Photon production from a non-equilibrium quark-gluon plasma

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Introduction

In the study of the *Quark-Gluon-Plasma*,

- An important question is the time scale for the *thermalization* and *isotropization* of the matter created in relativistic heavy ion collisions. Theoretical calculations in both the weak-coupling and strong-coupling limits find that the QGP created immediately after the initial nuclear impact ($\tau \sim 0.2$ fm/c) is highly anisotropic in local rest frame (LRF) momentum.
- Radiation of **photons** and **dileptons** are promising signals since they are electromagnetic probes that interact weakly with the QGP ($\alpha \ll \alpha_s$). As a result, once produced, they do not undergo significant interactions with the medium and carry largely undistorted information about the circumstances of their production to the detector.
- In this poster we focus on **photon** production using dissipative hydrodynamics by linearizing around an anisotropic background and, as a result, we are able to better describe early-time photon production and photon production near the transverse and longitudinal edges of the QGP.

Our results indicate that high-energy photon production is quite sensitive to the assumed level of initial momentum-space anisotropy of the QGP [1].

Methodology

In this work, we studied the impact of space-time dependent anisotropies on the photon differential spectrum and elliptic flow coefficient associated with photons emerging from the QGP as a function of high transverse momentum.

- We assume that the one-particle distribution function is of spheroidal form [2].
- The aHydro framework reduces to second-order viscous hydrodynamics in the limit of small anisotropy, but reproduces the dynamics of the QGP more reliably when there are large momentum-space anisotropies [3,4,5].
- For the rate, we included the two leading-order processes: Compton scattering and quark-antiquark annihilation.
- We integrated the rate over the space-time volume of the QGP using (3+1)D anisotropic hydrodynamics to provide the space time dependence of the anisotropy $\xi(x)$, the transverse momentum scale $\Lambda(x)$, and the flow velocity $u^\mu(x)$. The differential photon spectra is given by

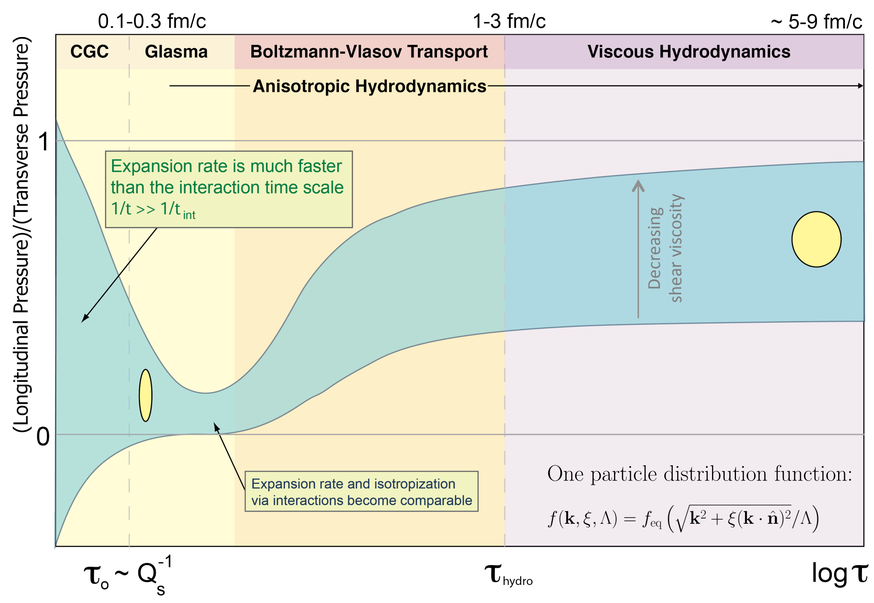
$$\frac{dN}{q_\perp dq_\perp dy} = \int_0^{2\pi} d\phi_q \int d^4x \left(E\frac{dR}{d^3q}\right)_{\rm LRF}. \tag{1}$$

- We also computed another important parameter **photon elliptic flow** (v_2) which results from the breaking of rotational symmetry around the beam-axis due to development of the hydrodynamic flow.

$$v_2(q_\perp, y) = \frac{\int_0^{2\pi} d\phi_q \frac{dN}{q_\perp dq_\perp dy\, d\phi_q}\cos(2\phi_q)}{\frac{dN}{q_\perp dq_\perp dy}}. \tag{2}$$

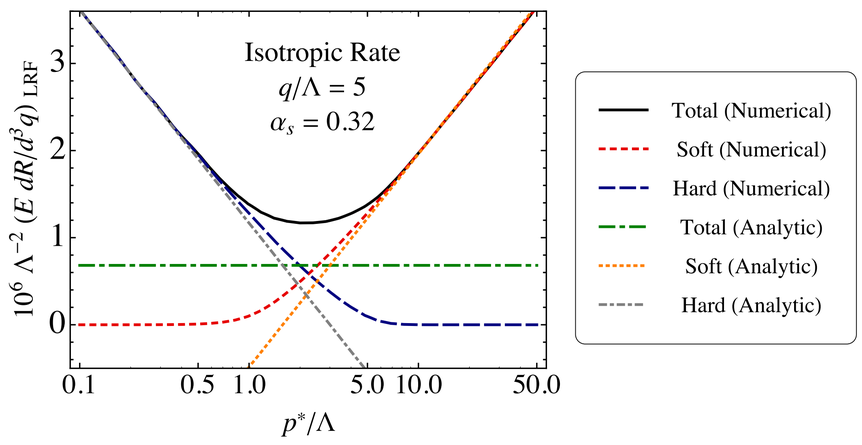
We assume a min-bias collision with $b = 9.5$ fm and we begin the aHydro evolution at $\tau_0 = 0.3$ fm/c. At τ_0, we assume that the produced matter has no transverse flow, i.e. $u_x(\tau_0, \mathbf{x}_\perp, \varsigma) = u_x(\tau_0, \mathbf{x}_\perp, \varsigma) = 0$, while the initial longitudinal flow is of Bjorken form $\vartheta(\tau_0, \mathbf{x}_\perp, \varsigma) = \varsigma$. We assume that the initial anisotropy field is homogeneous, $\xi(\tau_0, \mathbf{x}_\perp, \varsigma) = \xi_0$.

Anisotropic QGP



- Finite shear viscosity results in momentum-space anisotropies
- Anisotropy can be quite large
- Anisotropies present in both weak and strong coupling approaches
- Anisotropies modify the photon spectrum and thermal photon v_2

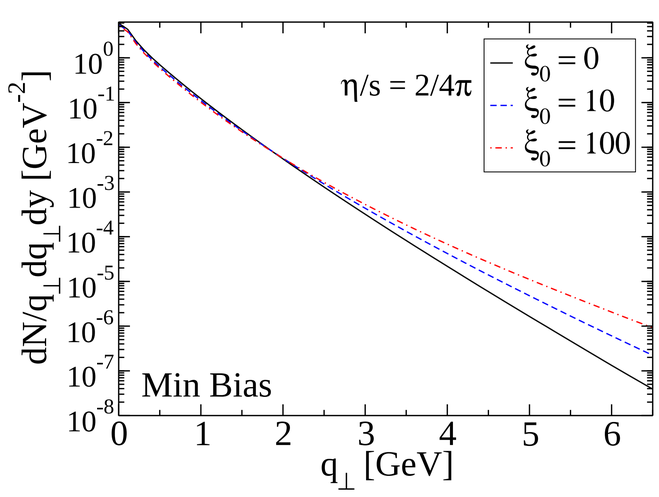
Photon rate



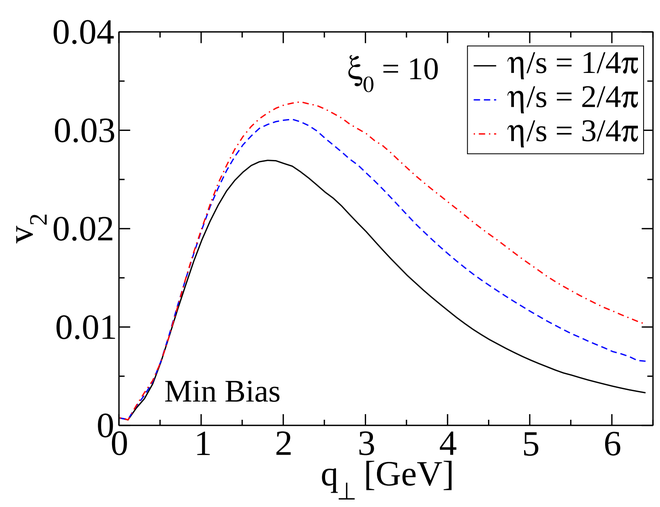
- The soft and hard contributions to the isotropic ($\xi = 0$) photon rate and the total rate obtained by summing these contributions.
- There is a logarithmic IR divergence at small p^*/Λ and logarithmic UV divergence at large p^*/Λ. However, even for large α_s, there is a window over which the result does not depend strongly on the choice of p^*.

Interesting Results

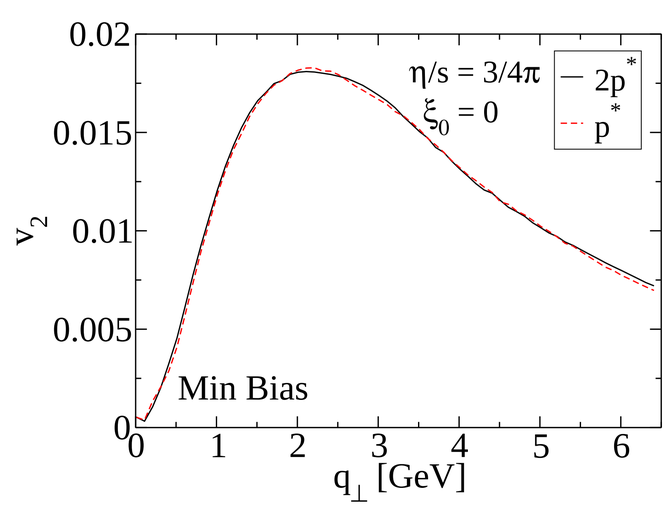
We now present our interesting results for the photon spectrum and elliptic flow of QGP-generated photons. We focus here on Pb-Pb collisions with nucleon-nucleon center of mass energies of $\sqrt{s_{\rm NN}} = 2.76$ TeV.



- There is significant variation in the high-energy photon spectrum as one changes the initial anisotropy of the QGP.



- The photon elliptic flow coefficient $v_2(q_\perp, y = 0)$ assuming $\xi_0 = 10$ for three different values of the shear viscosity to entropy density ratio of $4\pi\eta/s = 1$, 2, and 3. Increasing the shear viscosity of the QGP results in an increase in photon v_2.



- Photon v_2 is independent of the choice of the separation scale within numerical uncertainties.

Conclusions

- Our final results indicate that, if one holds the final particle multiplicity fixed, for fixed η/s, varying the initial momentum-space anisotropy ξ_0 resulted in significant variations of the high-transverse-momentum photon yields. We found that, at $q_\perp = 6$ GeV, there was approximately an order of magnitude variation in the photon yield when varying $0 \le \xi_0 \le 100$. This offers some hope to constrain the degree of QGP momentum-space anisotropy by fitting thermal plus prompt photon production at high energies to experimental data.
- We also calculated the elliptic flow coefficient v_2 associated with the azimuthal variation of the photon yields. Our results indicate that, for $4\pi\eta/s = 1$, the maximal photon v_2 coming from the QGP phase at LHC energies is approximately 2-3%. We find that increasing η/s or ξ_0 results in an increase in peak photon v_2.

Acknowledgements and References

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