Jet Tomography at Lower Energies

What can be learnt from RHIC

but not from the LHC

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Wayne State University

The emerging picture in the temperature dependence of viscosity

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Strongly Interacting Low-Viscosity Matter Created in Relativistic Nuclear Collisions

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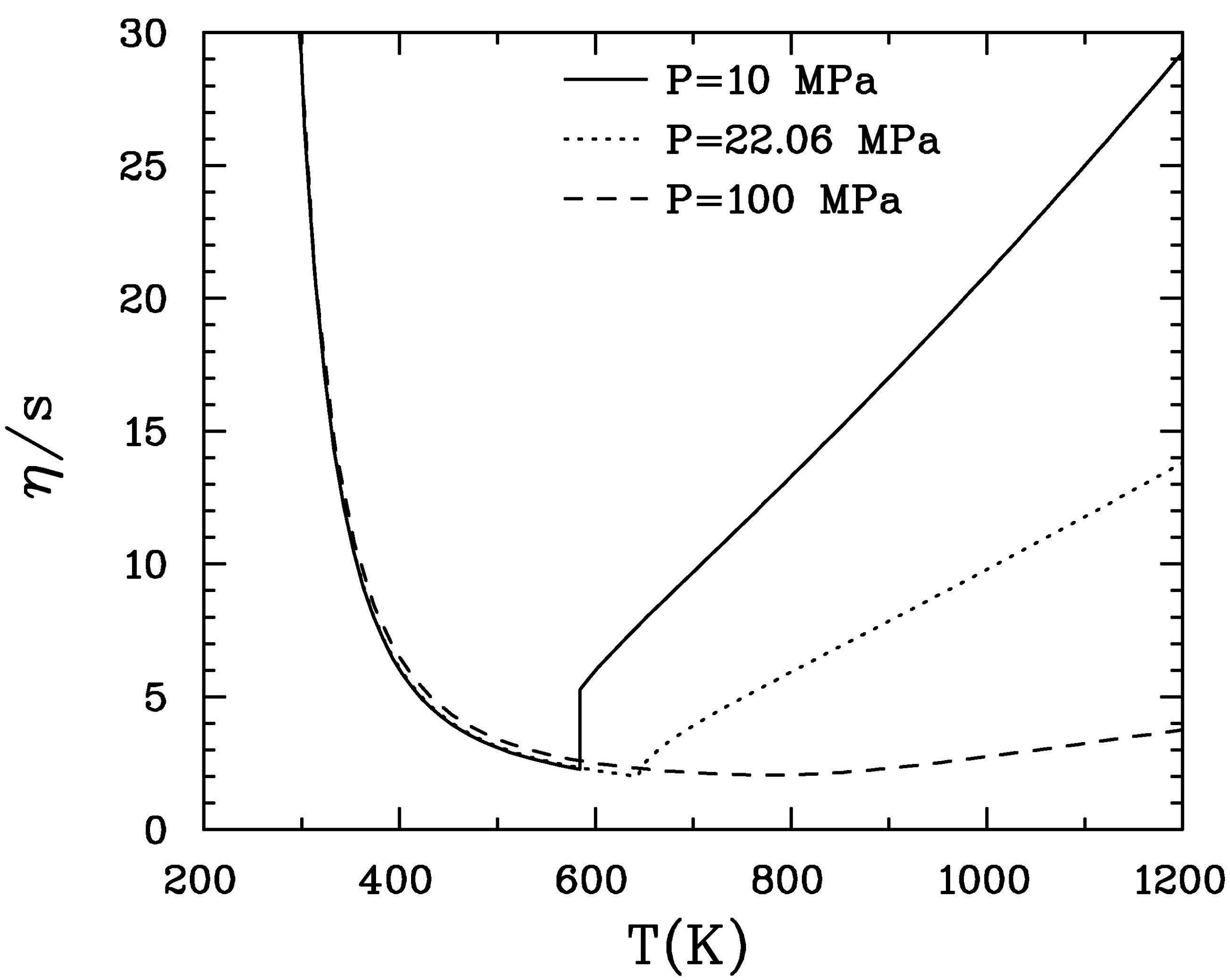

Is there a relationship between η and $\hat{q}$?

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Small Shear Viscosity of a Quark-Gluon Plasma Implies Strong Jet Quenching

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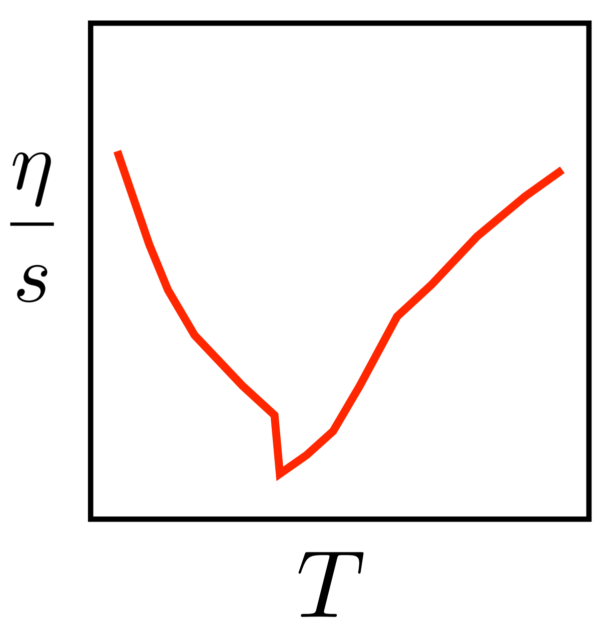
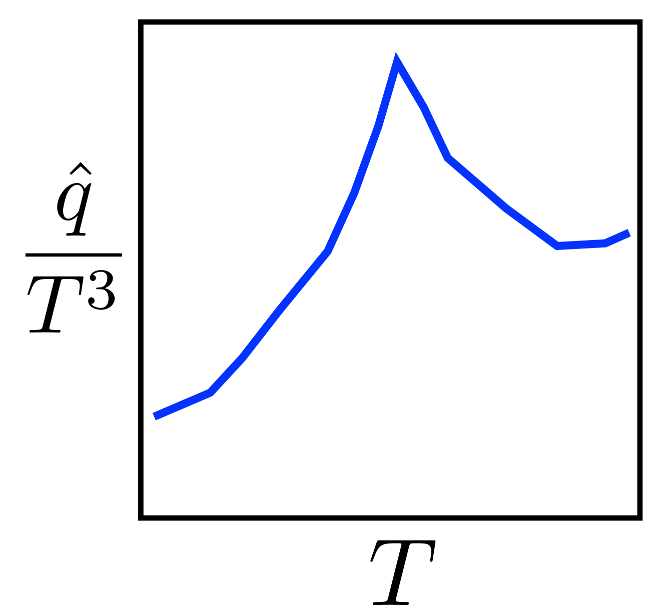
$$\frac{\eta}{s} \sim \frac{T^3}{\hat{q}}$$

For a weakly coupled medium, proportionality constant ~ 1





Where else in nature does something similar happen

Pretty much everywhere !

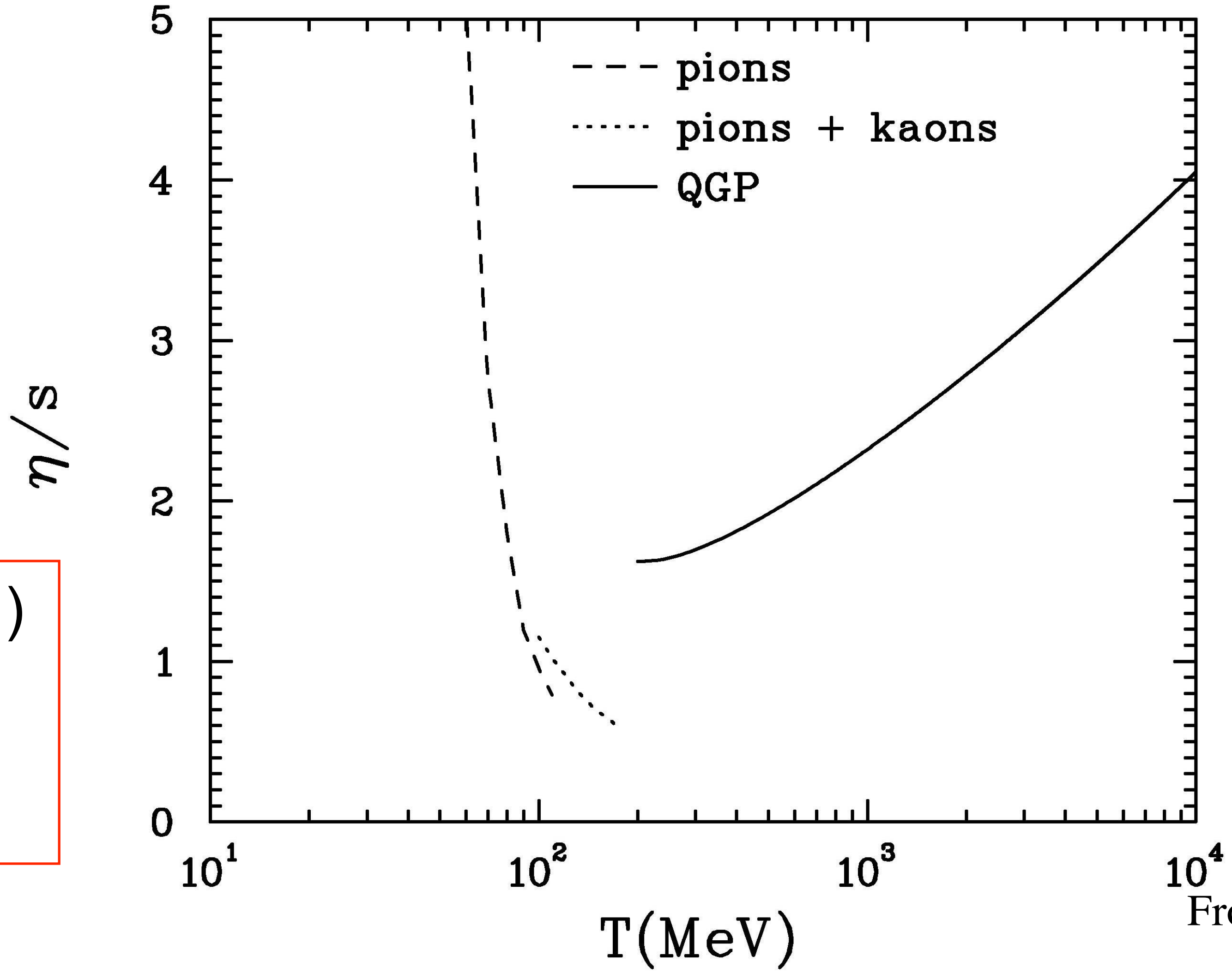
Critical opalescence

Does QCD show Critical opalescence ?

Is there some remnant of this in the cross over past the CP ?

Remnants of extremal behavior at $\mu \rightarrow 0$

Low T (*Prakash et al.*) using experimental data for 2-body interactions.



High T (Yaffe *et al.*) using perturbative QCD.

From talk by J. Kapusta at QM2006

QCD matter at RHIC and LHC is far from the critical point

Yet one still expects a minimum, at least theoretically!

Not inconsistent with any bulk measurement at RHIC/LHC

Any reason to expect a spike in $\hat{q}/T^3$?

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Angular Dependence of Jet Quenching Indicates Its Strong Enhancement near the QCD Phase Transition

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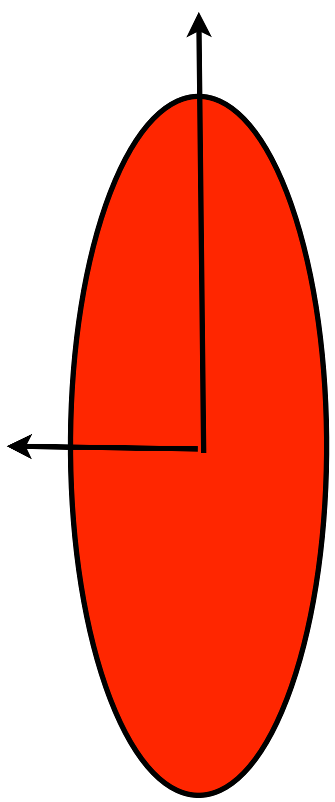
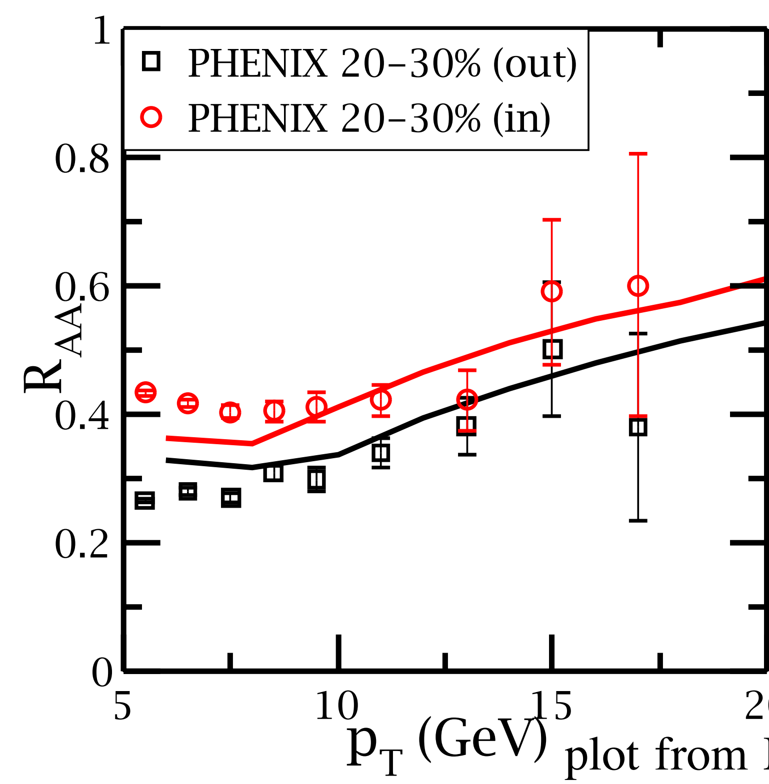
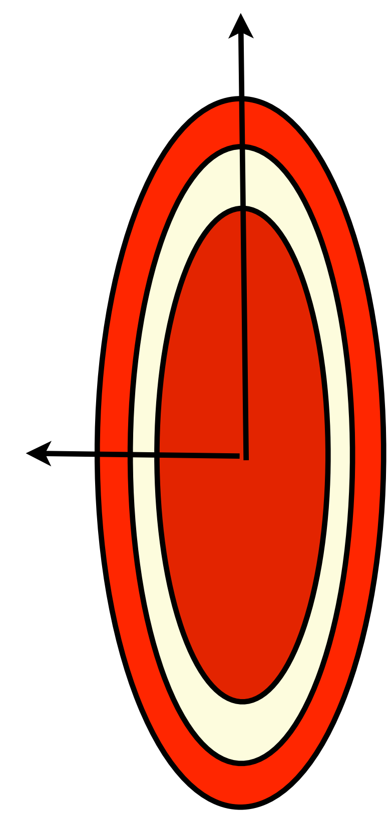




plot from Majumder and Shen

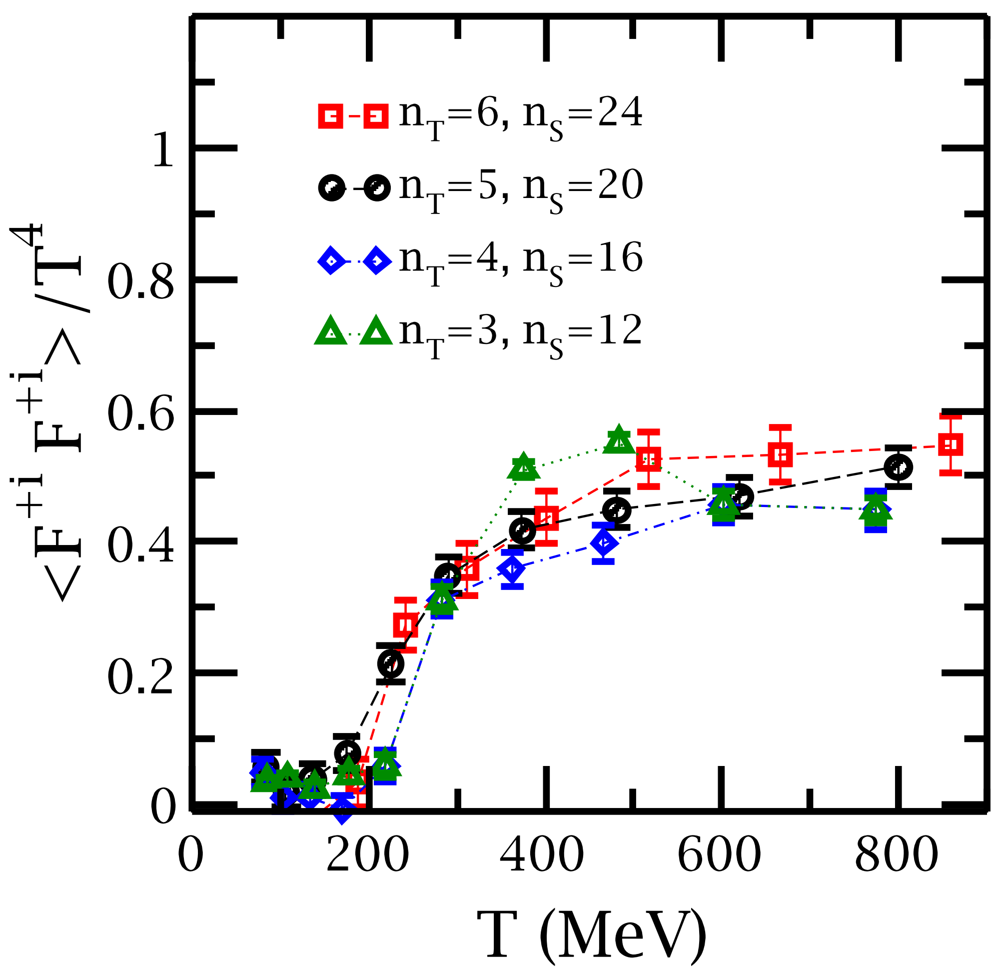


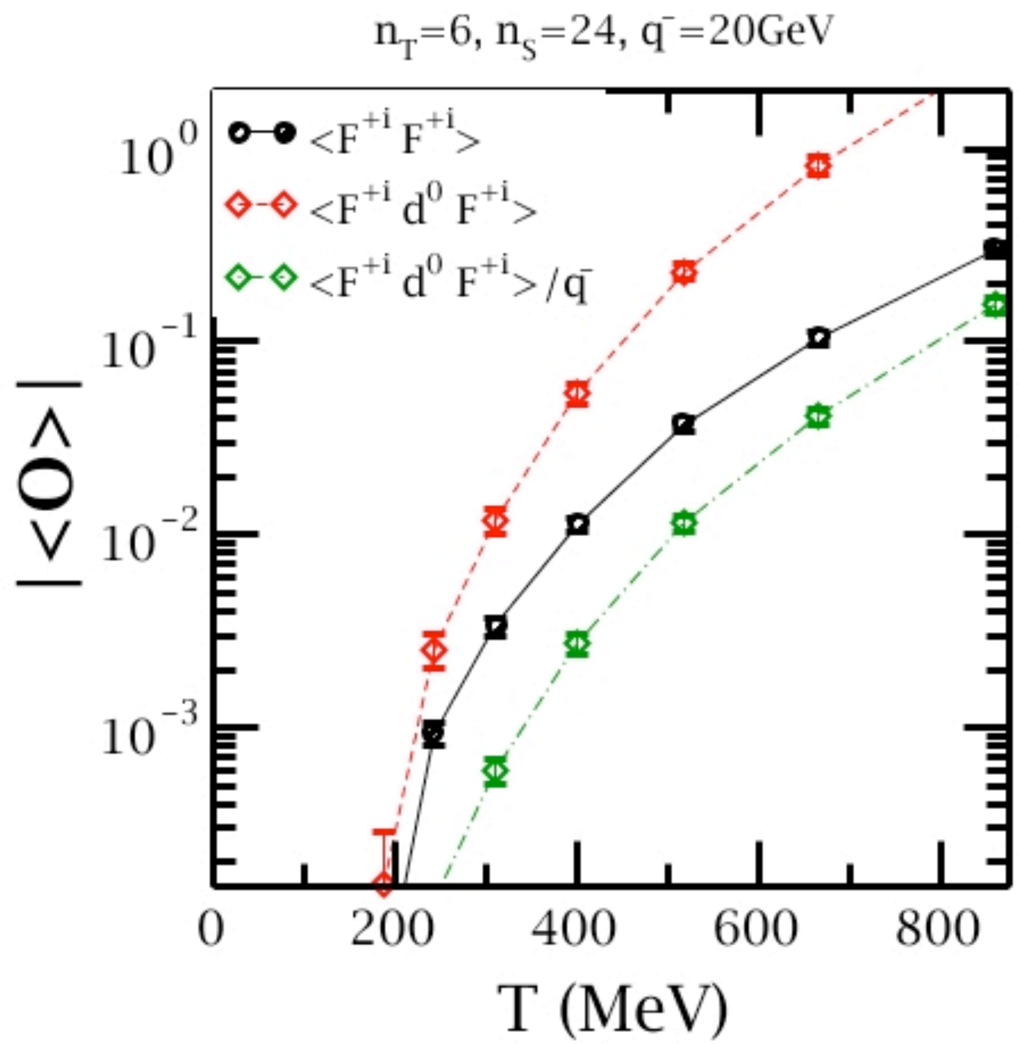
A non-monotonic behavior in q/T^3

A Lattice calculation of $\hat{q}$

Long story short: can analytically continue q to euclidean space and evaluate as a series

$$\langle M|F_{\perp}^{+\mu}\sum_{n=0}^{\infty}\left(\frac{-q\cdot i\mathcal{D}-\mathcal{D}_{\perp}^{2}}{2q^{-}Q_{0}}\right)^{n}F_{\perp,\mu}^{+}|M\rangle$$

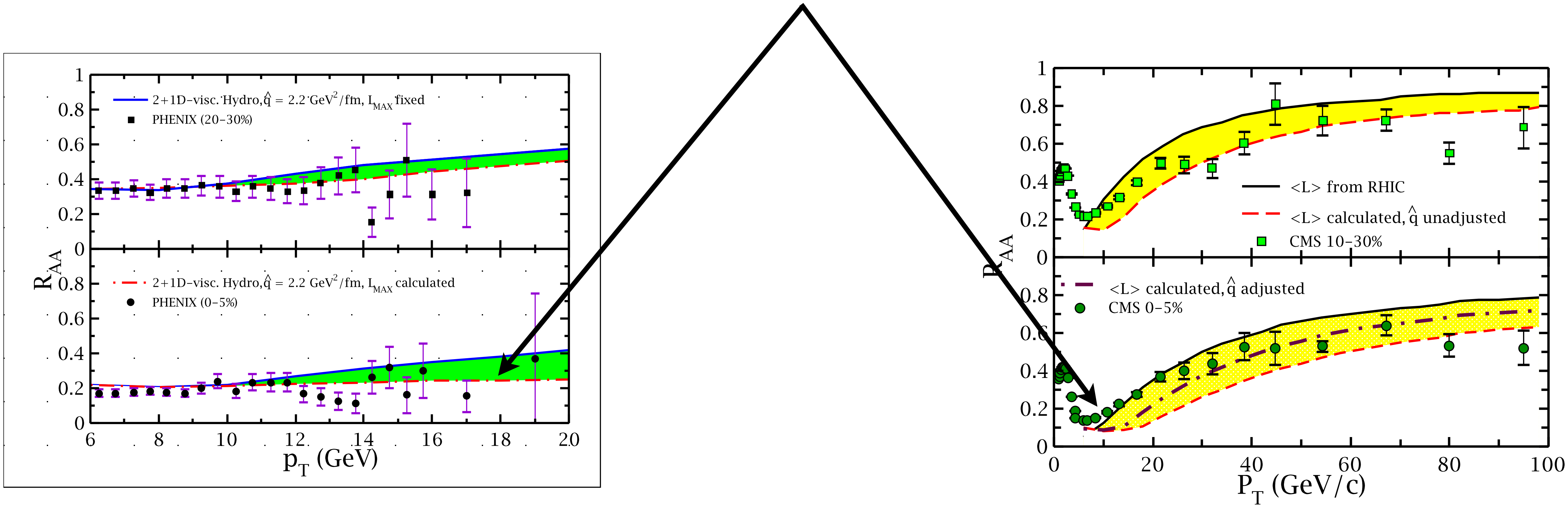




Note: quenched SU(2), results not inconsistent with a bump above T_C.

What exactly are we looking for?

Note: The QGP at RHIC and LHC already very opaque to most jets



Jets tend to disintegrate as they propagate through the QGP

We need very specific range of parameters to see a maximal scaled opacity $(\hat{q}/T^3)$.

A couple of things to keep in mind

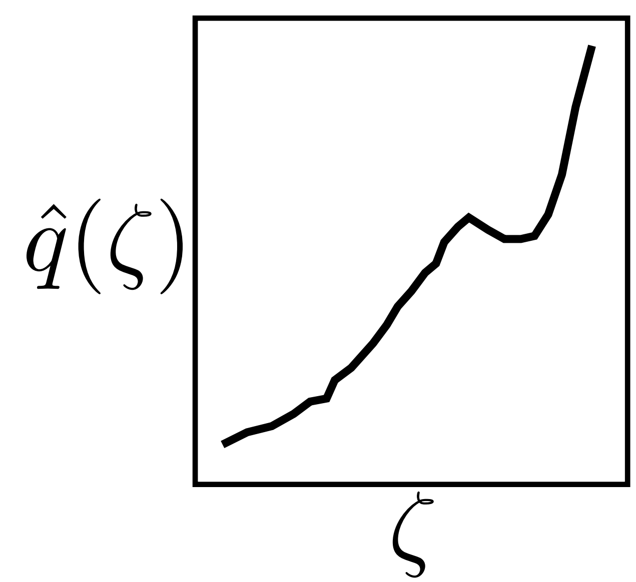
(I) Jet quenching is sensitive to

$$\int_{\text{Origin}}^{\text{Exit}} d\zeta q(\zeta)$$

And not to the scaled quantity

$$\int_{\text{Origin}}^{\text{Exit}} d\zeta \frac{q(\zeta)}{T^3(\zeta)}$$

Thus, we are looking for a wiggle in a steeply falling curve

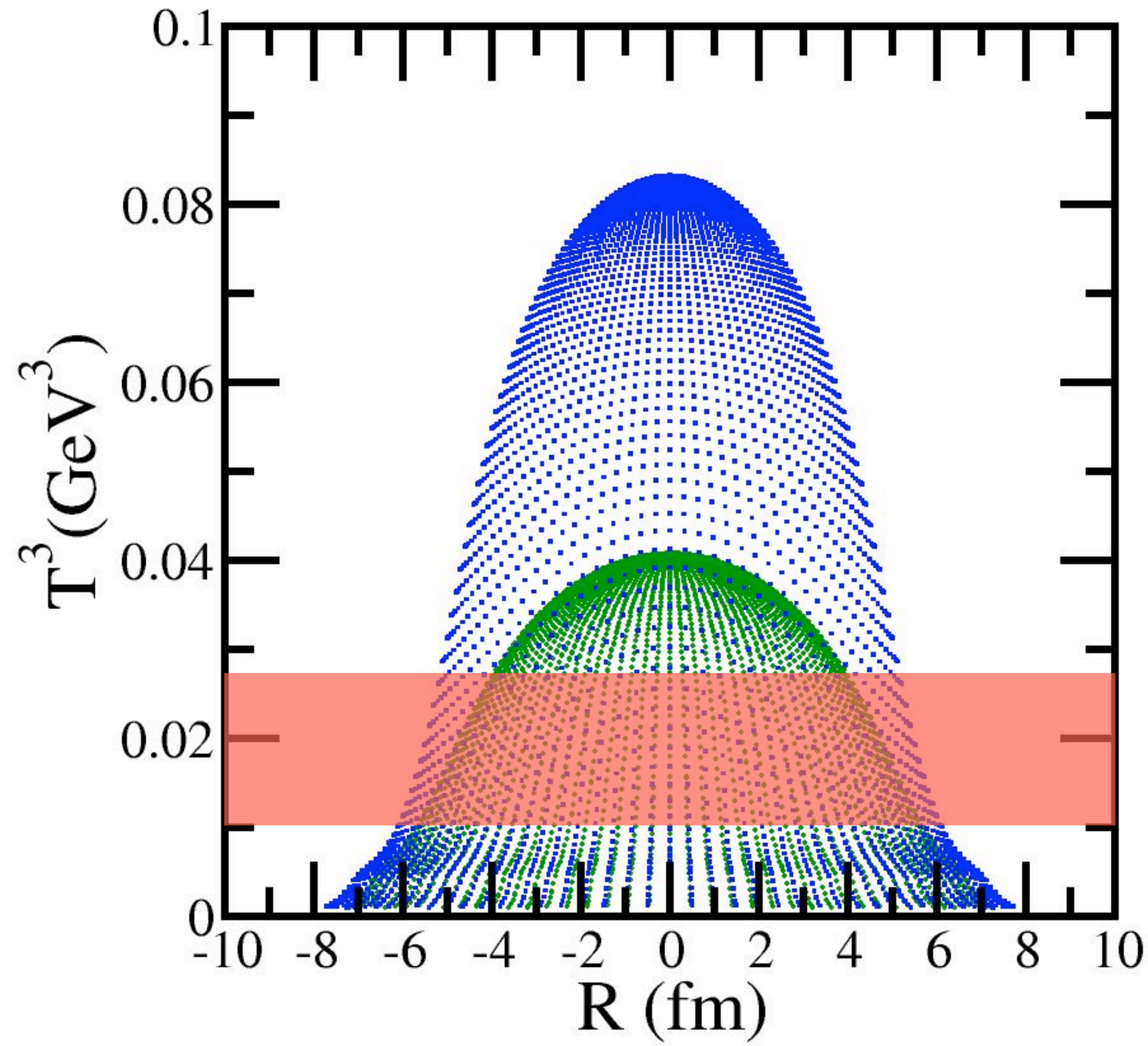


(II) At very high p_T a small R_{AA} does not mean the modification to the jet is as large as at lower p_T

If there is a wiggle at T_C, RHIC is a better place to look

T^3 profiles from
the OSU 2+1 D hydro, 0-5% evts

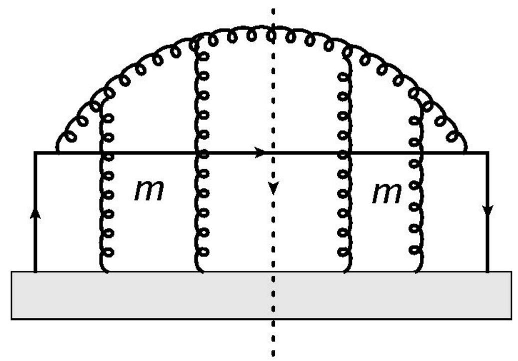
At LHC, region of non-monotonic
behavior suppressed by much
larger $\hat{q}$ values at earlier times



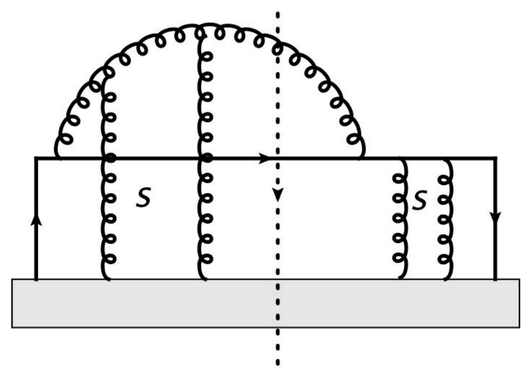
Region stretches for about
2fm/c at RHIC and 1fm/c at LHC

What kind of jets are best suited for probing this region

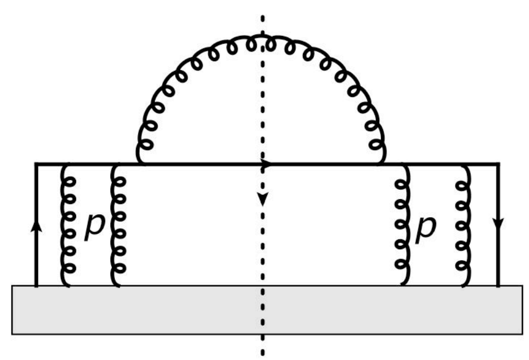
Results from a multiple scattering single emission calculation



$$\sim C_A^m \int dy \frac{l_\perp^2}{l_\perp^2} P(y) \int d\zeta \frac{2\hat{q}}{l_\perp^2}\left[2 - 2\cos\left(\frac{l_\perp^2}{2E}\zeta\right)\right]$$



$$\sim -\left(\frac{C_A}{2}\right)^s \int dy \frac{l_\perp^2}{l_\perp^2} y P(y) \int d\zeta \frac{\hat{q}}{l_\perp^2}\left[2 - 2\cos\left(\frac{l_\perp^2}{2E}\zeta\right)\right]$$



$$\sim (C_F)^p \int dy \frac{l_\perp^2}{l_\perp^2} y^2 P(y) \int d\zeta \frac{\hat{q}_Q}{l_\perp^2}\left[2 - 2\cos\left(\frac{l_\perp^2}{2E}\zeta\right)\right]$$

The modification is controlled by the parameter $\frac{\hat{q}L}{Q^2}$

If this is too small then jets not modified

If its too big then jets are completely quenched, ideal value ~ 0.1

Some counter-intuitive estimates!

In the region of the bump, $q_q \sim 0.5\ GeV^2/fm$

$q_g \sim 1\ GeV^2/fm$

Length is about 2fm at RHIC, thus qL ~1-2 GeV^2

Thus we need a $Q^2 \sim 10 - 20\ GeV^2$

If we want the jet to emit once in this region then

Formation time ~ $$\frac{E}{Q^2} \sim 1fm = 5GeV^{-1}$$

$$\Rightarrow E \sim 50 - 100GeV$$

At LHC, length of region is like 1fm, then qL ~0.5-1 GeV^2

thus for a $Q^2 \sim 5 - 10\ GeV^2$, need E ~ 25 - 50 GeV

Virtuality driven MCs

These are very hand wavy estimates

However, we now have the technology to
test these with virtuality driven MC on a medium
with a bump in $\hat{q}$

Results will appear soon!