Interference of thermal photons at RHIC

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Introduction

Quark-Gluon Plasma or QGP, a deconfined novel state of quarks and gluons in local thermal equilibrium, has become a subject of immense interest in the last couple of decades in relativistic heavy ion collision physics. For the space-time evolution of the system, a very powerful tool is provided by the study of quantum statistical interference between identical particles emitted from the expanding system produced in the collisions. The intensity correlation study using hadronic probes reveals only the later stages of the system expansion, whereas electreomagnetic radiation or photons expose the early hot and dense as well as the later (relatively) cooler stages of the evolving system, as photons are produced from each and every stages of it. Also photons do not suffer any final state interactions and produce undistorted signal at the detector. We show that the intensity correlation for thermal photons produced in relativistic collision of heavy nuclei gives rise to a unique structure in the outward correlation function due to the interference between the photons from quark matter and hadronic matter phases.

Interference of thermal photons

The spin averaged intensity correlation between two photons having momenta $\mathbf{k_1}$ and $\mathbf{k_2}$ emitted from a completely chaotic source $S(x,\mathbf{K})$ is expressed as:

$$C(\mathbf{q},\mathbf{K}) = 1 + \frac{0.5 \times \left|\int d^4x\, S(x,\mathbf{K}) e^{ix\cdot q}\right|^2}{\int d^4x\, S(x,\mathbf{k_1}) \ \int d^4x\, S(x,\mathbf{k_2})} \quad (1)$$

where $S(x,\mathbf{K})$ is the space-time emission func-

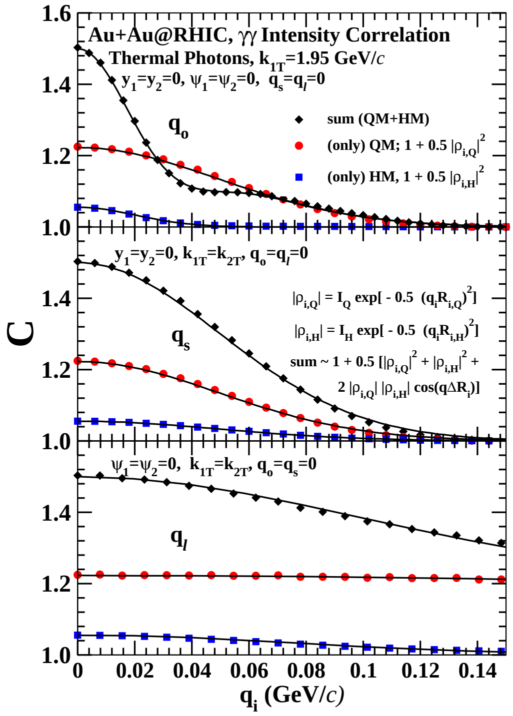

FIG. 1: q_o [upper panel], q_s [middle panel], and q_ℓ [lower panel] for thermal photons at RHIC for $\tau_0 = 0.2$ fm/c. Symbols denote the results of the calculation, while the curves denote the fits.

tion, and

$$\mathbf{q} = \mathbf{k_1} - \mathbf{k_2}, \ \ \mathbf{K} = (\mathbf{k_1} + \mathbf{k_2})/2 \ . \quad (2)$$

Denoting q_o, q_s, and q_ℓ as the outward, sideward, and longitudinal momentum differences (see Ref. [1] for the explicit expressions of q_o, q_s, and q_ℓ), the corresponding radii are obtained by approximating the correlation function as,

$$C(q_{\rm o}, q_{\rm s}, q_\ell) = 1 \ + \ 0.5 \ \times \exp\left[-\left(q_{\rm o}^2 R_{\rm o}^2 \ + \ q_{\rm s}^2 R_{\rm s}^2 + q_\ell^2 R_\ell^2\right)\right] . \quad (3)$$

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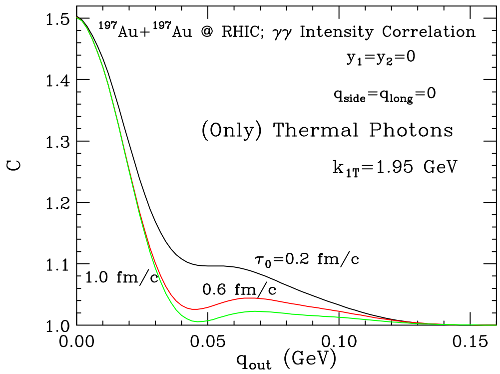

FIG. 2: τ_0 dependence of q_o at RHIC.

We use hydrodynamics (considering boost invariant longitudinal and azimuthally symmetric transverse expansion of the plasma) to model the evolution of the system, whereas the space time function S is approximated as the rate of production of photons (EdN/d^4xd^3k), from quark matter and hadronic matter phases with a transition temperature of about 180 MeV. The initial energy density is calculated by taking weighted sum of wounded nucleons and binary collision and the charged particle rapidity density at midrapidity is taken as 700 for RHIC.

The outward, sideward, and longitudinal correlation functions of thermal photons for 200A GeV Au+Au collisions (at b=0 fm and initial formation time of the plasma $\tau_0 = 0.2$ fm/c) at RHIC is shown in Fig. 1. The results are shown for a typical value of $k_T \approx 2.0$ GeV, as the thermal photons from quark matter and hadronic matter phases get competing contributions at this k_T value at RHIC energy. An unique structure can be observed in the outward correlation function in Fig. 1, which arises due to the interferences between the photons from quark matter and hadronic matter phases. The sum correlation function (as shown in Fig. 1) can be approximated as:

$$C(q_i) = 1 + 0.5\left[\,|\rho_{i,Q}|^2 + |\rho_{i,H}|^2 + 2\,|\rho_{i,Q}||\rho_{i,H}|\,\cos(\mathrm{q}\Delta\mathrm{R_i})\right]. \quad (4)$$

Here, ΔR_i stand for the space time separation of the two sources, and q is the 4-momentum differences for them. The source distributions in the two phases can be expressed as,

$$|\rho_{i,\alpha}| = I_i \exp\left[-0.5\,(\mathrm{q_i^2 R_{i,\alpha}^2})\right]. \quad (5)$$

i=o, s, and ℓ, and α denotes quark matter (Q) and hadronic matter (H) in an obvious notation.

The cross term in Eq. 4 clearly shows the interference between the two sources. The strength factors $\mathrm{I_Q}$ and $\mathrm{I_H}$ (see Fig. 1 for the definition) in the source functions are equal to $\mathrm{dN_Q/(dN_Q + dN_H)}$ and $\mathrm{dN_H/(dN_Q + dN_H)}$ respectively, which give the relative contributions from the two sources. The different radii (in fm) at RHIC from thermal photon having $k_T \approx 2$ GeV are obtained as,

$$\begin{aligned} R_{o,Q} &= 2.8,\ R_{o,H} = 7.0,\ \Delta R_o = 12.3, \\ R_{s,Q} &\approx R_{s,H} = 2.8,\ \Delta R_s \approx 0., \\ R_{\ell,Q} &= 0.3,\ R_{\ell,H} = 1.8,\ \Delta R_\ell \approx 0. \end{aligned}$$

We see that the temporal separation between the two sources (ΔR_o) is about 12 fm, which actually denotes the lifetime of the system, while the spatial separation of the two sources is almost negligible. The τ_0 dependent outward correlation function at RHIC is shown in Fig. 2 and the results show a strong sensitivity to the initial formation time of the plasma.

In conclusion, we show that the interference between photons from quark matter and hadronic matter phases gives rise to an interesting structure in the outward correlation function of thermal photons at RHIC having $k_T \approx 2$ GeV. This structure is also observed for central collisions of Pb+Pb at LHC energy for a lower k_T value (~ 1.5 GeV) as the initial temperature is much higher at LHC than RHIC (see Ref. [1] for details). The lifetime of the system can be estimated from the temporal separation of the two sources and the results are found to be sensitive to the initial formation time of the plasma.

References

[1] D. K. Srivastava and R. Chatterjee, [arXiv:0907:1360].