Jet Quenching at RHIC

First Results from the Spring, 2003 RHIC 200 GeV d+Au Run

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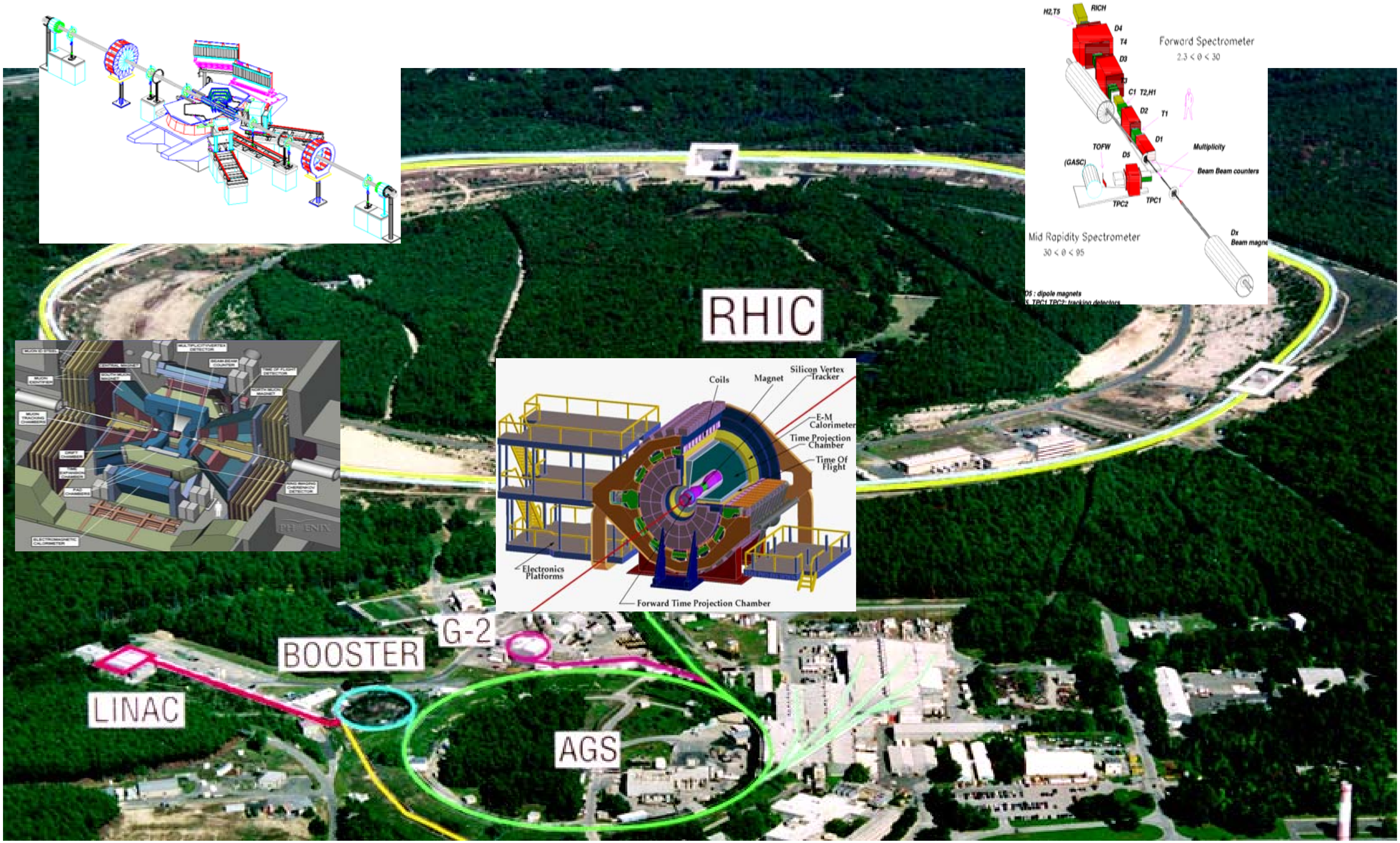
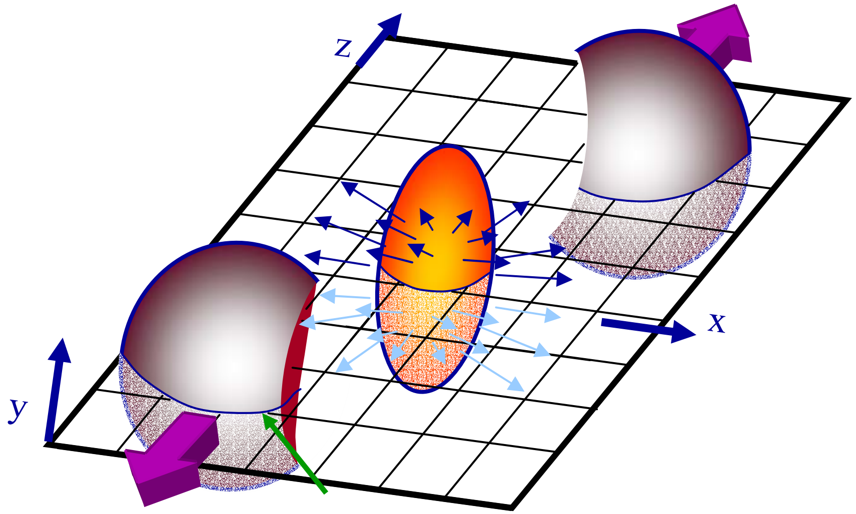
Outline

- What have we learned in Au+Au collisions?
- What did we see in d+Au collisions?


RHIC
Coils
Magnet
Silicon Vertex Tracker
E-M Calorimeter
Time Projection Chamber
Time Of Flight
Electronics Platforms
Forward Time Projection Chamber
Forward Spectrometer
Mid Rapidity Spectrometer
RICH
Multiplicity
Beam Beam counters
G-2
BOOSTER
LINAC
AGS

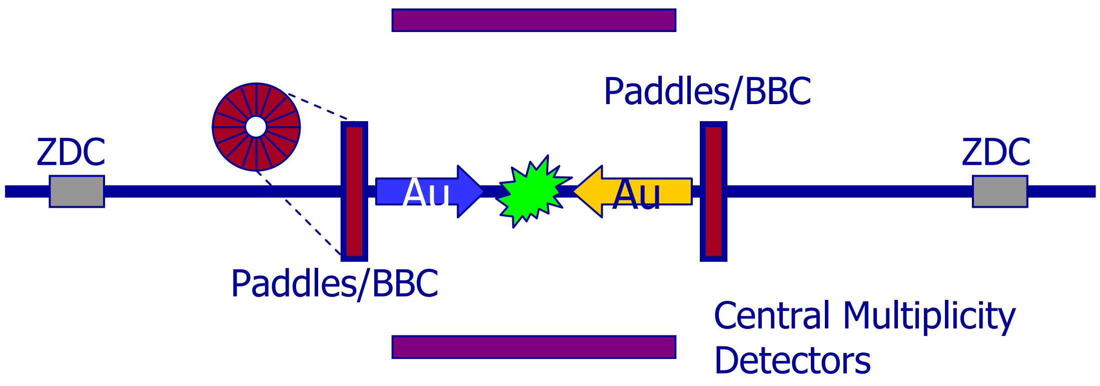
Geometry of heavy ion collisions

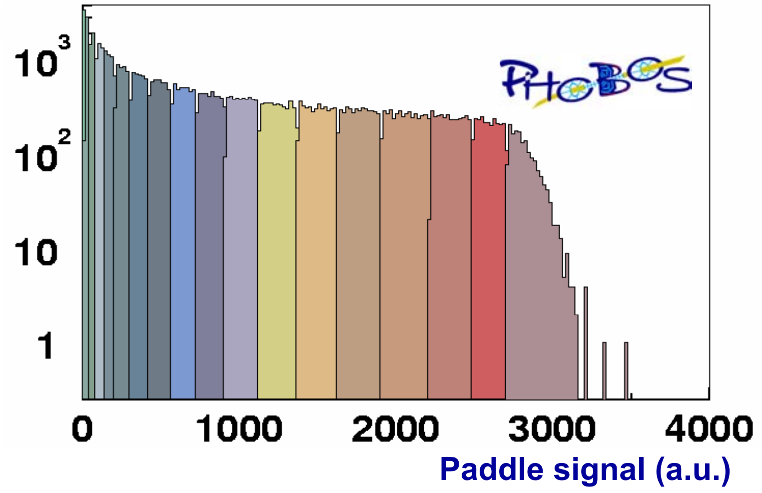


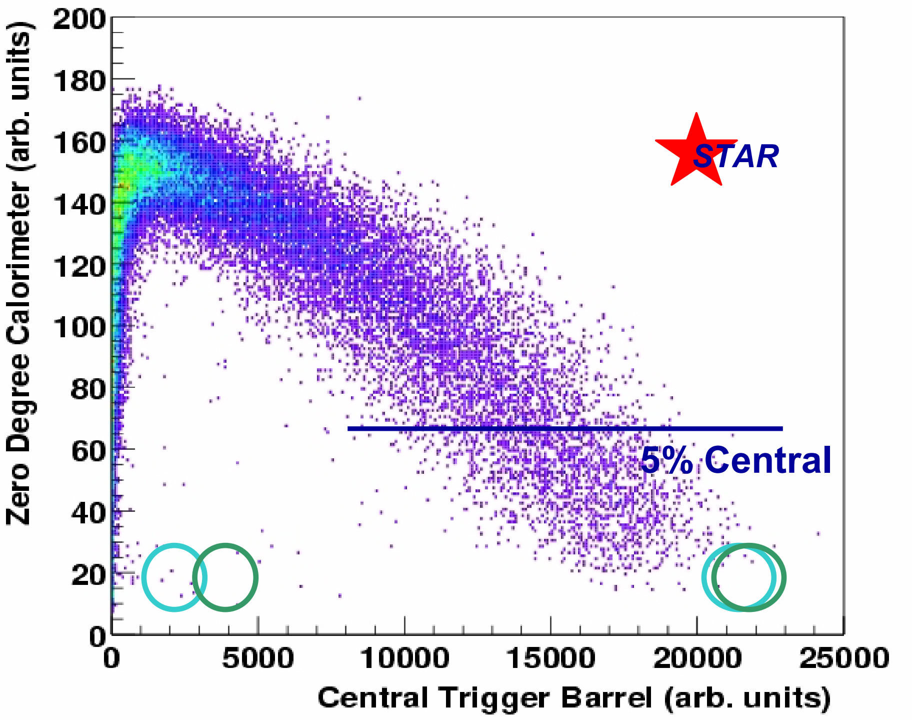
Number of participants: number of incoming nucleons in the overlap region

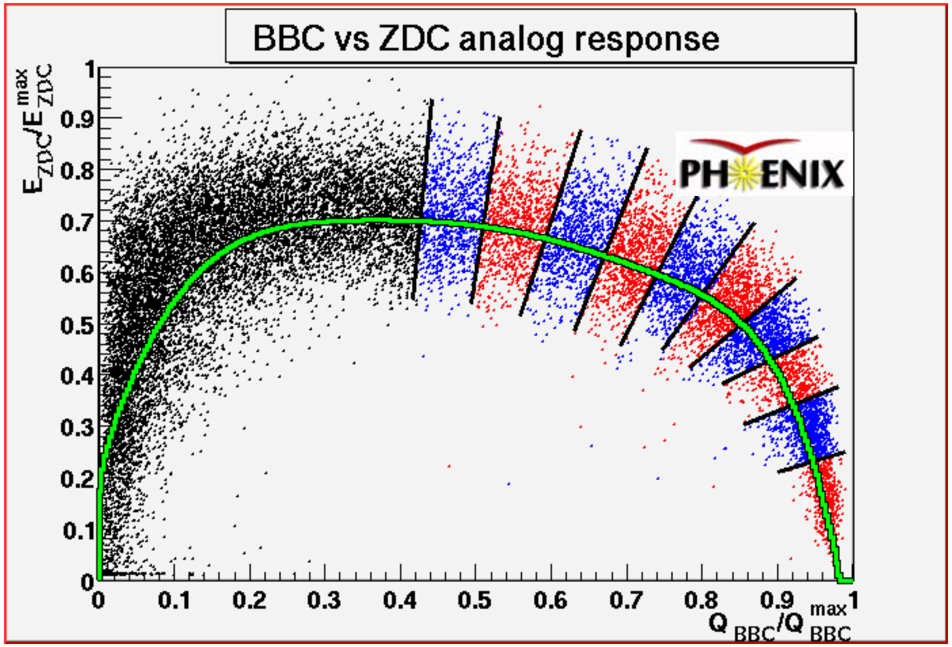
Number of binary collisions: number of equivalent inelastic nucleon-nucleon collisions

Experimental determination of centrality

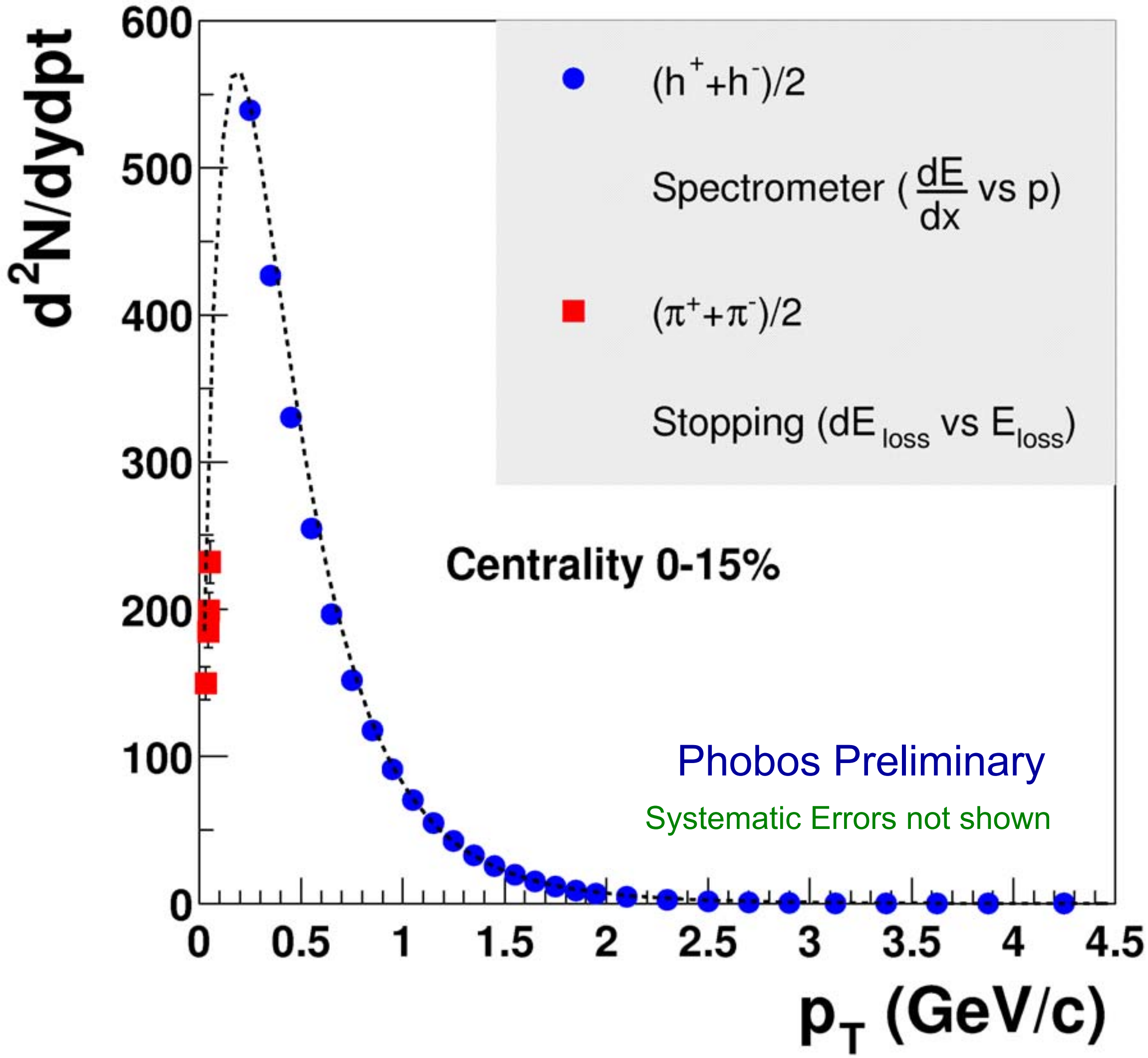




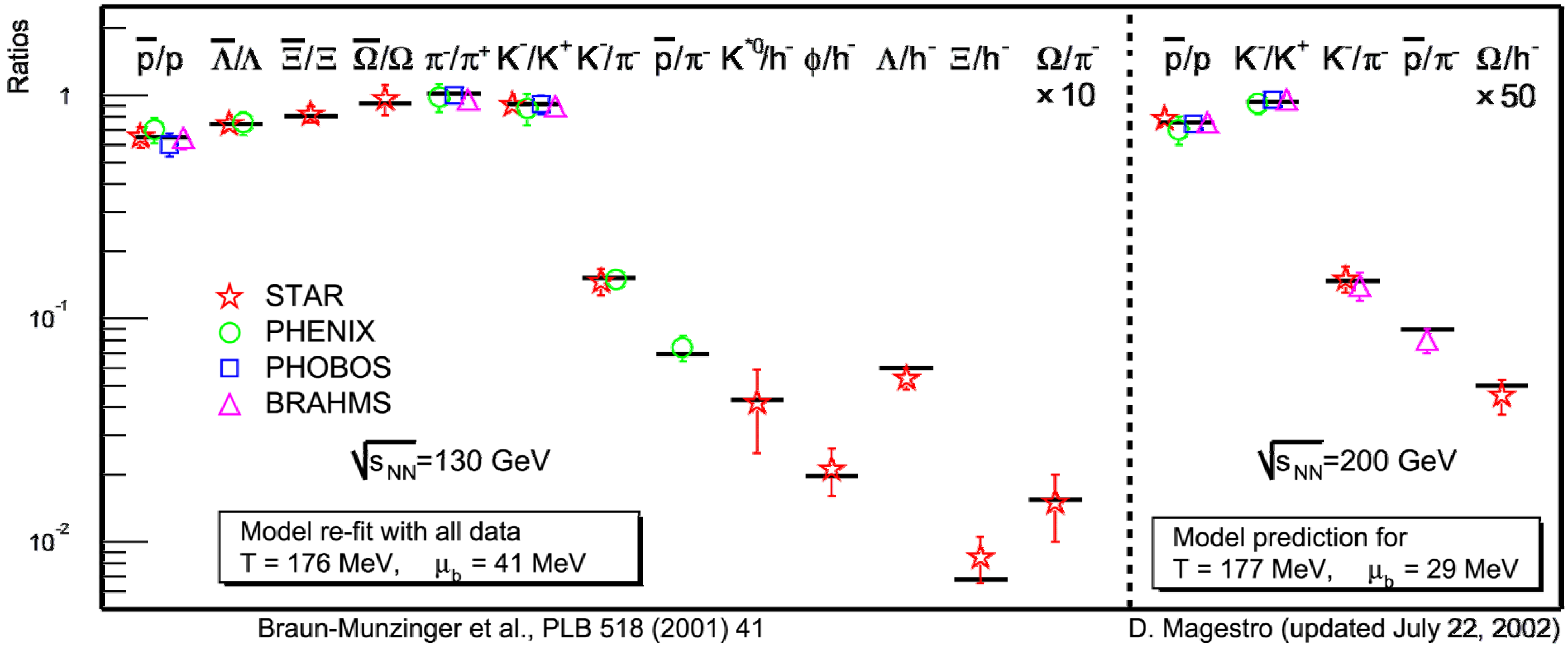




p_T distribution of charged particles



Chemical equilibrium?

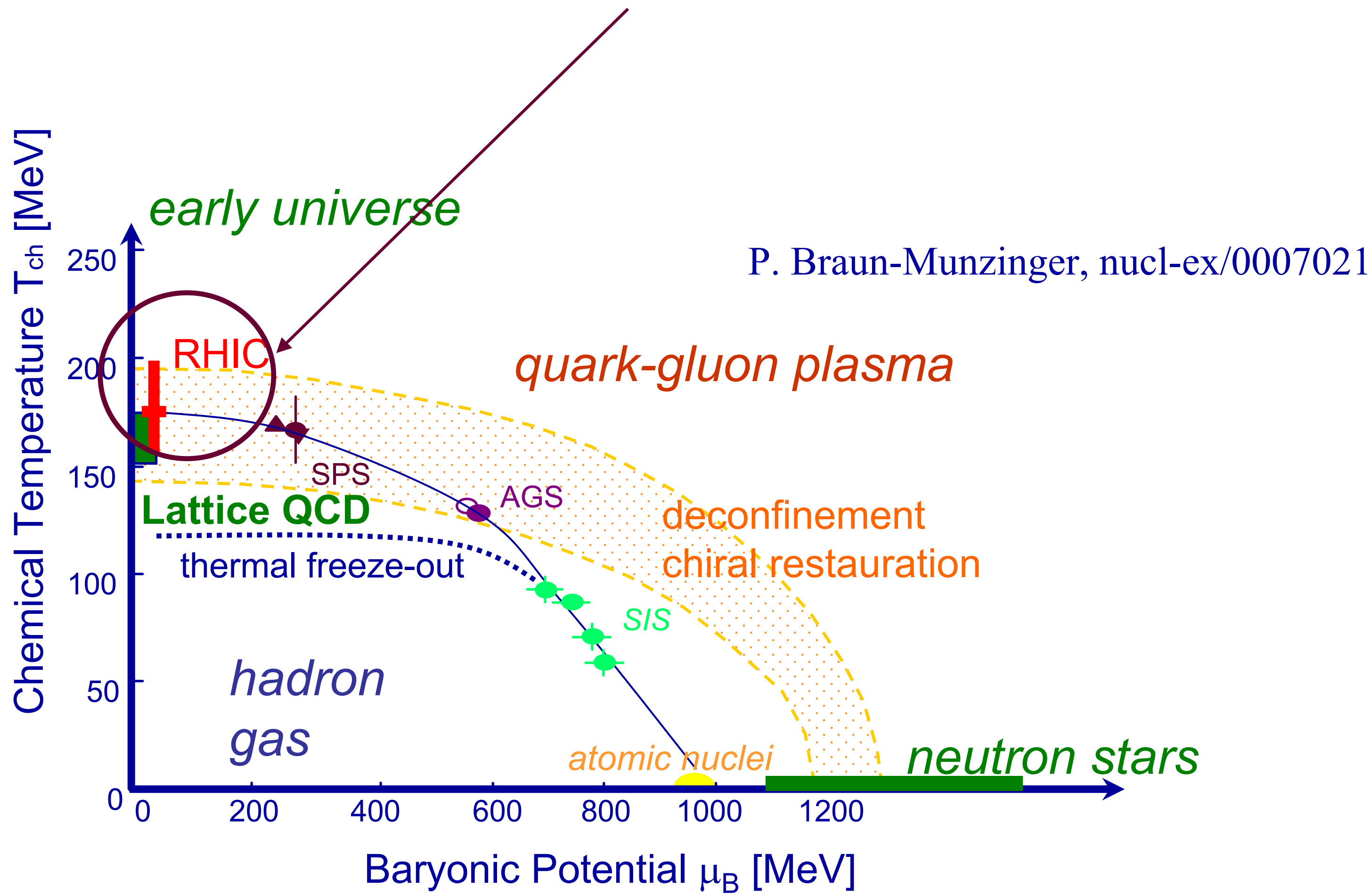


Thermal model: Partition fn with params T, μ_B, μ_s, μ_{I3}

Fit to ratios of antiparticle/particle: π, K, p, Λ, Ξ, K^*_0, ….

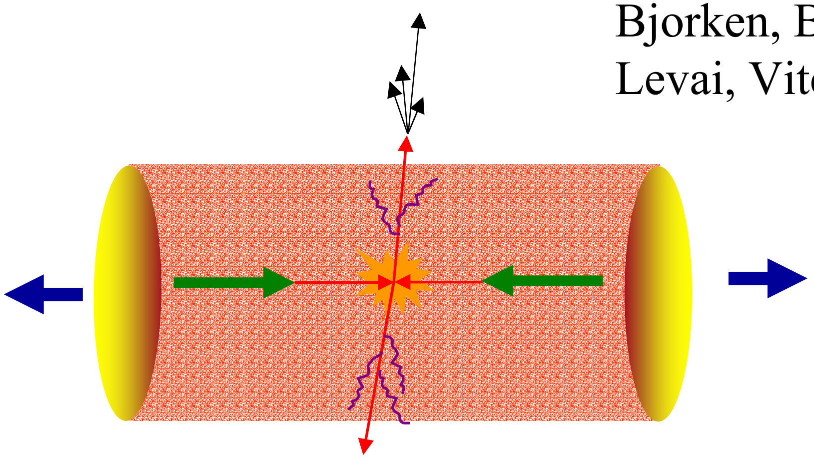
Phase diagram at chemical freezeout

Parameters from thermal model fit



Partonic energy loss in dense matter

Bjorken, Baier, Dokshitzer, Mueller, Pegne, Schiff, Gyulassy, Levai, Vitev, Zhakarov, Wang, Wang, Salgado, Wiedemann,…



Gluon bremsstrahlung

Multiple soft interactions:

$$\Delta E \approx \frac{C_R \alpha_S}{4} \hat{q} L^2$$

$$\hat{q} = \frac{\left\langle k_T^2 \right\rangle_{medium}}{\lambda} \propto \alpha_S \rho_{glue}$$

Opacity expansion:

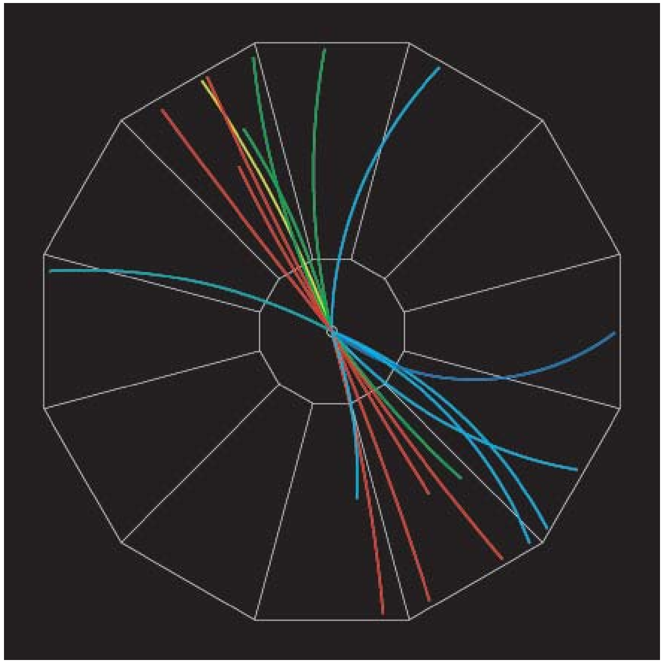
$$\Delta E = \pi C_A C_a \alpha_S^3 \int d\tau \rho_{glue}(\tau, r(\tau)) \tau Log\left(\frac{2E_{jet}}{\mu^2 L}\right)$$

Strong dependence of energy loss on gluon density ρ_{glue}:

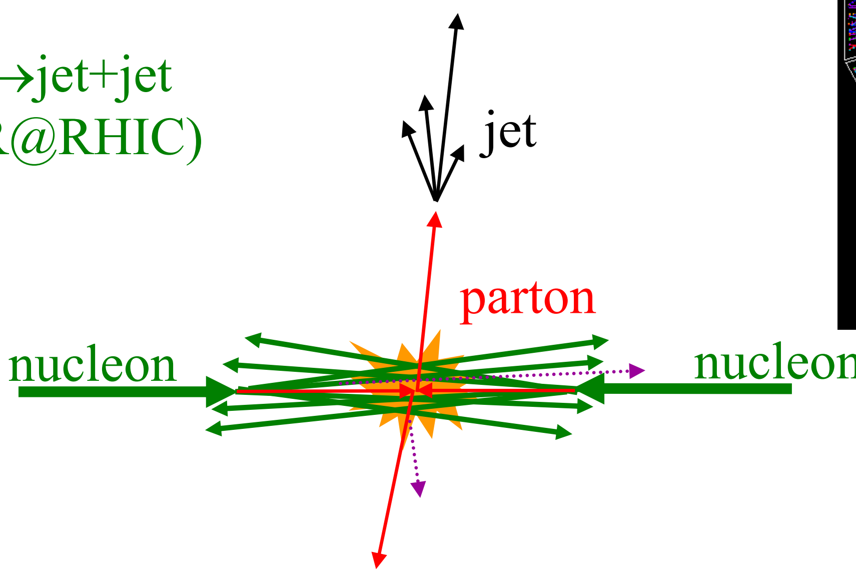
measure $\Delta E \Rightarrow$ color charge density at early hot, dense phase

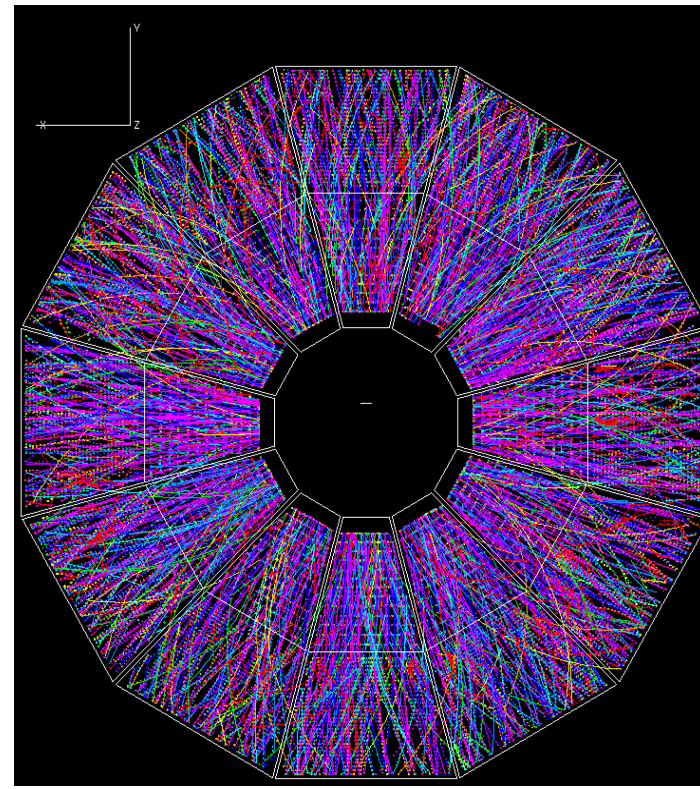
Jets at RHIC

Find this………in this



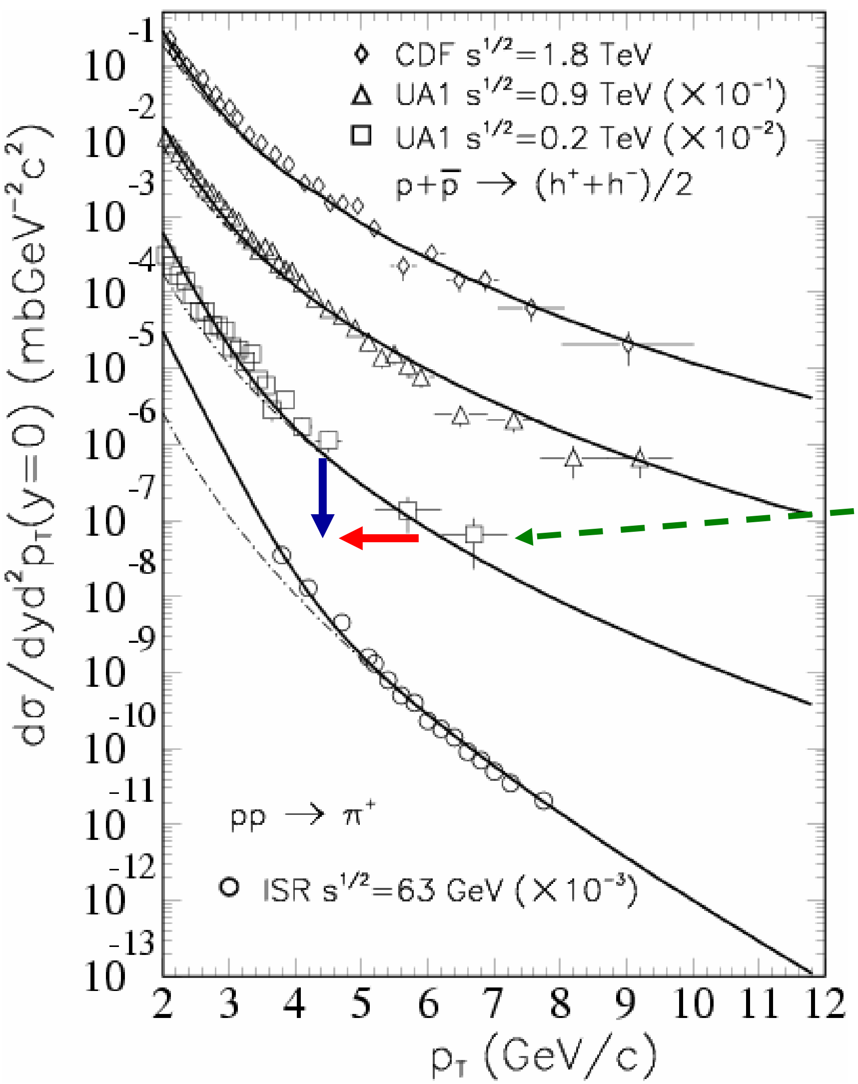
p+p →jet+jet
(STAR@RHIC)

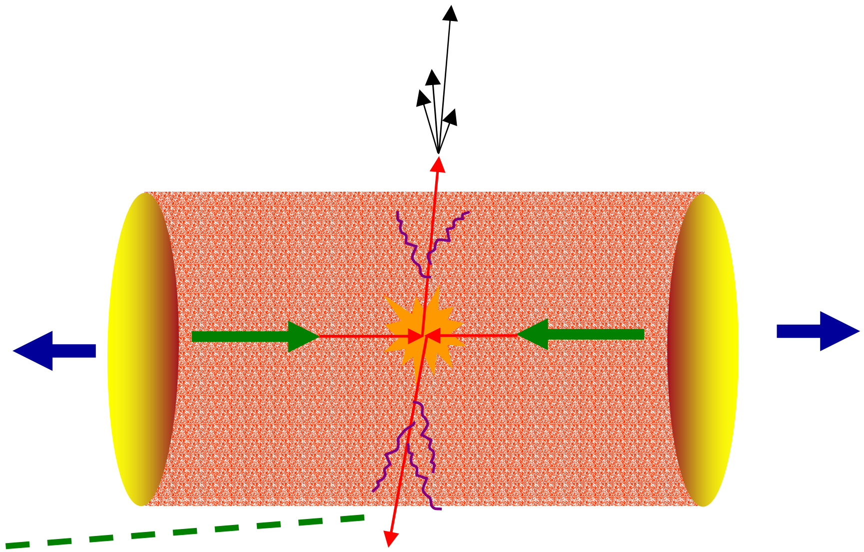




Au+Au → ???
(STAR@RHIC)

Partonic energy loss via leading hadrons





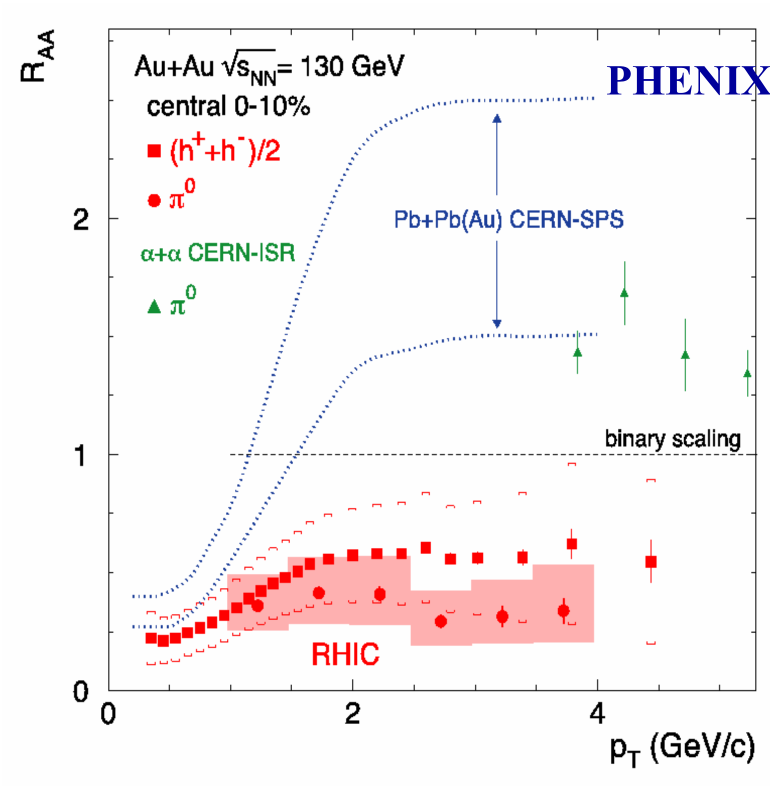
Energy loss ⇒
softening of fragmentation ⇒
suppression of leading hadron yield

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

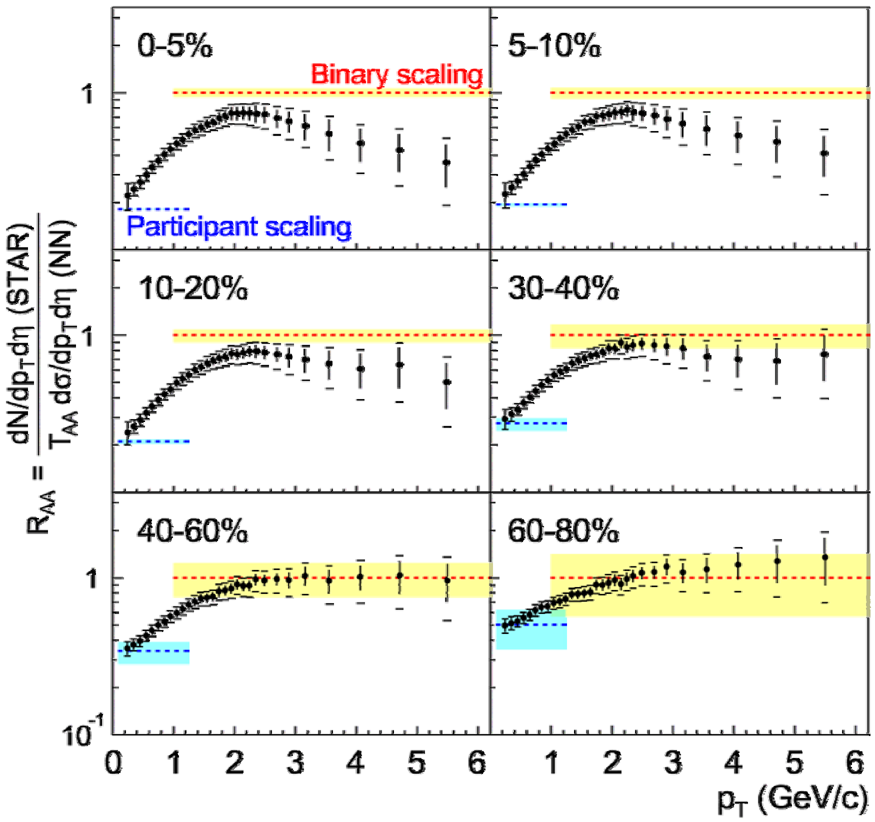
Binary collision scaling p+p reference

Suppression of inclusive yield at 130 GeV

PHENIX, PRL 88, 022301



STAR, PRL 89, 202301

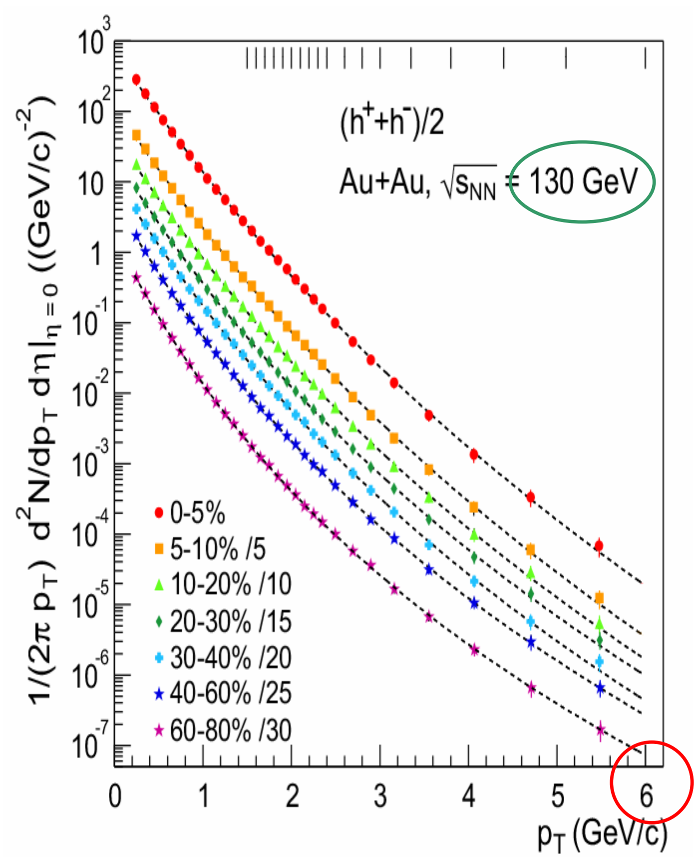


Both STAR and PHENIX see significant suppression

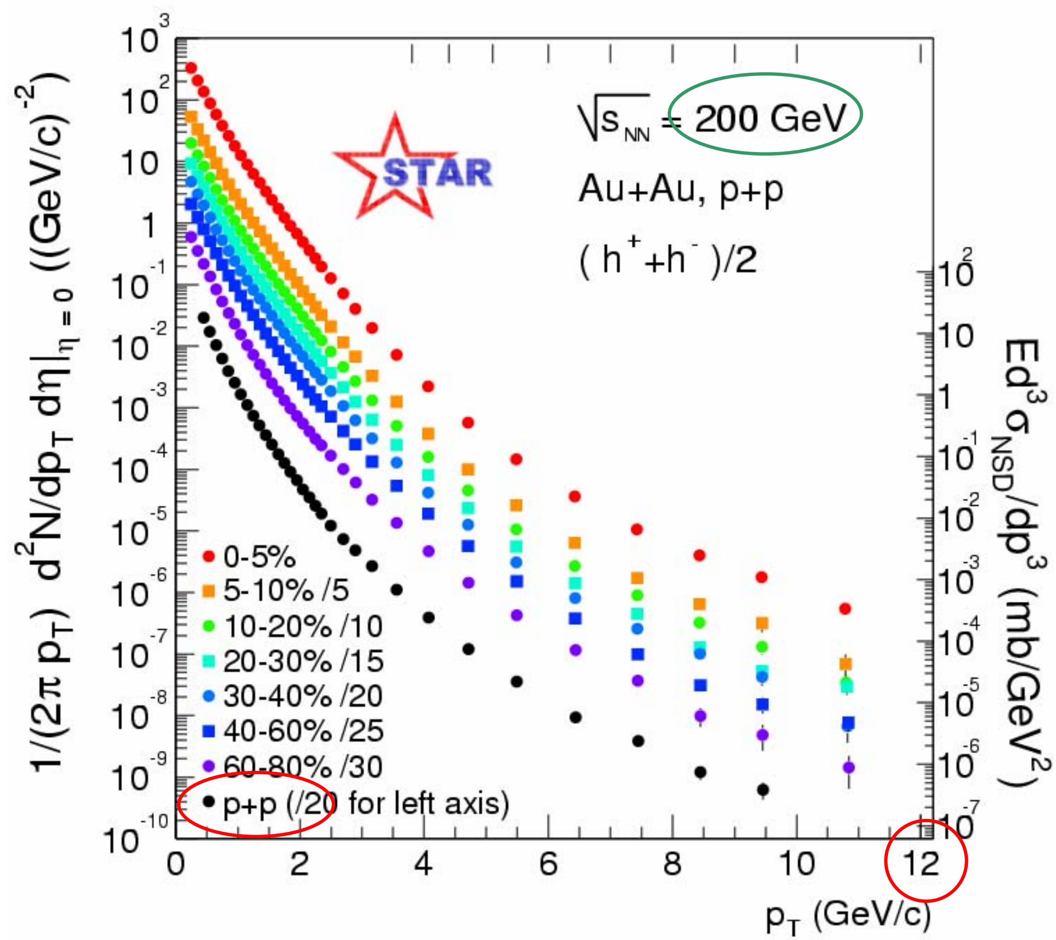
Limitation: Ambiguities in the reference spectra at 130 GeV

Au+Au and p+p: inclusive charged hadrons

PRL 89, 202301

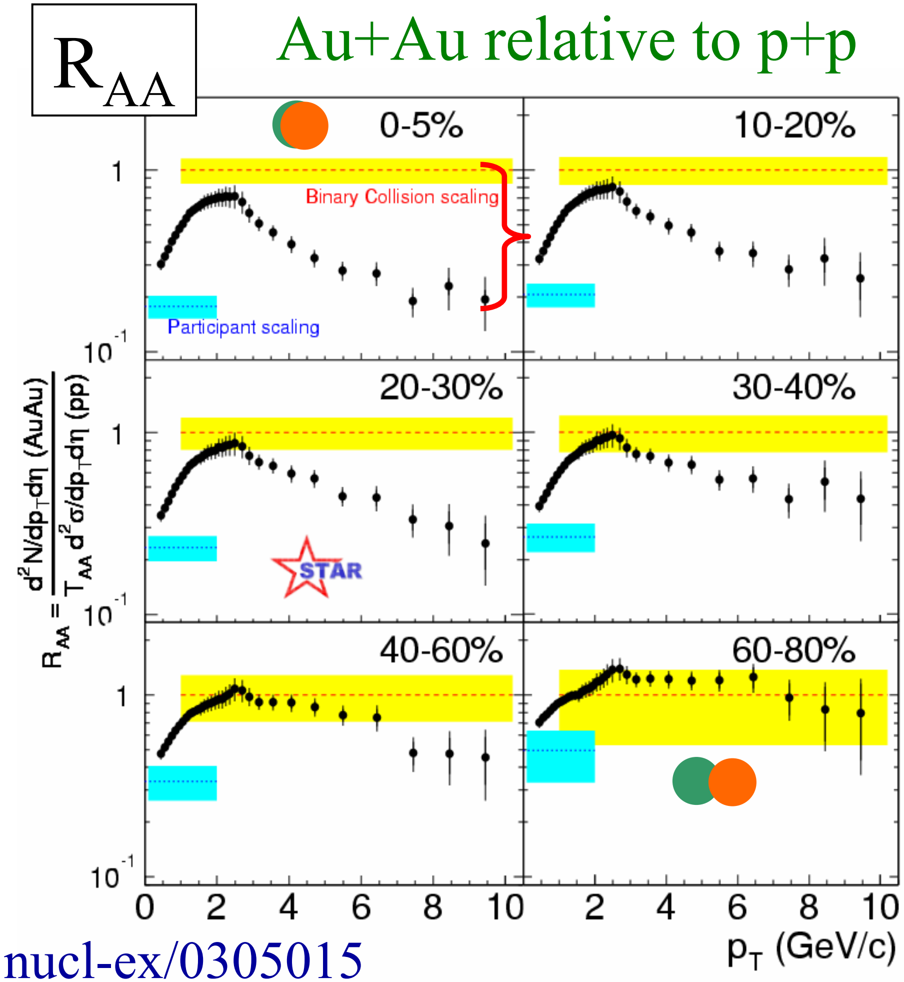


nucl-ex/0305015

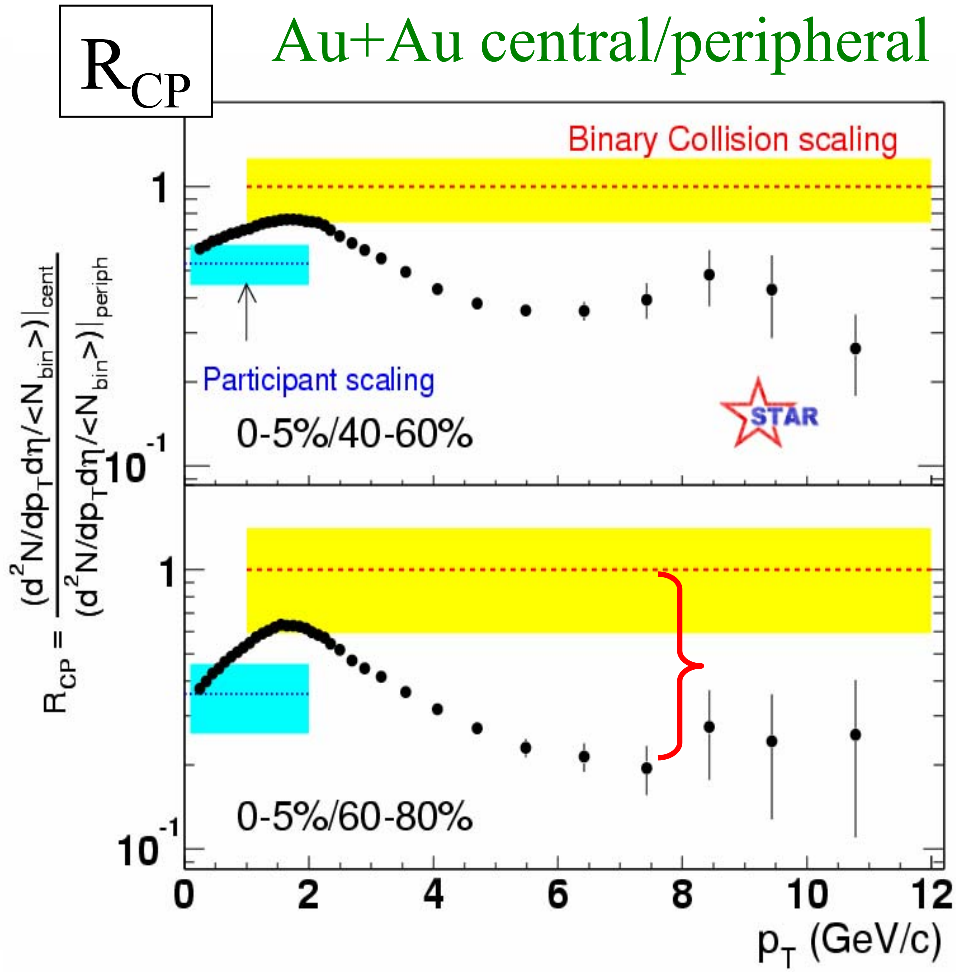


p+p reference spectrum ***measured*** at RHIC

Suppression of inclusive hadron yield

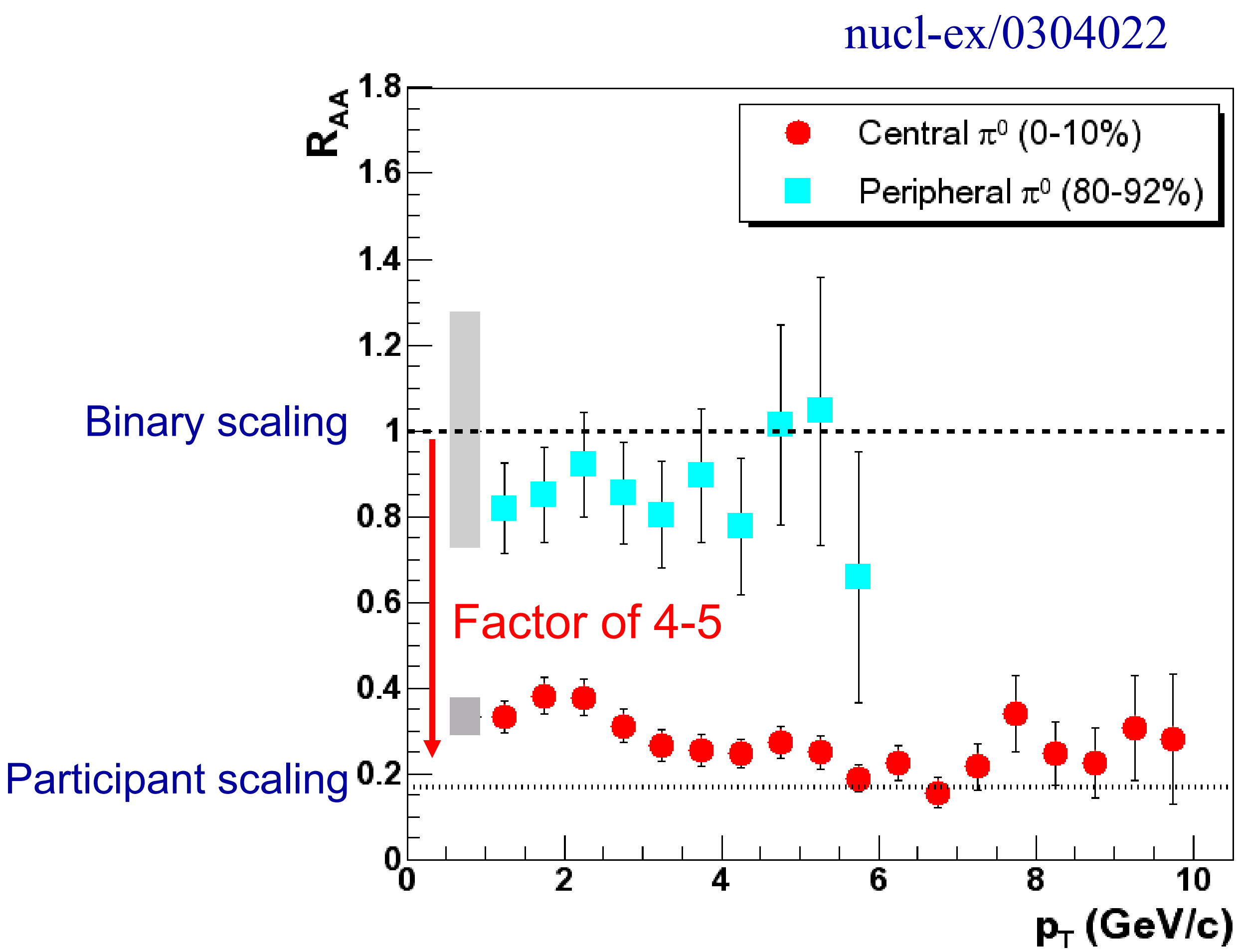


nucl-ex/0305015

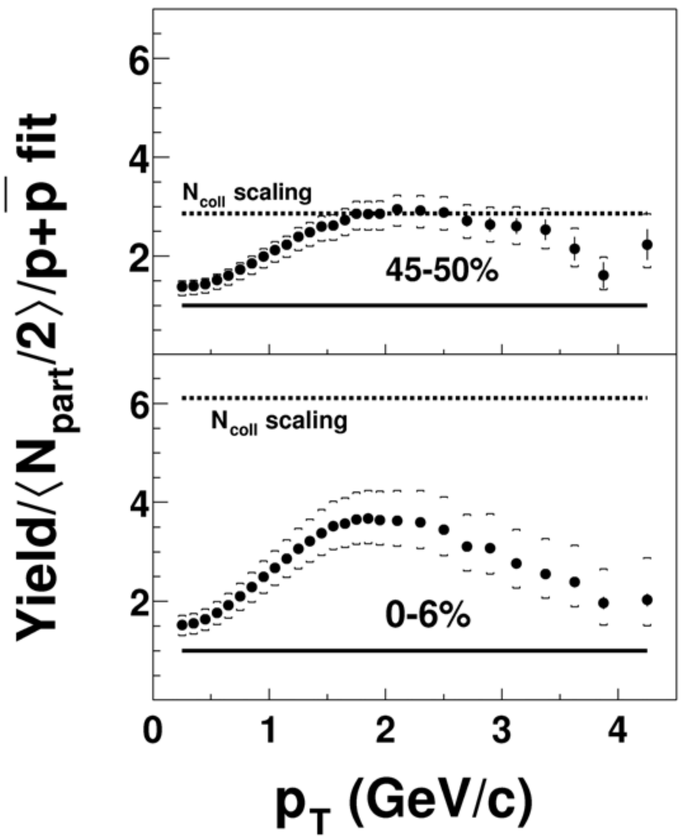


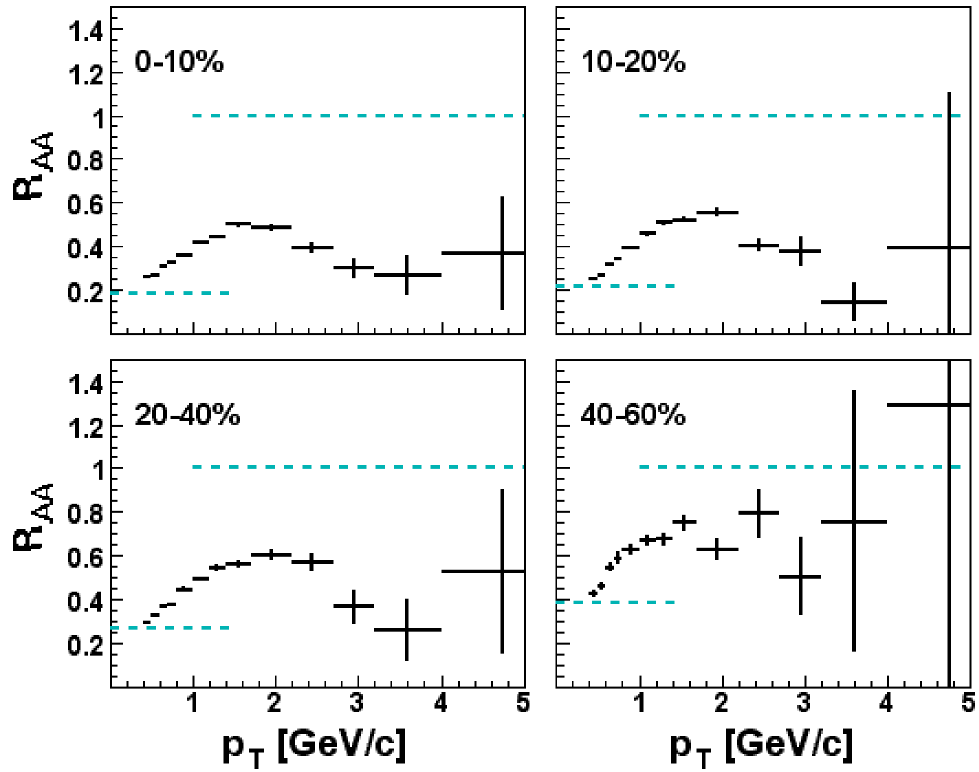
- central Au+Au collisions: factor ~4-5 suppression
- p_T>5 GeV/c: suppression ~ independent of p_T

PHENIX observes a similar effect



So do
PHOBOS ($\eta \sim 0.8$) and BRAHMS ($\eta \sim 2.0$)



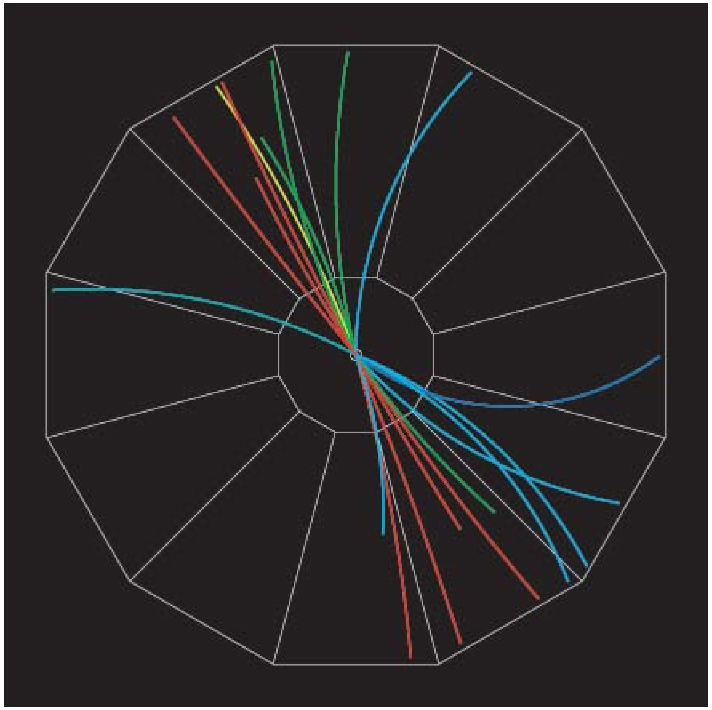


PHOBOS: nucl-ex/0302015

BRAHMS: nucl-ex/0307003
Also have $\eta = 0$

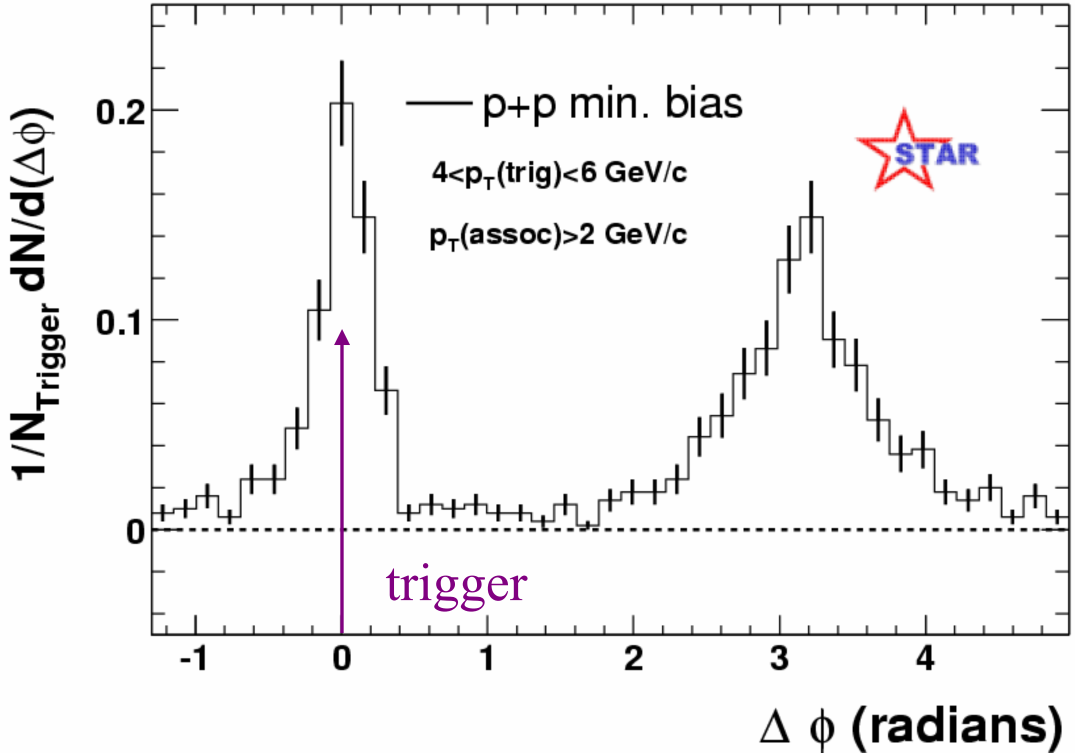
Jets and two-particle azimuthal distributions

p+p → dijet



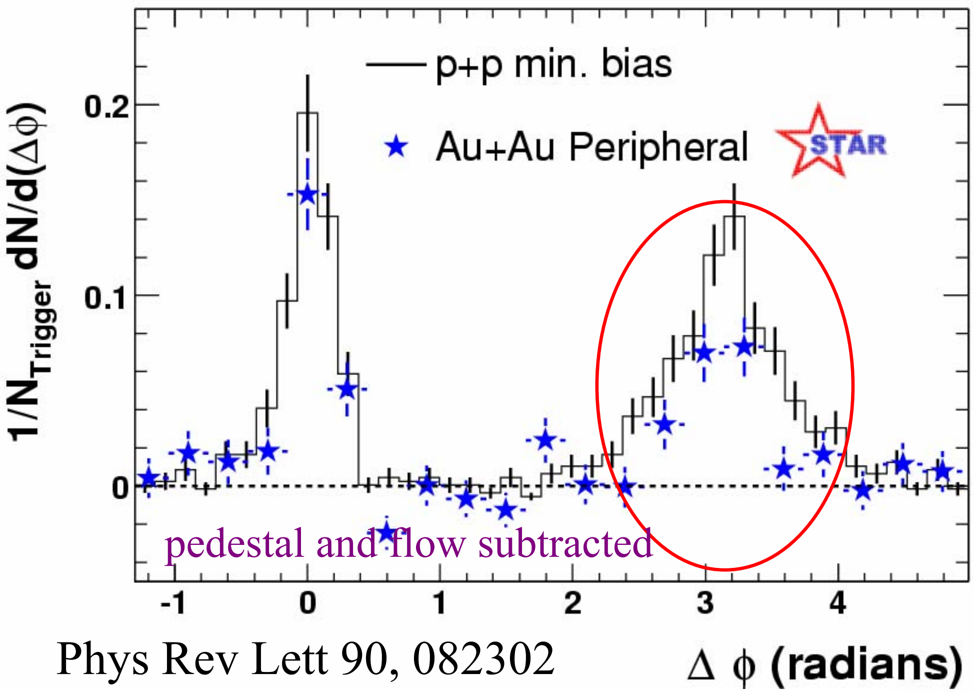
- trigger: track with p_T>4 GeV/c
- Δφ distribution: 2 GeV/c<p_T<$p_T^{trigger}$
- normalize to number of triggers

Phys Rev Lett 90, 082302



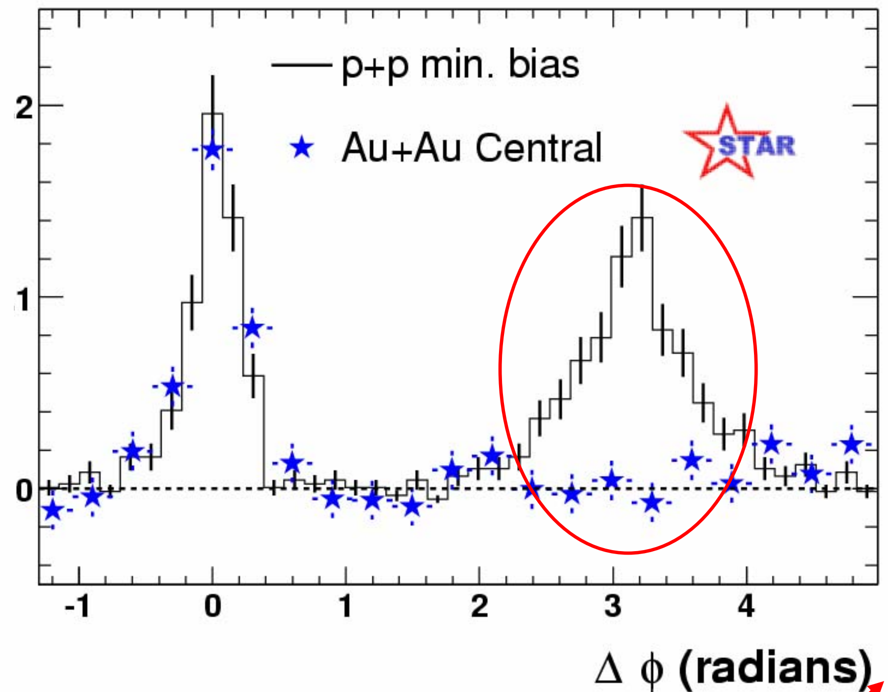
Azimuthal distributions in Au+Au

Au+Au peripheral

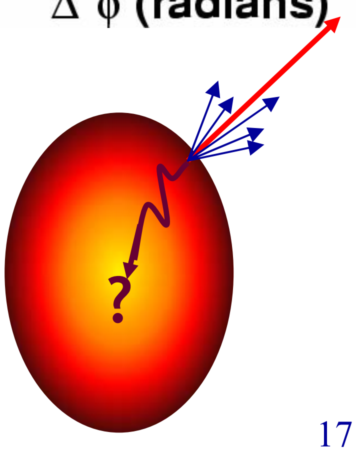


Phys Rev Lett 90, 082302

Au+Au central



Near-side: peripheral and central Au+Au similar to p+p



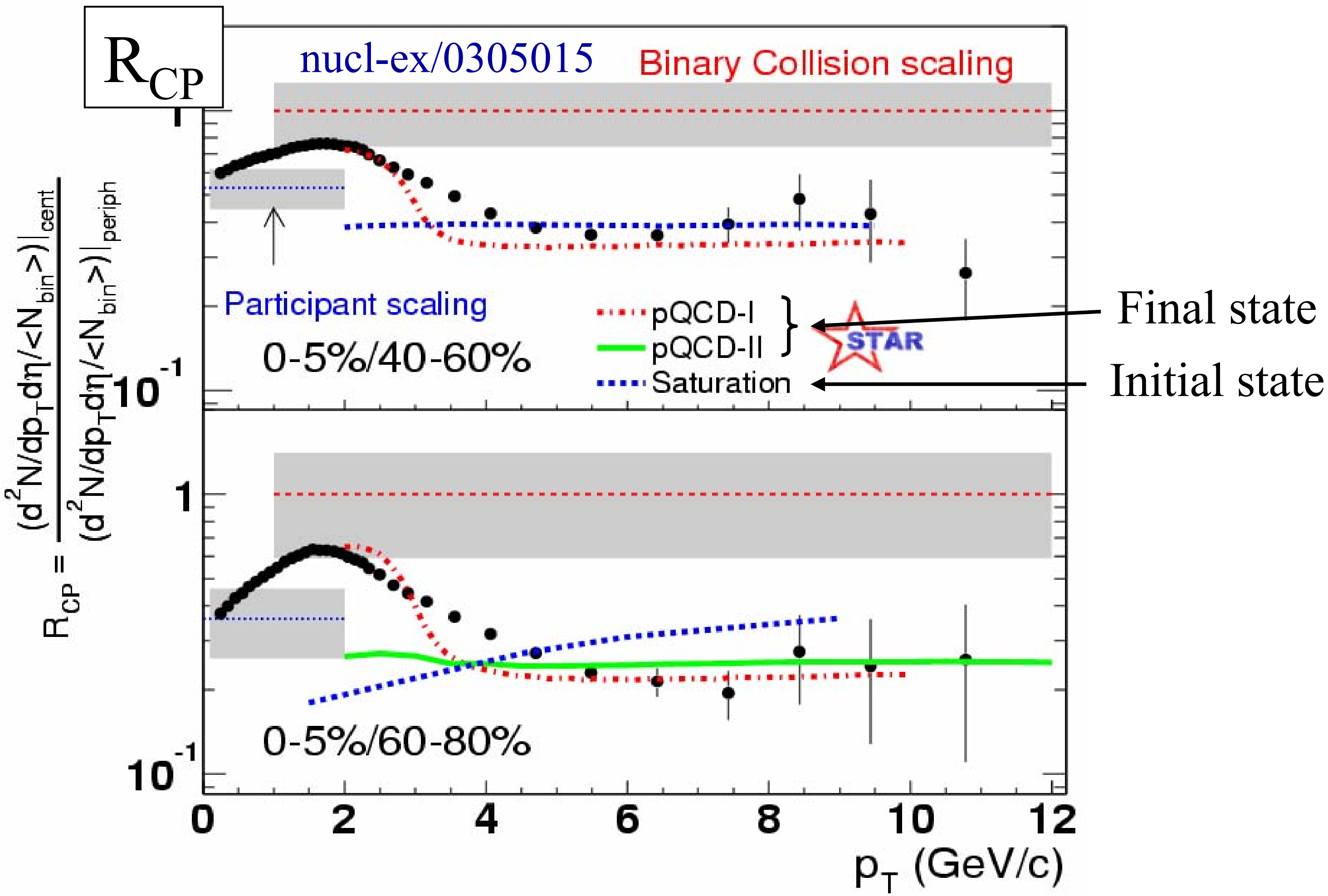
Strong suppression of back-to-back correlations in central Au+Au

Other effects that might change R_{AA}

- Initial- or final-state multiple scattering ("Cronin effect")
- Nuclear modifications of the parton distributions ("shadowing and anti-shadowing")
- Gluon saturation at high energy and low x
- Hadronic re-interactions

Theory vs. data

pQCD-I: Wang, nucl-th/0305010
pQCD-II: Vitev and Gyulassy, PRL 89, 252301
Saturation: KLM, Phys Lett B561, 93



p_T>5 GeV/c: well described by gluon saturation model (up to 60% central) and pQCD+jet quenching

Final-state hadronic rescattering

Eq. (2) of Gallmeister, Greiner, Xu:

$$t_F \approx 1...1.2(E/GeV)\,fm/c$$

For $5 < E_T < 12$ GeV/c,
<L/λ> decreases substantially

PRC 67, 044905

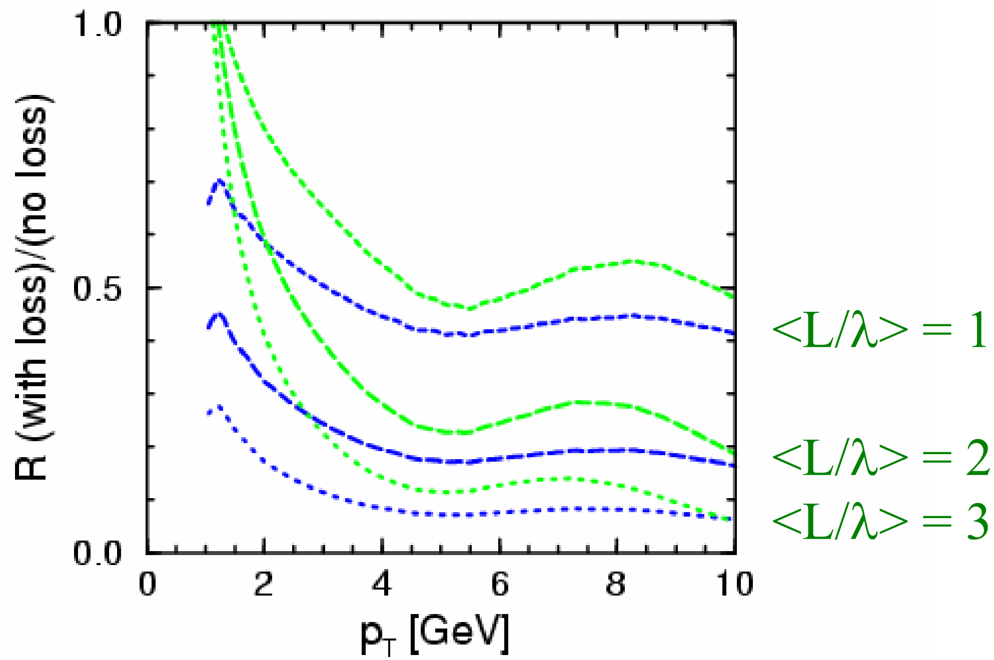
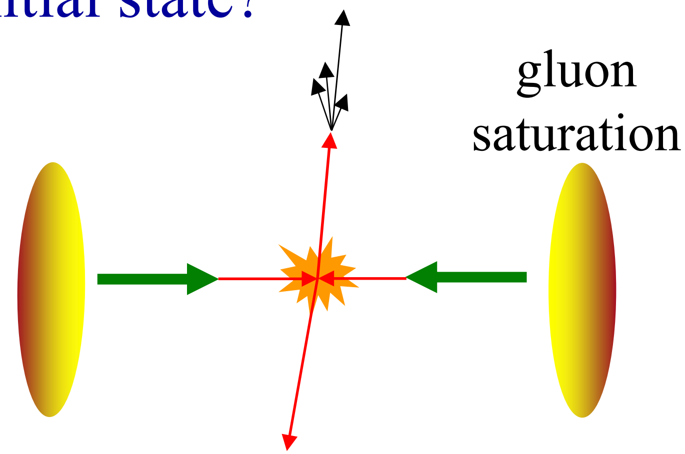


FIG. 9: The suppression factor $R(p_\perp)$ of charged hadrons at midrapidity for $\sqrt{s} = 200\,\mathrm{GeV}$ for $\langle L/\lambda \rangle \equiv 1, 2, 3$ (top to bottom) collisions according (in)elastic scattering on a ρ (blue) or elastic scattering on a π (green).

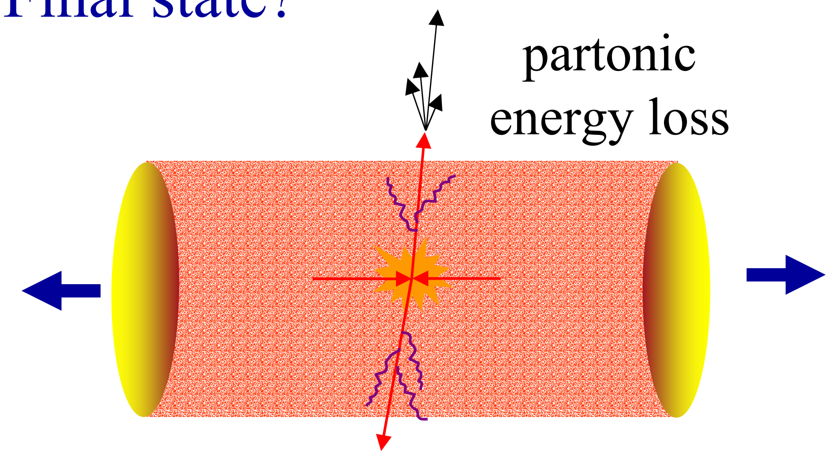
May also have difficulty explaining magnitude of near-side angular correlations

Is suppression an initial or final state effect?

Initial state?

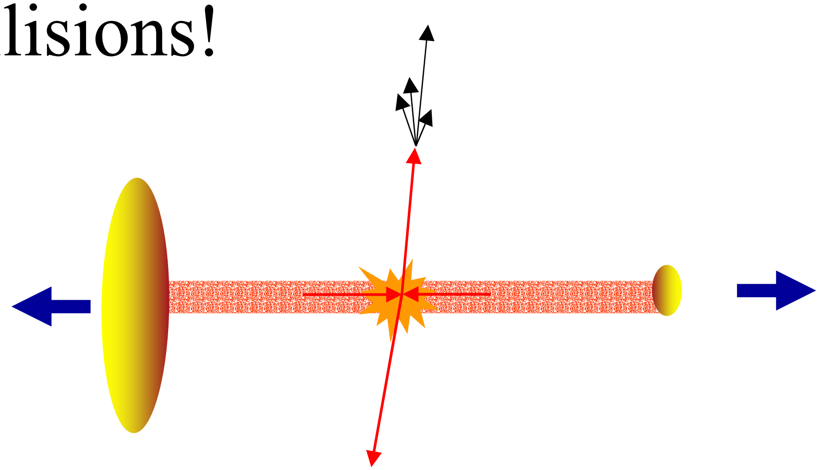


Final state?



How to discriminate? Turn off final state ⇒

d+Au collisions!

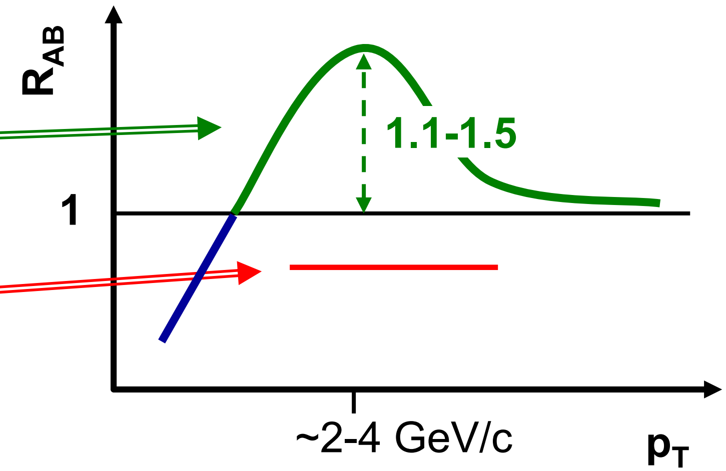


d+Au vs. p+p: Theoretical expectations

Inclusive spectra

If Au+Au suppression is final state

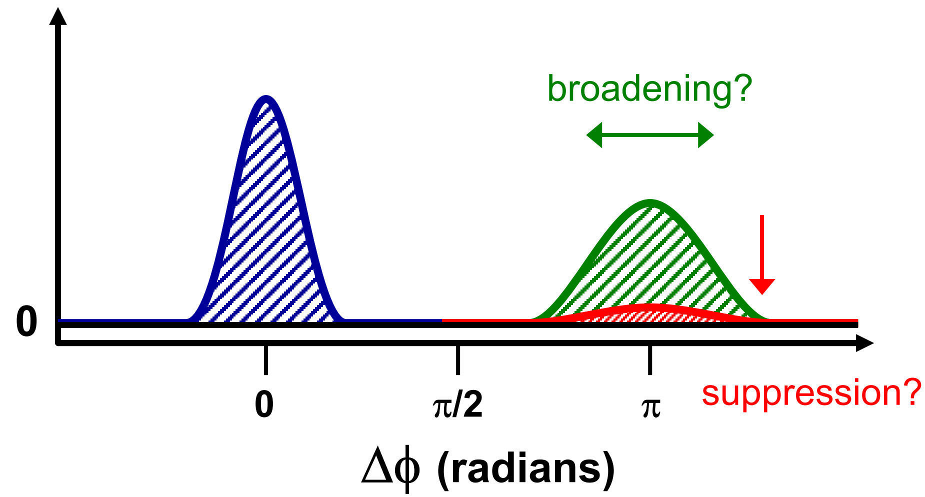
If Au+Au suppression is initial state
(KLM gluon saturation: 0.75)



High p_T hadron pairs

pQCD: no suppression, small broadening due to Cronin effect

saturation models: suppression due to mono-jet contribution?

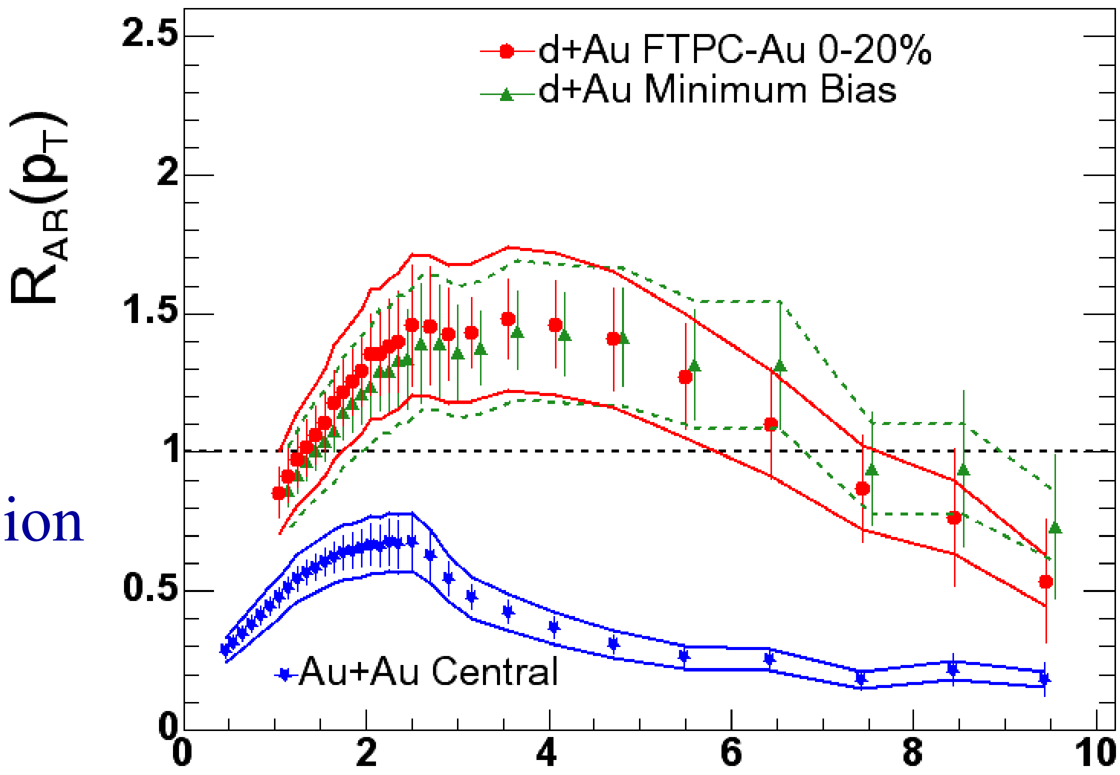


Inclusive yields relative to binary-scaled p+p

STAR: nucl-ex/0306024

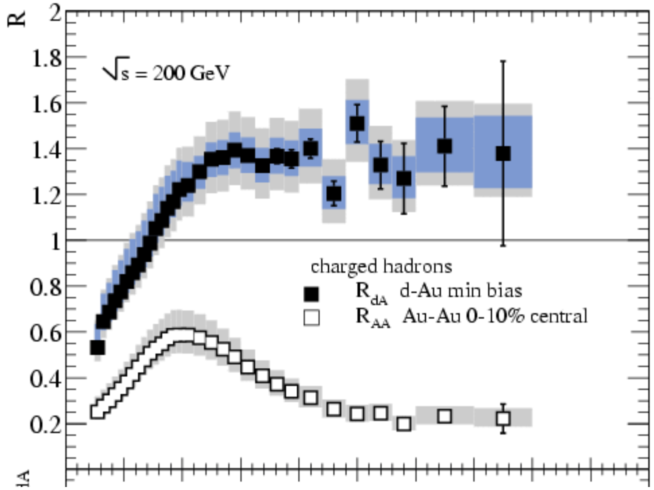
$$R_{AB} = \frac{dN^{AB} / dp_T d\eta}{T_{AB} d\sigma^{pp} / dp_T d\eta}$$

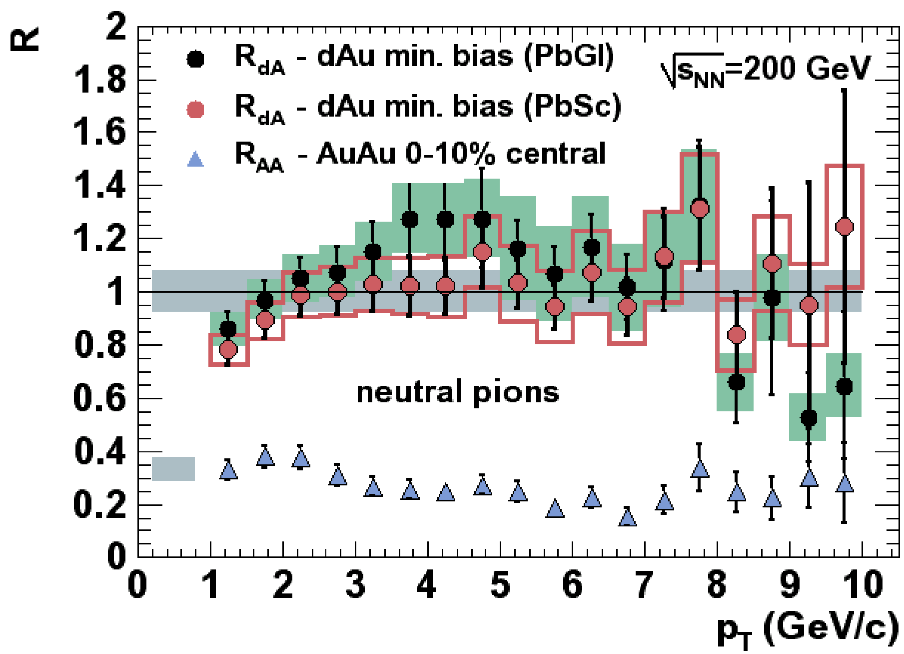
- d+Au : enhancement
  Au+Au: strong suppression

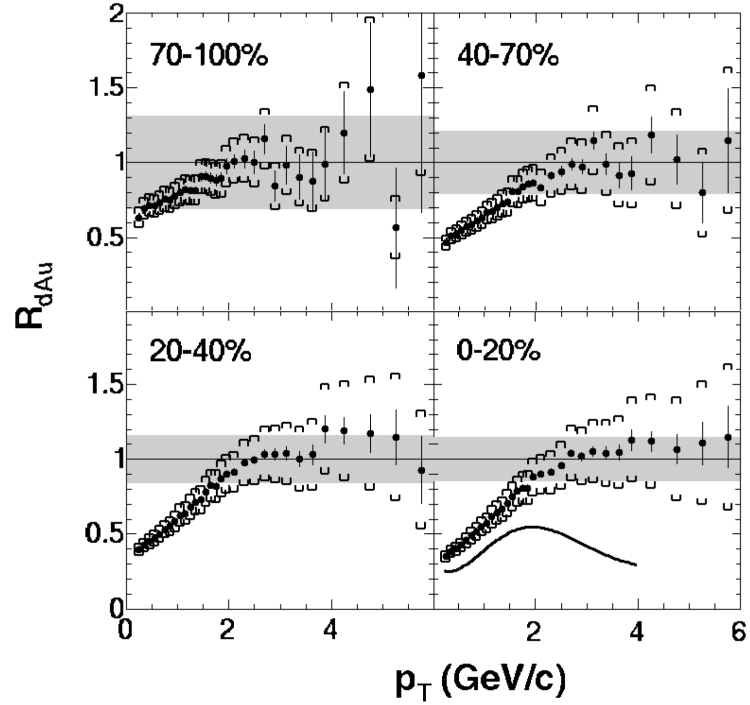


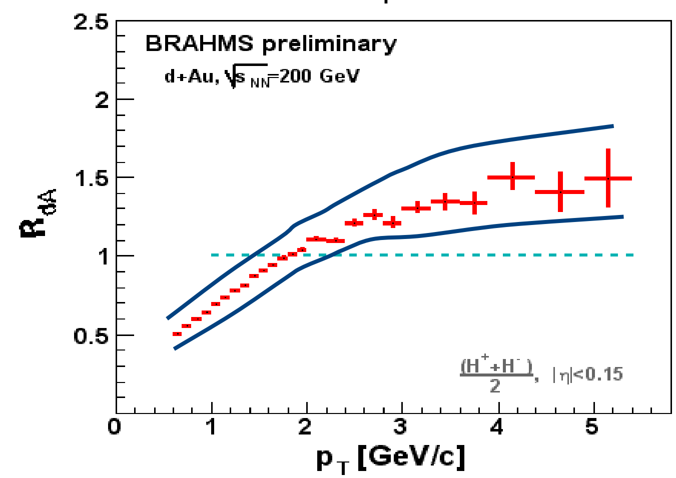
Suppression of the inclusive yield
in central Au+Au is a final-state effect

PHENIX, PHOBOS, BRAHMS find similar results





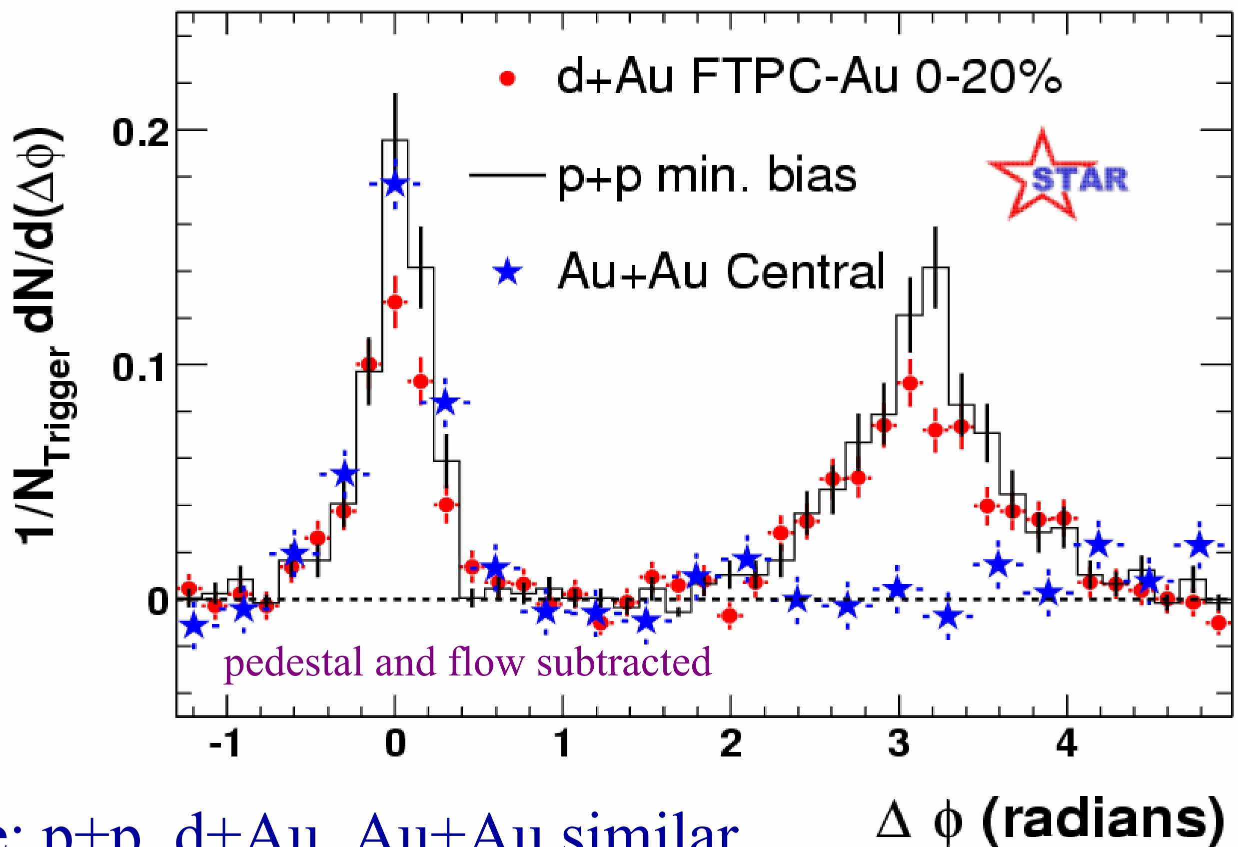




nucl-ex/0306021, nucl-ex/0306025; nucl-ex/0307003

Azimuthal distributions

nucl-ex/0306024



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

The **strong suppression** of the inclusive yield and back-to-back correlations at high p_T previously observed **in central Au+Au collisions** are due to **final-state interactions with the dense medium** generated in such collisions.

Have we found the Quark Gluon Plasma at RHIC?

We now know that Au+Au collisions generate a medium that

- is dense (pQCD theory: many times cold nuclear matter density)
- is dissipative
- exhibits strong collective behavior

This represents significant progress in our understanding of strongly interacting matter

We have yet to show that:

- dissipation and collective behavior both occur at the partonic stage
- the system is deconfined and thermalized
- a transition occurs: can we turn the effects off ?

Not yet; there is still work to do