Shining a Beam of Gluons Through Strongly Coupled QGP

Krishna Rajagopal

MIT

Hard Probes 2012; Cagliari, Italy; May 28, 2012

Jet Quenching @ LHC

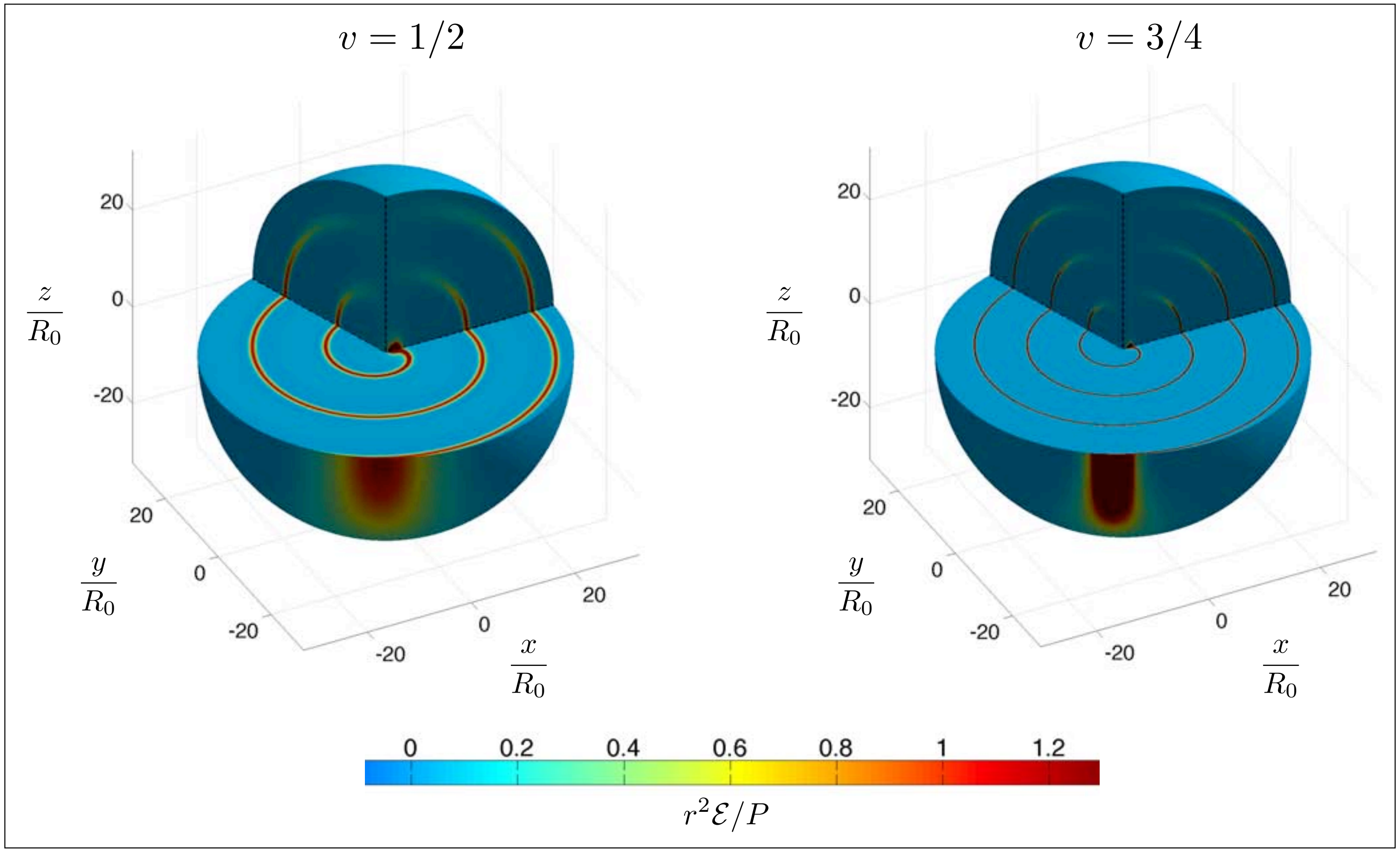
ATLAS & CMS, circa QM2011

- **Jet quenching apparent at the LHC, eg in events with, say, 205 GeV jet back-to-back with 70 GeV jet. Strongly coupled plasma, so strong jet quenching not a surprise**. . .
- **But, the 70 GeV jet looks like a 70 GeV jet in pp collisions. Same fragmentation function; same angular distribution. The "missing" energy is** *not* **in the form of a spray of softer particles in and around the jet.**
- **Also, 70 GeV jet seems to be back-to-back with the 200 GeV jet; no sign of transverse kick.**
- **The "missing" energy is in the form of many** ~ 1 **GeV particles at large angle to the jet directions.**
- **Interestingly, STAR and PHENIX see evidence of spray of softer particles around the lower energy jets at RHIC.**

- As if an initially-200-GeV parton/jet in an LHC collision just heats the plasma it passes through, losing energy without spreading in angle. Are even 200 GeV partons not "seeing" the quasiparticles at short distances?
- One line of theoretical response: more sophisticated analyses of conventional weak-coupling, high-parton-energy-limit, picture of jet quenching as due to parton energy loss by radiating gluons. Eg many talks at HP2012.
- We need a strongly coupled approach to jet quenching, even if just as a foil with which to develop new intuition.
- Problem: jet production is a weakly-coupled phenomenon. There is no way to make jets in the strongly coupled theories with gravity duals.
- But we can make a beam of gluons...

Synchrotron Radiation in Strongly Coupled Gauge Theories

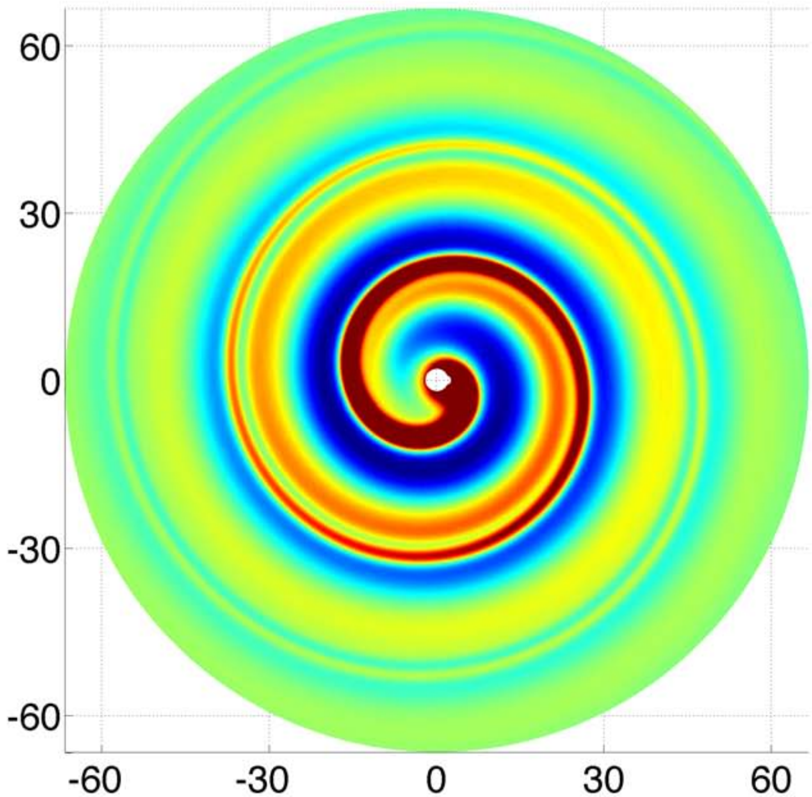
Athanasiou, Chesler, Liu, Nickel, Rajagopal; arXiv:1001.3880

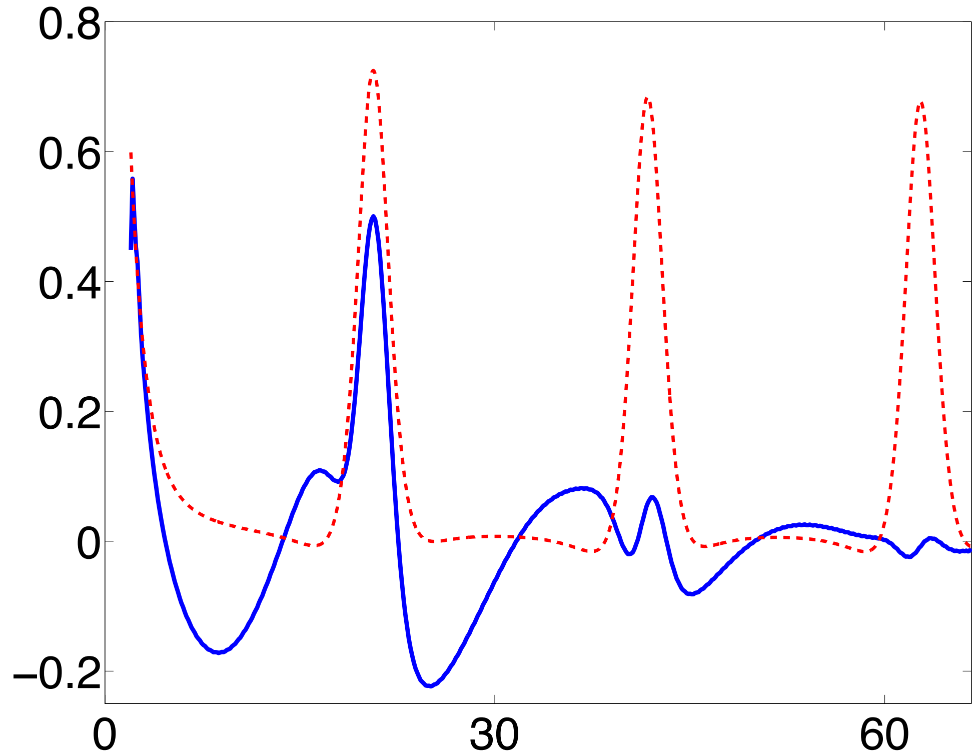


Fully *quantum mechanical* **calculation of gluon radiation from a rotating quark in a** *strongly coupled* **large** N_c *non abelian* **gauge theory, done via gauge/gravity duality. "Lighthouse beam" of synchrotron radiation. Surprisingly similar to classical electrodynamics. Now, shine this beam through strongly coupled plasma...**

Quenching a Beam of Gluons

Chesler, Ho, Rajagopal, arXiv:1111.1691

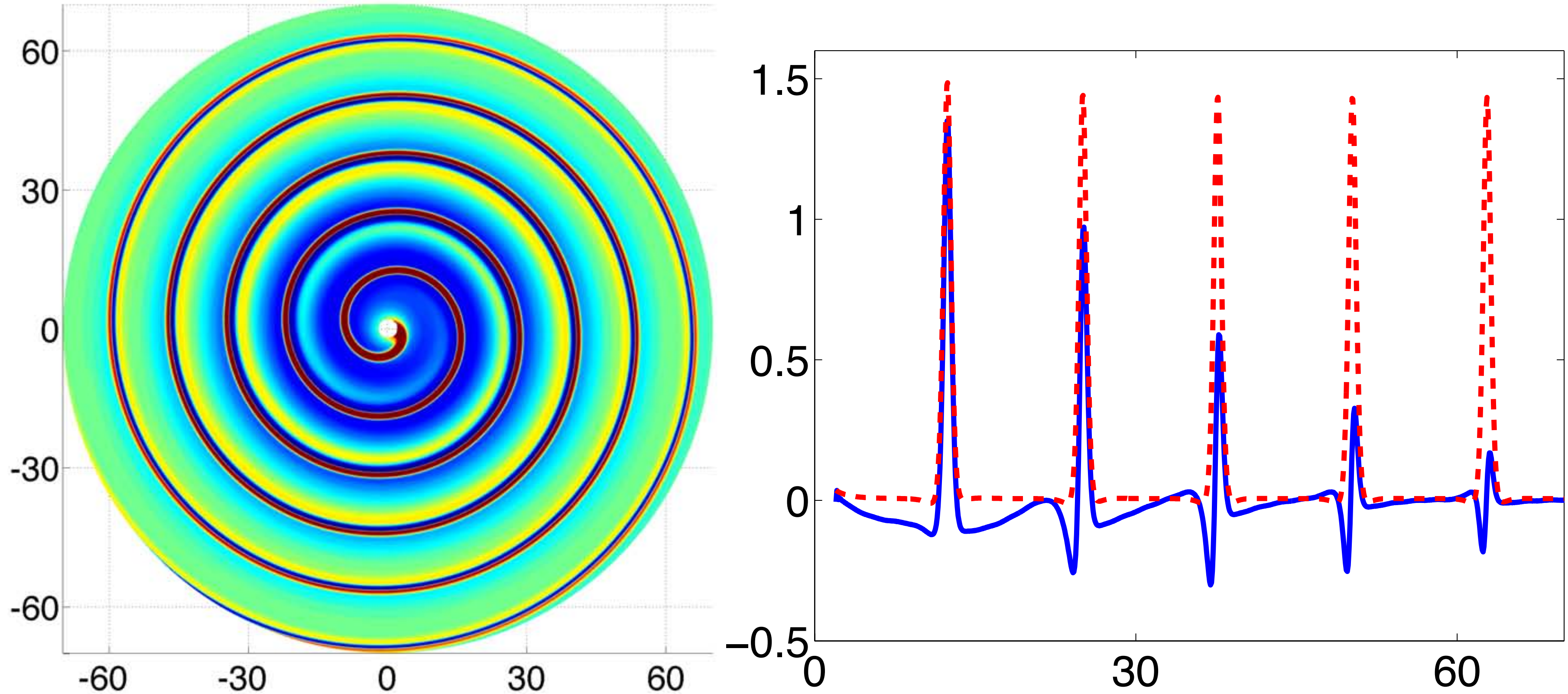




Quark in circular motion ($v = 0.3$; $R\pi T = 0.15$) makes a beam that is attenuated as it shines through the strongly coupled plasma, leaving a sound wave behind.

Quenching a Beam of Gluons

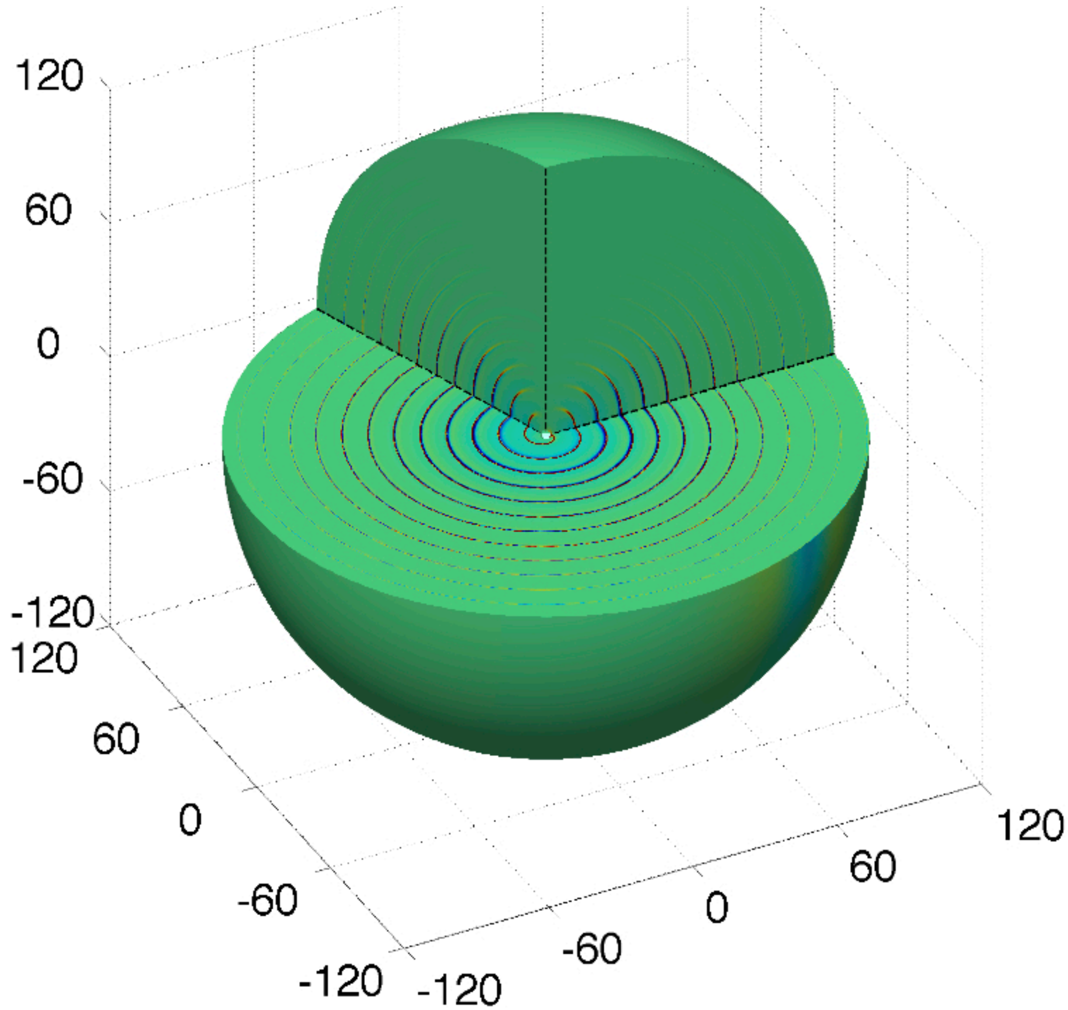
Chesler, Ho, Rajagopal, arXiv:1111.1691



Quark in circular motion ($v = 0.5$; $R\pi T = 0.15$) makes a narrower beam of higher-q gluons that is attenuated more slowly as it shines through the strongly coupled plasma, leaving a sound wave farther behind.

Quenching a Beam of Gluons

Chesler, Ho, Rajagopal, arXiv:1111.1691



An even narrower beam travels farther still, gets attenuated without spreading in angle.

Quenching a Beam of Gluons

Chesler, Ho, Rajagopal, arXiv:1111.1691

- **A beam of gluons with wave vector $q \gg \pi T$ shines through the strongly coupled plasma at close to the speed of light, and is attenuated over a distance $\sim q^{1/3}(\pi T)^{-4/3}$.**

- **Beam shows no tendency to spread in angle, or shift toward longer wavelengths, even as it is completely attenuated. Like jet quenching at LHC?**

- **Beam sheds a trailing sound wave with wave vector $\sim \pi T$. A beam of higher q gluons travels far enough that it leaves the sound far behind; sound presumably thermalizes. (LHC?) A beam of not-so-high q gluons does not get far ahead of its trailing sound wave over its whole attenuation length. (RHIC?)**

- **Other approaches to jet quenching in a strongly coupled plasma yield qualitatively similar conclusions.**

Shining Gluons through Liquid QGP

- A beam of gluons loses its energy by heating the strongly coupled plasma it propagates through, not by spreading in angle, and not by softening its "fragmentation function". At least reminiscent of jet quenching at the LHC.

- Differing jet-QGP interaction in RHIC and LHC regimes? Maybe. Or, maybe its just that the jets that make it out of a RHIC collision have not travelled as great a distance. I.e. at RHIC if a jet makes it out it was produced close enough to the edge of the droplet of liquid QGP that the sound waves it shed have not had time to thermalize and have not been left far behind, while at the LHC we see jets produced deeper inside, whose shed sound waves *have* largely thermalized.

How to see the quasiparticles??

(The talk that Minda Lekaveckas was planning to give tomorrow afternoon.)

- **We *know* that at a short enough lengthscale, a quasiparticulate picture of the QGP *must* be valid, even though on its natural lengthscales QGP is a strongly coupled fluid.**

- **Long-term challenge: understand *how* liquid QGP emerges from short-distance quark and gluon quasiparticles.**

- **First things first: how can we see the quasiparticles?**

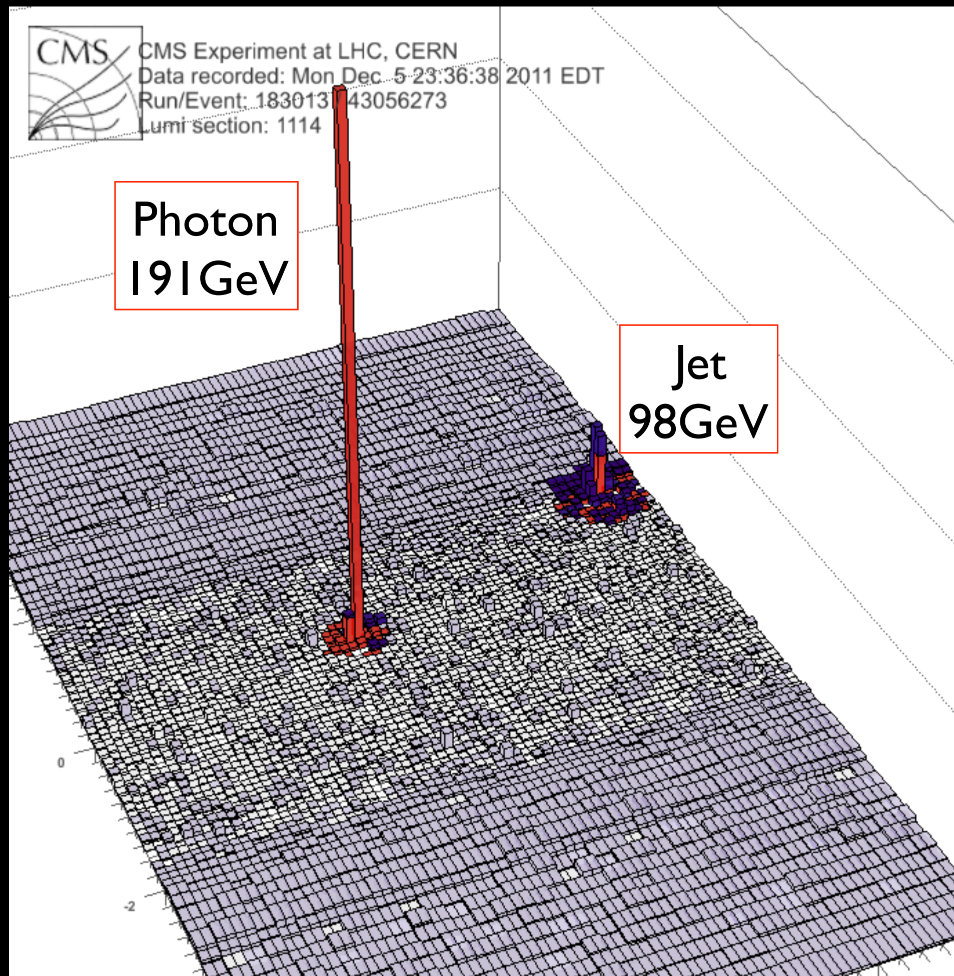
- **How did Rutherford find hard, apparently pointlike, nuclei in atoms — which he thought were droplets of plum pudding? How did Friedman, Kendall and Taylor find hard, apparently pointlike, quarks inside a proton — which with some poetic license we can think of as the smallest possible droplet of liquid QGP? Answer: large-angle scattering was not as rare as it would have been if atom/proton were liquid-like on all length scales!**

- **Look for rare large-angle scattering off liquid QGP.**

How to see the quasiparticles?

- **Gamma-jet events: Gamma tells you initial direction of quark. Measure deflection angle. Like Rutherford!**
- **Calculate $P(k_\perp)$, the probability distribution for the $k_\perp$ that a parton with energy $E \to \infty$ picks up upon travelling a distance L through the medium:**
  - $P(k_\perp) \propto \exp(-\# k_\perp^2/(T^3 L))$ **in strongly coupled plasma.** D'Eramo, Liu, Rajagopal, arXiv:1006.1367
  - **For a weakly coupled plasma made of point scatterers, $P(k_\perp) \propto 1/k_\perp^4$ at large $k_\perp$. In the strongly coupled plasma of an asymptotically free gauge theory, this must win at large enough $k_\perp$.** D'Eramo, Lekaveckas, Liu, Rajagopal, in progress
- **Expect Gaussian at low $k_\perp$, with power-law tail at high $k_\perp$. Large deflections rare, but not as rare as if the liquid were a liquid on all scales. They indicate point-like scatterers.**

2011: Detected 3000 photon-jet pairs in 10^9 PbPb collisions



Unbalanced photon-jet event in PbPb

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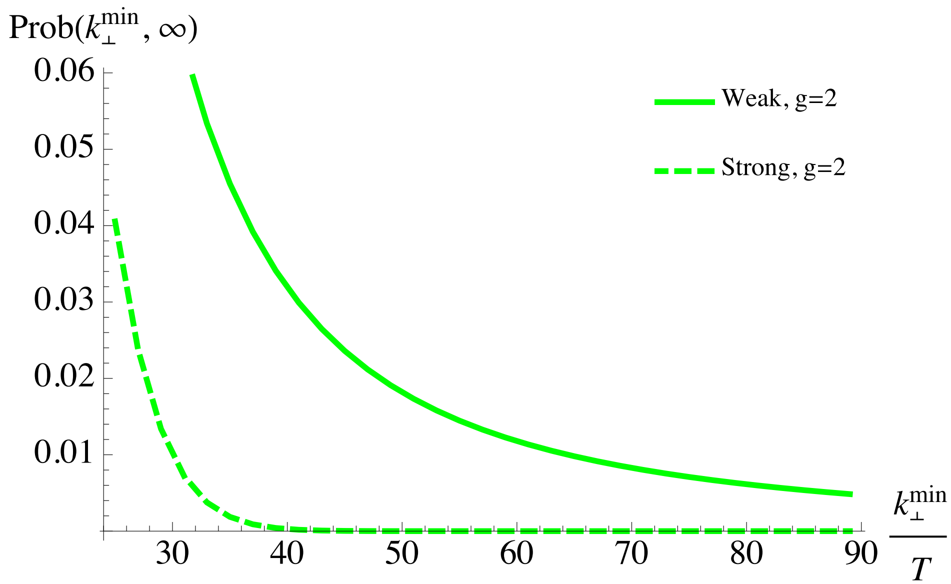

D'Eramo, Lekaveckas, Liu, Rajagopal, in progress

- **Probability that a parton that travels $L = 7.5/T$ through the medium picks up $k_\perp > k_{\perp \text{min}}$, for:**
  - **Weakly coupled QCD plasma, in equilibrium, analyzed via SCET+HTL. With $g = 2$, i.e. $\alpha_{\text{QCD}} = 0.32$.**
  - **Strongly coupled $\mathcal{N} = 4$ SYM plasma, in equilibrium, analyzed via holography. With $g = 2$, i.e. $\lambda_{\text{'t Hooft}} = 12$.**

- **Eg, for $T = 300$ MeV, $L = 5$ fm, a 60 GeV parton that picks up $70\,T$ of $k_\perp$ scatters by 20°.**

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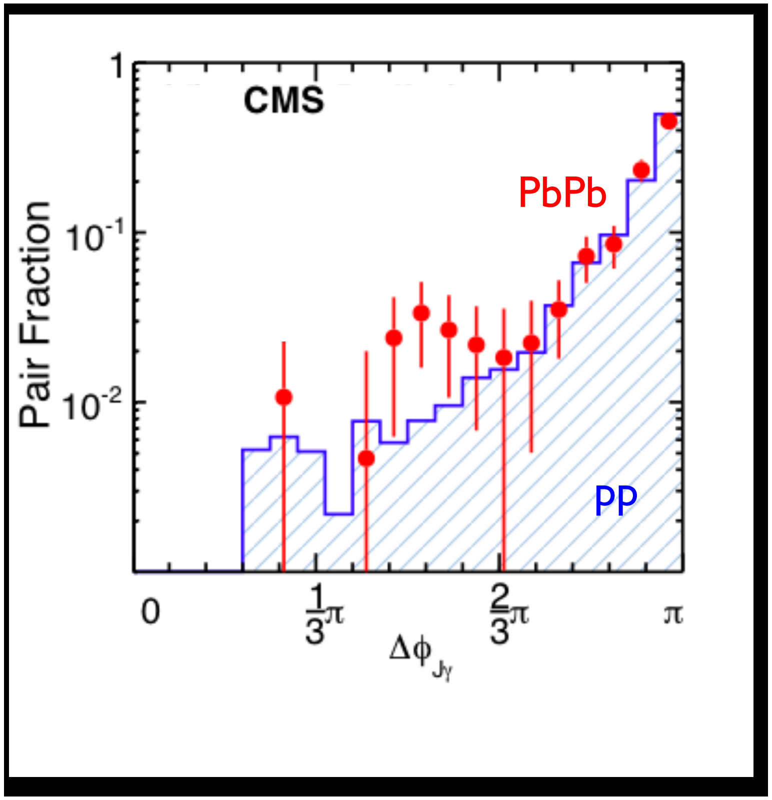
Measure the angle between jet and photon



CMS, arXiv:1205.0206

Tantalizing, but need many more events before this can be a "QGP Rutherford Experiment". Something to look forward to at HP2015?