Jet and photon polarization as a measure of QGP anisotropy

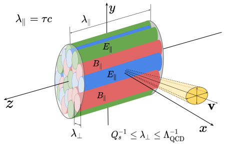
Siggi Hauksson
IPhT, Saclay

Quark Matter 2022,
April 6th

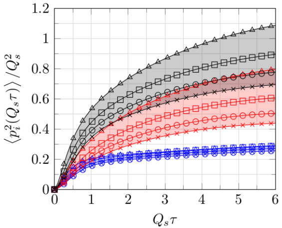
Collaborators: S. Jeon, C. Gale, E. Iancu

Jet broadening in the glasma

- Early stages of HIC dominated by strong gluon fields: Glasma
- Get significant jet broadening in glasma, $\widehat{q} \sim 10\,\mathrm{GeV}^2/\mathrm{fm}$.
- Broadening is highly anisotropic:
  - $\widehat{q}_z \neq \widehat{q}_y$ with $\widehat{q}_y = \frac{d\langle p_y^2 \rangle}{dt}$
- How does jet evoution in glasma differ from evolution in hydro?
- Can we use jets to learn about the glasma?



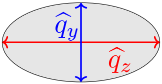
[Carrington, Czajka, Mrowczynski (2022)]



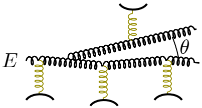
[Ipp, Muller, Schuh (2020)]

Gluon emission in anisotropic medium

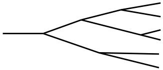
- Momentum broadening allows for gluon emission: Determines jet structure.



→



→

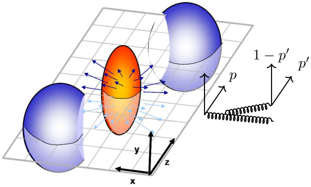


- In isotropic medium rate is $\Gamma \sim \alpha_s \, P(z) \, \frac{\sqrt{\widehat{q}}}{\sqrt{E}}$

- In anisotropic medium, total rate is basically same.

- Importantly, anisotropic broadening introduces net polarization of jet.

- Daughter parton prefers to have spin in beam direction.



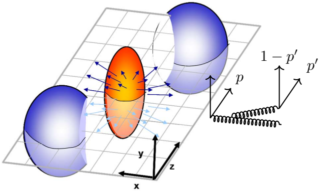
Jets in an anisotropic plasma

- Ensemble of gluons: Probability p of polarization in beam direction.
- Daughter parton has

$$p' - \frac{1}{2} = f(z)\left(p - \frac{1}{2}\right) + g(z)\,\frac{\widehat{q}_z - \widehat{q}_y}{\widehat{q}_z + \widehat{q}_y}$$

$$f(z) = \frac{\frac{1}{2}\left(z^2 + z(1-z)^2 + z\sqrt{(1-z)^2 + z^2 + z^2(1-z)^2}\right)}{(1-z)^2 + z^2(1-z)^2 + z^2}, \quad g(z) = A\,\frac{(1-z)^2(1+z^2)}{(1-z)^2 + z^2(1-z)^2 + z^2}$$

- Isotropic:
  Polarization reduced at each splitting.
- Anisotropic:
  Unpolarized mother radiates polarized daughter!
  - Soft daughter in glasma has $p' \approx 2/3$.
- Two competing effects.



Evolution equations for jets

- How does net spin build up in many subsequent splittings?
- Evolution equations ($D_{\text{tot}} = D_x + D_y, \widetilde{D} = D_x - D_y$)

  [For isotropic case see e.g. Blaizot, Iancu, Mehtar-Tani (2013).]

$$\frac{dD_{\text{tot}}(x,\tau)}{d\tau} = \int_x^1 dz\ \mathcal{K}_0(z)\sqrt{\frac{z}{x}}\,D_{\text{tot}}\left(\frac{x}{z},\tau\right) - \int_0^1 dz\ \mathcal{K}_0(z)\,\frac{z}{\sqrt{x}}\,D_{\text{tot}}(x,\tau)$$

$$\frac{d\widetilde{D}(x,\tau)}{d\tau} = \int_x^1 dz\ \mathcal{M}_0(z)\sqrt{\frac{z}{x}}\,\widetilde{D}\left(\frac{x}{z},\tau\right) - \int_0^1 dz\ \mathcal{K}_0(z)\,\frac{z}{\sqrt{x}}\,\widetilde{D}(x,\tau) + \int_x^1 dz\ \mathcal{L}_0(z)\sqrt{\frac{z}{x}}\,D_{\text{tot}}\left(\frac{x}{z},\tau\right)$$

- Remarkably, get fixed spin fraction at all $x \ll 1$

$$D_x + D_y \sim 1/\sqrt{x}, \qquad D_x - D_y \sim 1/\sqrt{x}$$

- Thermalized jet partons have net spin!
- What happens to polarization in at later times?
  - Can jet spin due to glasma be measured?

Backup

$$\frac{dD_{\mathrm{tot}}(x,\tau)}{d\tau} = \int_x^1 dz\, \mathcal{K}_0(z)\sqrt{\frac{z}{x}}\, D_{\mathrm{tot}}\left(\frac{x}{z},\tau\right) - \int_0^1 dz\, \mathcal{K}_0(z)\, \frac{z}{\sqrt{x}}\, D_{\mathrm{tot}}(x,\tau)$$

and

$$\frac{d\widetilde{D}(x,\tau)}{d\tau} = \int_x^1 dz\, \mathcal{M}_0(z)\, \sqrt{\frac{z}{x}}\, \widetilde{D}\left(\frac{x}{z},\tau\right) - \int_0^1 dz\, \mathcal{K}_0(z)\, \frac{z}{\sqrt{x}}\, \widetilde{D}(x,\tau) + \int_x^1 dz\, \mathcal{L}_0(z)\, \sqrt{\frac{z}{x}}\, D_{\mathrm{tot}}\left(\frac{x}{z},\tau\right)$$

where

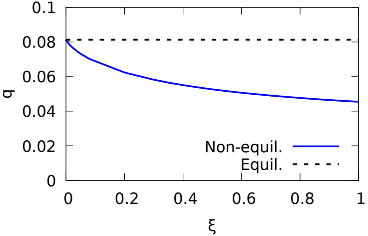
$$\mathcal{K}_0(z) \approx \frac{1}{z^{3/2}(1-z)^{3/2}},$$

$$\mathcal{L}_0(z) \approx A\, \frac{\widehat{q}_x - \widehat{q}_y}{\widehat{q}_x + \widehat{q}_y}\, \frac{(1-z)^{1/2}}{z^{3/2}}$$

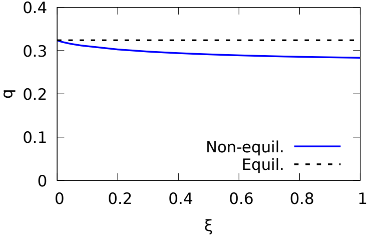
$$\mathcal{M}_0(z) \approx \frac{z^{1/2}}{(1-z)^{3/2}}$$

Backup

- In HTL kinetic theory, $\widehat{q}$ needs UV cutoff:
$\widehat{q} \sim g^4\Lambda^3 \int d^2p_\perp p_\perp^2 \left(\frac{1}{p_\perp^2}\right)^2 \sim g^4\Lambda^3 \log E/\Lambda$



$E \sim \Lambda,\ \theta = 0$



$E \sim 100\Lambda,\ \theta = 0$

- Different in glasma: Saturation scale is the cutoff.
$\widehat{q} \sim g^2Q_s^3 + g^4Q_s^3 \log E/Q_s$