Thermal photons from U+U collisions at RHIC

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U+U collisions at $\sqrt{s}_{NN}$=193 GeV at RHIC have gained a lot of attention in the relativistic heavy ion collision physics community in recent years [1]. The uranium nuclei (^{238}U) have a prolate shape and as a result, even the most central U+U collisions lead to different collision geometries [2] and consequently different values of observables produced in heavy ion collisions.

We calculate spectra and elliptic flow parameter v_2 of thermal photons from tip-tip and body-body configurations (which are the limiting cases of particle multiplicity) of full-overlap U+U collisions and compare the results with that obtained from Au+Au collisions at RHIC [3] energies. The major axes of the two incoming uranium nuclei are perpendicular to the beam axis in body-body collisions, whereas, for tip-tip collisions the major axes are along the beam direction. The overlapping zone in tip-tip collisions is circular in shape and produces larger initial temperature and higher particle multiplicity. On the other hand, the body-body collisions lead to an elliptical shape with larger volume of the overlapping zone and non-zero anisotropic flow parameters.

We use Woods-Saxon parameterization for the nuclear density distribution of the deformed uranium nuclei,

$$\rho(r,\theta) = \frac{\rho_0}{1 + exp([r - R(\theta)]/\xi)} \qquad (1)$$

where,

$$R(\theta) = R_0[1 + \beta_2 Y_2^0(\theta) + \beta_4 Y_4^0(\theta)] \qquad (2)$$

The spherical harmonic functions (Y_2^0 and Y_4^0) and the β values introduce the deformation from spherical shape in the uranium nucleus. We consider β_2 and β_4 as 0.28 and 0.093 respectively. R_0 is taken as 6.86 fm and the diffuseness parameter (ξ) is 0.44 fm. Using this parameterization in optical Glauber model we calculate the initial profile for tip-tip and body-body configurations for full overlap (b = 0 fm) U+U collisions at RHIC. A (2+1) dimensional longitudinally boost invariant hydrodynamic model with smooth initial density distribution is used to study the evolution for such systems. The initial formation time τ_0 is considered as 0.6 fm and the corresponding initial entropy densities for full overlap tip-tip and body-body collisions are taken as 167 fm^{-3} and 141 fm^{-3} respectively [2]. A lattice based equation of state is used and the final freeze-out temperature is considered as 140 MeV. We have also investigated how sensitive our results are to the different choices of the initial parameters.

The spectra and elliptic flow of thermal photons are calculated using state of the art photon rates, where next-to-leading order QGP rates are taken from [4, 5] and thermal photon production from the different hadronic channels are taken from [6].

FIG.1 shows the thermal photon p_T spectra for tip-tip and body-body configurations. The p_T spectrum from central (b = 0 fm) Au+Au collisions at RHIC is also shown for a comparison. We see different slopes of the spectra for the two orientations of uranium nuclei. The body-body collisions produce slightly more thermal photons compared to the tip-tip collisions in the low p_T ($<$ 1.5 GeV) region. However, photon production is significantly larger for tip-tip collisions in the higher p_T ($>$ 2 GeV) region. We have stated above that the produced fireball in tip-tip collision is smaller in size and has larger initial energy and/or entropy density and temperature

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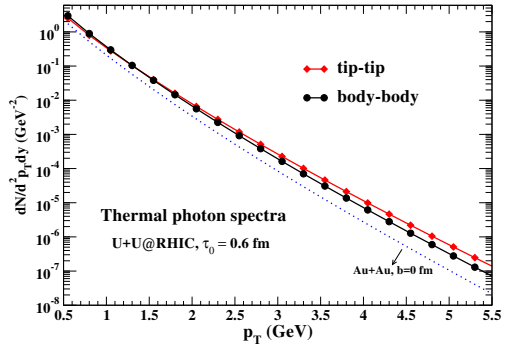

FIG. 1: Thermal photon spectra from full overlap U+U collision and central ($b = 0$ fm) Au+Au colliosion for initial time $\tau_0 = 0.6$ fm at RHIC.

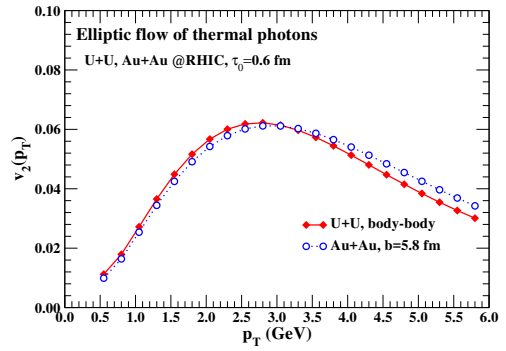

FIG. 2: Thermal photon v_2 for full overlap U+U collision and mid-central Au+Au collision for initial time $\tau_0 = 0.6$ fm at RHIC.

than the body-body configuration. Hence the higher initial temperature is responsible for more high p_T photons from the initial stages in tip-tip collision. On the other hand for body-body collisions, the larger production of low p_T photons is because of the larger hadronic volume. We expect that any other orientation of full overlap U+U collision will result in photon spectra lying in between the spectra from tip-tip (upper limit) and body-body (lower limit) collisions in the high p_T region.

The elliptic flow parameter $v_2(p_T)$ for body-body collisions is shown in FIG. 2. The $v_2(p_T)$ for tip-tip collisions is zero as the collision zone is circular and the pressure gradient is isotropic. However, we see significantly large elliptic flow for body-body collisions. In addition, this large flow is comparable to the $v_2(p_T)$ calculated from Au+Au collisions at RHIC at an impact parameter 5.8 fm. The qualitative nature of the spectra and elliptic flow parameter from two different orientations of uranium nuclei is found to be independent of the initial parameters of the model calculation.

Finally, we conclude that one can distinguish between the limiting orientations of full overlap U+U collisions by looking at the experimental data for photon v_2. In addition, the spectra and elliptic flow of photons from U+U collisions are complementary to the photon results from Au+Au collisions at RHIC and can be a valuable probe to study collision geometry and the initial state of the produced system in relativistic heavy ion collisions.

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