Energy loss effects on the Back-to-Back Correlations

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Collaboration with Tetsufumi Hirano (U of Tokyo)

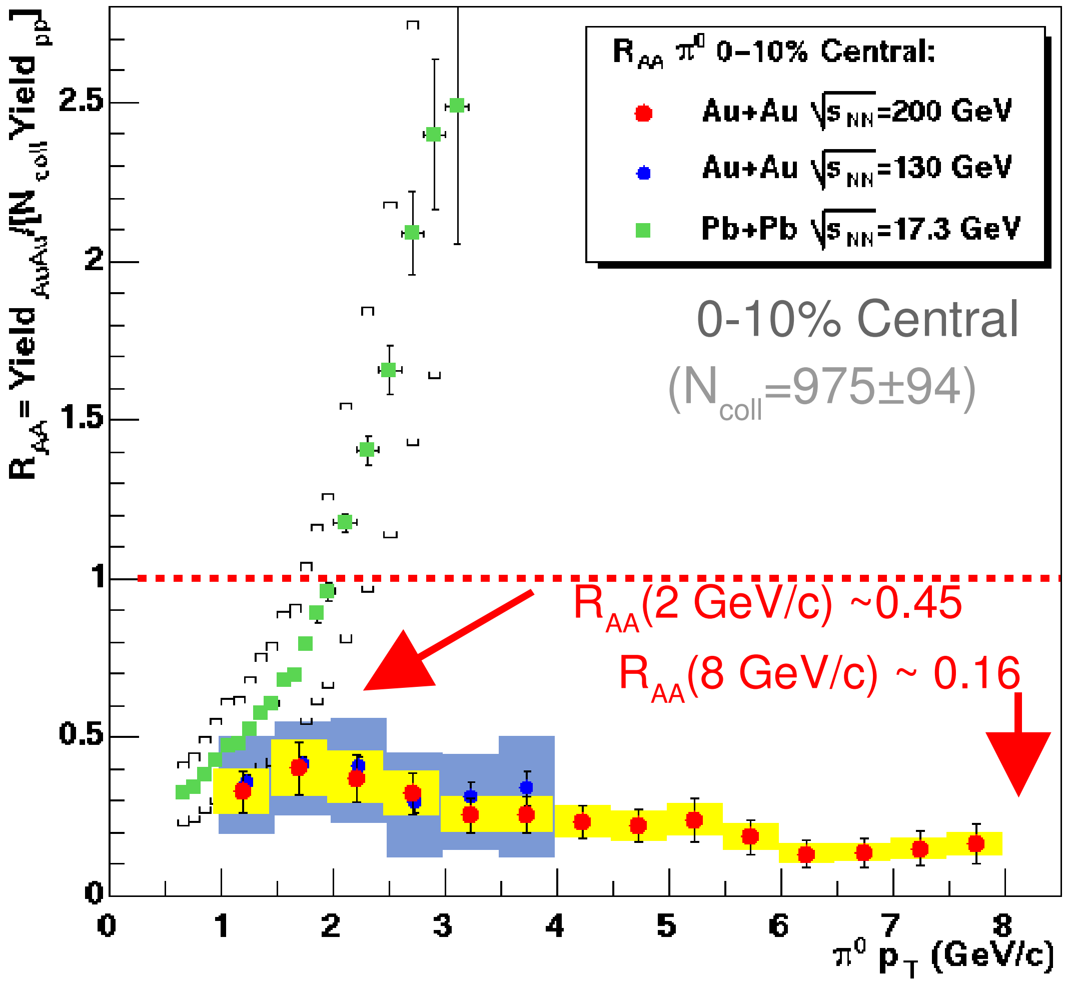
- Back-to-back correlations
- Suppression factors for pi, K, p.
- P_T dependence of p/pi, K/pi ratio

From 3D-hydro + jet simulation

References:
T. Hirano and Y. Nara, Phys. Rev.C 66, 041901 (2002).
T. Hirano and Y. Nara, nucl-th/0301042.

Trsnsverse dynamics at RHIC, BNL 3/6-3/8/2003

Suppression Factor (PHENIX)



$$R_{AA}(p_T) = \frac{dN^{AA}/d^2p_T\,d\eta}{\langle N_{coll}\rangle dN^{NN}/d^2p_T\,d\eta}$$

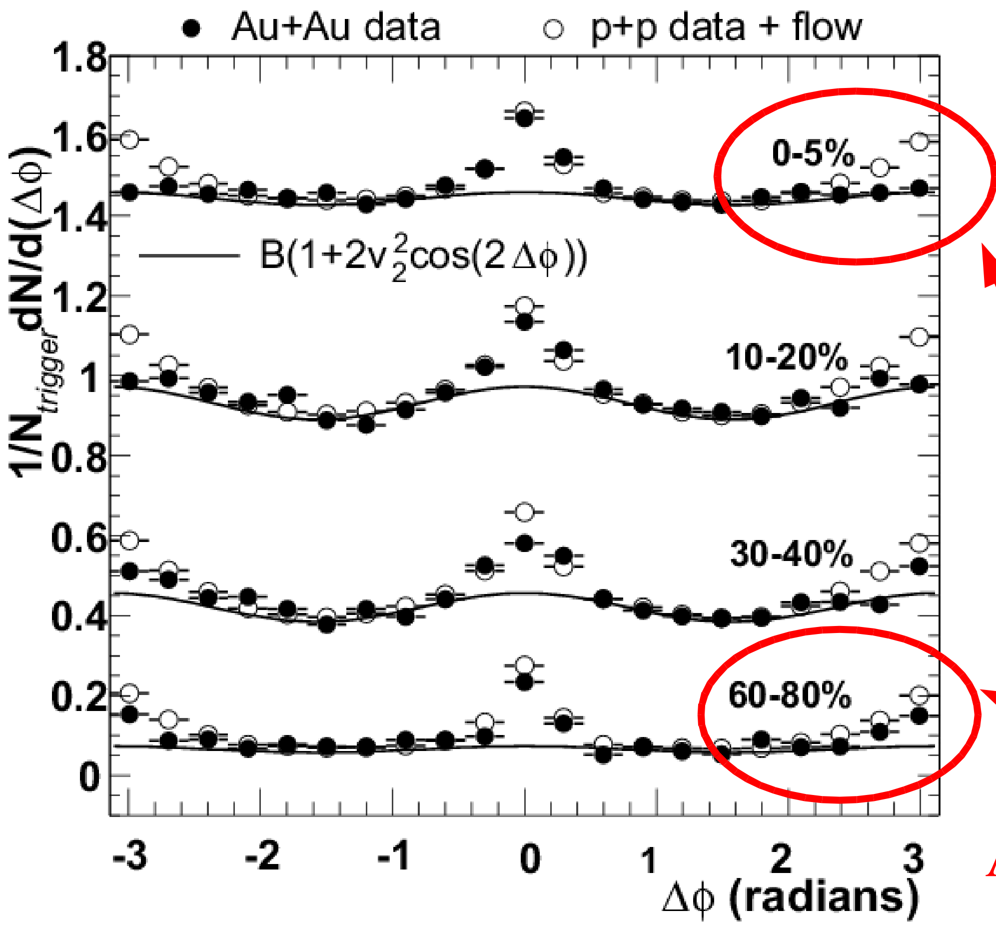
From D. d’Enterria, talk at QM2002.

Disappearance of back-to-back correlations in central Au+Au

STAR: nucl-ex/0210033

Triger particle 4<pT<6GeV/c

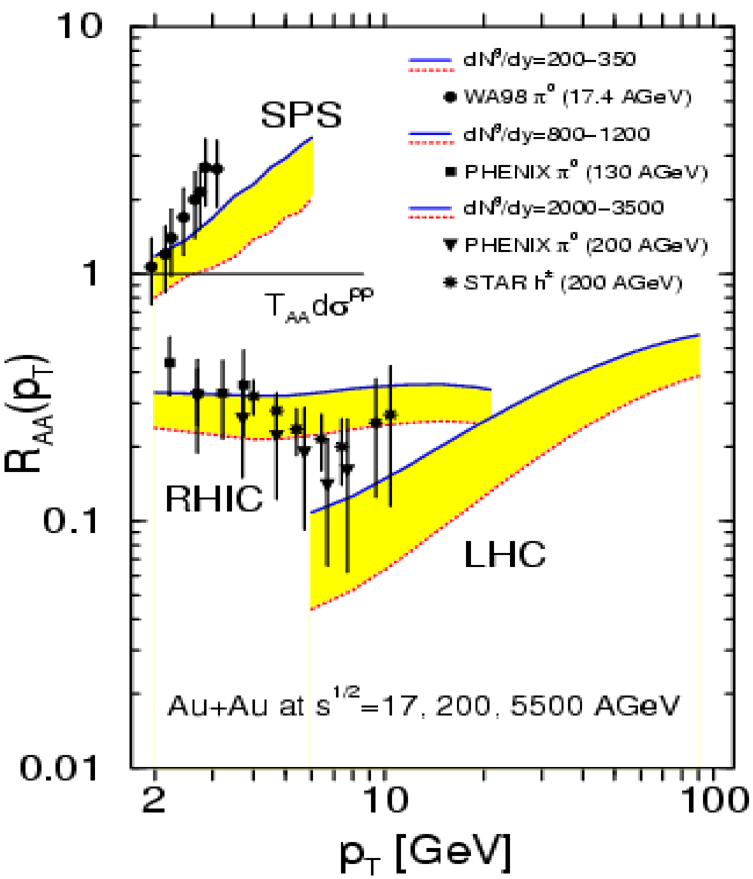
Associated particle
2GeV/c<pT<pTtrig



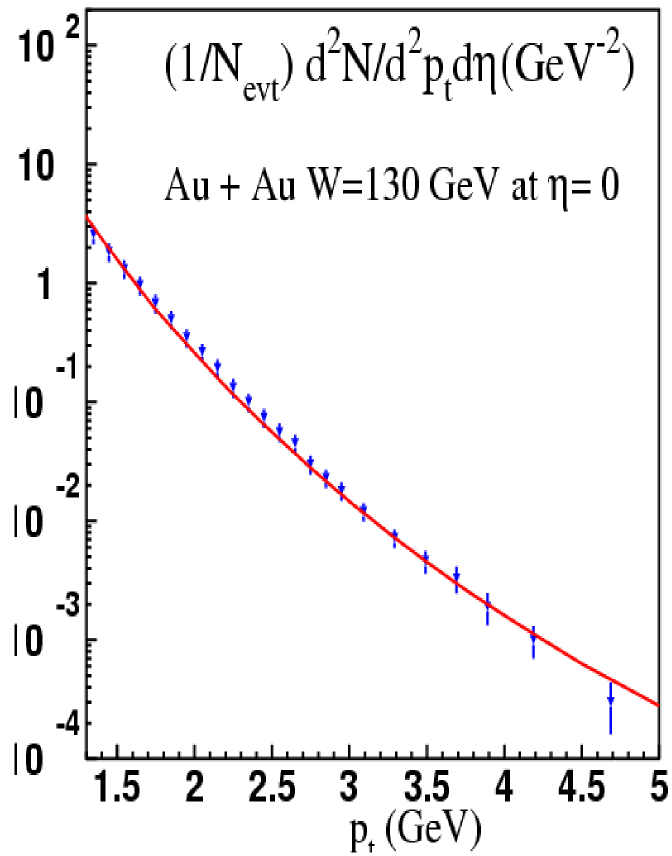
Azimuthal dist.(|ϕ|>1) = flow

Azimuthal dist.(|ϕ|>1) = flow+jets

Initial production or final interactions?

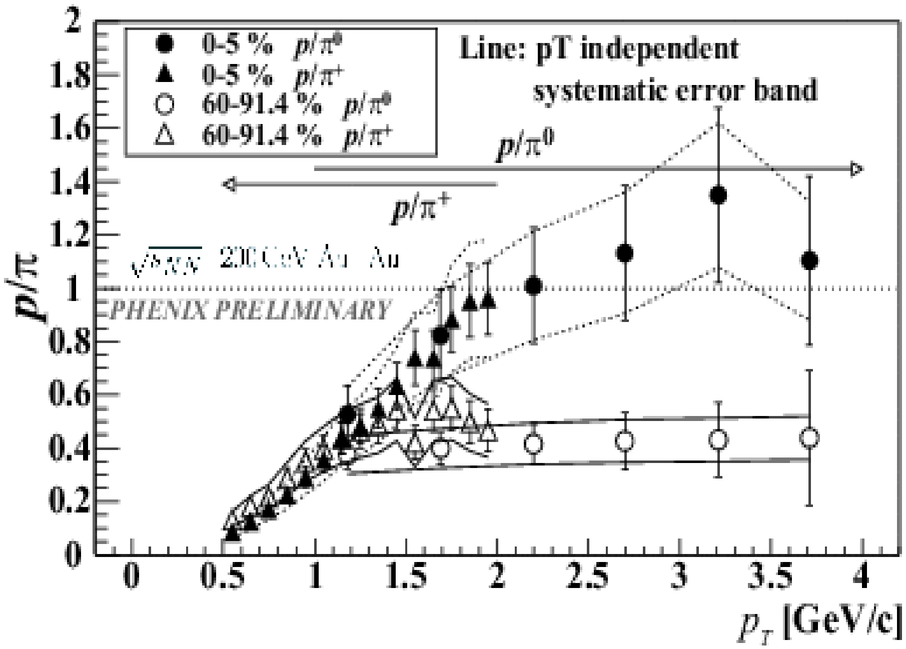


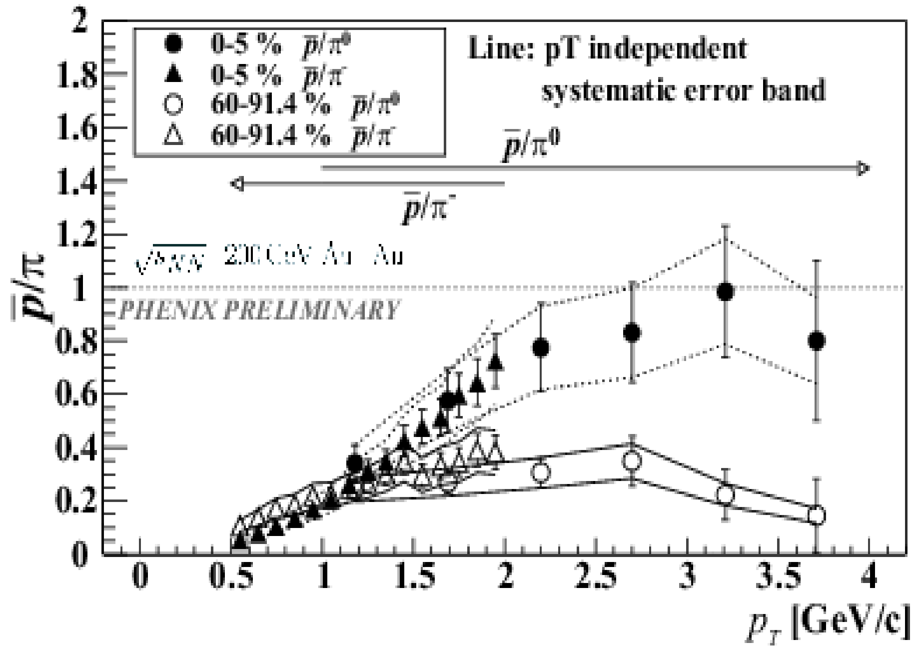
I. Vitev and M. Gyulassy,
Phys. Rev. Lett. 89, 252301 (2002)



D. Kharzeev, E. Levin and L. McLerran,
arXiv:hep-ph/0210332.

P/π ratio





PHENIX QM02, nucl-ex/0209030

Baryon junctions: I. Vitev, M. Gyulassy, P. R. C65(2002)041902(R).

Uncertainty of fragmentation function for protons? X. Zhang, G. Fai,hep-ph/0205008.

Parton coalescence: R. J. Fres, B. Muller, C. Nonaka, S. A. Bass, nucl-th/0301087,
V. Greco, C.M. Ko, P. Levai nucl-th/0301093,
D. Molnar, S. A. Sergei, nucl-th/0302014.

Radial flow

The high pT data at RHIC is the manifestation of the interactions of jets with the QGP matter?

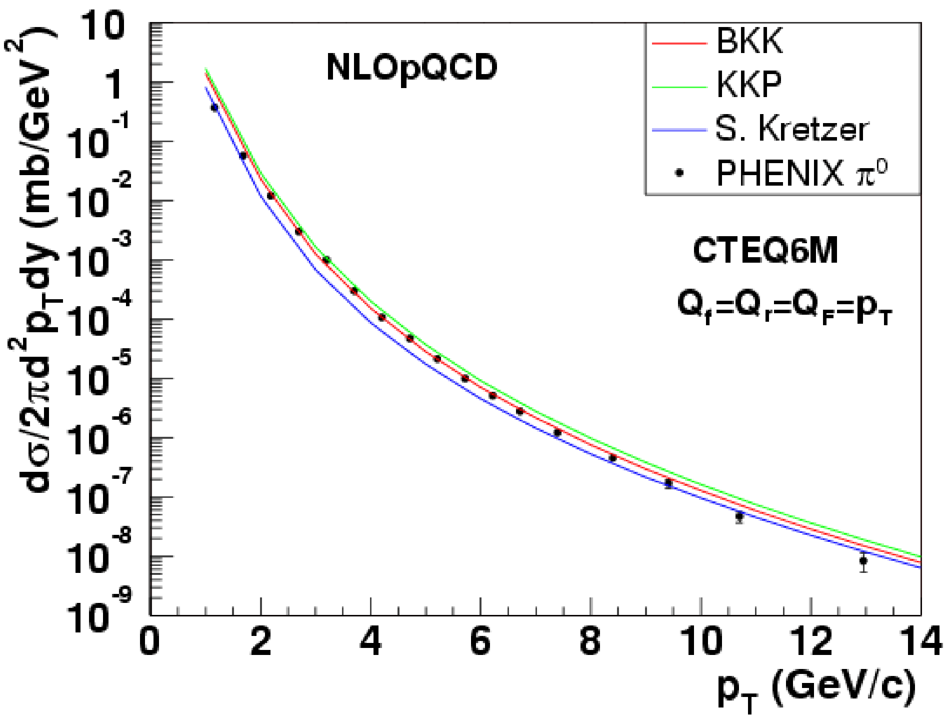
Purpose of this work:

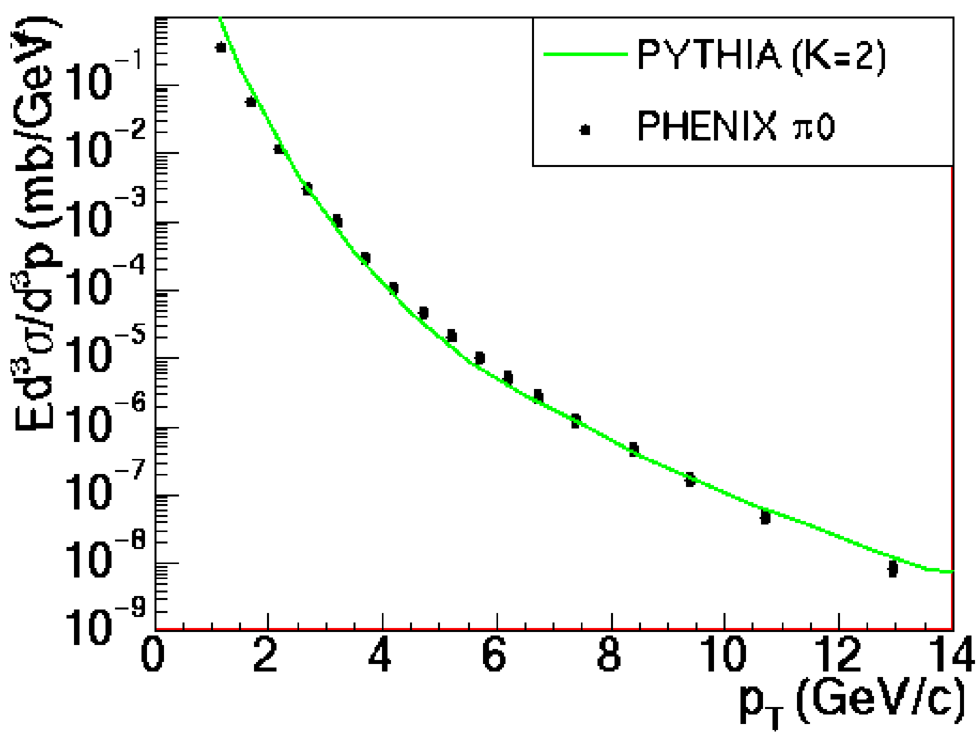
We try to understand the data with the following nuclear effects:

- Nuclear Intrinsic kT broadening
- Energy loss by gluon emission
- PT broadening

PQCD predictions are consistent in pp collisions at RHIC I

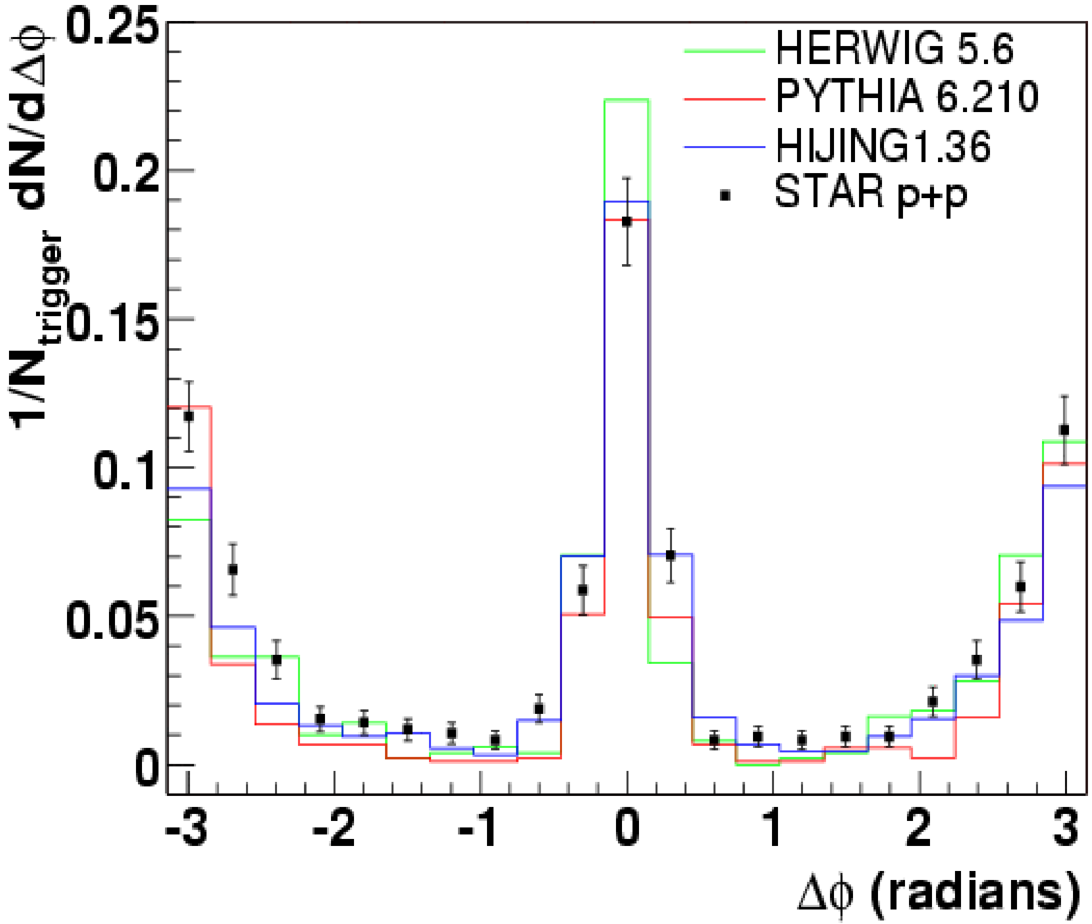
Fragmentation function dependence.





- BKK: J. Binnewies, B. A. Kniehl and G. Kramer, PRD52,4947(1995)
- KKP: B. A. Kniehl, G. Kramer and B. Potter, NPB582, 514 (2000)
- S. Kretzer: PRD62,054001 (2000).

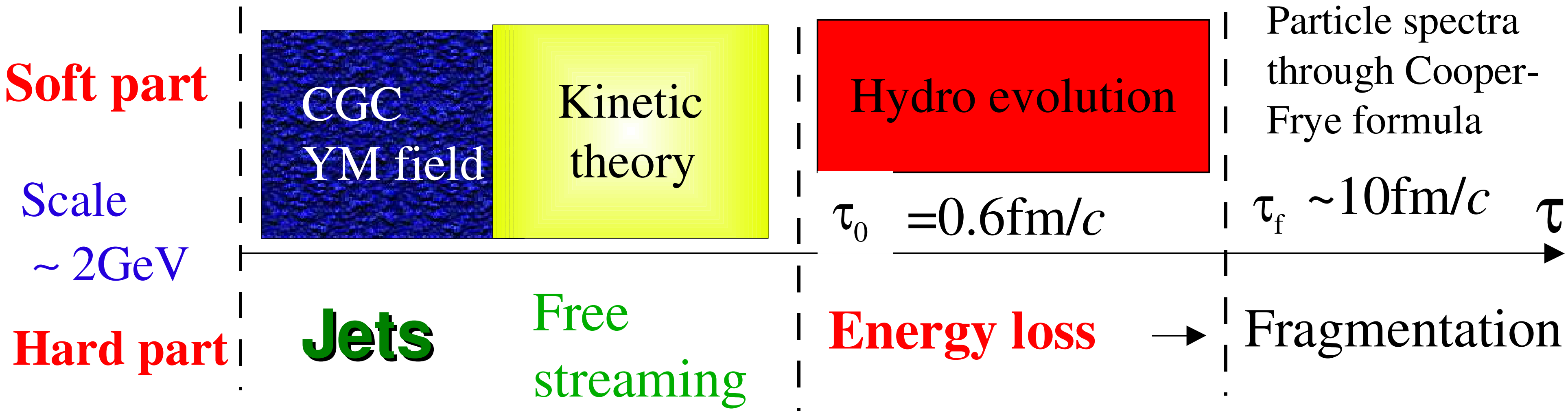
PQCD predictions are consistent in pp collisions at RHIC II



PQCD based Event Generators

- LO pQCD matrix element
- Initial state radiations
- Final state radiations.
- String or cluster hadronizations

Time Evolution of the system and the Hydro+Jet picture



• Hard part:
• no thermalization
For jets with p_T>2GeV/c,
$1/p_T$<0.1fm/c<<1fm/c
•Momentum dist. From PYTHIA ver. 6.2

• Soft part
• Thermalization time
= Initial time of fluids
•Initial parameters in hydro have been already tuned.

•After hydro simulation, all survival jets fragment into hadrons.

•We neglect interaction of fragmented hadrons.

Model

- Jet quenching
- Jet acoplanarity

Interplay between soft and hard is *important!*

Hydro + jet model

Soft (hydrodynamics)

- Space-time evolution of matter
- Phase transition between QGP and hadrons
- Particle spectra in low p_T region

Hard (mini-jets)

- Production of (mini-)jets
- Propagation through fluid elements
- Fragmentation into hadrons

Interaction between fluids and mini-jets through parton energy loss

Relativistic Hydrodynamics

Local thermalization

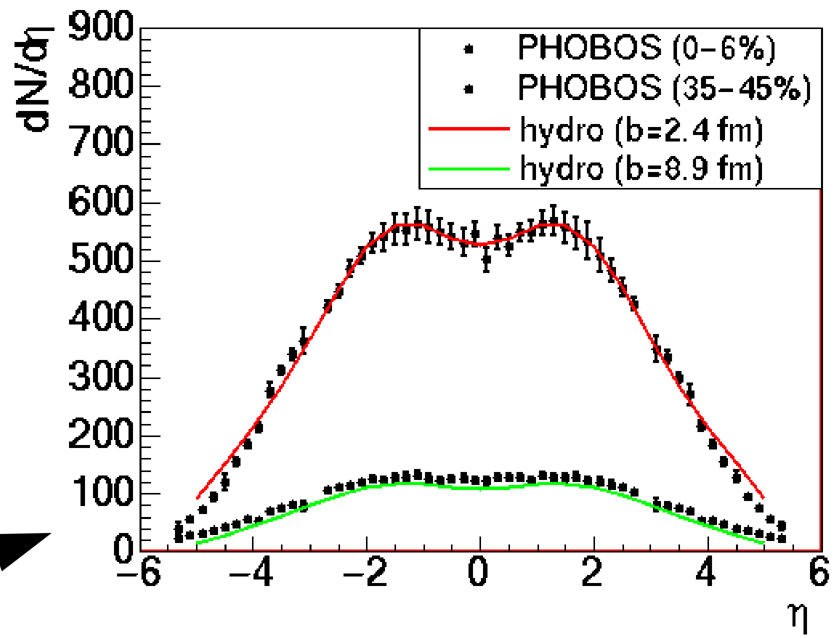
Perfect fluid:

$$\partial_\mu T^{\mu\nu} = 0 \qquad T^{\mu\nu} = (e+p)u^\mu u^\nu - p g^{\mu\nu}$$

Input

- Average Initial <e>= 6 GeV/fm^3
- Initial simulation time τ_0=0.6fm/c
- EoS
- Phase transition temp. Tc=170MeV
- Freeze out temp. T_{ch}, T_{th}

Determined by fitting the data

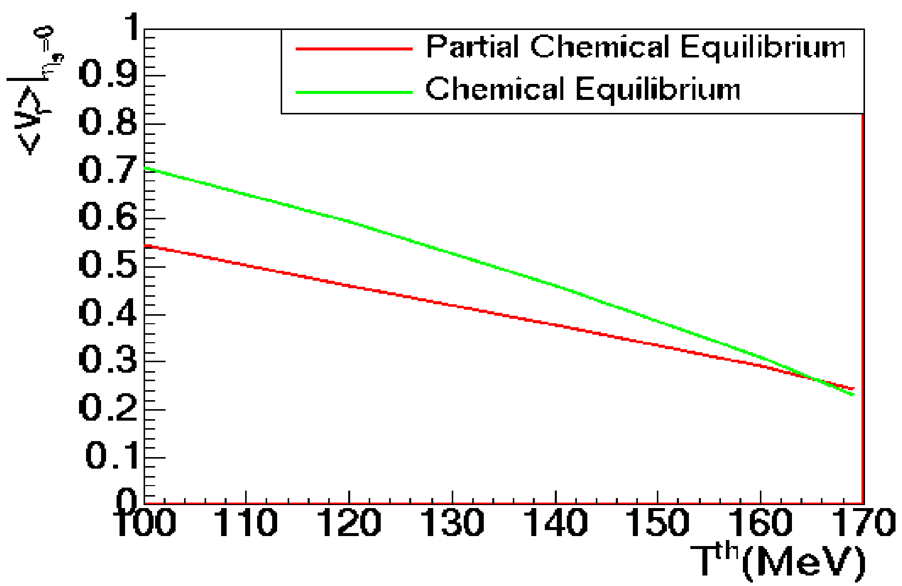


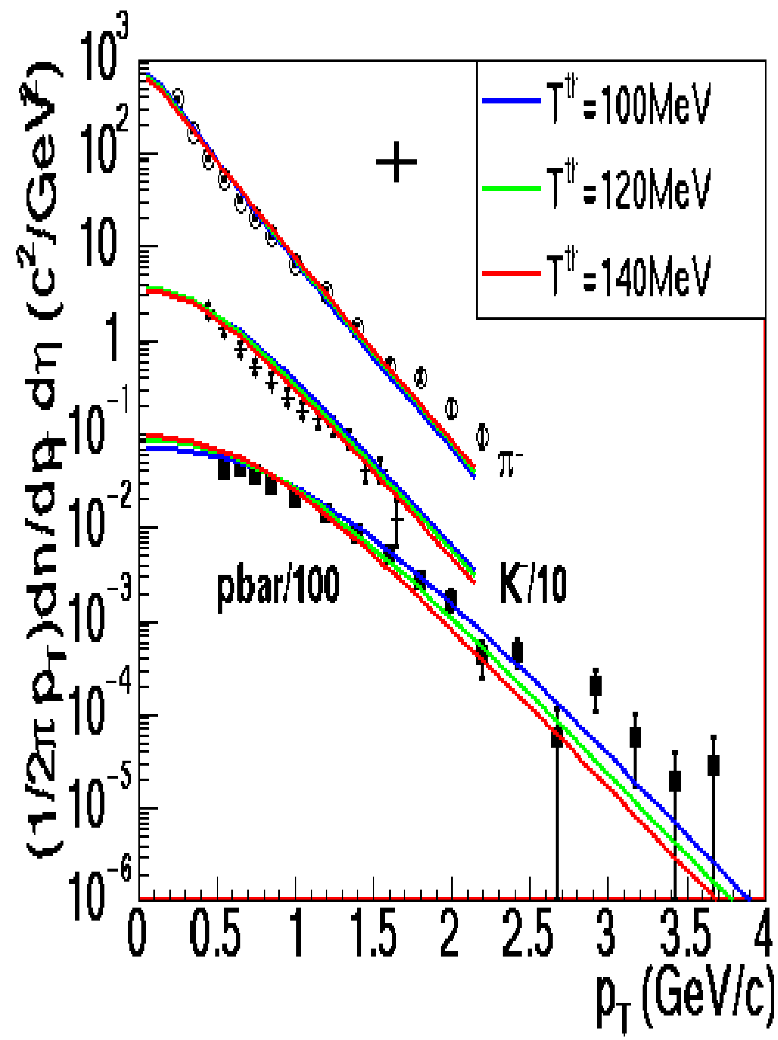
Hydro with the early chemical freeze-out

T. Hirano and K.Tsuda, PRC66(2002)

- Hadron phase cools down rapidly.
- Freeze-out hypersurface smaller.
- Radial flow 20% smaller.

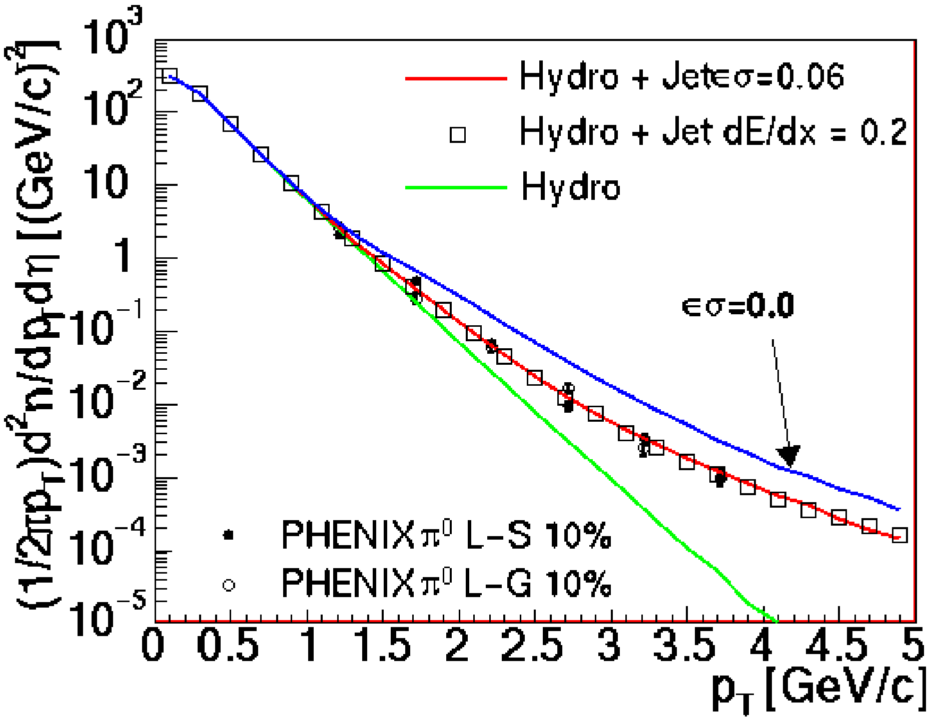
P_T slopes for pions are **insensitive** to the thermal freeze-out temperature.





PHENIX @130GeV

π^0 Spectra in $s_{NN}^{1/2}$=130 GeV Central Collisions



- *<dE/dx>~0.85 GeV/fm @τ_0=0.6 fm/c*
- *Onset of hard component p_T~1.5 GeV/c*

$$\frac{dE}{dx} = 0.06\,\rho(\tau, r)(GeV/fm)$$

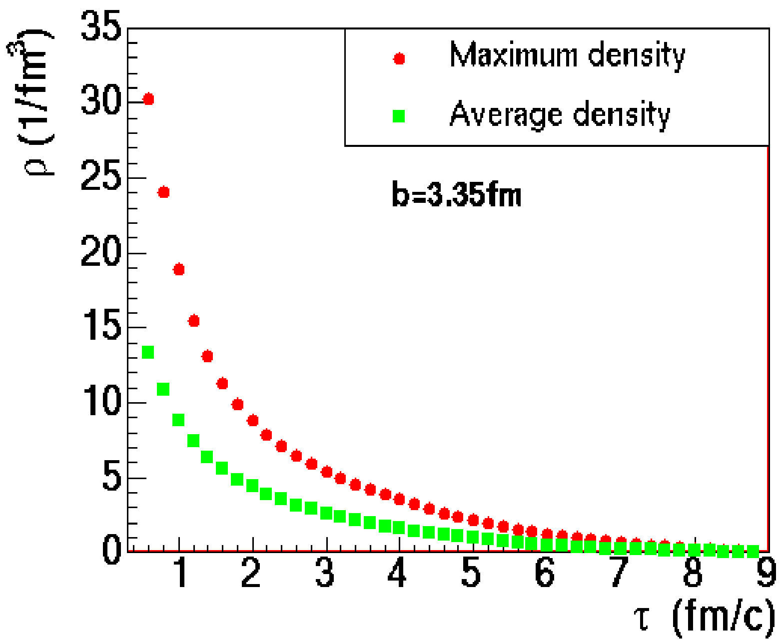
the best fit value

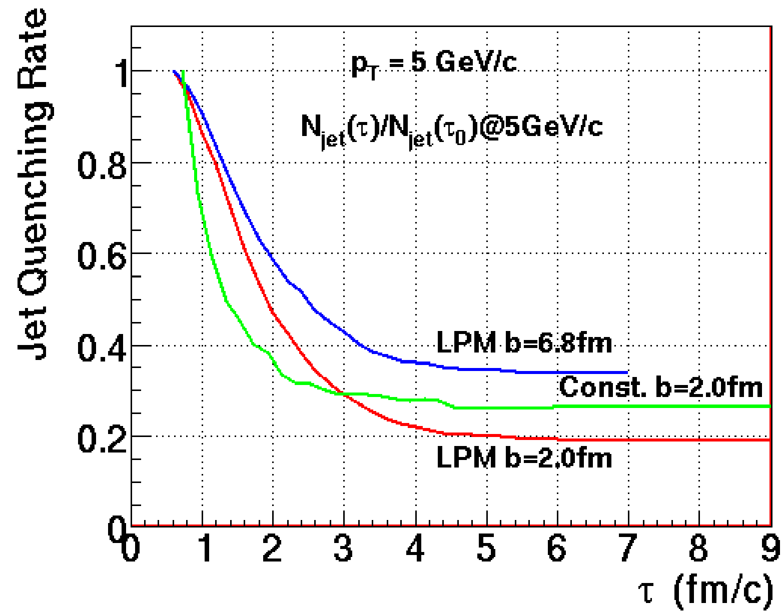
$\simeq$ 0.2 (GeV/fm)

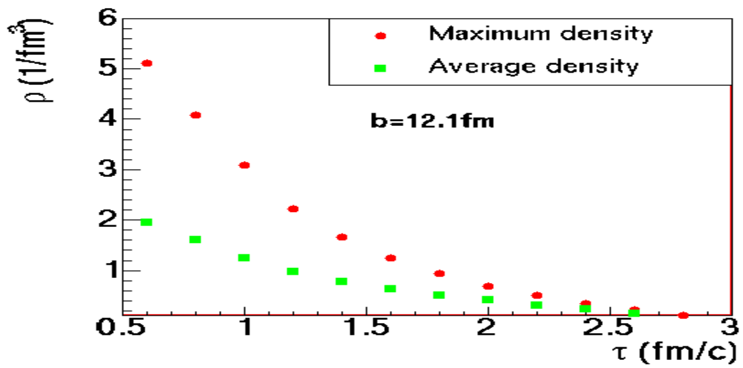
dE/dx = 0.25 (GeV/fm)

X.-N. Wang, NPA698(2002)296c

Jet Quenching Rate as a function of evolution Time



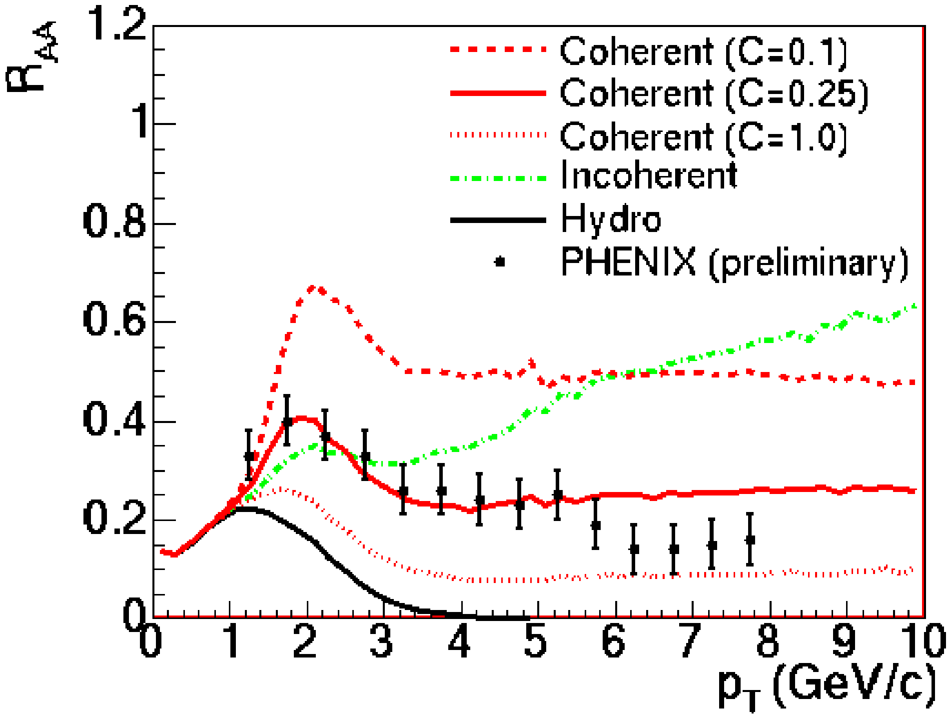




- GLV (LPM) case

$$\Delta E \propto \int \rho(\tau)\tau\, d\tau$$

Suppression Factor @200GeV



- Coherent model (GLV 1[st] order)
  $\Rightarrow$ Almost flat

$$\Delta E = C \int_{\tau_0}^{\tau_f} d\tau\, \rho(\tau, x(\tau))(\tau - \tau_0) \ln\left(\frac{2E}{L\mu^2}\right)$$

- Incoherent model($\varepsilon\sigma$=0.06)
  $\Rightarrow$ Increase with p_T

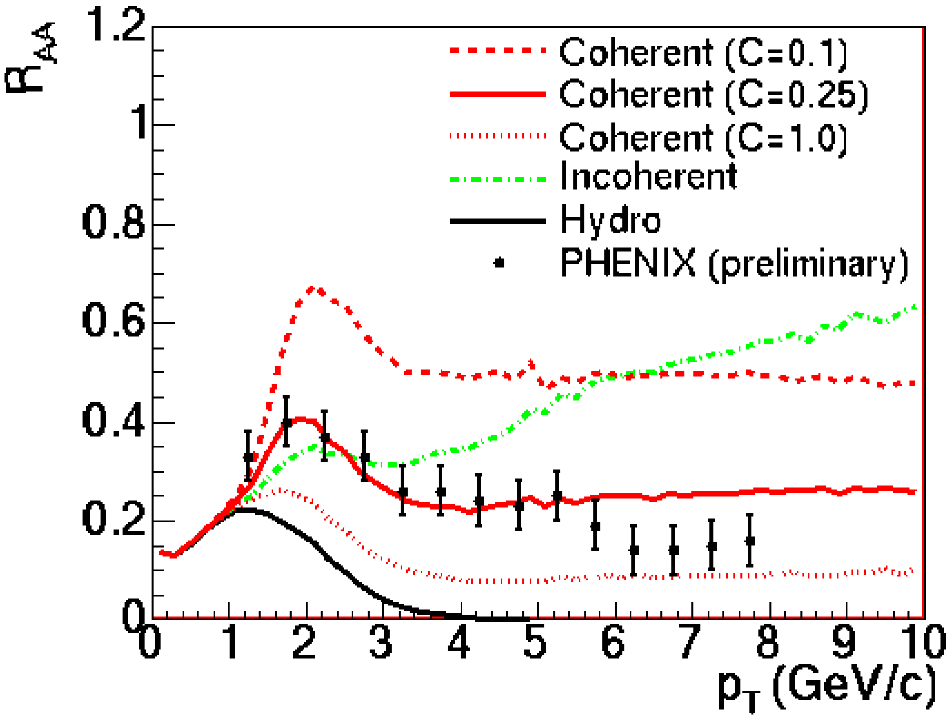
The coherent model with *C*=0.25 quantitatively reproduces the data below p_T~6 GeV/*c*

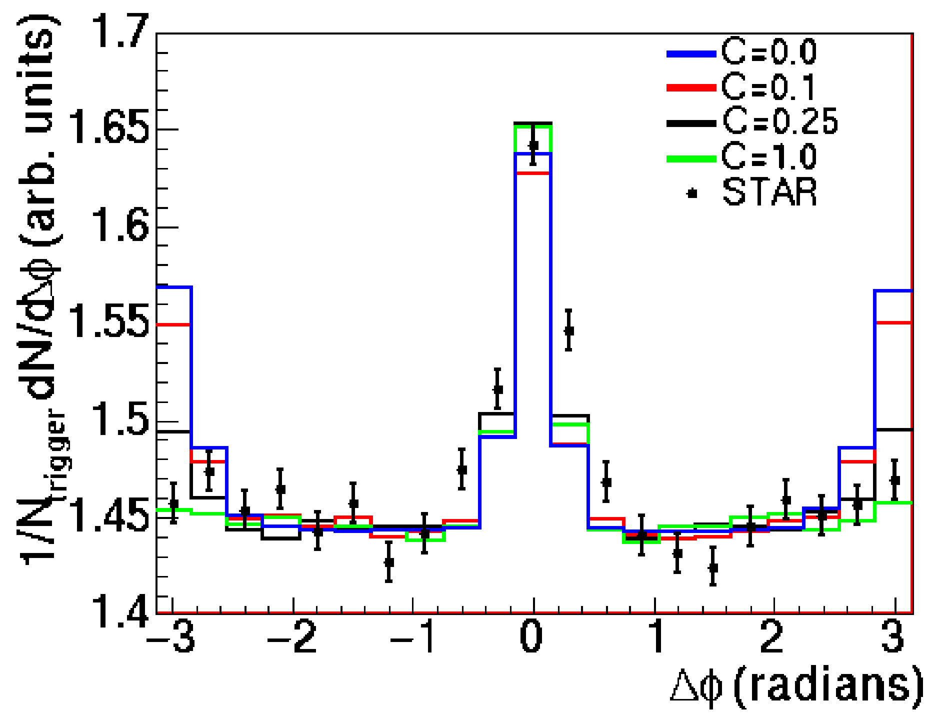
$$R_{AA}(p_T) = \frac{dN^{AA}/d^2 p_T\, d\eta}{\langle N_{coll}\rangle dN^{NN}/d^2 p_T\, d\eta}$$

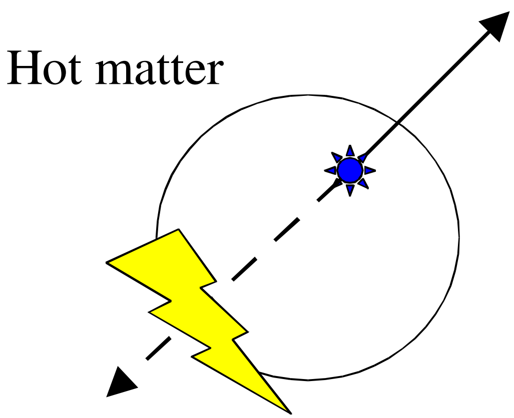
GLV: Gyulassy, Levai, Vitev

Data from D. d'Enterria, talk at QM2002.

1. Effect of Parton Energy Loss







Simultaneous reproduction of R_{AA} and C_2 ?

Another mechanism is needed!

Nuclear broadening of the transverse parton distributions

- R. D. Field, "Applications of Perturbative QCD"

  $$\langle k_T^2 \rangle_N = 0.9\, GeV^2 \; with \; Q^2 = p_T^2/2$$

- X.N. Wang , PRC61(2000) $\langle k_T^2 \rangle_N = 1.2 + 0.2\,\alpha_s(Q^2)Q^2$

  $$\langle k_T^2 \rangle_A = \langle k_T^2 \rangle_N + \delta[\nu(b) - 1]$$

- Y.Zhang, G. Fai, G. Papp, G. G. Barnafoldi, and P. Levai, PRC65(2002)

  $$\langle k_T^2 \rangle_{Pb} \approx 2\, GeV^2$$

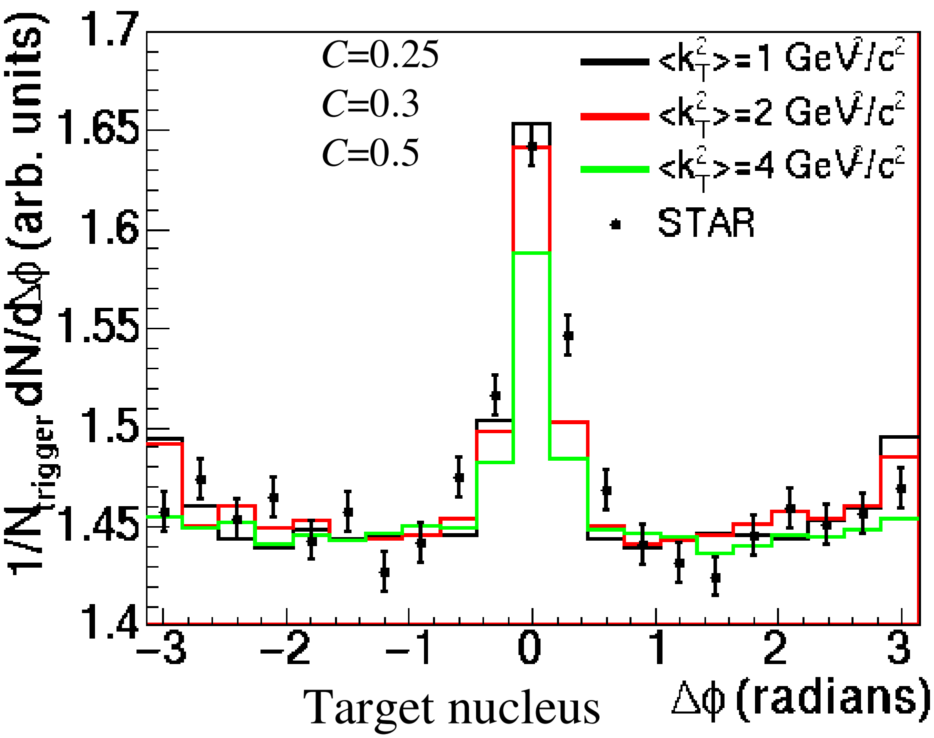
- A.Dumitru, L. Frankfurt, L.Gerland, H.Stoker, and M. Strikman PRC64,(2001)

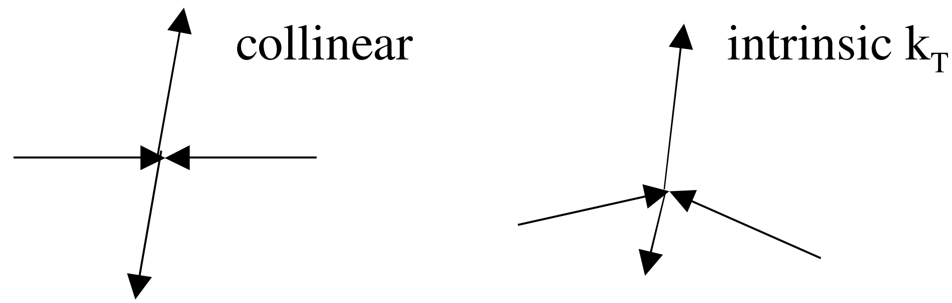
WA98, photon $\langle k_T^2 \rangle_N = 1.3 - 1.5\, GeV^2 \; with \; Q^2 = 4p_T^2 \, , K = 2$

$$\langle k_T^2 \rangle_{Pb} \approx 2\, GeV^2$$

$\langle k_T^2 \rangle_A \approx 2\, GeV^2$ From fixed target experiments.

2. Effect of Intrinsic k_T

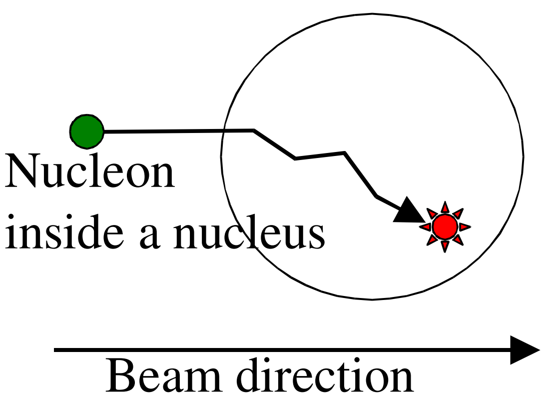




Intrinsic k_T is insufficient
to the disappearance of
back-to-back correlation!

$$\langle k_T^2 \rangle \sim 2\,\mathrm{GeV}^2/c^2\ \text{@SPS}$$

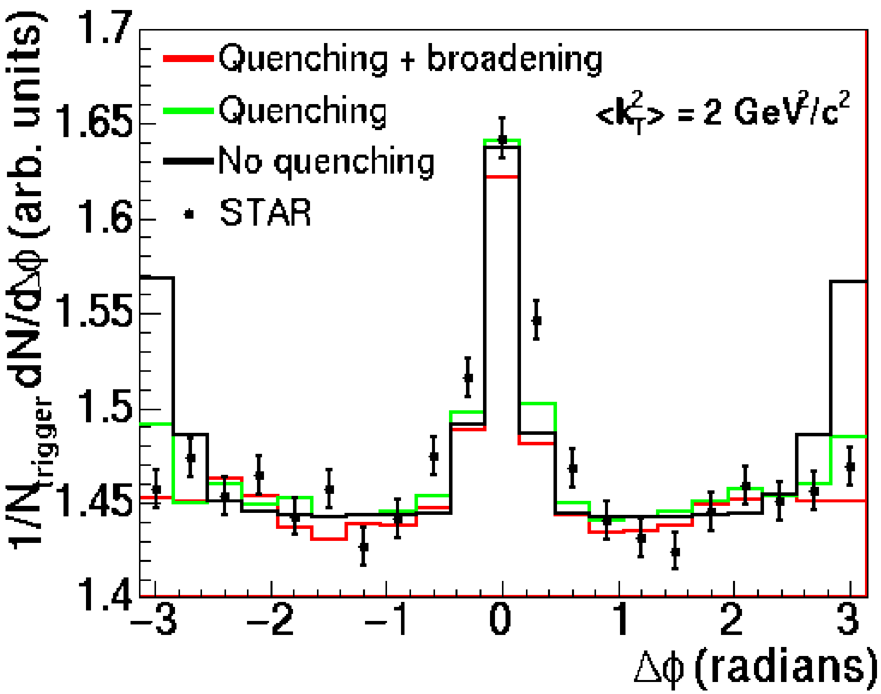
Target nucleus

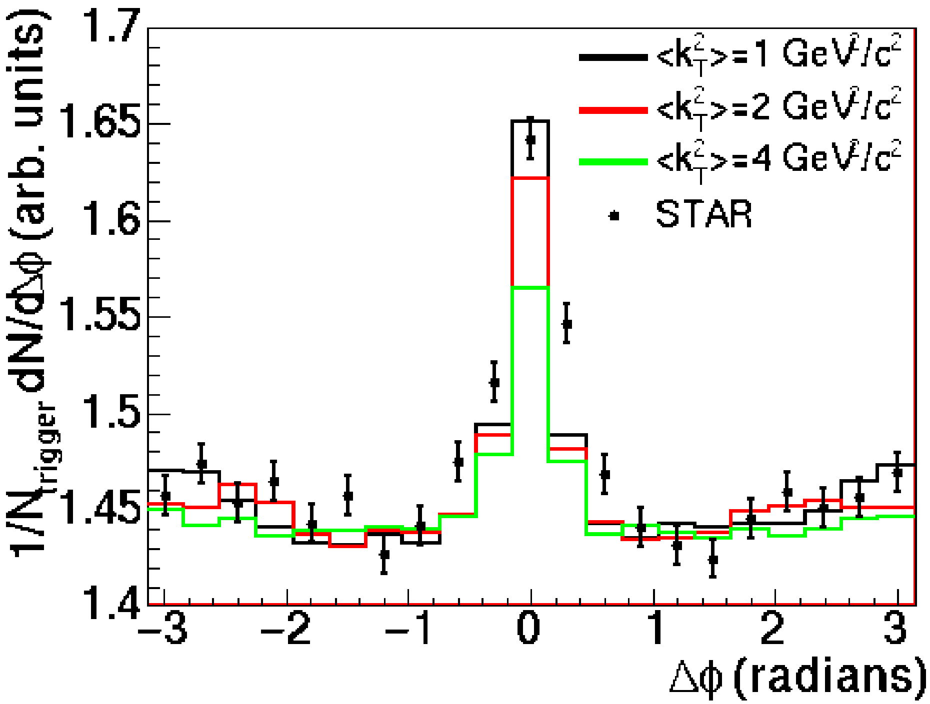


c.f. For C=0.25 with $<k_T^2>=4$ (inconsistent with R_{AA})
there is back-to-back correlation.

3. Effect of Broadening

Broadening of the jet momentum is closely related to energy loss





$$\langle p_\perp^2 \rangle = (\alpha_S N_C / 4)^{-1} |dE/dx|$$

Transverse momentum orthogonal to its direction of motion

R.Baier *et al.*, (1997)

Reduction of the away-side peaks:

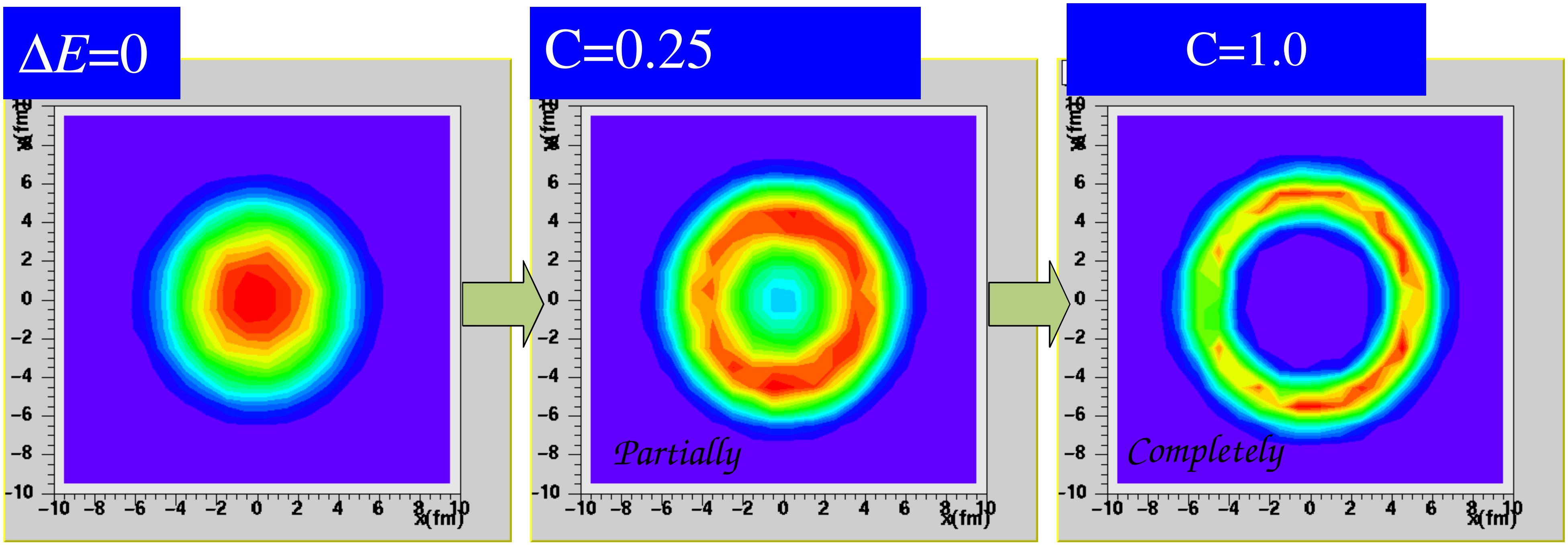
~60% from parton energy loss & intrinsic k_T

~40% from broadening

Surface Emission Dominance ?

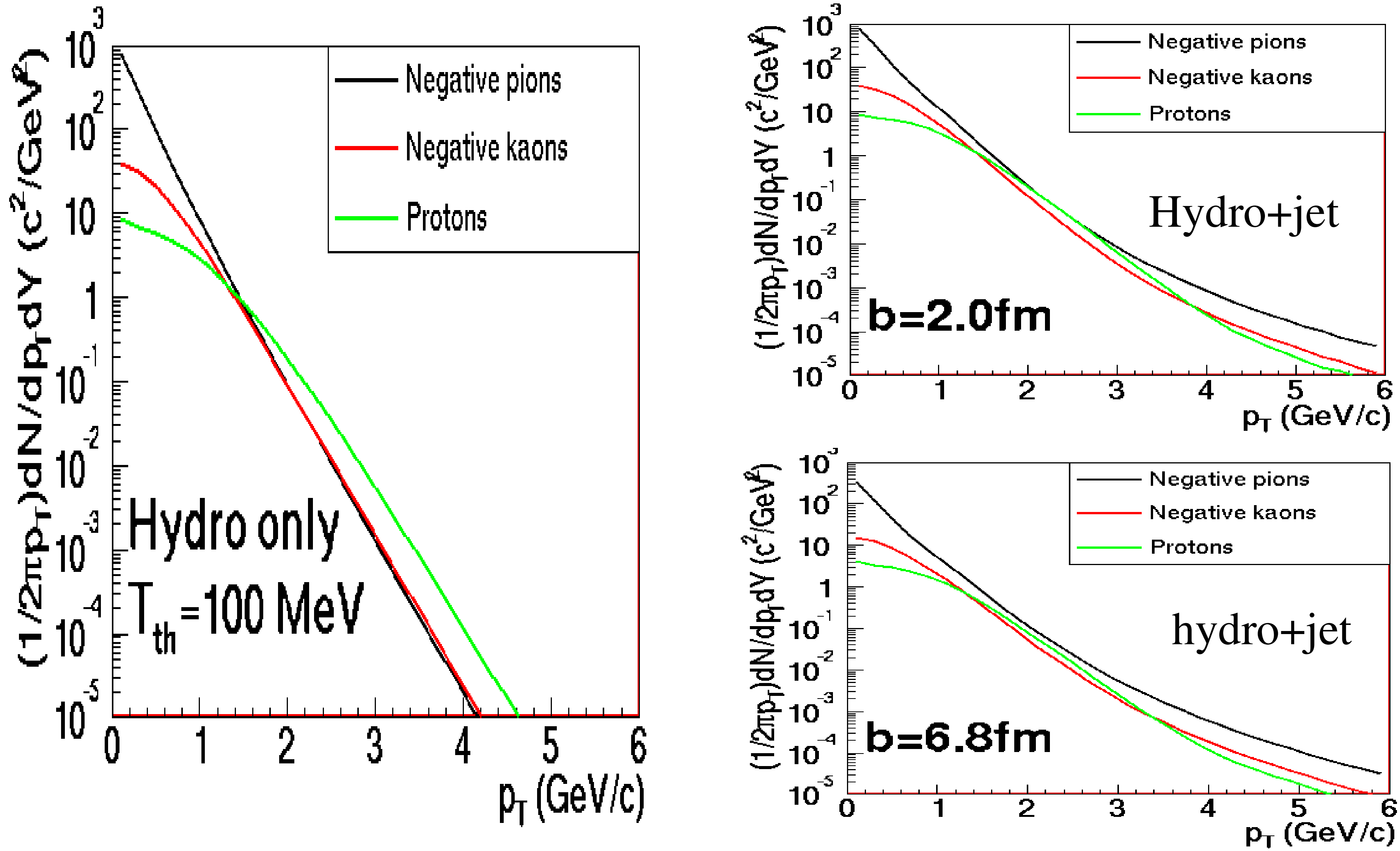
Initial positions of jets which survive at final time

$$\langle k_T^2 \rangle = 1\, GeV^2$$

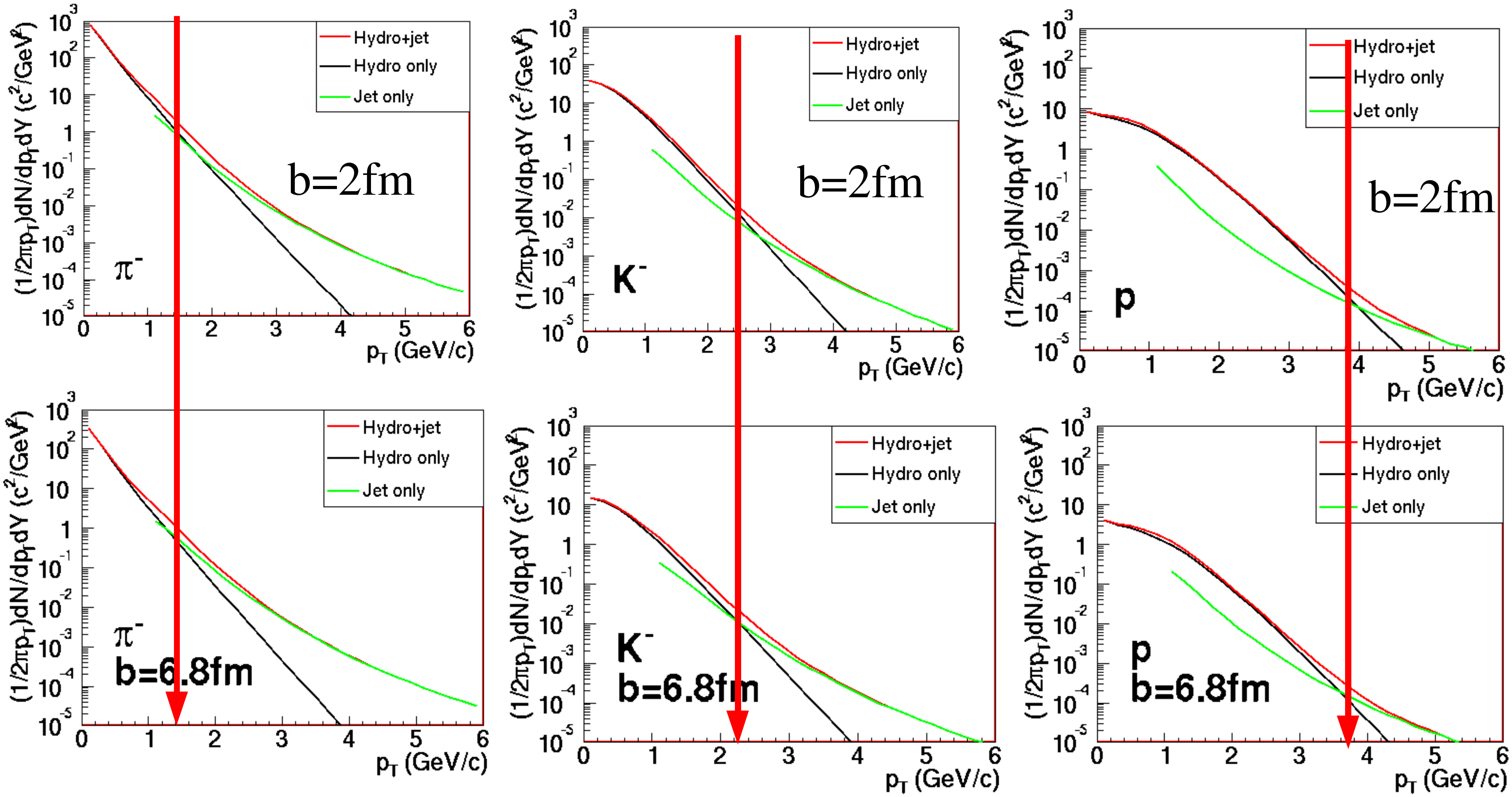


An interesting signature may be events in which the hard collision occurs near the edge of the overlap region with one jet escaping without absorption and the other fully absorbed. -- J. D. Bjorken, FERMILAB Pub -82/56-THY (1982).

Transverse momentum spectra

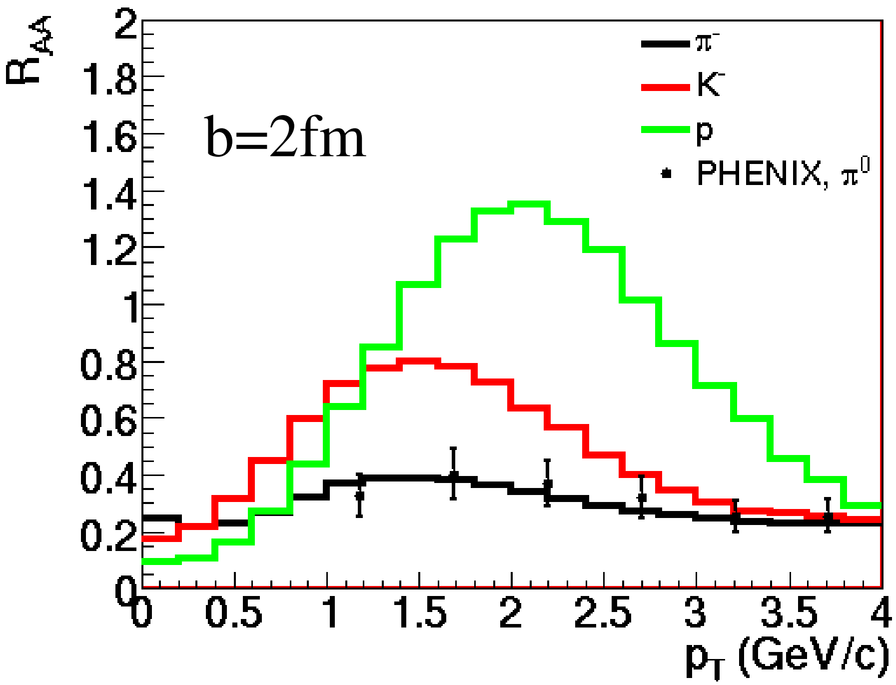


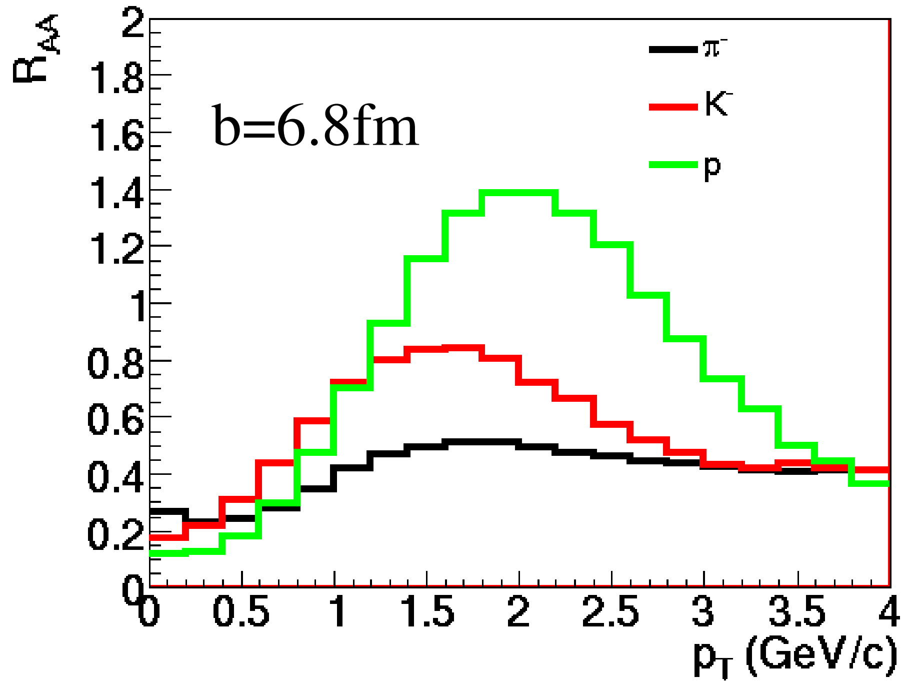
Interplay between Soft and Hard



Crossing point moves toward high momentum with mass.

Suppression factor for pi, K, p



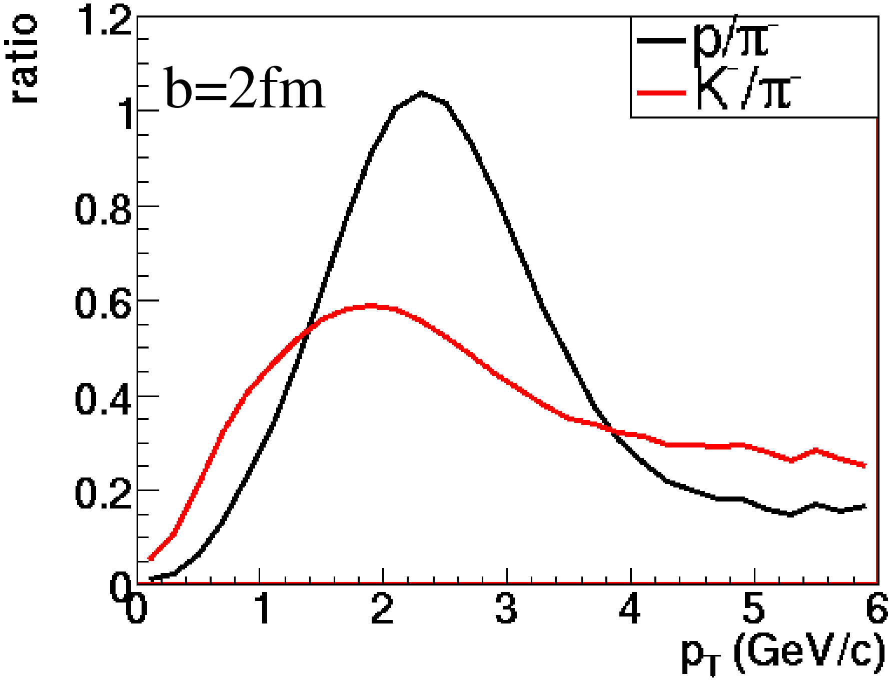


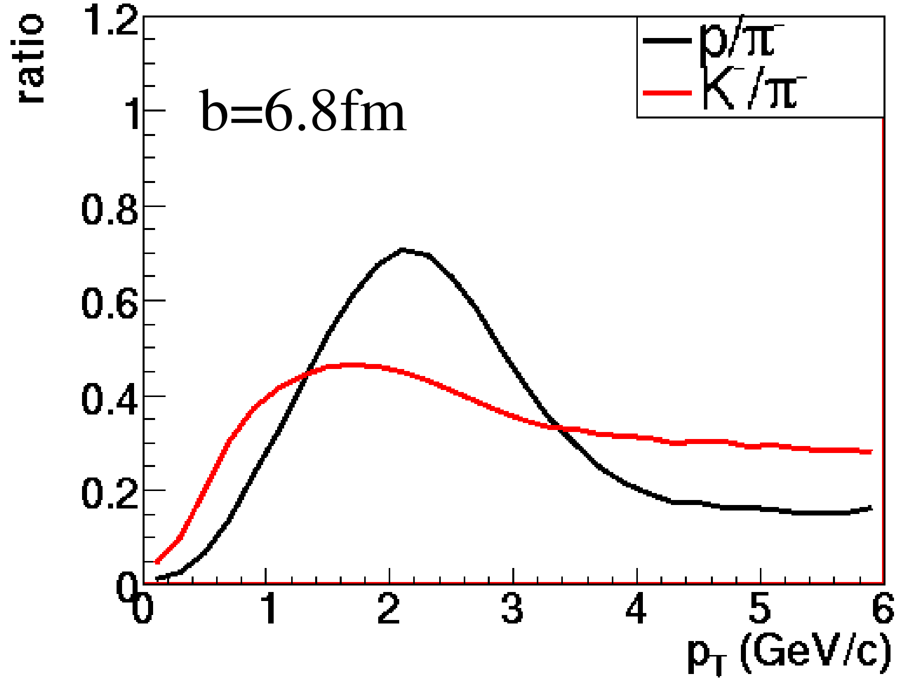
R_{AA} for proton > 1: interplay between radial flow and jet quenching?

No!

Proton yield from pQCD is 10 times smaller than that of hydro at 2GeV/c!

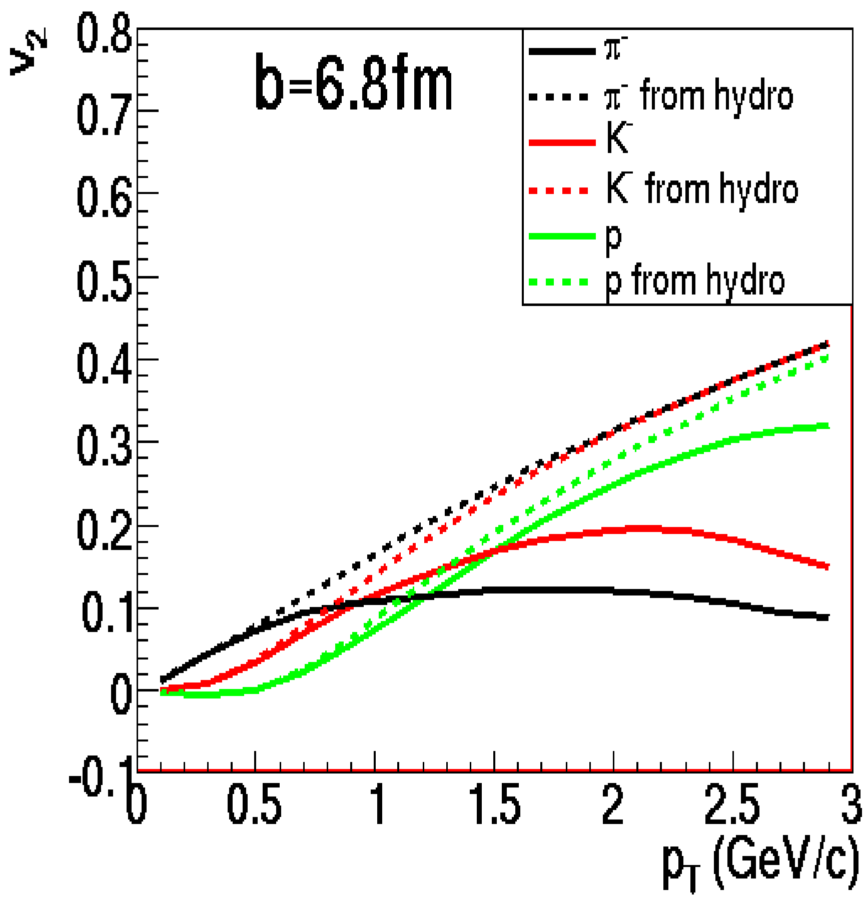
Ratio as a function of pT

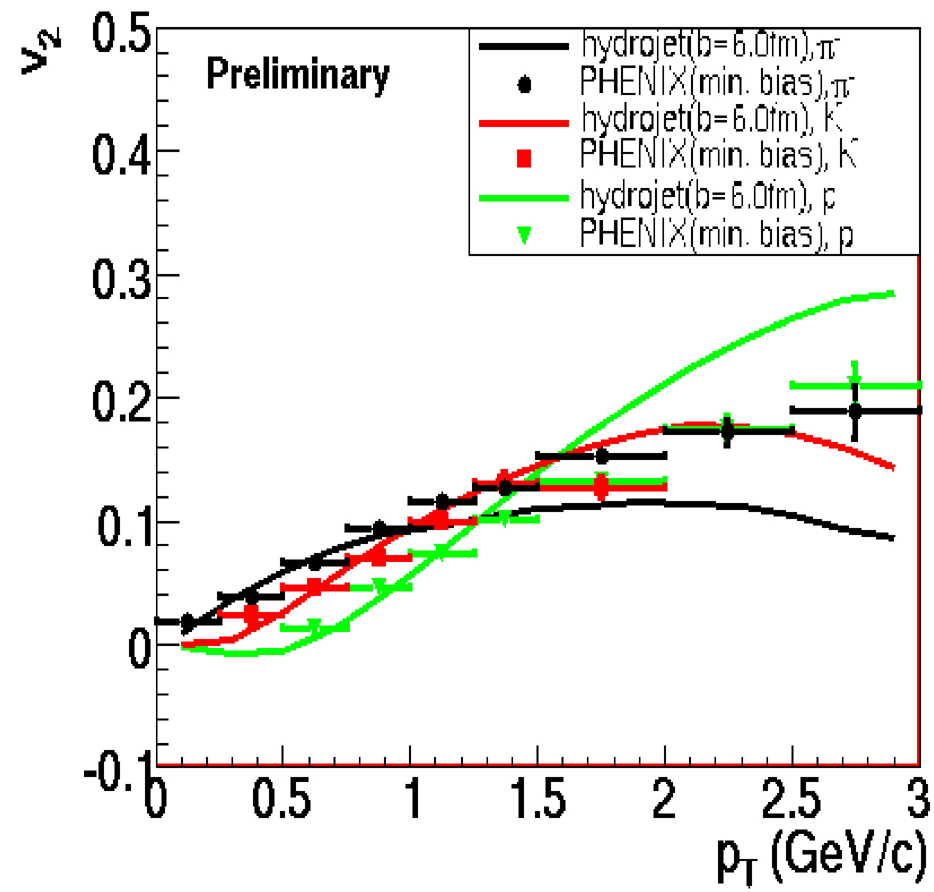




p/pi > 1 can be explained by hydrodynamic radial flow.

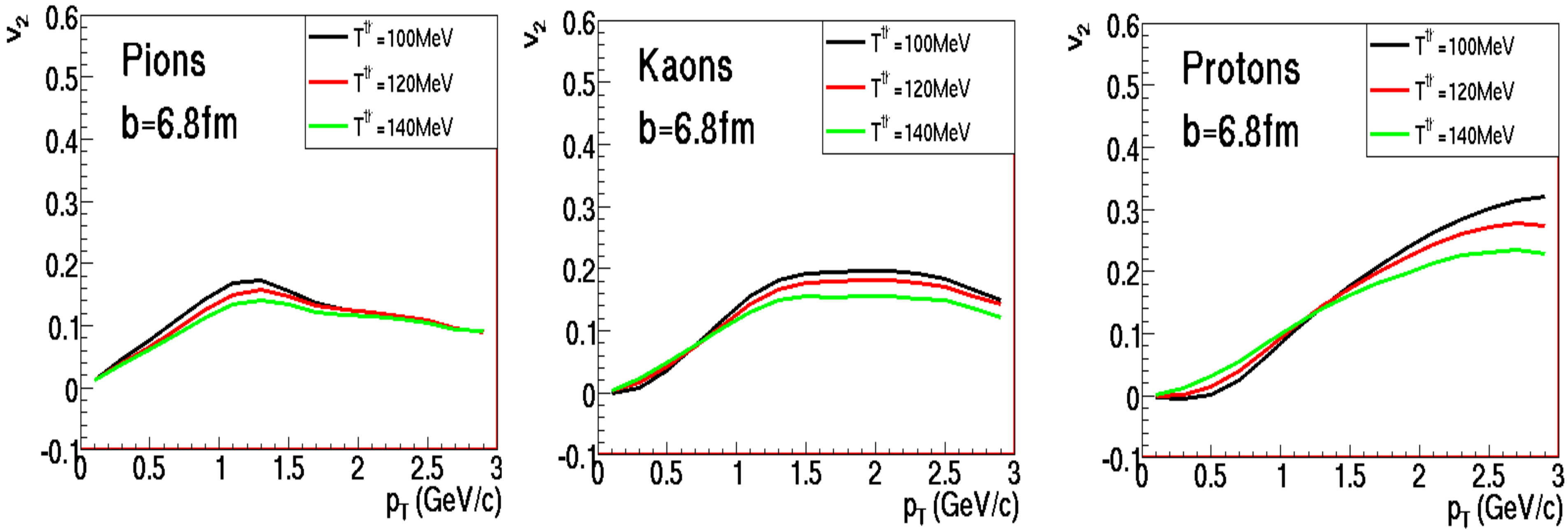
Elliptic flow for pi, K, p





hydro+jet model explains the crossing behavior of v2 for identified particle.

Thermal freeze out temperature dependence on the elliptic flow



T_{th} dependence on the v2 is rather large for protons.

Summary and conclusions

We studied the suppression factor and back-to-back correlations using hydro+jet model.

- Energy loss
- With broadening
- Intrinsic parton transverse momentum

All these effects are important to understand the disappearance of back-to back correlations in central Au+Au collisions.

- Energy loss occurs at the very early times less than 3fm/c.
- Partial surface emission of jets.

Consequence of the radial flow

- Transition point from soft to hard in transverse momentum is different in pions, kaons and protons.
- proton/pion > 1 and R_{AA} > 1 for proton.
- Crossing in v2.