Isotropization time of quark gluon plasma from direct photon at RHIC

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Introduction

The primary goal of relativistic heavy ion collisions is to create a new state of matter, called quark gluon plasma (QGP) and to study its properties through various indirect probes. Out of all the properties of the QGP, the most difficult problem lies in the determination of isotropization and thermalization time scales ($\tau_{\rm iso}$ and $\tau_{\rm therm}$). Studies on elliptic flow (upto about $p_T \sim 1.5-2$ GeV) using ideal hydrodynamics indicate that the matter produced in such collisions becomes isotropic with $\tau_{\rm iso} \sim 0.6$ fm/c.On the other hand, using second order transport coefficients with conformal symmetry, it is found that the isotropization/thermalization time has sizable uncertainties.Consequently, there are uncertainties in the initial temperature as well. Electromagnetic probes have been proposed to be one of the most promising tools to characterize the initial state of the collisions [1].Because of the very nature of their interactions with the constituents of the system they tend to leave the system without much change of their energy and momentum. In fact, photons (dilepton as well) can be used to determine the initial temperature, or equivalently the equilibration time.

Earlier works [2–4] on photon production assume isotropy from the very beginning, i. e. $\tau_{\rm iso} = \tau_i$ (QGP formation time). In view of the absence of a theoretical proof behind the rapid thermalization and the uncertainties in the hydrodynamical fits of experimental data, such an assumption may not be justified. Instead of equating the thermalization/isotropization time to the QGP formation time, in this work, we will introduce an intermediate time ($\tau_{\rm iso}$) to study the effects of early time momentum-space anisotropy on the total photon yield and compare it with the PHENIX photon data [5–7]. In the present model the space-time evolution, during the interval $\tau_i < \tau < \tau_{\rm iso}$, is modeled as in Ref. [8, 9]. For the evolution from $\tau_{\rm iso}$ to τ_F (freeze-out time) we use $(1+2)d$ ideal hydrodynamics.

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Formalism

The anisotropic distribution functions which appear in the Compton or annihilation processes can be obtained by squeezing or stretching an arbitrary isotropic distribution function along this direction in momentum space,

$$f_i(\mathbf{k},\xi,p_{hard}) = f_i^{iso}(\sqrt{\mathbf{p}^2+\xi(\mathbf{p}.\mathbf{n})^2}, p_{\rm hard}(\tau,\eta)) \quad (1)$$

where $\mathbf{n}$ is the direction of anisotropy and ξ is a parameter controlling the strength of the anisotropy with $\xi > -1$. The hard momentum scale p_{hard} is directly related to the average momentum in the parton distribution functions. Phenomenological models have been used to obtain the time evolutions of $p_{\rm hard}$ and ξ [8, 9]. The p_T distribution of photons is then evaluated using standard kinetic theory (See Ref. [10].

To compute the photon rate from the hot hadronic matter, we follow Ref. [11] for $M\,M \rightarrow M\,\gamma$ (M denotes low lying mesons) and Ref. [12] for $B\,M \rightarrow B\,\gamma$ (B denotes baryon).

We consider the initial temperature $T_i = 440$ MeV and formation time $\tau_i = 0.1$ fm/c

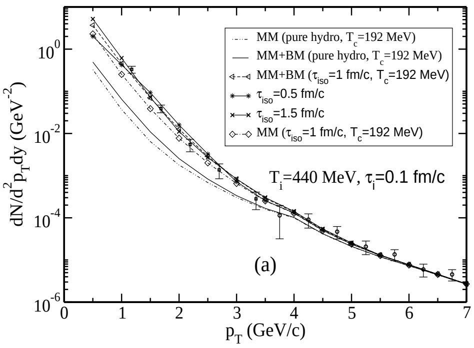

FIG. 1: (Color online) Photon transverse momentum distributions at RHIC energies for for three different values of the τ_{iso} with initial condition: $T_i = 440$ MeV, $\tau_i = 0.1$ fm/c and $T_c = 192$ MeV.

which are consistent with $dN/dy \sim 1100$ measured at RHIC energies. It is to be mentioned that in our case $\tau_{\rm iso}$ is always less than transition time, τ_c.

The presence of initial state momentum anisotropy and the importance of the contribution from baryon-meson reactions we plot the the total photon yield assuming hydrodynamic evolution from the very begining as well as with finite $\tau_{\rm iso}$ in Fig. (1). It is clearly seen that some amount of anisotropy is needed to reproduce the data. We note that the value of $\tau_{\rm iso}$ needed to describe the data also lies in the range 1.5 fm/c $\geq \tau_{\rm iso} \geq 0.5$ fm/c. Detail results for various intial conditions and transition temperatures will be reported.

Summary and Conclusion

We have calculated total single photon transverse momentum distributions by taking into account the effects of the pre-equilibrium momentum space anisotropy of the QGP and late stage transverse expansion on photons from hadronic matter with various initial conditions. To describe space-time evolution in the very early stage we have used the phenomenological model described in Ref. [8]. The total photon yield is compared with the PHENIX photon data. Within the ambit of the present model it is shown that the data can be described quite well if $\tau_{\rm iso}$ is in the range of $0.5 - 1.5$ fm/c for all the combinations of initial conditions and transition temperatures considered here.

References

[1] J. Alam, S. Sarkar, P. Roy, T. Hatsuda, and B. Sinha, Ann. Phys. **286**, 159 (2001).

[2] J. Alam, J. K. Nayak, P. Roy, A. K. Dutt-Mazumder, and B. Sinha, J. Phys. G **34**, 871 (2007).

[3] D. K. Srivastava, Eur. Phys. J. C **10**, 487 (1999).

[4] S. Turbide, C. Gale, E. Frodermann and U. Heinz, Phys. Rev C **77**, 024909 (2008).

[5] S. S. Adler et al., Phys. Rev. Lett. **94**, 232301 (2005).

[6] S. S. Adler et al., Phys. Rev. Lett. **98**, 012002 (2007).

[7] A. Adare et al., PHENIX Collaboration, arXiv:0804.4168v1 [nucl-ex].

[8] M. Martinez and M. Strickland, Phys. Rev. C **78**, 034917 (2008).

[9] L. Bhattacharya and P. Roy, Phys. Rev. C **78**, 064904 (2008).

[10] L. Bhattacharya and P. Roy, Phys. Rev. C **79**, 054910 (2008).

[11] S. Turbide, R. Rapp, and C. Gale, Phys. Rev. C **69**, 014903 (2004).

[12] J. Alam, P. Roy, and S. Sarkar, Phys. Rev. C **68**, 031901(R) (2003).