Quenching of high-p_T hadrons: Alternative scenario

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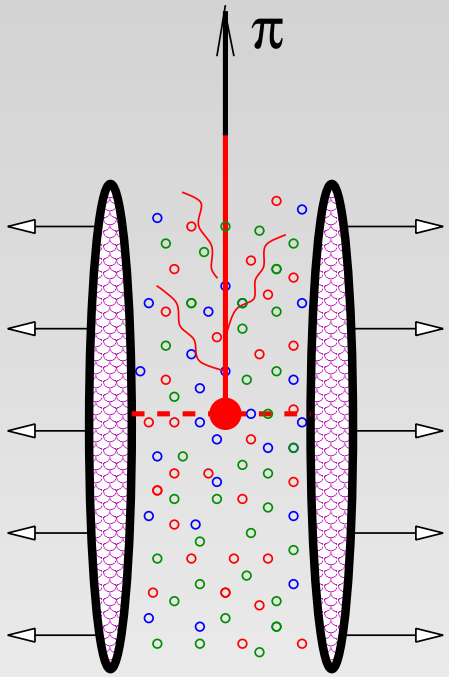
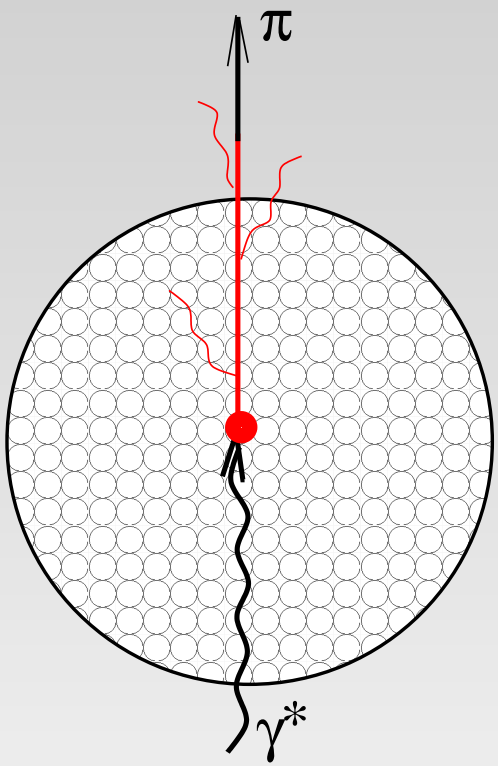
Hadron quenching in heavy ion and electron-nucleus collisions



RHIC − LHC

$E_\pi = p_T < 20$ GeV/c

The geometry and kinematics are uncertain: the model must be tested somewhere else.

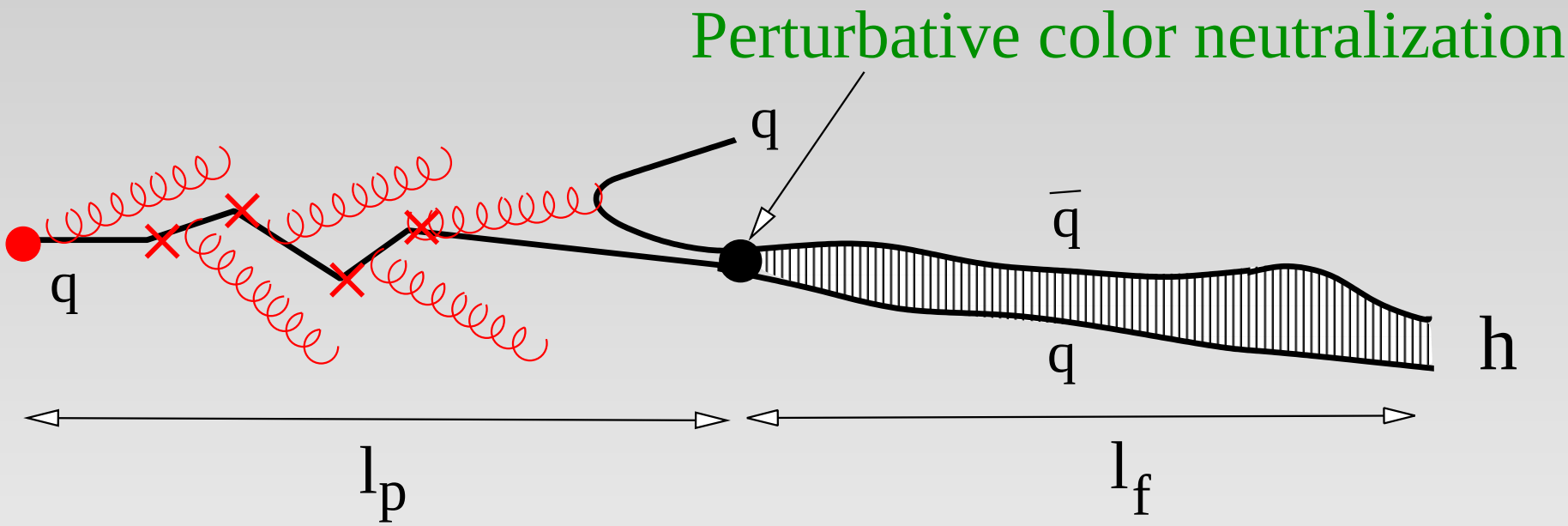


HERMES − JLAB

$E_\pi < 20$ GeV/c

The density, geometry, kinematics are known. Q^2 and ν are uncorrelated. The best way to test models.

Perturbative hadronization



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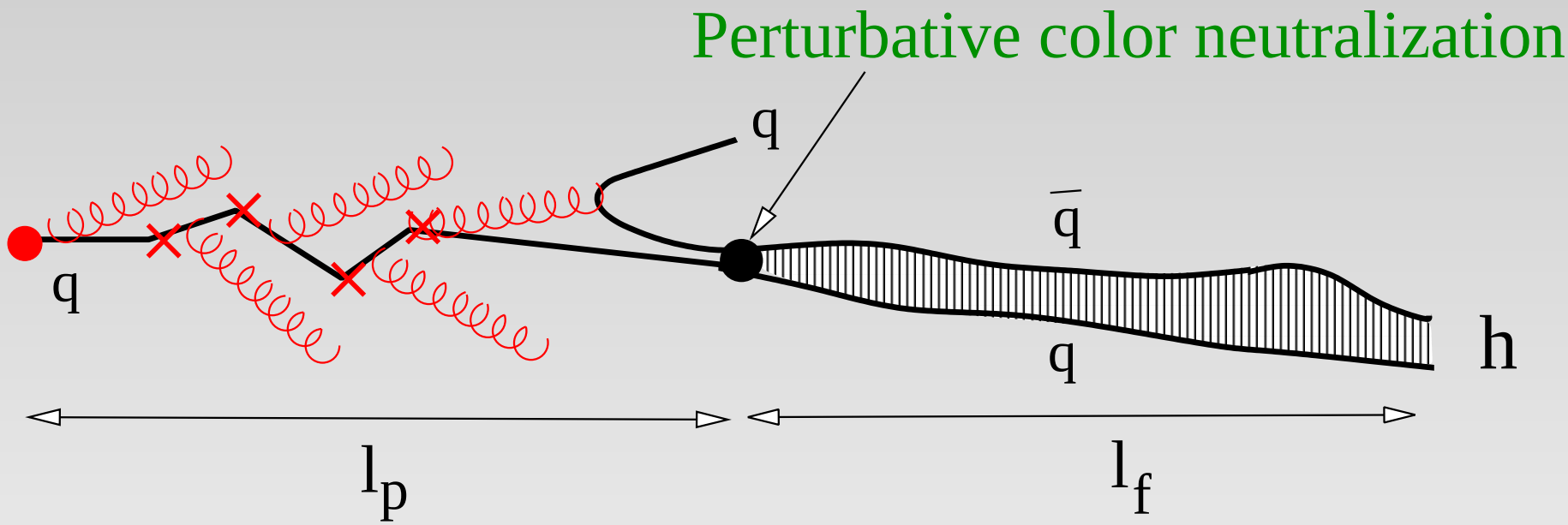
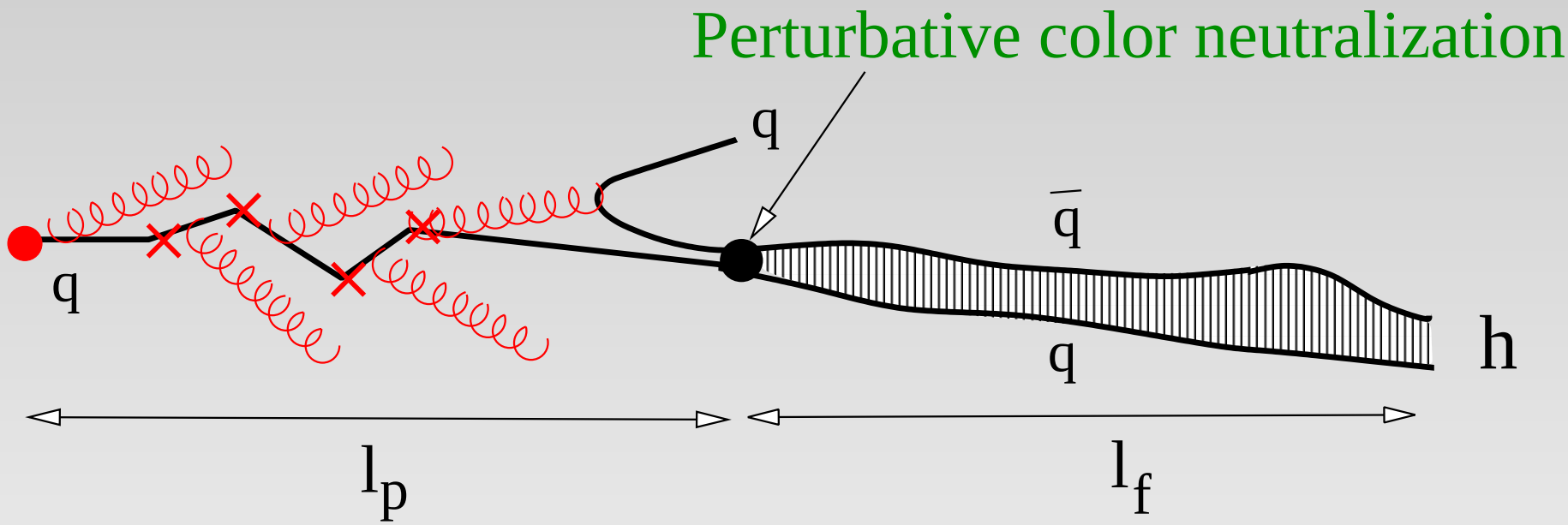


Two sources of hadron quenching:

(i) energy loss of the parton prior production of a pre-hadron;

Perturbative hadronization



Two sources of hadron quenching:

(i) energy loss of the parton prior production of a pre-hadron;

(ii) attenuation of the pre-hadron in the medium (absorption).

Perturbative hadronization

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However, even in the string model this distance is not long, e.g. at $E_h = p_T = 10\,\mathrm{GeV}$ and $z = 0.7$,

$$l_p = \frac{E_h}{\kappa}(1 - z_h) = 3\,\mathrm{fm}$$

B.K. & F.Niedermayer (1983)

A.Bialas & M.Gyulassy (1987)

Dissipation of energy by a highly virtual quark is more intense, therefore l_p should be even shorter.

p_T broadening in DIS

The mean pathlength of a hadronizing quark in nuclear medium can be directly measured via p_T-broadening:

$$\langle l \rangle = \frac{\Delta \langle p_T^2 \rangle}{z^2 \, \hat{q}}$$

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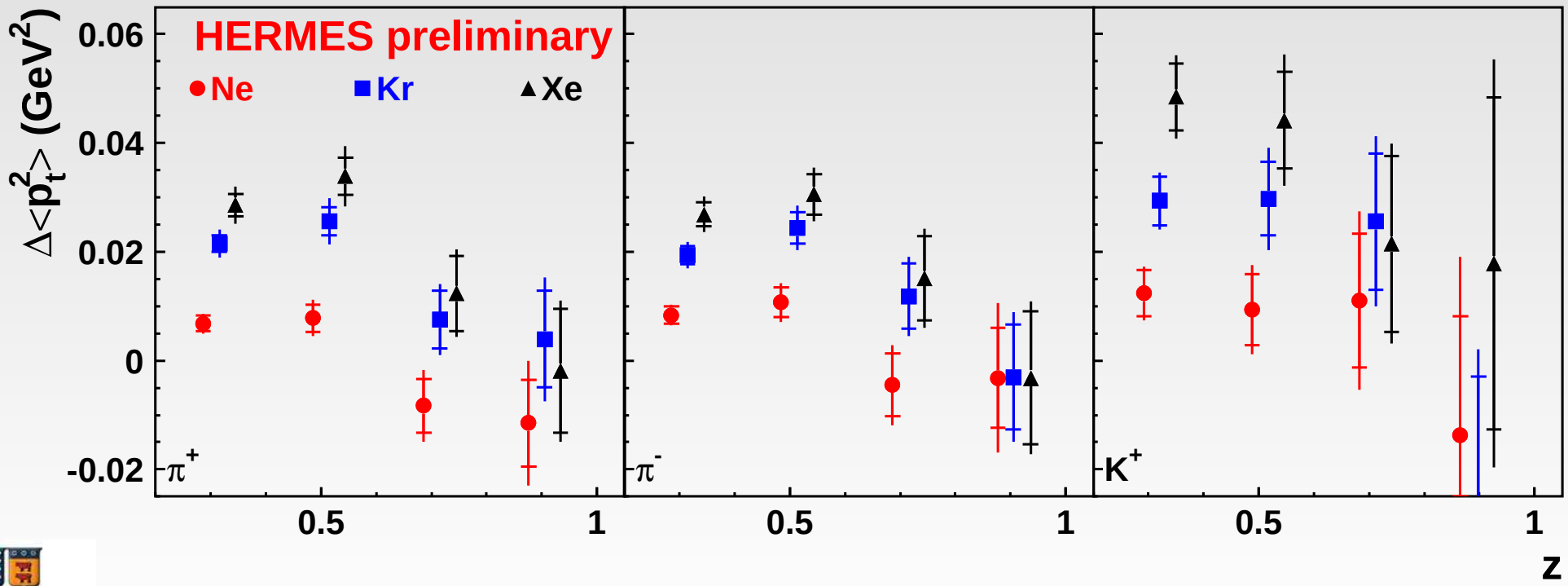

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p_T broadening in DIS

There is a consensus between different sources of information about the transport coefficient $\hat{q}$ in nuclei.

	Dipole 10 - 20 GeV	BDMS -	Drell-Yan 200 - 800 GeV	Cronin 200 - 800 GeV
$\hat{q}$ (GeV^2 / fm)	0.042	0.045	0.026 - 0.056	0.033 - 0.037

Thus, the mean pathlength of the quark in Kr and Xe at $z = 0.7$ and $\langle \nu \rangle = 13.4$ GeV is very short:

$$\langle l \rangle \approx 0.6 \pm 0.4 \text{ fm}$$

- Absorption of the produced prehadron plays key role in quenching of pions produced in DIS off nuclei.

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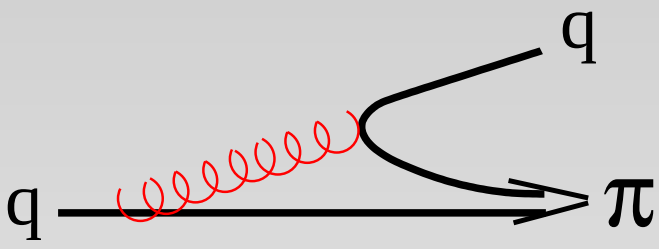
Time evolution of a high-p_T jet

Born approximation for the fragmentation function

$$\frac{\partial D_{q/\pi}(z,k)}{\partial k^2} \propto \frac{1}{k^4} z^2(1-z)^2$$



E.Berger (1979)

Changing the variable to

$$l_c = \frac{2z(1-z)E}{k^2}$$

one gets a constant distribution over pion production length,

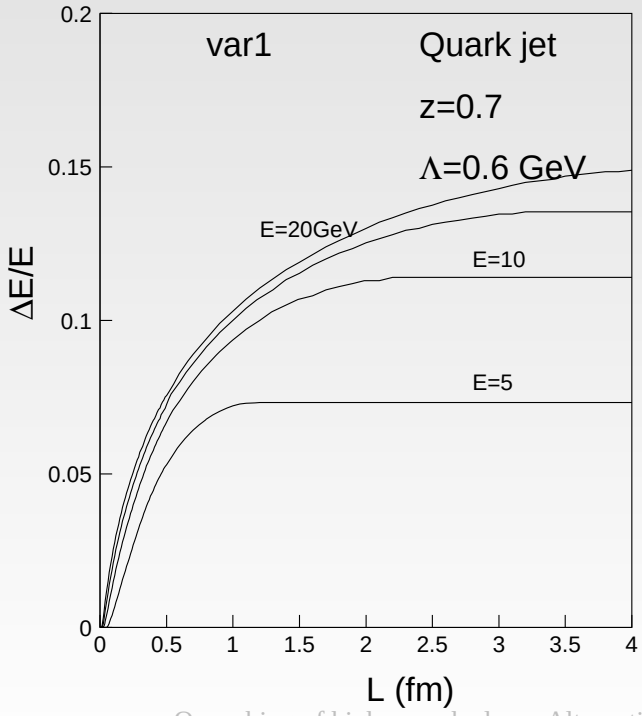
$$\frac{\partial D_{q/\pi}(z,l_c)}{\partial\, l_c} \propto z(1-z)$$

Time evolution of a high-p_T jet

The produced high-p_T "bare" quark has no field with transverse frequencies $k < p_T$. It can be expanded over Fock states containing different number of gluons, which are radiated in accordance with their coherence times. The quark has lower energy in higher Fock components, correspondingly, the fractional pion momentum should be redefined:

$$z \Rightarrow \tilde{z}(l) = \frac{z}{1 - \Delta E(l)/E},$$

where $\Delta E(l)$ is vacuum energy loss. To respect energy conservation only gluons with $\omega < E(1-z)$ contribute to $\Delta E(l)$.



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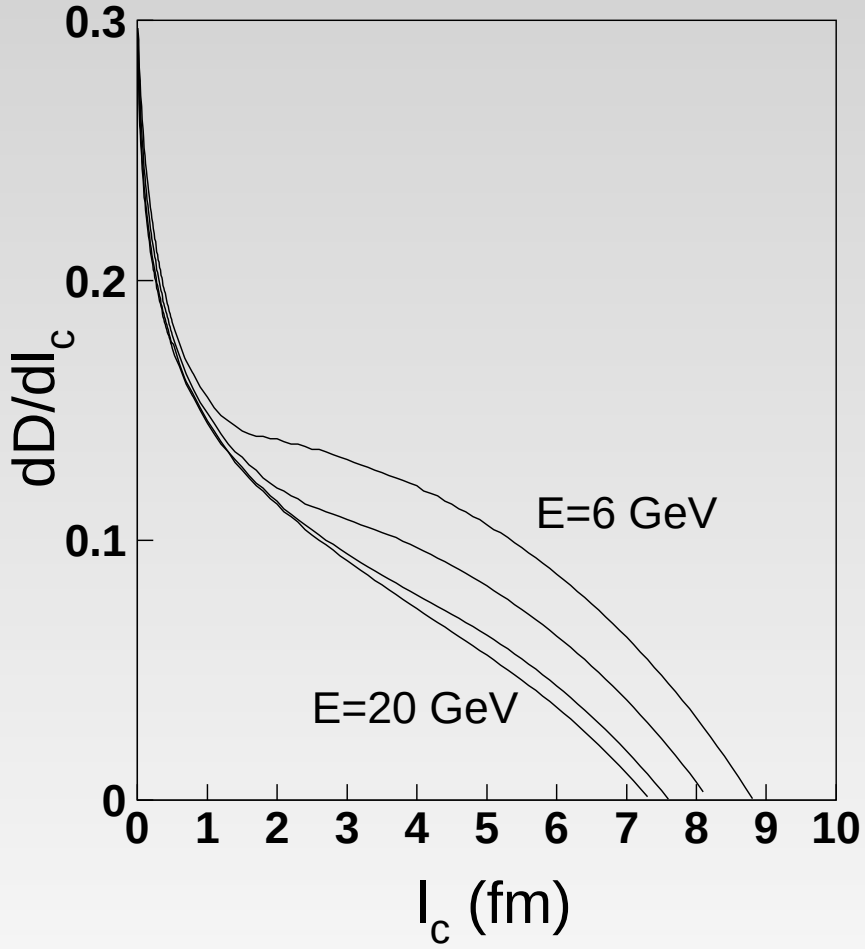
Time evolution of a high-p_T jet

The rest nonradiated gluons produce Sudakov suppression,

$$S(z,l) = e^{-\langle n_g(z,l)\rangle}$$

The l_c distribution of pions is modified by gluon radiation,

$$\frac{\partial D_{q/\pi}(z,l_c)}{\partial\, l_c} \propto \tilde{z}(l_c)[1-\tilde{z}(l_c)]\, S(z,l_c)$$



Weak energy dependence, $\langle l_c\rangle$ slowly decreases with energy.

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Quenching of high-p_T hadrons

For central collision of nuclei with constant density,

$$R_{AA} = \frac{\langle l_c^2 \rangle}{R_A^2} \left[1 - A \frac{L}{\langle l_c \rangle} + B \frac{L^2}{\langle l_c^2 \rangle} \right] ,$$

where the effective absorption length is,

$$L^3(E) = \frac{3E}{8 R_A \rho_A^2 X}$$

The prehadron dipole is produced with a rather large starting separation,

$$\langle r_T^2 \rangle \approx \frac{2\langle l_c \rangle}{zE} + \frac{1}{E^2}$$

e.g. at $E_\pi = 10\,\mathrm{GeV}$ the initial dipole size is $r_T \sim 0.3\,\mathrm{fm}$.

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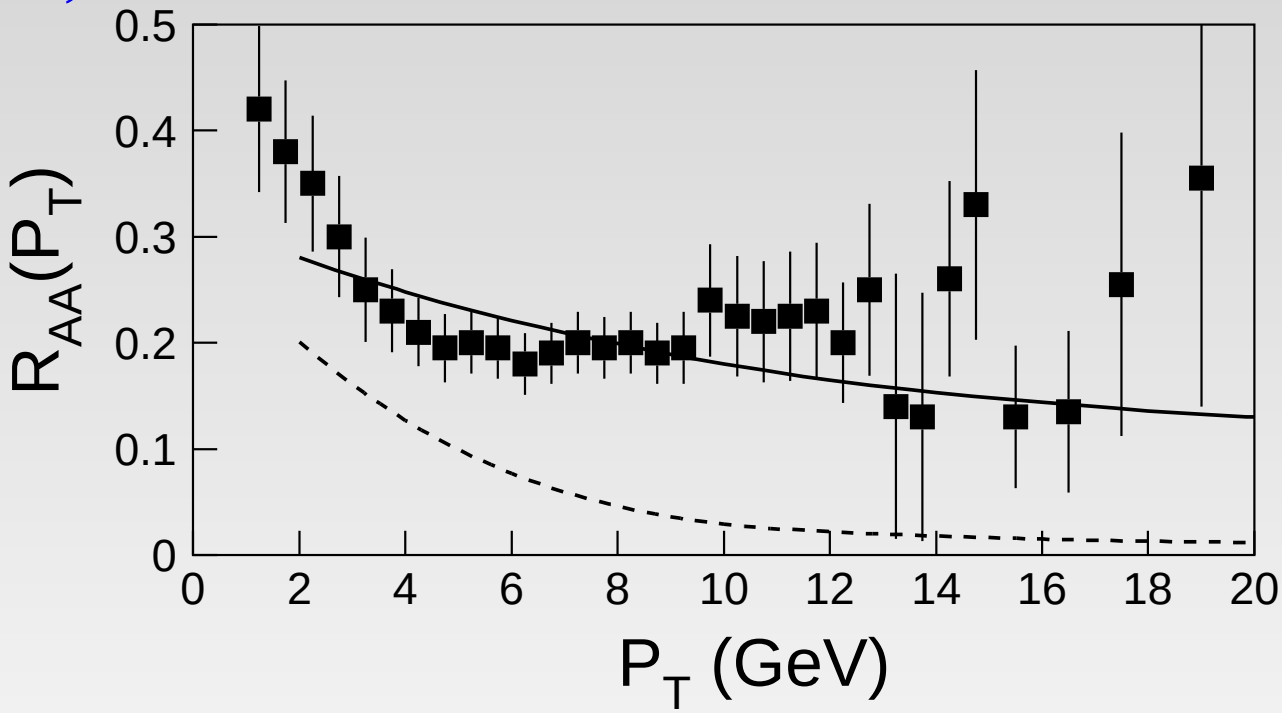
Quenching of high-p_T hadrons

For such a large dipoles the survival probability in a dense medium is vanishingly small. Assuming that $L \ll \langle l_c \rangle$ we arrive at a simple result,

$$R_{AA} = \frac{\langle l_c^2(p_T) \rangle}{R_A^2}$$



No unknowns!

Suppression is independent of the medium density. The suppression is not to be fitted, but can be predicted.

Discussion

- If the density of the created medium is high, the production length of a prehadron colorless dipole controls the suppression R_{AA} which decouples from the medium density.

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- The A-dependence is predicted to be $R_{AA} \propto A^{-2/3}$. If $R_{AA} = 0.2$ for $Au - Au$ central collision, it has to be $R_{AA} = 0.42$ for $Cu - Cu$ in excellent agreement with data.

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- Vacuum energy is the same for heavy and light quarks. Therefore, heavy flavors must be suppressed same way as pions, even somewhat more, since their fragmentation function is shifted to larger z, so l_c is shorter.

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- Since $L \propto p_T^{1/3}$, the neglected absorption terms rise with p_T and eventually will take over. Then $R_{AA}(p_T)$ will start rising. At LHC this will happen at larger p_T, than at RHIC.

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Backup slides