Jet physics : from RHIC to LHC

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Jets at low $\sqrt{s}$: RHIC p+p
studied by di-hadron correlation

Jet "quenching" at RHIC in Au+Au :

- first look at inclusive high p_T hadro-production suppression
- Jet suppression in central Au+Au @ RHIC
- Jet re-appearance @ RHIC at high p_T

The mechanism of quenching : gluon radiative energy loss in-medium

$\Rightarrow \hat{q}$ the transport coefficient

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100 - 150 GeV - jets at LHC :

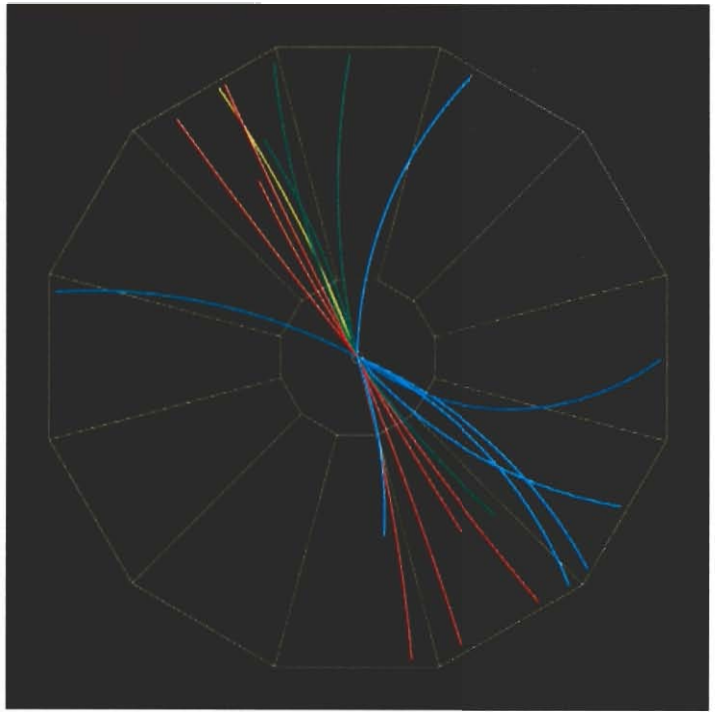
- interior black hole again ?
- new method : jet cone multihadron analysis

Emission pattern of the "quenched" energy ?
" Mach - cones " ?

RHIC @ $\sqrt{s} = 200$ GeV

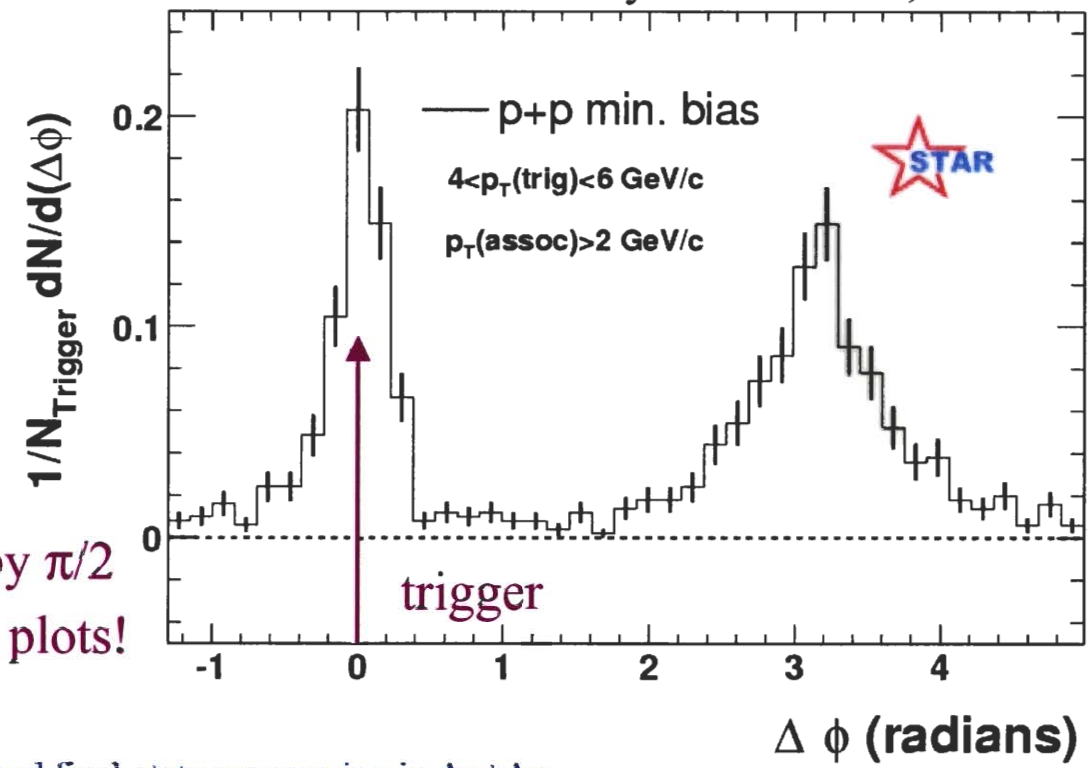
Jets and two-particle azimuthal distributions

p+p → dijet



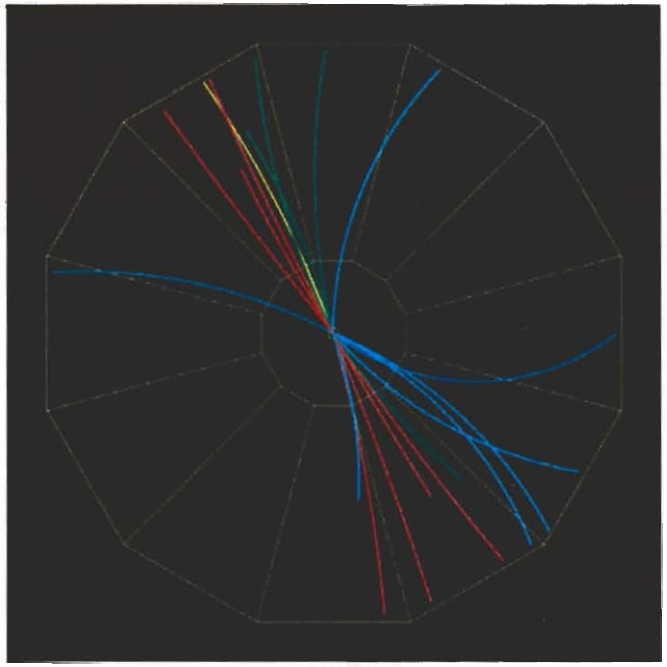
- trigger: highest p_T track, p_T>4 GeV/c
- $\Delta\phi$ distribution: 2 GeV/c<p_T<$p_T^{trigger}$
- normalize to number of triggers

Phys Rev Lett **90**, 082302

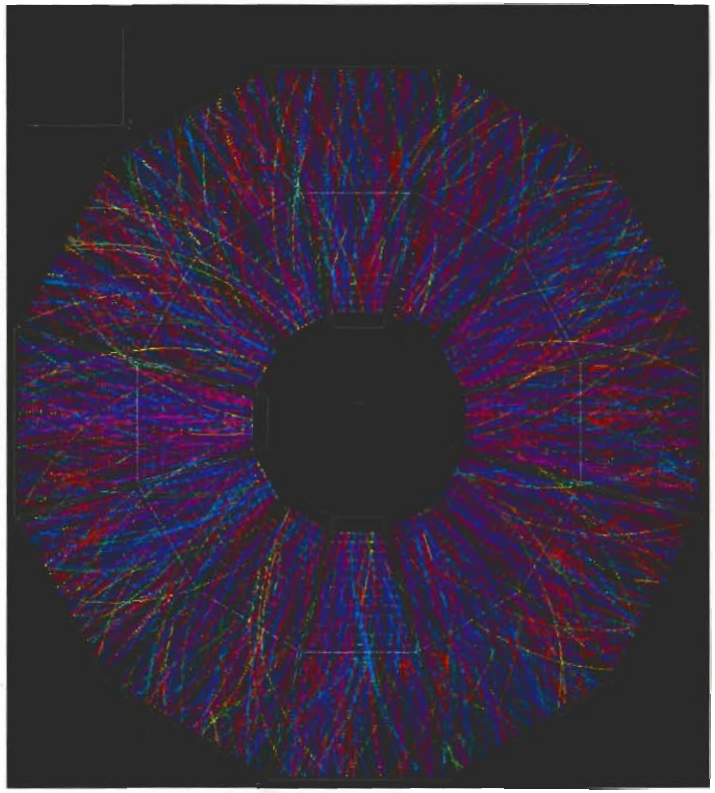


N.B. shifted horizontally by $\pi/2$ relative to previous STAR plots!

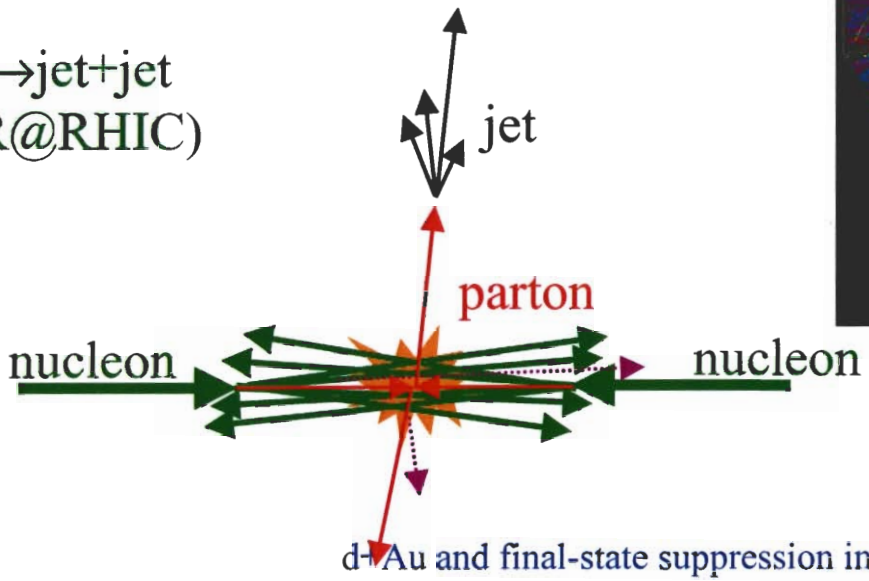
Jets at RHIC



Find this…….in this

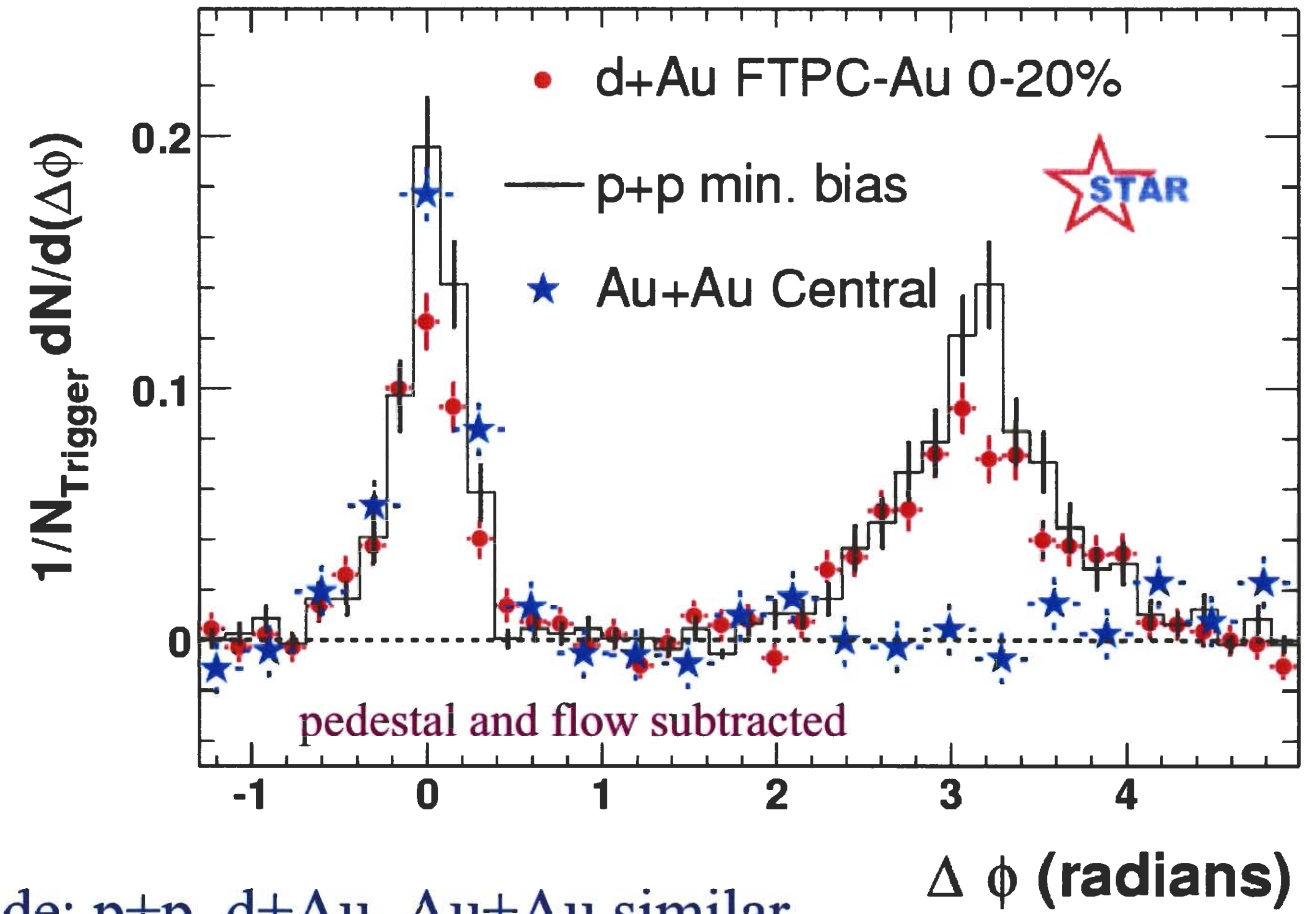


p+p →jet+jet
(STAR@RHIC)



Au+Au →???
(STAR@RHIC)

Azimuthal distributions

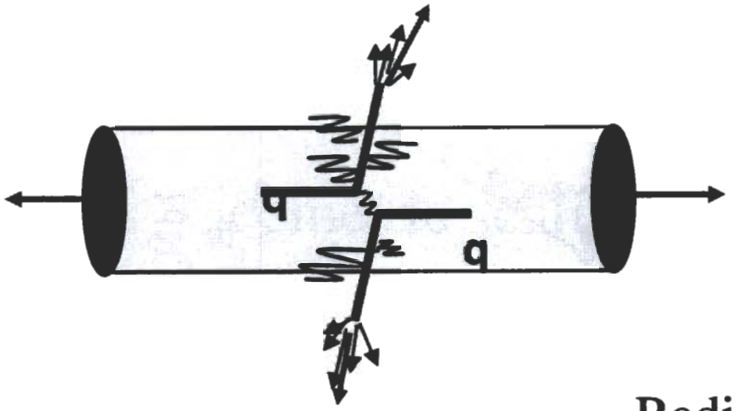


Near-side: p+p, d+Au, Au+Au similar

Back-to-back: Au+Au strongly suppressed relative to p+p and d+Au

Suppression of the back-to-back correlation in central Au+Au is a final-state effect

Jet Quenching

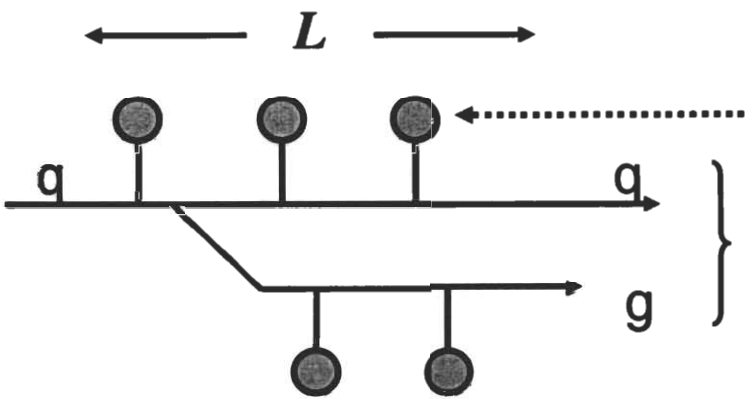


from perturbative QCD

High-energy parton loses energy by rescattering in dense, hot medium.

!! well controlled source

Radiative energy loss: $dE/dx \sim \rho L \langle k_T^{\,2} \rangle$



Scattering centers = color charges

medium modifed jet

Can be described as medium effect on the final parton fragmentation to hadrons h with p_T fraction $0 < z \leq 1$

$$D_{p\to h}(z,Q^2) \to \tilde{D}_{p\to h}(z,Q^2) \approx D_{p\to h}\left(\frac{z}{1-\Delta E/E}, Q^2\right)$$

the "fragmentation function" partons → hadrons gets modified

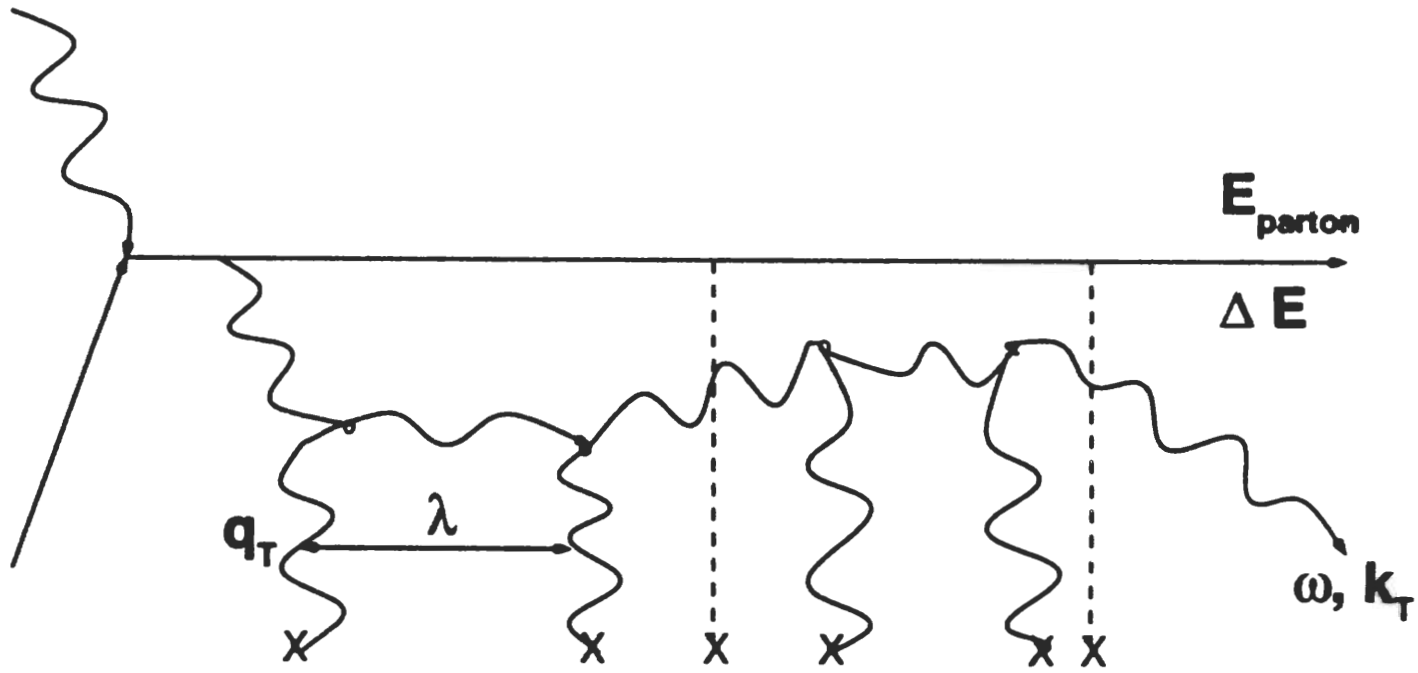


Figure 3.14: Typical gluon-radiation diagram, adapted from [166]

Energy loss in QCD

vs. in medium path L

$\frac{dE}{dx} \propto \hat{q} L \rightarrow \langle \Delta E \rangle_L \propto \hat{q} L^2$

Density of scattering centers

Scattering "power" of QCD medium:

$$\hat{q} = \rho \int q^2 dq^2 \frac{d\sigma}{dq^2} \equiv \rho\sigma \left\langle k_T^2 \right\rangle = \lambda_F^{-1} \left\langle k_T^2 \right\rangle$$

Property of medium (range of color force)

For power law parton spectrum ($\sim p_T^{-\nu}$) energy loss leads to an effective momentum shift for fast partons (BDMS):

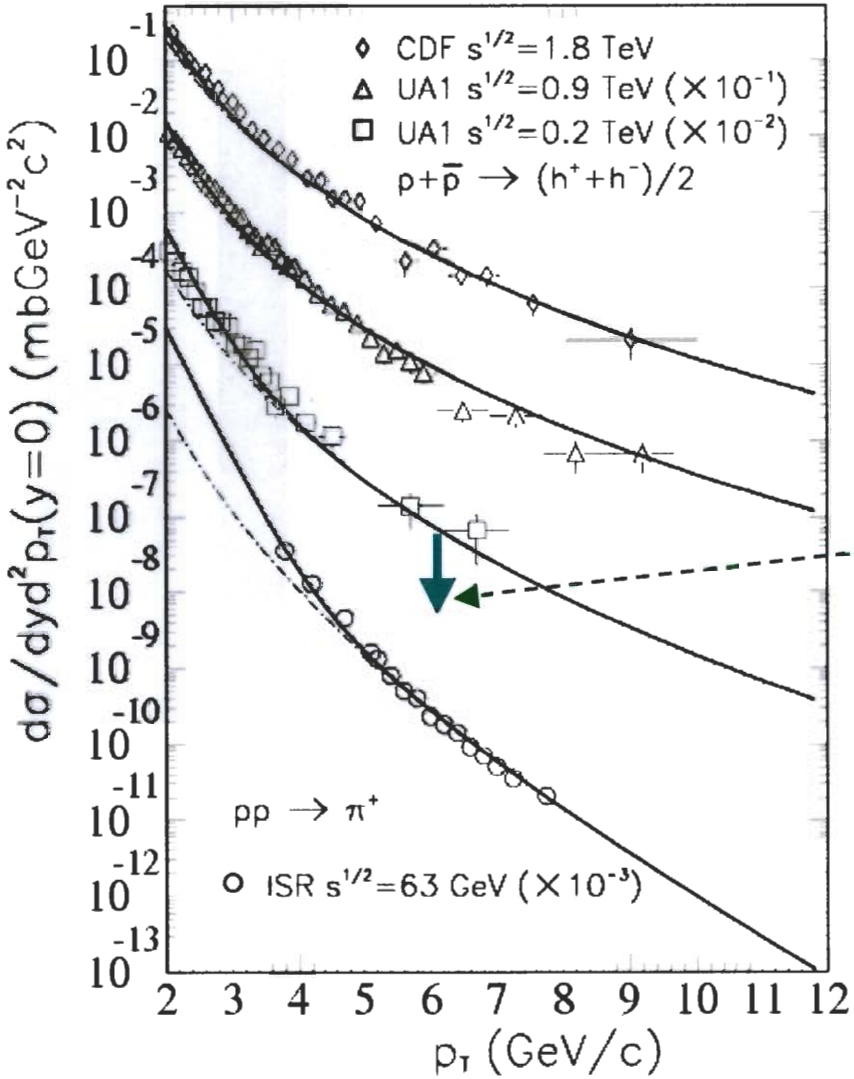
- Liu, Rajagopal, Wiedemann hep-ph/0605178

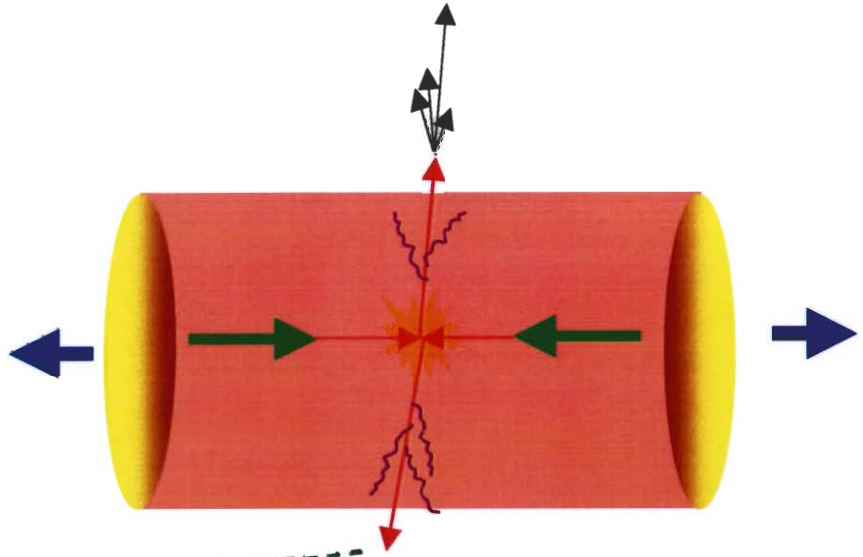
$$\Delta p_T \approx -\alpha_s \sqrt{\pi \hat{q} L^2 p_T / \nu}$$

With expansion:

$$\hat{q} \quad \Rightarrow \quad \hat{q}_{\text{eff}} = \frac{2}{L^2} \int_{\tau_0}^{L} d\tau (\tau - \tau_0) \hat{q}(r_\tau, \tau)$$

Partonic energy loss via leading hadrons





Energy loss ⇒ softening of fragmentation ⇒ suppression of leading hadron yield

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA}\, d^2\sigma^{NN}/dp_T d\eta}$$

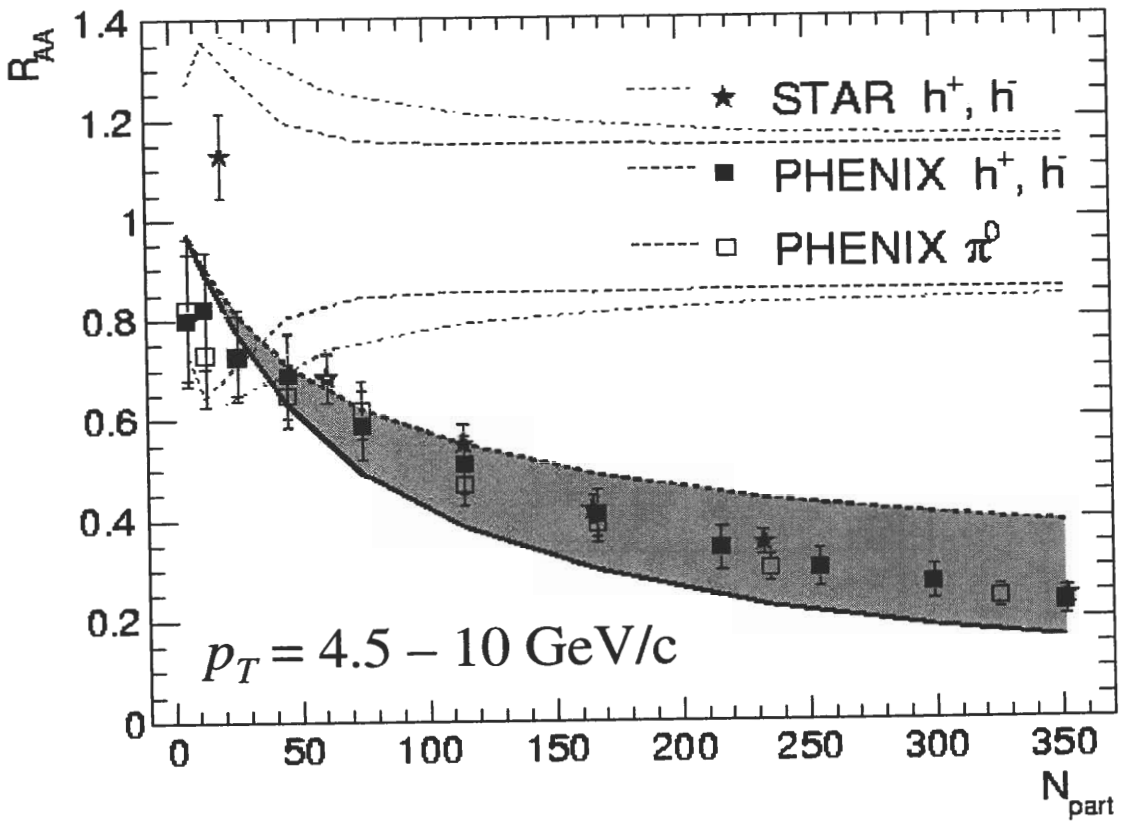
Binary collision scaling p+p reference

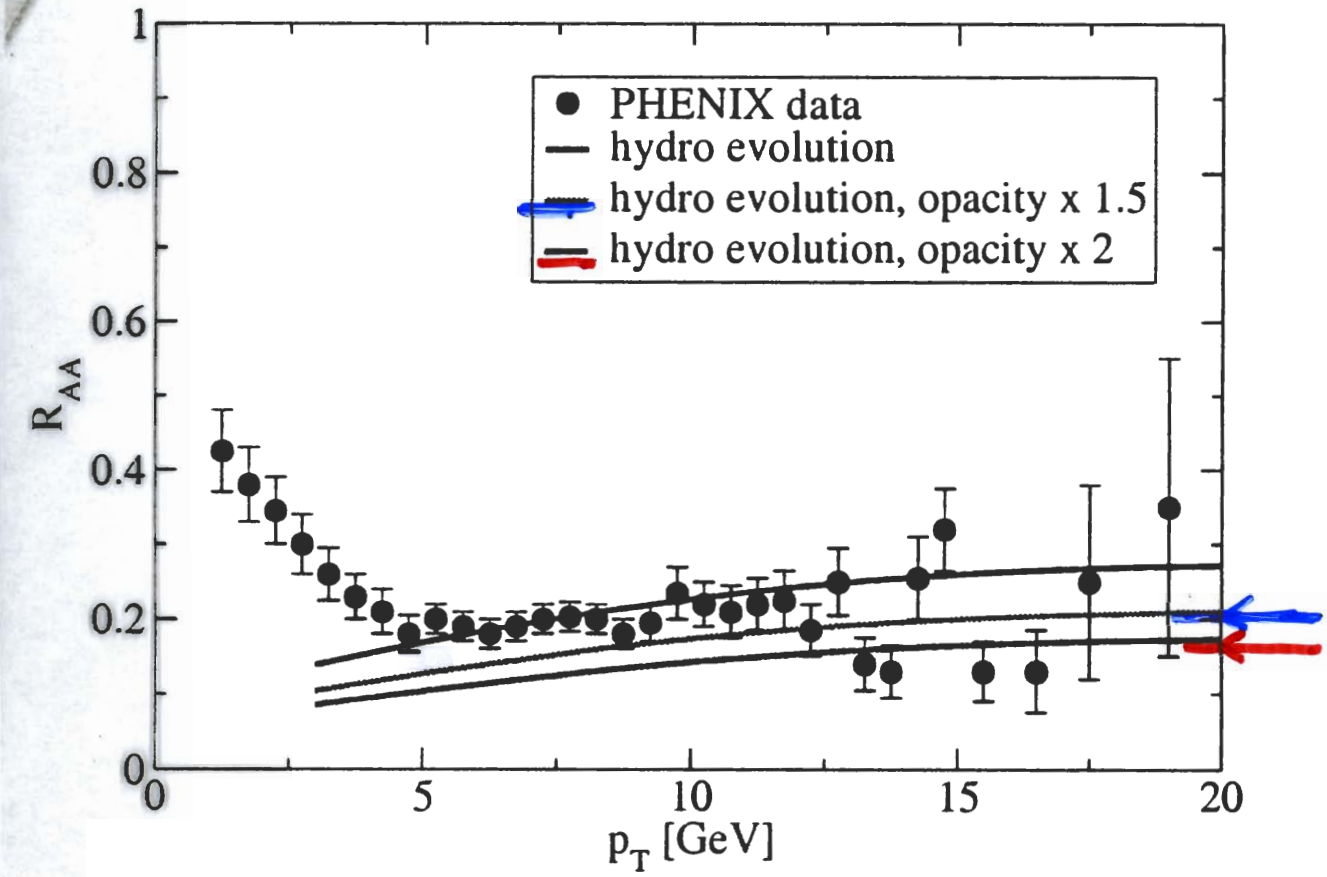
Energy loss at RHIC

- Data can be fitted with a large loss parameter for central collisions:

$$\langle \hat{q} \rangle \approx 10 \text{ GeV}^2/\text{fm}$$

(Dainese, Loizides, Paic, hep-ph/0406201)

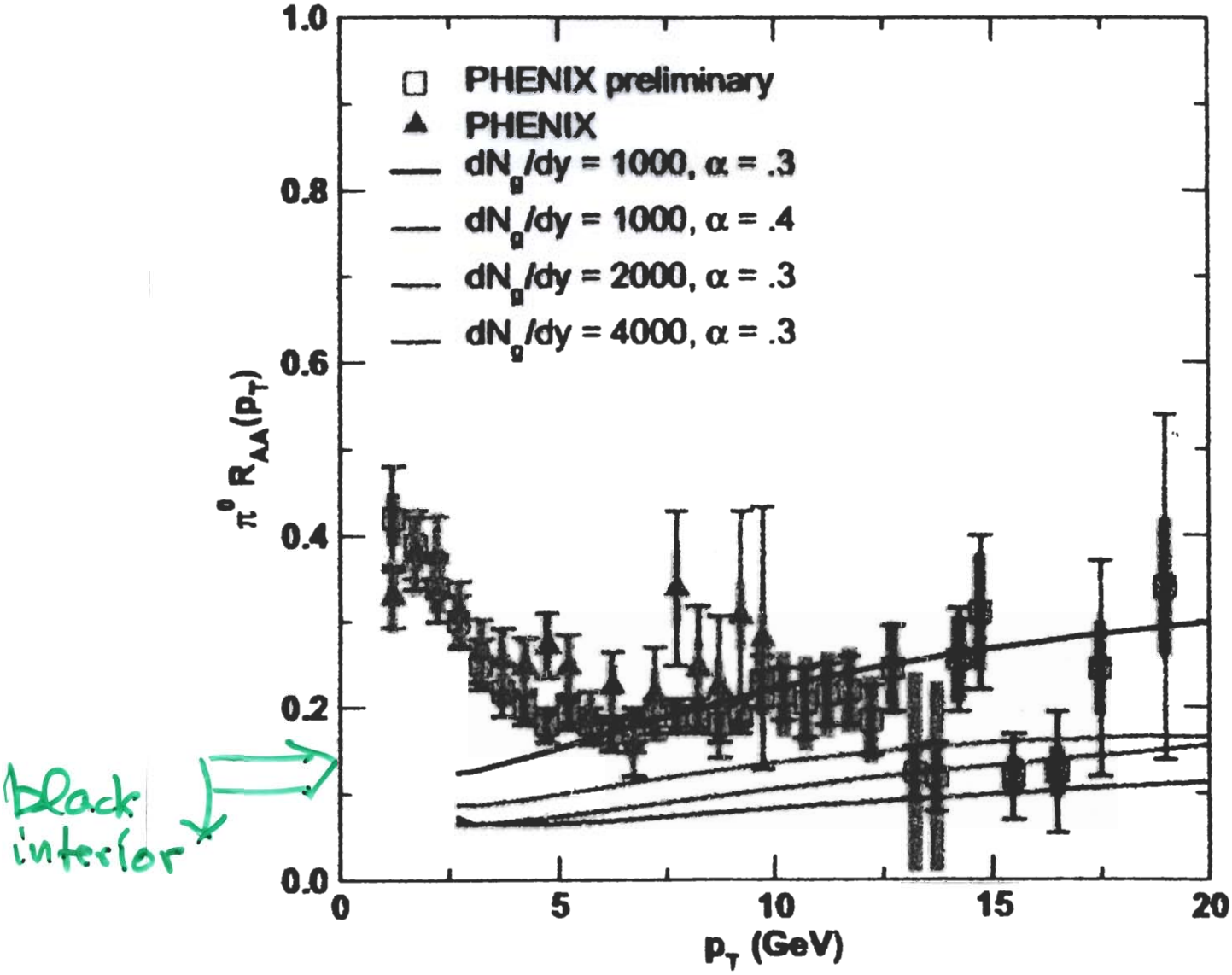




RHIC Au + Au @ 200 GeV
central coll. → π^0

Saturation !

"Black interior" +
surface production



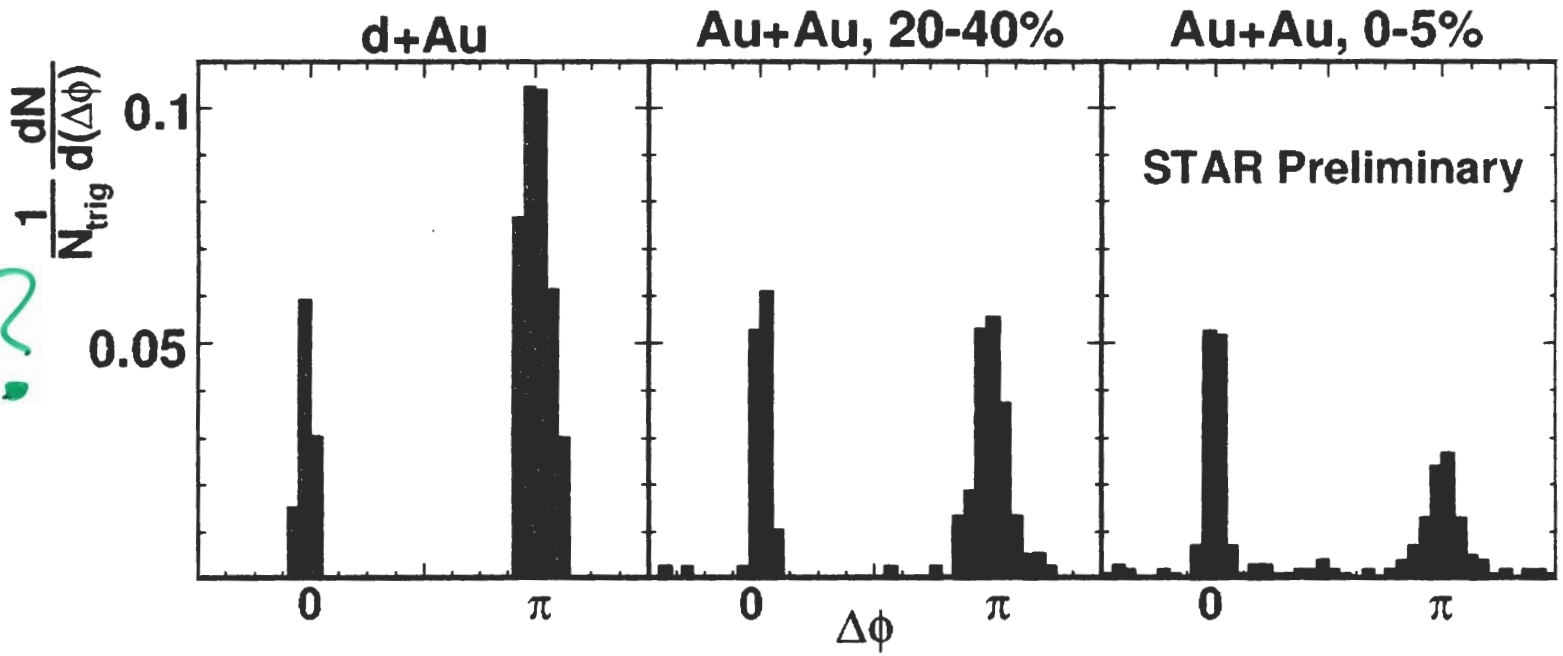
R_{AA} for RHIC PHENIX central Au+Au $\rightarrow \pi^0$

The "Gyulassy and Vitev" – model
W. Horowitz nucl-th/0610024

$$\hat{q} = \alpha_s \frac{2}{L} \frac{1}{R_A^2} \frac{dN_{gluons}}{dy} \Big/ \text{midrap.}$$

RHIC Dijet → hadron correlation

Re-appearance? at high E_T.



STAR data Nucl. Phys. A774 (2006) 573 : Trigger 8 → 15 GeV associates > 6 GeV

→ primordial parton 12-20 GeV

$R_{AA}^{jj} \approx 0.25$

FIGURES

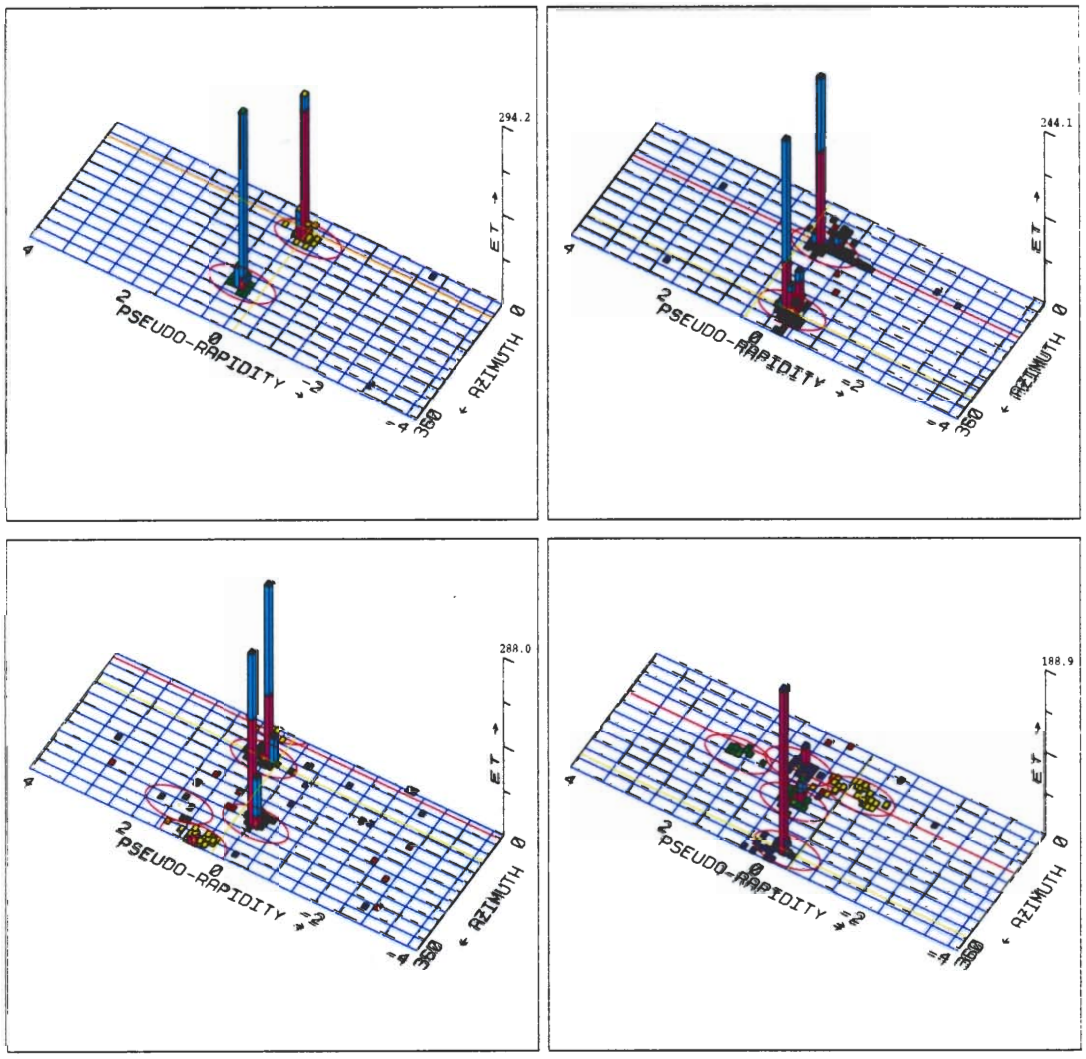


FIG. 1. Jet events in the CDF calorimeter. A jet clustering cone of radius 0.7 is shown around each jet. Clockwise from the upper left they are identified as two-jet, two-jet, five-jet and three-jet. Tracks for these events are shown in Figure 2.

Number of jets per Pb+Pb at $\sqrt{s} = 5.5$ TeV

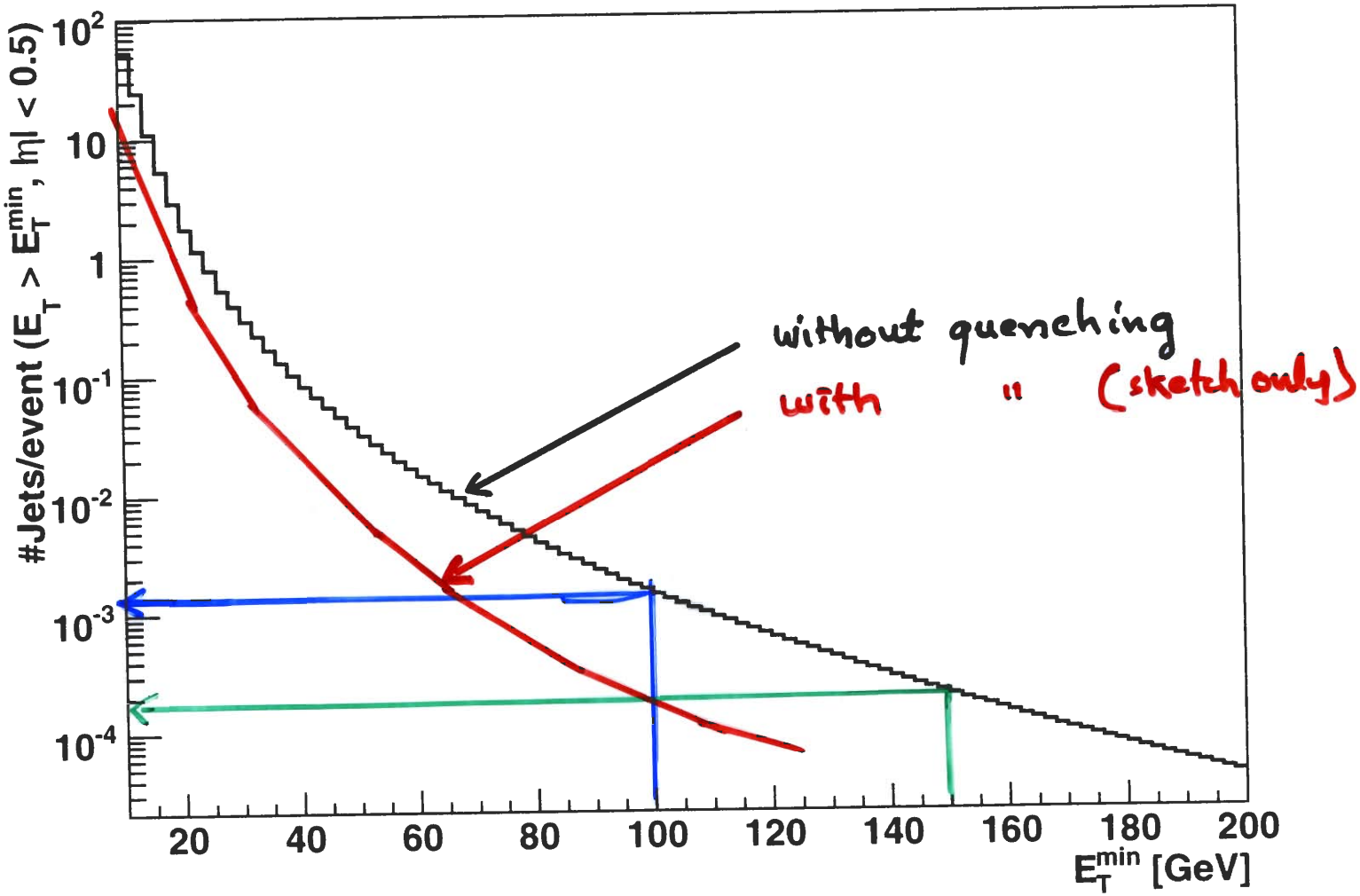


Figure 6.357. Average number of jets with $E_t > E_t^{min}$ and $|\eta| < 0.5$ per event in the 10% m central Pb–Pb collisions.

ALICE acceptance

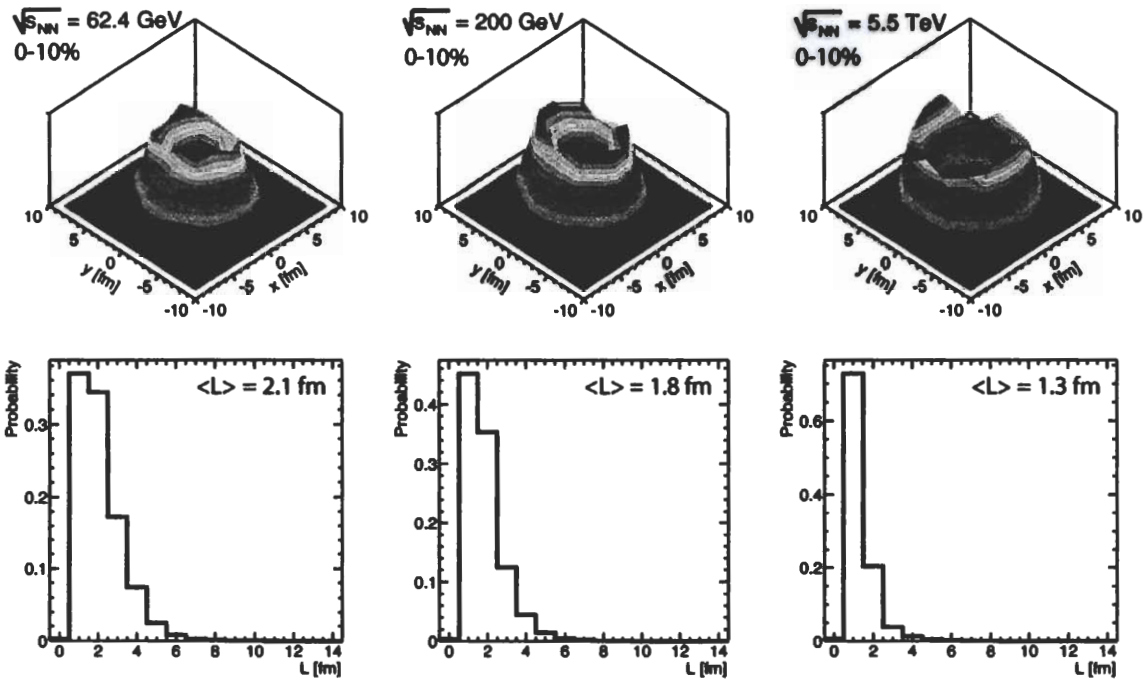


Figure 3.35: Distributions of parton production points in the transverse plane (upper row) and in-medium path length (lower row) for partons that escape the medium and produce hadrons with $p_T > 5$ GeV in central Au–Au collisions at 62.4 and 200 GeV and in central Pb–Pb collisions at 5.5 TeV. The quantity $\langle L \rangle$ denotes the average of the path-length distribution. All plots are in the non-reweighted case.

LHC $\sqrt{s} = 5.5$ TeV : jet attenuation

Pb+Pb central coll.

$\hat{q}$:
12 GeV^3
24 "
98 "

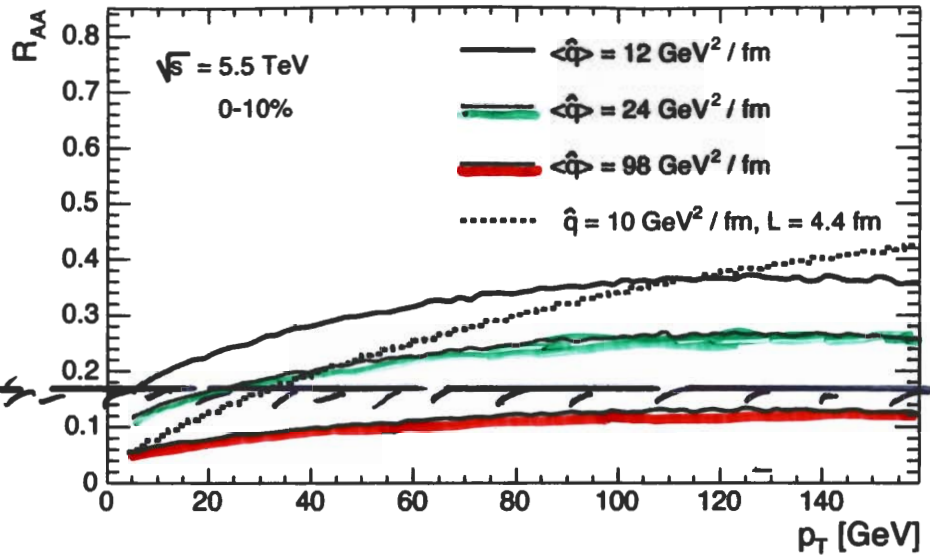


Figure 3.41: R_{AA} as a function of p_T for 0–10% most central collisions at LHC energy obtained by PQM. The calculations in the parton-by-parton approach (solid lines) are compared to a calculation for fixed transport coefficient and length (dashed). All graphs are in the non-reweighted case.

Black interior limit:

- The surviving jets stem from the dilute surface of the collision system, and from the (small) fraction of partons that did not emit a significant gluon.
- In this case, the non-abelian $\langle \Delta E \rangle \propto L^2$ can not be extracted due to strong coupling
- But, never mind: at least we learn how large $\hat{q}$ can get at LHC: characterization of the primordial ($T \approx 600$ MeV?) plasma.

In Medium Attenuation of Jet Fragm. Fct.

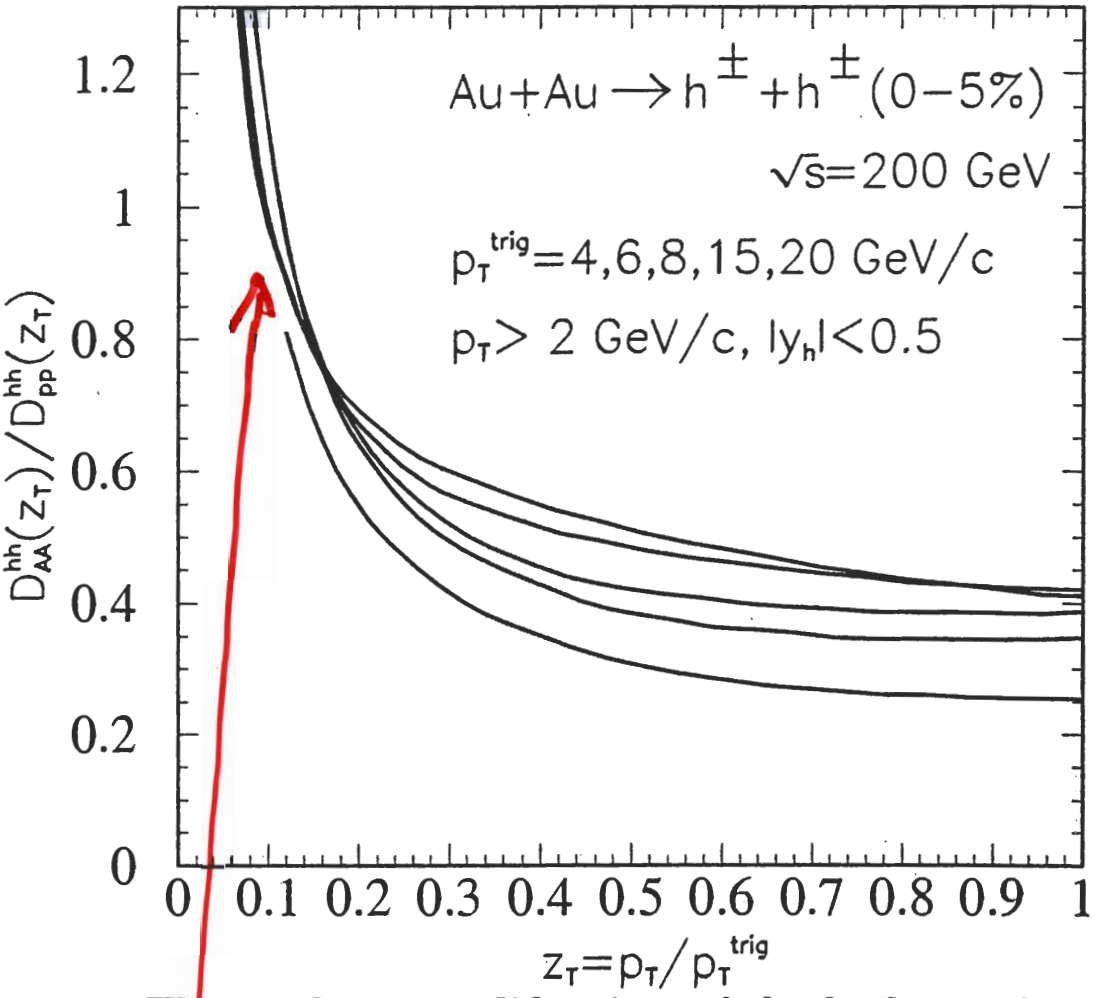


FIG. 6. The medium modification of the hadron-triggered fragmentation function, defined as the ratio of hadron-triggered fragmentation functions in central $Au + Au$ and $p + p$ collisions for different values of p_T^{trig} (increasing from lower to top solid lines).

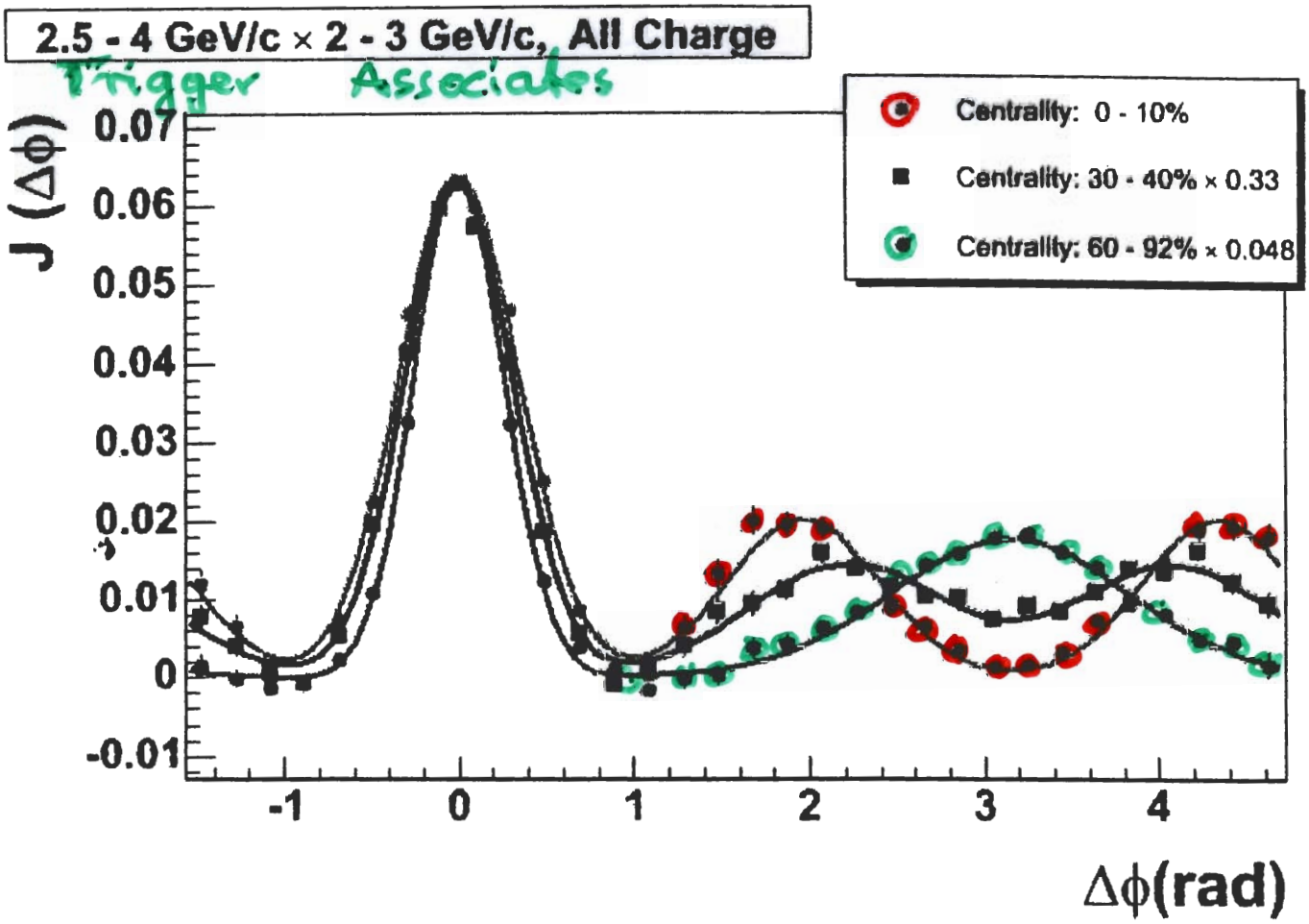
X. N. Wang et al. QM04
HIJING : attenuation ⊕ expansion

"The LP - law" in fixed geometry

noticed now
enhancement at low p_T
found @ RHIC !

Y. Akiba / Nuclear Physics A 774 (2006) 403–408

PHENIX Au+Au → dijet $\sqrt{s}$ = 200GeV



6. Jet modification in Au+Au collisions with different centralities.

"Conical emission" in head-on coll.

ΔE of primordial parton in-medium

⇓

soft emission at $\Delta\phi = \pi \pm 70°$

"Mach-cone" hydro-focusing?!