2)**, 258 (2015).

Different chapters of the thesis is organized on the basis of the first eight (08) publications of the above list. However, as mentioned above, as per a norm of the University of North Bengal (UNB), which is to insert at least one reprint of the published papers, a photo-copy of the ninth publication is given at the end of the thesis. A full list of my publications is given in the list of publications section.

I would now like to take the opportunity to tie in some personal remarks. In the year 2006, I started my research career as a Junior Research Fellow at the Variable Energy Cyclotron Centre (VECC), Kolkata. At VECC I worked on low-energy experimental nuclear physics. Later in the year 2008 I moved on to join the Physics Department of UNB, and since the year 2010 I have been working on the physics analysis of experimental data on relativistic heavy-ion collision(s). The entire work presented here would have not been possible without the support, advice and encouragement that I have received from many persons during my research work. My primary thanks will go to my thesis supervisor, Professor Amitabha Mukhopadhyay of the Department of Physics, UNB for his guidance, encouragement and support. I deeply acknowledge the discussions I had with him right from my M.Sc. days, which kept me motivated all the time throughout my career. I would like to convey my sincere thanks to all my teachers and colleagues for their advice, support and words of encouragement. I express my deep sense of gratitude to Professor P. L. Jain of the State University of New York at Buffalo, USA for providing us with the emulsion plates and for allowing us to use the data collected thereof in the present investigation. My special thanks should also go to all my fellow friends of UNB. My friendship with Akhil, Souvik, Billo, Lal, Nairita, Rumisha and many others helped me to remain motivated during this challenging period. I wish to thank the supporting staff of the Department of Physics of UNB for their cooperation and help. I wish to take this opportunity also to thank my wonderful teachers at school and college who have inspired me at various stages of my life. I express my humble regards and sincere gratefulness to all my family members for their patience, love and continuous encouragement. Their inspiration and affection have helped me to overcome many hurdles in my life.

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