Photon polarization as a measure of the anisotropy of the quark-gluon plasma

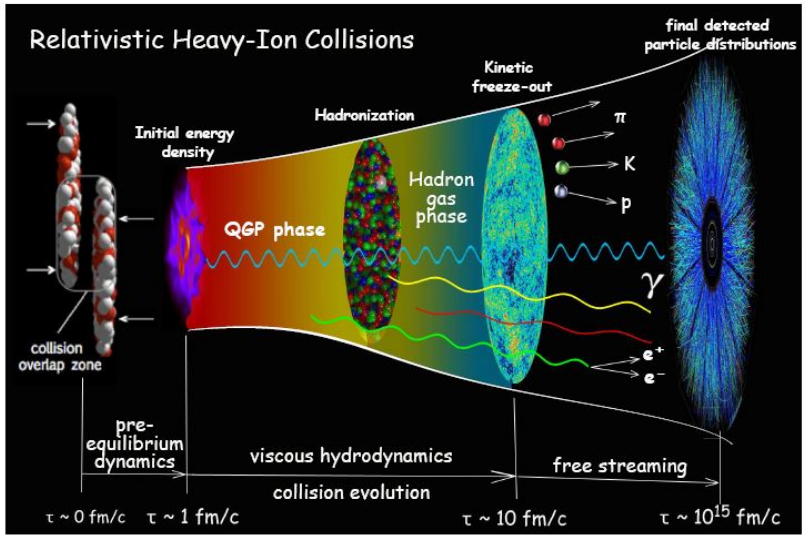
Siggi Hauksson
IPhT, CEA-Saclay

QCD@LHC 2022, Orsay
December 2nd 2022

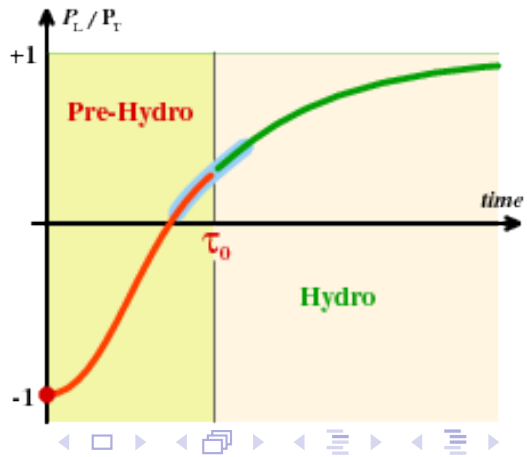
In collaboration with C. Gale.

Introduction

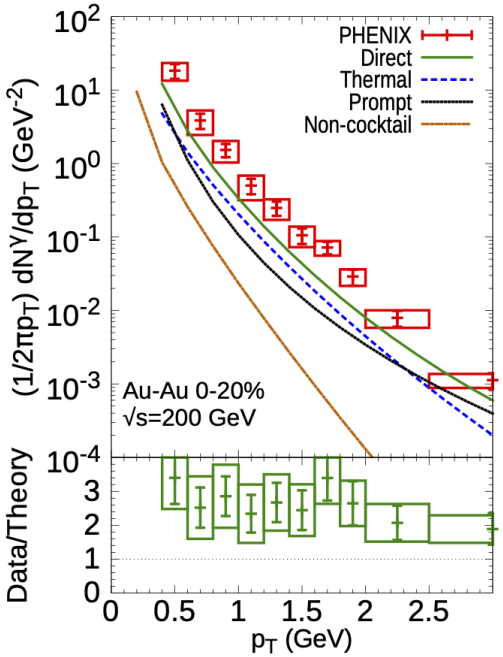
- Heavy-ion collisions produce a QGP fluid.
- The QGP has large pressure anisotropy.
- Photons are emitted at all stages, including early anisotropic stage.
- Specific signature of QGP anisotropy is **photon polarization**.
- How big is this effect?
- Difficult measurement.



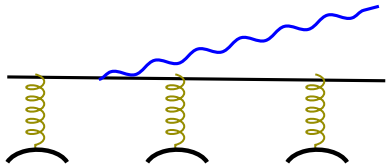
[Shen (2014)]



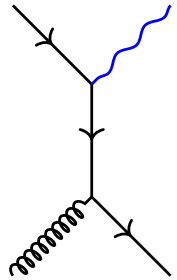
Photon emission in thermal equilibrium



[Paquet et al. (2015)]



[Aurenche, Gelis, Kobes, Zaraket (1998); Arnold, Moore, Yaffe (2001)]

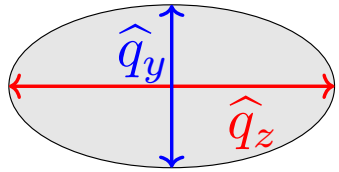


[Baier, Nakkagawa, Niegawa, Redlich (1992); Kapusta, Lichard, Seibert (1991)]

- Two main channels at leading order ([Ghiglieri, Hong, Kurkela, Lu, Moore, Teaney (2013)] for NLO):
- In bremsstrahlung quark radiates due to soft gluon kicks.
- All number of kicks need to be resummed.

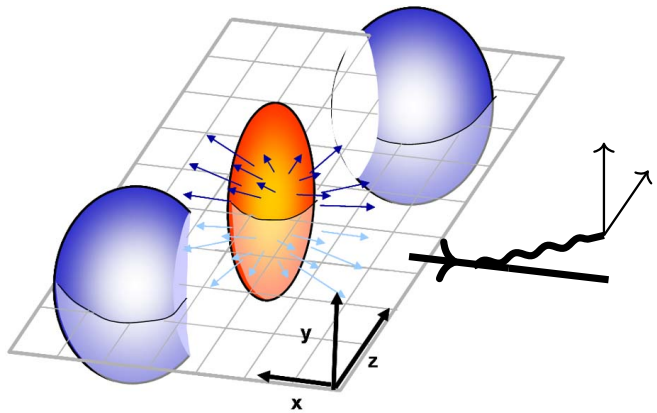
Polarized photon emission out of equilibrium

- Kicks can have a preferred direction.
  - Then opening angle has a preferred direction.



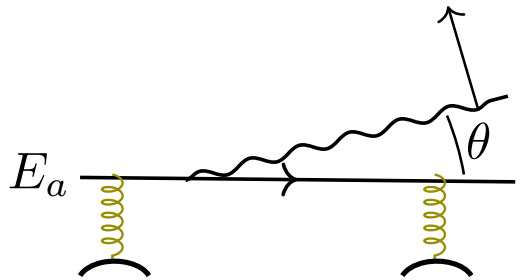
- Photon polarization tends to align with opening angle.
  - Hard splitting functions ($\zeta = k/E$):

$$F_{\text{in}} = \frac{(2-\zeta)^2}{\zeta} > F_{\text{out}} = \zeta$$



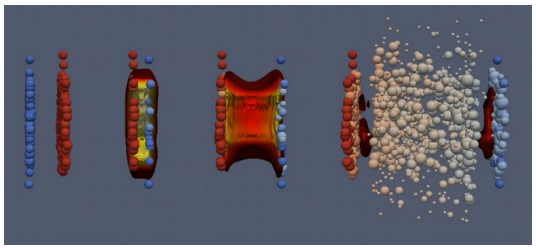
- Also get polarized photons from two-to-two scattering with final photon.

[Baym, Hatsuda (2014)]



Collision kernel for medium kicks

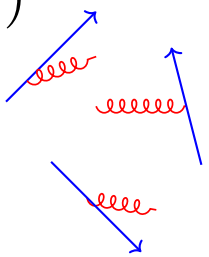
- Pressure anisotropy leads to anisotropy in radiated gluons.
- Rate of gluon kicks given by



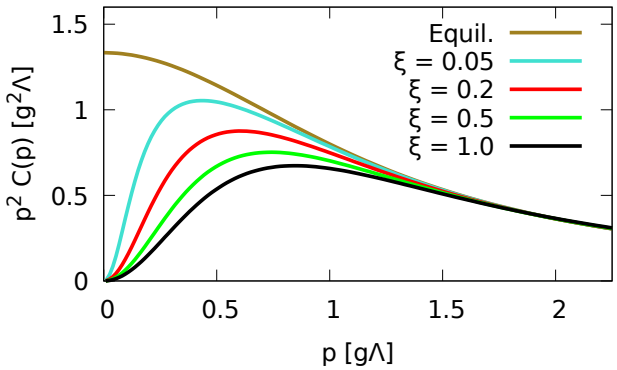
[Bernhard et al. (2019)]

$$\mathcal{C}(\mathbf{q}_\perp) = g^2 C_F \int \frac{dq^0 dq_\parallel}{(2\pi)^2} \left\langle \{A^\mu, A^\nu\} \right\rangle (Q) v_\mu v_\nu \, \delta(v \cdot Q)$$

[For equilibrium e.g.: Aurenche, Gelis, Zaraket (2002); Caron-Huot (2008); Panero, Rummukainen, Schaefer (2014)]



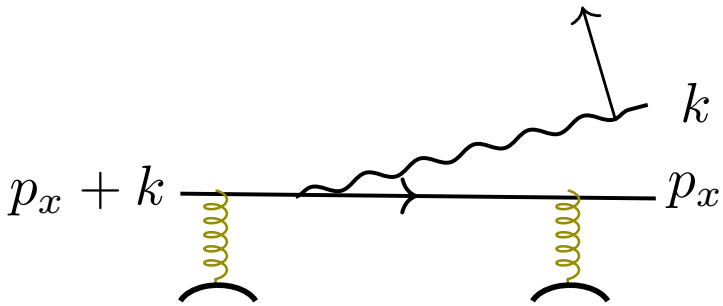
- Heart of much physics in QGP:
  - kinetic theory
  - jets
  - thermalization in bottom-up scenario
    [Baier, Mueller, Schiff, Son (2001)]
- Not fully known out of equilibrium.



[Hauksson, Jeon, Gale (2021)]

Photon production rate

- Rate for z polarization is



$$k\frac{d\Gamma_z}{d^3k} \sim \alpha_{EM} \int dp^x \; n_f(k+p^x)\left[1-n_f(k+p^x)\right] \frac{k}{p_x^2(k+p_x)}$$
$$\times \left[F_{\rm in}(\zeta)\,{\rm Re}\int d^2p_\perp \; p_z \mathbf{f}_z + F_{\rm out}(\zeta)\,{\rm Re}\int d^2p_\perp \; p_y \mathbf{f}_y\right],$$

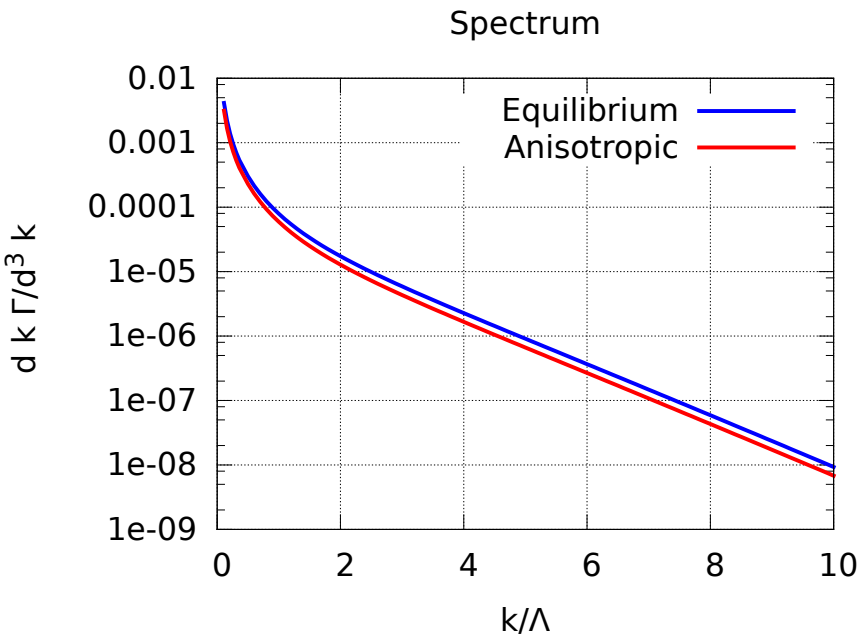
$$2\mathbf{p}_\perp = i\delta E\,\mathbf{f}(\mathbf{p}_\perp) + \int \frac{d^2q_\perp}{(2\pi)^2}\,\mathcal{C}(\mathbf{q}_\perp)\left[\mathbf{f}(\mathbf{p}_\perp) - \mathbf{f}(\mathbf{p}_\perp+\mathbf{q}_\perp)\right]$$

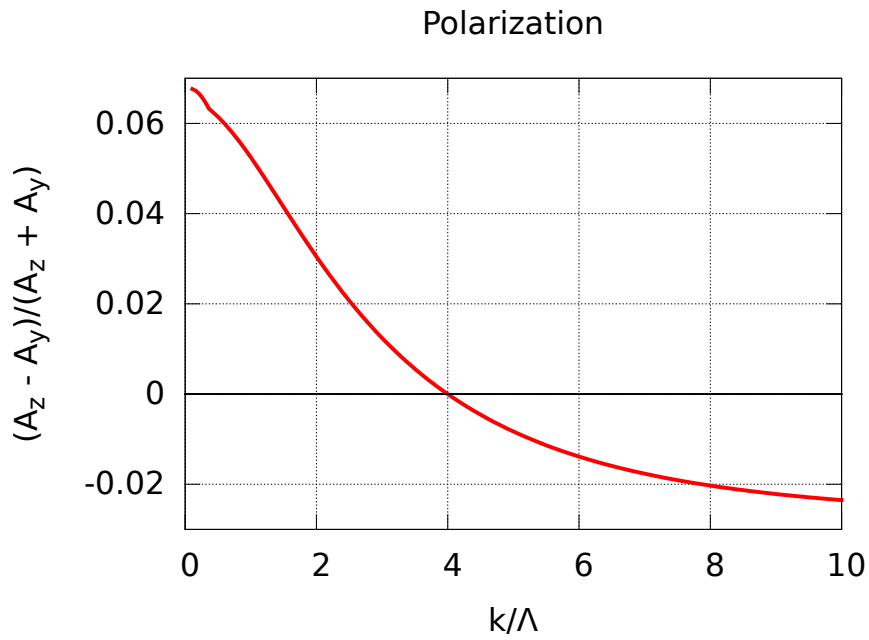
- Use toy model for collision kernel

$$\mathcal{C}(\mathbf{q}_\perp) = g^2 C_F T \left(\frac{1}{q_\perp^2} - \frac{1}{q_\perp^2 + m_{D0}^2 + \xi M^2\cos^2\phi}\right)$$

Results

- Results for $\xi = 1.0$, roughly $P_L/P_T = 0.3$.



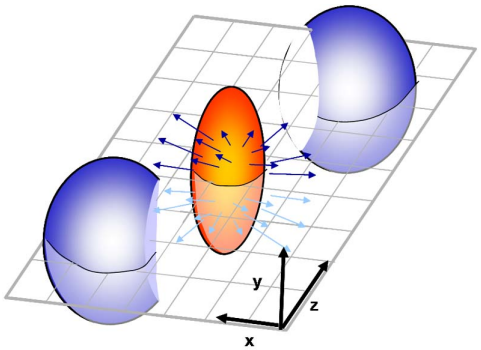


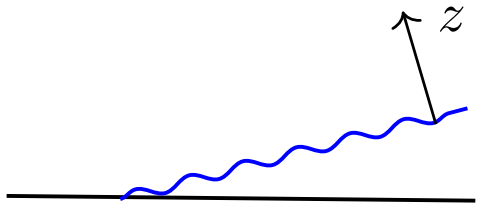
- Quantify polarization with $(A_z - A_y)/(A_z + A_y)$, where $A_z = k\, d\Gamma_z/d^3k$.
- Get polarization between -3% and 7%.

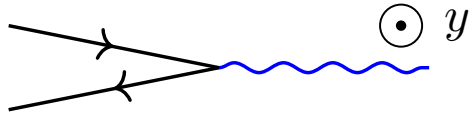
Results

$$\mathcal{C}(\mathbf{q}_\perp) = g^2 C_F T \left(\frac{1}{q_\perp^2} - \frac{1}{q_\perp^2 + m_{D0}^2 + \xi M^2 \cos^2 \phi} \right)$$

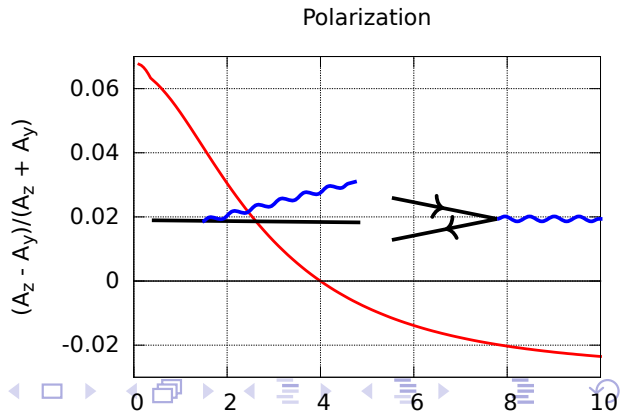
- More screening gives reduced spectrum.
  - Partially helps with v_2 puzzle?
- Two competing channels for polarization.







- Each wins out for different k.
- Need folding with hydrodynamics as well as 2-to-2 scattering for predictions.



Conclusions

- Polarized photons are a direct signal of pressure anisotropy in HIC.
- Give information about non-equilibrium collision kernel.
- Have evaluated for a toy model of the kernel.
- Get around $5\,\%$ polarization.
  - Two competing channels.
- Measurements?