Elliptic and triangular flow of thermal photons at RHIC and LHC from event-by-event hydrodynamic model

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Hydrodynamics with event-by-event (e-by-e) fluctuating initial conditions (IC) is considered more realistic than a smooth initial-state-averaged density distribution in recent past to study the evolution of the hot and dense Quark-Gluon Plasma created in collisions of heavy nuclei at relativistic energies [1].

A significant enhancement in the production of thermal photons for $p_T >$1 GeV/c has been seen due to fluctuations in the IC and consequently better agreement of the direct photon data in the region p_T 2–4 GeV/c has been observed both at RHIC and at the LHC energies. The enhancement in the production of thermal photons is an early time effect due to the presence of hotspots in the fluctuating IC. At the initial stages of the system evolution these hotspots produce more high p_T photons compared to a smooth IC and make the spectra flatter [2]. In addition, the effect of IC fluctuation in found to be more pronounced for peripheral collisions than for central collisions and it is more at RHIC than at the LHC energy.

We calculate the elliptic and the triangular flow parameters v_2 and v_3 of thermal photons as a function of p_T both at RHIC and at the LHC energies for different centrality bins using e-by-e hydrodynamics with fluctuating initial conditions.

The standard two parameter Woods Saxon nuclear density distribution and Monte Carlo Glauber model is used in this e-by-e hydrodynamic framework. We consider wounded nucleon profile where the initial entropy density is distributed around the participants using a

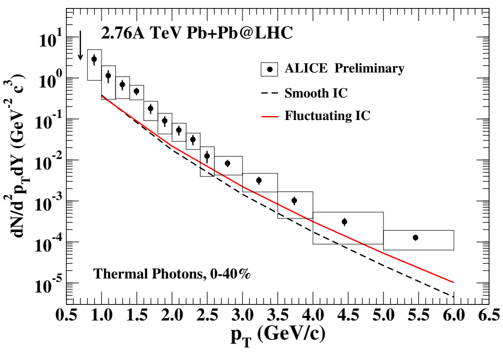

FIG. 1: Thermal photon spectra from smooth (SIC) and fluctuating (FIC) initial conditions for 0–40% central collisions of Pb+Pb at 2.76A TeV at LHC along with ALICE preliminary direct photon data [5].

2-dimensional Gaussian distribution function

$$s(x,y) = \frac{K}{2\pi\sigma^2} \times \sum_{i=1}^{N_{\rm WN}} \exp\left(-\frac{({\rm x}-{\rm x_i})^2+({\rm y}-{\rm y_i})^2}{2\sigma^2}\right).$$

K is a normalization constant, (x_i, y_i) is the position of the ith nucleon on transverse plane and σ is the most important parameter in the Eqn above which decides the granularity or the size of the initial density fluctuations. We consider a default value of σ = 0.4 fm which has been used extensively to explain the charge particle spectra and elliptic flow. The initial formation time τ_0 of the plasma is taken as 0.17 and 0.14 fm respectively at RHIC and LHC energies from EKRT minijet saturation model. A lattice based equation of state is used and temperature at freeze out is considered at 160 MeV which reproduces the pion spectra well both at RHIC and LHC. We use state-of-the-art rates (QGP rates from [3] and

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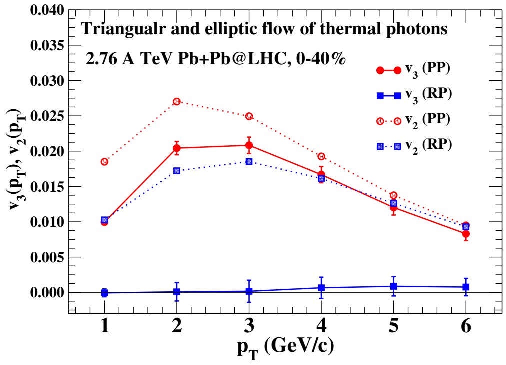

FIG. 2: Triangular and elliptic flow of thermal photons from 2.76A TeV Pb+Pb collisions at LHC [6]. Flow parameters calculated with respect to the participant plane (PP) and reaction plane (PP) angles are shown separately.

hadronic rates from [4]) to calculate the spectra and the anisotropy flow parameters from that [2, 5].

Thermal photon spectra from smooth and fluctuating IC for 2.76A TeV Pb+Pb collisions at LHC and for 0–40% centrality bin along with ALICE preliminary direct photon data are shown in Fig 1. We consider a sufficiently large number of random events and calculate spectra and v_2 from each of those events and then average over the v_2 results to get the final elliptic flow from fluctuating IC. v_2 as a function of p_T calculated with respect to the participant plane (PP) angle is found to be significantly larger than the v_2 from smooth IC in the region $p_T > 2$ GeV/c. v_2(PP) also found to be larger than the v_2 calculated with respect to the reaction plane (RP) angle. However, we see that the increase is v_2 due to IC fluctuation is not sufficient to explain the experimental data (see [5]) at RHIC and LHC.

The elliptic flow results found to depend strongly on the value of the initial parameters σ and τ_0. The initial density distributions become relatively smoother for larger values of σ and we get smaller v_2. A smaller τ_0 implies a larger initial temperature of the plasma and more high p_T photons from the early stages of the system evolution. However, flow fields are very small at initial time and as a result we see smaller elliptic flow (at larger p_T values) for smaller τ_0 compared to the result obtained at larger τ_0 values.

The triangular flow parameter v_3 of thermal photons calculated with respect to PP is found to be non-zero, positive, and comparable to the elliptic flow result in the higher p_T region (see Fig. 2) [6]. Whereas, as expected, v_3 calculated with respect to RP is close to zero as shown in figure. We see that the initial geometry as well as the fluctuation driven larger transverse flow velocity both play significant role in determining photon v_3. In order to understand the effect of IC fluctuation on the v_2 and v_3 better we study the correlation between flow parameters and their corresponding initial state anisotropies from their e-by-e distributions [7]. We see relatively stronger correlation between v_2 and ϵ_2 than between v_3 and ϵ_3.

We conclude that the thermal photon elliptic and triangular flow results at different centrality bins and beam energies would be valuable to understand the IC fluctuation as well as the photon v_2 puzzle.

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