DILEPTON PRODUCTION FROM QUARK GLUON PLASMA USING NON-EQUILIBRIUM THERMODYNAMICS

BIKASH SINHA
Variable Energy Cyclotron Centre, Bhabha Atomic Research Centre
1/AF, Bidhan Nagar, Calcutta -700 064, India

Abstract : The importance of the approach phase to the thermodynamic equilibrium has been investigated for dilepton production from Quark-gluon plasma - an effective temperature for the quarks as Brounian particle in a heat bath of gluons has been suggested. The spectrum for low invariant mass is, as a consequence, sharper.

For collisions of two nuclei at ultrarelativistic energy it is expected that normal cold hadronic matter will make a phase transition to a plasma of quarks and gluons, (QGP)[1,2]. The fireball of compressed and hot hadronic matter transforms to a ball of quark-gluon matter beyond a certain critical temperature and then cools off to hadronic matter as the temperature falls with the expansion of the fireball. The space-time evolution of the fireball however tends to mask the signals of the QGP and the memory of its formation tends to get erased at the point of detection. Leptons which interact weakly with hadrons retain the original memory of QGP more efficiently than hadrons; similarly hard photons interacting electromagnetically with the immediate medium will also retain signatures of the plasma. In both cases however the space-time evolution of the fireball has to be taken into account. Recently for two colliding nuclei, this has been carried out by solving Landau's hydro-dynamical equation[3,4].

As suggested[3,4], subsequent to the collision between two heavy ions two leading clusters, moving with nearly the velocity of light in opposite directions, carry away the baryon numbers of the two heavy ions. In the central region of rapidity lies some fluid, composed immediately after the collision, of a quasi-free streaming set of quarks, antiquarks and gluons. Dileptons from this fluid are emitted in the central region of rapidity. The initial configuration of the fluid, in this model, has cylindrical symmetry which is preserved during the subsequent evolution. It is well established by now[3,4] that the initial conditions for hydrodynamical flow are Lorentz invariant with respect to the longitudinal motion of the fluid elements. These initial conditions are imposed at a proper time $\tau = \tau_o$, $\tau = \sqrt{t^2 - z^2}$; τ_o is a priory however unknown.

Between $\tau = 0$ and $\tau = \tau_o$, the evolution of the plasma cannot be described by hydrodynamics. Further there are two equilabration points in the time scale corresponding to equilibration achieved for the gluons and afterwards the quarks and the antiquarks. The difference in this two equilabration time is because gluon-gluon interaction is much stronger (eight colour degrees of freedom) than quark-gluon or quark-quark (three colour degree of freedom) interaction. Defining τ_g as the gluon equilabration time and τ_o as the quark-gluon equilabration time, the scenario of dileption production turns as follows. Between $0 < \tau < \tau_g$ there is no equilibrium whatever and the production of dileptions in this quantal stage is governed primarily by Drell-Yan mechanism, high invariant mass and therefore of no great relevance to our calculation. It is the approach to equilibrium phase $\tau_g < \tau < \tau_o$ a regime where quarks still have not achieved thermal equilibrium but gluons have is of great interest to us. For $\tau > \tau_o$ the full rigour of thermodynamics can be used.

Although the concept of temperature is somewhat ambiguous in the approach phase, we can consider a temperature T for the gluons, now acting like a heat bath with the quarks as the Brownian particle "walking" randomly in the gluon heat bath. In this scenario the Brownian particles, the quarks, correspond to a temperature like parameter $T_{eff} = T\,(1 - e^{-2\gamma_q \tau})$ where γ_q is the frictional co-efficient of the quarks related to the diffusion co-efficient by $\gamma_q = D / 2m_q kT$.

In the above relation T corresponds to the temperature of the heat bath with the friction co-efficient $\gamma_q \sim 1/\tau_q$. The interesting aspect of this relation is that for large τ effectively $T_{eff} \Rightarrow T$ when quarks and gluons are in thermodynamic equilibrium whereas as $\tau \to 0$, T_{eff} in essence has no meaning, reflecting as it were the breakdown of the thermodynamic picture.

Taking R as the radius of the colliding nuclei the solution of the temperature profile is therefore (in the approach phase)

$$T(\gamma,t)_{t < \tau_g} \equiv T\,(1 - e^{-2\gamma\tau}) \quad \text{for } r < R \;,$$

$$_{t \geq \tau_g} = 0 \qquad\qquad \text{for } r \geq R$$

We have used the Baym solution[4] for τ larger than τ_q. Taking into account the u, d and S quarks the dilepton production rate is given by[5]

$$\frac{dN}{d^4X\, dM^2} = [\,\alpha M^2 T^2 / (2\Pi)^4] \; [\,5/3\, F_L(u,Z) + \frac{1}{3}\, F_S(u)]$$

For the approach phase T_{eff} is used to represent the temperature; for $\tau > \tau_q$ the Baym[4] solution of the hardon equation is used.

The most interesting conclusion of this analysis is that the dimuon spectrum dN/dM as a function of the invariant mass M is much more sharply peaked for small M than obtained by ignoring the contribution from the approach phase : The parameters taken for our analysis are : Critical temperature for deconfinement T_C = 0.16 GeV; T_o = 0.18 GeV, R = 7 fm and τ_q = 1 fm. The parameters chosen are just to illustrate a particular result. Results with other representative parameters will also be presented.

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