Jet Medium Interaction

Guang-You Qin

Wayne State University

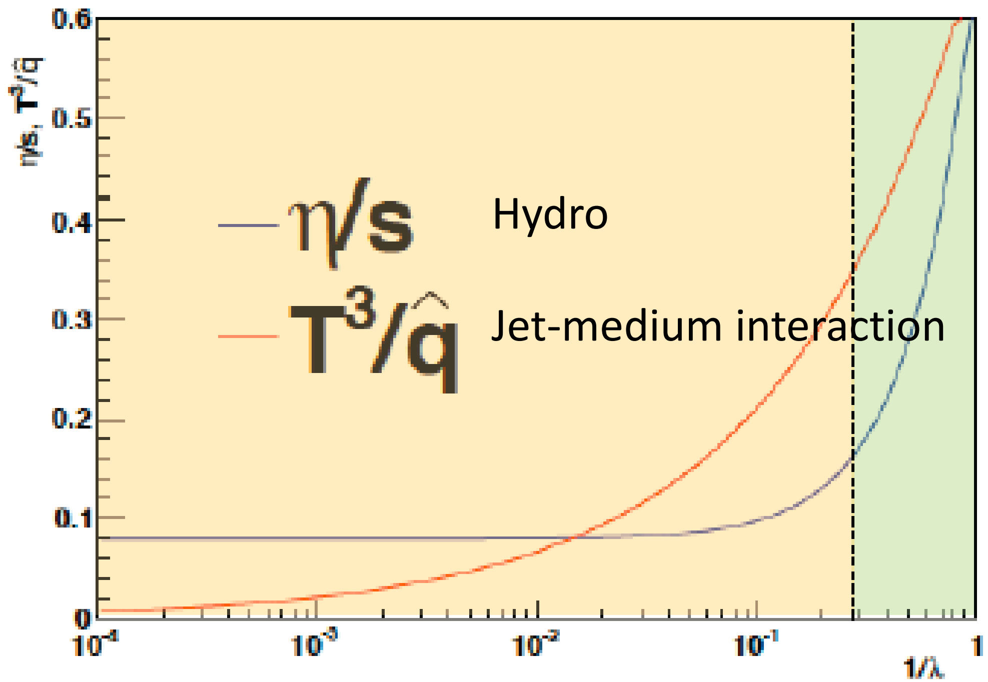
2nd workshop on jet modification in the LHC & RHIC era

August 20-22, 2013

Outline

- Jet-medium interaction: running from RHIC to LHC
- Multiple emissions
- Energy loss from jet cone
- Medium modification of jet profile
- Medium response to jet transport

Probing QGP via jet-medium interaction



At weak coupling

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

At strong coupling

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

Majumder, Muller, Wang, PRL 2007

Jet-medium interaction & jet (correlation) observables might allow to probe both (jet energy loss & medium response)

From RHIC to LHC

- **The medium coupling & jet-medium interaction at the LHC are weaker than at RHIC**
  - **Both medium & jets are different (separate two?)**
  - **Running couplings (jet-medium coupling, the coupling among medium constituents)**
  - **Jet transport coefficients running? Big or small effect?**

- **Collisional component of energy loss not important for R_{AA}? How about heavy flavors, full jets, medium response?**
  - **Relative contribution from radiative and collisional (transverse & longitudinal) components**

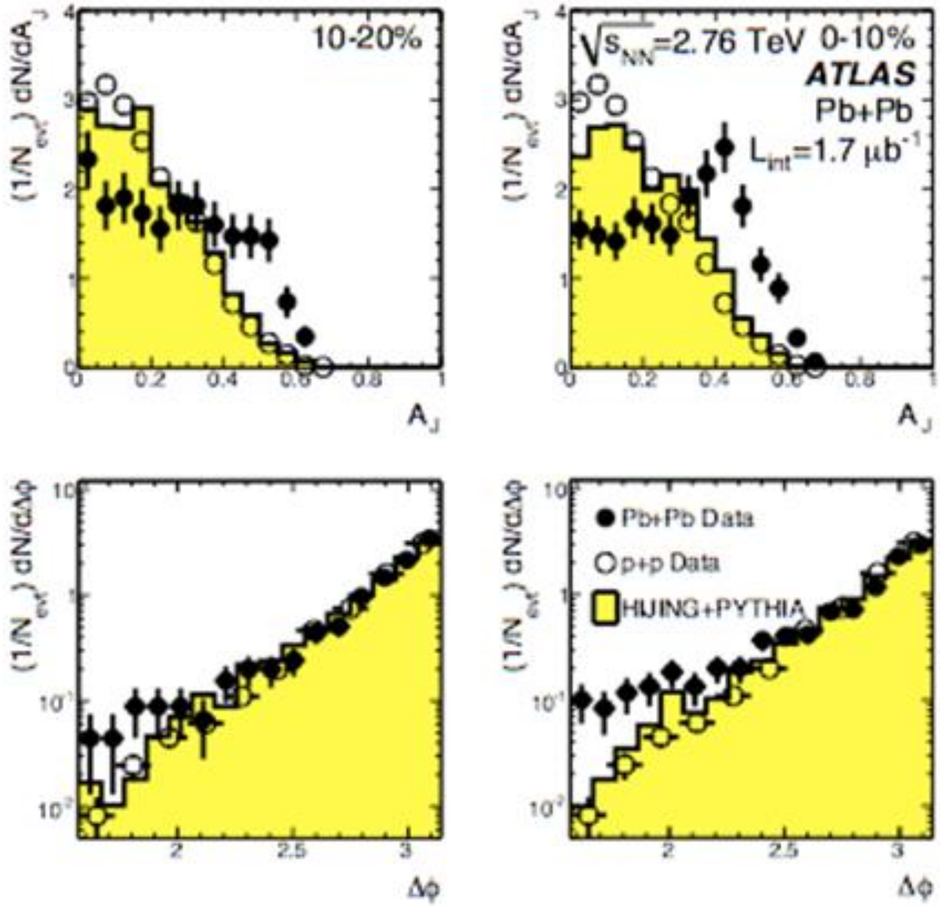
Multiple emissions: strongly-ordered vs. independent

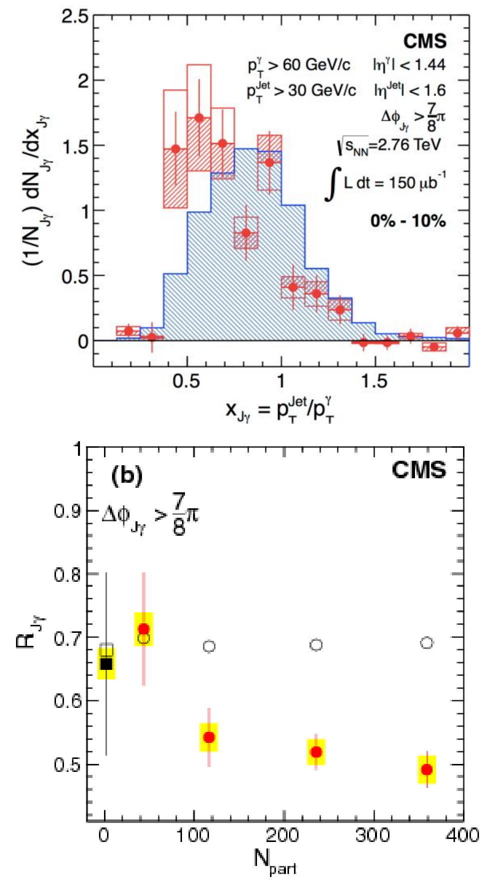
- **Vacuum is better understood**
  - Angular ordering due to strong interference effect

- **Are multiple emissions in medium are strongly ordered or independent?**
  - Coherence is lost and interference effect is suppressed, due to the scatterings of medium constituents (Mehtar-Tani, Salgado, Tywoniuk, PLB 2012, Blazot, Dominguez, Iancu, Mehtar-Tani, JHEP 2013)

- **How different between these two scenarios (observables)?**
  - Medium-modified DGLAP equation vs. rate equation

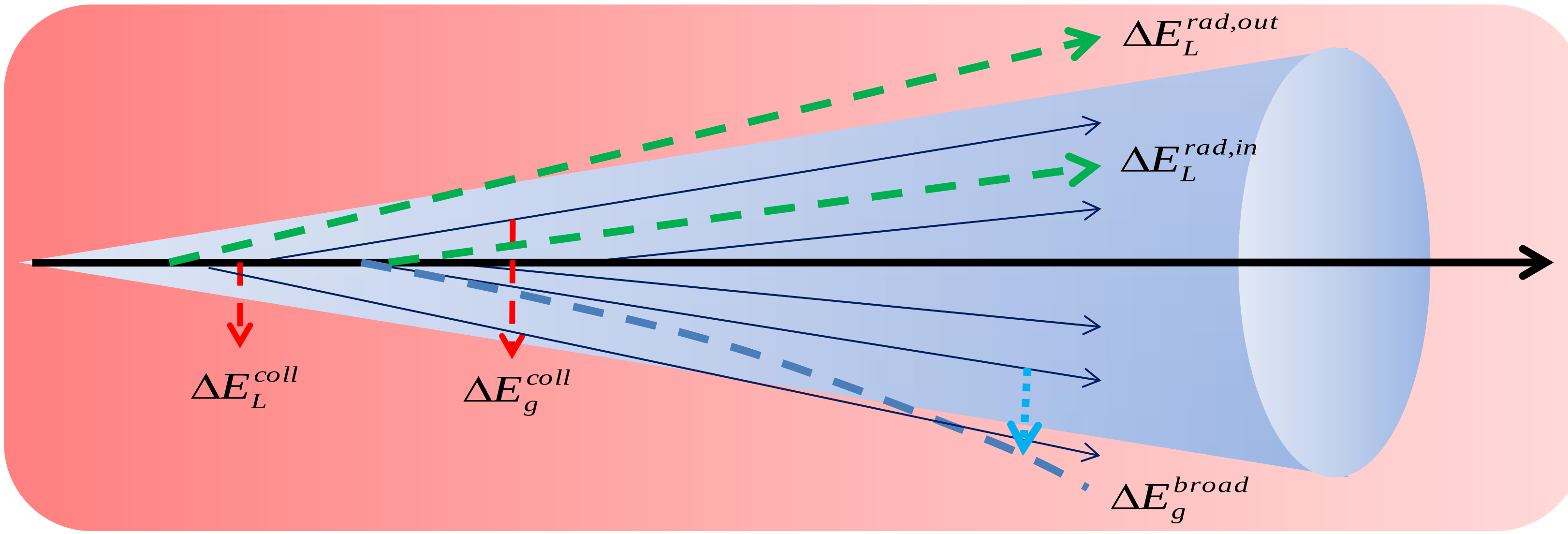
Full jets: radiative, collisional, broadening, flow…?





What are the main mechanisms for the energy loss from jet cone?

Jet shower evolution in medium

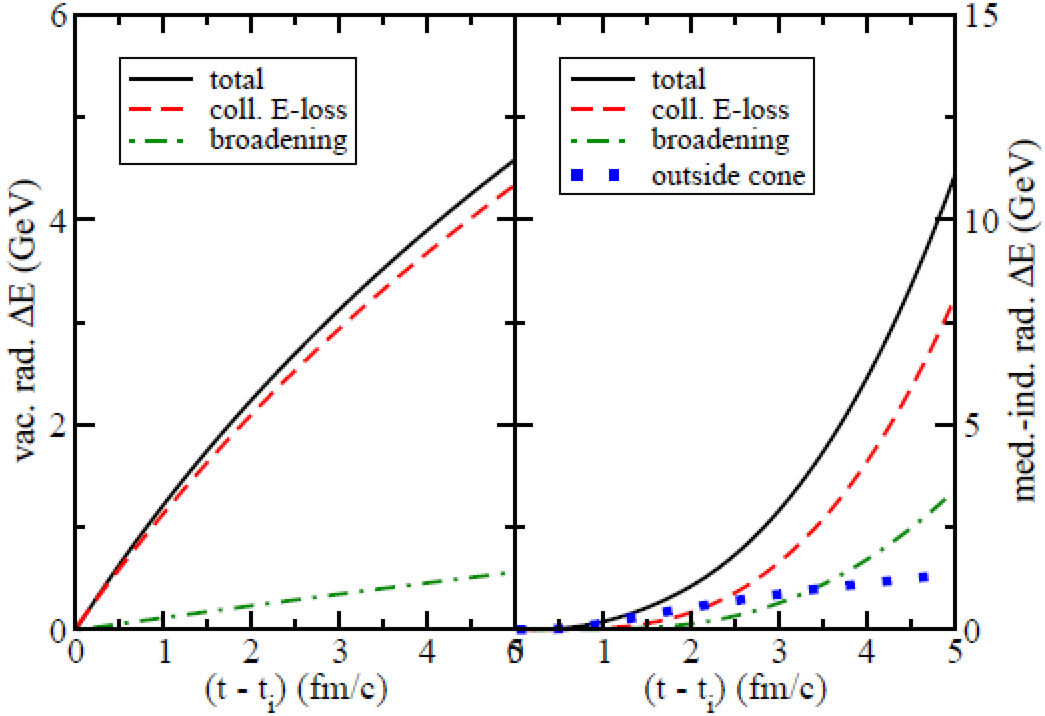


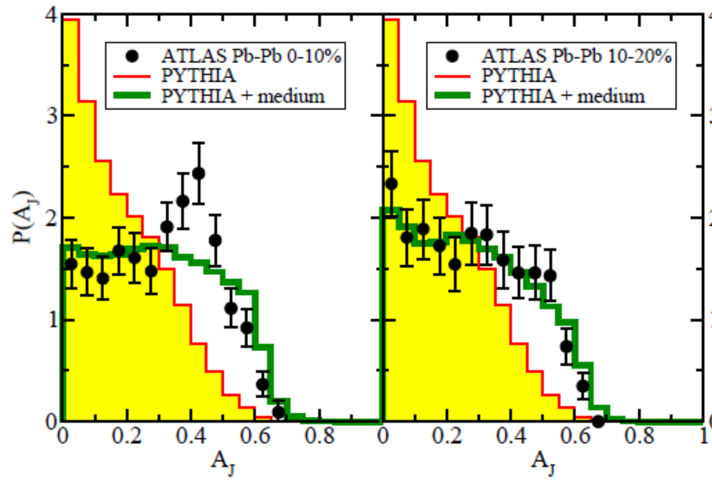
$$\frac{df_g(\omega, k_\perp^2, t)}{dt} = \hat{e}\,\frac{\partial f_g}{\partial \omega} + \frac{1}{4}\,\hat{q}\nabla^2_{k_\perp} f_g + \frac{dN_g^{med}}{d\omega dk_\perp^2 dt}$$

$E_{tot} = E_{in} + E_{lost}$
$= E_{in}$ (emission)+ E_{out}(emission) + E_{out}(broadening) + E_{coll}(thermalization)

GYQ and Muller, PRL 2011, arXiv: 1012.5280

Jet cone energy loss & dijet asymmetry



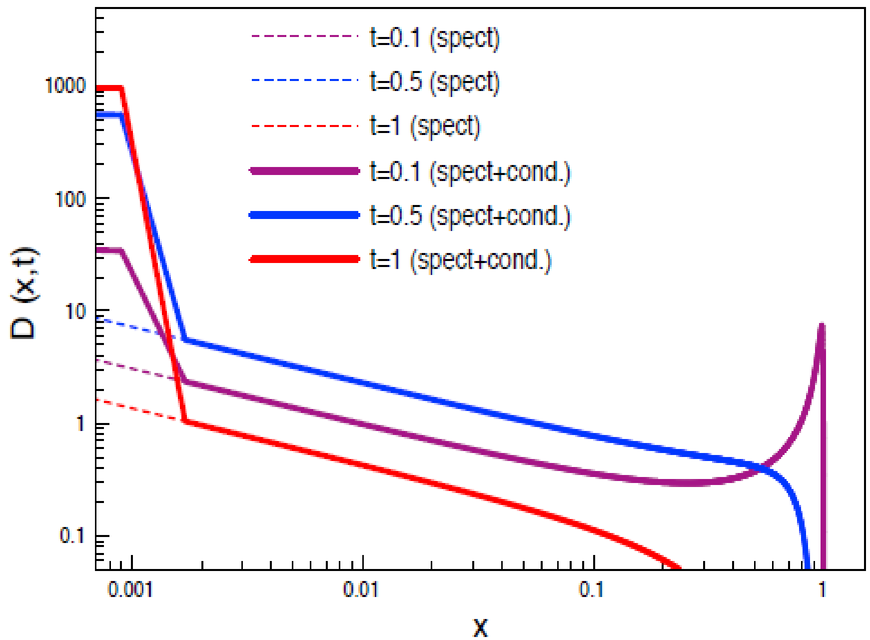


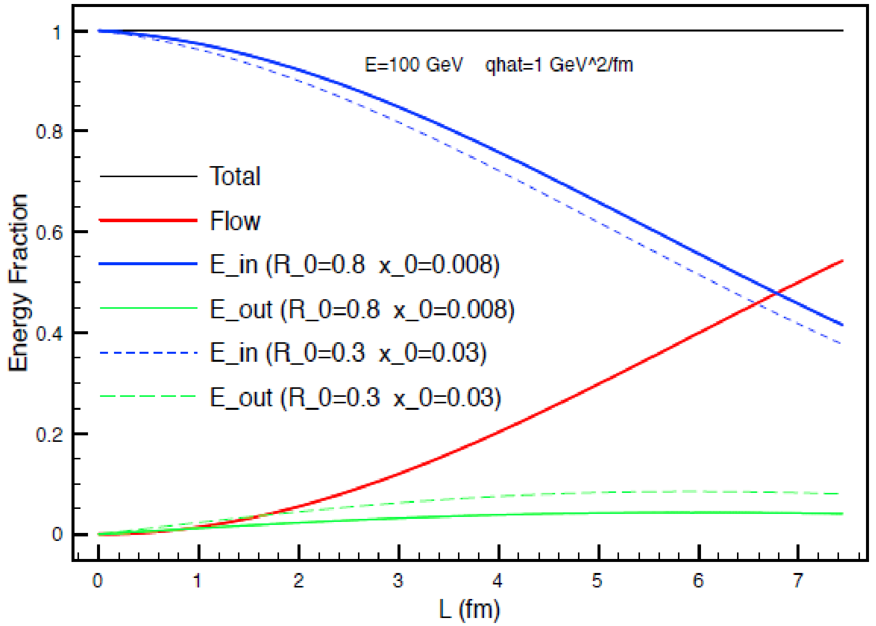
GYQ and Muller, PRL 2011, arXiv: 1012.5280

E_{tot} = E_{in} + E_{lost}
= E_{in} (emission)+ E_{out}(emission) + E_{out}(broadening) + E_{coll}(thermalization)

***Changing** E_0=2**GeV to E_0=1GeV produces -20% q^{hat} change for describing the data.**

Radiation, energy flow, condensate, …





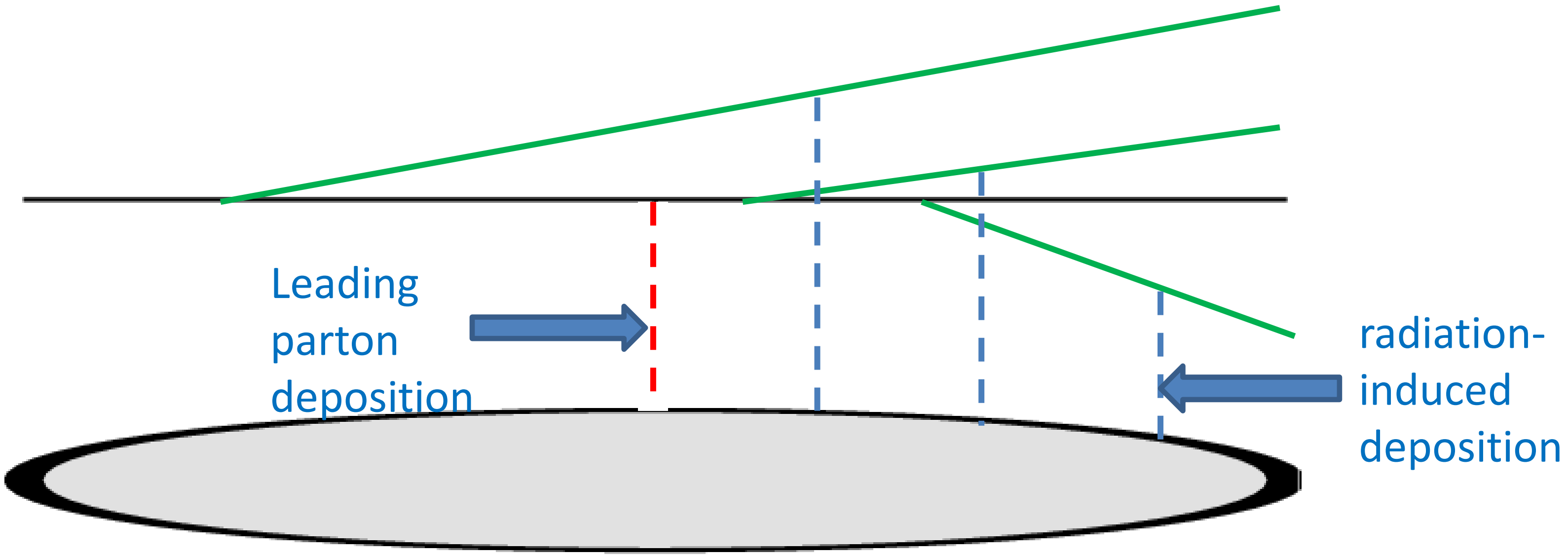
Three different phase spaces for radiative gluons separated by two scales: x_0 & x_{th}

$$E_{tot} = E_{in}\,(x>x_0) + E_{out}(x_{th}<x<x_0) + E_{flow}$$

E_{flow} independent of jet cone & temperature …

Blaizot, Iancu and Mehtar-Tani, arXiv:1301.6102

Energy deposition: leading parton vs. jet shower

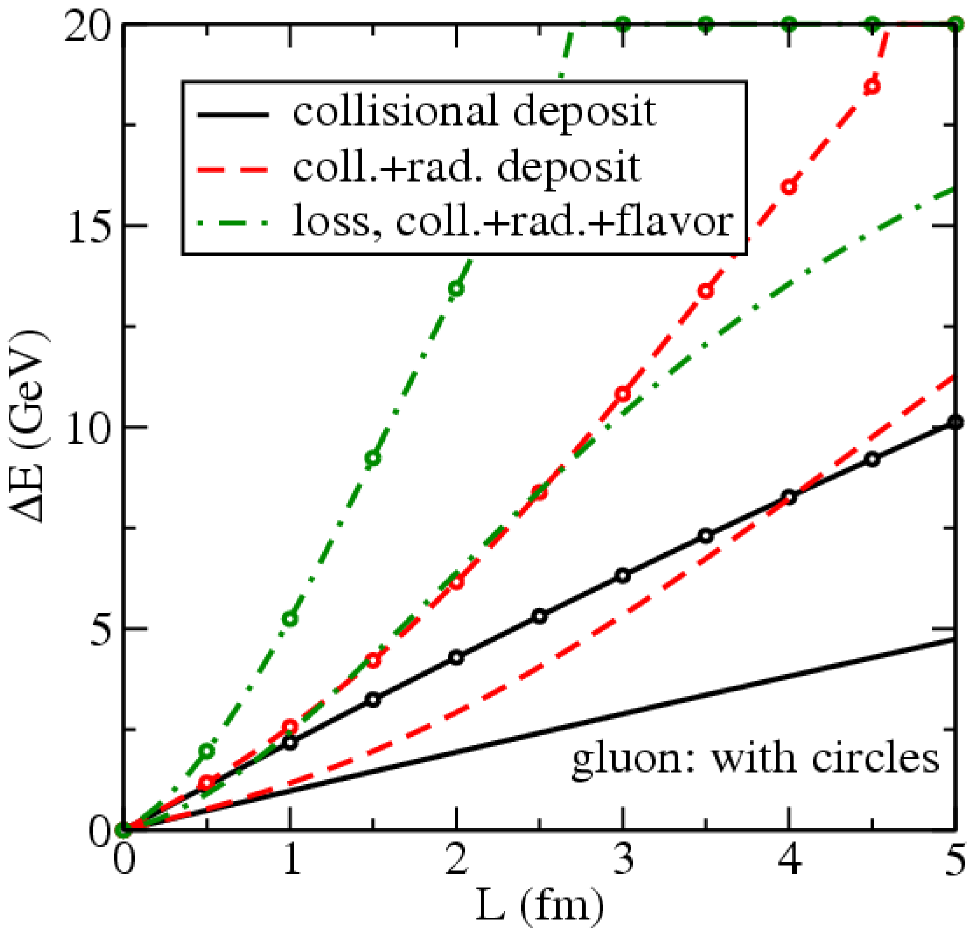


GYQ, Majumder, Song, Heinz, PRL (2009)

$$\frac{d\Delta E_q(E,Q^2)_{\zeta_i}^{\zeta_f}}{d\ln Q^2} = \frac{\alpha_s}{2\pi}\int dy \int_{\zeta_i}^{\zeta_f} d\zeta \tilde{P}_{q\to qg}(y,\zeta,Q^2,E) \left[\Delta E_q(E,Q^2)_{\zeta_i}^{\zeta} + \Delta E_q(yE,Q^2)_{\zeta}^{\zeta_f} + \Delta E_g((1-y)E,Q^2)_{\zeta}^{\zeta_f}\right]$$

Similar evolution equations for momentum deposition!

Energy deposition: leading parton vs. jet shower



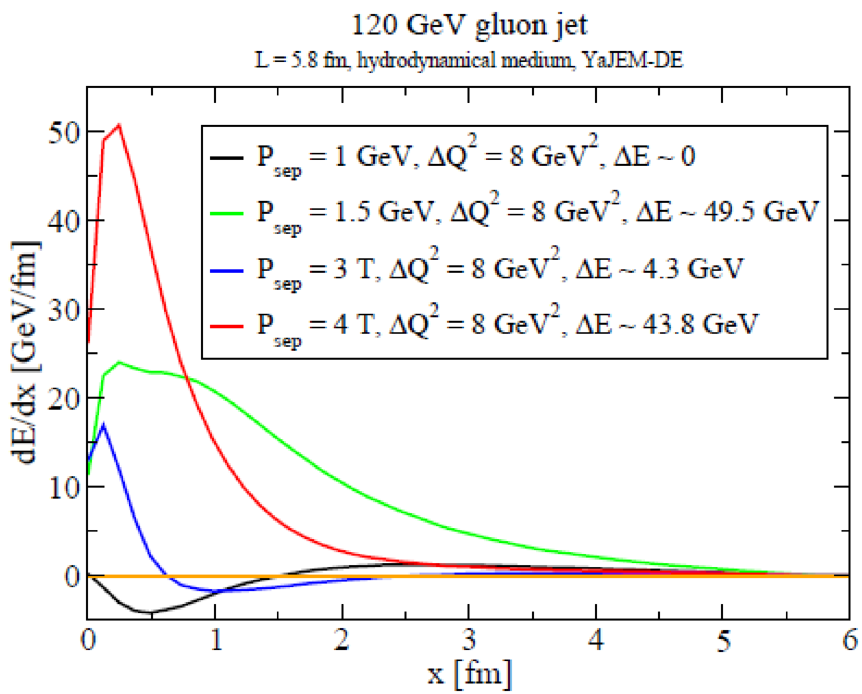
Use HTL result as input at scale μ_0=4T

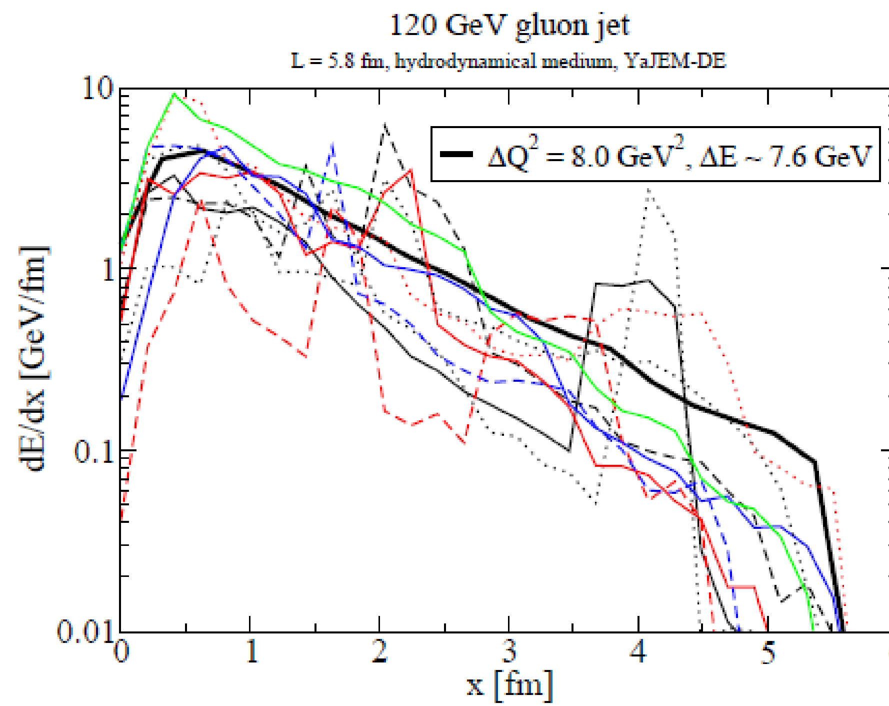
$$\frac{d\Delta E(\mu_0, E)}{d\zeta} = \frac{C_R \alpha_s(\mu_0^2) m_D^2}{4} \ln\left[\frac{4ET}{m_D^2}\right]$$

***Energy/momentum deposition* by a jet shower is much enhanced with the inclusion of shower partons**

GYQ, Majumder, Song, Heinz, PRL (2009)
Similar results from Neufeld, Muller, PRL (2009)

Energy deposition





Different separation scales lead to different energy deposition profiles

Event-by-event energy deposition in an expanding & cooling medium

T. Renk, arXiv: 1306.2739

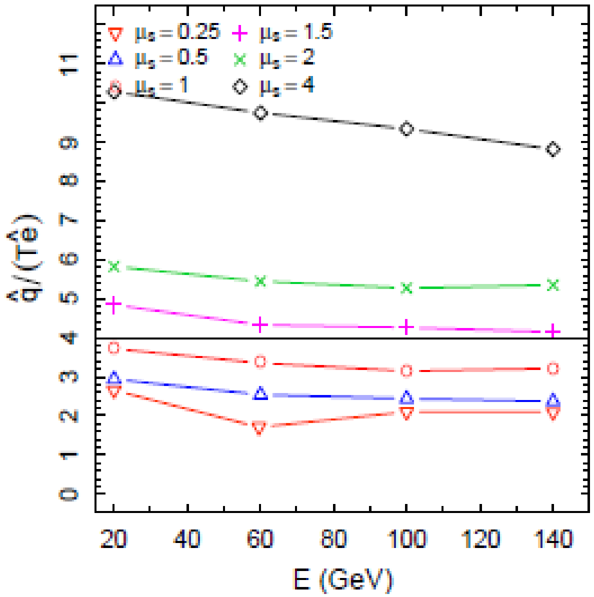
Energy loss from full jets

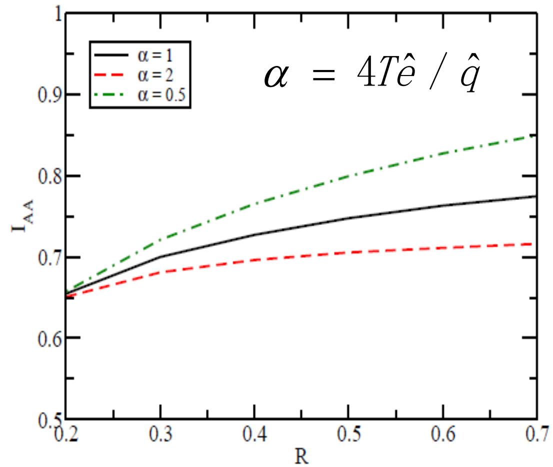
- **Jet cone energy loss is different from leading parton energy loss**
  - **Radiative components (relatively soft) vs. leading parton (hard)**
  - **Radiation: high energy (z) vs. low energy (z), small angle vs. large angle**
  - ***Radiative, collisional, broadening*, deposition, thermalization, energy flow, condensate, turbulent flow**

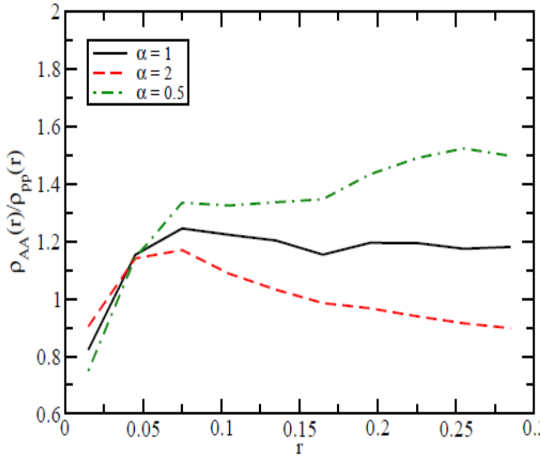
- ***What are relevant (separation) scales, parameters? How to choose/determine them, e.g., x_0 , x_{th}, or E_0, E_{sep}? Are they intrinsic properties of the medium that jets probe? The dependence of observables on these scales?***

- **Can we distinguish different mechanisms?**
  - **The relative importance of different mechanisms are controlled by parameters in the model**

Jet transport coefficients







GYQ, arXiv: 1210.6610

Coleman-Smith, Muller, arXiv: 1209.3329

They probe medium structure & might be calculated from LQCD

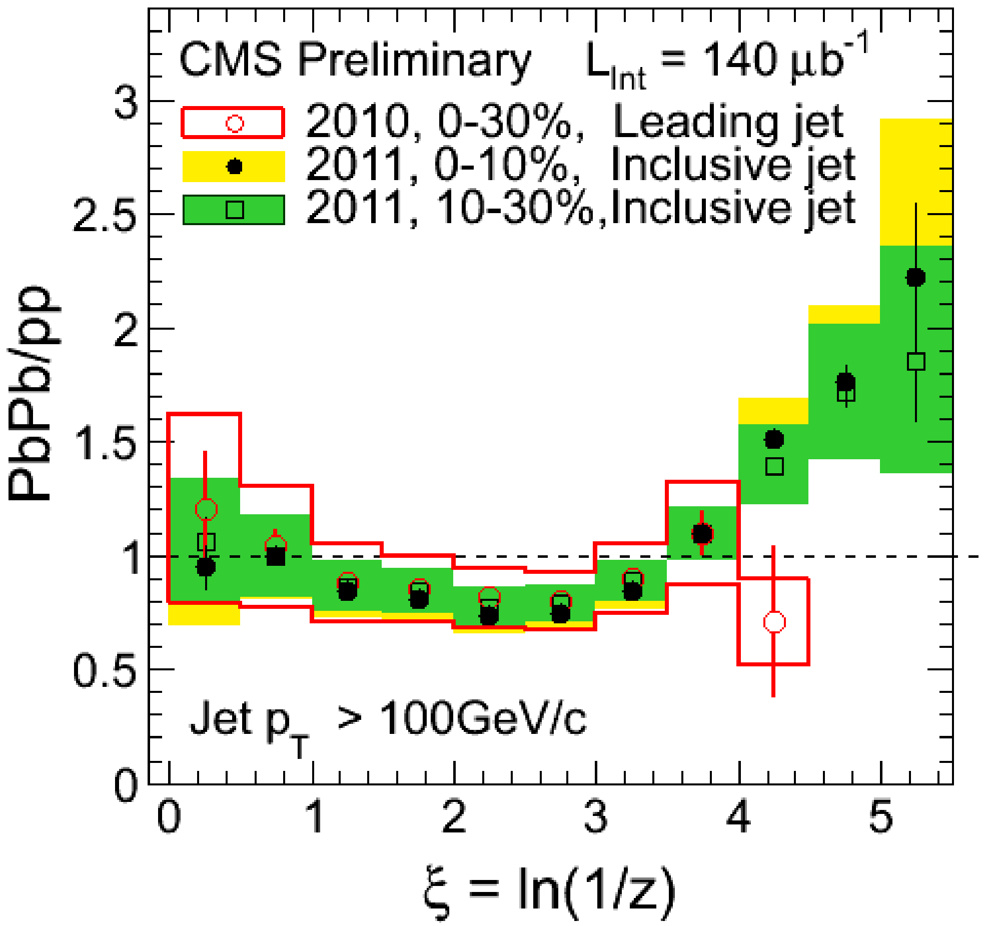
The relative sizes of longitudinal and transverse jet transport coefficients could reflect the masses of medium constituents.

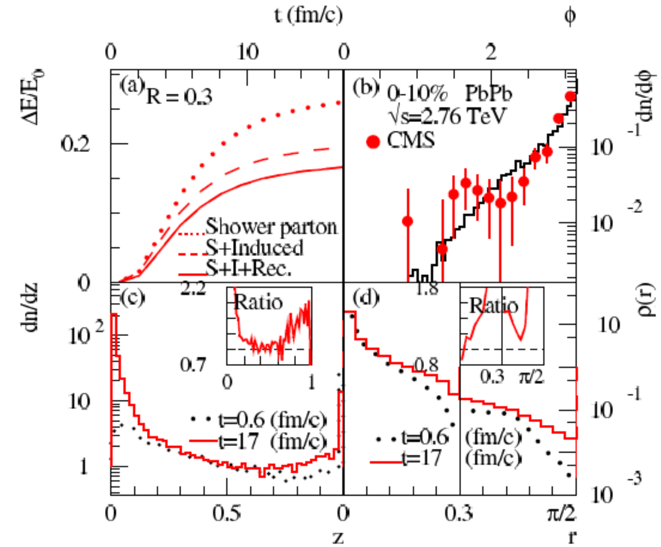
Other relevant coefficients than q^{hat} & e^{hat}? What else they can tell?

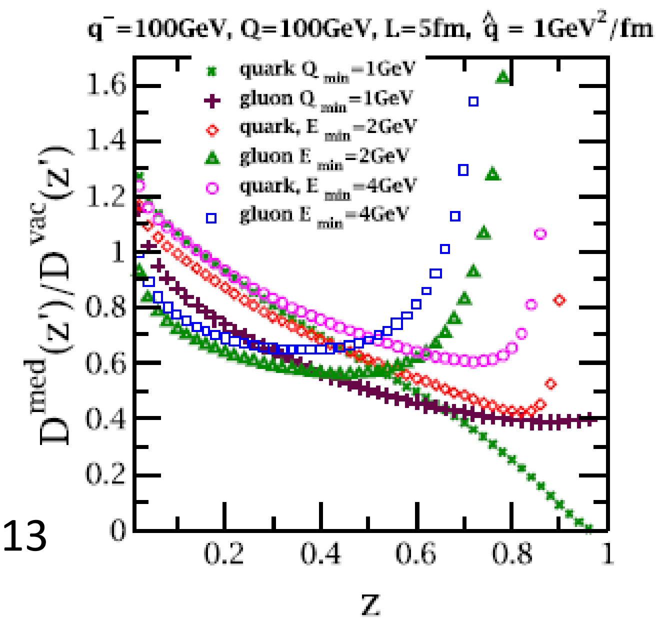
May be reflected in the jet cone size dependence and jet shape/profile.

Other observables sensitive to them? Heavy flavors? Final state correlations?

Medium modification of jet profiles







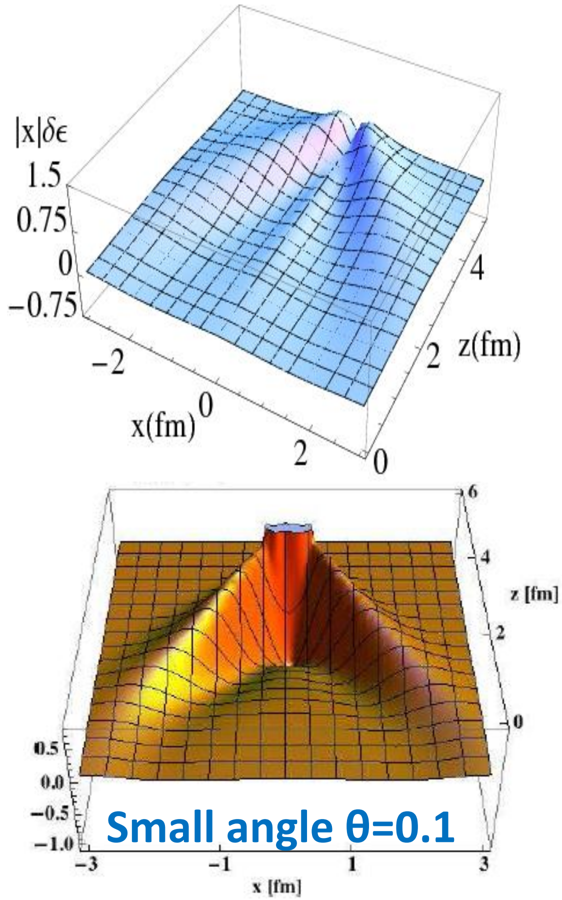
Wang, Zhu, arXiv: 1302.5874; Majumder, PRC, 2013

Medium modification of jet profiles

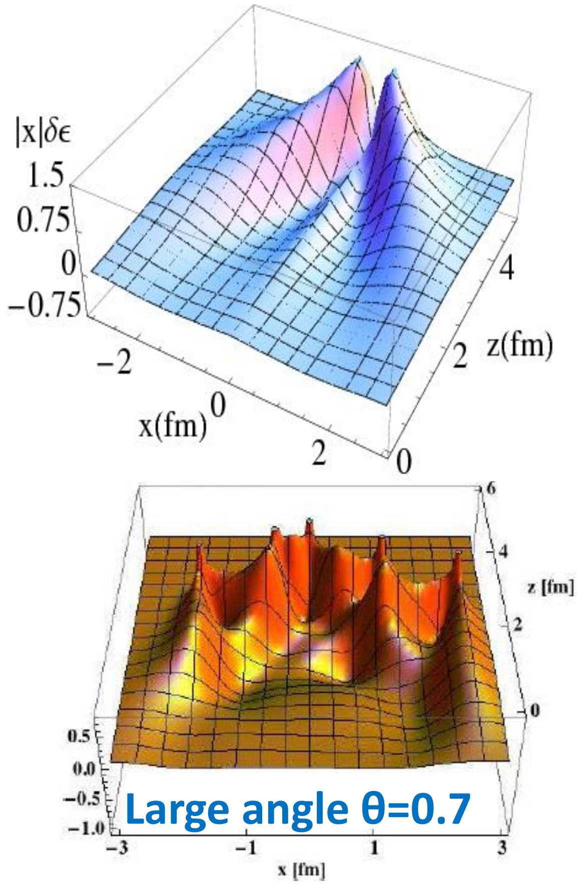
- **Enhancement at small z and the suppression at intermediate z**
- **Enhancement or no modification at z=1?**
- **How does the hadronization affect the final jet profiles?**
- **Which observables are not sensitive to hadronization?**
  - **jet total energy observables (dijet A_J asymmetry, gamma-jet asymmetry, jet R_{AA})**
  - **transverse profiles**
  - **longitudinal profiles**
  - **correlations**

Medium response to jet transport

Primary parton



Parton shower



GYQ, Majumder, Song, Heinz, PRL 2009; Neufeld, Vitev, PRC 2012

Medium response to jet transport

- **Mach cone from jet-medium interaction? Can we detect it?**

- **Correct energy/momentum deposition profiles**
  - **Both energy and momentum components**
  - **Both leading partons and radiated showers**
  - **Complete 1+3D space-time deposition information**
  - **Realistic expanding/cooling medium**

- **Do the deposited energy/momentum (recoiled partons) thermalize?**
  - **Diffuse into the medium or show up in the jet cone?**
  - **How to separate them (biased jets, final state correlations)?**

- **Jets + hydro vs. parton cascade?**
  - **Recoiled partons in PCM vs. source term in hydro**
  - **Simulate jet in-medium evolution and medium response simultaneously**