The study of strangeness in exploring the QCD phase diagram

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One of the goals of relativistic heavy ion collisions is to create quark gluon plasma(QGP) and to understand the quantum chromodynamic(QCD) phase transition. Several experiments have been performed at Alternating Gradient Synchrotron(AGS), Super Proton Synchrotron(SPS), Relativistic Heavy Ion Collider(RHIC) and at the Large Hadron Collider(LHC). Some future experiments are also planned at Facility for Antiproton and Ion Research(FAIR), NICA etc. Both experimental and theoretical investigations are on to analyse the spectra of particles (photons, leptons and hadrons). In this talk, the study of strangeness in exploring the QCD phase diagram would be discussed.

1. Introduction

Collins and Perry in 1975 predicted a super dense matter in the form of quark soup when density exceeds that of normal nuclear matter[1]. Again, the first principle quantum chromodynamics(QCD) calculation based on lattice computation also predicts a plasma of quarks and gluons at high temperature and zero baryon chemical potential[2, 3]. Such a super dense and hot state is expected to have been existed in the universe after few microseconds of the Bigbang. The whole universe was in that state. The core of the neutron star is also proposed to have super dense quark matter. The hunt for the search of such hot-dense quark matter phase started towards the end of the last century. Several experiments were performed by colliding large nuclei at ultra relativistic energies at Super Proton Synchrotron(SPS), Relativistic Heavy Ion Collider(RHIC) and at the Large Hadron Collider(LHC). Experimental observations suggest that quark gluon plasma(QGP) is formed in relativistic heavy ion collisions at top SPS [4], top RHIC [5]and at LHC energies. From the observations, it is known that a strongly coupled QGP- a non-abelian fluid, is produced.

Intense theoretical research has also been complemented to understand the properties of QGP phase. Nucleons within the relativistically accelerating nuclei when collided as projectile with similar target system, quarks which are the constituents of nucleons may get liberated beyond certain threshold energy and may create QGP. Equilibrium matter both in the form of quarks or nucleons(hadrons) constitute different QCD phases. This is the subject of our interest. The collisions of two nuclei at high energies thus provide the opportunity to study the dynamics of a non-abelian fluid like QGP and also the QCD phase diagram.

Several signals were proposed to detect quark matter in heavy ion collisions and to understand its thermodynamic properties. Study of strangeness in this regard play a crucial role to understand QCD matter in different phases-hadronic and quark gluon plasma[6].

N. Cabibbo and G. Parisi in 1975 proposed a QCD phase diagram [7] in a baryonic density-temperature plane. They have conjectured the existence of two phases in the diagram-one where quarks are confined and another where they are deconfined or uncon-

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fined. After several pioneering experiments and many theoretical calculations of last two decades, the phase diagram is also not fully understood. However, some important progresses have been made. Some of the important questions are yet to be addressed regarding this quark-hadron QCD phase transition. One among them is to know whether the transition is first order, or second order, or a smooth crossover. Lattice based quantum chromodynamics(lQCD) calculation predicts a smooth crossover at a temperature T_c =154 ± 9 MeV at zero net baryon density[2]. Astrophysical calculation for the core of neutron star show a 1st order quark-hadron transition at high baryon density and at low temperature. From both these predictions, a critical end point (CEP) may be expected in the phase boundary of the quark hadron phase transition. Investigating the restoration and breaking of chiral symmetry in case of quark-hadron transition, Asakawa *et al.* [8] proposed a 1st order chiral transition within the ambit of Nambu-Jona-Lasino model and discussed about the phase diagram of chiral transition in $T - \mu$ plane (μ is the baryon chemical potential).

It may be worth to point out the other type of transition in case of quark-hadron phase change, i.e., confinement-deconfinement transition. Basically, two types of quark hadron transitions are conceptualised. Confinement-deconfinement transition which is due to the confinement property of QCD and the chiral transition which is related to the breaking or restoration of chiral symmetry. The chiral symmetry is broken in the hadron world and restored in QGP. It is pertinent to remind here that the confinement (color) is not confirmed analytically from perturbative calculation as QCD at long distance or low energy is not perturbative. However, numerical calculation based on lattice confirms the confinement[9], although clear physical picture is yet to explored. Interestingly, lattice calculation shows that at zero net baryon density, both confinement and chiral transition occur at the same temperature. As already mentioned above, recent lattice calculation predicts the temperature, T_c=154±9 MeV at zero baryon chemical potential[2].

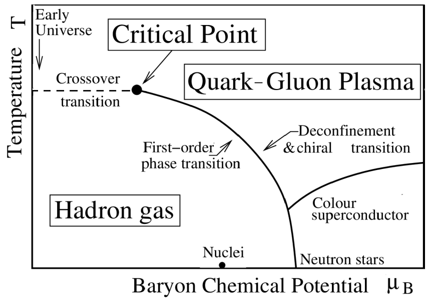

FIG. 1: A schematic diagram in $T - \mu_B$ plane.

Many phase diagrams have been conjectured in this regard and yet to be verified through the observations from relativistic nuclear collisions. Two such conjectured diagrams in the last decade are depicted in Fig.1. Coming back to the relativistic nuclear collision program, we know that both light and heavy nuclei are collided with very high energy with the ambition to create a hot and dense quark matter and to study QCD phase diagram. The hot and dense matter created after collision may be hadronic or partonic(quark-gluon) in nature. But the properties of both would be helpful to characterise the QCD phase diagram. The hot and dense matter created due to the collisions is popularly called as a fire ball. The fire ball expands and cools gradually. The expansion can be mentioned in the following way (just overlooking the intermediate processes).

A+A $\rightarrow$ QGP $\rightarrow$ Hadrons (Detector)
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Grossly two above scenarios are possible. Modelling through out the evolution exactly is quite difficult at present. However, the evolution of the fire ball till hadronization(if QGP is produced initially) in most of the cases is modelled through hydro dynamical equations(although clear mechanism of hadronization is not known). Then transport approach is followed to evaluate the yield of hadrons and other particles which is then compared