Quenching of light hadrons at RHIC
In
a collisional energy loss scenario

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Plan

- Motivation
- Present status of collisional energy loss
- Our formalism
  - Energy loss
  - Nuclear modification factor
- Results
- Discusson

Motivation

- Non-photonic electron data shows much larger suppression than expected
- These data reflect the energy loss of heavy quarks
- Mainly radiative loss has been discussed in the literature : dead cone effect => less energy loss => less suppression of the decay product coming from heavy quarks
- Radiative energy loss seems to fail to describe the non-photonic single electron data (Wicks et. al, JPG 34, 2007)
- Activities started to re-visit the importance of collisional energy loss for heavy as well as light quarks

Present status of collisional energy loss

1. Peigne et al (JHEP 04, 2006)

Collisional energy loss is suppressed in comparison to infinite medium

2. Djordjevic (PRC 74, 2006)

For characteristic QCD medium scales finite size effects are negligible

3. Wang X.- N. (PLB650, 2007)

Interference between elastic amplitude and that of gluon radiation reduces the effective energy elastic loss

4. Adil et. Al (PRC75 2007)

Similar results for collisional loss as 2

Contd.

5. Dutt-Mazumder et. al (PRD 74 2005)

Below certain energy (Ec) collisional energy loss dominates (details will be shown)

6. Peshier et al. (EPJC 2007), Braun et al. (PRD75 2007)

running coupling constant $\alpha_s = \alpha_s(p, T)$

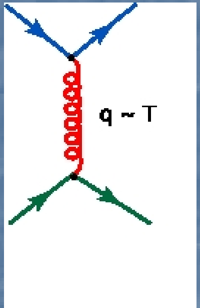
$T \sim 2T_c$, dE/dx ~ 1.6 GeV/fm for a 100 GeV quark

Collisional energy loss is of the same order as radiative loss

Collisional energy loss

$$\frac{dE}{dx} = \frac{1}{v}\int dE'(E - E')\frac{d\Gamma}{dE'}$$

Bjorken



$$\frac{dE}{dx} = \frac{8\pi}{3}\left(1 + \frac{N_f}{6}\right)\alpha_s^2 T^2 \ln\frac{q_{\max}}{q_{\min}}$$

Infra-red divergent

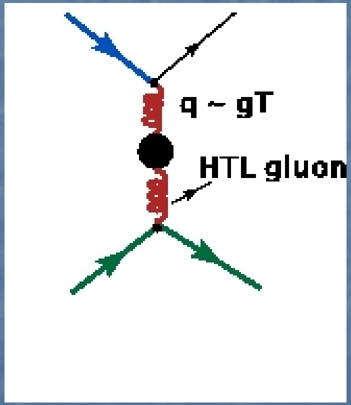
Way out : Shielding of divergent by plasma effects

Sum of two diagrams separated by intermediate scale q* (gT << q* << T)

(i) Soft scale (gT < q < q*) : HTL propagator

(ii) Hard scale (q* < q <T) : bare propagator

Cancellation of arbitrary scale q*



Energy loss contd.

- Consider small angle qq scattering (t-channel)
- Assume energy $E_{jet} >> T$

$$\left(\frac{dE}{dx}\right)_{\rm hard} \sim \alpha_s^2 T^2\, c_{qq} \ln \frac{ET}{q^{*2}}$$

Bare gluon propagator

and

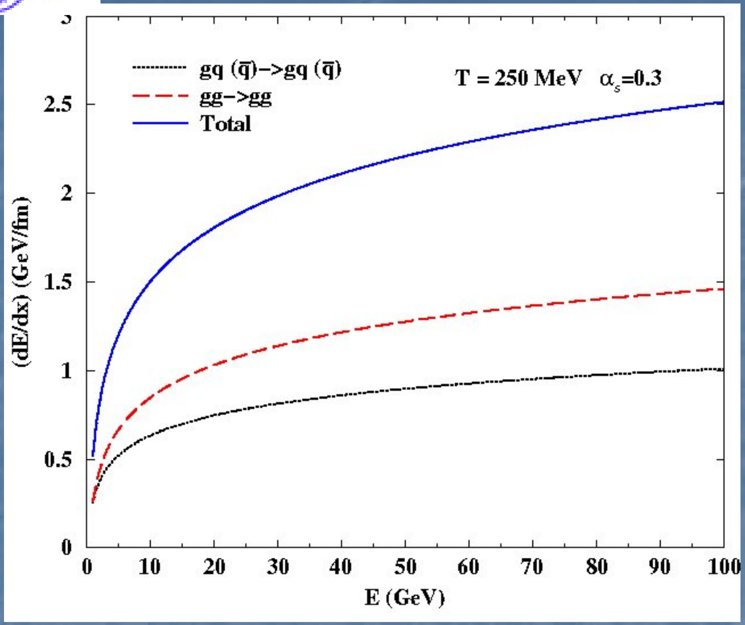
$$\left(\frac{dE}{dx}\right)_{\rm soft} \sim \alpha_s^2 T^2\, c_{qq} \ln \frac{q^{*2}}{g^2 T^2}$$

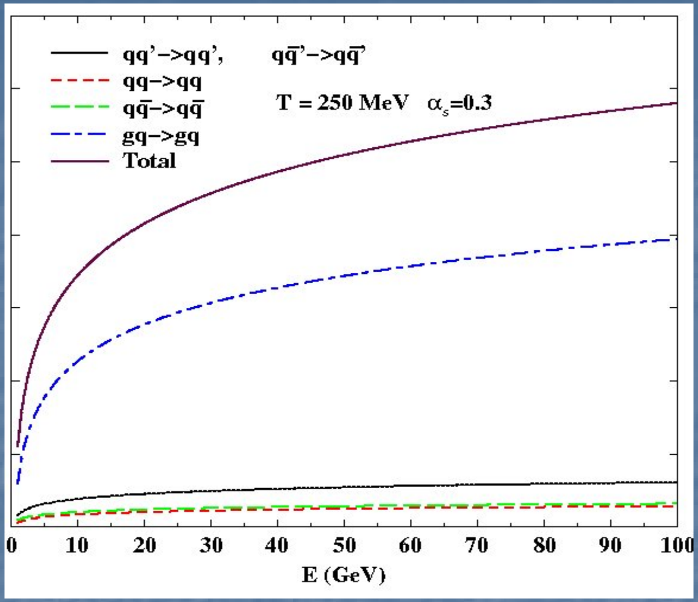
HTL gluon propagator

Hard + soft : independent of q*

$$\left(\frac{dE}{dx}\right)_{\rm soft} \sim \alpha_s^2 T^2\, c_{qq} \ln \frac{E}{g^2 T}$$

Dutt-Mazumder et al. PRD 74 2005





$\frac{dE_q}{dx}$ **is of the order of 0.8 GeV/fm for a 20 GeV quark**

Factor of 2 -3 more than previously calculated

Justifies not to neglect the collisional energy loss

Collisional vs. Radiative

(PRD 74 2005)

$$\Delta E_{GLV} = \frac{C_F \alpha_s}{N(E)} \frac{L^2 \mu^2}{\lambda} ln(\frac{2E}{\mu^2 L}),$$

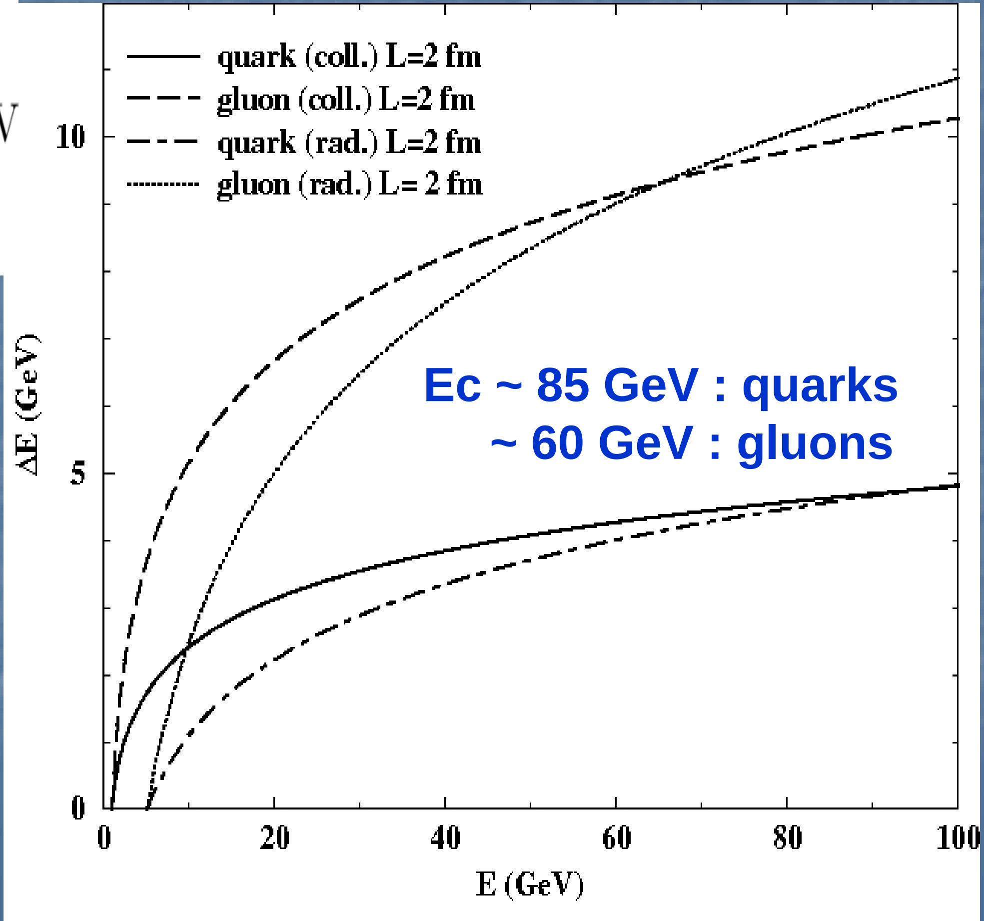
Important!!!!

$N(E) = 7.3, 10.0, 24.4$ for $E = 500,\ 50,\ 5$ GeV

$N(E \to \infty) = 4$

there might be domains where collisional loss could be comparable to radiative loss

***N(E)* = 10**
μ=1 GeV
L/λ = 4



Ec ~ 85 GeV : quarks
~ 60 GeV : gluons

Transverse momentum distributions hadrons : Nuclear modification factor

(Roy et al. PRC 2006, Alam et al. NPA 2007)

p_T distribution :

Standard pQCD calculation : modification of the

FF $$D(z,Q^2) : z \rightarrow z^* = \frac{z}{1-\Delta z} : \Delta z = \frac{\Delta E}{E}$$

equal amount of energy loss for each parton

Essential to evaluate parton p_T spectra dynamically : FOKKER PLANCK APPROACH

Boltzmann Equation

- **Small angle scattering more frequent ~ $O(g^2T)$**

Collisional integral reduces to appropriately defined diffusion and Drag coefficients

- **System of quarks, antiquarks, and gluons**
- **Inject partons with given initial distributions**
- **Study of time evolution as the system expands and cools**

Fokker-Planck Equation

$$\frac{\partial f}{\partial t} - \frac{p_z}{t}\frac{\partial f}{\partial p_z} = \frac{\partial(\eta \mathbf{p} f)}{\partial \mathbf{p}} + \frac{\partial (D f)}{\partial \mathbf{p}^2}$$

Solution by Green’s function technique:

$$E\frac{dN}{d^3p^f} = \int d^3p_0^f \, G(p^f, t|p_0^f, t_i) E_0 \frac{dN}{d^3p_0^f}$$

All the jets are not produced at the same space time point

Path length traversed by these partons before fragmentation are not same

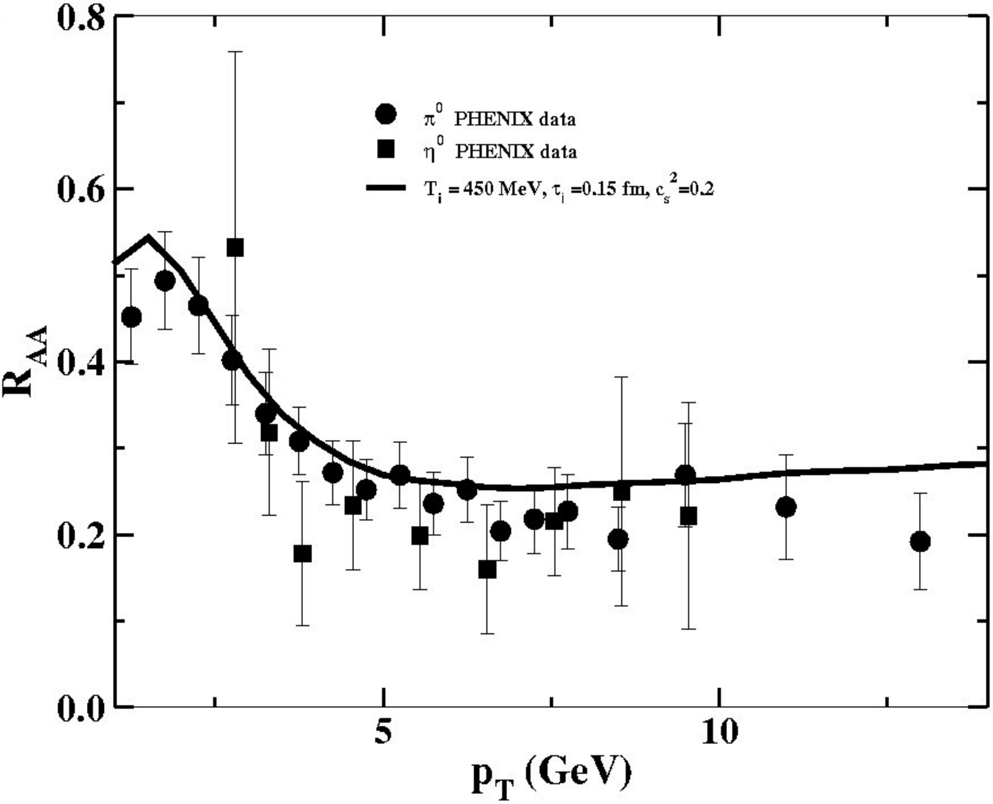
Temperature also varies along the trajectory of the partons

Jet produced at (r,ϕ) spends a time t_L or equivalently traverses a distance L ~ t_L and this is not a measurable quantity : time average

Finally,

$$\frac{dN^{\pi^0(\eta)}}{d^2p_T dy} = \sum_f \int d^2r \mathcal{P}(r) \int_{t_i}^{t_L} \frac{dt}{t_L - t_i} \int \frac{dz}{z^2} D_{\pi^0(\eta)/f}(z, Q^2)|_{z=p_T/p_T^f} \times E\frac{dN}{d^3p^f}$$

Nuclear modification factor



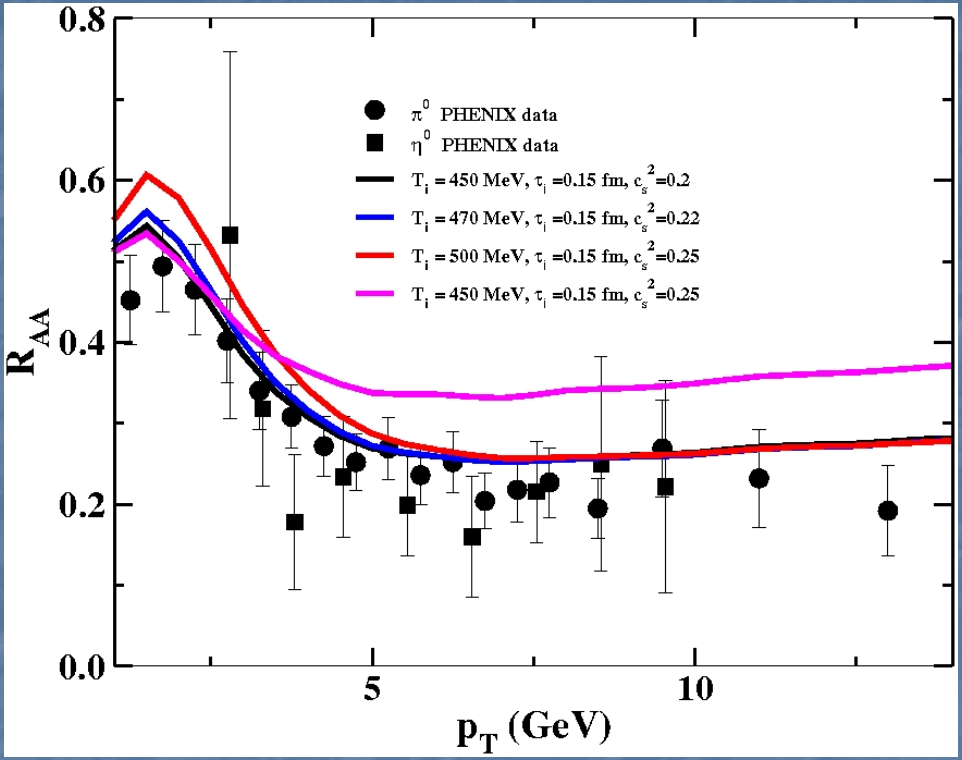
$$R_{AA}(p_T) = \frac{\frac{dN^{\pi^0(\eta)}_{AA}}{d^2p_Tdy}}{\left[\frac{dN^{\pi^0(\eta)}_{AA}}{d^2p_Tdy}\right]_0}$$

Fits the Phenix data quite well

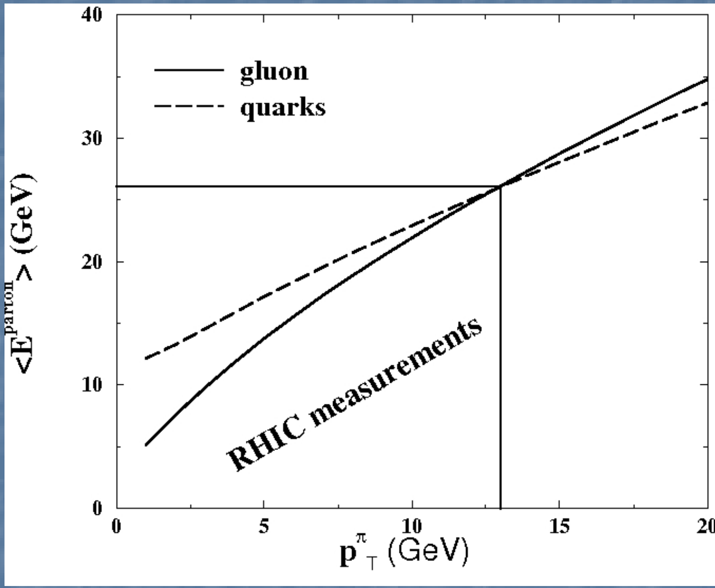
Tendency to rise at high p_T : radiation starts to dominate

Detail calculation including both collisional and radiative losses should be considered for quenching of high p_T hadrons

R_{AA} is sensitive to initial temperature velocity of sound initial thermalization time



Reasonable combination : T_i =450 MeV, c_s^2=0.2, and t_i=0.15 fm/c



Importance of coll. and rad. losses :
the average energy of parton $<E> = p_T^h/<z>$

$<E>_{max}$ ~ 26 GeV : ***maximum average energy to produce pions with p_T in the range of 1-13 GeV***

Summary and Discussion

- Reviewed the current theoretical status of collisional energy loss
- Divergence is removed by plasma effects
- Included all possible diagrams for a given process
- Domains in energy: collisional loss dominates over radiative energy loss
- Nuclear modification factors for π^0 and η : fragmentation of dynamically evolved parton distribution
- With parameters relevant for RHIC the data is well reproduced
- Not surprising because for RHIC data quenching factor $Q(p_T) \sim 0.2$ where collisional energy loss plays important role

THANK YOU