Study of relativistic heavy ion collisions using photon anisotropic flow

Rupa Chatterjee[1]* and Pingal Dasgupta[2]
[1] *Variable Energy Cyclotron Centre, HBNI, 1/AF, Bidhan Nagar, Kolkata 700064, India and*
[2] *Key Laboratory of Nuclear Physics and Ion-beam Application (MOE), Institute of Modern Physics, Fudan University, Shanghai 200433, China*

Anisotropic flow (v_n) produced in relativistic heavy ion collisions is considered to be a response of the initial spatial anisotropy of the overlapping zone between two colliding nuclei. The observation of the large anisotropic flow of hadrons at RHIC and LHC energies provides strong confirmation of collectivity and early thermalization of the produced hot and dense matter in such collisions [1]. Photons are emitted from all stages of the evolving fireball and their emission is quite sensitive to the initial temperature of the system formed. Thus, photon observables can be a potential probe to study the initial state as well as the evolution of the Quark Gluon Plasma (QGP) produced in relativistic heavy ion collisions [2–4].

The anisotropic flow of photons as a function of the transverse momentum p_T shows interesting nature due to the relative contributions of thermal radiation from QGP and hadronic matter phases [5–7]. The prompt photons produced from initial hard scatterings dominate the direct photon spectra in the region $p_T > 3$ GeV. However, it has been shown that only the thermal radiation directly contribute to the anisotropic flow of photons. The prompt contribution indirectly affect the anisotropic flow by adding extra weight factor in the estimation of direct photon v_n.

It is well known that the results from theoretical model calculations can not explain the spectra and anisotropic flow of photons simultaneously at RHIC as well as at the LHC energies. This is known as *direct photon puzzle* [4, 7]. We suggest that the ratio of photon anisotropic flow parameters as a function of p_T can be a potential observable to understand the initial state as well as the direct photon puzzle [8] in relativistic heavy ion collisions [8].

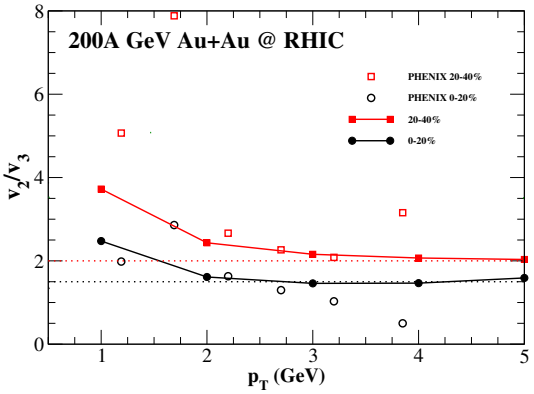

FIG. 1: Ratio of elliptic (v_2) and triangular (v_3) flow parameters of thermal photons from 200A GeV Au+Au collisions at RHIC for 0–20% and 20–40% centrality bins using hydrodynamical model calculation [8]. The experimental data by PHENIX Collaboration [9] are shown for a comparison.

The elliptic (v_2) and triangular (v_3) flow parameters of photons show similar qualitative nature as a function of p_T at RHIC and LHC energies. However, the elliptic flow is estimated to be larger compared to the triangular flow parameter for a particular centrality bin. In addition, the photon elliptic flow parameter shows stronger sensitivity to the collision centrality compared to the triangular flow parameter.

We see that the ratio of photon v_2 and v_3 clearly shows the dominance of the thermal radiation by minimizing the effect of non-thermal contributions. The photon v_2/v_3 also

*Electronic address: rupa@vecc.gov.in

shows different p_T dependent nature compared to the individual anisotropic flow parameters. For Au+Au collisions at RHIC, the ratio rises with smaller values of p_T in the region p_T <2 GeV. However, it does not change significantly for p_T >2 GeV as shown in Fig. 1. A similar qualitative nature has been seen for the ratio calculated at the LHC energy for Pb+Pb collisions. It is to be noted that we do not see any correlation between the photon v_2 and v_3 from their event-by-event distributions at different p_T values.

The individual elliptic and triangular flow parameters underpredict the experimental photon v_n data by a significant margin. However, their ratio is found to be in relatively better agreement with the data at RHIC [9] (see Fig. 1) in the p_T region 2 to 3.5 GeV. The ratio increases for more peripheral collisions as the relative enhancement of photon v_2 compared to v_3 is more for 20–40% centrality bin compared to the 0–20% centrality bin.

The v_2/v_3 ratio is found to be sensitive to the initial parameters of the model calculation in different p_T regions compared to the individual elliptic and triangular flow parameters. A small change in initial formation time (τ_0) affects the ratio in the smaller p_T region. Whereas, a small variation in τ_0 affects the individual flow parameters mostly in the larger p_T region. In addition, we do not see a significant change in the ratio even when a much smaller value of the final freeze-out temperature is considered.

It has been shown in earlier studies that the directed flow parameter v_1 of photons shows a different p_T dependent nature compared to the elliptic and triangular flow parameters [10]. We see both positive and negative values of photon v_1 depending on the range of the transverse momentum. The photon v_1 is totally dominated by the radiation from the QGP phase and the contribution of the photons from hadronic medium is only marginal. Thus, v_1/v_2 and v_1/v_3 of photons can also be one valuable observable to study the initial state formed in relativistic heavy ion collisions. In addition, the v_1/v_n (n=2,3) ratio is expected to be sensitive to the hadronic phase unlike the v_2/v_3 of photons.

We conclude that a simultaneous measurement of the individual photon anisotropic flow parameters along with the ratio of the anisotropic flow parameters would be quite useful in constraining the initial conditions and also to understand the direct photon puzzle in relativistic heavy ion collisions.

Acknowledgments

We would like to thank the VECC computer facility. PD acknowledges the support of the National Natural Science Foundation of China under Grants No. 11835002 and No. 11961131011. Discussions with Dinesh Kumar Srivastava are gratefully acknowledged.

References

[1] P. Kolb and U Heinz, *Hydrodynamic description of ultrarelativistic heavy ion collisions Quark gluon plasma*, R. C. Hwa (ed.) *et al.*, p634 (2003).
[2] D. K. Srivastava, J. Phys. G **35**, 104026 (2008).
[3] C. Gale, PoS **High-pT2017**, 023 (2019).
[4] R. Chatterjee, Pramana **95**, no.1, 15 (2021).
[5] R. Chatterjee, E. S. Frodermann, U. W. Heinz and D. K. Srivastava, Phys. Rev. Lett. **96**, 202302 (2006).
[6] R. Chatterjee, D. K. Srivastava and T. Renk, Phys. Rev. C **94**, no.1, 014903 (2016).
[7] R. Chatterjee, P. Dasgupta and D. K. Srivastava, Phys. Rev. C **96**, no.1, 014911 (2017).
[8] R. Chatterjee and P. Dasgupta, arXiv:2106:15922.
[9] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. C **94**, no.6, 064901 (2016).
[10] P. Dasgupta, R. Chatterjee and D. K. Srivastava, J. Phys. G **47**, no.8, 085101 (2020).