Effect of running coupling on photons from jet - plasma interaction in relativistic heavy ion collisions

Lusaka Bhattacharya[1,*] Mahatsav Mandal [1,†] and Pradip Roy [1]
[1] *High Energy Physics Division, Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata-700 064, INDIA*

Introduction

Heavy ion collisions have received significant attention in recent years. Various possible probes have been studied in order to detect the signatures of quark gluon plasma (QGP). Study of direct photon and dilepton spectra emanating from hot and dense matter formed in ultra-relativistic heavy ion collisions is a field of considerable current interest. 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 almost unscattered.

Photons are produced at various stages of the evolution process. Here we elaborate a new class of photon emission process, the jet conversion mechanism (jet-plasma interaction) [2] which occurs when a high energy jet interacts with the medium constituents via annihilation and Compton processes.

The suppression of single electron data [3] is more than expected which led to the rethinking of the importance of collisional energy loss in the context of RHIC data. It is also shown by Braun et. al [4] that the collisional energy loss increases substantially if the strong coupling is treated as function of temperature and momentum and if, in addition to t-channel process, the inverse Compton reaction is considered. A recent calculation, using a reduced screening mass and running coupling the collisional energy loss is six times larger than that with the constant coupling [5]. It explains the single electron data quite well with collisional loss alone. However, in order to see the effects of energy loss on jet-photon one should also incorporate the radiative energy loss for completeness and this has to be done in the same formalism in a realistic scenario.

*Electronic address: `lusaka.bhattacharya@saha.ac.in`
†Electronic address: `mahatsav.mandal@saha.ac.in`

Formalism

The lowest order processes for photon emission from QGP are the Compton scattering and annihilation process. The total cross-section diverges in the limit t or $u \to 0$. These singularities have to be shielded by thermal effects in order to obtain infrared safe calculations. Apart from the thermal interactions of the plasma partons, interaction of a leading jet parton with the plasma was found to be a very important source of photons.

The differential photon production rate for this process is given by:

$$E\frac{dR}{d^3p} = \frac{\mathcal{N}}{2(2\pi)^3}\int \frac{d^3p_1}{2E_1(2\pi)^3}\frac{d^3p_2}{2E_2(2\pi)^3}\frac{d^3p_3}{2E_3(2\pi)^3} \times f_{jet}(\mathbf{p_1})f_2(E_2)(2\pi)^4\delta(p_1+p_2-p_3-p) \times |\mathcal{M}|^2(1\pm f_3(E_3)) \quad (1)$$

The phase space distribution of the participating jet is dynamically evolved by solving Fokker-Planck equation. We treat the strong coupling constant (α_s) as function of momentum and temperature (for details see [4]) while calculating the drag and diffusion coefficients. In case of jet-photon production, since the photon energy is almost equal to the jet energy, one has to include the radiative loss to account for the high p_T photons. However, in order to see the effects of both the collisional and radiative energy losses, one must device a formalism in which both the mechanisms can

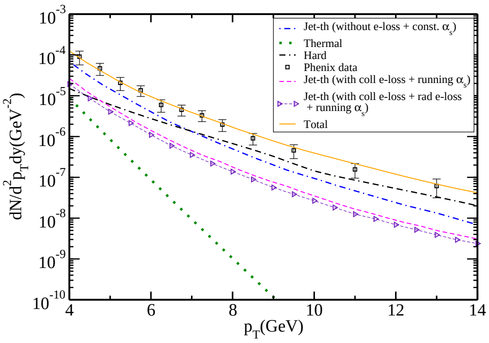

FIG. 1: (Color online) p_T distribution of photons at RHIC energy with $T_i = 0.446$ GeV and $\tau_i = 0.147$ fm/c. The red (blue) curve denotes the photon yield from jet-plasma interaction running (constant) α_s. The black (green) curve corresponds to hard (thermal) photons. The orange represents the total yield compared with the Phenix measurements of photon data [6]

be taken into account in a consistent manner. The two mechanisms are not entirely independent, i.e., the collisional loss may influence the radiative loss. Thus both should be included to calculate transport coefficients

Result

In order to compare our results with high p_T photon data measured by the PHENIX collaboration [6], we have to evaluate the contributions to the photons from other sources, that might contribute in this p_T range.In Fig. 1 the results for jet-photons corresponding to the RHIC energies are shown, where we have taken $T_i = 446$ MeV and $t_i = 0.147$ fm/c. The individual contributions from hard and bremsstrahlung processes are also shown for comparison. We also show the yields corresponding to the cases with constant α_s and running α_s with collisional energy loss alone. It is observed that the spectra in the case of collisional energy loss with running coupling is depleted by a factor $2 - 2.5$ compared to the case where the strong coupling is constant. This is expected as the energy loss is more by a similar factor in the former case. The yield further reduces when both the mechanisms of energy loss are included. The total photon yield consisting of jet-photon, photons from initial hard collisions, jet-fragmentation and thermal photons is compared with the PHENIX photon data [6]. It is seen that the data is well reproduced in our model.

Conclusions

We have calculated the transverse momentum distribution of photons from jet plasma interaction with running coupling, i. e. with $\alpha_s = \alpha_s(k, T)$ where we have included both collisional and radiative energy losses.

Phenix photon data have been contrasted with the present calculation and the data seem to have been reproduced well in the low p_T domain. The energy of the jet quark to produce photons in this range ($4 < p_T < 14$) is such that collisional energy loss plays important role here. It is shown that inclusion of radiative energy loss also describes the data reasonable well.

References

[1] J. Alam, S. Sarkar, P. Roy, T. Hatsuda, and B. Sinha, Ann. Phys. **286** 159 (2000).

[2] R. J. Fries, B. Muller, and D. K. Srivastava, Phys. Rev. Lett. **90**, 132301 (2003).

[3] S. S. Adler et al., Phenix Collaboration, Phys. Rev. Lett.**96** 032301 (2006).

[4] J. Braun and H-J. Pirner, Phys. Rev. D**75**, 054031 (2007).

[5] P. B. Gossiaux and A. Aichelin, Phys. Rev. C**78**, 014904 (2008).

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