Photon flow harmonics v_n with chemical equilibration and non-ideal gas distribution

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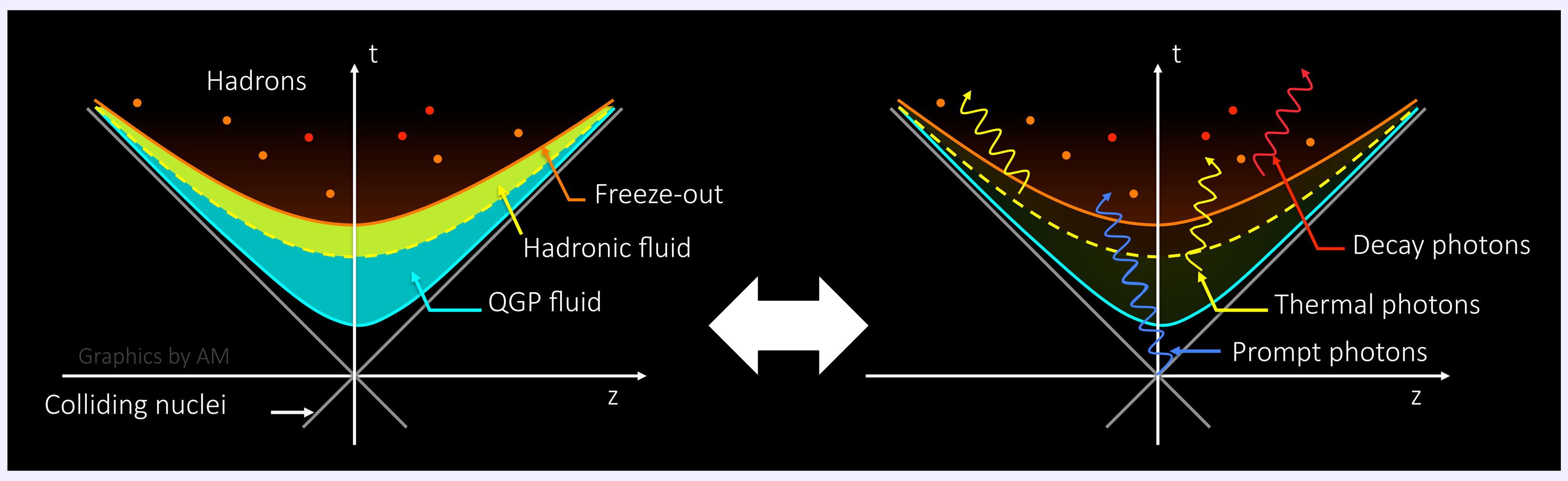
Abstract

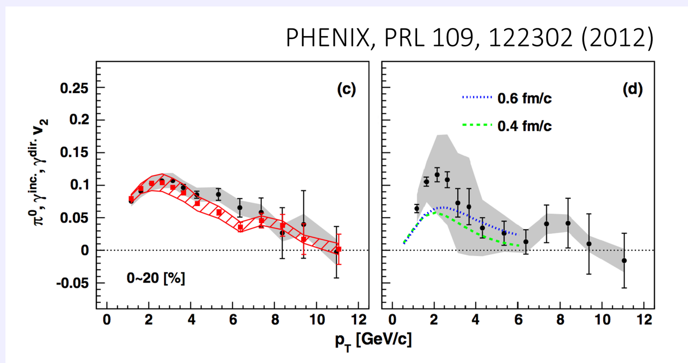
Elliptic and triangular flow of direct photons are experimentally found to be larger than those of hydrodynamic estimations, which is recognized as "photon puzzle". I show numerically that (i) late quark chemical equilibration and (ii) in-medium corrections of parton distributions lead to suppression of early photons and to enhancement of photon anisotropy.

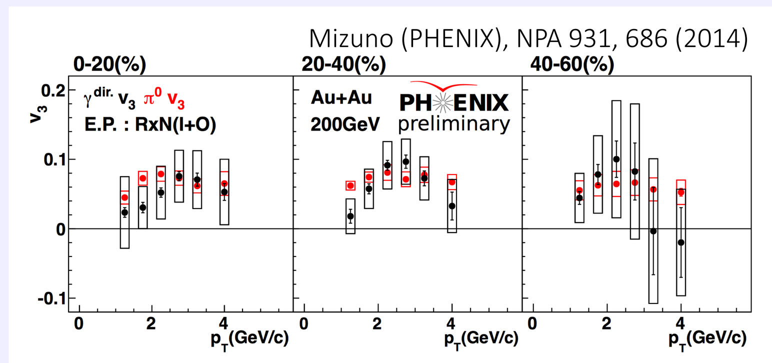
1. Introduction



⇨ Photons remember the "history" of time evolution unlike hadrons

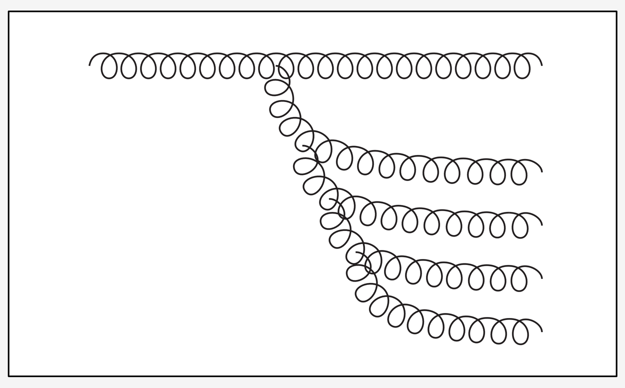
- Direct photon v_n are larger than hydro calculations: "photon puzzle"





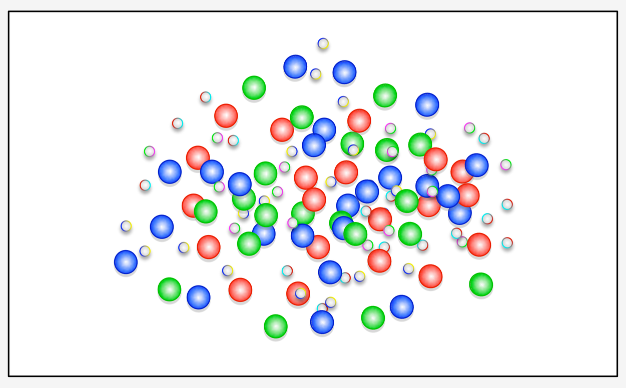
I discuss possible enhancement of thermal photon v_n by quark chemical equilibration and in-medium modification of distributions

2. Quark chemical equilibration



Color glass condensate

⇨ ~ 1 fm/c



Quark-gluon plasma

- Chemical equilibration can take longer than thermalization

⇨ Early photon emission is suppressed by the absence of quarks

⇨ Overall thermal photon v_n is enhanced

- Hydrodynamic equations of motion

Energy-momentum conservation

$$\partial_\mu T_q^{\mu\nu} + \partial_\mu T_g^{\mu\nu} = 0$$

Rate equations

$$\partial_\mu N_q^\mu = 2r_b n_g - 2r_b \frac{n_g^{\text{eq}}}{(n_q^{\text{eq}})^2} n_q^2$$

$$\partial_\mu N_g^\mu = (r_a - r_b) n_g - r_a \frac{1}{n_g^{\text{eq}}} n_g^2 + r_b \frac{n_g^{\text{eq}}}{(n_q^{\text{eq}})^2} n_q^2 + r_c n_q - r_c \frac{1}{n_g^{\text{eq}}} n_q n_g$$

r_a: Rate of gluon splitting

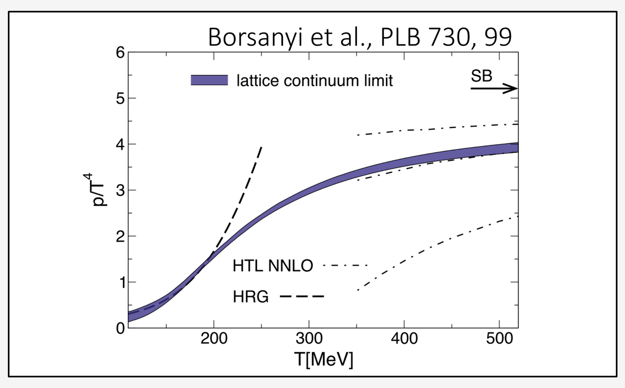
r_b: Rate of quark pair production

r_c: Rate of gluon emission from quarks

⇨ Chemical relaxation time $\tau_{\text{chem}} \sim 1/r_b$

*Equilibrium densities are calculated in the quasiparticle model (Sec. 3)

3. In-medium effective distributions



Lattice QCD equation of state (EoS)

⇔ ✗

$$f_0^i = \frac{1}{\exp(E_i/T) \pm 1}$$

Ideal gas distributions

- The QGP is *not* an ideal gas

⇨ The effective number of the degree of freedom is smaller at large T

⇨ Suppression of photons from hot fluid elements leads to more v_n

- Quasiparticle model

Effective distributions

$$f_{\text{eff}}^i = \frac{1}{\exp(\omega_i/T) \pm 1} \quad \text{where} \quad \omega_i = \sqrt{p^2 + m_i^2} + W_{\text{eff}}^i$$

Partition function, energy density and pressure

$$\ln Z_i = \pm V \int \frac{g_i d^3p}{(2\pi)^3} \ln \left[1 \pm \exp\left(-\frac{\omega_i}{T} \right) \right] - \frac{V}{T} \Phi_i$$

$$e = \sum_i \int \frac{g_i d^3p}{(2\pi)^3} \omega_i f_{\text{eff}}^i + \Phi \,, \quad P = \frac{1}{3} \sum_i \int \frac{g_i d^3p}{(2\pi)^3} \mathbf{p} \frac{\partial \omega_i}{\partial \mathbf{p}} f_{\text{eff}}^i - \Phi$$

W_{eff}^i: Effective interaction energy , Φ: Background field contribution

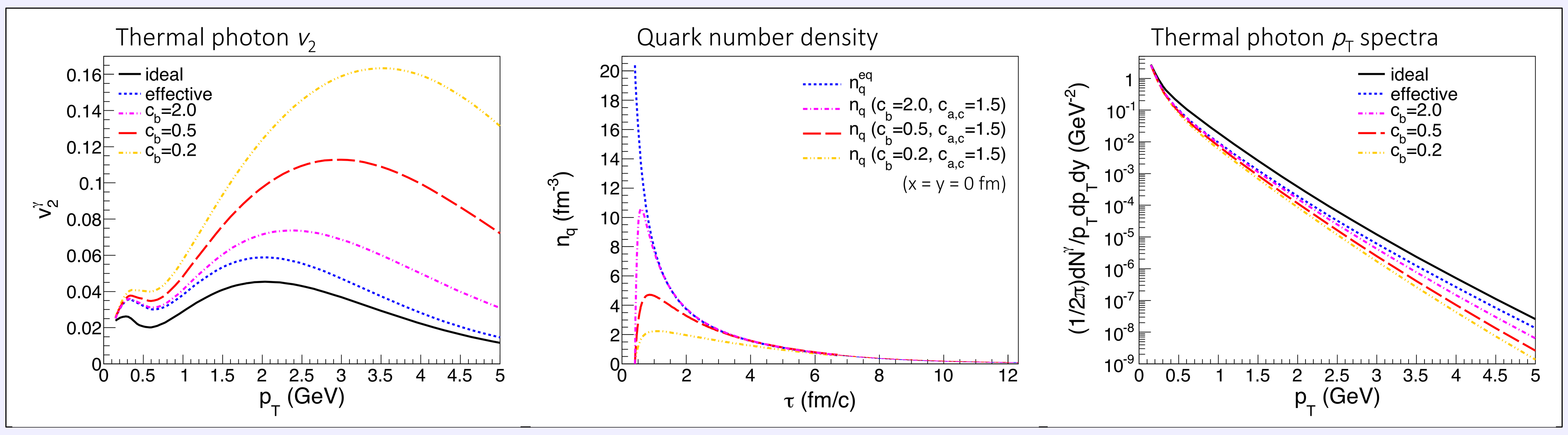
⇨ Determined by matching e and P to the lattice QCD EoS

+ thermodynamic condition $\left.\frac{\partial \Phi_i}{\partial T}\right|_{\mu_B} = -\int \frac{g_i d^3p}{(2\pi)^3} \left.\frac{\partial \omega_i}{\partial T}\right|_{\mu_B} f_{\text{eff}}^i$

4. Numerical analyses

- (2+1)-D ideal hydrodynamic model
  - Initial gluon energy distribution: MC Glauber (200 GeV Au-Au collisions at $b = 6$ fm)
  - Initial gluon number distribution: $n_g^{\text{eq}} + n_q^{\text{eq}}/2$
  - EoS: lattice QCD Borsanyi et al., PLB 730, 99
  - Chemical equilibration rate: $r_i = c_i T$

- Photon emission rate
  - Hadronic phase: Turbide, Rapp and Gale, PRC 69, 014903
  - QGP phase: Strickland, PLB 331. 245



- Thermal photon v_2 is enhanced by in-medium correction and late chemical equilibration
- $\tau_{\text{chem}} \sim 1/c_b T$ with $T = 0.2$ GeV is consistent with the simulations
- Thermal photon p_T spectrum is reduced; the effect of in-medium correction is visible at low p_T

5. Summary and outlook

- Chemical equilibration and in-medium corrections to parton distribution would be important for understanding the "photon puzzle"
- Reduction of particle spectra implies possible importance of additional photon emission mechanisms in late stages
- Future prospects include estimation of prompt photons and introduction of chemically non-equilibrated equation of state (Cf. Gelis et al., JPG 30, S1031)