0.1 Overview of QGP

The regular name Quark Gluon Plasma is given to the deconfined segment of quark to be counted and this can take place when the quark count number and temperature is very high. An important goal of high-energy heavy ion physics is to discover the section plan of quark be counted in unique areas of baryon density and temperature to verify the existence of the new quark depend phase.When composite states known as hadrons drop their individuality and dissolve into a soup of its constituents-quarks and gluons, a new state of nuclear count number i.e. Quark-gluon plasma (QGP) come out which two exists at extraordinarily high temperatures and densities.The presence of this unique phase of matters used to be unfilled in the mid-seventies .Two years later, it was comprehended that the participate non-Abelian field concept of inter-quark forces-quantum chromodynamics (QCD) -forecasts their failing at trivial distances i.e. asymptotic freedom . Lattice QCD (LQCD) derivations ratify that a exchange in the state of matter (phase transition), from a gloom impartial hadronic matter to a pattern conducting gas of almost free quarks and gluons, is likely via high-energy heavy-ion interactions. Using the contemporary accelerator facilities like RHIC and LHC in an AB collision it is feasible to create an intermediate 'fireball' of adequately excessive energy/matter density, so that one can call it a 'state' having certain equilibrium properties.

0.2 Progress towards AB collision Process

In a heavy ion collision the generated system undergoes various different phases which occur due to the sensitivity of various probes to the various stages of the collision. The Figure 0.1 in below section shows these stages and can be concised as described below:

- **(i)Pre-equilibrium:** For interacting with each other, right after the interactions , thermal equilibrium is attained by the created particles in the collision region. This is assumed to be fast In notional relativistic hydrodynamical models, whereas an exact mechanism for this are far away. Hard parton scattering occurs in this collision stage, producing high-$p_\perp$ probes like direct photons ,heavy quarks and jets. Throughout this stage extreme heating and compressionof matter occurs.

- **(ii)QGP phase:** A fireball is created after the tiny pre-equilibration time , where thermal and chemical equilibrium may be established depending on the initial circumstances. Uncertainly if a QGP like state is

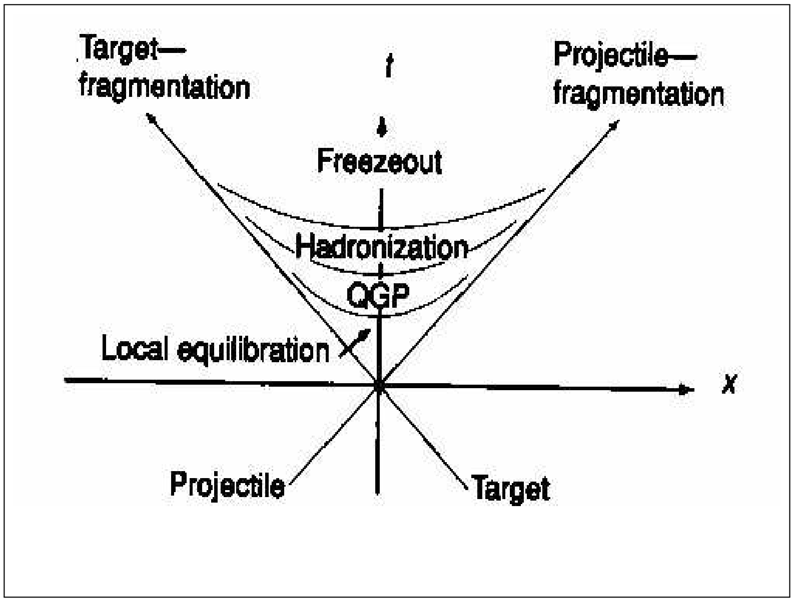

Fig. 0.1: Exposition of QGP space space-time evolution .

produced it will be controlled by either string-string or parton-parton scattering and the energy density is anticipated to touch a great value. At or around the Hagedron limit of temperature which is T $\approx$ 170 MeV the transition from a hadron gas to the quark gluon plasma state may happen.The system expands due to the tremendously huge pressure gradient compared to surrounding vacuum, after attaining local thermal equilibrium. The evolution of the system can be designated by relativistic hydrodynamical appraoch.Here, the viscosity nearly attaining the ideal limit, hence, transmuting the expansion to perform like a ideal fluid.

- **(iii)Hadronization:** Untill the temperature drops below a critical temperature T_c t hroughout the expansion of the system it cools down . It prompts a transition of phase triggering the quarks and gluons to be restricted into the hadrons again. It is anticipated to belong among the QGP and the hadronic state, where gluons and quarks are again restricted into hadrons at an acute point and also assumed as a mixed phase. In this phase the entropy density is transmitted to lower d.

o. f and thus, the system is prohibited from a rapid development and cooling due to the 'softest point' well-defined by a smallest amount of energy density or pressure (ε/p) in the EOS.Actually the precise mechanism of hadronization is unidentified. The system can uphold limited thermal equilibrium for the inelastic collisions.

- **(iv)Freeze-out:** The system carry on growing and cooling like a hot hadron gas succeeding hadronization process. By inelastic and elastic collisions, produced particles carry on interaction with one aother.Inelastic collisions end first for the smaller cross section as matched to the elastic collisions throughout auxiliary enlargement procedure .The partons progressively begin to create various color neutral particles and recombine., thereby the temperature of the fireball is decreasing as in the hadronic phase ,the system keeps a combined expansion thru h-h elastic collisions.Therefore the chemical richness of the produced particles will freeze out.The momentum variations of produced particles will be fixed and elastic collisions endure until the system is excessively dilute for them to occur.

0.2.1 Hydrodynamical approach of quark gluon plasma

In high energy heavy-ion collisions relativistic hydrodynamics has been significantly applied.The conservation laws with the equation of state, viscosity and heat conductivity of the fluid can be related by using hydrodynamics . So the properties of count number and waft are intimately connected .We confident to analyze about the EOS of nuclear count by examining the drift in heavy ion collisions. However, in realistic situations, it is a inspiring mission due to the fact of the hydrodynamical nonlinear nature of the equations and countless mysteries in the hydrodynamical description of heavy-ion collision. Relativistic hydrodynamics presents a simple image of the space-time evolution of the warm or dense count produced in the central rapidity area of relativistic N-N collision.It makes use of the essential conservation laws of strength and momentum to build an equation of motion for the evolving system. In this phase I have mentioned two crucial hydrodynamical models, namely, the Bjorken model and the Landau model.Likewise, specific concluding clarifications about the hydrodynamical models have been furnished.

0.2.2 Landau's Hydrodynamic Model

Fermi in 1950 was the first to suggest an ingenious method of applying thermodynamics to multiple meson production in high energy collisions. The method proposed was based on the assumption that in a high energy collision of nucleons, all of the energy appears at the instant of the collision in a Lorentz contracted small volume due to strong interaction. Fermi proposed that one could then use a statistical method to calculate the multiplicities and spectra of the produced particles.

Landau reexamined Fermis original idea,arguing that one does not expect the number of finally emitted particles (mesons) to be determined only by equilibrium condition at the instant of collision, i.e., the system is strongly interacting even after the collision, and the number of particles becomes definite only when the interaction among them becomes small. Landau was the first to introduce relativistic hydrodynamics to describe the expansion stage of the strongly interacting matter. According to the hydrodynamical model of Landau when two nucleons collide, a compound system is formed, and energy is released in a small volume V subject to a Lorentz contraction in the transverse direction. At the instant of collision, a large number of "particles" are formed. The "mean free path" in the resulting system is small compared with its dimensions, and statistical equilibrium is set up.

In the second stage of collision, the system expands and it may be regarded as the motion of an ideal fluid (zero viscosity and zero thermal conductivity).During the process of expansion the "mean free path" remains small in comparison with the dimension of the system, and this justifies the use of hydrodynamics.

Since the velocity in the system is comparable with that of light, relativistic hydrodynamics is used. Particles are formed and absorbed in the system throughout the first and second stages of the collision. The high density of energy in the system is of great significance. The number of particles is not an integral of the system, on account of the strong interaction between the individual particles.

In this model when two nucleons collide (in a central collision) a compound system is formed. If we consider two equal nuclei of mass number A in the Landau picture, the total energy of the system in the center of mass frame, W_{cm},is defined as:

$$W_{cm} = AE_{cm} = 2Am_N\gamma_{cm} \tag{0.1}$$

The initial energy density, ε, is calculated by

$$\varepsilon = \frac{W_{cm}}{V} = \frac{2Am_N\gamma_{cm}}{V_{rest}/\gamma_{cm}} = 2\varepsilon_{mn}\gamma_{cm}^2 \tag{0.2}$$

where V is the Lorentz contracted volume and ε_{nm} is the energy density of nuclear matter approximately.

$$\varepsilon_{mn} = \frac{Am_n}{V_{rest}} \tag{0.3}$$

V_{rest} is the volume of the nucleus at rest.

$$V_{rest} = \frac{4\pi}{3}R^3 = \frac{4\pi}{3}r_0^3 A \qquad r_0 = 1.2fm \tag{0.4}$$

Similarly, the initial baryon number density

$$\rho = \frac{2A}{V} = \frac{2A}{V_{rest}/\gamma_{cm}} = 2\rho_{nm}\gamma_{cm} \tag{0.5}$$

where ρ_{nm} is the baryon number density of normal nuclear matter.

$$\rho_{nm} = \frac{A}{V_{rest}} \tag{0.6}$$

In terms of the inelasticity factor K(K≈1), the initial energy density is given by,

$$\varepsilon = K\frac{\sqrt{s}}{V} = 2\gamma_{cm}^2 K\varepsilon_0 \tag{0.7}$$

ε_0 is the energy density of hadron.
The energy - momentum and entropy-conservation equations which play a crucial role in relating the prediction of hydrodynamic calculations to experimental observables in heavy ion collisions can be mathematically stated as

$$\partial_\mu T^{\mu\nu} = 0 \tag{0.8}$$

$$\partial_\mu (s u^\mu) = 0 \tag{0.9}$$

Here, $T^{\mu\nu}$ is the relativistic stress energy tensor, s is the entropy density and u^μ is the four velocity $(\gamma, \gamma v)$. $T^{\mu\nu}$ can be calculated from the usual transformation laws for a tensor under a "boost" $A^\mu_\alpha(v)B_\beta(v)T^{\alpha\beta}$ such that,

$$T^{ij} = P\delta^{ij}; \quad T^{mn} = T^{nm} = 0; \quad T^{00} = \varepsilon \tag{0.10}$$

In the above equation P is the pressure and ε is the energy density including the rest mass. If it is assumed that there is no entropy generation or loss in the system, then equations (0.8) and (0.9) describe the hydrodynamic evolution of the system.
In 1953, Landau solved the hydrodynamic equations for one-dimensional as well as three-dimensional motion. Khalatnikov obtained an exact solution for the one-dimensional motion which gave the same result as Landau in the asymptotic region.
Limitations of landau's model: A necessary condition for the applicability of the Landau picture to central relativistic nucleus-nucleus collision is that the nucleons in the front part of each of the colliding nuclei must lose

all of their kinetic energies in the center of mass frame while traversing the other nucleus. This demands that the average energy loss of these nucleons per unit length be greater than the critical value given by,

$$\left(\frac{dE}{dz}\right)_{critical} = \frac{E_{cm}/2}{(2R/\gamma_{cm})} \tag{0.11}$$

Although, the above equation yields satisfactory results for values of $E_{cm} <$ 10 GeV but, for ultra relativistic energies such as $E_{cm} \approx 200$ GeV at RHIC, it becomes too large to be attainable. Hence, Landau picture breaks down as the required stopping power becomes too large. Furthermore, in contrast to the Fermi and Landau approaches the thickness of the colliding nuclei cannot become infinitely small in the ultra-relativistic region. Also, in this model the boundary condition is specified at the time of maximum compression, where the whole matter is distributed in a small volume. However, particle production is not an instantaneous process and it shows the characteristics of space time correlation which is not taken into account in Landaus model. In short, the main criticisms of the Landau model are:
1. Neglect of leading particle effect.
2. Removal of radiation energy due to deceleration required in the model for full stopping.
The above mentioned difficulties in Landaus model can, however be removed if one assumes that during the collision the valence quarks move without much interaction and the energy carried by the gluon fields is stopped in collision volume This assumption is justified because the gluon- gluon interaction cross section is larger than quark-quark interaction due to color degeneracy of the gluons. The gluon field thermalises after a certain time providing the initial condition of Landau model.
A turning point in the history of hydrodynamics was the 1983 Bjorken paper where he applied the boost invariant solution of hydrodynamics to relativistic nucleus-nucleus collisions. Below is given some highlights of the Bjorken Hydrodynamical model.

0.2.3 Bjorken Hydrodynamic model

Bjorken described the space-time evolution of the hadronic matter in the central rapidity region in extreme relativistic nucleus-nucleus collisions. He assumed that at sufficiently high energy there existed a “central-plataeu” structure for the particle production as a function of the rapidity variable, be it nucleus-nucleus, nucleon-nucleus, or nucleon-nucleon collision.The essence of this assumption was that the space-time evolution of the system looked essentially the same in all center-of-mass-like frames, i.e., in all frames where the emergent excited nuclei are, shortly after the collision, highly Lorentz contracted volumes receding in opposite direction from the collision point at the speed of light. It is assumed that shortly after the collision the strongly interacting matter reaches a state of local thermal equilibrium and subsequently expands adiabatically. The evolution of the system is determined by its initial conditions and the equation of state (EoS) , which relates the energy and the baryon density to the pressure exerted by the system, and which is subject to the constraints of local conservation of energy, momentum, and currents (e.g., baryon number). The energy-momentum tensor $T^{\mu\nu}$ and the current density j^{μ} of an ideal non-dissipative fluid are given by,

$$T^{\mu\nu}(x) = [\varepsilon(x) + p(x)]\, u^{mu}(x) u^{\nu}(x) - g^{\mu\nu}(x) \tag{0.12}$$

$$j^{mu}(x) = n(x) u^{\mu}(x) \tag{0.13}$$

where $\varepsilon(x)$ is the energy density, $p(x)$ the pressure, and $n(x)$ the conserved number density at point x and $u^{\mu}(x) = \gamma(x)[1, \overline{v}(x)]$ is the local four velocity of the fluid. Note that $u^{\mu}u_{\mu} = 1$. The conservation laws are written in the form of continuity equations,

$$\partial_{\mu} T^{\mu\nu}(x) = 0 \quad and \quad \partial_{\mu} j^{\mu}(x) = 0 \tag{0.14}$$

The EoS describes how macroscopic pressure gradients generate collective flow. One has to solve,

$$\partial_{\mu}[(\varepsilon + P) u^{\mu} u^{\nu} - g^{\mu\nu} P] = 0 \tag{0.15}$$

Multiply with u_{ν} and use $u_{\nu}\partial_{\mu}u^{\mu} = 0$ to write

$$u^{\mu}\partial_{\mu}\varepsilon + (\varepsilon + P)\partial_{\mu}u^{\mu} = 0 \tag{0.16}$$

Dropping the transverse co-ordinates one can write,

$$t = \tau coshy \quad and \quad z = \tau sinhy \tag{0.17}$$

in terms of the spacetime rapidity (y), so that $u^{\mu} = (t/\tau, 0, 0, z/\tau)$, where the Lorentz invariant proper time τ=t/γ=$\sqrt{t^2 - z^2}$ and $u_z = z/t = tanhy$ is the longitudinal velocity. The Bjorken equation

$$\frac{\partial \varepsilon}{\partial \tau} + \frac{\varepsilon + P}{\tau} = 0 \tag{0.18}$$

can now be arrived at. One can also use $\varepsilon = \lambda P$, where $\lambda = dP/d\varepsilon = c_s^2$, the elastic wave velocity in the medium, is a constant e.g., $c_s^2 = 1/3$ for an ideal gas of massless particles. Therefore,

$$\frac{\partial\varepsilon}{\partial\tau} + \frac{(1+\lambda)\varepsilon}{\tau} = 0 \Rightarrow \varepsilon(T_f) = \varepsilon(\tau_i)\left(\frac{\tau_i}{\tau_f}\right)^{1+\lambda} \tag{0.19}$$

From thermodynamics one can write

$$\varepsilon + P = Ts + \mu_B n_B \tag{0.20}$$

For zero net baryon density,

$$d\varepsilon = Tds \;\; and \;\; s = \frac{(1+\lambda)\varepsilon}{T} \Rightarrow s(\tau_f) = s(\tau_i)\left(\frac{\tau_i}{\tau_f}\right) \tag{0.21}$$

Also,

$$T\frac{ds}{d\tau} = \frac{d\varepsilon}{d\tau} = -\frac{(1+\lambda)\varepsilon}{\tau} = -\frac{sT}{\tau} \tag{0.22}$$

$$\Rightarrow \frac{ds}{d\tau} + \frac{s}{\tau} = 0 \Rightarrow T(\tau) = (1+\lambda)\frac{\varepsilon(\tau)}{s(\tau)} = T(\tau)\left(\frac{\tau_i}{\tau_f}\right)^{\lambda} \tag{0.23}$$

A phase transition from the QGP phase to a hadron gas causes a softening of the EoS.As the temperature crosses the critical temperature, the energy and entropy densities increase rapidly while the pressure rises slowly. The derivative of pressure to energy density (p/ε) has a minimum at the end of the mixed phase, known as the softest point. The diminishing driving force slows down the build-up of flow. The initial conditions which are input parameters, describe the starting time of the hydrodynamic evolution and the relevant macroscopic density distributions at that time. The hydrodynamic evolution is terminated by implementing the freeze out condition which describes the breakdown of local equilibrium due to decreasing local thermalization rates. In non-central collisions, driven by its internal asymmetric pressure gradients, the system will expand more strongly in the direction of the reaction plane than perpendicular to the reaction plane. As time evolves, the system becomes less and less deformed. To estimate the initial energy density of a Bjorken-type fluid element therefore, one has to go to the fluid rest frame.

All particles are originating from a cylindrical volume of cross-section area A, which actually is the overlap area of the interacting nuclei, and of length $u_z t$. We concentrate on a thin slab of thickness dz centered between the two pancake-like moving nuclei (Fig. 0.2).The point of impact of the collision is assumed to be the origin ($z = 0$) of our frame of reference. Therefore $dz =$

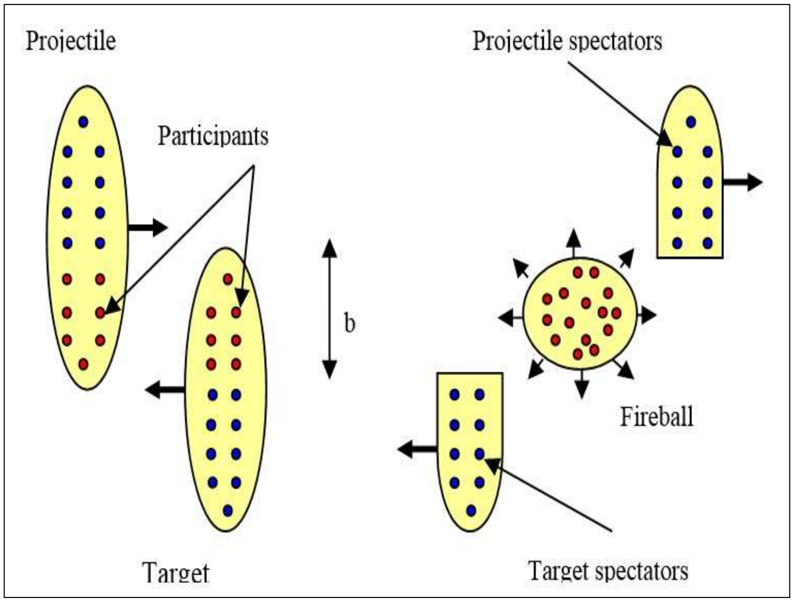

Fig. 0.2: Figure showing NN collision geometry

τ coshydy, and ignoring collisions between the produced hadrons, one can write the energy density as,

$$\varepsilon_{BJ} = \frac{\Delta E}{\Delta V} = \frac{E}{A}\frac{dN}{dz} = \frac{m_\perp}{\pi R^2 \tau}\frac{dN}{dy} = \frac{1}{\pi R^2 \tau}\frac{dE_\perp}{dy}. \qquad (0.24)$$

Taking the proper time $\tau \sim 1$ fm/c and (dN/dy) to be the central rapidity density of produced particles, this relation was first derived by Bjorken . However, a perfect fluid must undergo an isentropic expansion, and the entropy of the expanding fireball S should be a conserved quantity. In terms of entropy density $s = S/V$ for one-dimensional expansion, therefore to compensate the Lorentz contraction a relation like $s_i\tau_i = s_f\tau_f$ should hold between an initial (τ_i) and final (τ_f) proper time. As it will be shown later, for massless particles, $\varepsilon = g\frac{\pi^2}{30}T^4$ and $s \propto T^3$, where T is the temperature and g is number of the degrees of freedom. Correspondingly,

$$T_i^3\tau_i = T_f^3\tau_f \Rightarrow \tau_f\tau_i\frac{T_i}{T_f}^3 \quad and \quad \varepsilon_f = \varepsilon_i\left(\frac{\tau_i}{\tau_f}\right)^{4/3} \qquad (0.25)$$

which is in contradiction with Bjorkens formula, $\varepsilon_{BJ} \sim \tau^{-1}$. The energy density formula should therefore, be modified as

$$\varepsilon = \frac{1}{\pi R^2 \tau_0}\frac{dE_\perp}{dy}\left(\frac{\tau_f}{\tau_i}\right)^{1/3} = 2\varepsilon_{BJ} \qquad (0.26)$$

0.2.4 Comparison between Landau and Bjorken model

Exact regularly, the estimations are expressed that the Landau model is appropriate at lower beam energies, while the Bjorken model is proper for the description of ultrarelativistic collisions.The actual condition is additionally composite. As discussed earlier that the hadron rapidity distributions detected at the RHIC energies are designated well by the Gaussian profiles, which advises the effectiveness of the Landau model even at the maximum available energies.Till the collisions studied at RHIC do not exhibit the baryon stopping, suggesting validity of Bjorken approach we also exposed this.Moreover at highest RHIC energies we deal with a kind of mixture of Landau and Bjorken like behaviour- baryons in the colliding nuclei are still travelling while,the rapidity variations are Gaussian type.Evidently the more innovative hydrodynamical codes are required to define the performance of matter produced in ultra-relativistic HIC.

0.2.5 Allusions towards QGP

One must identify signals to test whether or not the system produced in a high energy heavy ion collision was in a 'primordial' plasma phase. QGP after its formation subsequently expands and cools below the confining temperature T_c so that the hadrons are formed and at freeze-out, they decouple from the fireball. The hot and dense hadron gas forms a background in this case. The task in identifying QGP signals is rather difficult because one requires a precise knowledge of the HG under extreme conditions of temperature and density. The pictures for a HG we employ either involves an equilibrated statistical system
or an ideal, non-interacting system or we consider nuclear collisions as multiple, coherent hadron-hadron collisions etc. We are not sure that such idealized pictures can describe the ultra relativistic heavy-ion collision in a realistic manner. The standard method used in the QGP diagnostics is to compare the predictions of heavy-ion collisions incorporating the presence of QGP with the predictions of models involving the dynamics of hot, dense HG. In case we find any anomalous difference between two types of the pictures, we can subscribe it to an exotic phenomenon like QGP formation.
In high energy nuclear collisions, two beams of nucleons collide. The quarks and gluons are confined in the colliding nucleons. After the primary collisions, we expect multiple scatterings and hence entropy rapidly increases and the system quickly thermalizes. An important question which we investigate, is whether confinement survives this thermalization. In case confinement survives, we have hadrons in the system and if it does not, we then have a QGP

in the fireball. Thus we primarily investigate in the QGP diagnostic studies whether deconfinement has really occurred in the heavy-ion collisions. The main proposals are:

- **Strangeness enhancement:** The hadrons resulting after QGP formation will confirm a very large number of strange mesons and antibaryons so that we will get a larger value for the ratio K^+/π^+, $\overline{\Lambda}/\Lambda$, $\overline{\Xi}/\Xi$ etc. Enhancement of strangeness also indicates (partial) restoration of chiral symmetry in dense, hot matter. We have recently found that by suitably formulating the EOS for QGP and HG phases separately, one can propose some unique signatures. For example, $\Phi/(\rho+\omega)$, $\overline{\Lambda}/\Lambda$, $\overline{\Xi}/\Xi$ etc. are anomalously large when QGP is formed. However, recent experimental ratios can be explained on the basis of HG without QGP formation .

- J/Ψ **Suppression:** With the J/Ψ a tiny bound state made of a pair of heavy charm quark and antiquark, we can probe the very early stages of the collisions. Contrary to the ρ, the J/Ψ has a very long lifetime and it decays into dileptons only when it is far from the collision zone. However, as pointed out by Matsui and Satz , the binding of the J/Ψ meson is sensitive to the screening of the c - $\overline{c}$ potential by a quark-gluon plasma, and the meson bound state will not survive in a hot enough quark-gluon plasma. Hence the original argument suggesting that a decrease of the observed J/Ψ yield could reveal the formation of the quark gluon plasma. An alternative scenario for the J/Ψ suppression involves J/Ψ collisions with hard "deconfined" gluons present in the quark-gluon plasma first run of experiments at CERN indeed showed that the rate of J/Ψ production was less than the rate expected from extrapolations of nucleon-nucleon collisions. But it soon appeared that this phenomenon, as well as the corresponding one observed in proton-nucleus collisions, could be accounted for by what is usually referred to as nuclear absorption . A J/Ψ produced somewhere in the nucleus has to cross a certain region of nuclear matter before escaping, and because it can interact inelastically with nucleons on its way out, it may be destroyed. A survival probability can then be defined, exp(-L/λ), where L is the distance traveled by the J/Ψ in nuclear matter, and $\lambda = 1/(\text{n}\sigma_{abs})$ an absorption mean free path with n the nuclear density. Several analysis lead to a value of σ abs of the order of 6 to 7 mb .

- **Jet Quenching:** In relativistic heavy ion collision when a parton of one hadron within an incoming nucleus collide with a parton within another incoming nucleus from opposite direction, then various partons with very high transverse momenta are produced which fly off to all possible directions from collision points and finally fragment into narrow cones of hadrons called jets. These highly energetic secondary quarks, antiquarks and gluons are commonly referred in theory as jet partons. When some of these jet partons enter the thermalized medium, they interact with the medium particles and loose energies and momenta before hadronizing. This loss is observed through a mathematical ratio, is known as nuclear modification factor, 'R_{AA}'. R_{AA} defined as

$$R_{AA}(P_{\perp}, b) = \frac{\frac{dN_{AA}}{d^2_{p_{\perp}}dy}}{T_{AA}(b) \times \frac{d\sigma_{pp}}{d^2_{p_{\perp}}dy}} \tag{0.27}$$

This ratio shows the energy loss of any jet parton and commonly called jet quenching. It was fist suggested by Bjorken that any jet particle traveling inside a bulk partonic matter must loose a significant part of its energy before hadronizing. The numerator of the ratio shows a single particle transverse momentum distribution of a jet parton produced in nucleus-nucleus collision and traveling through thermal medium. The denominator part has single particle distribution of same species of jet parton produced in proton on proton collision multiplied by nuclear thickness function '$T_{AA}(b)$' which is a proton to nucleus scaling factor(if AA collision is an incoherent superposition of pp collision) and is a function of impact parameter 'b'. If we suppose that no jet quenching has taken place, then the ratio must be unity for all jet momenta. However if the ration tends to be less than unity, it serves as a definite measure for jet suppression in the medium . This particular mathematical entity is a suitable candidate as a signature of formation of a themalized medium of deconfined quarks and gluons or QGP.

- **Photon production:** Among the proposed 'probes' of the QGP are directly produced photons. However, there are also many other processes capable of producing photons. For thermal photons, the main background at low momenta comes from the decay of hadrons, mainly π^0 and η of high momenta. There are, in addition, direct photons from Compton scattering. The observation depends very much on how well the hadron decays can be identified and eliminated.Kapusta et al found that the dominant contributions come from the annihilation processes $q\overline{q} \to q\gamma$, $q\overline{q} \to \gamma\gamma$, from the QCD Compton process $qg \to q\gamma$, $q\overline{g} \to \overline{q}\gamma$ and from the electromagnetic bremsstrahlung of quarks $q \to q\gamma$. Photons interact only electromagnetically with the medium and so their

mean free paths are much larger than the transverse size of the region of hot matter created in any nuclear collision. As a result, high-energy photons produced in the interior of the plasma usually pass through the surrounding matter without interacting, carrying information directly from wherever they are formed to the detector. Unfortunately photons can also be emitted during the hot hadron phase because many hadrons are electrically charged. Pions and ρ mesons are the main constituents of such a phase. Scientists have expected that the dominant contributions come from the $\pi\pi \to \rho\gamma$, $\pi\rho \to \pi\gamma$, $\pi\pi \to \eta\gamma$, $\pi\eta \to \pi\gamma$ reactions and the $\omega \to \pi^0\gamma$, $\rho^0 \to \pi^+\pi^-\gamma$ decays. Thus there is a huge amount of background noise.
If the thermally produced photon component can be extracted from the background, it will provide an excellent thermometer for ultrarelativistic nuclear collisions. Experiments searching for these photons observed an enhancement of the number of photons at high energies, but we cannot yet be absolutely certain that it originated from free quarks. Here we suppose that we put hadron gas in one box and QGP in another, and maintain them at then same temperature T. We make the walls transparent to the photons. Can we tell which box contains the QGP by measuring the photon spectrum? Since quarks and gluons have different momentum distributions in the QGP and hadrons phase, by analysing the photon spectrum one can get information about transition to the QGP phase. Hydrodynamic models applied to QGP have shown that the increase in photons having large transverse momenta $p_\perp$ is the QGP signal. A measurement of direct photon production in Pb + Pb collisions at 158A GeV has been carried out in the CERN WA98 experiment.

- **lepton pair production enhancement:** Photons, real or virtual (i.e., decaying to lepton pairs e^+ e^- and $\mu^+\mu$), produced in relativistic heavy-ion collisions are collectively called as electromagnetic probes. Emission of electromagnetic radiation is believed to be one of the most promising and efficient tools to characterize the initial state of heavy-ion collisions. Virtual photons decay into dileptons which carry the memory of the formation of the direct photons. Following are the main processes for direct photon production in the QGP medium :

  (i) Annihilation Process : The annihilation process involves production of a gluon and a photon

$$q + \overline{q} \to \gamma + g \tag{0.28}$$

(ii) QCD Compton scattering :This process involves scattering of a gluon off a quark or an antiquark

$$g + q \to \gamma + q \tag{0.29}$$

$$g + \overline{q} \to \gamma + \overline{q} \tag{0.30}$$

Besides the emission of photons from the quark-gluon plasma, photons can also be emitted from the hadronic processes such as, pion annihilation, interaction of pion with 0 meson and interaction of charged pion with neutral pion. Hard nucleon-nucleon collision as well as the decays of final-state mesons after freeze-out also contribute in the photon production.

As no further interaction of photons takes place with the medium, thus carry the intact information about the interior of the fireball. the photon production rate and photon momentum distribution provide the information on the thermodynamic condition of the medium at the moment of their formation .

- **Dilepton production:** In QGP, the quarks and antiquarks annihilate to create virtual photons, γ^*, which decay into lepton pairs (l^+l^-). The system of the produced lepton - antilepton pair is referred to as dilepton or l^+l^- pair. The dilepton (l^+l^-) is characterized by dilepton invariant mass squared $M^2 = (P_{\parallel}^+ + P_{\parallel}^-)^2$, where $P_{\parallel}^+$ and $P_{\parallel}^-$ are the four-momenta of the dilepton - and dileptons transverse momentum $\mathrm{p}_\perp = (P_{\parallel}^+)_\perp + (P_{\parallel}^-)_\perp$, where $(P_{\parallel}^+)_\perp$ and $(P_{\parallel}^-)_\perp$ are the transverse momenta of the dilepton.
Once these dileptons are created, they must pass through the collision region to particle detectors. They interact electromagnetically and have large mean free paths. The produced lepton pairs, therefore, do not suffer further collisions before reaching the detectors and thus carry the unscathed information about the interiors of the fireball.
The lepton pair production can also take place via Drell- Yan process, decays of hadron resonances and charmonia and $\pi^+\pi^-$ annihilation.

- **Fluctuations:** Lattice calculations are associated with divergence of susceptibilities in the proximity of the QCD critical point and hence lead to fluctuations in various observables. The fluctuations of these observables act as one of the key probes of the deconfinement phase transition. Large fluctuations of energy density or temperature is expected if the phase transition is of the first-order. However,second-order phase transition leads to specific heat divergence and reduces the

fluctuations drastically if the matter freezes out at the critical temperature. Fluctuations of the conserved quantities like electric charge, baryon number or strangeness are predicted to be significantly reduced in QGP scenario as they are generated in the early stage of the plasma, created in high-energy heavy-ion collisions with quark and gluon as degrees of freedom . The fluctuations generated at the QGP stage will increase as the system evolves in time .
The fluctuations not only depend on the type and order of the phase transition but also on the speed by which collision zone goes through the transition, the degree of equilibration, the subsequent hadronization process, the amount of rescattering of hadrons during hadronization and freeze-out . Fluctuations studied in heavy-ion collision experiments are : ratios of charged particles , baryon number multiplicity , net charge , mean p_T , etc.

- **Hanbury-BrownTwiss (HBT) Effect:** Identical particle correlation or interferometry, provides information on the reaction geometry, and hence provides important information about the spacetime dynamics and system lifetime of nuclear collisions. The information about the spacetime structure of the particle emitting source created in AB collisions obtained from the measured particle momenta, can be extracted by the method of the so called ‘two-particle intensity interferometry techniques also called the Hanbury-Brown-Twiss’ (HBT) effect . The method was initially developed to measure the angular size of distant stars. The two-particle correlation arises from the interference of particle wave-functions, where interference is defined as a phenomenon associated with the superposition of two or more waves. Such correlation depends on whether the particles are bosons or fermions. Also the degree of interference depends on the degree of coherence of the emitting source of particles produced in such collisions, which reaches a maximum for a completely incoherent source. HBT is a useful method to understand the crucial reaction mechanism and equation of state (EoS) of the particle emitting source in relativistic heavy-ion collisions where the QGP is expected to be formed. LQCD predicts a very soft EoS near about the QCD critical point (T_c = 173 ± 15 MeV), and a sudden decrease in $dp/d\varepsilon$ (= c_s^2) value from what is obtained in the $T > 2T_c$ region , c_s being the speed of sound in QCD medium.

- **Flow:** Anisotropic flow is an important observable, being sensitive to the effective degrees of freedom in relativistic heavy-ion collisions. It provides information about the Equation-Of-State (EOS) and collective properties and confirms early thermalization in the hot and dense fireball created in a collision. In non-central heavy-ion collisions, initial spatial anisotropy of the nuclear overlap zone is converted into momentum space anisotropy of particle distribution via the operation of azimuthally anisotropic pressure gradient. This leads to an anisotropic azimuthal distribution, $dN/d\varphi$, of particles emitted from the collision zone. Anisotropic particle distributions were first suggested [32] as a signal of collective flow in ultra-relativistic heavy-ion collisions. The azimuthal distribution of particle emission is analyzed with respect to the reaction plane in terms of the following Fourier expansion [33]:

$$E\frac{d^3N}{dp_\perp^2 dy d\varphi} = \frac{1}{2\pi}\frac{d^2N}{p_\perp dp_\perp dy}(1 + 2\sum_{n=1}^{\infty} v_n cos[n(\varphi - \Psi_R)]) \qquad (0.31)$$

where v_n are referred to as Fourier or flow coefficients, which depends on N_{part}, φ is the azimuthal angle of the particle and Ψ is the azimuthal angle of the reaction plane in the laboratory frame. The first two coefficients in the Fourier expansion, are known as the directed and elliptic flows. The $v_1 = < \cos\varphi >$ corresponds to the strength of the directed flow, whereas $v_2 = < \cos 2\varphi >$ quantifies the strength of the elliptic flow. The magnitude of v_2 is sensitive to the initial conditions and EOS of the hot and dense fireball. The higher order flow harmonics, such as v_3, v_4, v_5, etc., are sensitive parameters for studying initial state fluctuations and to obtain η/S ratio, where η is shear viscosity over entropy density (S) of the fluid produced in a collision.