RHIC WINTER WORKSHOP

LBN LABORATORY

BERKELEY, JANUARY 1999

PARTON ENERGY LOSS

R. BAIER (BIELEFELD)

CONTENT

- PROPAGATION OF ENERGETIC PARTONS IN DENSE MATTER (MOTIVATION: SEARCH FOR QGP)
  - COLLISIONAL ENERGY LOSS DUE TO ELASTIC SCATTERING (HEAVY QUARK IN CHEMICAL NON-EQUILIBRATED QG PLASMA)
  - MULTIPLE SCATTERING AND INDUCED GLUON RADIATION

    MAINLY CASE OF EXPANDING MEDIUM /
    RESULTS FOR ENERGY LOSS
  - WHAT TO EXPECT : COLD VS. HOT MEDIUM
  - WHAT NEXT: JET PROPERTIES / ANGULAR DISTRIBUTION
- PREDICTIONS - PROCESSES INFLUENCED BY ENERGY LOSS (A FEW EXAMPLES)

. RECENT
RESULTS (IN 1998)
AND FROM WORK IN PROGRESS

IN COLLABORATION WITH

M. DIRKS (BIELEFELD)
K. REDLICH (WROCLAW)
} ON COLLISIONAL ENERGY LOSS OF HEAVY QUARK +)

Yu. L. DOKSHITZER (MILANO / St. PETERSBURG)
A. H. MUELLER (COLUMBIA, N.Y.)
D. SCHIFF (ORSAY)
} ON MEDIUM-INDUCED RADIATIVE ENERGY LOSS OF PARTONS ++)

+) hep-ph/9809214 / TFT 98 PROCEEDINGS, REGENSBURG

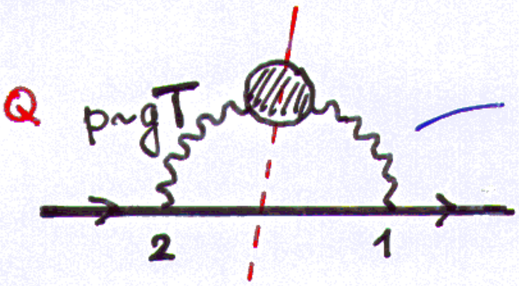
++) NUCL. PHYS. B531 (1998) 403;
PHYS. REV. C58 (1998) 1706

COLLISIONAL ENERGY LOSS OF A HEAVY QUARK IN QGPLASMA – HIGH T –

(OUT-OF- CHEMICAL EQUILIBRIUM

– E.G. "HOT GLUE" SCENARIO (E. SHURYAK)

Γ NOT A MEMBER OF THE HEAT BATH



SPACE-LIKE ($p^2<0$)

QUARK Q WITH E MASS M

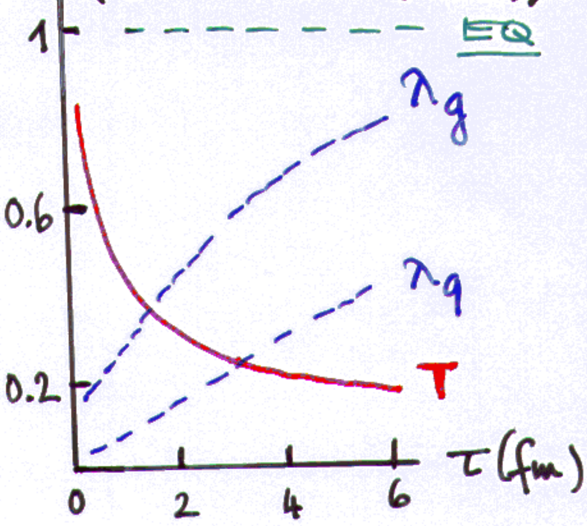
ENERGY WEIGHTED GLUON-PROPAGATOR "$p_0 D_{21}(p,T)$" IN CTP-FORMALISM

ELASTIC Qq AND Qg SCATTERING

FUGACITY:

$$n(x,p) = \lambda(x)\, n_{eq}(p_0/T)$$

(BIRO ET AL. (1993))



RESULT:

DYNAMICAL SCREENING FOR SOFT GLUON-EXCHANGE WHEN $p^2<0$ /LANDAU DAMPING/

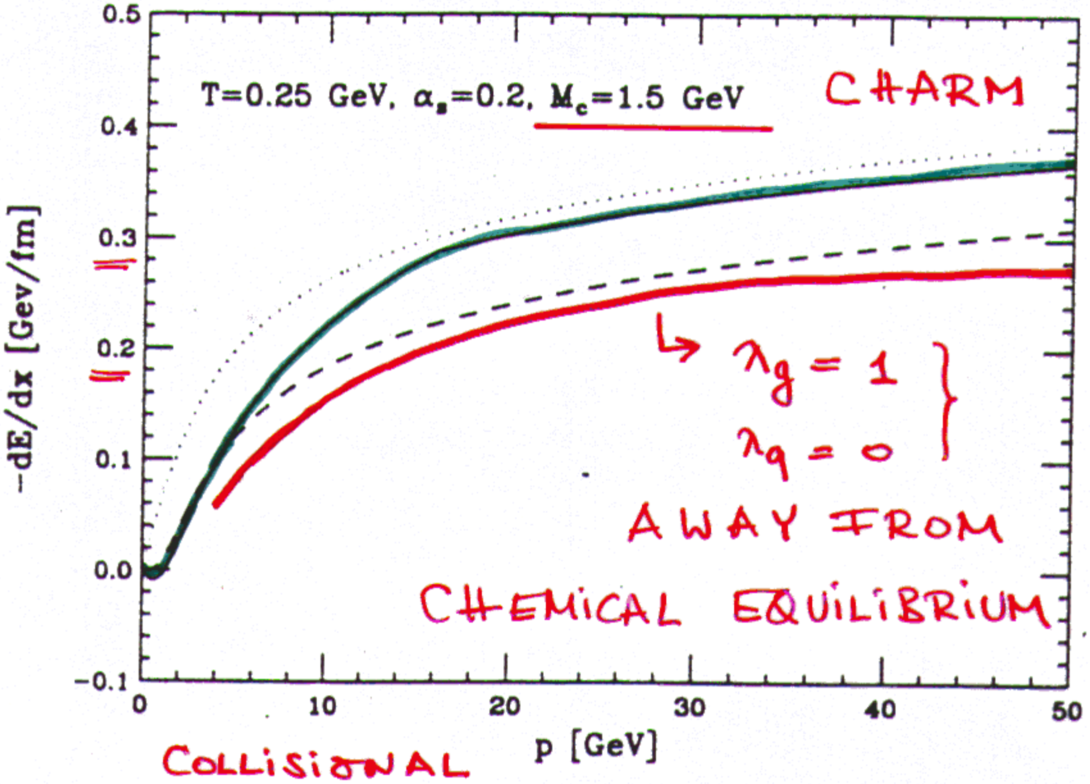
EVEN FOR CHEMICAL NON-EQUILIBRIUM

FINITE RESULTS FOR $-dE/dx$

FOR $E \gg M^2/T$:

$$-dE/dx = \frac{g^2 \tilde{m}_g^2}{2\pi} \ln\left[0.920\sqrt{\frac{ET}{\tilde{m}_g^2}}\; 2^{\frac{\lambda_q N_f}{2(6\lambda_g+\lambda_q N_f)}}\right],$$

$$\tilde{m}_g^2 = \frac{g^2 T^2}{3}\left(\lambda_g + \lambda_q N_f/6\right)$$



COLLISIONAL

FIG. 2. Energy loss dE/dx of a charm quark as a function of its momentum for $T = 250$ MeV and $\alpha_s = 0.2$. The complete result to leading order in g_s (solid curve) is compared to previous calculations by Thoma and Gyulassy (dashed curve) and Bjorken (dotted curve).

E. BRAATEN AND M. H. THOMA (1991)

- EQUIL. DISTRIBUTIONS

$-\frac{dE}{dx}$ DOES NOT BECOME LARGE,

i.e. $< 1\,\mathrm{GeV/fm}$

PARTON

PROPAGATION AND RADIATION IN DENSE MATTER

- DOMINANT EFFECTS :

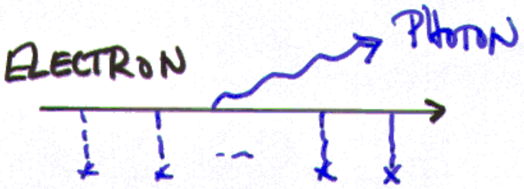
M. GYULASSY + X.-N. WANG (94)

{R.B., Yu. L. DOKSHITZER,
S. PEIGNÉ, D. SCHIFF (95)

QED

ELECTRON IS SCATTERED ON  TRAJECTORY

PHOTON FIELD (WITHOUT ELECTRON INTERACTION!) ON A STRAIGHT LINE



LANDAU-
POMERANCHUK-
MIGDAL
PHENOMENON

QCD

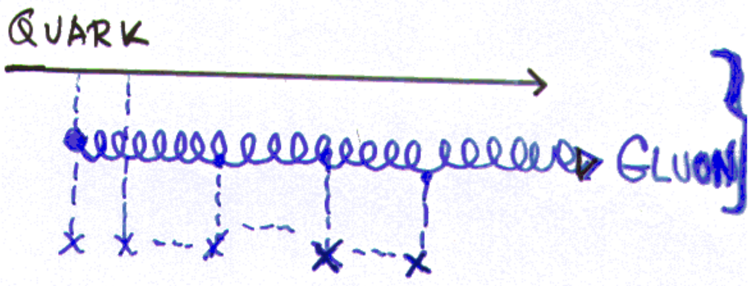
QUARK ON ≃ STRAIGHT LINE

GLUON RADIATION

FIELD SUFFERS MULTIPLE SCATTERINGS
- ZIG-ZAG TRAJECTORY

GLUON SELF-INTERACTION

DUE TO COLOUR

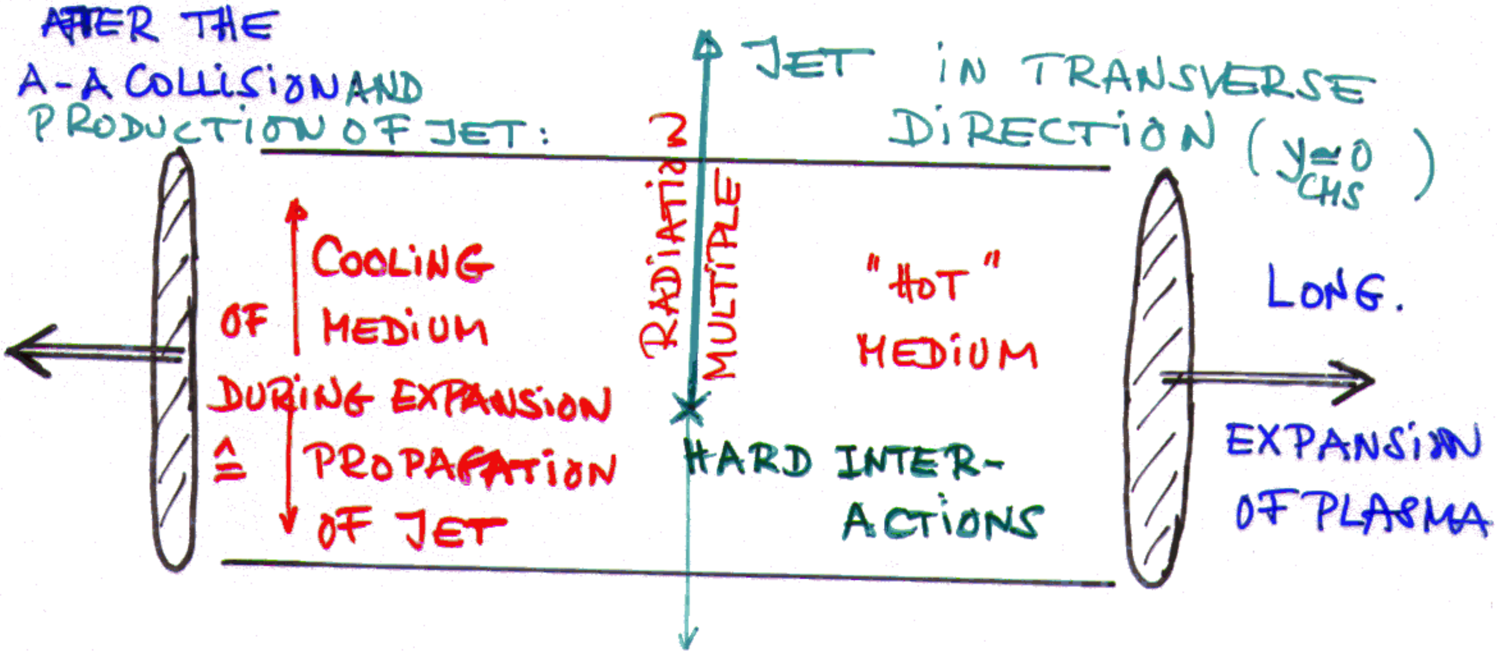


⟹ INTERFERENCES ("BDMPS"/ B.G. ZAKHAROV)

(ANGLES ⟹ TRANSVERSE MOMENTA)

EXPANDING MEDIUM (FINITE LENGTH)

BROADENING AND ENERGY LOSS OF JETS PRODUCED IN (EARLY) HARD COLLISIONS
IN HEAVY-ION COLLISIONS



JET PRODUCED AT $\tau \simeq 0$, ENTERS HOT MEDIUM FORMED AT τ_0 ($\tau_0 \to 0$) AND PROPAGATES "SEEING" COOLER LAYERS OF MATTER

ACCORDING TO $\boxed{\text{BJORKEN'S} \quad T^3 \tau^\alpha = \text{CONST}}$
$(0 \le \alpha \le 1)$

LONGITUDINAL EXPANSION LAW

$$\text{I.E.} \begin{cases} \alpha = 0 & \text{(FIXED TEMPERATURE)} \\ \alpha = 1 & \text{IDEAL MASSLESS GAS} \end{cases}$$

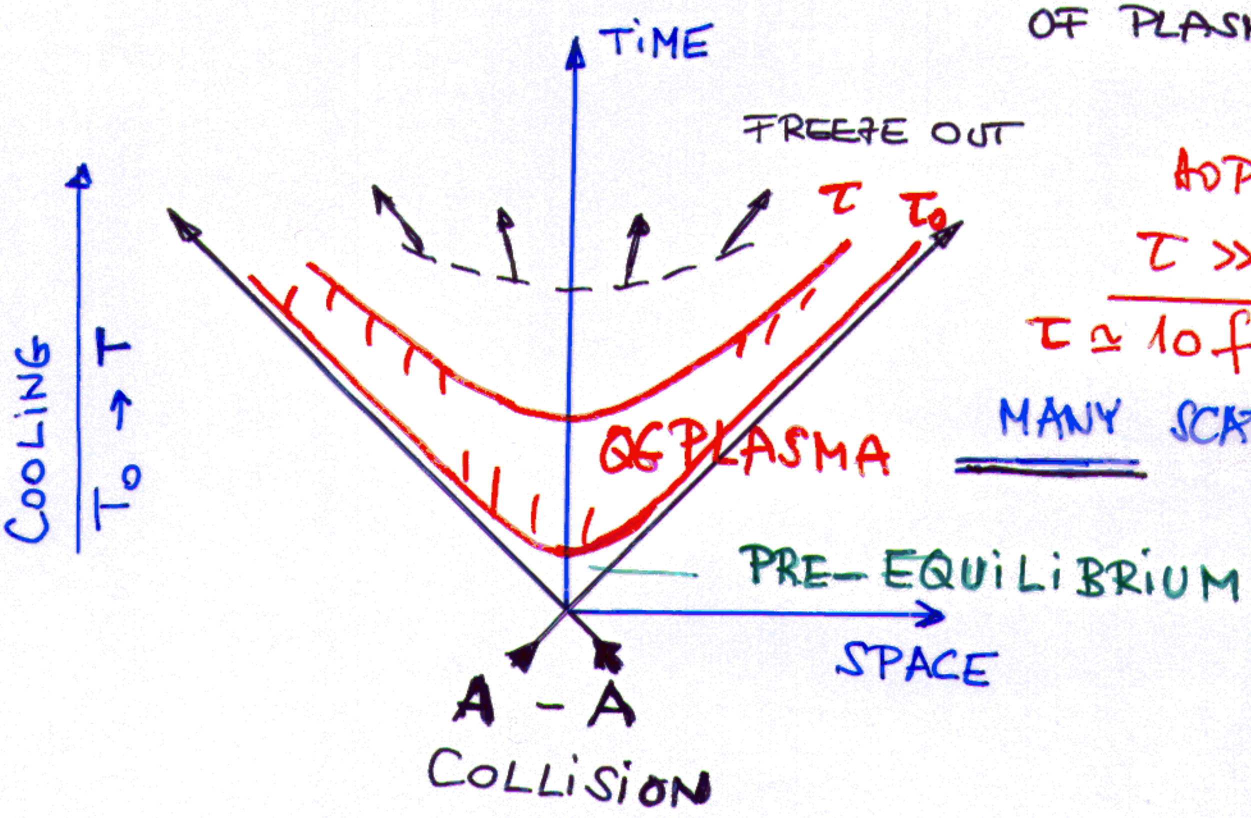
α.. KEPT CONSTANT IN THE CALCULATION

BJORKEN'S PICTURE

LONGITUDINAL EXPANSION IN x-DIRECTION:

$\tau = \sqrt{t^2 - x^2}$

τ.. PROPER TIME OF PLASMA



HOPE:

$\tau \gg \tau_0$

$\tau \simeq 10$ fm

MANY SCATTERINGS

τ_0.. "THERMALIZATION TIME"

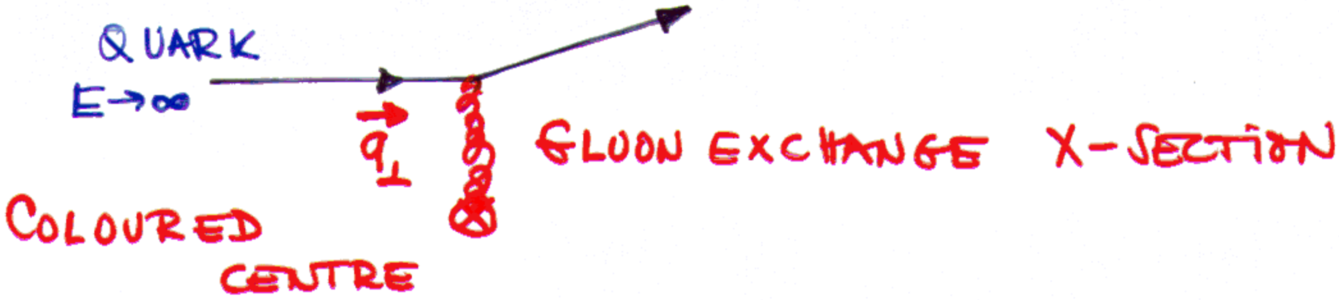
ESTIMATE $\tau_0 \lesssim 1$ fm

FOR ENERGY LOSS: $\tau_0 \rightarrow 0$ LIMIT EXISTS

JET PROPAGATION IN TRANSVERSE DIRECTION

MODEL FOR BASIC SCATTERING

- PARTONIC MEDIUM / PLASMA



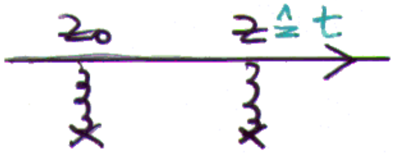
SCREENED ("DEBYE") "POTENTIAL"

$$V(\vec q_\perp^{\,2}) \equiv \frac{1}{\sigma}\frac{d\sigma}{d^2\vec q_\perp} = \frac{\mu^2}{\pi(\vec q_\perp^{\,2}+\mu^2)^2}$$

(M. GYULASSY + X.N. WANG MODEL) – <u>NO</u> COLLISIONAL LOSSES

EXPANDING MEDIUM: $\mu = \mu(T) \hat{=} \mu(z)$

- BETWEEN SCATTERINGS:
  SURVIVAL PROBABILITY



$$\exp\left[-\int_{z_0}^{z} dz'\,\underline{\underline{\rho(z')}}\,\sigma(z')\right]$$

(**NO EXPANSION** $\exp\left[-\frac{z-z_0}{\lambda}\right]$

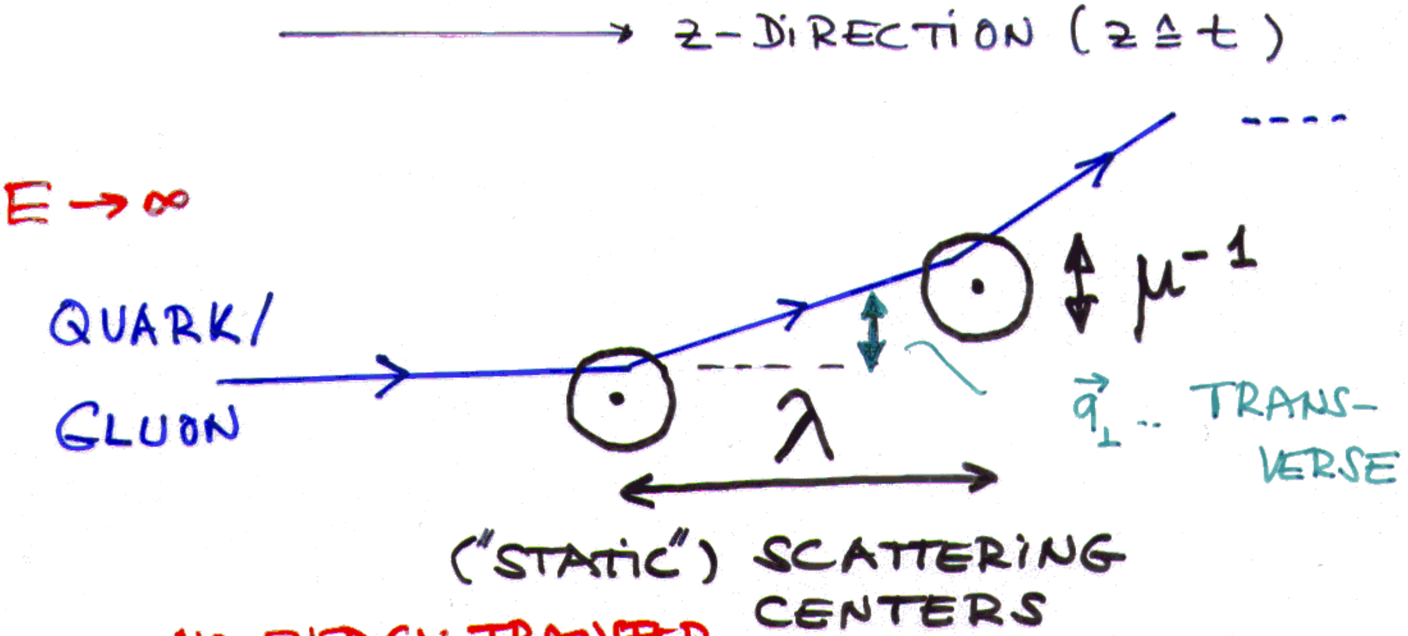
λ.. MEAN FREE PATH)

ρ.. DENSITY OF THE MEDIUM $\rho(T) \Rightarrow \rho(z)$

PROPERTIES OF MEDIUM – INTERACTION WITH QUARK / GLUON

MULTIPLE SCATTERING:

MEAN FREE PATH $\lambda \gg \mu^{-1}$ .. RANGE OF INTERACTION



NO ENERGY TRANSFER

E.G. PROPERTIES OF THE MEDIUM

ESTIMATES FOR HOT QCD, LEADING ORDER WITH $T \to \infty$

pQCD AT HIGH T:

$$\lambda \simeq \frac{1}{g_s^2 T} \gg \mu^{-1} \simeq \frac{1}{g_s T}$$

FOR $g_s(T) \to 0$

STRONG COUPLING

$\boxed{\text{ACTUAL DEPENDENCE: } \hat{q} \simeq \mu^2/\lambda}$

μ .. DEBYE (SCREENING) MASS AT HIGH TEMPERATURE T

PROPERTIES OF EXPANDING QG PLASMA

J.D. BJORKEN (PRD <u>27</u> (1983) 140)

- LONGITUDINAL EVOLUTION: $\frac{d\epsilon}{d\tau} = - \frac{\epsilon + p}{\tau}$

  HYDRODYNAMICS <u>IN τ</u>

- EQUATION OF STATE: $\epsilon = p\,(3 + \Delta_1)$

<u>pQCD:</u> $p = \frac{\pi^2}{90} T^4\, n(T) \quad \Rightarrow \Delta_1 \equiv \frac{1}{n} \frac{\partial n(T)}{\partial \ln T}$

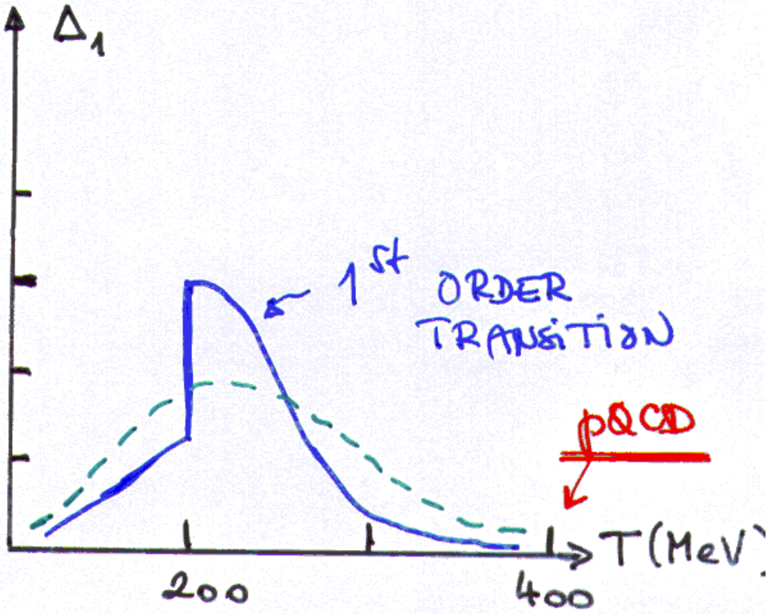
$$n(T) = 16 \left\{ F_0 + \dots + \left(\frac{\alpha_s}{\pi}\right)^2 \left[-\frac{165}{8}\left(1 + \tfrac{5}{12} n_f\right)\left(1 - \tfrac{2}{33} n_f\right) \times \ln\left(\mu/2\pi T\right) + \dots \right] + \dots \right\}$$

DUE TO INTERACTIONS:

$$\Rightarrow \Delta_1 = \frac{165}{8}\Big|_{n_f = 0} \left(\frac{\alpha_s}{\pi}\right)^2 \left(1 + \mathcal{O}(\alpha_s^{1/2})\right) \quad \left(\simeq 0.2\,;\ \alpha_s \simeq 1/3\right)$$

- RELATION TO T:

$$\frac{dp}{dT} = s = \frac{\epsilon + p}{T}$$



Δ_1 = CONST: ASSUMED!

$$\left(\frac{T}{T_0}\right)^3 = \left(\frac{\tau_0}{\tau}\right)^{\alpha}$$

$$0 \leq \alpha = \frac{1}{\underbrace{1 + \Delta_1/3}_{\equiv 3 v_{SOUND}^2}} \leq 1 \quad ; \quad v_{SOUND}^2 = \frac{1}{3 + \Delta_1} \leq \frac{1}{3}$$

"STATIC" ↑ FREE GAS

MAIN RESULT :

ENERGY LOSS (PER UNIT DISTANCE)
IN A HOT, FINITE SIZE MEDIUM L

QUARK PRODUCED INSIDE THE MEDIUM ($\tau_0 \to 0$ LIMIT) BY HARD SCATTERING AND TRAVERSES THE MEDIUM A DISTANCE L

$$-\frac{dE}{dz} = \frac{2}{2-\alpha}\left(-\frac{dE}{dz}\Big|_{\substack{\text{STATIC}\\ T=\text{CONST}}}\right)$$

NOTE : $\alpha = 1$ IDEAL GAS , $\alpha = 0$ $T =$ CONST

$$\leq 2\left(-\frac{dE}{dz}\Big|_{\text{STATIC}}\right)$$ i.E. "BOUNDED"!

AND

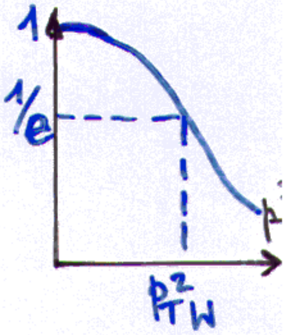
$$-\frac{dE}{dz}\Big|^{\text{INSIDE}}_{\text{STATIC}} = \frac{\alpha_s N_c}{4}\,\hat{q}(L)\,L \qquad \left(L \underset{E\to\infty}{\ll} \sqrt{\frac{E}{\hat{q}(L)}} \right.$$

i.E. AT $T = T(L)$ ... AFTER PASSING DISTANCE L

COHERENCE / INTERFERENCE :
INDEPENDENT OF $T_0 \gg T(L)$! $\quad \hat{q} \cong \frac{\mu^2(T)}{\lambda(T)}$
ALTHOUGH PASSED HOT T_0 LAYERS

RELATION TO BROADENING ("INCOHERENT") :

$$-\frac{dE}{dz} = \frac{\alpha_s N_c}{2}\,\frac{1}{2-\alpha}\,L\,\frac{\partial}{\partial L}\,p^2_{\perp W}(L)$$



E.G. $\alpha = 1$, $p^2_{\perp W}(L) \propto \hat{q}(L)\,L\,\underline{\ln(L/\tau_0)}$

$$= \int^{L} dt\,\hat{q}(t)$$

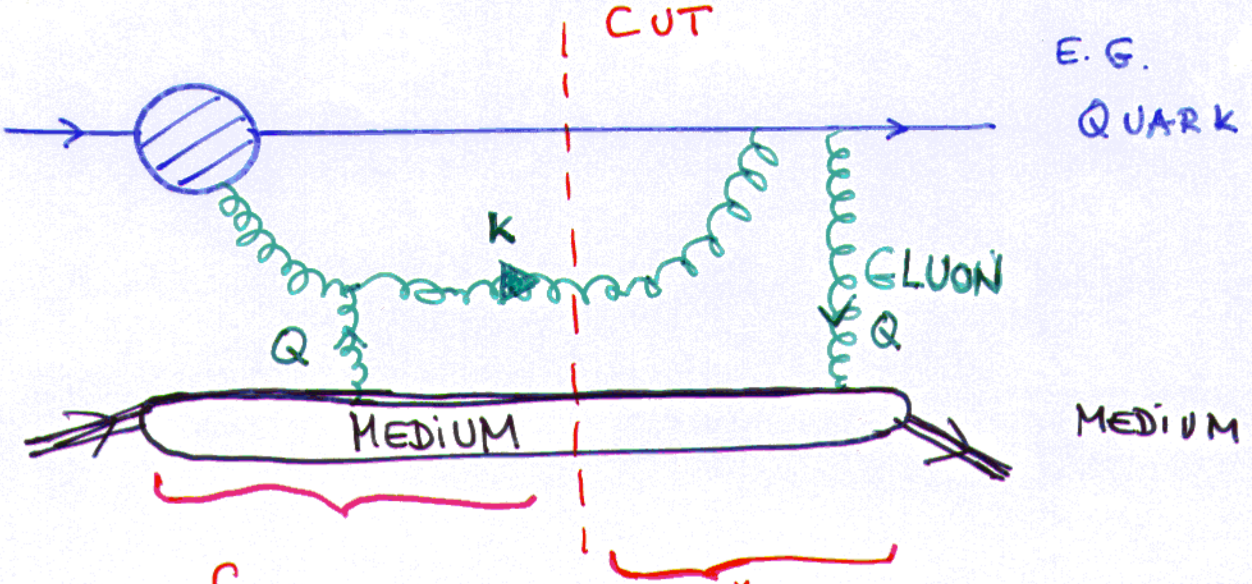
CRUCIAL OBSERVATION:

GLUON SPECTRUM INDUCED BY MULTIPLE SCATTERINGS IS DOMINATED BY

INTERFERENCE TERM OF AMPLITUDES

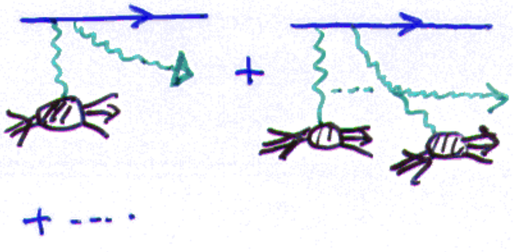
COHERENCE / FORMATION TIME

E.G. ONE CONVENIENT PRESENTATION FOR AN IMPORTANT CONTRIBUTION

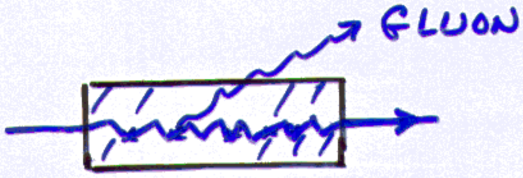


$$\hat{=}\ \alpha_s \int f \otimes f^*_{BORN}$$

CONTAINS ALL THE MULTIPLE INTERACTIONS: + RADIATION



COHERENCE LENGTH - GLUON SPECTRUM - RADIATIVE ENERGY LOSS



$\leftarrow l_c \rightarrow$: EFFECTIVELY ONLY <u>ONE</u> SCATTERING CENTER

$$l_c = (t_{FORM})_{l_c} \simeq \frac{\omega}{\langle k_\perp^2 \rangle_{l_c}} \simeq \frac{\omega}{l_c \, \mu^2/\lambda}$$

$$\Rightarrow 1/l_c \simeq \sqrt{\frac{\mu^2}{\lambda}\frac{1}{\omega}}$$

- MEDIUM OF FINITE LENGTH L

• $L \gtrsim L_{CR} = l_c(E) = \sqrt{E/\hat{q}(L)}$

• GLUON EMISSION PER UNIT DISTANCE - <u>SUPPRESSE</u>

$$\frac{\omega dI}{d\omega dz} \simeq \frac{1}{L}\frac{\omega dI}{d\omega}\Big|_L \simeq \frac{1}{l_c}\underbrace{\frac{\omega dI}{d\omega}\Big|_{l_c}}_{\text{SINGLE} = \frac{\alpha_s}{\pi}N_c}$$

$$\simeq \frac{\alpha_s}{\pi}N_c \underline{\sqrt{\frac{\mu^2}{\lambda}\frac{1}{\omega}}}$$

• LOSS : $\underline{-\frac{dE}{dz}} = \int_0^{\omega_{fact}} d\omega \, \frac{\omega dI}{d\omega dz}$

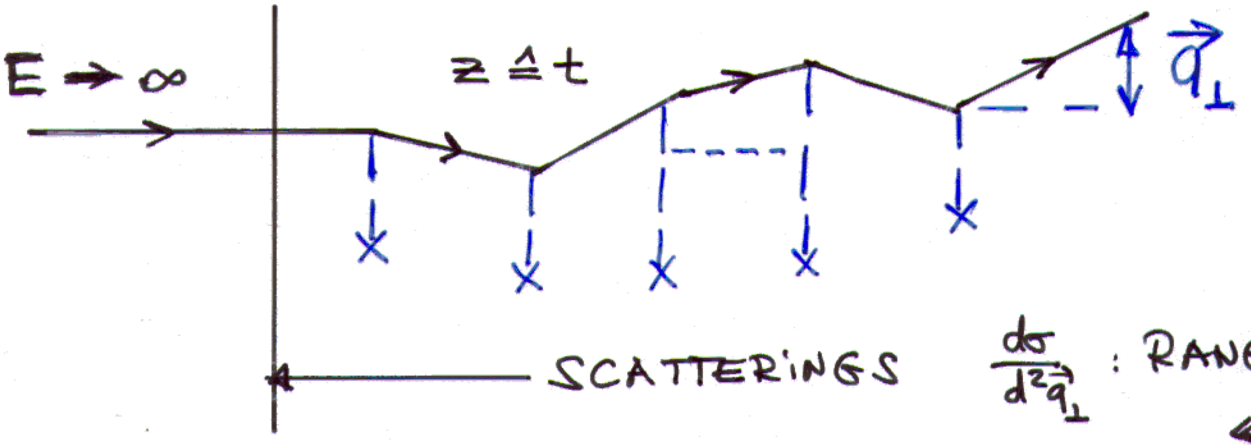
FOR $E \to \infty$

$L \ll L_{CR}$

$\Leftrightarrow \omega_{fact} \simeq \frac{\mu^2}{\lambda} L^2 < E$

$$\simeq \frac{\alpha_s}{\pi} N_c \sqrt{\frac{\mu^2}{\lambda}} \sqrt{\omega_{fact}} \simeq \underline{\frac{\alpha_s}{\pi} N_c \hat{q} L}$$

EQUATIONS - JET BROADENING



$\frac{d\sigma}{d^2\vec q_\perp}$: RANGE $1/\mu \ll \lambda$

PROBABILITY DISTRIBUTION IN $\vec q_\perp$ AND t

MASTER EQUATION

$$\frac{\partial f(\vec q_\perp,t)}{\partial t} = -\int f(\vec q_\perp,t)\,\rho(t)\,\frac{d\sigma}{d^2\vec q_\perp'}(\vec q_\perp-\vec q_\perp',t)\,d^2q_\perp' \quad \text{.. LOSS}$$

$$+\int f(\vec q_\perp',t)\,\rho(t)\,\frac{d\sigma}{d^2\vec q_\perp'}(\vec q_\perp'-\vec q_\perp,t)\,d^2q_\perp' \quad \text{-- GAIN}$$

$V(\vec q_\perp,t) = \frac{1}{\sigma}\frac{d\sigma}{d^2\vec q_\perp}$ AND μ, λ MAY DEPEND ON t

(EXPANDING MEDIUM)

IMPACT SPACE : $\underline{\tilde V(\vec b,t) = \int d^2\vec q_\perp\, e^{-i\vec b\cdot\vec q_\perp}\, V(\vec q_\perp,t)}$

$$\lambda(t)\,\frac{\partial \tilde f(\vec b,t)}{\partial t} = -\underbrace{\left(1-\tilde V(\vec b,t)\right)}_{}\tilde f(\vec b,t)$$

"DIPOLE TYPE CROSS SECTION"

QCD: $\vec b \simeq 0 \quad 1-\tilde V(\vec b,t) \simeq \vec b^2/4\;\mu^2(t)\,\underbrace{\ln(1/\vec b^2)}_{}$

TRANSPORT COEFFICIENT : $\hat q(t) = \frac{\mu^2(t)}{\lambda(t)}\tilde v$

EQUIVALENCE BETWEEN BDMPS AND FUNCTIONAL INTEGRAL APPROACH BASED ON "DOMINANCE" OF DIPOLE CROSS SECTIONS

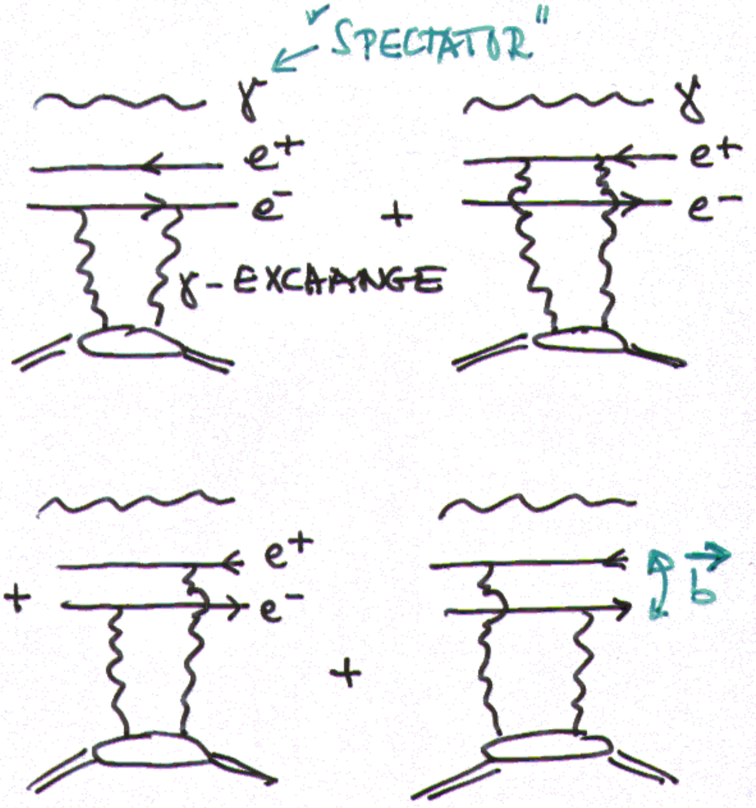
(B.G. ZAKHAROV††)

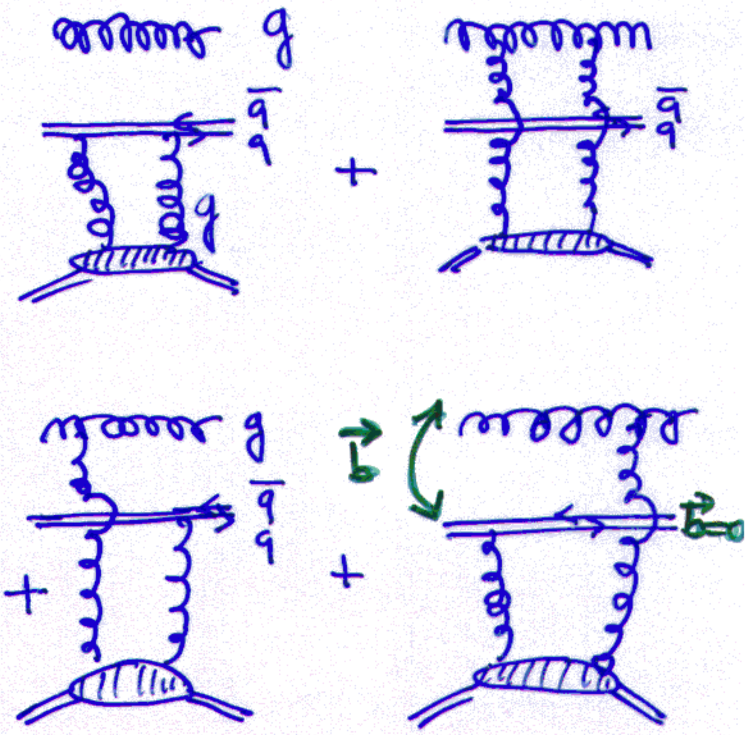
$$\int d^2\vec{q}_\perp \left(1 - e^{-i\vec{b}\cdot\vec{q}_\perp}\right) \frac{1}{\sigma}\frac{d\sigma}{d^2\vec{q}_\perp}$$

$$\hat{=} \; 1 - \tilde{V}(\vec{b}) \overset{\text{QCD}}{\simeq} \frac{\vec{b}^2}{4}$$ UP TO LOG FACTORS

QED

QCD (x=0, SOF
+ COLOUR FACTORS





2-GLUON EXCHANGE
q̄q.. OCTET

IMPORTANCE OF GLUON INTERACTING WITH THE MEDIUM
(COLOUR SINGLET X-SECTION)

---

†† PHYS. ATOM. NUCL. 61 (1998) 838

- (SOFT) GLUON RADIATION (HERE FOR $N_c \to \infty$)

$$\frac{\partial \vec{\tilde{f}}(\vec{b},t)}{\partial t} = \Big[\underbrace{-\frac{i}{2\omega}\vec{\nabla}_{\vec{b}}^{2}} - \frac{\vec{b}^{2}}{4} 2\hat{q}(t)\Big]\vec{\tilde{f}}(\vec{b},t)$$

QUANTUM MECHANICS : PHASE $\exp[it\vec{k}_\perp^2/2\omega] = \exp[it/t_{form}]$

$\vec{\tilde{f}}$ .. TWO-POLARIZATIONS FOR GLUON

"SCHROEDINGER" EQ. FOR "HARMONIC" OSCILLATOR WITH (IMAGINARY) FREQUENCY, WHICH IS TIME DEPENDENT IN EXPANDING CASE:

$$\hat{q}(t) \simeq t^{-\alpha} \qquad 0 \leq \alpha \leq 1$$

- MEDIUM INDUCED (SOFT) GLUON SPECTRUM

$$\frac{\omega\, dI^{\text{QUARK-OUTSIDE}}}{d\omega\, dz} \simeq \frac{\alpha_s N_c}{\pi^2} \mathrm{Re}\Big\{ \int_{\tau_0}^{L} dt_2 \int_{\tau_0}^{t_2} dt_1\, \hat{q}(t_2)\hat{q}(t_1) \int \frac{d^2\vec{b}}{(2\pi)^2}\Big[\vec{\tilde{f}}^{*}(\vec{b};t_2,t_1)\cdot \vec{\tilde{f}}_{BORN}(\vec{b};t_2)\Big]\Big|_{\omega}^{\omega\to\infty}\Big\}$$

i.E. INTERFERENCE

AND GREEN: $\vec{\tilde{f}}(b;t_2,t_1) = \int d^2\vec{b}'\, G(\vec{b},t_2;\vec{b}',t_1)\vec{\tilde{f}}_{BORN}(\vec{b}';t_1$

$$\vec{\tilde{f}}_{BORN}(\vec{b}) \sim i\pi\vec{b}$$

QUARK / GLUON JET AND EXPANDING QG PLASMA
(BASED ON SOFT EMISSION $x \to 0$)

"ESTIMATE" FOR ENERGY LOSS ("INSIDE")

- FIXED TEMPERATURE ; $E \to \infty$

$$-\frac{dE^{quark}}{dz} \hat{=} \frac{\alpha_s N_c}{4} \frac{\mu^2}{\lambda_q} L \ln(L/\lambda_q)$$

$$\mu^2/\lambda_q \hat{=} \frac{48}{\pi} \alpha_s^2 \zeta(3) T^3 \quad (n_F = 2)$$

TAKE $T \simeq 200$ MeV, $L = 10$ fm (FINITE SIZE)

$$-\frac{dE^{quark}}{dz} \simeq \mathcal{O}(1) \ln(L/\lambda_q)\ \mathrm{GeV/fm} \qquad (\alpha_s \simeq 1/3)$$

$$\lesssim (1-2)\ \mathrm{GeV/fm}$$

NOTE α_s^3-DEPENDENC

- EXPANDING CASE : $T_{FINAL}(L) \simeq T_c \simeq 200$ MeV

HARD QUARK JET

$$-\frac{dE^{quark}}{dz} \lesssim \mathcal{O}(4\ \mathrm{GeV/fm})$$

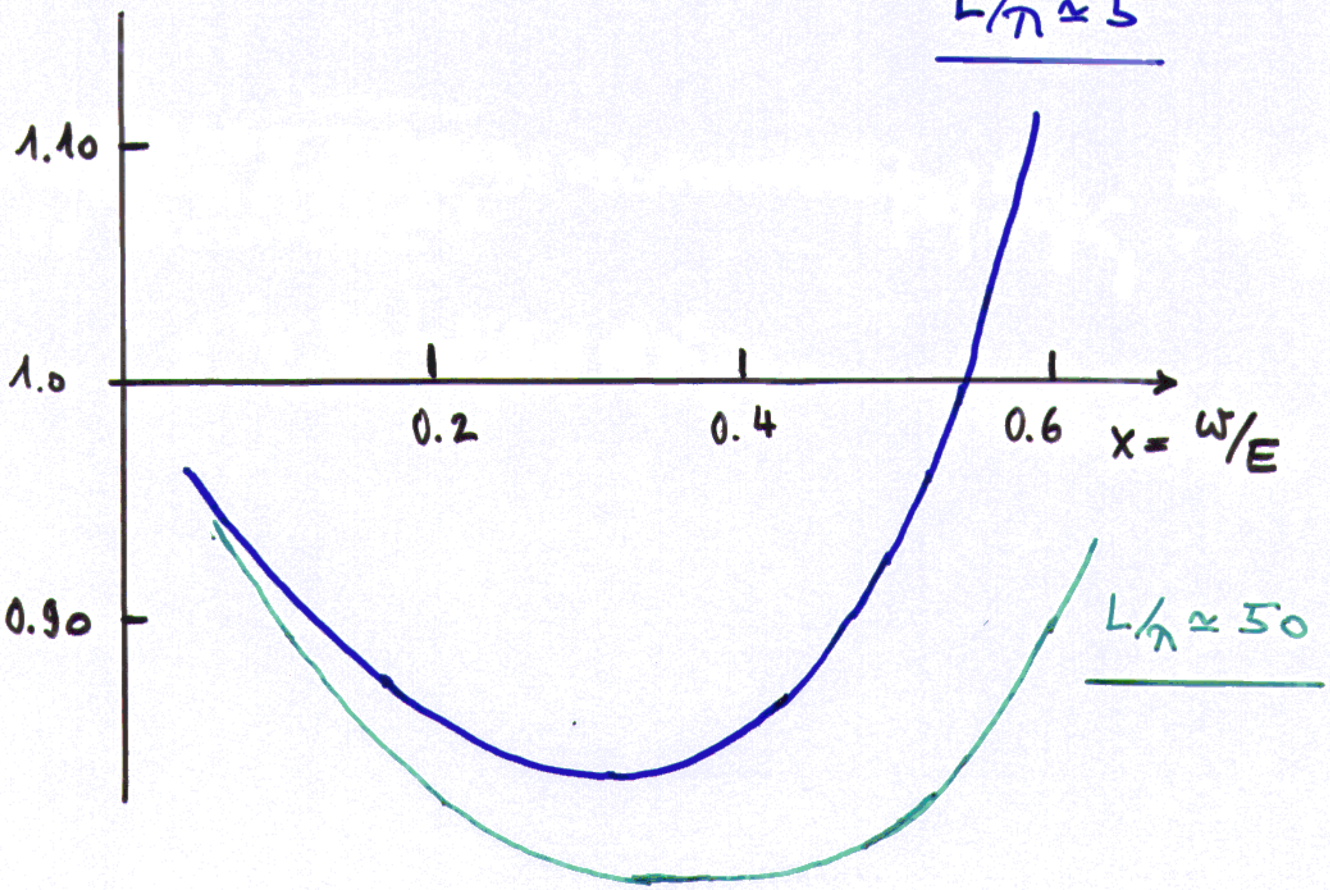
WITH $L = 10$ fm

$$\Rightarrow \Delta E^{GLUON} = N_c/C_F\, \Delta E^{QUARK} \simeq 9/4\, \mathcal{O}(40\ \mathrm{GeV})$$

LARGE JET ATTENUATION IN QGP

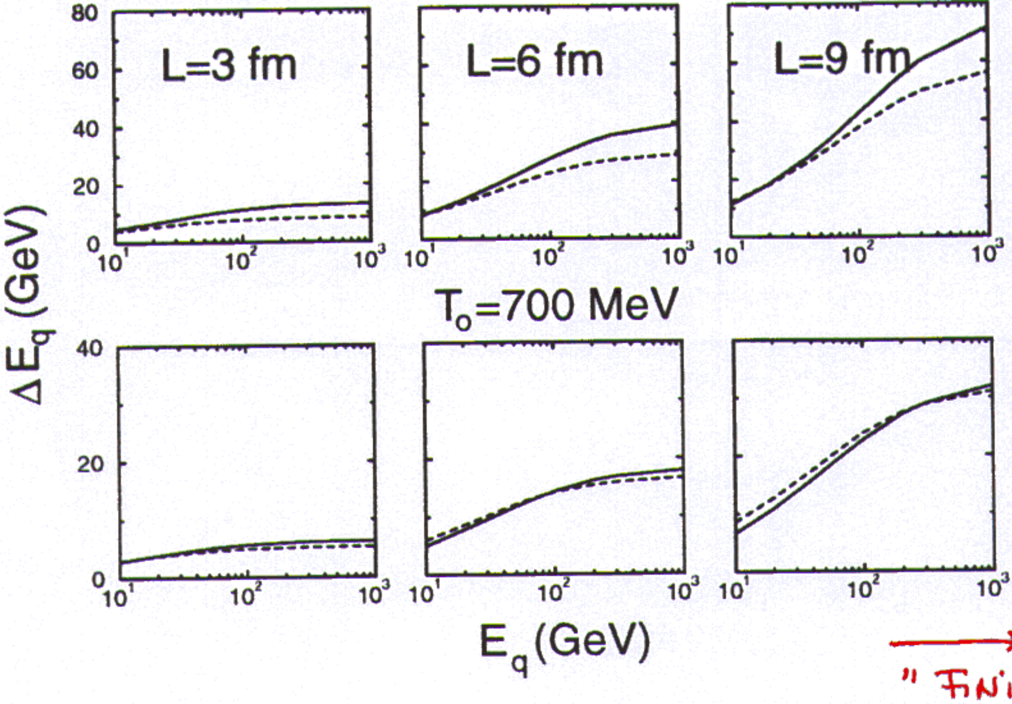
(REMARK: FOR LARGE JET ENERGIES $\mathcal{O}$(100 GeV

$\frac{\text{HARD}}{\text{SOFT}}$ GLUON RADIATION



$\Longrightarrow$ SOFT APPROXIMATION FOR ESTIMATING ENERGY LOSS IS JUSTIFIED

(NOTE: SOFT EMISSION $\simeq \omega^{-1/2}$)



→

"FINITE" SIZE

$E \to \infty$

Figure 1: The quark energy loss as a function of the quark energy for $m_q = 0.2$ GeV, $m_g = 0.75$ GeV (solid line) and $m_g = 0.375$ GeV (dashed line).

EXPANDING MEDIUM

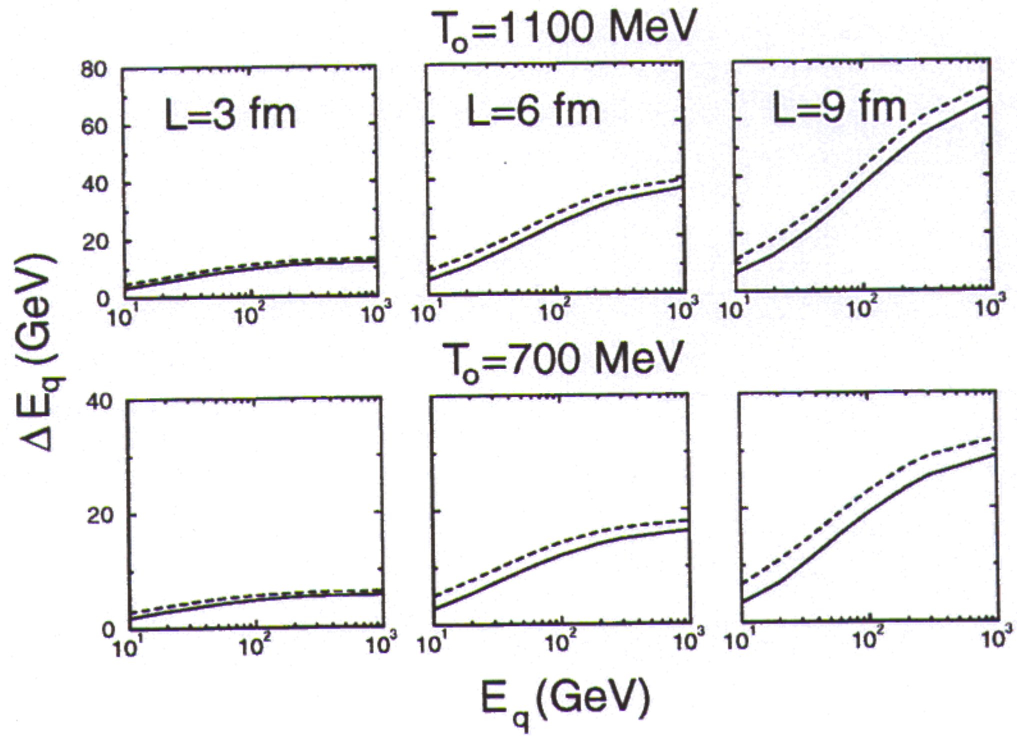


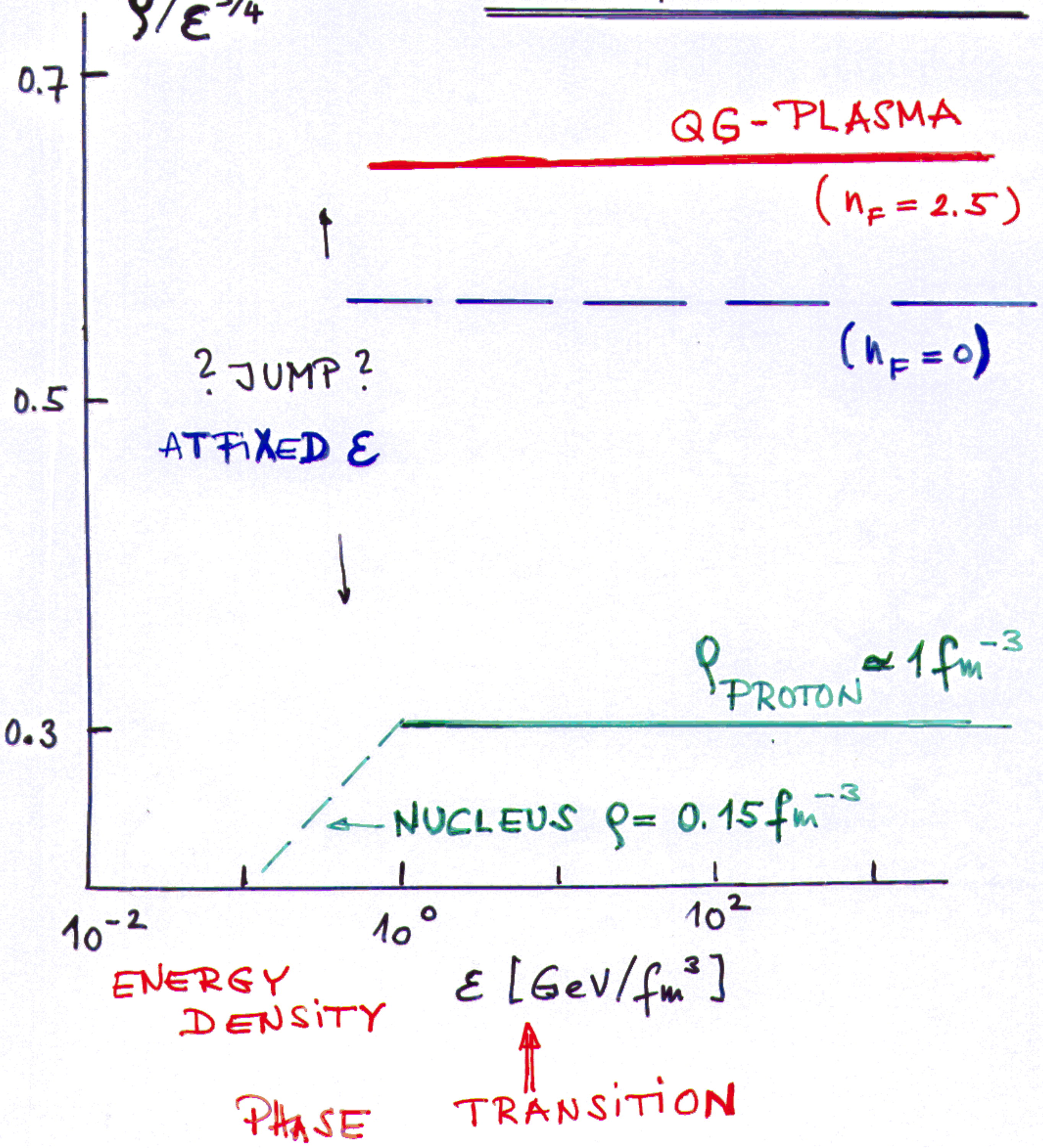
Figure 2: The quark energy loss as a function of the quark energy for $m_g = 0.75$ GeV, $m_q = 1.5$ GeV (solid line) and $m_q = 0.2$ GeV (dashed line).

B. G. ZAKHAROV (hep-ph/9807396)

CAN ONE EXPECT

"DISCONTINOUS" BROADENING AND ENERGY LOSS ? (AT FIXED ε)

$\Delta E \propto \rho$ AND $\langle p_T^2 \rangle \propto \rho$



"TRANSPORT COEFFICIENT" $\hat{q}$

IS EXPRESSED BY

- **HOT / PLASMA** ⇒

$$\hat{q} \equiv \frac{\mu^2}{\lambda_g}\tilde{v} \simeq \sum_{P=g,q} \underbrace{\rho_P(T)}_{\text{PARTONS IN PLASMA-DENSITY}} \underbrace{\int_0^{Q^2} d^2\vec{q}_\perp\, \vec{q}_\perp^{\,2} \frac{d^2\sigma_{gP}}{d^2\vec{q}_\perp}}_{\text{"WEIGHTED" GLUON-PARTON } \underline{X}}$$

VIA GLUON-EXCHANGE

$\rho(T) \simeq T^3$

- **COLD / NUCLEAR MATTER**

$$\hat{q} \equiv \frac{\mu^2}{\lambda_g}\tilde{v} \simeq \frac{4\pi^2\alpha_s N_c}{N_c^2-1}\,\rho_{MATTER}\; \times \underbrace{G_N(x, Q^2)}_{\text{GLUON STRUCTURE FUNCTION}}$$

$x \simeq 0.05 - 0.1$

$Q^2 \simeq \mathcal{O}(10\ \text{GeV}^2)$

i.e. LOSS ≈ DENSITY OF MEDIUM × "EFFECTIVE" GLUON-MEDIUM $\underline{X}$ / STRUCTURE FUNCTION

(HOT MEDIUM : $xG_q(x, Q^2) \simeq \frac{\alpha_s C_F}{\pi} \ln Q^2$)

MEASUREMENT OF ENERGY LOSS FOR A JET:

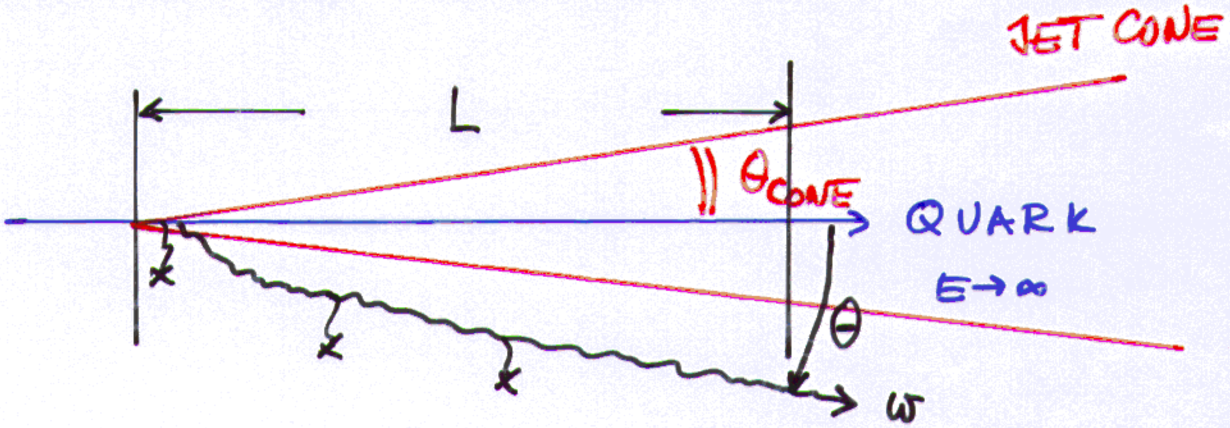
ANGULAR DISTRIBUTION OF GLUON RADIATION

CHARACTERISTICS:

$$t_{FORM} \simeq \frac{\omega}{\langle k_\perp^2 \rangle_L} = L$$

RANDOM WALK $\langle k_\perp^2 \rangle_L = \mu^2 L/\lambda$

$$\left.\begin{array}{l} t_{FORM} \simeq \frac{\omega}{\langle k_\perp^2 \rangle_L} = L \\ \langle k_\perp^2 \rangle_L = \mu^2 L/\lambda \end{array}\right\} \langle k_\perp^2 \rangle_L \simeq \sqrt{\frac{\mu^2}{\lambda}\omega}$$



RADIATION ANGLE $\langle \theta^2 \rangle_L \propto \frac{\langle k_\perp^2 \rangle_L}{\omega^2} = \frac{\sqrt{\mu^2/\lambda}}{\omega^{3/2}}$

ESTIMATE: ENERGY LOSS $\Delta E = \frac{\alpha_s N_c}{4} \mu^2/\lambda \, L^2$

- $\omega \simeq \Delta E$ AND $\mu^2/\lambda = \frac{\Delta E}{\left(\frac{\alpha_s N_c}{4}\right) L^2}$

$$\Rightarrow \langle \theta^2 \rangle_L \simeq \frac{2}{\sqrt{\alpha_s N_c}\, \Delta E \, L}$$

$$\left\{\begin{array}{l} \Delta E = 20 \text{ GeV} \\ L = 10 \text{ fm} \\ \sqrt{\langle \theta^2 \rangle_L} \simeq 3^\circ \end{array}\right.$$

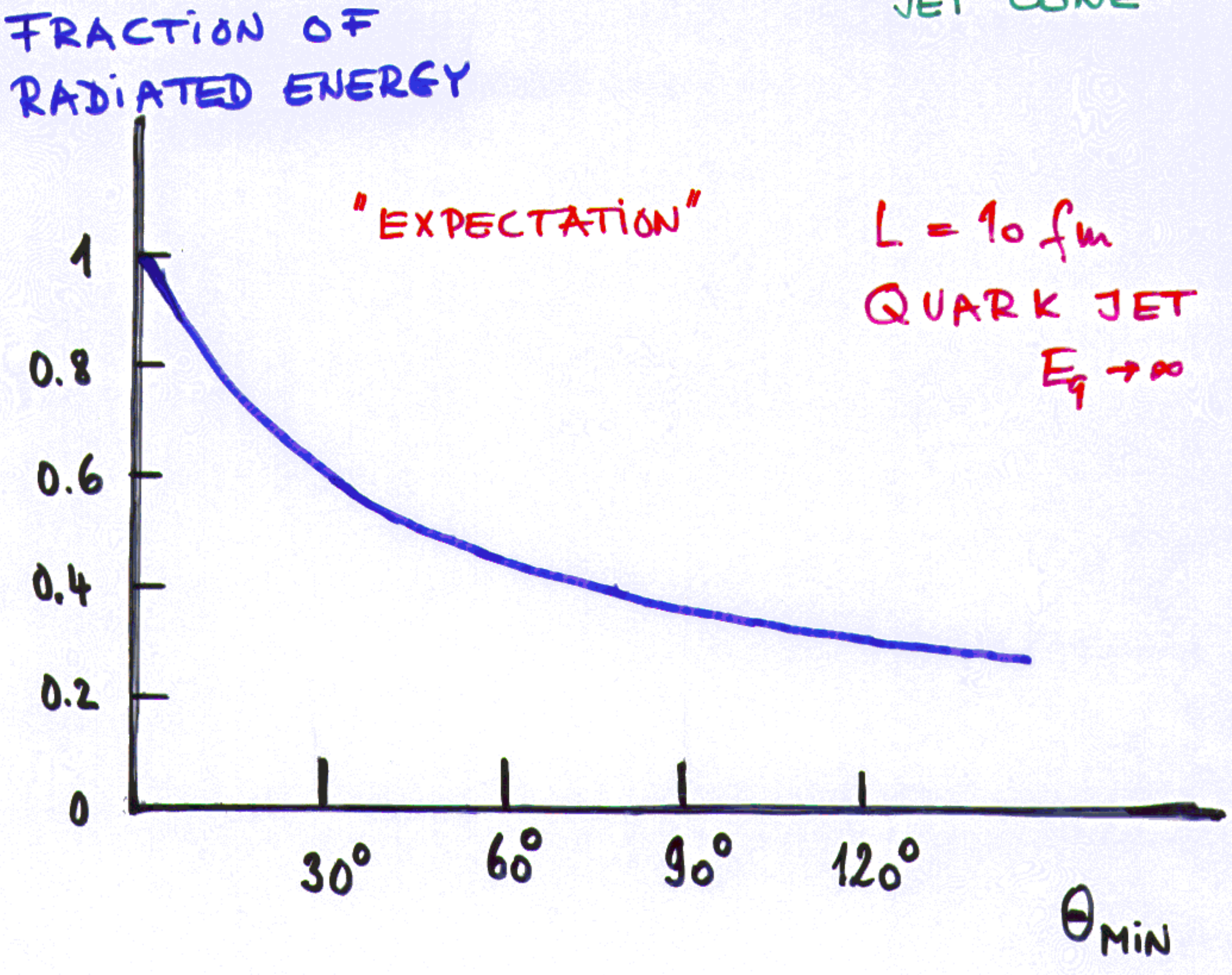
REQUIRES SMALL CONES $\theta_{CONE} \lesssim \sqrt{\langle \theta^2 \rangle_L} \simeq 5^\circ$!

(I. P. LOKHTIN AND A. M. SNIGIREV, PL B440 (98) 163)

AIM TO PREDICT:

$$\int_{\theta_{MIN}}^{\infty} \frac{\omega dI}{d\omega dz d\theta} d\omega d\theta \Big/ \left(- \frac{dE}{dz}\right)$$

θ_{MIN} .. ANGULAR JET CONE



L = 10 fm
QUARK JET
$E_q \to \infty$

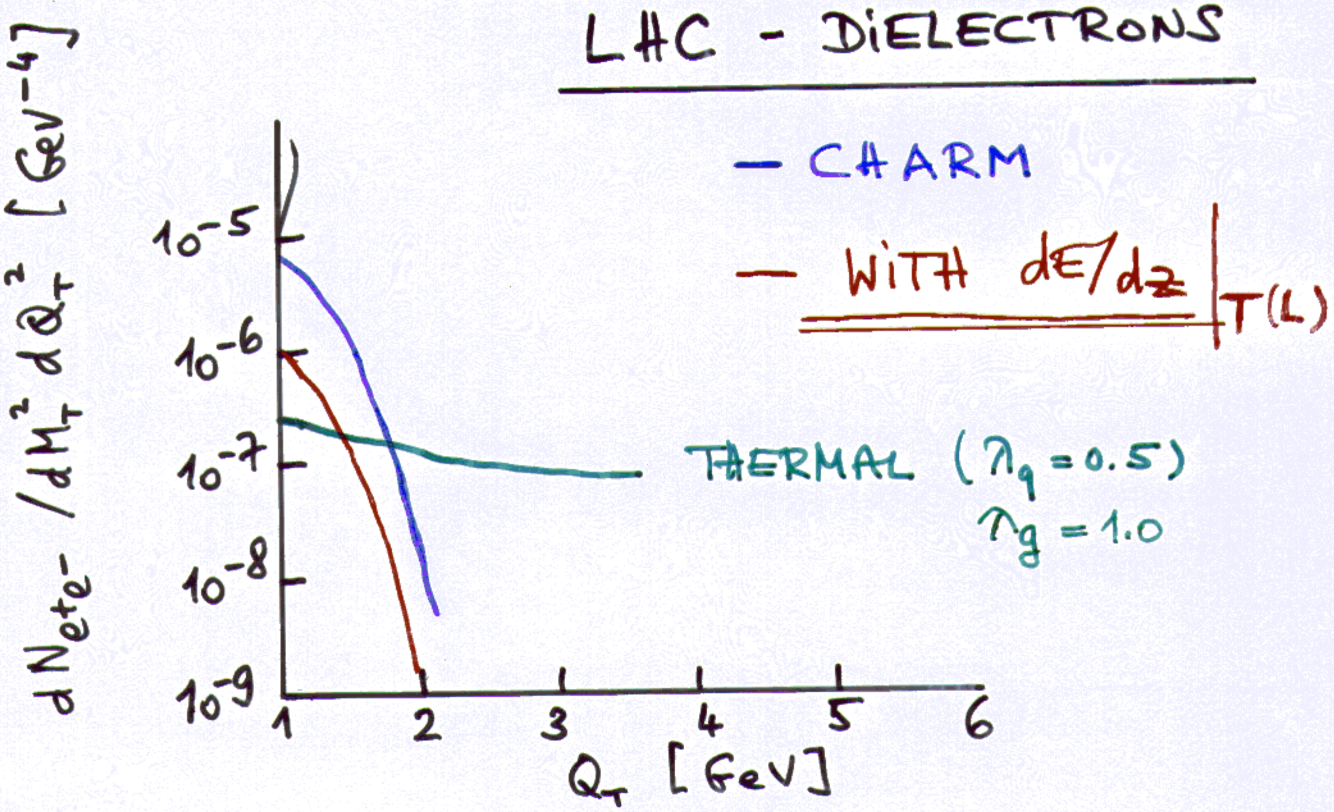
(IN PROGRESS)

COLD VS. HOT MATTER
ETC.

APPLICATIONS

A FEW SELECTED EXAMPLES

LHC - DIELECTRONS



WITH CUTS: $p_T^{e^\pm} > 2$ GeV
$5.25 < M_\perp < 5.75$ GeV } ALICE

DILEPTON SIGNAL IN HEAVY-ION COLLISIONS - EXPANDING MEDIUM

K. GALLMEISTER, B. KÄMPFER AND O.P. PAVLENKO
(PL **B419** (98) 412)

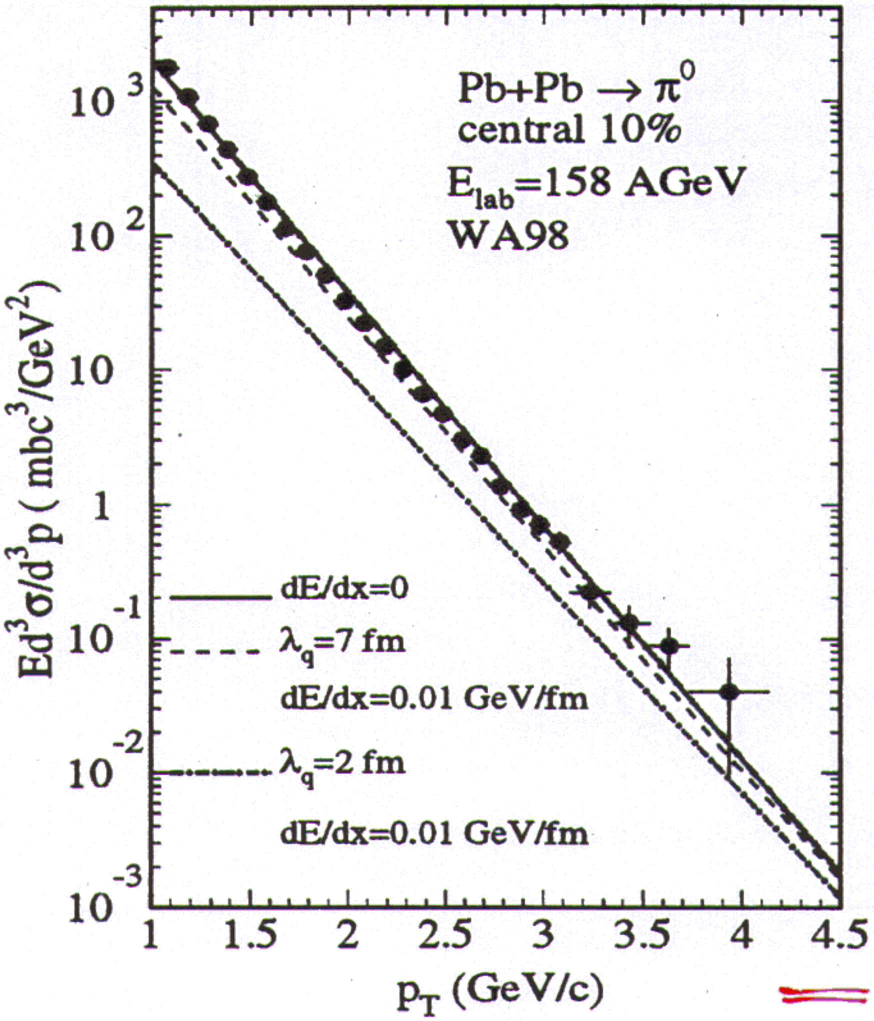
- PHENOMENOLOGICAL SIGNIFICANCE OF (INITIAL STATE) ENERGY LOSS (IN EXPANDING QCD-PLASMA)

XIN-NIAN WANG : nucl-th/9812021

PRL 81 (98) 2655

PRC 58 (98) 2321

WHERE TO SEE ENERGY LOSS ?



Parton model calculations of single-inclusive spectra of π^0 with different values of parton energy loss dE_q/dx and mean free path λ_q in central $Pb + Pb$ collisions at $E_{\rm lab} = 158$ AGeV/. The Experimental data are from Ref. [11].

REMARK : "SMALL" JET ENERGIES
< 10 GeV

M. GYULASSY AND P. LEVAI

hep-ph/9807247

• "JET QUENCHING AND CRONIN ENHANCEMENT IN A+A AT $\sqrt{s}$= 20 VS 200 AGeV"

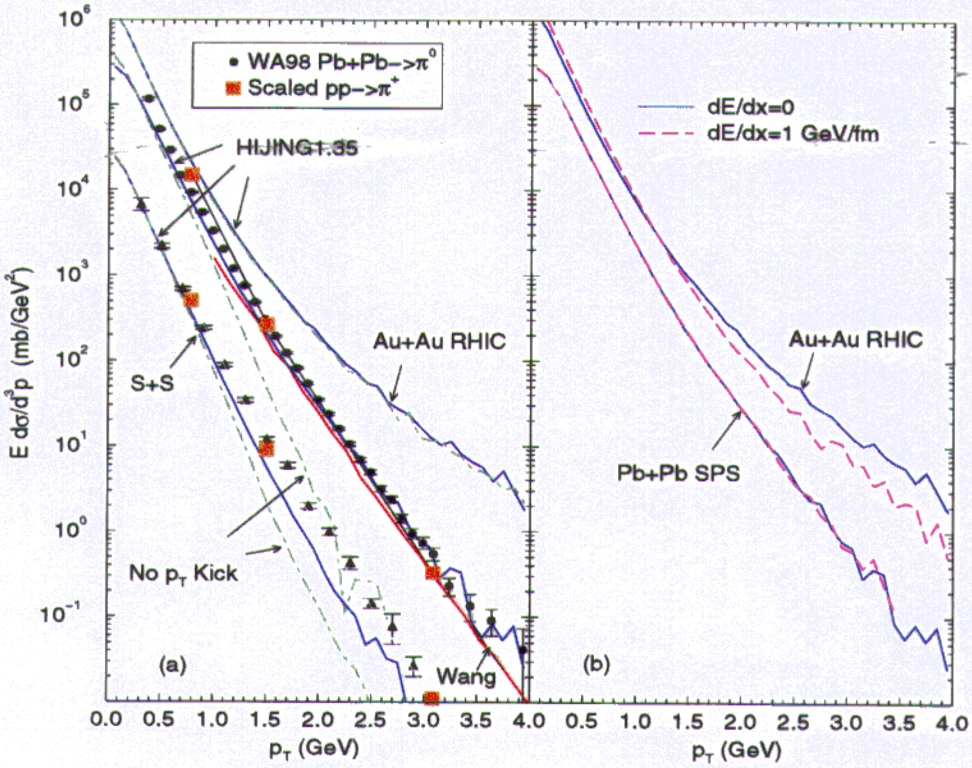


Figure 1: Invariant $A + A \to \pi^0$ cross section for central collision at SPS and RHIC energies are compared. a) The WA80 $S + S$ data [4] (triangles) and the preliminary WA98 $Pb + Pb$ data [1] (dots) are compared to HIJING1.35 [11] with soft $p_\perp$ kicks (full lines) and without p_T kicks (dot-dashed curves). The later scale with the wounded projectile number times σ_{AA} times the invariant distribution calculated for pp. The parton model curve from Ref. [2] is labeled by 'Wang'. The filled squares show $pp \to \pi^+$ data scaled by the (Glauber) number of binary collisions times σ_{AA} for both SS and $PbPb$. b) Jet quenching, predicted at RHIC energies[6], is not significant at SPS energies in the HIJING model.

SUMMARY

- THEORETICAL POINT OF VIEW:

  REMARKABLE PROPERTIES OF PARTON PROPAGATION THROUGH DENSE MATTER

  RADIATIVE MEDIUM INDUCED LOSS $\gg$ COLLISIONAL LOSS

  RADIATIVE ONE DUE TO INTERFERENCE/ DOMINATED BY INTERACTING GLUON

- TESTABLE PREDICTIONS:

  E.G.

$$(-\Delta E)_{\mathrm{QGPLASMA}} \gg (-\Delta E)_{\substack{\mathrm{NUCLEAR}\\ \mathrm{MATTER}}}$$

$$-dE/dz \simeq \frac{\alpha_s N_c}{2} L \frac{\partial}{\partial L} p_T^2(L) \lesssim \frac{\alpha_s N_c}{2} \hat{q}(L) L$$

- ANGULAR DISTRIBUTION OF ENERGY LOSS (IN PROGRESS) - JET PROPERTIES

- ACTUAL TESTS AND FORTHCOMING EXPERIMENTS
  - DILEPTONS, E.G. FROM CHARM
  - γ- JET IN A + A
