Thermal radiation from an expanding viscous medium

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Experimental results indicate that the initial state of matter produced in nuclear collisions at the Relativistic Heavy Ion Collider(RHIC) and Large Hadron Collider(LHC) might be a thermalised state of quarks and gluons, known as QGP. This hot and dense partonic matter expands and gradually cools down as the system evolves with time, and beyond a critical temperature T_c is converted into hadronic matter. During this evolution of the system, dissipative processes occur which are quantified by different transport coefficients. The study of various observables which are affected by dissipative processes can lead to a quantitative estimation of the transport coefficients. We have calculated the effect of viscous expansion on the photon spectra produced in heavy ion collisions with an aim to extract the coefficient of shear viscosity of the hot and dense medium from the relative shift of the transverse momentum spectra of photons.

The photon production rate from a reaction of the type: $1 + 2 \to 3 + \gamma$ at a temperature T is given by the equation

$$\frac{dR}{d^2p_T dy} = \frac{\mathcal{N}}{16(2\pi)^8} \int p_{1T} dp_{1T} dp_{2T} d\phi_1 dy_1 dy_2$$
$$f_1 f_2 (1 \pm f_3) \frac{\overline{|\mathcal{M}|^2}}{|p_{1T}\sin(\phi_1 - \phi_2) + p_T \sin\phi_2|_{\phi_2 = \phi_2^0}}$$

where $\overline{|\mathcal{M}|^2}$ is the invariant amplitude for the process.

The effects of viscosity on photon production enter through two main factors, (a) modification of phase space factor due to deviation of the system from equilibrium and (b) the space time evolution of the matter governed by dissipative hydrodynamics.

The first viscous correction to the distribution function of interacting particles from shear viscosity η for a (1+1) dimensional boost invariant expansion is given by,

$$f = f_0[1 + \frac{\eta/s}{3T^3\tau}\{p_T^2 - 2m_T^2 \sinh^2(y - \eta_s)\}]$$

where s is the entropy density, η is the coefficient of shear viscosity and y and η_s are the rapidities of the interacting particles and space-time respectively.

The modification of the space-time evolution dynamics due to dissipative processes can be obtained from relativistic viscous hydrodynamics. The resulting cooling law in the presence of shear viscosity in the QGP phase is given by the equation

$$T = T_i\left(\frac{\tau_i}{\tau}\right)^{1/3} + \frac{2}{3\tau_i}\left(\frac{\eta}{s}\right)_Q \left[\left(\frac{\tau_i}{\tau}\right)^{1/3} - \frac{\tau_i}{\tau}\right]$$

where we have assumed that the system achieves thermal equilibrium at a proper time τ_i after the collision at an initial temperature T_i. We see that due to the presence of viscosity in the cooling law, the lifetime of the system has increased due to entropy being generated within the system on account of dissipative processes. For the hadronic phase also a similar equation results. This is given by

$$T = T_c\left(\frac{\tau_H}{\tau}\right)^{1/3} + \frac{2}{3\tau_H}\left(\frac{\eta}{s}\right)_H \left[\left(\frac{\tau_H}{\tau}\right)^{1/3} - \frac{\tau_H}{\tau}\right]$$

These two equations provide the nature of $T-\tau$ profile in the presence of shear viscosity.

Normally, the initial temperature (T_i) and the thermalisation time (τ_i) are constrained by the measured hadron multiplicity (dN/dy) at the freeze out temperature. This approach

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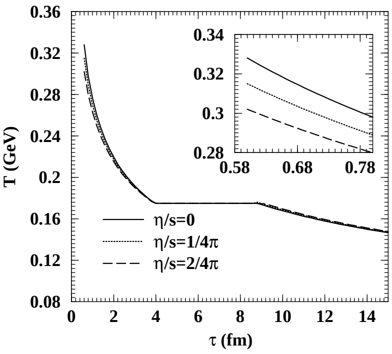

FIG. 1: Variation of temperature T with proper time τ for different values of η/s.

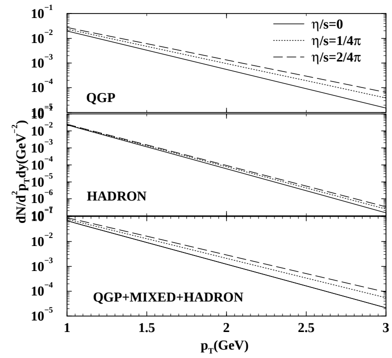

FIG. 2: p_T distribution of thermal photons for different values of η/s in the scenario (i).

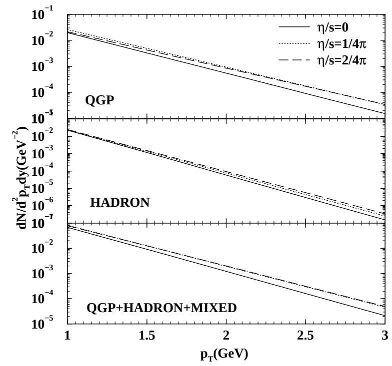

FIG. 3: p_T distribution of thermal photons for different values of η/s in the scenario (ii).

is valid for an ideal system with no viscosity where the time reversal symmetry is valid. However, for a viscous system the entropy at the freeze-out point (which is proportional to the multiplicity) contains the initially produced entropy as well as the entropy produced during the space time evolution due to non-zero viscosity. Therefore, the amount of entropy generated during the evolution has to be subtracted from the total entropy at the freeze-out point and the remaining part which is produced initially should be used to estimate the initial temperature. Following this process, for a given dN/dy (which is associated with the freeze-out point) and τ_i the magnitude of T_i is found to be lower in case of viscous dynamics compared to ideal flow as seen in Fig. 1.

For a comparative study, the effect of viscosity on photon spectra is examined in two scenarios. In (i) the effect of viscosity is taken only in phase space factor and in (ii) the effect of finite η/s is taken both in the phase space factor as well as in the evolution dynamics. In the following we present the photon spectra corresponding to these scenarios up to a maximum transverse momentum of 3 GeV. We have estimated that beyond this value the viscous correction becomes comparable to equilibrium emission.

Fig. 2 shows results for scenario (i) where we see that the higher values of η/s make the spectra flatter indicating the system will take longer time to cool down due to viscous heating. The spectra for the hadronic phase are qualitatively similar to that of QGP but the effect is quantitatively small. However, as seen in Fig. 3, the spectra for QGP phase in scenario (ii) show a partial compensation to the enhancement in the photon production rate due to the viscous modification of the phase space factor on account of the reduction of T_i. In the hadronic phase we can see no such compensation since in this case the initial temperature is fixed at critical temperature T_c.

References

[1] S.Mitra, P. Mohanty, S. Sarkar and J. Alam, arXiv:1107.2500.