Concluding Remarks

The general conclusions that one can draw from both theoretical and experimental pursuit in high-energy heavy-ion research for over three decades, can now be briefly summarized. Finite temperature lattice QCD has confirmed that for vanishing baryon density, at a critical temperature $T_c \approx 150 - 180$ MeV, strongly interacting matter undergoes a transition from a medium of colour singlet hadronic constituents to one of deconfined coloured quarks and gluons [1]. The transition turns a hadronic state of spontaneously broken chiral symmetry, into one where this symmetry is restored (QGP). Experimental evidences on high-energy AB collisions suggest that the onset of deconfinement starts at low SPS energies [2]. An initial energy density $\epsilon_i \approx 250$ GeV/fm^3 could possibly be reached at the moment of maximum nuclear overlap in central ^{197}Au+^{197}Au collisions with $\sqrt{s_{NN}} = 200$ GeV at the RHIC. The corresponding value for central ^{208}Pb+^{208}Pb collisions at LHC would be around $\epsilon_i \approx 7500$ GeV/fm^3. One can compare these values with the critical energy density required for a QCD phase transition, which is $\epsilon_c \approx 1 - 10$ GeV/fm^3. It is expected that at such high energies, relativistic hydrodynamics can describe the space-time evolution of AB collision. Typical expected values for different stages of space-time evolution of AB collisions are about $0.1 - 0.3$ fm for the pre-equilibrium stage, about $1 - 5$ fm for the plasma phase, and $20 - 40$ fm for the freeze out stage [3]. As far as QGP is concerned it would not be improper to say that, a QGP like state has perhaps already been created. However, only at the LHC energy such a state is expected to be sufficiently dense and long lived, so that its existence can be identified without any ambiguity. In the following subsections we have tried to briefly outline the lessons we have learned from the experiments performed during the AGS - SPS era, from those in the RHIC, and from our own investigation in one of the SPS experiments on dynamical fluctuation of produced charged particles.

AGS - SPS lessons: The major findings of the experiments performed using BNL-AGS and CERN-SPS facilities can be summarized in the following way [4, 5].

1. The initial energy densities measured in different AGS and SPS experiments lie somewhat within the range of $\epsilon_i \approx 1 - 3.5$ GeV/fm^3, a value exceeding the threshold of deconfinement. As expected ϵ_i has been found to increase with the centrality of the collision. The apparent temperature obtained from the transverse mass distributions of different hadrons, appeared to increase with the particle mass. Such observation allows us to determine the freeze out temperature and transverse flow velocity. At SPS in Pb+Pb collisions, it was found that freeze out takes place at about 140 MeV, and the central region is expanding at about half the velocity of light.

2. The observed dilepton invariant mass spectrum in the region between ϕ and J/psi mesons showed an excess over the cocktail of different known lepton pair production processes. Such excess has been attributed to thermal emission, only a small fraction of which actually originates in the hot early stage of the evolution. It does not necessarily require a QGP scenario to explain the experimental results in this regard. Some photon excess over that coming from known hadronic decays have been observed. The interpretation still remains an open issue.

3. J/psi production has been found to be suppressed in different light and heavy-ion induced experiments. The suppression always increases with centrality of the collision. In central Pb-Pb collision at the SPS an additional anomalous suppression has been observed. This observation is probably the first signal for colour deconfinement through parton condensation, which does not require any thermalization.

4. Hadron abundances showed expected enhancement in strangeness production. The enhancement increases with the strangeness content of the particles. The yield per unit rapidity per participant relative to the corresponding pA yields has been found to be ≈ 15 times larger in central Pb+Pb collisions for $\Omega^-, \bar{\Omega}^+ : \ |S| = 3$. No model could explain the full spectrum of abundance of different strange hadrons.

5. Results on HBT correlation study did not show the expected increase of source radii with increasing collision energy. The source radius is essentially determined by the initial nuclear size and is independent of collision energy. From AGS to SPS and from Au+Au

to Pb+Pb, in contrast to larger expected values $R_{side} \approx R_{out} \approx 5-6$ fm has been found. As H. Satz pointed out [4], at SPS the colour deconfinement seems to occur at the beginning of the collision evolution, and thermalization along with collective behaviour at the end. For QGP formation we need both to occur at the early stage of collision.

RHIC lessons: The matter created at the RHIC behaves almost like a perfect fluid, low on its viscosity. The RHIC data also conclusively indicated occurrence of a striking set of new phenomena. Some of the major observations of RHIC experiments are once again summarily furnished below [5, 6].

1. Transverse momentum spectra of hadrons of different species showed interesting features. The $\bar{p}$ yield is comparable to the p yield, and the yield ratio seems to be constant up to $p_t \sim 4$ GeV/c. Both the p and $\bar{p}$ yields are comparable to the π yield at and around $p_t \sim 2$ GeV/c. For $p_t > 2$ GeV/c a significant fraction of total particle yield comes from baryons.

Besides the above, strong suppression in different hadronic p_t spectra has been observed in central Au+Au collisions at RHIC. The invariant differential cross-section scaled with the average number of binary NN collisions and the corresponding NN cross-section, differ significantly from unity in central AA collisions. The observation is consistent with the predicted energy loss of the parent light quarks and gluons due to induced gluonic radiation, when they traverse the dense coloured medium.

2. An elliptic flow resulting from a pressure gradient developed in the almond shaped collision zone is another interesting phenomenon observed in the RHIC. The data showed an evidence of fast thermalization, a critical pre-requisite of QGP formation, is achieved. A common collective flow velocity was observed for hadrons of different species. The observation is consistent with a perfect fluid model [7].

3. Another exciting phenomenon observed in the RHIC was the suppression of back to back jet-like correlation. In contrast to the observations from d+Au and pp collisions, the away side dihadron azimuthal correlation at $\Delta\varphi \approx \pi$ disappears in central Au+Au collisions. Such a conical configuration may be an outcome of fast jet movements in a fluid medium, where either Mach type or Cerenkov type shock waves are generated. The structure of the away side azimuthal correlation is consistent not only with conical emis-

sion, but also with other interpretations.

4. RHIC results obtained from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV on the dynamical fluctuation of net electrical charge of a particular hadron species (say pion) show a strong dependence on the centrality of the collision. Lattice QCD calculations predict an enhanced charge fluctuation for hadronic phase, and a suppression of the same in QGP phase. The measured values of fluctuation are larger than the predicted value from charge conservation, and they are close to the prediction of a resonance gas picture. From top SPS energy to RHIC, the extent of dynamical net charge fluctuation remains essentially unaltered with collision energy. Thus significant suppression in the net charge fluctuation is yet to be observed. Higher order moments of net charge distribution may yield significant results.

5. The J/psi suppression at RHIC was expected to be larger than that observed in the SPS. Experimentally no additional suppression could be found. Two possible interpretations for this can be given - (i) regeneration of bound charm pairs during the late expansion stages that experience large production of charmness at high density, and (ii) the observed suppression in the SPS is probably a result of screening of higher mass resonances like the ψ', χ_c. One will have to wait for the LHC results to confirm one possibility or the other.

In RHIC experiments it has thus been demonstrated that in comparison to elementary NN collision, in AA collision there exists a universal suppression of high p_t hadron production, which indicates the presence of a dense colour deconfined medium. The azimuthal asymmetry occurring as a result of opposite side jet quenching mechanism, can be utilized to verify the QCD law on energy loss of leading partons in a deconfined medium [8].

Lessons from the Present Investigation: The present analysis of a sample of central and semi-central ^{32}S-Ag/Br events at 200A GeV/c, shows several interesting features on dynamical fluctuation of produced charged particles within limited phase-space intervals. From the three different statistical methods adopted in our investigation namely intermittency, multifractality and erraticity, major observations of our analysis have once again been briefly discussed below.

Presence of weak intermittency, beyond a simple Bose-Einstein type of correlation between like sign charged particles, has been established. The computer code FRITIOF based on the Lund string fragmentation model on AB collision, could not account for the observed effect. Presence of higher order (more than two particle) correlation could be found from our result on normalized exponents. The factorial correlator analysis shows that the bin to bin correlations are short ranged. A critical examination of the intermittency index leads to conclude that, (i) it's neither necessary to invoke a QCD second order phase transition nor to assume an intermixing of different phases to interpret the observed behaviour, and (ii) probably there has not been a Landau-Ginzburg type of phase transition either [9]. Another important result of the present investigation is the Levy index ($\mu \approx 1.2$), that not only indicates presence of non-Poisson type wild singularities in the phase-space distribution of produced particles, but also characterizes a hierarchical pattern between correlations of successive order. The intermittency phenomenon is not dimension independent. An extension of the technique to 2-d revealed stronger intermittency effects. In stead of the originally proposed self-similar nature of dynamical density fluctuation [10], the observed behaviour of SFM in 2-d has been interpreted in terms of self-affinity. This is a consequence of anisotropy in distributions along different (η and φ) directions. Using a Hurst parameter the extent of anisotropy could be reduced with unequal partitioning of phase-space interval in different directions. Exact reasons for the observed dynamical fluctuations are not clear from the above analysis. As mentioned above, some of the possibilities can be excluded. Whereas, a few other like the intranuclear cascade mechanism or the non-thermal phase transition, or both, can be put in a conjectural form as possible mechanisms behind the observed behaviour of our data [11]. In intermittency analysis there is enough evidence of multifractal structures being involved in the spatial distribution of shower tracks in our event sample. When subjected to specific multifractal methods of analysis, the ^{32}S-Ag/Br data show expected behaviour. A multifractal spectrum, the anomalous Renyi dimensions, and the multifractal specific heat are some of the major outcomes of the analysis. The multifractal specific heat obtained from our analysis though reinforces the idea of multifractality in particle density distribution, it does not possess the same universal value as claimed in [12]. The event space fluctuation of SFM has been studied with the help of erraticity technique applied to the η distribution as well as X_η gap distribution. The results are qualitatively consistent with the expectation and they are also in agreement with other results on AB collision. All erraticity parameters are obtained, most important of which is the entropy index $\bar{\mu}_q$. A smooth model like the FRITIOF code fails to replicate the experimental results on erraticity.

While looking for dynamical fluctuations in narrow phase-space regions several precautions should be taken. As has been pointed out in [9] the causes that can influence our result, are either automatically taken care of in the emulsion technique itself, or they are accommodated in our bias of event sample and methods of analysis. The emulsion technique does not allow us to determine the p_t and charge values of produced particles. These factors desisted us to draw strong conclusions from the analysis of our data. However, there are a few scopes of improvement (which is always there!), that can be taken up in future investigations. One can accumulate a larger statistics and study the effect of centrality of collision by extending the analysis to smaller subsamples of events (see Chapter 2) of differing $< n_s >$ values. One can also use other event samples and event generators e.g., UrQMD, and compare their predictions with those of the present data set.

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