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

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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.
Photon emission in thermal equilibrium

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

\[ C(q_{\perp}) = g^2 C_F \int \frac{dq^0 dq_{\parallel}}{(2\pi)^2} \langle \{ A^\mu, A^\nu \} \rangle (Q) v_\mu v_\nu \delta(v \cdot Q) \]

[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.

[Bernhard et al. (2019)]

[Hauksson, Jeon, Gale (2021)]
Photon production rate

- Rate for $z$ polarization is

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

$$2p_\perp = i\delta E f(p_\perp) + \int \frac{d^2q_\perp}{(2\pi)^2} C(q_\perp) [f(p_\perp) - f(p_\perp + q_\perp)]$$

- Use toy model for collision kernel

$$C(q_\perp) = g^2 C_F T \left( \frac{1}{q_\perp^2} - \frac{q_\perp^2 + m_{D0}^2}{q_\perp^2} + \frac{1}{\xi M^2 \cos^2 \phi} \right)$$
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
  $A_z = k \frac{d\Gamma_z}{d^3k}$.

- Get polarization between $-3\%$ and $7\%$. 
Results

\[ C(q_\perp) = g^2 C_F T \left( \frac{1}{q_\perp^2} - \frac{1}{q_\perp^2 + m_{D0}^2 + \xi M^2 \cos^2 \phi} \right) \]

- 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?