Concluding Remarks

This thesis is based on some statistical analysis of local density fluctuation and cluster formation of charged particles produced in high-energy nucleus-nucleus interaction(s). Experimental data on angular distribution of shower tracks coming out of ^{28}Si-Ag/Br interaction at an incident energy in the laboratory system $E_{\rm lab} = 14.5$A GeV are used. To understand the mechanism of multiparticle production we systematically compare the experimental results with those obtained from event samples simulated by a microscopic transport model namely the Ultra-relativistic Quantum Molecular Dynamics (UrQMD). For the first time in the history of AB collision, we have also implemented a charge reassignment algorithm that mimics the Bose-Einstein correlation (BEC) to the UrQMD output in the form of an after burner. It has to be however remembered that a real BEC can be incorporated into any model only by appropriately symmetrizing the underlying bosonic fields, which is an extremely difficult task. On more than one occasion our ^{28}Si-Ag/Br results are compared with ^{32}S-Ag/Br results at $E_{\rm lab} = 200$A GeV, allowing thereby to examine the effect of different collision energies on colliding systems of more or less same geometrical size. Though at the end of each chapter a section is devoted to discuss the results obtained from a particular method of analysis, we thought that to conclude it would be prudent to summarize the major observations of the present investigation together, and put each of them under a close scrutiny. We are aware that multiparticle production is a soft hadronic process and pertains to very late stages of any high-energy AB collision. Therefore, only by using statistical tools it would be too ambitious a project to probe into the more interesting early evolutionary and/or thermodynamically equilibrated stages of the 'fireball'. Nevertheless, multiparticle production mechanism itself is a complex dynamical process that should be examined from different perspectives through a colliding system and/or collision energy scan.

First of all we observe that the total ^{28}Si-Ag/Br interaction cross-section at $E_{\rm lab} = 14.5$A GeV incident energy, is consistent with the prediction of a simple participant – spectator model. In this regard a small mismatch between the theoretical estimation and experimental observation can be attributed to personal errors, an aspect inherent to any emulsion experiment. As we have with us only a subsample of ^{28}Si-Ag/Br events and not the entire minimum bias sample, we have not presented any multiplicity distribution in the thesis. In emulsion experiments the criterion of selecting Ag/Br events ($n_h > 8$) excludes a significant fraction of Ag/Br events. The pseudorapidity distribution of the shower tracks (caused by produced charged mesons moving at relativistic speed) can be approximated by a Gaussian distribution. Corresponding UrQMD generated distribution also possesses this Gaussian nature, though there is a small overall shift between the centroids of the two distributions. The Bjorken's energy density, determined from the central pseudorapidity density of a sub-sample of high multiplicity ^{28}Si-Ag/Br events ($n_s > 50$) is very close to the LQCD estimated value ($\sim$ a few GeV/fm^3) needed to augment the transition from a color neutral hadronic state to a color conducting extended QCD state. However, the single Gaussian description of the pseudorapidity distribution(s) is(are) compatible to significant stopping of the projectile by the target, as expected at such collision energies ($E_{\rm lab} = 14.5$A GeV). Therefore, the fireball created in ^{28}Si-Ag/Br collision must be rich in baryon number. The experimental azimuthal angle distribution of shower tracks on the other hand is significantly different from the UrQMD generated one. The azimuthal asymmetry observed in the experimental distribution, can perhaps be attributed to a combination of two effects, (i) some dynamical effect – a collective behavior of shower track emission during the collision process, and (ii) experimental deficiency – small efficiency to detect shower tracks that are moving exactly towards or away from the observer's eyes.

Single particle density distribution of shower tracks in high multiplicity ^{28}Si-Ag/Br events exhibit random fluctuations consisting of sharp peaks and deep valleys. Using the technique of scaled factorial moments (SFM) we could characterize these fluctuations, apparently devoid of any regular pattern, in terms of a finite set of regularly behaving parameters. The SFM can by definition suppress any Poisson distributed statistical background (noise) present in the data. We could identify that the unusually large particle density values, irrespective of their exact analytic form, possess a dynamical component, which with decreasing phase space resolution size (δX) asymptotically approaches a singularity obeying a scale invariant power-law. The UrQMD generated sample does not exhibit any such behavior, i.e. no significant change in the SFM values with phase space resolution size. Even inclusion of BEC in the UrQMD output can only partially recover the power-law type of scaling in simulated data, and that too in the two dimensional analysis. Therefore, certain amount of correlated emission must be present in the experiment which is beyond the known sources of correlation like BEC. In the framework of a simple intermittency model (α model), we observe that within errors intermittency in the ^{28}Si-Ag/Br case is almost as strong as it is in the ^{32}S-Ag/Br case, and slightly stronger in ^{16}O-Ag/Br interaction at $E_{\rm lab} = 200$A GeV. Therefore, within the energy range $E_{\rm lab} \sim 10 - 100$A GeV, the size of the colliding objects has perhaps a greater influence on the intermittency strength than the collision energy involved. We also observe that in all interactions the intermittency effect in the azimuthal plane is consistently stronger than that on the pseudorapidity axis. This may be an outcome of the kinematic conservation laws (before collision such transverse degrees of freedom were absent), or a more complicated hitherto unknown dynamical reason. There is a definite indication of non-thermal phase transition in the intermittency pattern in the azimuthal plane. Another important observation is that, while the power-law type of scaling is self similar down to the experimental resolution in one dimension, it is self-affine in two dimension. In ($\eta - \varphi$ plane) self-similarity is retrieved only when independent phase space directions are partitioned differently by invoking an appropriate 'roughness' parameter (H). Two-dimensional intermittency is always stronger than one-dimensional intermittency.

The intermittency technique not only enables us to characterize the local particle densities belonging to a particular bin, but it also allows us to examine the bin-to-bin correlations in terms of the two fold SFM or factorial correlators. Our experimental results in this regard, namely the scaling-laws and sum rules etc., are in conformity with the α-model, and are indicative of short range correlation. UrQMD predictions, even after being supplemented by the BEC, fall short of the experiment. The correlation that we find in these analysis originates mainly from two or three particle correlation, while presence of genuine higher order correlations (of order more than three) are seldom statistically significant. We have also examined the event space fluctuation of the SFM called the erraticity analysis. In the SFM distribution we notice that while most of the single event SFM values are restricted within a small interval, some events have really high SFM values. It is speculated that this kind of event space fluctuation of SFM is chaotic in nature, and should be characterized in terms of a new set of moments called the erraticity moments. We found that the erraticity moments in ^{28}Si-Ag/Br interaction at $E_{\text{lab}} = 14.5$A GeV abide by appropriate scaling-law, and the corresponding erraticity parameters also behave as expected. Small difference between the experiment and simulation do exist, and the ^{28}Si-Ag/Br results are qualitatively similar to the ^{32}S-Ag/Br or ^{16}O-Ag/Br results reported earlier.

The self-similar nature of dynamical fluctuation as observed in our intermittency analysis, has inspired us to extend the scope of our investigation to the domain of fractals. Using several statistical techniques we have observed that the shower track distribution both in the experiment and in the simulation(s) are multifractal in nature. The methods of detrended multifractal analysis have so far not been very widely used for AB experiments. As far as multifractal patterns are concerned, on most of the occasions there is hardly any difference between the experiment and the corresponding simulation. There may be more than one reason behind this kind of apparent anomaly between the intermittency results which show some degree of correlated emission in the experiment, and the multifractality results which to a large extent agrees with the uncorrelated UrQMD data. One reason may be that the techniques of multifractal analysis adopted are not very sensitive to correlated emission. The second reason may be that in multifractal analysis there is no robust technique of eliminating the statistical noise from the data. Only when we take into account the random number generated mass exponent τ_q^{sta}, the (multi)fractal parameter $(q-1-\tau_q)$ drops down very close to its equivalent quantity, the intermittency exponent (ϕ_q). The third reason may be that the fractal nature of a distribution should actually be examined under the limiting condition $\delta X \rightarrow 0$, which because of the finite event multiplicity cannot in practice be achieved in any real experiment. Notwithstanding these shortcomings it is worthy to mention that there are statistically significant differences in the multifractal singularity spectra and in the generalized dimension values, obtained from the experiment and generated by the simulation. The experimental singularity spectrum is always wider than the simulated one, while the experimentally obtained generalized dimensions change with the order of the (multi)fractal moments and are always smaller than the corresponding UrQMD simulated values. The simulated generalized dimensions also do not always change significantly with its order, and they are closer to the topological dimension of the supporting space.

We have also tried to find out unusual structures in the azimuthal distribution (if there is any) of shower tracks coming out of ^{28}Si-Ag/Br events at $E_{\rm lab}$ = 14.5A GeV, compared the results with those of ^{32}S-Ag/Br events at $E_{\rm lab}$ = 200A GeV as well as with the BEC supplemented UrQMD and RQMD generated events. Except for observing strong correlation(s) in the central particle producing region and occasional formation of jet-like structures, nothing very unusual was found from this analysis. The difference(s) between experiment(s) and simulation(s) is/are often very small. Once again the methodology itself does not allow us to be very conclusive about the probable mechanism(s) of formation of such unusual azimuthal structure(s). Our wavelet analysis of ^{28}Si-Ag/Br and ^{32}S-Ag/Br data once again shows that clusters of particles are formed at different locations on the pseudorapidity axis and at different scales of resolution. The wavelet technique has also not so far been used in many AB experiments, and probably there has so far not been any comparison with any simulated result. The experiments differ from the corresponding UrQMD or UrQMD+BEC predictions. Therefore, with all probability the clusters result from some nontrivial dynamics other than the BEC. As per a norm of our university, at the end we have attached the reprint of one of our published papers on collective flow analysis on ^{28}Si-Ag/Br interaction at $E_{\rm lab}$ = 14.5A GeV, measured the flow angles and flow parameters, and compared the results with those obtained from ^{84}Kr-Ag/Br interaction at $E_{\rm lab}$ = 1.52A GeV. Though collective emission of particles is present in both cases the Kr-induced experiment behave in a more systematic manner, and the present results are consistent with those obtained from previous such similar experiments.

The thesis contains some new results on multiparticle emission data obtained from some conventional as well as some not so frequently used statistical tools. An effort however small it may be, has been made even to modify the simulation technique employed. In view of the upcoming CBM experiment to be held at FAIR, GSI, Germany, designed to study baryon rich 'fireballs' produced in AB collisions, in near future these results may eventually come out to be more than useful. In spite the best of our intentions there is no denial that several physics outputs of the present investigation could be put forward only in the form of conjectures. If it were not for the constraint imposed by limited statistics and experimental technique, we could have been more confident and more specific about our conclusions, e.g. by studying the centrality dependence and/or the dependence on the number of binary NN collisions involved in AB collision. As a final statement, one may say that with the advent of new and more sophisticated detecting devices the days of nuclear emulsion technique as an effective tool of experimental nuclear/particle physics research may be numbered, but there are still some scopes of using this age old technique where event statistics is not a very important factor, but direct observation and spatial resolution are.