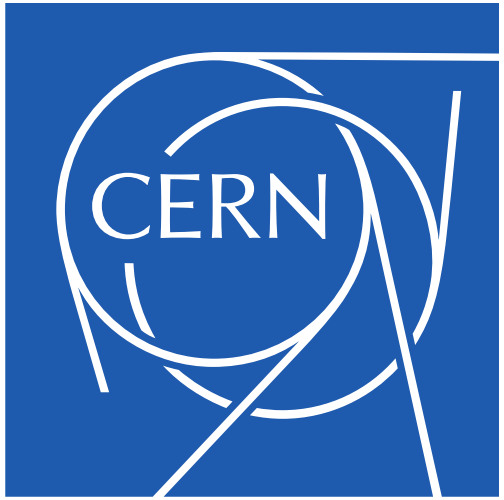
Probing the formation and evolution of quark-gluon plasma in nuclear collisions

Jasmine Brewer

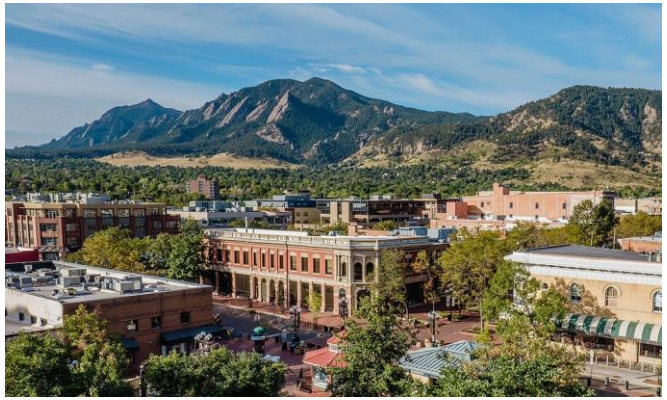


Bozeman, MT

Boulder, CO

University of Colorado Boulder

Undergrad
2011-2015



Boston, MA

MIT

PhD
2015-2020

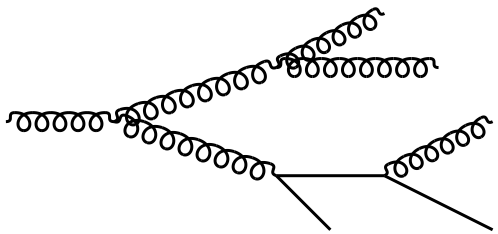
Heavy-ion collisions

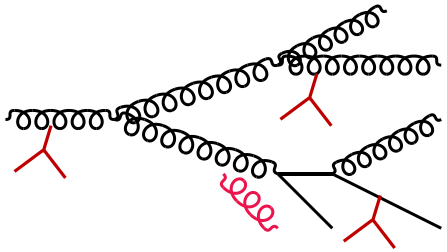
energy

Momentum transfer

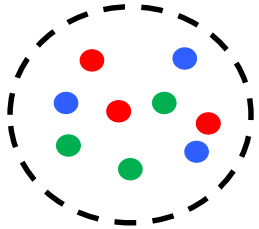
high energy scatterings

energy loss





Asymptotic freedom

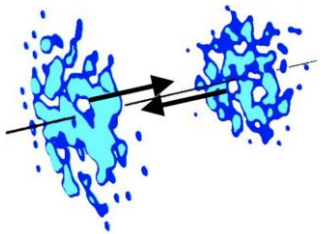


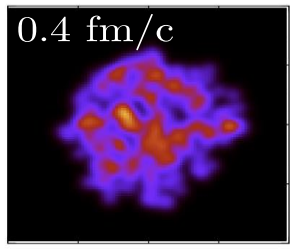
~ 100 GeV

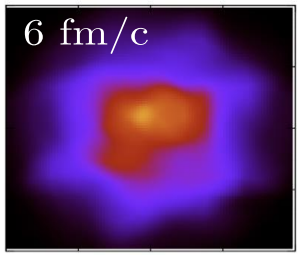
far from equilibrium initial state

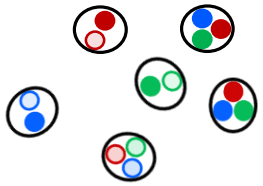
hydrodynamics

hadron gas

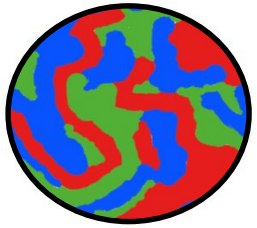








Perfect liquid

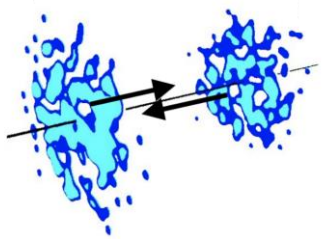


~ 1 GeV

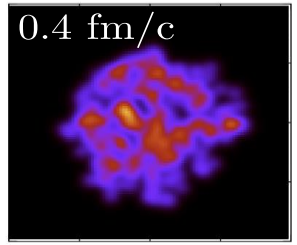
~ 1 fm/c

~ 10 fm/c

time



Stages of thermalization in QCD

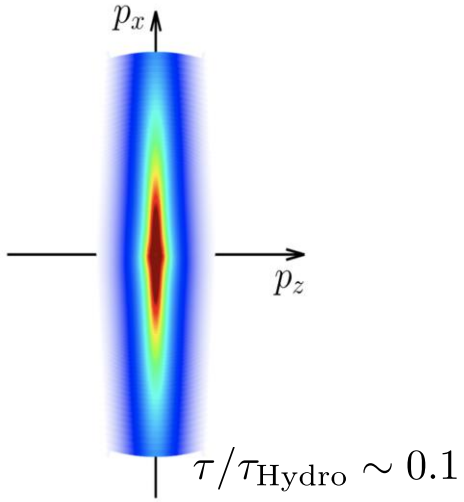


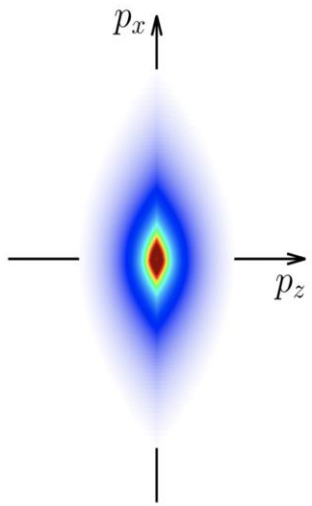
QCD equilibration at weak coupling in kinetic theory

Universality far-from-equilibrium

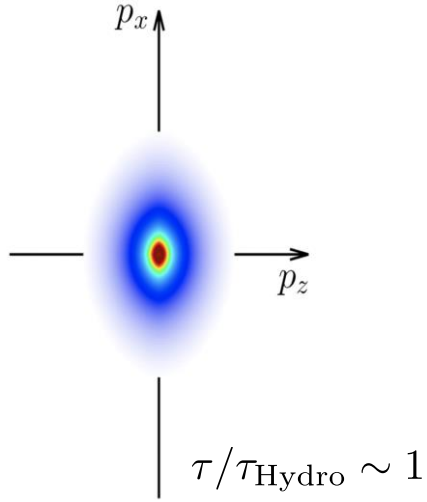
$$f(p_\perp, p_z; \tau) \to \tau^\alpha \, w\left(\tau^\beta p_\perp, \tau^\gamma p_z\right)$$

Rapid expansion





Collisional equilibration



Fixed points:

Free-streaming

$(\alpha, \beta, \gamma) = (0, 0, 1)$

Non-thermal

- Large f $(-2/3, 0, 1/3)$
- Small f $(-1, 0, 0)$

Thermal

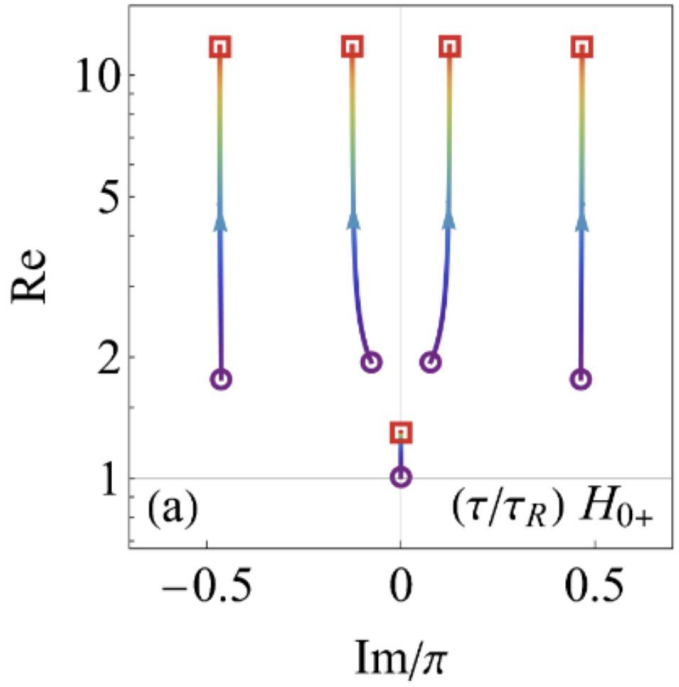
$(0, 1/3, 1/3)$

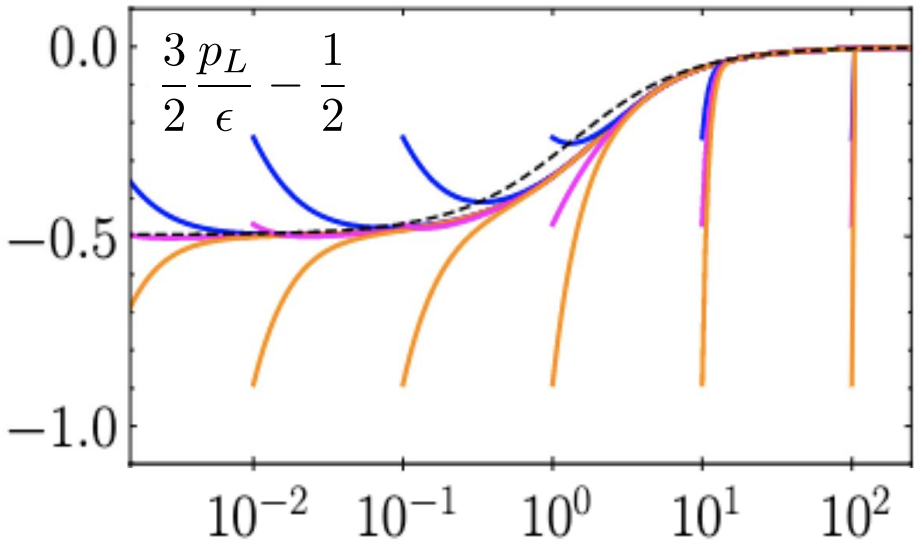
JB, Schiehing-Hitschfeld, Yin [2203.02427]

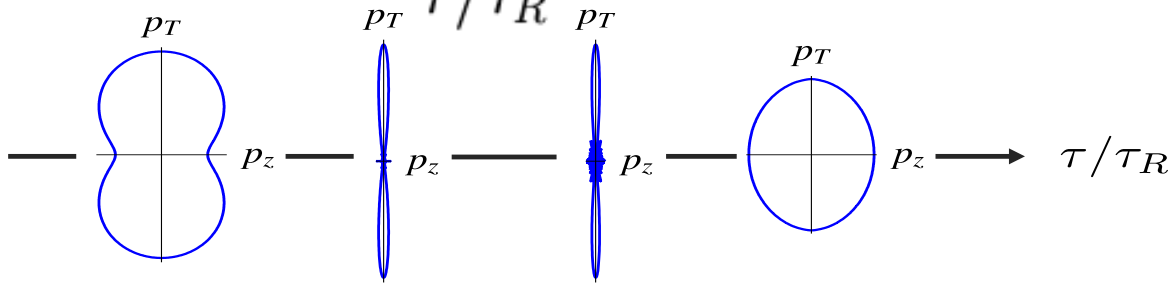
Ground state: far-from-equilibrium slow mode

Initial conditions decay to ground state on time scale set by energy gap

JB, Yan, Yin [1910.00021]



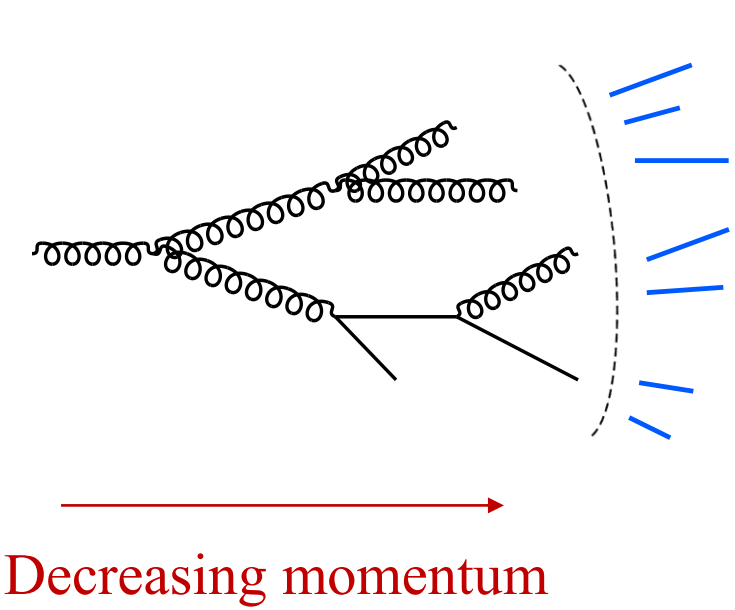




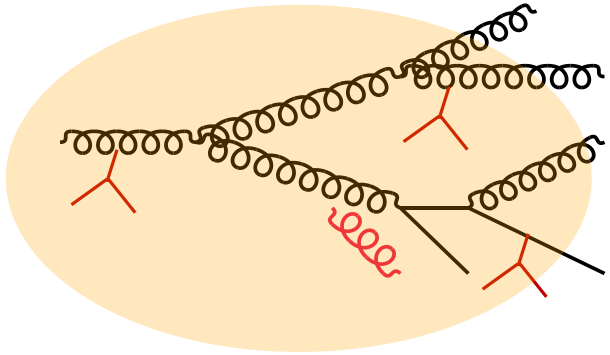
Momentum-space anisotropy may evolve slowly far-from-equilibrium

JB, Ke, Yan, Yin; *upcoming*

Jets as a probe of the quark-gluon plasma



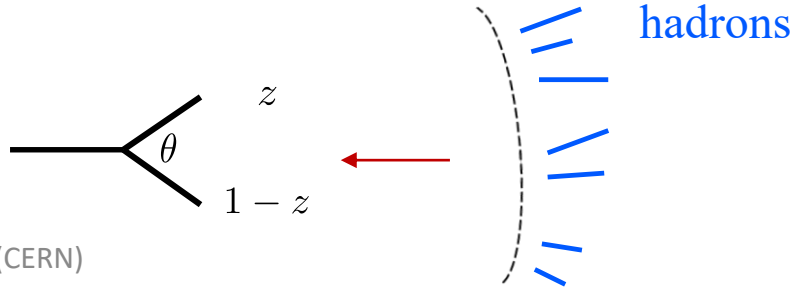
Decreasing momentum

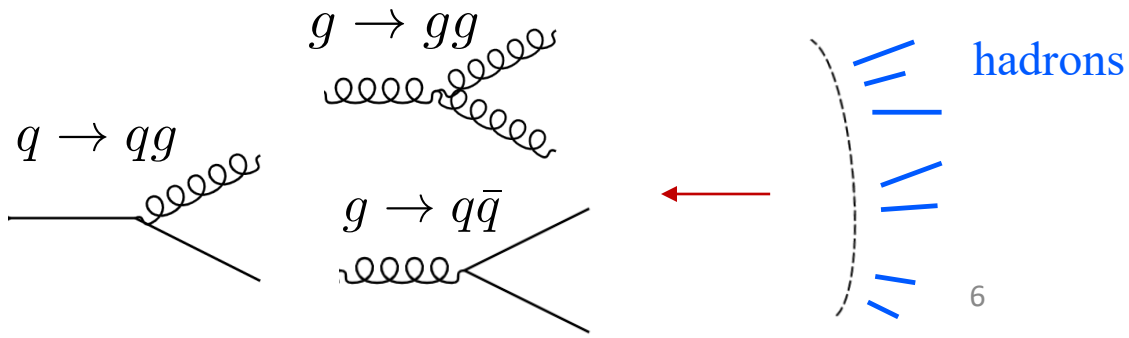


Probes

- momentum-dependence of interactions
- Spatial location of splittings

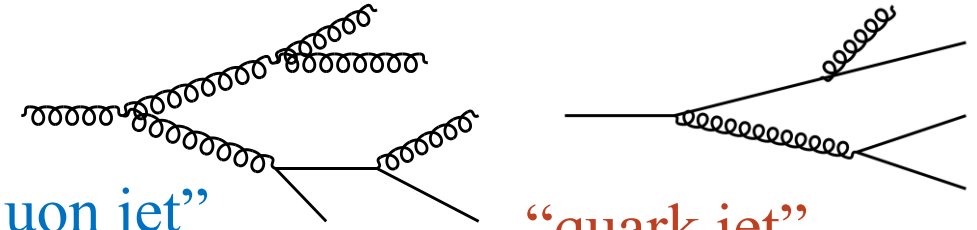
Building a picture of a medium-modified jet from phenomenology





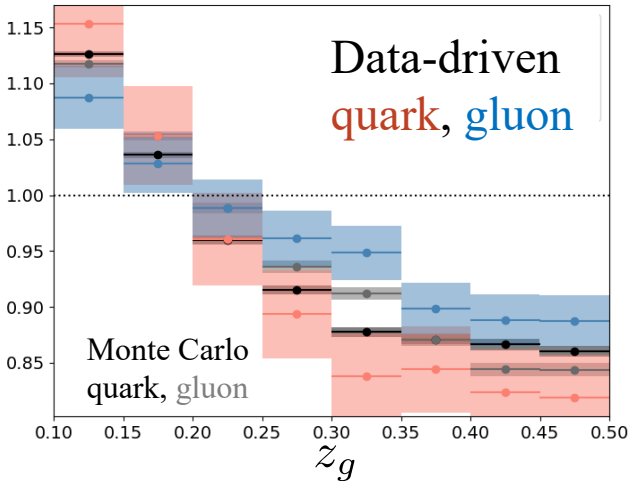
Accessing parton flavor of QCD splittings

- Modification of jets initiated by a quark or gluon

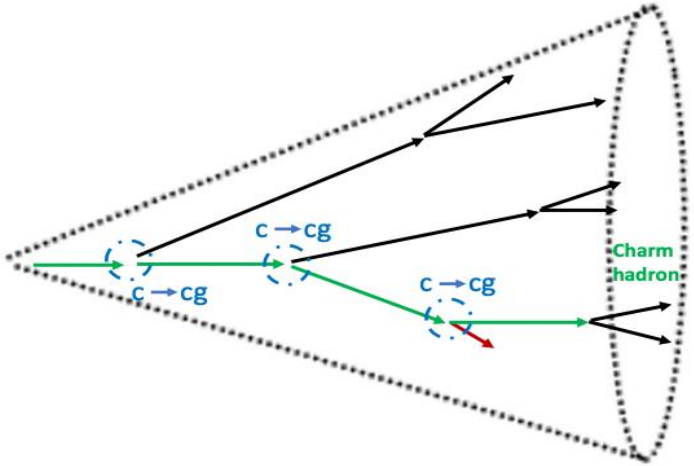


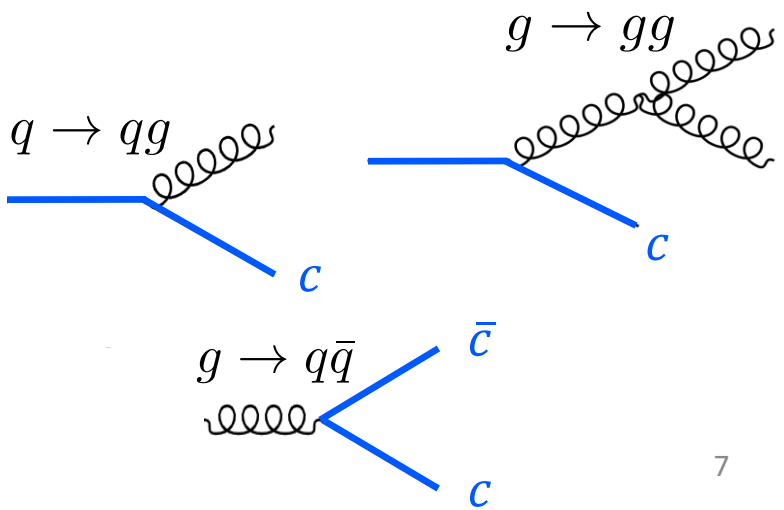
JB, Jesse Thaler, Andrew Patrick Turner [2008.08596]; Ying, JB, Chen, Lee [2204.00641]

Modified q,g splitting functions

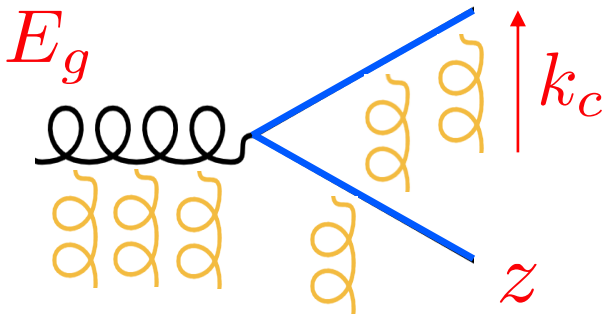


- Modification of later splittings in the shower: heavy quarks





Modification of the $g \to c\bar{c}$ splitting function



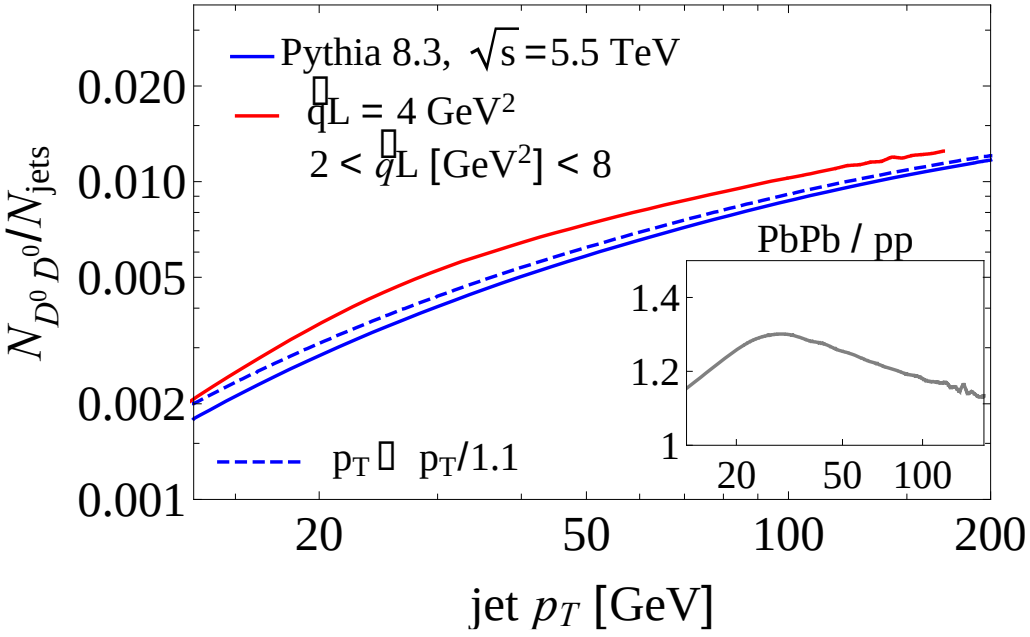
Arbitrarily-many soft gluon interactions with a medium of length L

$$P_{g\to c\bar{c}}(E_g, k_c^2, z) = P^{\text{vac}}_{g\to c\bar{c}}(k_c^2, z) + P^{\text{med}}_{g\to c\bar{c}}(E_g, k_c^2, z)$$

Results of the calculation:

- Medium-enhanced rate of $c\bar{c}$ production!

  gluons promoted above threshold

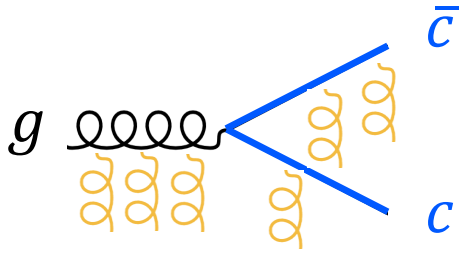


Attems, JB, Innocenti, Mazeliauskas, Park, van der Schee, Wiedemann [2203.11241, 2209.13600]

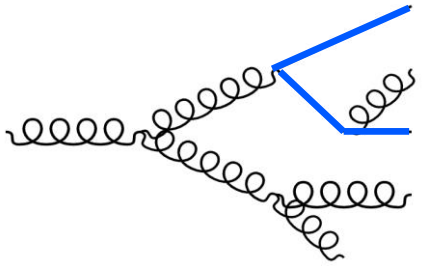
Unique phenomenology of the modified $g \to c\bar{c}$ splitting

- Momentum transfer-dependence of medium interactions

Broadening of splittee momenta due to medium interactions



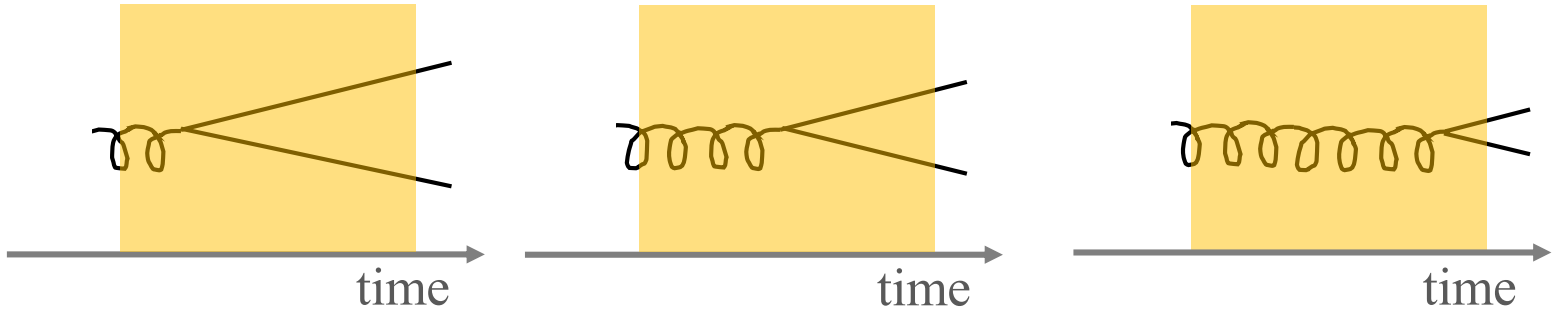
…Including at lower scales in the shower



- Spatial location of QCD splittings

Gluons have a "lifetime" proportional to their energy/virtuality

- Access modification of $c\bar{c}$ pair at later times in the QGP



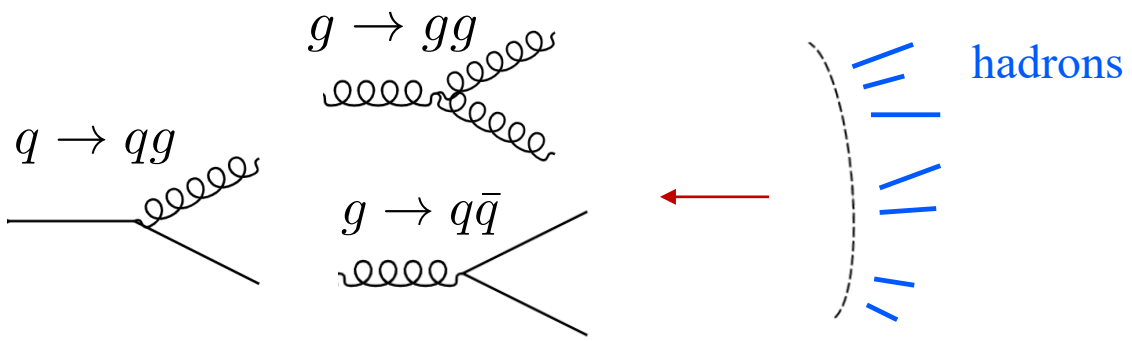
$\sim 1 - 6$ fm delay for $20 - 100$ GeV gluons

Increasing gluon energy

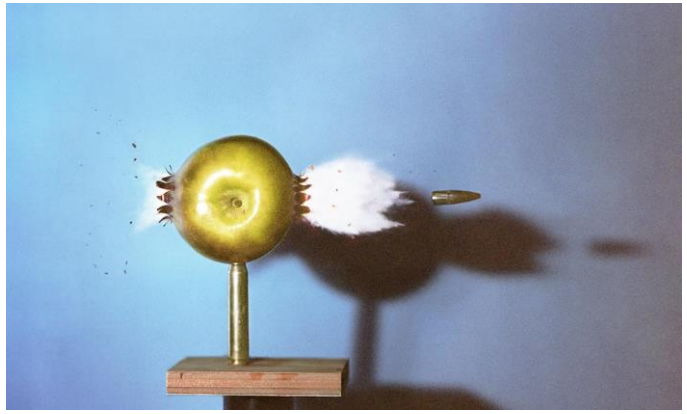
Another time-delayed probe: Apolinario, Milhano, Salam, Salgado [1711.03105]

Outlook

- Medium modification of all QCD splittings from phenomenology



- Intersection of jets and equilibration



Jet features are sensitive to response of the medium

Observables to disentangle this: Brewer, Brodsky, Rajagopal [2110.13159]

Access to non-equilibrium effects in the medium