Traces of non-equilibrium on the power spectrum of quark gluon plasma

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Introduction

The main aim of the heavy ion collision experiments at Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) is to create and characterize a new state of matter called Quark Gluon Plasma (QGP). This is a state of matter that might have existed in the early universe after a few micro-second of the big bang. In this context creation of QGP in heavy ion collisions in the laboratory are termed as "little bangs". One of the motivation to create and study QGP in the laboratory is to understand the state of the universe in the micro-second old era. The study of anisotropy of temperature fluctuation in the Cosmic Microwave Background Radiation (CMBR) on surface of last scattering, when the universe was about 300,000 years old, has helped in extracting crucial information about the universe, like matter content of universe.

Properties of QGP formed in Heavy Ion Collision at Relativistic Energies (HICRE) are extracted by analyzing the phase space distribution of particles produced in such collisions e.g. study of anisotropy reveals information on fluid properties of QGP- like its viscosity with the help of the theoretical models based on hydrodynamics and kinetic theory. In this regard theoretical investigations of effect of different physical processes in the QGP medium on the final particle anisotropy is important.

In this work an approach similar to that of the theoretical study of CMBR temperature anisotropy has been adopted to investigate the effect of initial state inhomogeneity and perturbations in the hydrodynamically evolving QGP. These effects have been studied through the anisotropic momentum distribution of parton at surfaces of different temperatures. The evolution of the perturbations has been studied within the ambit of Boltzmann Transport equation (BTE) in evolving QGP background. The evolution of background is studied by solving (3+1)D relativistic hydrodynamic equations. The momentum anisotropy of partons of QGP medium is expressed in terms of spherical harmonics.

Formalism

The non-equilibrium perturbations at space-time position $x = (t, \vec{x})$ is expressed as deviation, $\delta f(x, \vec{p})$ of single particle distribution function, $f(x, \vec{p})$ from its equilibrium value, $f_0(\vec{p})$ where $\vec{p}$ is the momentum of particle. The evolution of δf is obtained by solving the BTE, $p^\mu \partial_\mu f = (p \cdot u)C[f]$, with $f(x, \vec{p}) = f_0(\vec{p}) + \delta f(x, \vec{p})$, where u^μ(x) is the fluid four velocity of the hydrodynamic background. We have considered relaxation time approximation(RTA) for collision term of BTE. The relaxation time(τ_R) is temperature (T) dependent quantity. T is obtained by solving hydrodynamic equations. The background interacts with the perturbation through the T-dependent τ_R and u^μ. The solution for δf is given in Ref.[1].

The interaction of this perturbation with the background is implemented through the hydrodynamic field $T(x)$ and u^μ(x). These fields for QGP medium formed in HICRE are obtained by solving the hydrodynamic equations [2].

The perturbation which has negligible effects on the background evolution is considered here. The disentanglement of the effects of perturbation will be very useful in extracting the properties of QGP.

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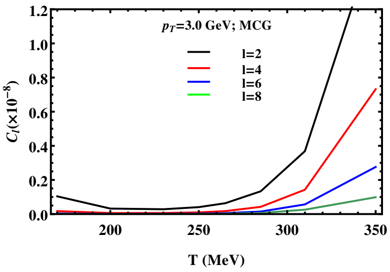

FIG. 1: Variation of C_l with T for inhomogeneous background obtained using Monte-Carlo Glauber(MCG) initial condition.

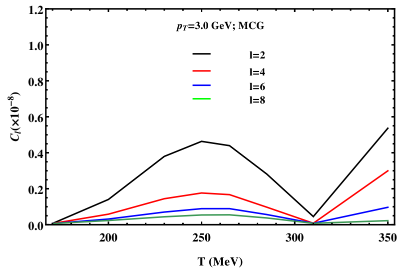

FIG. 2: C_l vs T: in presence of perturbation carrying energy density fraction, $\delta\epsilon/\epsilon \sim 0.01$

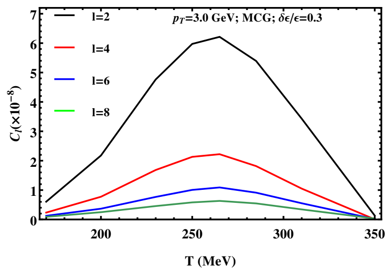

FIG. 3: C_l vs T plot: in presence of perturbation carrying energy density fraction, $\delta\epsilon/\epsilon \sim 0.3$

Such small perturbation that are spatially anisotropic in transverse plane, expressed in polar coordinates(r, ϑ), has been taken as: $\delta f(p, \vec{x}, t_0) = A_0 \exp\left[-r(1 + a_n \cos n\vartheta)\right]$ with $a_n = 0.3$, $A_0 = K\frac{C}{(1+p_T/B)^\beta}$, where p_T is the transverse momentum of partons, $C = 9.113 \times 10^{-4}(1/MeV^2)$; $B = 1459MeV$ and $\beta = 7.7$ [2]. In Ref [2] the value of K is taken to be 3.6 such that energy density carried by the perturbation($\delta\epsilon$)- $\delta\epsilon/\epsilon \sim 0.01$. We also consider value of K to be such that $\delta\epsilon/\epsilon \sim 0.3$ so that the nature of effect of such perturbations is better understood. We consider $n = 2$ for initial anisotropy.

The anisotropy of partons distribution (EdN/d^3p) at surfaces of constant temperature of the hydrodynamically evolving QGP medium is expressed in spherical harmonic basis [2] as $E\frac{dN}{d^3p} = \bar{N} + \sum_{l=1}^{\infty}\sum_{m=-l}^{l} a_{lm}(p_T, T)Y_{lm}(\theta, \phi)$. The parton distribution at such surfaces is obtained using method similar to that of Cooper-Fry prescription for hadronization from freeze out surfaces. We study the variation of anisotropic coefficient C_l (where $C_l(p_T, T) = \frac{1}{2l+1}\sum_m |a_{lm}|^2$) with constant temperature surfaces along the evolution of QGP background.

Results

It is found that presence of initial inhomogeneity in the energy density of QGP background is traceable from non-zero value of C_l for odd l's [2]. Fig. 1 and Fig. 2 shows variation of C_l with temperature for $p_T = 3$ GeV partons for cases where non-equilibrium perturbation is absent and where such perturbation is present respectively [2]. Fig. 3 shows the result when strength of perturbation is increased as mentioned earlier. This shows clear distinction in the nature of effect of perturbations on the evolution of power spectrum, which may help in disentangling the effect of such perturbations and hence in extracting the properties of the medium.

Acknowledgments

G. S. acknowledges the support from Department of Atomic Energy, Govt. of India for this work.

References

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