Energy Dependence of the Jet Quenching Parameter $\hat{q}$

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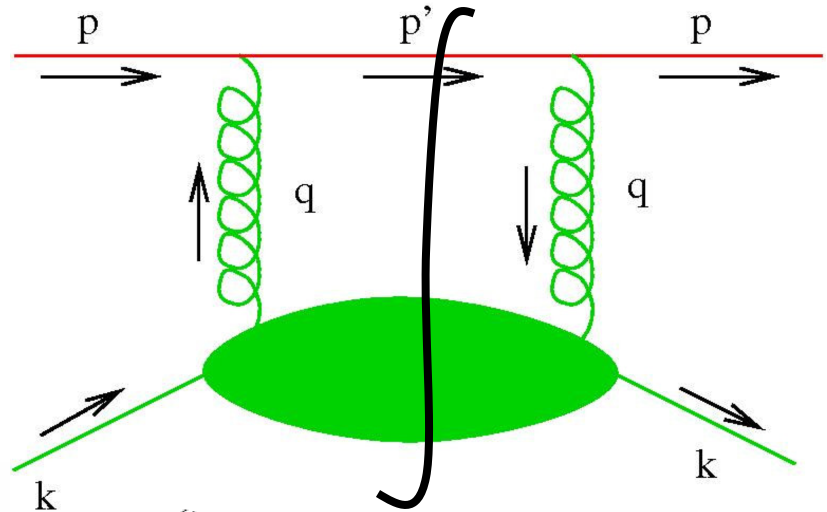
Introduction

Transverse broadening of the probe:

$\Rightarrow$scattering with thermal particles

$$\hat{q}_R = \rho \int dq_T^2 \frac{d\sigma_R}{dq_T^2} q_T^2$$



A closer look leads to

$$\hat{q}_R = \frac{4\pi^2 C_R}{N_c^2 - 1} \rho \int_0^{\mu^2} \frac{d^2 q_T}{(2\pi)^2} \int dx \delta\left(x - \frac{q_T^2}{2p^-\langle k^+ \rangle}\right) \alpha_s(q_T^2) \phi(x, q_T^2)$$

E 3T

Unintegrated gluon distribution function

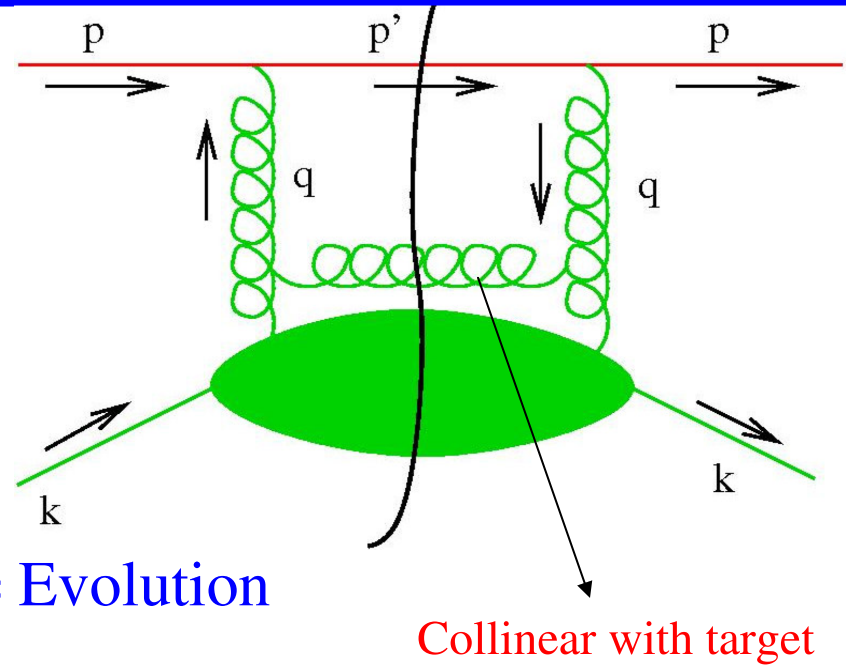
The value of x decreases with the probe energy!

If the gluon distribution is independent of x

$$\hat{q}_R \approx \frac{4\pi^2 C_R}{N_c^2 - 1} \rho \alpha_s(\mu^2) x G(x, \mu^2)$$

Gluon distribution per scattering center

Evolution



High Energy Jets

$\Rightarrow$ x is small

Large momentum transfer

$\Rightarrow$ large scales μ^2

The gluon distribution function grows = Evolution

Since both x^{-1} and the scale are large

$\Rightarrow$ Evolution via the Double Logarithmic Approximation (DLA)

For scales $\mu \gg \mu_D$ the medium effects on the evolution are small

$\Rightarrow$ We use vacuum DLA evolution

Initial Conditions

For thermal particles, $\hat{q}$ is computed via HTL

$\phi(x,q_T)$

$$\hat{q}_R = \frac{4\pi^2\alpha_s C_R}{N_c^2-1}\rho\int dx\frac{dq_T^2}{(2\pi)^2}\delta(x-\frac{q_T^2}{2p^-\langle k^+\rangle})\underline{2N_c\alpha_s\frac{\pi^2}{6\zeta(3)}q_T^2|\mathcal{M}_{Rb}|^2}$$

With the HTL propagator:

$$\mathcal{M}_{Rb}\approx\left[\frac{1}{q^2+\mu_D^2\pi_L(x_q)}-\frac{(1-x_q^2)\cos\phi}{q^2(1-x_q^2)+\mu_D^2\pi_T(x_q)+\mu_{\rm mag}^2}\right] \qquad x_q=\frac{\omega}{q}\approx\frac{3xT}{q_T}$$

For a maximum momentum transfer of order T

$$xG(x,\mu)=\int^{\mu}\frac{d^2q_T}{(2\pi)^2}\phi(x,q_T^2)$$

$$xG(x,\mu^2)\approx C_A\frac{\alpha_s}{\pi}\frac{\pi^2}{6\zeta(3)}\frac{1}{2}\left[\frac{3}{2}\ln\frac{\mu^2}{\mu_D^2}+\frac{1}{3}\ln\frac{\mu_D}{xT}\right]$$

We use this as initial condition at μ=T

Saturation in QGP

The growth of the gluon distribution is tamed by saturation effects

The saturation scale is estimated from the linearized evolution

$$Q_s^2(x) = \frac{4\pi^2 N_c \alpha_s\left(Q_s^2\right)}{N_c^2 - 1} \rho x G(x, Q_s^2)\, \mathrm{min}(L, L_c)$$

The QGP density is much larger than the nuclear density

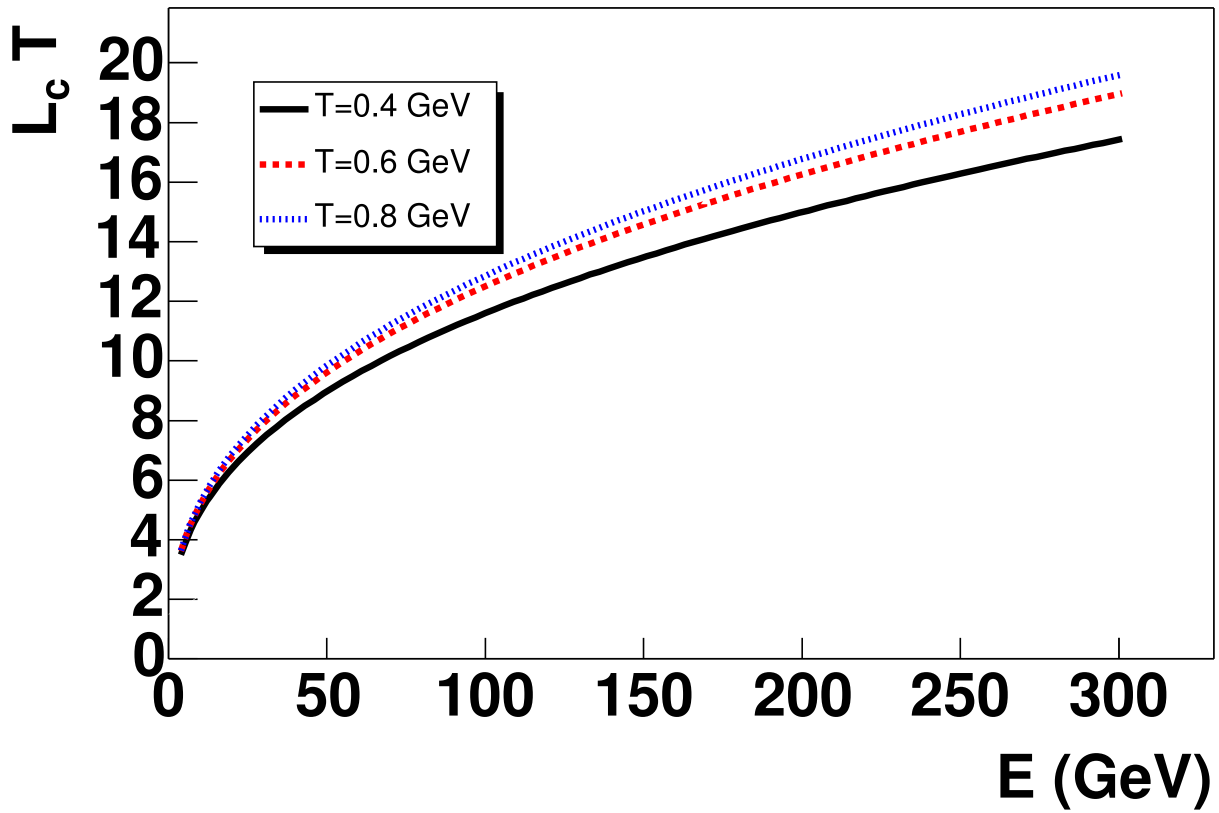
Saturation sets at larger x

The saturation scale is larger

Large $Q^2_s \Rightarrow$ the coherence length becomes smaller than in the nucleus

$$L_c = \frac{1}{xT} \approx \frac{6ET}{Q_s^2}\frac{1}{T}$$

Coherence Length



L_c is comparable to typical path length

L_c = 5 fm for E=300 GeV and T=0.6 GeV

The effect of Λ_{QCD} leads to non trivial scale dependence

$\hat{q}$ from the Thermal Gluon Distribution

Simplified treatment of the unintegrated gluon distribution

Linear evolution from initial condition for $Q^2 > Q^2_s$

Constant unintegrated distribution for $Q^2 < Q^2_s$

$$\phi(x,Q^2)=\phi(x,Q^2_s)$$

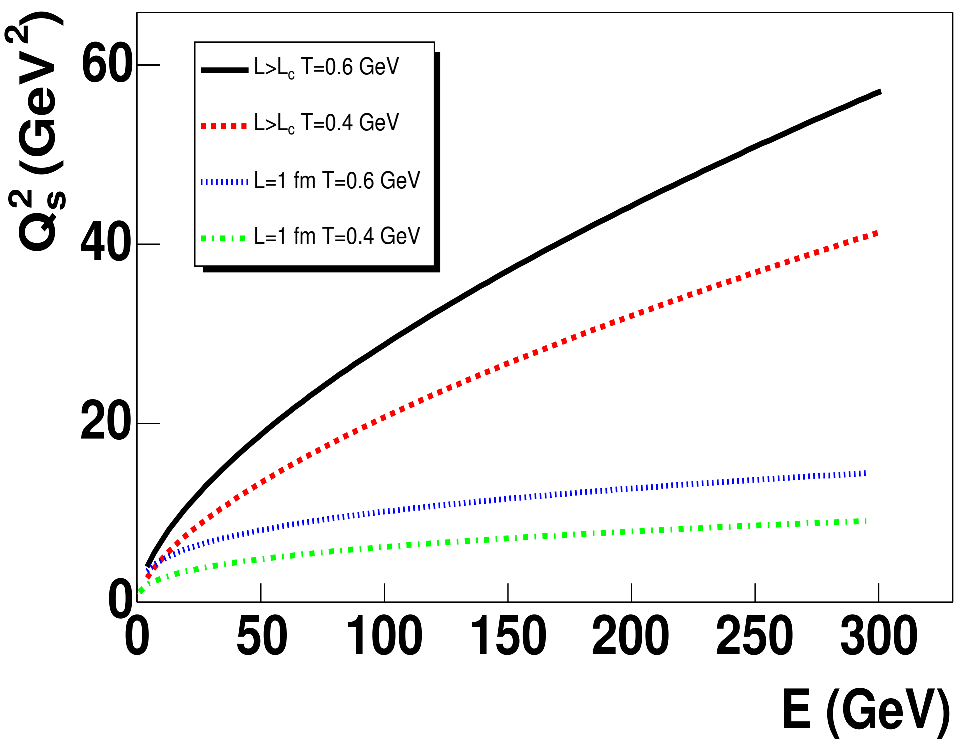
The integration of ϕ over the $x=q^2_T/Q^2_{max}$ is approximated by

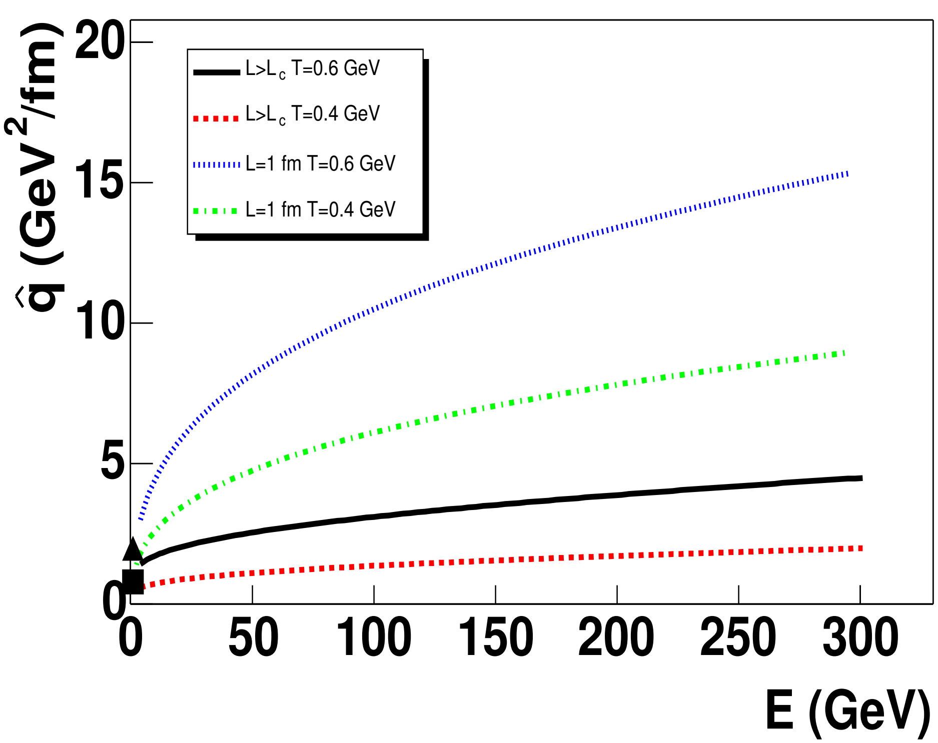
$$\hat{q}_R = \frac{C_R}{N_c}\frac{Q_s^2}{\min(L,L_c)}\frac{\ln\frac{1}{x_m}}{\ln\frac{Q_s^2(x_m)}{\Lambda^2}} \times \left[\frac{\delta_L}{\sqrt{\pi\frac{b}{N_c}\ln\frac{1}{x_m}\ln\left(\ln\frac{Q_s^2}{\Lambda^2}\Big/\ln\frac{\mu^2}{\Lambda^2}\right)}} + \frac{1}{\ln\left(\ln\frac{Q_s^2}{\Lambda^2}\Big/\ln\frac{\mu^2}{\Lambda^2}\right) - \frac{\ln(1/x_m)}{\ln(Q_s^2(x_m)/\Lambda^2)}}\right]$$

Q^2_{max}=6ET

The transport coefficient is determined by the saturation scale (as expected)

Energy Dependence



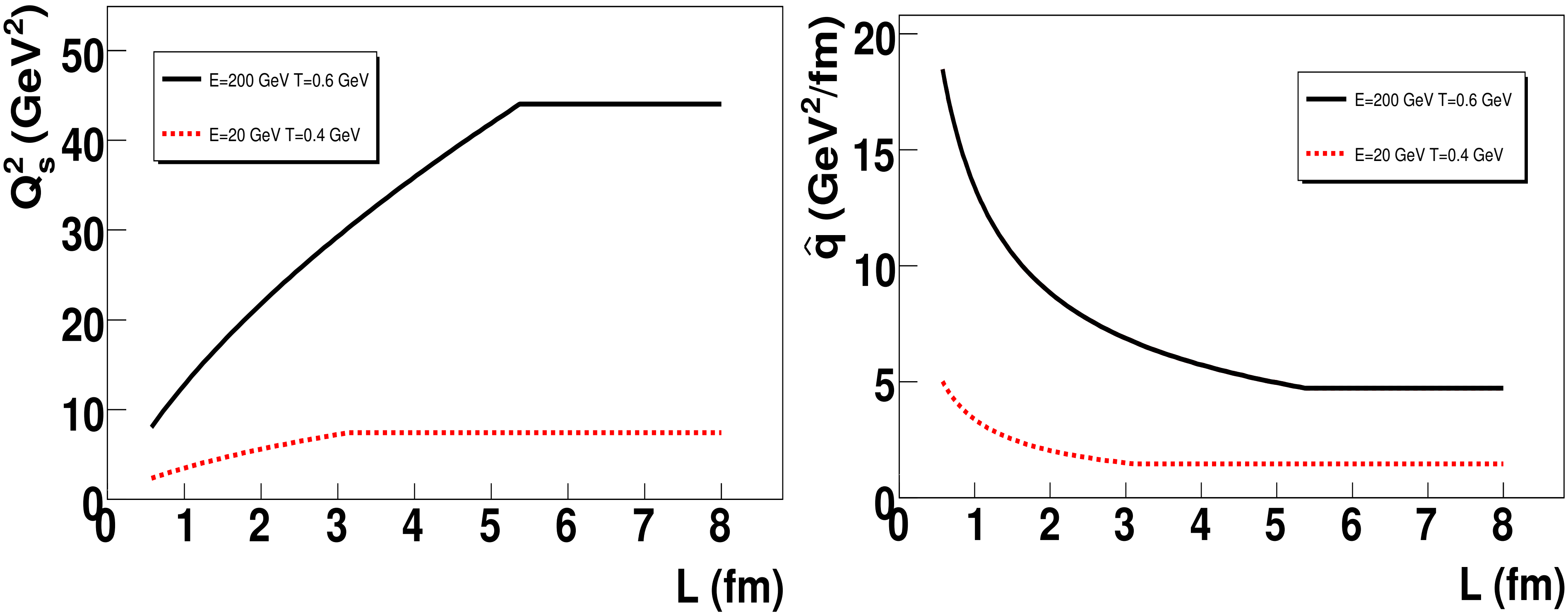


We obtain large values for the saturation scale (large density)

For L>L$_c$ fast grow $\quad Q_s^2 \sim \dfrac{ET}{Q_s^2 T} \;\Rightarrow\; Q_s^2 \sim \sqrt{E}$

Significant energy dependence of the transport parameter.

Non Trivial Length Dependence



Evolution leads to a non trivial length dependence

The abrupt change for $L=L_c$ is a consequence of simplified treatment

Apparent divergence of $\hat{q}$ is due to $Q_s^2 \sim L^p$, $p \approx 0.7$ (from numerics)

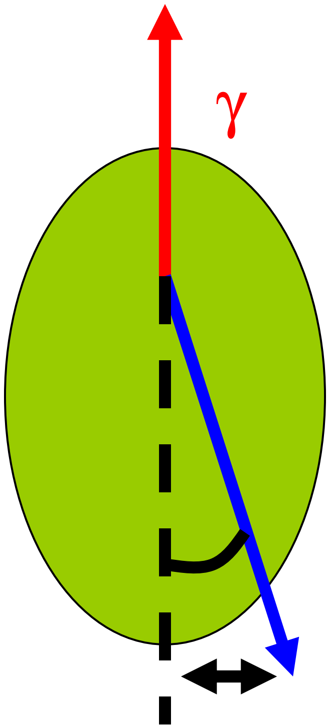
Direct Measurement of $\hat{q}$

Look for γ + jet events

γ gives the initial direction

The back-jet broadens in its propagation

The jet acoplanarity gives the transferred momentum



Since γ does not loose energy, the typical length is the average length

Cross check for the jet energy loss since it depends on the broadening

Conclusions

- $\hat{q}$ is determined from the unintegrated gluon distributions

  High energy jets probe the small x region

- The growth of the gluon distribution leads to saturation (in the plasma)

  Large densities lead to large Q_s

- q depends on the saturation scale (as expected)

  Rapidity dependent Q_s leads to energy dependent $\hat{q}$

- The energy and length dependence of $\hat{q}$ is significant in the kinematic range of LHC jets.

Back up