Measuring initial temperature through photon to dilepton ratio in heavy ion collision.

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Abstract. Theoretical calculation of transverse momentum($p_T$) distribution of thermal photons and dileptons originating from ultra-relativistic heavy ion collisions suffer from several uncertainties since the evaluation of these spectra needs various inputs which are not yet known unambiguously. In the present work the ratio of the $p_T$ spectra of thermal photons to lepton pairs has been evaluated and it is shown that the ratio is insensitive to some of these parameters.

1. Introduction

It is expected that the collision of heavy ions at ultra-relativistic energies would create a thermalised system of elementary particles like quarks and gluons. The interaction of these quarks and gluons produces real and virtual photons (dileptons). In principle, photons and dileptons can be used as effective tools to understand the initial state of the matter formed in heavy ion collision [1, 2, 3, 4]. However, in practice, difficulties arise firstly in the separation of thermal radiation from quark gluon plasma(QGP) and from those produced in initial hard collisions and from the decays of hadrons. Secondly, the evaluation of thermal photon and dilepton spectra need various inputs such as initial temperature($T_i$), thermalisation time($\tau_i$), equation of state(EOS), critical temperature($T_c$) for quark-hadron phase transition, freeze-out temperature($T_f$) etc., which are not known unambiguously. In the present work we evaluate the ratio, $R_{em} = (d^2N_\gamma/d^2p_Tdy)_{y=0}/(d^2N_{\gamma\gamma}/d^2p_Tdy)_{y=0}$, of thermal photons to dileptons for different initial energy densities and show that some of the uncertainties mentioned above get canceled in the ratio.

In section 2 the invariant yield of thermal photons and lepton pairs have been discussed. The dynamics of the space time evolution have been discussed in section 3. Finally, section 4 is devoted to results and discussions.
Electromagnetic probes

2. Production of thermal photons and lepton pairs

The $p_T$ distribution of thermal photons from heavy ion collisions in a first order phase transition scenario can be written as

$$\frac{d^2 N_\gamma}{d^2 p_T dy} = \sum_{i=Q,M,H} \int_i \left( \frac{d^2 R_\gamma}{d^2 p_T dy} \right)_i d^4 x$$

(1)

where $Q, M, H$ represents QGP, mixed (coexisting phase of QGP and hadrons) and hadronic phases respectively. $(d^2 R/d^2 p_T dy)_i$ is the production rate of photon from the phase $i$ at a temperature $T$, which is convoluted with the expansion dynamics through space-time integration over $d^4 x$. The complete calculation for emission rate of photons from QGP to $O(\alpha \alpha_s)$ as done in ref [5] has been considered in the present work. The rate of photon production in the hadronic phase has been taken from [6, 7, 8, 9]. Similarly the invariant transverse momentum distribution of thermal dileptons is given by:

$$\frac{d^2 N_{\gamma^*}}{d^2 p_T dy} = \sum_{i=Q,M,H} \int_i \left( \frac{d^2 R_{\gamma^*}}{d^2 p_T dy dM^2} \right)_i dM^2 d^4 x.$$  

(2)

The limits for integration over $M$ can be fixed from the experimental measurements. In the plasma phase the lepton pair production rates to $O(\alpha^2 \alpha_s)$ have been considered [10, 11]. The decays of vector mesons $\rho \rightarrow e^+ e^-$, $\omega \rightarrow e^+ e^-$ and $\phi \rightarrow e^+ e^-$ have been considered for the dilepton production in the hadronic phase. See [12] for details.

3. Space-time evolution

The space time evolution of the system has been studied using ideal relativistic hydrodynamics assuming longitudinal boost invariance and cylindrical symmetry [13, 14]. The initial temperature ($T_i$) and thermalisation time ($\tau_i$) are constrained by the following equation for an isentropic expansion:

$$T_i^3 \tau_i \approx \frac{2\pi^4}{45\zeta(3)} \pi R_A^2 a_k \frac{dN}{dy}.$$  

(3)

where, $dN/dy$= hadron multiplicity, $R_A$ is the radius of the system, $\zeta(3)$ is the Riemann zeta function and $a_k = \pi^2 g_{eff} / 90$, $g_{eff}$ being the degeneracy of the initial phase. In the present work we assume $T_c = 192$ MeV. We use the Bag model EOS for the QGP phase. For the EOS of the hadronic matter, all the resonances with mass $\leq 2.5$ GeV have been considered [15]. Electromagnetic spectra have also been evaluated with lattice EOS [16] and results are compared with those obtained from phenomenological EOS (i.e, bag model for QGP and hadronic resonance gas for low temperature hadron phase).

4. Results and Discussions

The input parameters considered for SPS, RHIC and LHC energies have been shown in table-I. The invariant mass spectra of dileptons and transverse momentum spectra
The ratio, $R_{em}$, as function of $p_T$ is shown for different mass windows (a) for SPS energy (b) RHIC energy.

Figure 2. (a) Ratio at LHC energy (b) The sensitivity of $R_{em}$ to $T - c$ when dilepton spectra is integrated over $M = 2m_\pi$ to $m_\phi$.
Table 1. The values of various parameters - $\tau_i$, $T_i$, $T_f$ and hadronic multiplicity $dN/dy$ - used in the present calculations.

| Accelerator | $\frac{dN}{dy}$ | $\tau_i (fm)$ | $T_i (GeV)$ | $T_f (MeV)$ |
|-------------|-----------------|-------------|-------------|-------------|
| SPS         | 700             | 1           | 0.2         | 120         |
| RHIC        | 1100            | 0.2         | 0.4         | 120         |
| LHC         | 2100            | 0.08        | 0.70        | 120         |
| LHC         | 4000            | 0.08        | 0.85        | 120         |

the parameters mentioned above, the effect on the ratio is small, e.g. if we change $T_c$ from 192 to 170 MeV then the invariant yield of photons at RHIC energy changes by 8.5% and dilepton spectra by 13% at $p_T = 2 GeV$. In contrast, $R_{em}$ changes by 5%. $R_{em}$ depends on $T_c$ very weakly as evident from the results shown in figure 2b for RHIC. The effect of flow and medium effects on hadrons \[21\] on the ratio is negligibly small. The transverse mass distribution of the dileptons for various invariant mass windows measured by NA60 \[22\] and PHENIX \[23\] collaborations could also be reproduced with the initial conditions shown in table-I. The details will be published elsewhere.

5. References

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