Photon elliptic flow and formation time of QGP

Rupa Chatterjee* and Dinesh K. Srivastava
Variable Energy cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata-700064, India

Introduction

Heavy ion collisions at relativistic energies offer a unique opportunity to study the properties of a new phase of matter in the regime of extremely high temperature and density, known as Quark-Gluon Plasma (QGP). Anisotropic flow or in particular elliptic flow of identified particles is considered among the key observables to explore the properties of QGP, as it directly reflects the re-scatterings among the produced particles in the medium. It is well known that, photon elliptic flow at early times or at large p_T reflects the momentum anisotropies of the initial partonic phase [1] of the expanding system. Photons, both real as well as virtual, are emitted throughout the lifetime of the system, and also, they leave the interaction zone unscathed just after their production. This makes them one of the most efficient probes of the produced hot and dense system. We show that, the elliptic flow parameter $v_2(p_T)$ for thermal photons at RHIC can be very useful to estimate the formation time (τ_0) of the plasma or the onset of collectivity and thermalization in the medium. We also show that photon v_2 at SPS energy can play a very significant role to distinguish between the 'with' and 'without' phase transition scenarios.

τ_0 dependent photon v_2 at RHIC

We calculate the elliptic flow of thermal photons at RHIC for different τ_0 (ranging from 0.2 to 1.0 fm/c, in steps of 0.2 fm/c) keeping the total entropy or the charged particle rapidity density of the system fixed [2]. τ_0 dependent photon v_2 for semi-central collision of Au nuclei at RHIC, along with individual contributions from quark matter (QM) and hadronic matter (HM) phases are shown in Fig. 1. A smaller value of τ_0 implies a larger initial temperature, which manifests into a larger production of high p_T photon in the QGP phase or a flatter p_T spectrum. However, the photons from HM are not affected significantly with changing τ_0 as the transition temperature remains fixed. Photon flow at large p_T is completely dominated by v_2(QM), or the flow contribution from QM. At early times or at large p_T, v_2(QM) is very small and it rises with smaller values of p_T. Thus, for smaller τ_0, the value of v_2(QM) is smaller than its value for larger τ_0 and similar is the sum v_2. On the other hand we find that the p_T spectra as well as $v_2(p_T)$ of hadrons depend only marginally on the value of τ_0. $v_2(p_T)$ of ρ mesons at different τ_0 for semi-central collision of Au nuclei at RHIC is shown in Fig. 2. Early start of flow at smaller τ_0 drives the freeze-out to happen sooner and the overall flow of hadrons, which acquires its final value much earlier before freeze-out, does not change significantly.

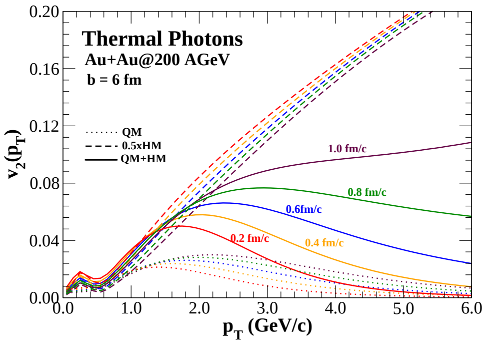

FIG. 1: τ_0 dependent $v_2(p_T)$ of thermal photons at RHIC. QM and HM contributions are shown separately along with the sum v_2.

*Electronic address: rupa@veccal.ernet.in

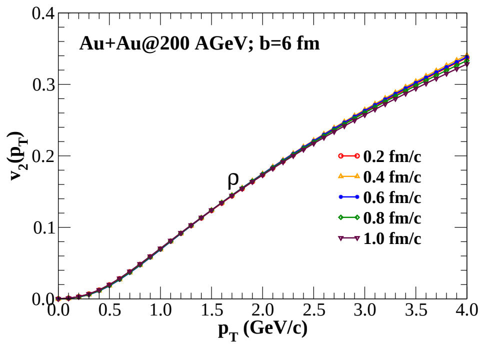

FIG. 2: τ_0 dependent $v_2(p_T)$ of ρ mesons at RHIC.

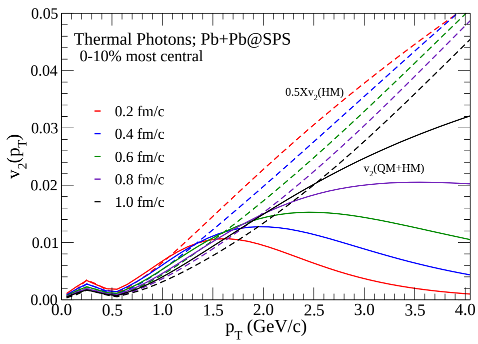

FIG. 3: τ_0 dependent $v_2(p_T)$ of thermal photons at SPS along with v_2 contribution from HM.

τ_0 dependent photon v_2 at SPS

Single photons measured by the WA98 Collaboration [3] for 158A GeV Pb+Pb collisions at SPS is considered as an important turning point of the heavy ion collision study using electromagnetic radiations. Some earlier studies have even explained the WA98 data considering only the formation of a hot hadronic gas in the collision, and without any QGP phase. We have reanalyzed the WA98 single photon data by incorporating several new improvements in the theoretical field of prompt and thermal photon production from heavy ion collisions [4]. The emission of thermal photons is estimated by considering boost invariant azimuthally anisotropic hydrodynamic expansion of the plasma along with a well tested equation of state which follows a first order phase transition at some critical temperature T_c ($\sim$ 164 MeV). A quantitative explanation of the WA98 data is obtained by combining thermal photons at different τ_0 with $\kappa\times$ prompt photons, where the factor κ is attributed to the Cronin effect in case of nucleus-nucleus collisions as well as to the photons from pre-equilibrium phase.

It is well known that, except for thermal photons, all other sources of photons do not contribute significantly to the elliptic flow of direct photons for $p_T \leq$ 5.0 GeV. Again, the thermal photon v_2 tracks the $v_2(QM)$ at large p_T, which is of completely different nature compared to the monotonically rising $v_2(p_T)$ of photons from HM as shown in Fig. 3. Thus we argue that, experimental determination of photon v_2 at SPS energy can distinguish between the two scenarios of with and without phase transition (*i.e,* with and without QGP formation) from the different nature of photon v_2 for the two cases. We also show that photon v_2 at SPS energy is sensitive to the value of τ_0 [see solid lines of Fig. 3], and this formation time can be estimated precisely by measuring the flow parameter.

In conclusion, we show that the photon v_2 at RHIC and at SPS energies is quite sensitive to the initial formation time of the plasma, which gives a direct access to estimate the value of τ_0 accurately. We also suggest that, photon flow can be a very powerful tool to distinguish between the two phase transition scenarios at SPS energy.

References

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