Directed flow of thermal photons from Cu+Au collisions at RHIC

Pingal Dasgupta,* Rupa Chatterjee, and Dinesh Kumar Srivastava
Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata-700064, India

Collision of heavy nuclei at ultra relativistic energies produce a strongly coupled color deconfined state of partons (i.e. quarks and gluons) over a small volume which is known as the Quark-Gluon Plasma (QGP). The same QGP phase is also believed to have existed a few microseconds after the Big Bang [1]. Various experiments performed at the Super Proton Synchrotron (SPS) at CERN, the Relativistic Heavy Ion Collider (RHIC) at BNL and the Large Hadron Collider (LHC) at CERN have provided significant insights about the properties of the QGP. Relativistic hydrodynamics has emerged as one of the most successful frameworks which explain most of the hadronic observables at low p_T ($\leq$ 3 GeV) [4]. Direct photons (i.e. photons which are not produced in electromagnetic decay processes) are known as another equally important probe to study the properties of relativistic heavy ion collisions [5–7]. Unlike hadrons, direct photons are emitted during the entire time evolution of the produced hot and dense matter. Thus they carry the direct signatures of their production points. However, the hydrodynamic model calculations that simultaneously explain the spectra and anisotropic flow of charged hadrons in heavy ion collisions, fail to reproduce the photon spectra and anisotropic flow parameters simultaneously at RHIC [8, 9] and LHC energies [10, 11]. We address this as *direct photon puzzle*.

Many attempts have been made to resolve this puzzle. The inclusion of fluctuations (i.e, event-by-event study) in the description of initial-state has increased significantly the elliptic flow parameter (v_2) of thermal photons [12, 13] compared to the v_2 obtained from the smooth initial conditions. Such initial-state fluctuations also give rise to a significantly large triangular flow parameter (v_3) [14]. However, it has been seen that these sophisticated event-by-event calculations are still unable to explain the experimental data of direct photon v_2 and v_3 [15, 16]. We know that v_2 and v_3 strongly depend on the relative contribution of photon production from the QGP and the hadronic phases [17]. It is to be noted that the QGP and hadronic matter contributions to photon v_2 is maximum near the transition temperature (T_c). Recent studies have indicated that we might have missed some thermal photon contribution from the hadronic phase near the T_c [18] and therefore, photon observables which are mostly dominated by the QGP radiation would help us to understand this better.

In the present work we calculate the directed flow parameter v_1 of thermal photons as a function of transverse momentum from event-by-event fluctuating initial conditions at RHIC. We consider an asymmetric system of Cu+Au at 200A GeV at RHIC and use a 2+1 ideal hydrodynamical framework [19] where the equation of state is taken from the lattice-based calculations [20]. The QGP and hadronic rates of thermal photon production are taken from [21–23]. We observe a significant non-zero directed flow in the Cu+Au system, where, the value of v_1 strongly depends on the transverse momentum. v_1 is found to be negative for $p_T \leq 3$ GeV and positive for larger p_T value. The origin of this directed flow is the dipole-like asymmetry in the initial energy density distribution. We observe that the thermal photon v_1 is completely dominated by the QGP phase in the p_T range 1–6 GeV. The v_1 result is also found to be sensitive to the value of initial formation time of the plasma. We conclude that the comparison

*Electronic address: pingaldg@vecc.gov.in

of v_1 as a function of p_T with the experimental data would help us to understand the *direct photon puzzle* [24].

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