High momentum particle suppression in Au-Au collisions at RHIC.

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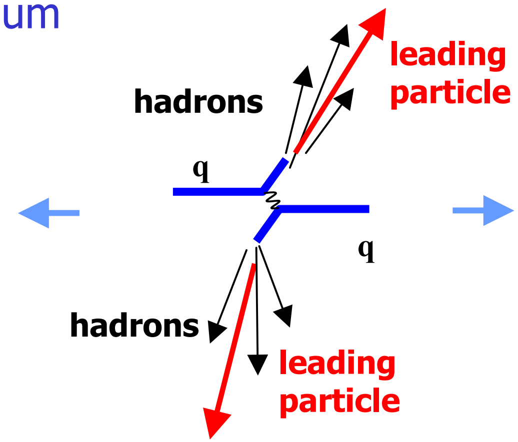
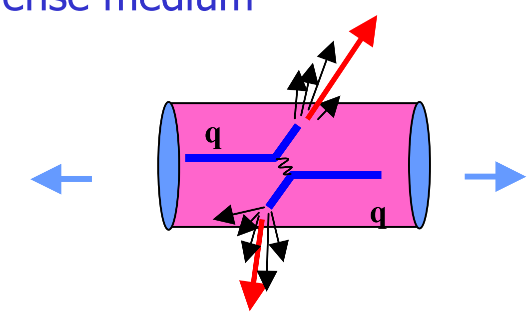
New Observable

In vacuum



In a dense medium

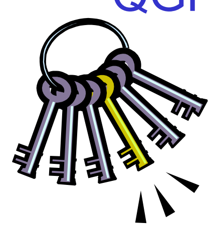


At energy regime of RHIC, hard scattering processes become important:

(Hard scattered partons fragment in Jets of hadrons of high momentum)

new "observable" is becoming available : Jets

Jets production rate can be calculated in pQCD.



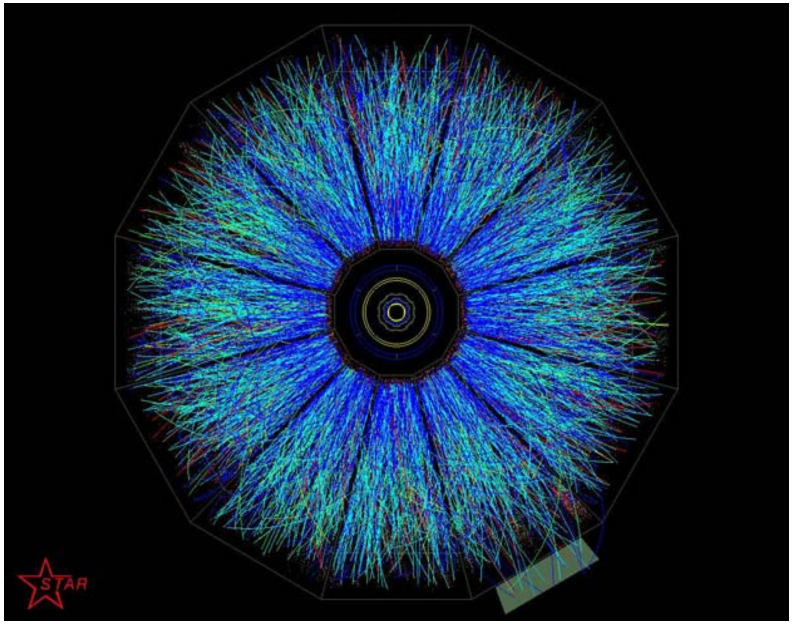
QGP has direct consequences on jet production rate: "jet quenching"

Partons loose energy traversing dense matter.

The jets becomes broader and show anisotropy

Not trivial !

+



In the high multiplicity environment of a Heavy Ion Collision, it is difficult to reconstruct jets

Indirect measurement through high p_T particles

We concentrate on charged particles (negative and positive hadrons) and on neutral pions

Something new at RHIC ?

Is there really something new happening?

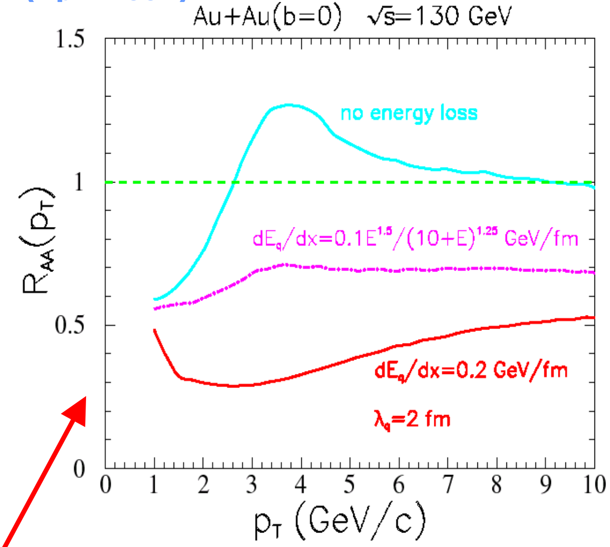
We need a base-line for comparison :

use nucleon-nucleon coll. at the same energy

apply simple scaling behaviours

Deviations from simple super-positions of elementary reactions as well as deviations from measurements of the same quantity at other energies and collision-systems indicate that something interesting is happening.

E. Wang and X-N. Wang, nucl-th/0104031 (April 2001)



Theory predictions under different assumptions

Elementary Reactions

N-N reference

Spectra of charged particles measured over a large energy range but not at 130GeV/c

Interpolate data with :

$$\sigma_{pp} = d^2N/dp_t^2 = A\,(p_0+p_t)^{-n}$$

In absence of nuclear effects, A-A collisions are a superposition of N-N reactions.

Hard scattering processes scale as:

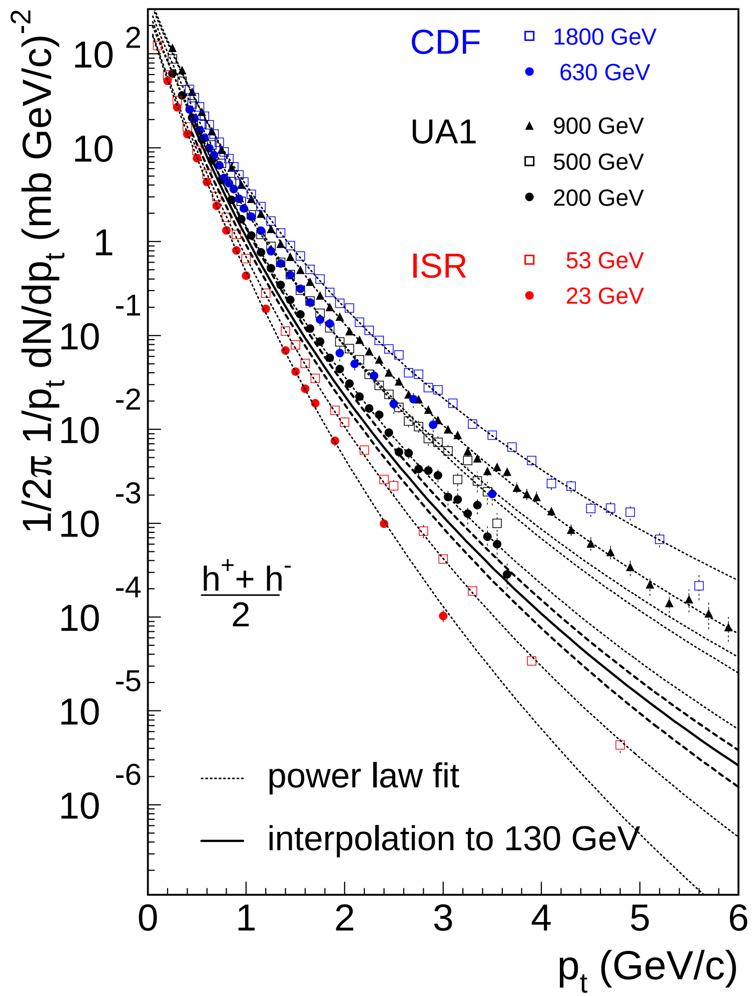
the number of independent nucleon-nucleon binary collisions: <Nbinary>

Expected yield in A-A :

$$\text{Yield}_{A\text{-}A} = \text{Yield}_{N-N} \cdot \langle N_{binary} \rangle$$

(for the A-A centrality class)

Compiled by A. Drees (QM2001)



P_T Spectra

Two observables:

charged particles

neutral pions

PbGl and PbSc

2 centrality selections:

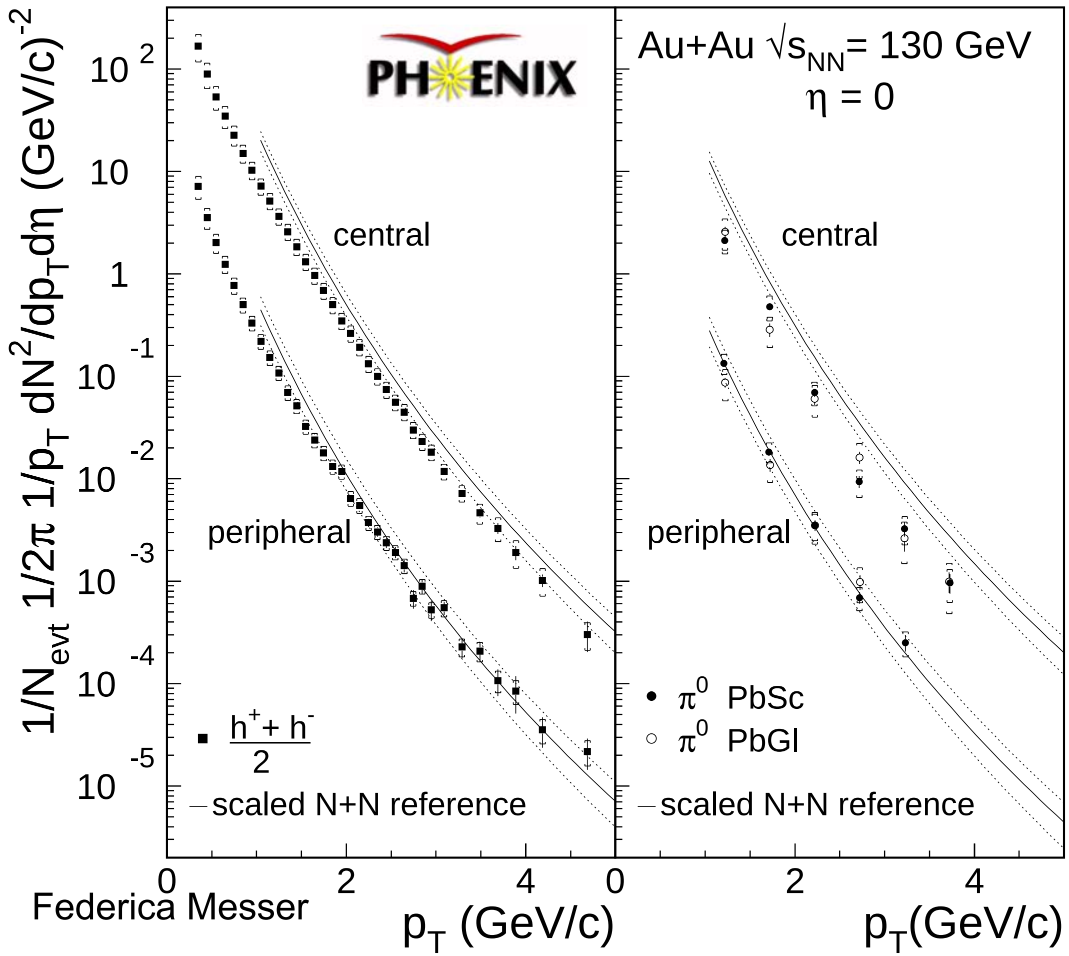
central (0-10%)

peripheral (60-80%)

3 analysis with different systematics

Compared with the point-like scaling of N-N collisions

Phys. Rev. Lett. (88) 2002



Nuclear Modification Factor

From measurement:

$$\text{Yield}_{A\text{-}A} = \frac{1}{N_{evt}} \cdot \frac{d^2N}{2\pi \cdot p_T \cdot d_{p_T} d\eta}$$

$$R_{A-A}(p_T) = \frac{\text{Yield}_{A-A}}{\langle N_{binary} \rangle \cdot \text{Yield}_{N-N}}$$

At high p_T (where hard scattering processes dominate),

$R_{A\text{-}A}$ should be 1 (in absence of nuclear effects)

Departures from 1 are a measure of the nuclear effects:

$R_{A\text{-}A}$ is called also Nuclear Modification Factor

Nuclear Effects at RHIC

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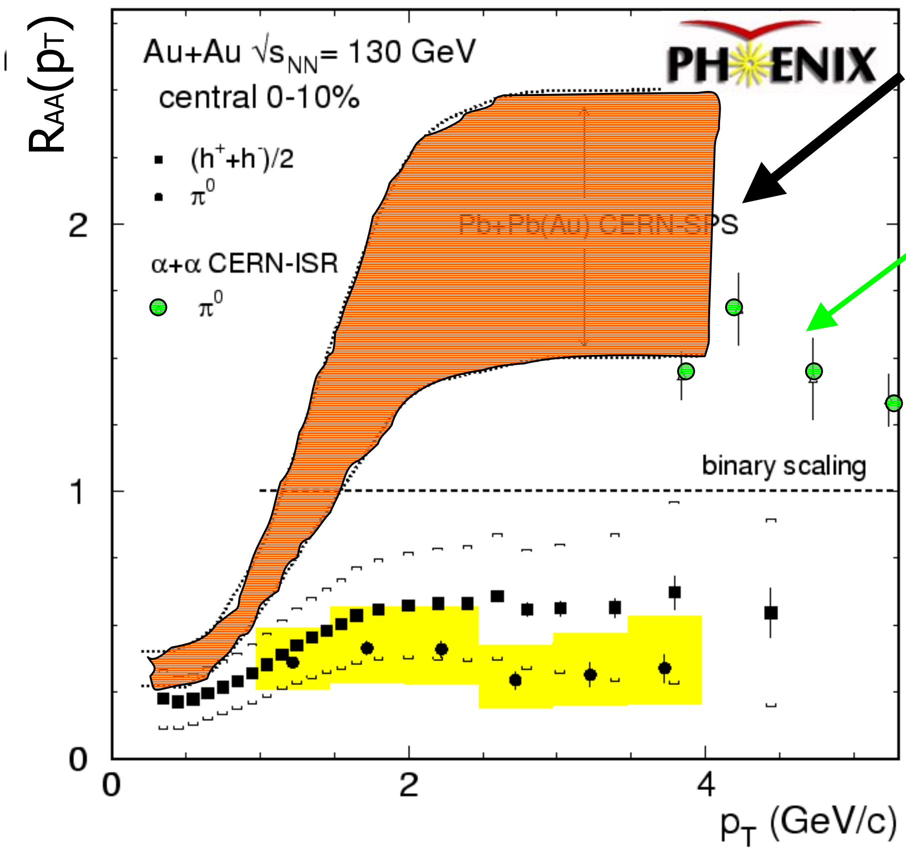

Range of uncertainty at lower energy $\sqrt{s}$ =17GeV

$\alpha-\alpha$ at $\sqrt{s}$ =31GeV

$$R_{A-A}(p_T) < 1$$

Charged particles:

increase up to p_T = 2GeV/c

saturate at R_{AA} ~ 0.6

Neutral pions:

roughly constant at R_{AA} ~ 0.4

Central / Peripheral

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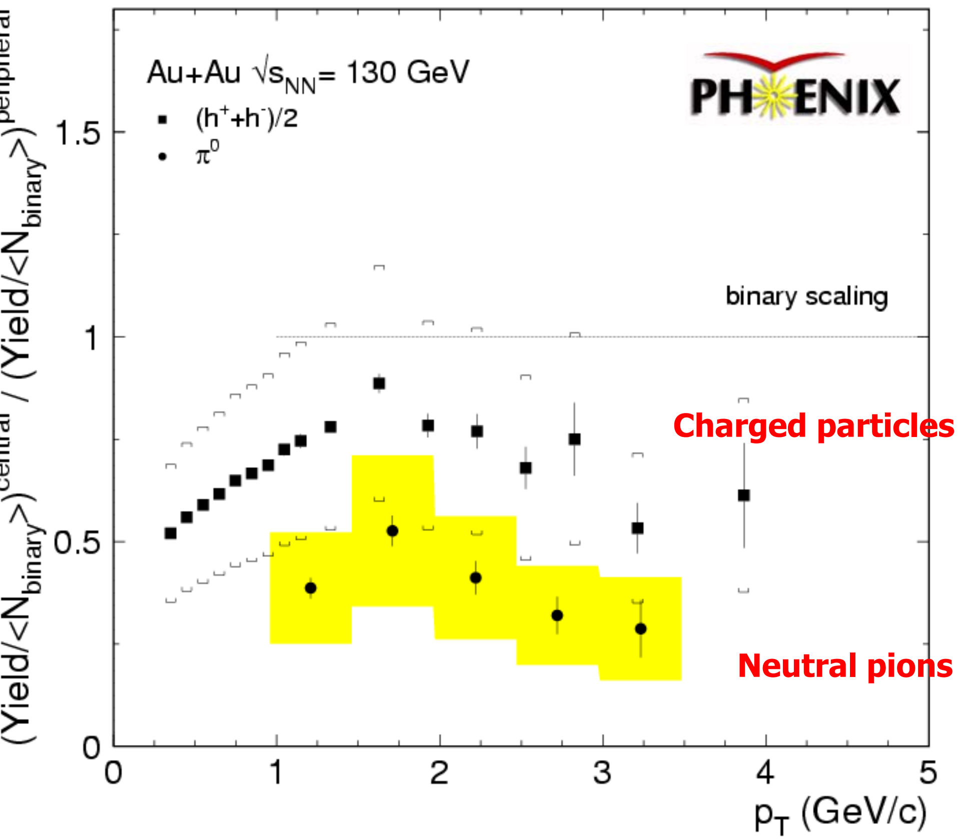


To reduce the systematic errors due to the N-N reference:

$$\frac{\text{Yield}_{\text{central}} / \langle N_{\text{binary}} \rangle_{\text{central}}}{\text{Yield}_{\text{peripheral}} / \langle N_{\text{binary}} \rangle_{\text{peripheral}}}$$

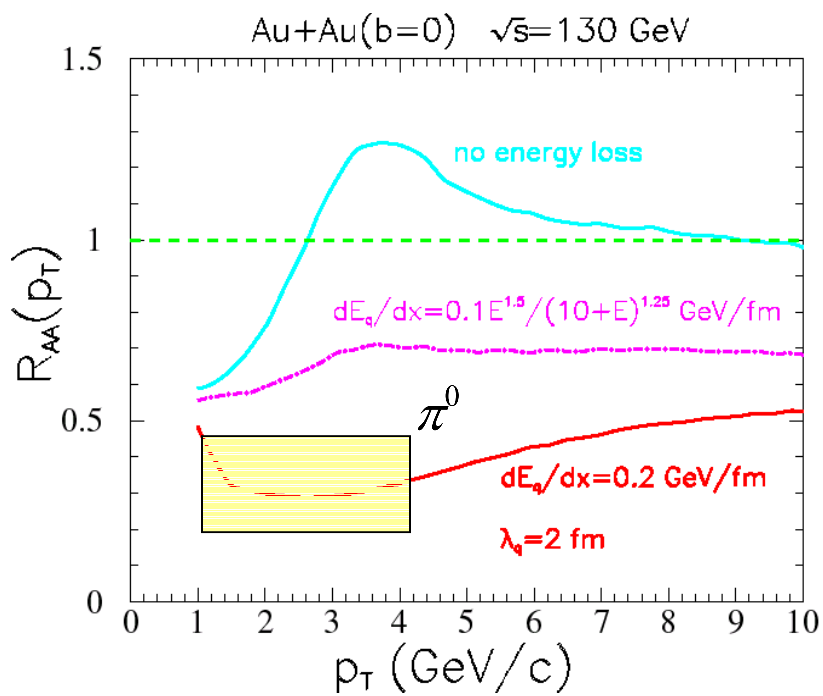
$$\langle N_{\text{binary}} \rangle_{\text{central}} = 905 \pm 96$$

$$\langle N_{\text{binary}} \rangle_{\text{peripheral}} = 20 \pm 6$$

Large systematic error on the number of binary collisions in the peripheral class

Theory Comparison

E. Wang and X-N. Wang, nucl-th/0104031 (April 2001)



Theoretical predictions for the "nuclear modification factor" R_{AA} under different assumptions

No Energy Loss

Fix Energy Loss (dE/dx = 0.2 GeV/fm)

Energy dependend dE/dx.

Seems to favour the Energy Loss scenario but

NOTE: Calculations are model dependent

YES !

Unlike at lower energies,

at RHIC we observe in central collisions for both charged particles and neutral pions a suppression at high p_T relative to:

- Binary scaling
- Peripheral collisions
- Expected Cronin effect (Initial multiple scattering effect)

Data are not inconsistent with parton energy loss calculations (“jet quenching”)

PHENIX

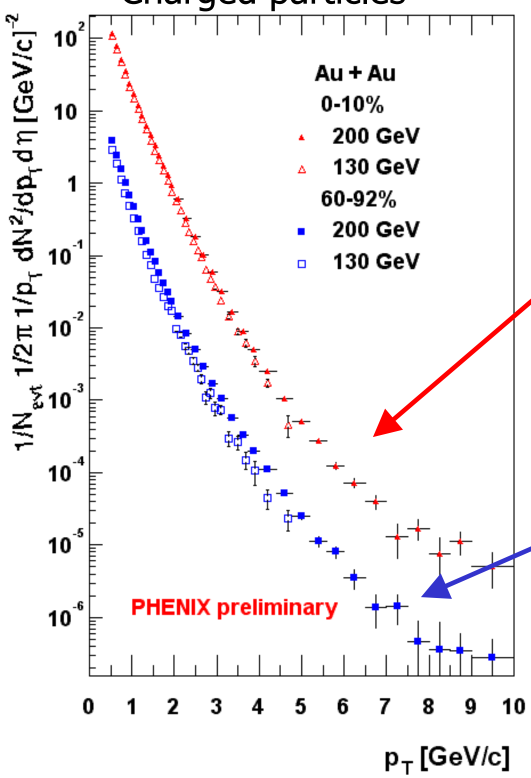
130 vs 200 GeV/c

Higher statistic allow to reach higher transverse momenta.

Qualitatively the same effect is present

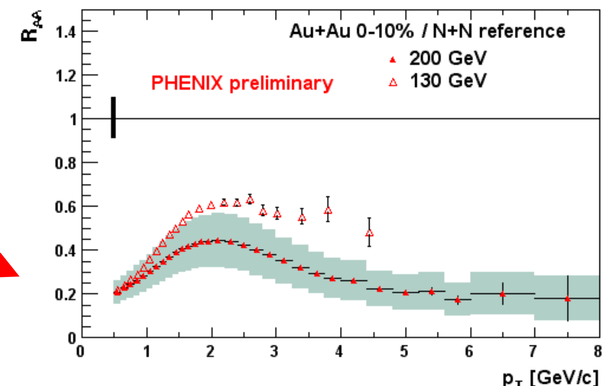
Increased magnitude or different particle composition ?

Charged particles

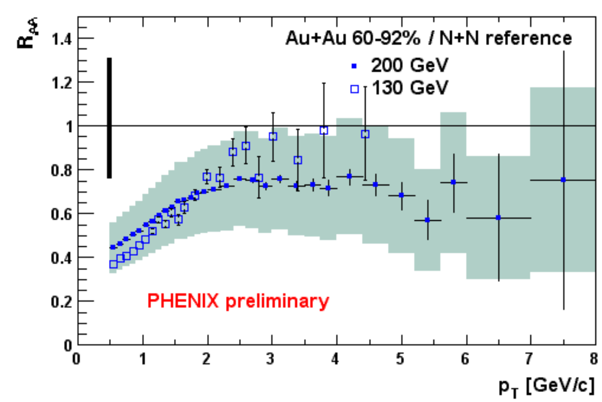


central

peripheral



Charged particles



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Summary

In RHIC collisions at 130 GeV/c, we measure the suppression of high p_T particles up to 4GeV/c for:

- charged particles
- neutral pions
- - gradual evolution of the suppression as a function of centrality

At 200 GeV/c we observe the same effects over a broader range in momentum in three different channels:

- charged particle up to 8 GeV/c
- neutral pions (not shown)
- identified charged pions above 5GeV/c (not shown)
- All analysis have very different systematics
- To reduce systematic errors we have measured our 'own' N-N reference

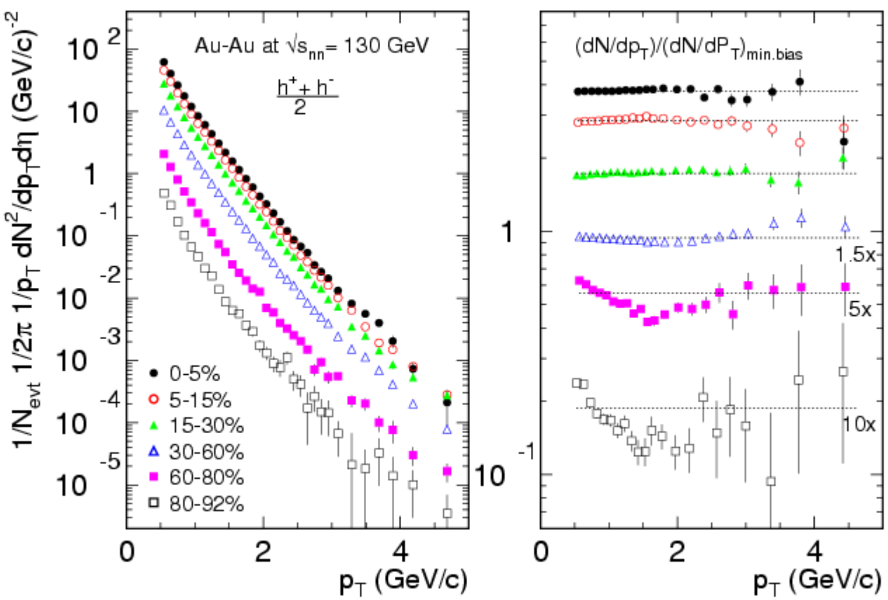
Qualitatively consistent with theory predictions with include formation of an opaque medium

Few suggestions for questions

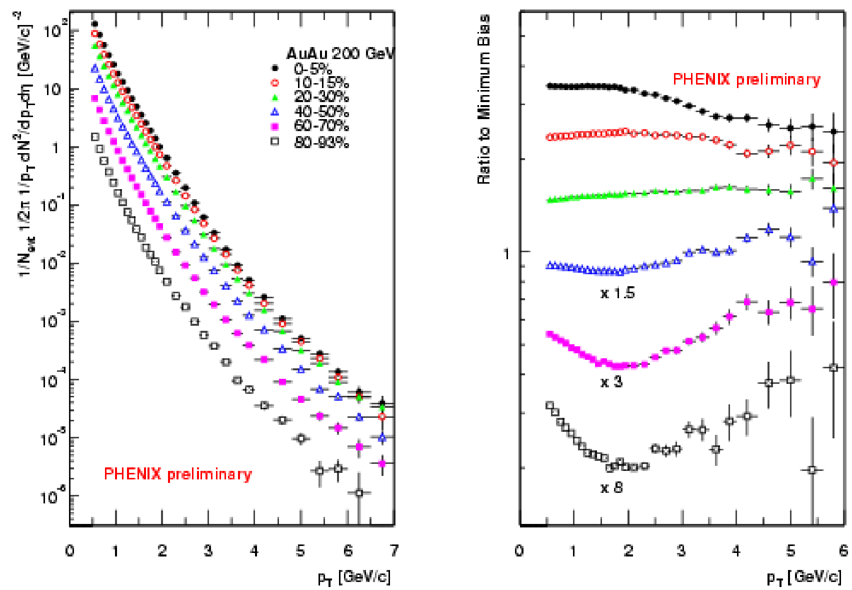
- What is the centrality evolution of the suppression ?
- Is there some particle species dependence ?
- Do you see evidence of jets in A-A collisions at RHIC ?
- What are the next steps ?
  - analyze charged particle in p-p collision
  - d-A collision run
  - study particle species dependence
  - Angular dependence of the suppression:
    - study correlation with the plane of the reaction

Centrality Evolution

130 GeV/c nucl-ex/0207010



200 GeV/c



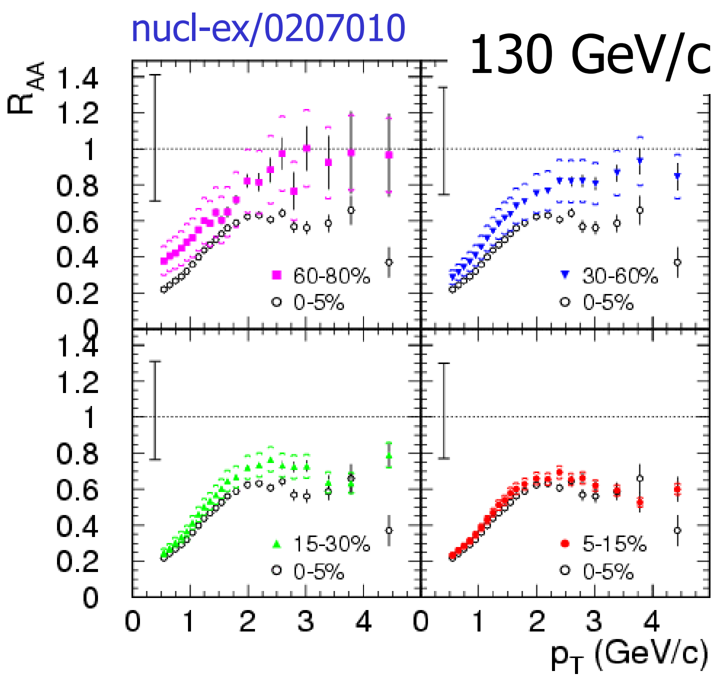
Continuous evolution of the shape:

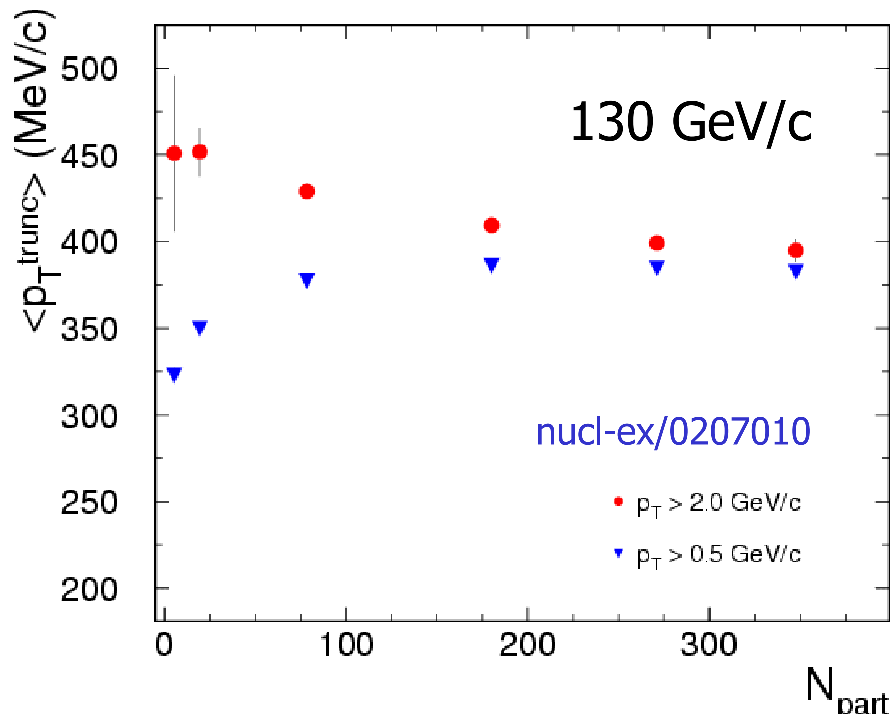
-- pronounced power law in peripheral

-- more exponential spectrum in central

Similar behaviour in 130 and 200 GeV/c

Centrality evolution of R_{AA}





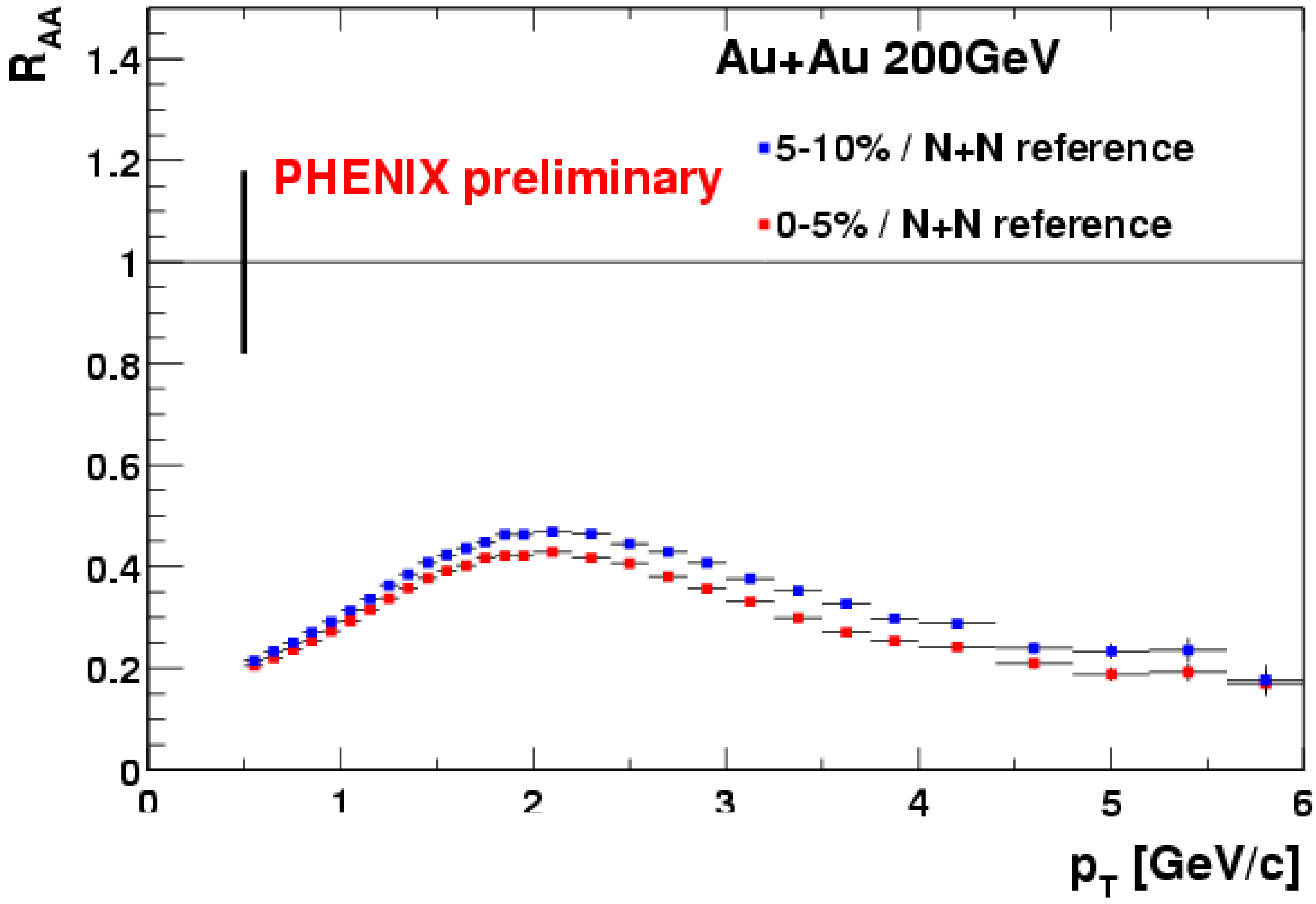
R_{AA} shows a continuous evolution as function of centrality.

The truncated average p_T:

$\langle p_T \rangle - p_T^{min}$ is studied as function of centrality.

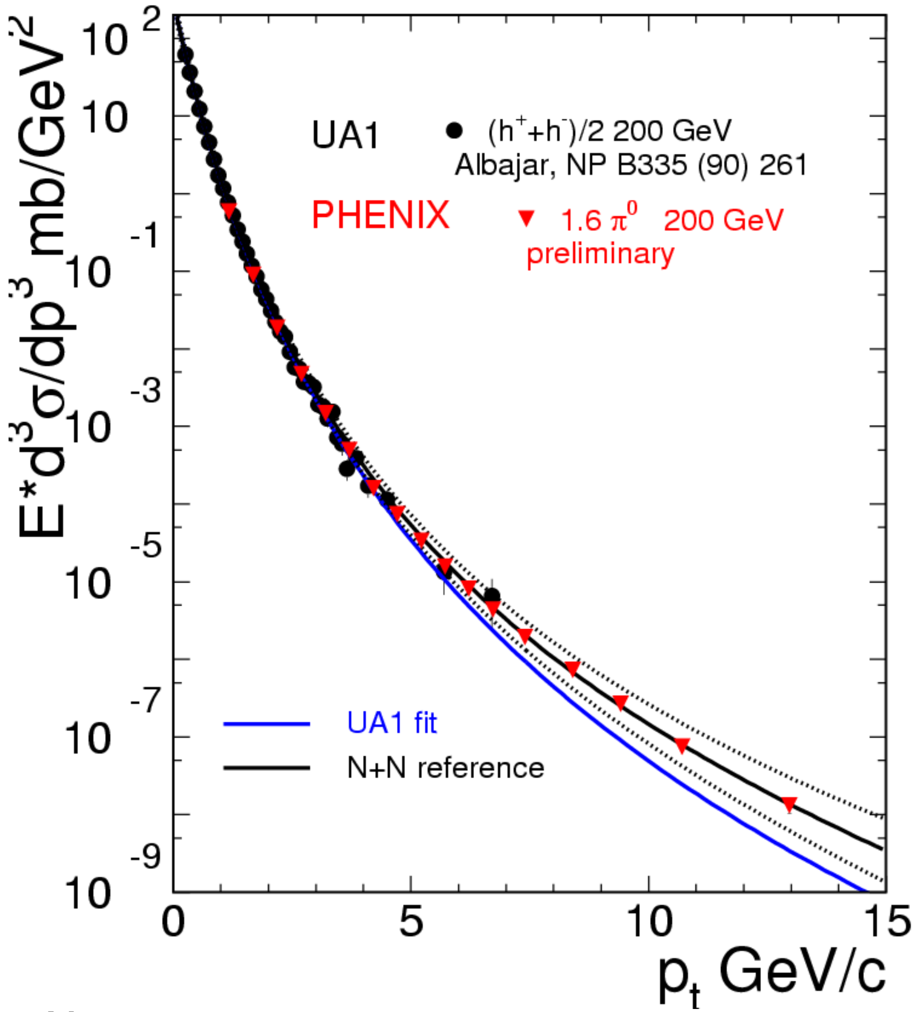
It increases for pT > 0.5 GeV/c but decreases for pT > 2GeV/c

- Continues increases of suppression towards central collisions
- Suppression more pronounced at high p_T



Our N-N reference

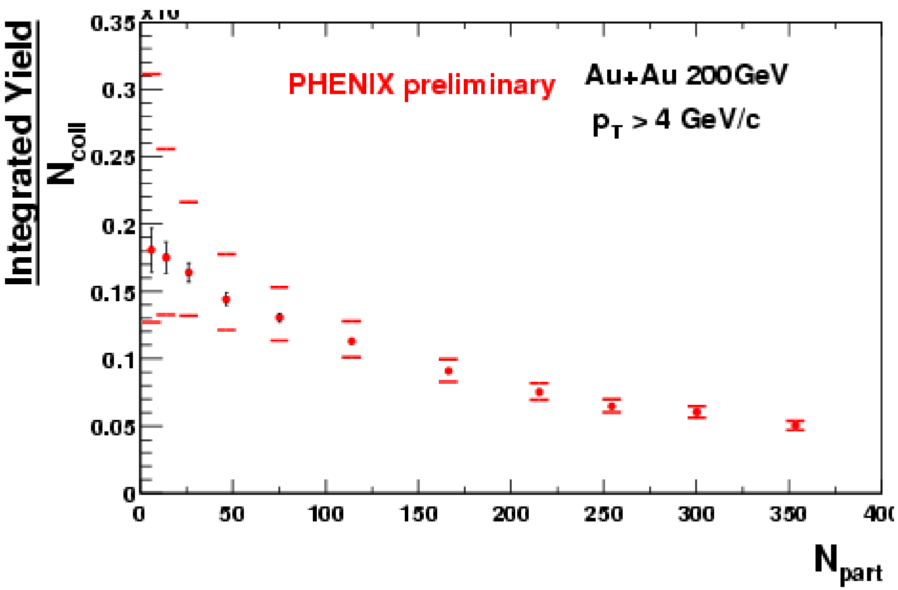
- PHENIX measures neutral pions up to 13GeV/c at mid rapidity.
- Comparison of scaled neutral pions to UA1 data (charged hadrons) at the same energy.
- Neutral pions above the UA1 fit (extrapolated at high pt)



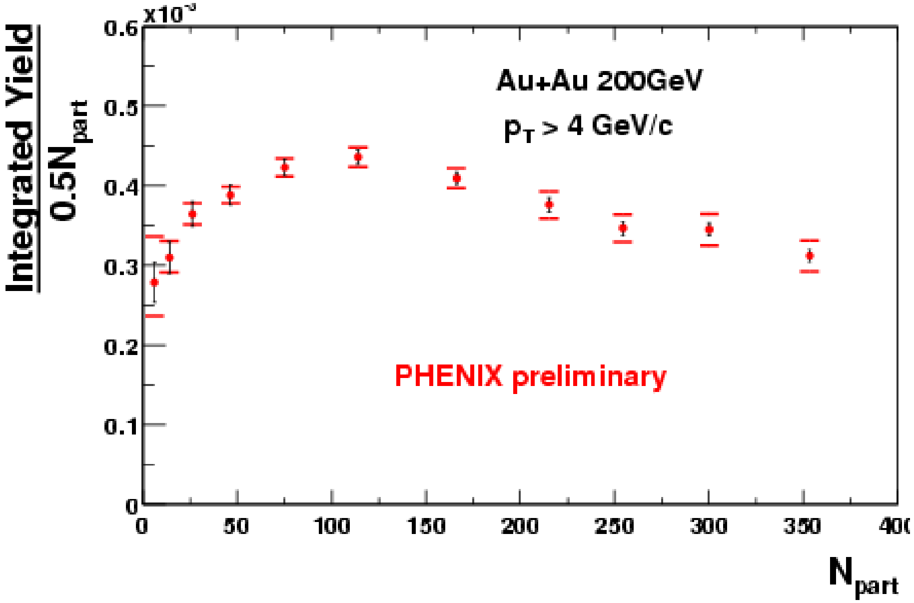
Testing different scaling

Charged particles

Scaling with Ncollisions



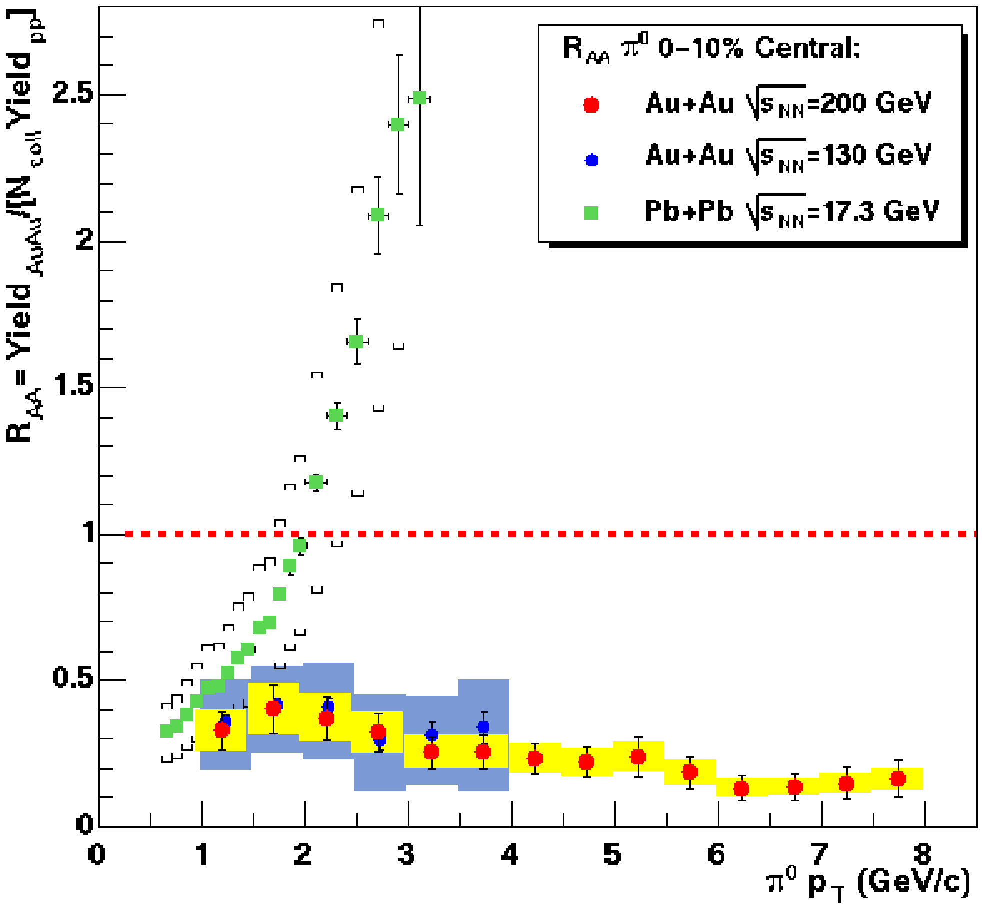
Scaling with Nparticipants



Neutral pions

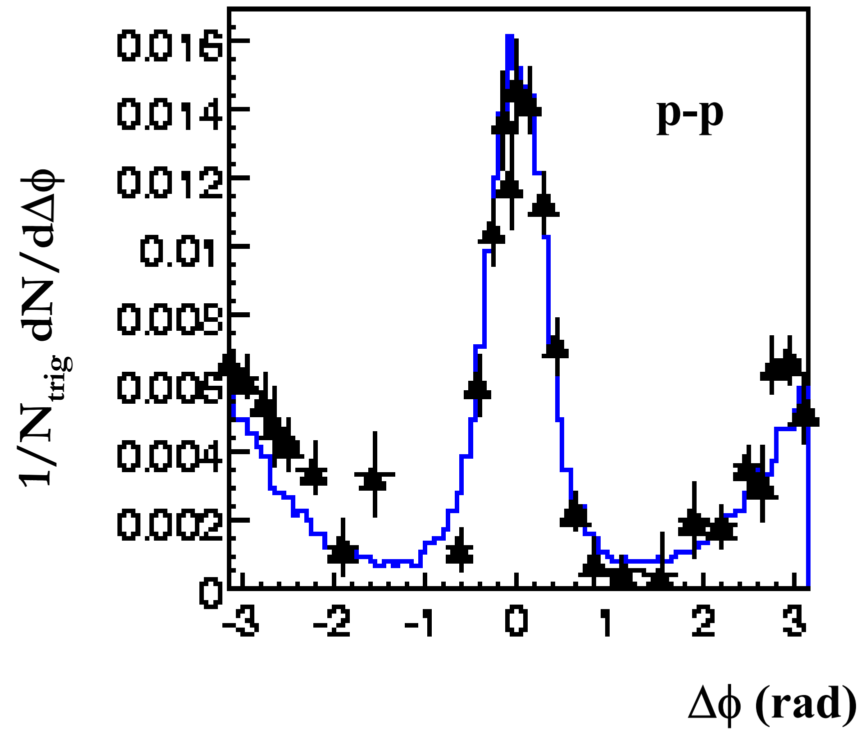
Similar effects are observed for neutral pions.

At 8 GeV/c (at 200GeV/c) suppression factor is ~6.



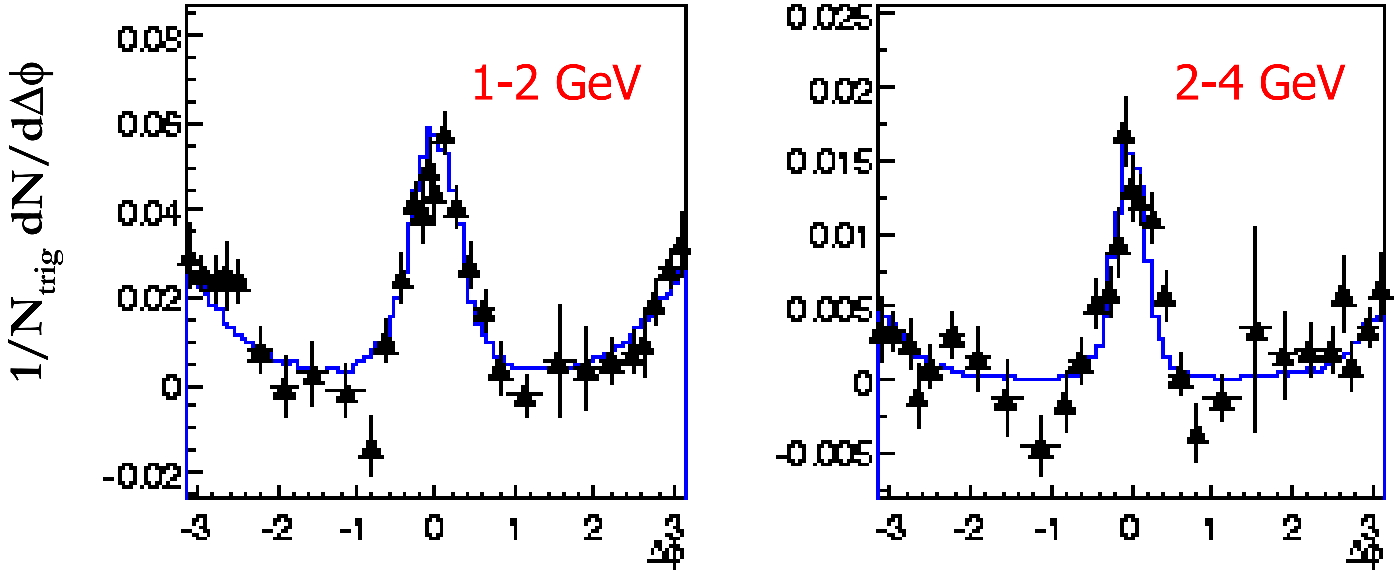
Jet signature

In p-p we observe strong angular correlation for high transverse momentum particles (neutral-charged).
The shape is described by PYTHIA.



Au-Au

- Semi-central Au-Au collisions
- PYTHIA



Known Nuclear Effects

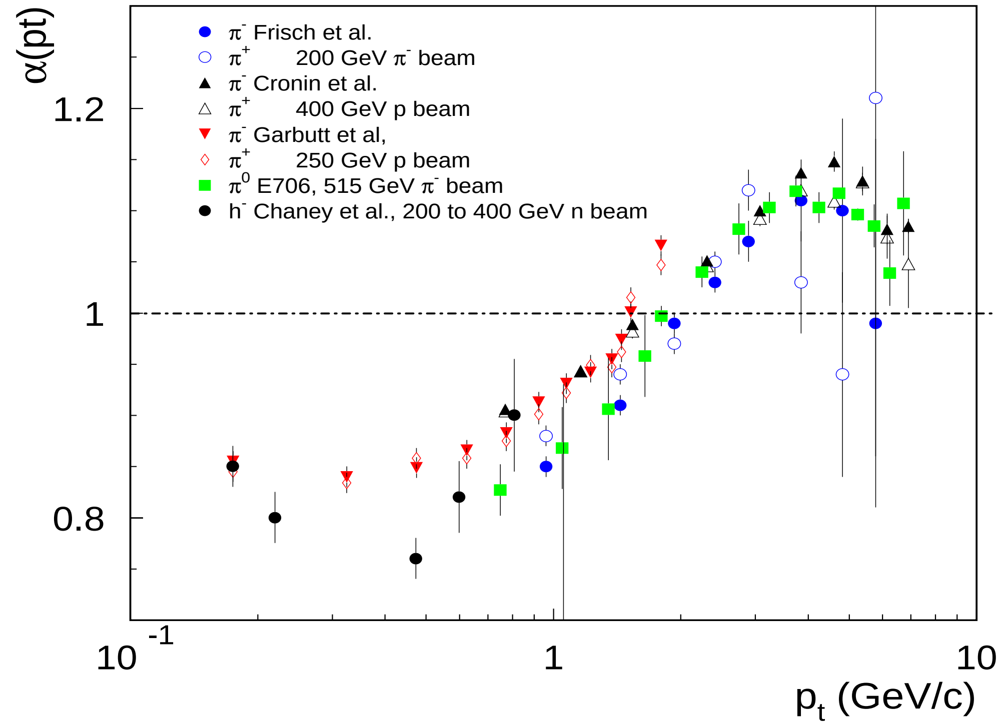
Modifications due to nuclear effects have long history (1975):

Cronin Effects in p-A

$$\sigma_{pA} = A^{\alpha(p_t)}\,\sigma_{pp}$$

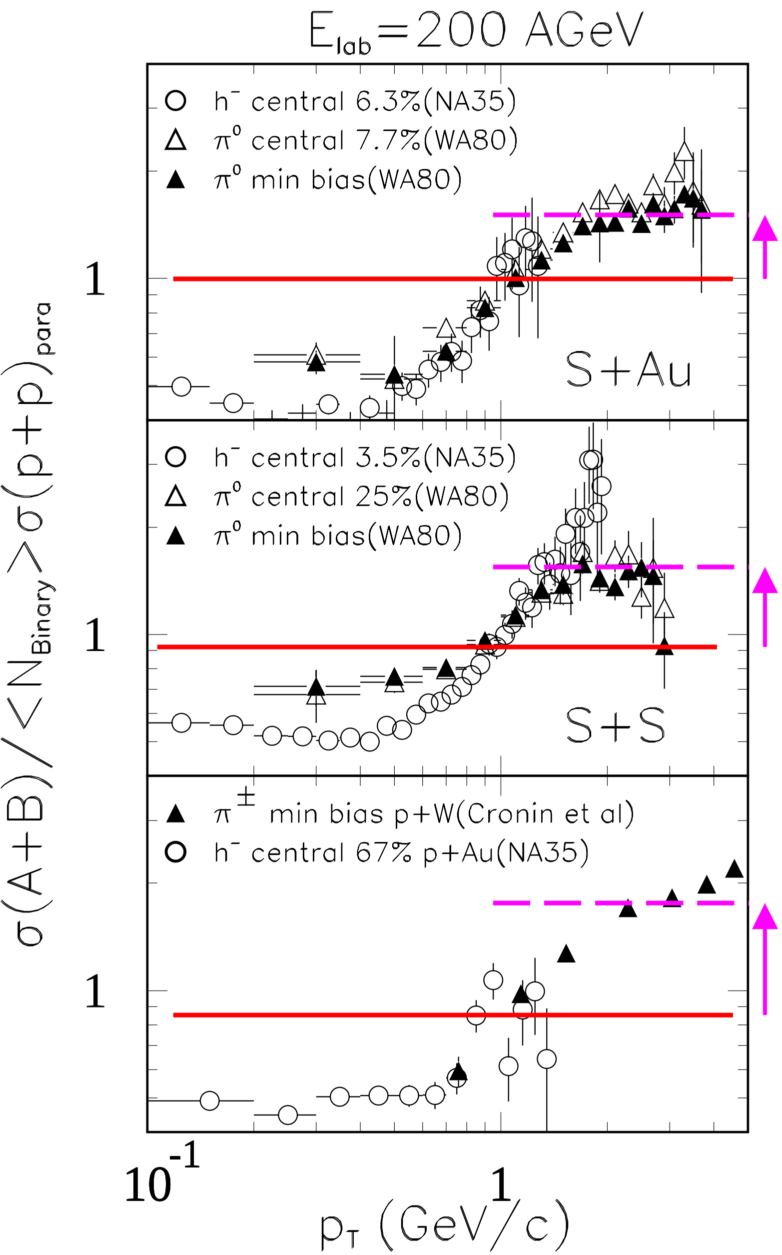
"anomalous" nuclear enhancement above 1.5-2GeV/c

(initial state multiple scattering)



Shadowing at smaller p_T

Known Effects

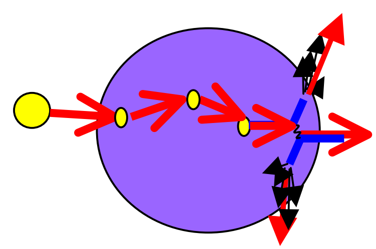


X.N.Wang, nucl-th/0104031

p-A data as well as A-A data at smaller energies show an excess above unity:

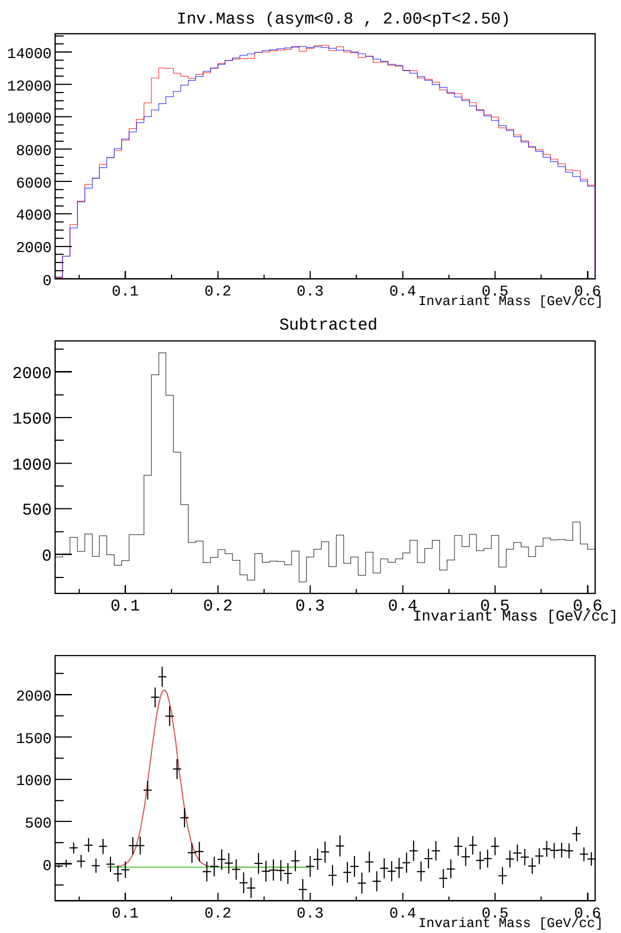
known as Cronin Effect

(initial multiple scattering)



$R_{A-A}(p_T) > 1$

Detection Methods



Neutral Pions decay in two photons

Yield extracted from invariant mass dist.

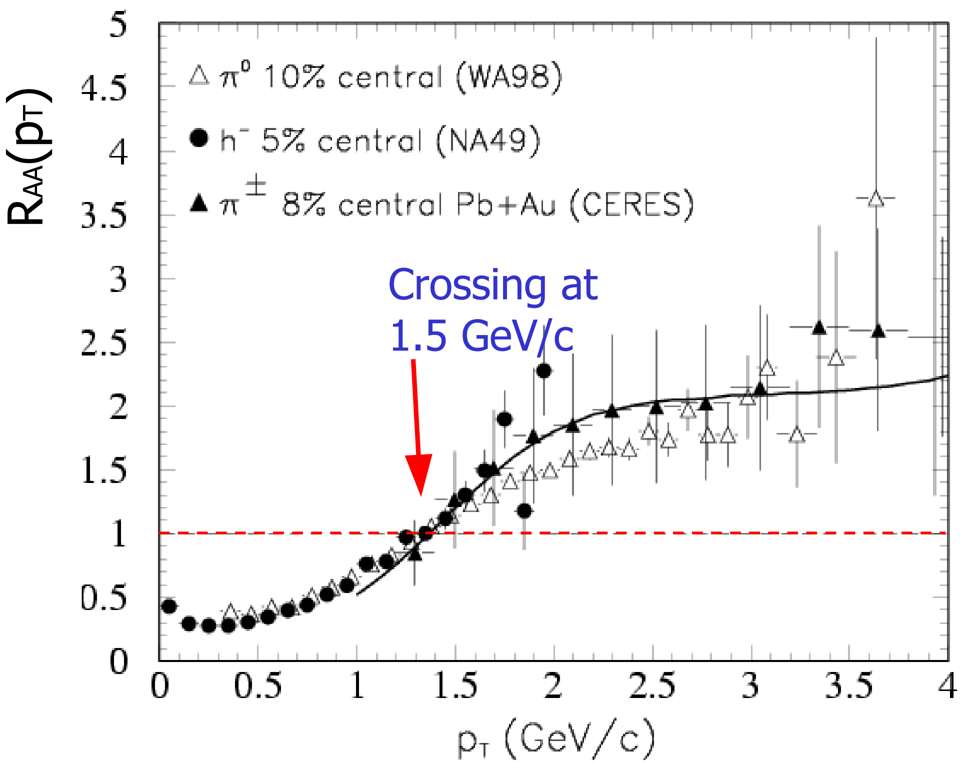
Energy scale verification:

- invariant mass peak location vs p_T
- E/p ratio for electron tracks

Charged particles are detected using tracking chambers (sensitive to the charge) and momenta is measured through the deflection of the tracks into a magnetic field.

Nuclear Effects at CERN

Compilation of X.N. Wang



At CERN-SPS energies :

R_{AA} (p_T) for **central** Pb-Pb(Au) collisions exhibits the "Ordinary" Cronin Effect

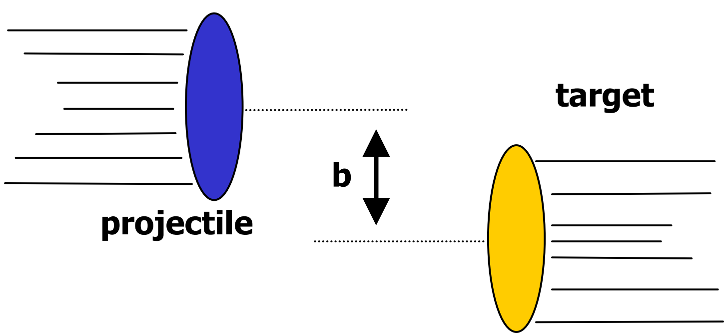
$$R_{A-A}(p_T) = \frac{\text{Yield}_{A-A}}{\langle N_{binary} \rangle \cdot \text{Yield}_{N-N}} > 1$$

Characterizing the collision

Not all the collisions are the same:

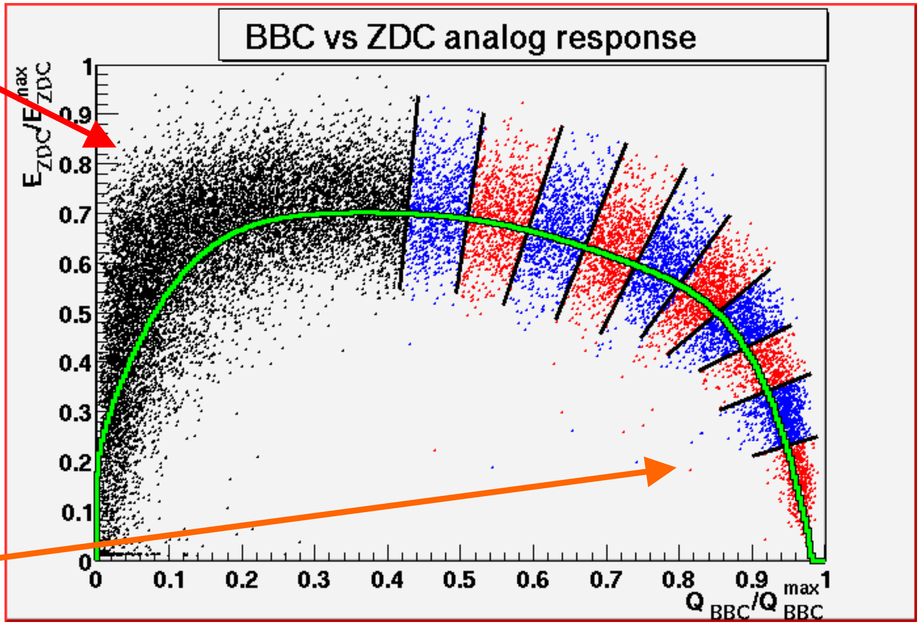
most of them are "peripheral":

large impact parameter, small overlap of the two nuclei, small reaction region



fewer are "central":

small or zero impact parameter, large overlap of the nuclei, large reaction volume



Scaling N-N reactions

In absence of nuclear effects, A-A collisions are a superposition of N-N reactions.

Hard scattering processes scale as:

the number of nucleon-nucleon binary collisions: $\langle N_{binary} \rangle$

Expected yield in A-A :

$$\text{Yield}_{A\text{-}A} = \text{Yield}_{N-N} \cdot \langle N_{binary} \rangle$$

(for the A-A centrality class)