Probing the initial stage of heavy ion collisions through photon observable

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Direct photons produced in relativistic nuclear collisions serve as a valuable probe to investigate the hot and dense initial state and the subsequent evolution of the resulting fireball. These photons are emitted throughout the expansion of the system, experience minimal re-scattering within the medium, and convey undistorted information from the production points to the detector [1]. The inclusive photon spectrum measured in heavy ion experiments contains a huge background originating from the 2-γ decays of long-lived hadrons, predominantly π^0 and η mesons. However, recent significant advancements in background subtraction methodologies have resulted in the acquisition of reasonably clean direct photon data, marked by minimal error bars.

Direct photons can be divided into several subcatagories depending in their origin, each shedding light on different aspects of the collision dynamics [2]. These include prompt photons, pre-equilibrium photons, thermal photons, and jet photons. The prompt photons populate the high p_T part of the direct photon spectrum and are emitted from the initial hard scatterings. Whereas, the pre-equilibrium photons are those emitted from the fireball before it gets thermalized. The passage of high p_T jets through the plasma can also produce photons and contribute to the direct photon spectrum significantly. The photons from the hot and dense Quark Gluon Plasma (QGP) phase and from the hot hadronic matter are termed as the thermal photons.

The initial studies of photon production in relativistic nuclear collisions were mostly dedicated to know about the initial temperature of the system and its property via thermal radiation. However, in recent times, the study of direct photons has revealed additional significant possibilities. These include photon anisotropic flow as quark gluon plasma viscometer, azimuthal anisotropy of the initial QGP phase using photon flow, formation time of QGP, information about system size and lifetime from photon intensity interferometry and many more.

While it is experimentally challenging to distinguish photons with different origins, theoretical calculations offer a valuable means to address this issue where different contributions to the direct photon spectrum can be studied separately. The next to leading order perturbative QCD calculations for prompt photons have been used successfully to explain the direct photon spectrum from p+p collisions at relativistic energies. An excess of direct photon production over the scaled results from p+p collisions has been reported from heavy ion collisions both at RHIC and at the LHC energies. This excess production is ascribed to the emission of thermal radiation originating from the quark-gluon plasma and the hot hadronic matter.

The state of the art rates of photon production from quark-gluon plasma as well as from hadronic matter are available for quite some time now which have been used extensively to estimate the thermal photon production at different beam energies and collision systems.

One of the most intriguing findings of the past decade has been the experimental measurement of anisotropic flow, particularly el-

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liptic flow exhibited by photons [3]. The thermal radiation completely dominate the photon anisotropic flow as the non-thermal contributions in the spectrum are not subjected to the collectivity of the produced medium.

Initial theoretical model calculations predicted that the photon elliptic flow from non-central collisions would show different p_T dependent nature compared to the elliptic flow of hadrons [4]. It has also been shown that the photon elliptic flow is quite sensitive to the initial formation time of the plasma where a larger τ_0 would result in larger p_T dependent elliptic flow compared to a smaller τ_0.

However, the very first result from Au+Au collisions at RHIC (by PHENIX Collaboration) showed that experimental data is significantly larger than theory result although the data show similar p_T dependent nature as predicted by theoretical model calculation [3]. Not only the elliptic flow, the triangular flow of photons is also not explained satisfactorily by theoretical model calculations [5]. Comparison with available data at different beam energies have shown that advanced theoretical model calculations are not able to explain the direct photon spectra and anisotropic flow simultaneously. This is known as direct photon puzzle [6].

Recent studies have suggested that the ratio of photon anisotropic flow can be a potential parameter to understand the direct photon puzzle by minimizing the uncertainty caused by the presence of non-thermal contributions in the final result [7]. Photons elliptic flow estimation from deformed systems as well as at very high beam energies have shown promising results, experimental determination of which can be useful to understand the direct photon puzzle better [8–10].

In has been argued recently that the presence of alpha clustered structure in light nuclei (^{12}C, ^{16}O) can give rise to initial state spatial anisotropies and subsequently large anisotropic flow parameters when collided with heavy nuclei at relativistic energies [11]. As the emission of electromagnetic radiation is sensitive to the initial state, photon observables in collisions of clustered nuclei with heavy ions can result in significantly different result compared to results obtained in collision of unclustered nuclei [12]. The triangular flow of photons in collisions of alpha clustered C with heavy nuclei is estimated to be significantly large compared to the elliptic flow parameter using a hydrodynamical model calculation at RHIC energy. Whereas, the elliptic flow is estimated to be larger than the triangular flow parameter in the absence of initial clustered structure. These results can be quite valuable not only to understand the direct photon puzzle but also to know more about the alpha clustered structures in light nuclei.

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