NON-STATISTICAL FLUCTUATION OF SINGLY CHARGED PARTICLES PRODUCED IN ^{16}O-Ag/Br INTERACTION AT 200A GeV/c

ABSTRACT

One of the major objectives of doing research in the field of high-energy heavy-ion physics is to study the properties of nuclear matter under extreme thermodynamic conditions. It is generally held that nucleons, i.e. color neutral baryons, if and when subjected to very high temperature and/or pressure, are going to loose their individual identities and melt into a soup of more fundamental constituents of matter namely, the quarks and gluons. Depending upon the initial conditions of the collision, a quark-gluon matter may equilibrate to form a transient state called the quark-gluon plasma (QGP). With evolving time such a state expands and cools down, and ultimately freezes out to form a number of color neutral hadrons in the final state of the collision. It is claimed that a strongly interacting quark-gluon state at a high-temperature and low baryon density, has already been created in the heavy-ion experiments held at the Relativistic Heavy-ion Collider (RHIC), and Large Hadron Collider (LHC). It is however not the case that a higher energy will necessarily favor a QGP formation. In this regard issues like baryon stopping and nuclear transparency have serious implications. It has been speculated that a QGP at a high baryon density can be created even at a lower temperature than that produced in the RHIC/LHC. In this context experiments involving lower collision energies and analysis of the data obtained thereof have their importances.

The present thesis is based on some results obtained from a series of analysis made on the local structures of the phase space distribution of singly charged particles produced in ^{16}O-Ag/Br interaction at an incident momentum $p_{\rm lab} = 200A$ GeV/c. The experimental data used in this investigation have been collected from a nuclear emulsion experiment (EMU-08) held in the year 1987 at the Super-Proton Synchrotron of CERN, Geneva. We have systematically examined various issues related to multiparticle production like, (i) the dynamical fluctuations present in the pseudorapidity (η) and azimuthal angle (φ) distributions, (ii) the self-similar and/or self-affine behavior of such fluctuations with diminishing phase space resolution, (iii) correlations between particles present in different phase space points, (iv) (multi)fractal nature of the dynamical fluctuations, (v) presence of unusual structures in the η and φ-distributions and cluster formation, and (vi) correlation among particles produced in the forward and backward η-hemispheres. The experimental results have been systematically compared with a microscopic transport model known as the ultra-relativistic quantum molecular dynamics (UrQMD). In addition, we have implemented a charge reassignment

algorithm that mimics the Bose-Einstein Correlation (BEC) between identical mesons as an after burner to the UrQMD output. On several occasions we have also compared the experimental results with those obtained from the ^{32}S-Ag/Br interaction at $p_{\rm lab} = 200A$ GeV/c. We summarize below the contents of different chapters presented in this thesis.

In **Chapter 1** we have qualitatively reviewed various aspects of high-energy nucleus-nucleus (AB) collisions. The importance of AB collision in the context of QGP formation in laboratories, gross physical properties of the QGP along with its astrophysical and cosmological relevances have been summarily discussed. The kinematic variables that are used to formulate the dynamics of an AB collision are systematically introduced. Different stages of the space-time evolution of AB collision are serially outlined. The QCD phase diagram (*temperature – chemical potential* plot) has been explained in the context of a QGP $\rightarrow$ hadron transition and some other phases that may be created in AB collisions under different kinematic conditions. The global scenario of AB collision experiments is summarily discussed. Some general features of the QGP, like its thermodynamics, hydrodynamics, observables that can be used to diagnose the QGP formation etc., are summarily described. Major experimental signatures of the QGP formation in high-energy AB collisions are summarily described. A review of the experimental results on global features of multiparticle emission in AB collisions has been summarized.

In **Chapter 2** we have discussed some salient features of the nuclear emulsion technique, like the scanning of emulsion plates, track formation and track structure, track selection and event selection criteria, and angle measurement etc.. The present investigation is confined only to the distributions of shower tracks, i.e. singly charged particles moving with relativistic speed, produced in the ^{16}O-Ag/Br interaction at $p_{\rm lab} = 200A$ GeV/c. Gross characteristics of the experimental data, like the η-distribution, φ-distribution and distribution of the pseudorapidity density $\rho = N_{ev}^{-1}\,(dn_s/d\eta)$ of the shower tracks coming from ^{16}O-Ag/Br interaction, are presented in this chapter. For comparison, similar results obtained from the ^{32}S-Ag/Br interaction at the same incident momentum per nucleon have also been incorporated. A charge reassignment algorithm that can mimic the Bose-Einstein correlation into the UrQMD output has been described. Distributions obtained from the event samples generated by the UrQMD and modified by the charge reassignment algorithm, have also been shown for comparison. The simulation results reasonably well match the gross features of corresponding experiments.

Chapter 3 presents the results obtained from an intermittency analysis of the spatial fluctuations of shower track densities in the ^{16}O-Ag/Br interaction at $p_{\rm lab} = 200A$ GeV/c. The intermittency analysis is performed by evaluating the scaled factorial moments (SFMs) in the η-space, in the φ-space and in the (η, φ)-plane. Our analysis shows that dynamical components in particle density fluctuations are present in η, φ and (η, φ) spaces. We find

that in one dimension such fluctuations are self-similar in nature, while the same is self-affine in two-dimension. Factorial correlators, cumulant moments and oscillatory moments are some other issues that are closely related with the intermittency analysis. Our results on factorial correlators indicate that short range correlations among the shower tracks are present not only in narrow phase space intervals but also in intervals that are separated by a distance along the pseudorapity axis. The results are consistent with the predictions of a simple intermittency (α) model. Oscillatory moments on the other hand are derived from the factorial cumulants, where correlations present in every higher order moment are made free from those coming from the corresponding lower order moments. The observation is consistent with the prediction of a QCD parton shower model. In almost all cases the UrQMD simulations can not match the experimental results on intermittency and related issues. Inclusion of BEC in the simulation does not significantly improve the situation either.

While most of the SFMs calculated for individual events are not large valued, SFMs with very large values are not very rare to find out. These large valued SFMs result from high multiplicities in narrow phase space intervals. We have calculated the SFMs on an event-by-event basis and studied their fluctuations for the ^{16}O-Ag/Br event sample in terms of the erraticity moments and erraticity parameters. The results obtained from erraticity analysis are also incorporated in **Chapter 3**. We find that the event space fluctuations of the SFMs are chaotic in nature, both in experiment and in simulation. In this regard the ^{16}O-Ag/Br and ^{32}S-Ag/Br experimental data do not behave very differently. The simulation produces significantly smaller values of chaoticity parameter than the respective experiment.

We have characterized the self-similar nature of η-density of particles in terms of the multi-fractal moments and presented the results obtained from this analysis in **Chapter 4**. Several methods of analysis like (i) Hwa's moments, (ii) Takagi's moments, (iii) the multifractal de-trended methods, and (iv) the visibility graph & sandbox algorithm have been adopted in our analysis. We find that our experimental data on the ^{16}O-Ag/Br and ^{32}S-Ag/Br interactions can be described in terms of a set of regularly behaving multifractal parameters, but so can be the simulated data too. If multifractality is really an outcome of some kind of hadronic or partonic cascading process, then this should not be the case. We have noticed that none of these methods can filter out the statistical noise present in the experimental data. However, the outcome of our visibility graph (VG) analysis is quite different from those obtained from the other methods. In the VG method statistically significant differences in the multifractal spectra between the experiment and respective simulation are observed. Large fluctuations in the density values that are not very frequently available, are multifractal in nature, whereas more abundant small fluctuations are found to be almost monofractal.

In **Chapter 5** we have looked for clusters of particles in the η and φ-distributions of the shower tracks. Presence of ring and/or jet-like structures is predicted as a possible outcome of Cerenkov gluon emission and/or Mach shock wave formation in the nuclear/partonic medium. Shower track emission data in the ^{16}O-Ag/Br and ^{32}S-Ag/Br interactions at 200A GeV/c are analyzed to find out jet/ring-like structures. Jet structures restricted within narrow regions of (η, φ) are found in our data. Such structures are more pronounced in the ^{32}S-Ag/Br than in the ^{16}O-Ag/Br interaction. In this chapter we have also presented a continuous wavelet analysis of the shower track η-distributions. Presence of cluster structures in the experimental data is confirmed from this analysis. The scale and location of such clusters are determined. Statistically significant differences between the experiment and respective UrQMD simulation are found.

In **Chapter 6** short and long-range correlations in the shower track emission data have been examined. Relative covariances of shower track multiplicities in the η-windows located in the forward and backward hemispheres are measured by varying the separation between the windows and the window size. Evidences of short range correlations have been confirmed from the study, which could not be reproduced either by the UrQMD or the UrQMD+BEC simulations. Such correlations are more pronounced in the ^{32}S-Ag/Br data than in the ^{16}O-Ag/Br data. This chapter also presents a study on a roughness parameter associated with the η-distributions of the shower tracks. Presence of large particle concentrations within narrow η-intervals is verified by using this method. The data have been analyzed in terms of the ω-measure and Φ-measure. The results indicate the presence of non-Poissonian multiplicity distributions in narrow η-intervals, and presence of short range correlations. We find that the AB collisions considered in this analysis are not mere incoherent superpositions of many nucleon-nucleon collisions.