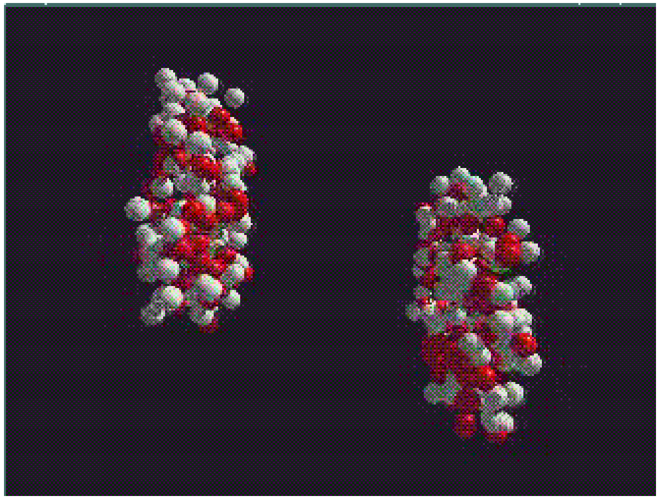
Heavy Ion Physics

Short overview by Urs for TH retreat
4 Nov 2010, Thoiry



How do collective phenomena and macroscopic properties of matter emerge from fundamental interactions?

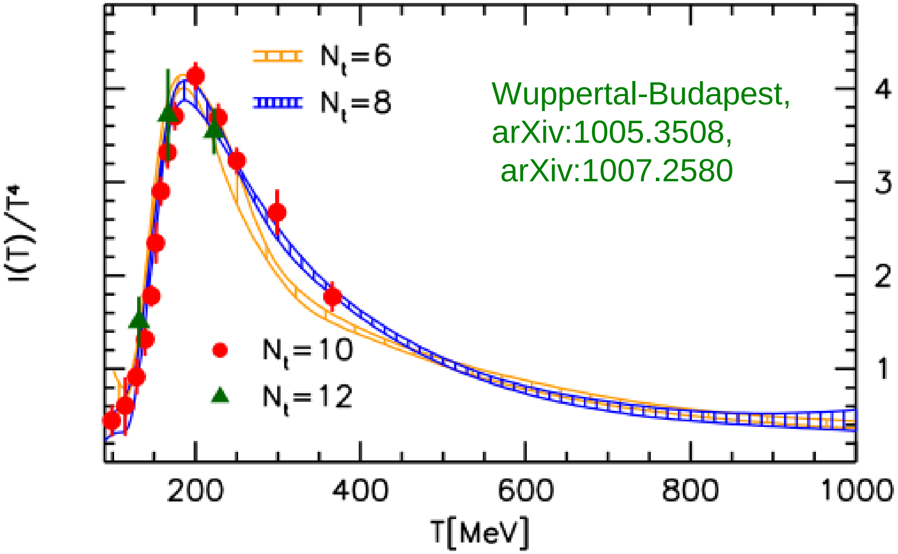
QCD @ high temperature / density

Aim: calculate from 1st principles properties of QCD plasma

- Equation of state
- Transport coefficients (viscosities, conductivities)
- Susceptibilities
- Relaxation times
- …

Tools:

- Lattice QCD at finite T $\quad \varepsilon_c \approx (3-5)\, \varepsilon^{cold}_{nuclear \quad matter}$



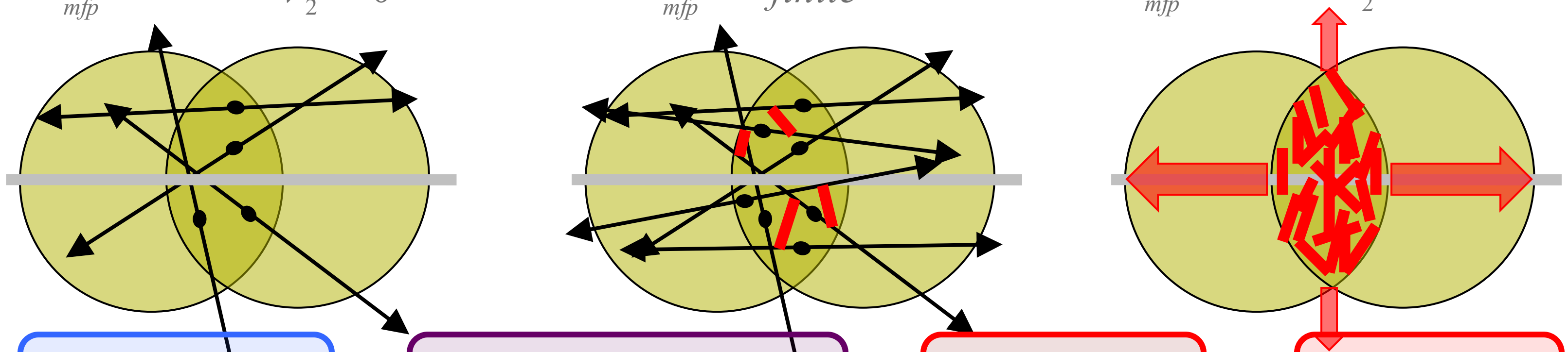
- Finite temperature perturbation theory (for T >> T_c)

- AdS/CFT correspondence to study properties of non-abelian plasmas (not really QCD, but provides generic insight)

Heavy Ion Phenomenology: bulk evolution

Mean free path vs. collectivity

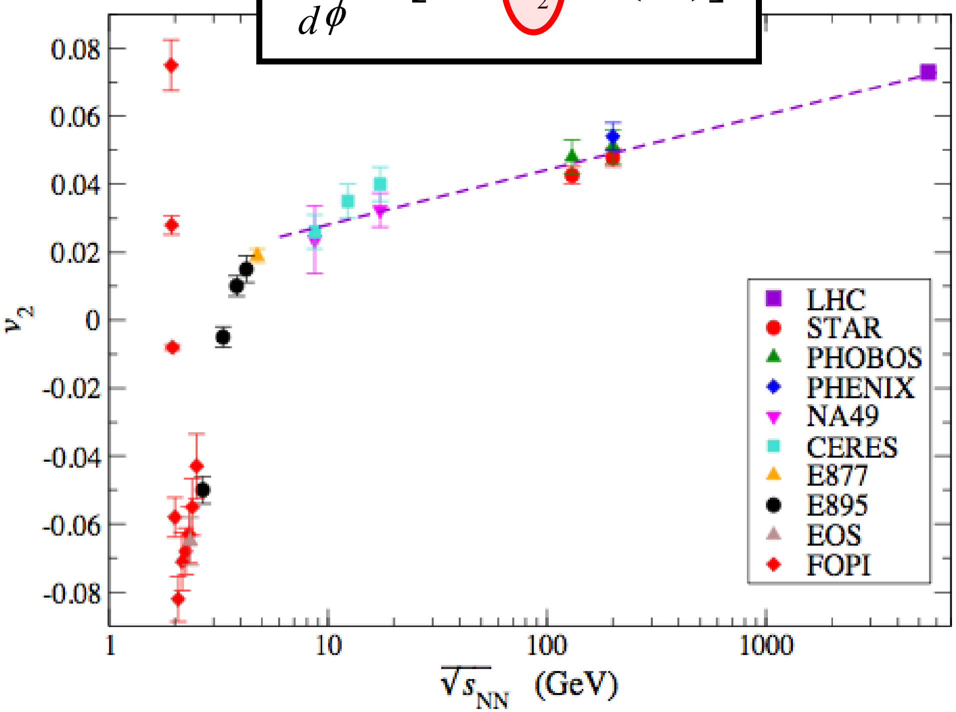
$\lambda_{mfp} \approx \infty \Rightarrow v_2 = 0$ | $\lambda_{mfp} \approx finite$ | $\lambda_{mfp} \approx 0 \Rightarrow v_2 = \max$

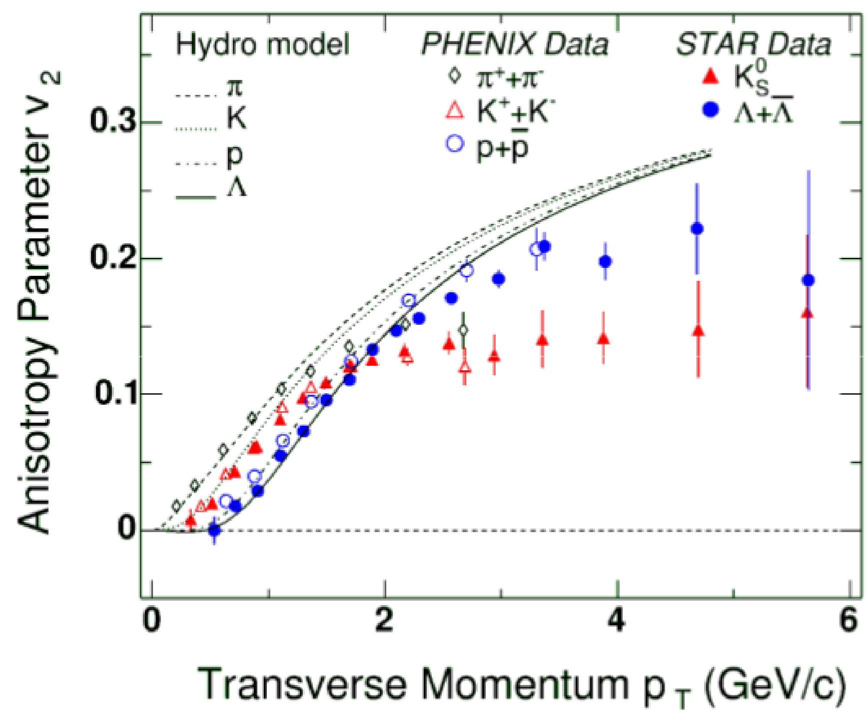


Theory tools:

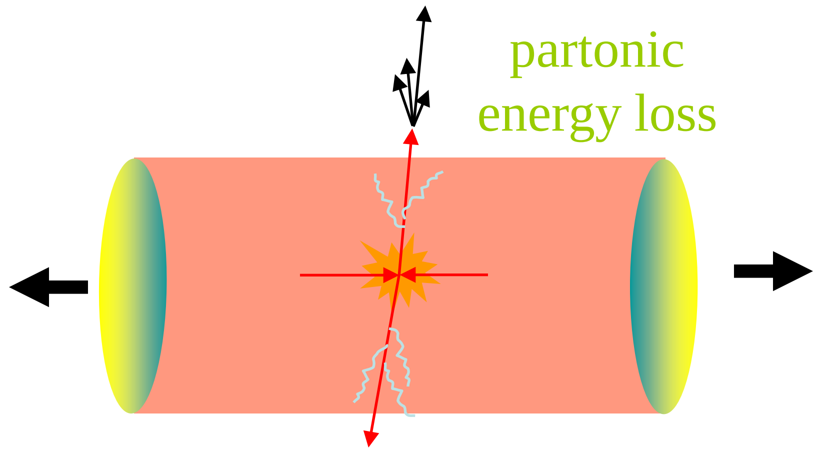
Free streaming → Particle cascade (QCD transport theory) → Dissipative fluid dynamics → Perfect fluid dynamics

$$\frac{dN}{d\phi} \propto \left[1 + 2 v_2 \cos(2\phi)\right]$$



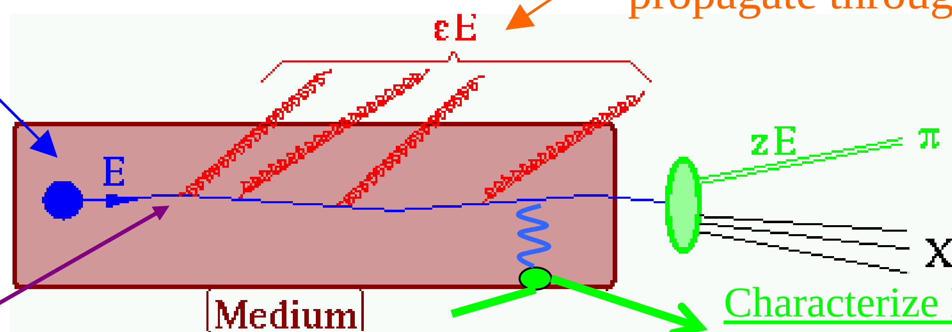


Hard Probes in Heavy Ion Collision



How does this parton thermalize?

How does this radiation fragment/ propagate through the medium?

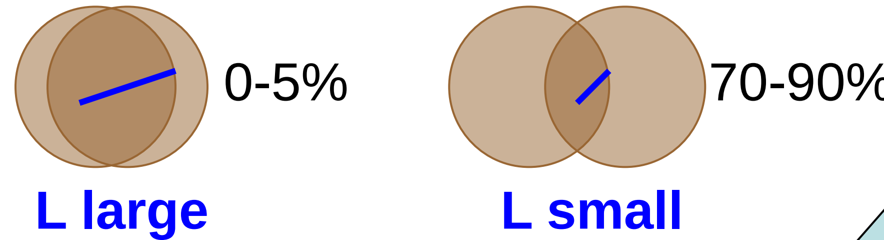


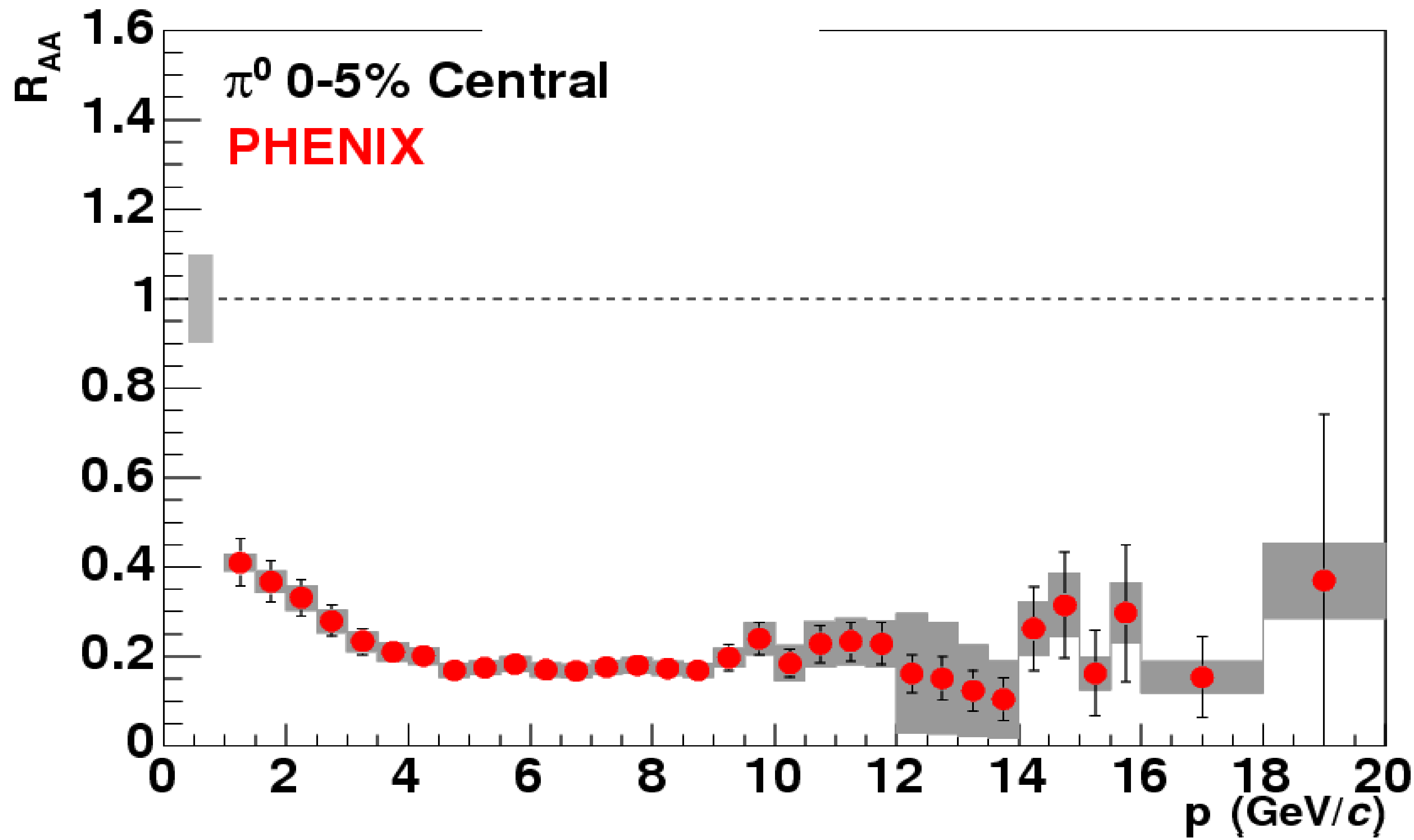
What is the dependence on parton identity?

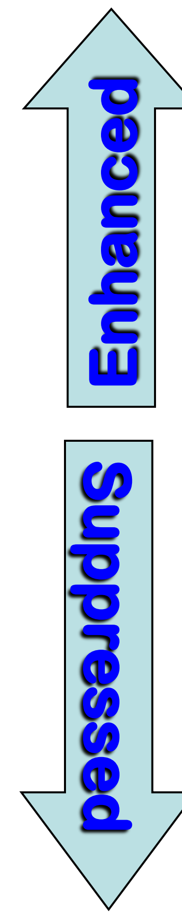
Characterize Recoil: What is kicked in the medium?

“Jet Quenching” at RHIC

$$R_{AA}(p_T,\eta) = \frac{dN^{AA}/dp_T\,d\eta}{n_{coll}\ dN^{NN}/dp_T\,d\eta}$$

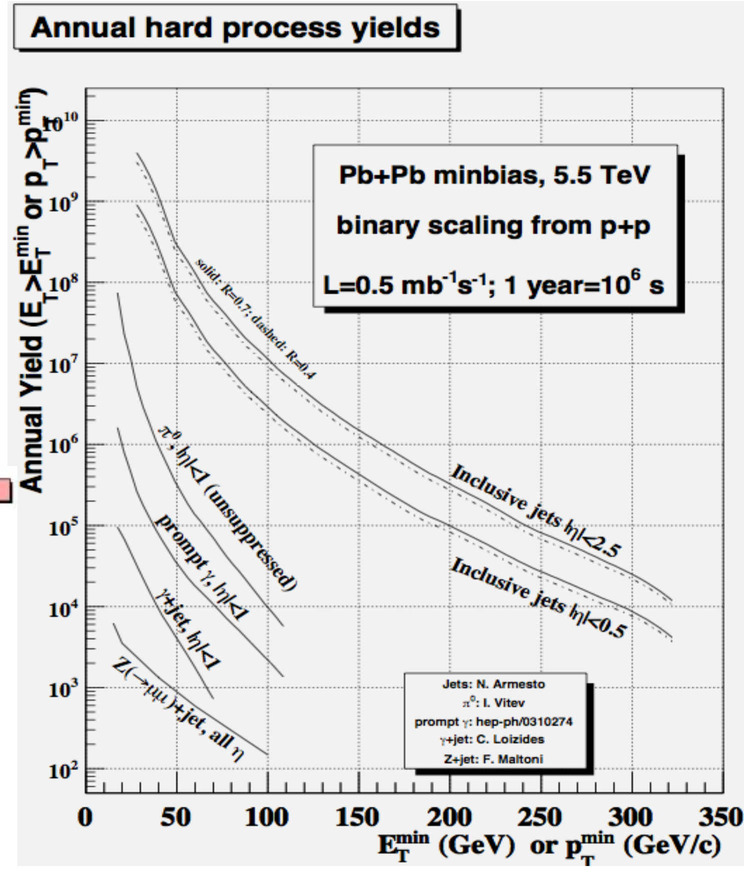




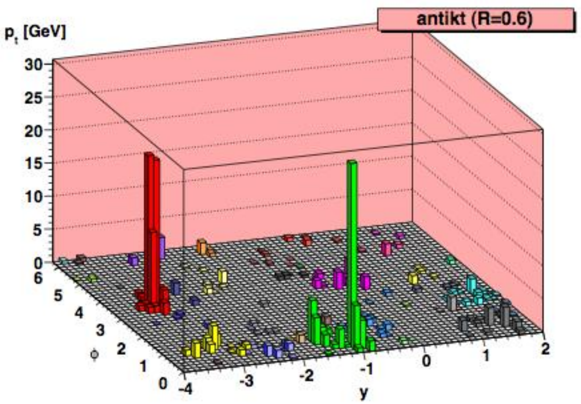


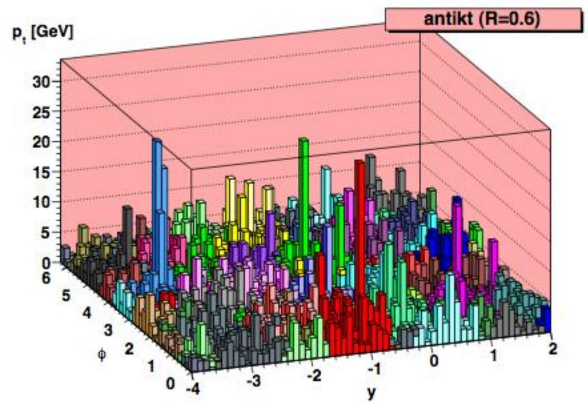
TH Challenges for Hard Probes @ LHC

Abundant yield of hard processes
+ robust signal
(medium sensitivity >> uncertainties)
= detailed understanding

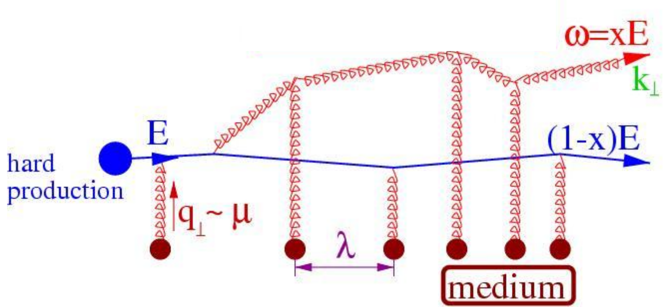


How to find jets in HICs?



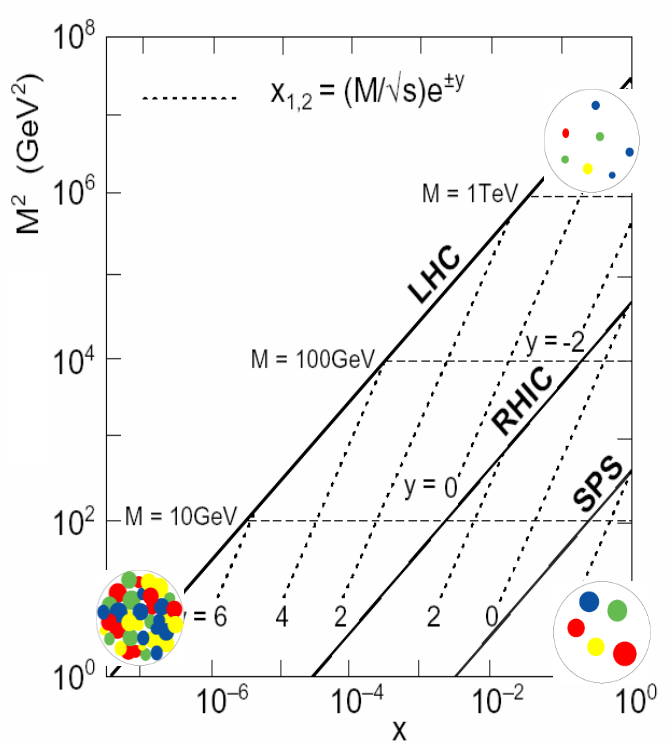


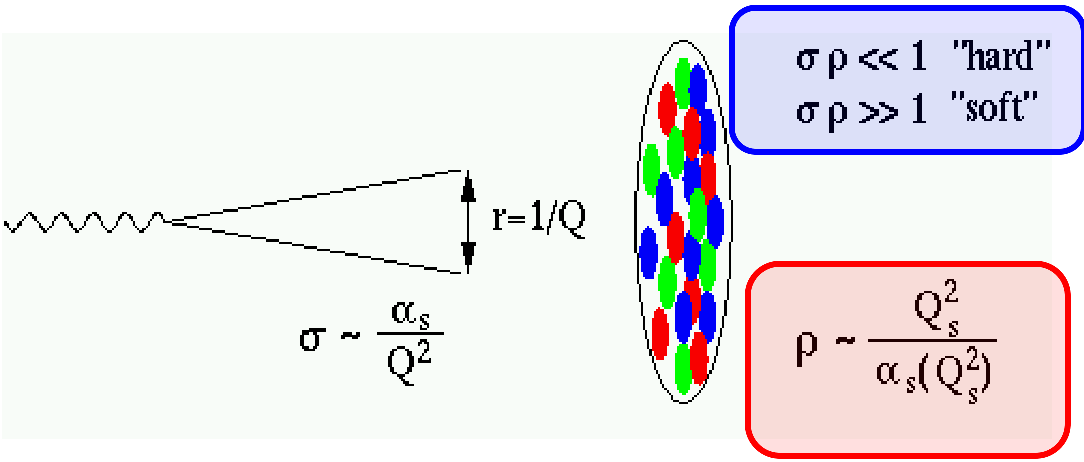
Medium-induced modifications of jets: theory tools



- How to interface 'standard' description of hard processes with medium effects?
- Non-abelian LPM-effect, MC implementation?

QCD @ high parton density





At high $\sqrt{s_{NN}}$, standard distinction between **hard** and **soft** breaks down:

- At small-x, parton densities $\rho \sim Q_s^2/\alpha_s(Q_s^2)$ are **saturated**

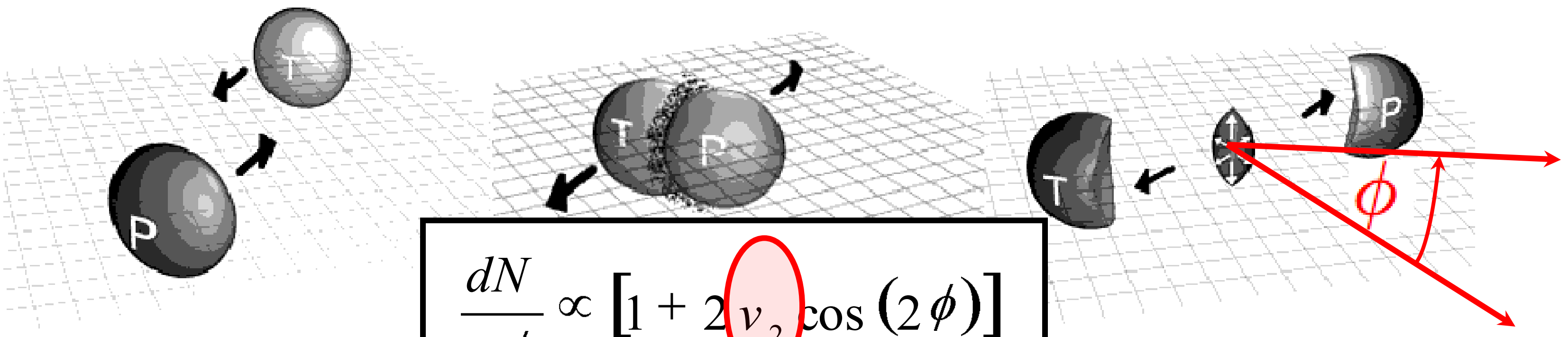
  up to large scales $Q^2 < Q_{sat}^2(\sqrt{s})$ $\qquad Q_{sat}^{2\ A} \approx \boxed{A^{1/3}}\, Q_{sat}^{2\ p}$

- Coupling constant is small $\boxed{\alpha_s(Q_{sat}^2(x) \gg \Lambda_{QCD})}$

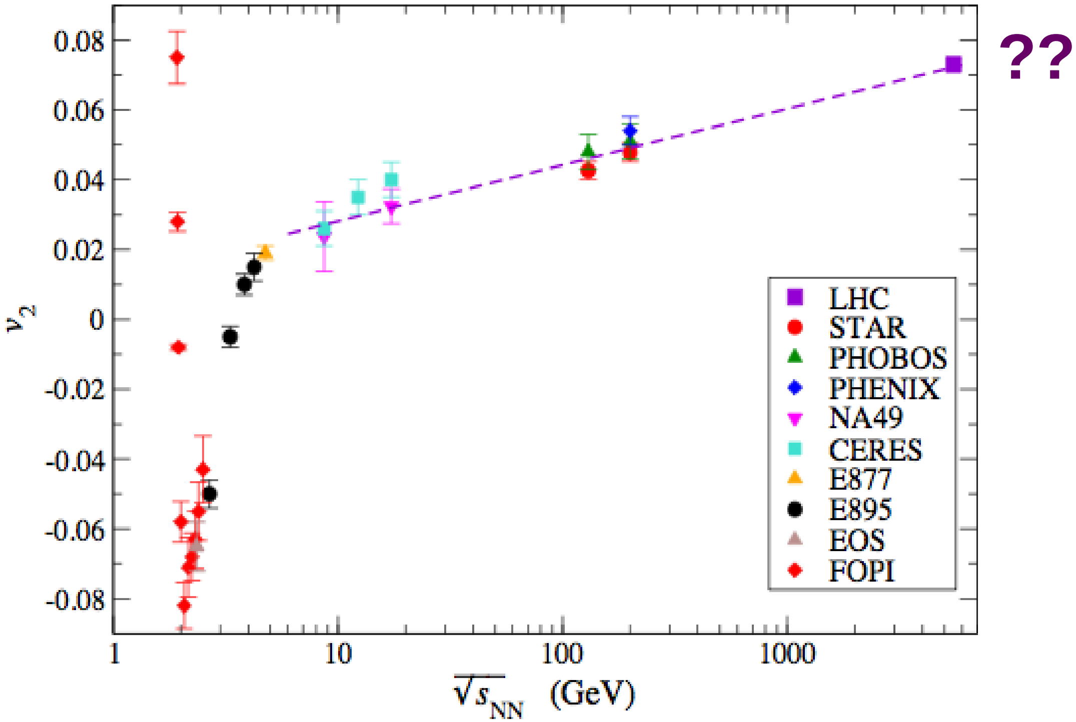
⇨ Non-linear QCD evolution in perturbative regime.

BACK-UP

I. Elliptic Flow:
Hallmark of a collective phenomenon

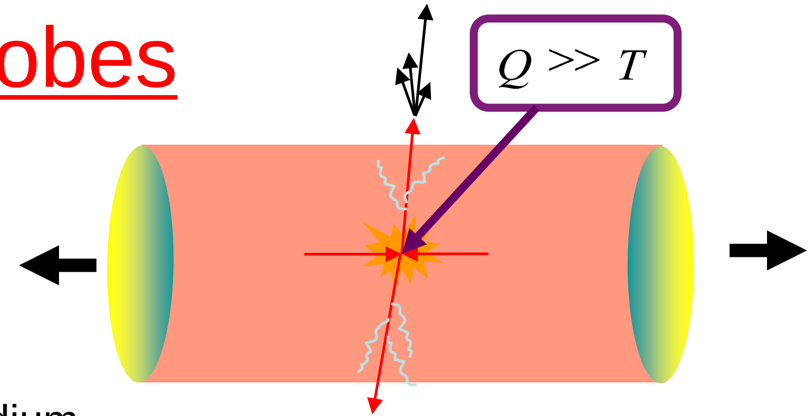


$$\frac{dN}{d\phi} \propto [1 + 2 v_2 \cos(2\phi)]$$

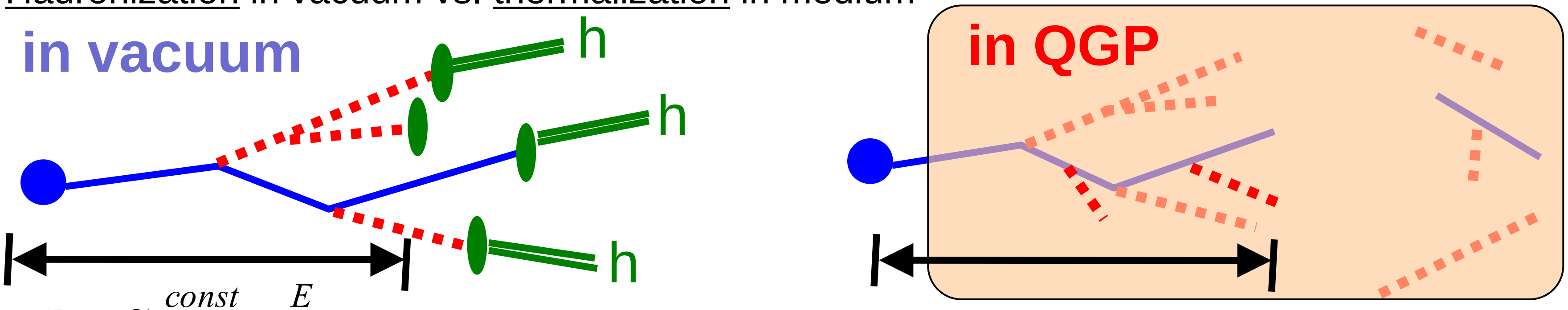


II. Hard Probes

• In Pb+Pb @ LHC embed hard processes in dense nuclear environment

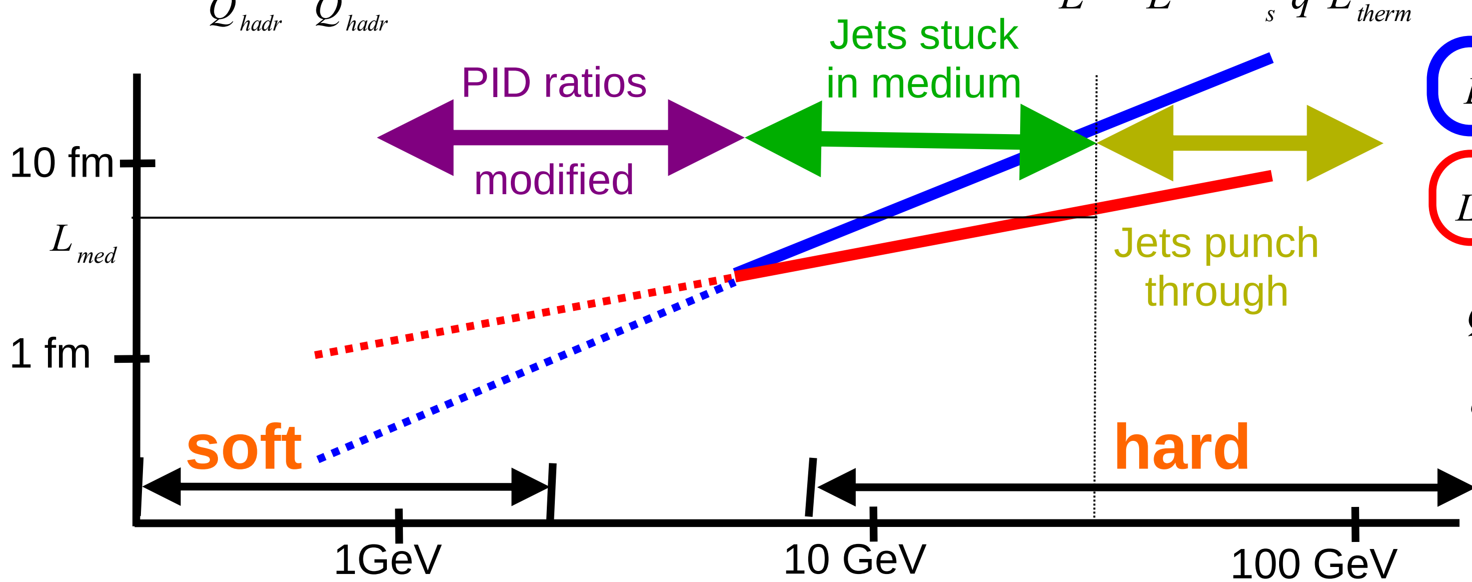


• Hadronization in vacuum vs. thermalization in medium



$$L_{hadr} \cong \frac{const}{Q_{hadr}} \frac{E}{Q_{hadr}}$$

$$\Delta E \equiv E \approx \alpha_s \hat{q} L^2_{therm}$$



$L_{hadr} \propto E / Q^2_{hadr}$

$L_{therm} \propto \sqrt{E/\hat{q}}$

$Q_{hadr} \approx 1\ GeV$

$\hat{q} \approx 10\ GeV^2 / fm$