Phases of matter in the BRAHMS experiment

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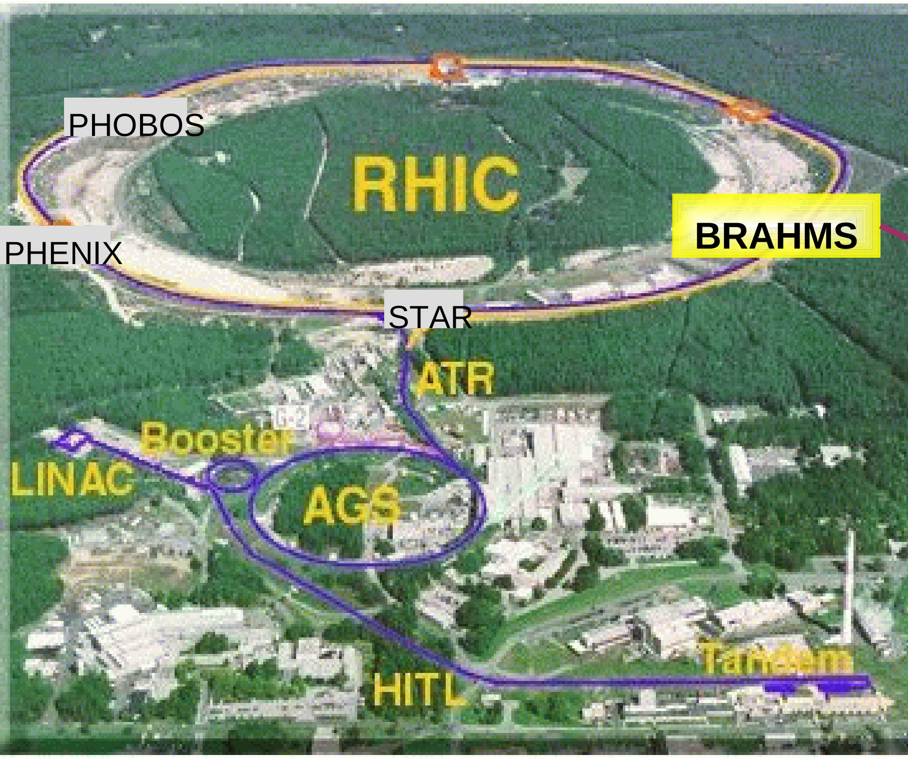
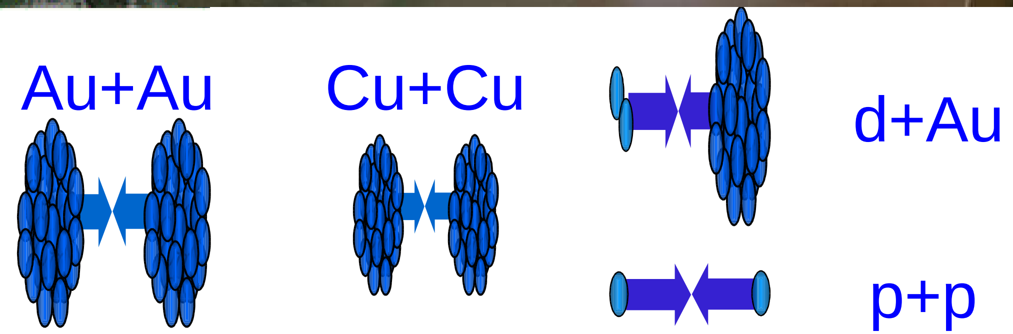
Relativistic Heavy Ion Collider



energies:

$\sqrt{s_{NN}}$=200GeV,

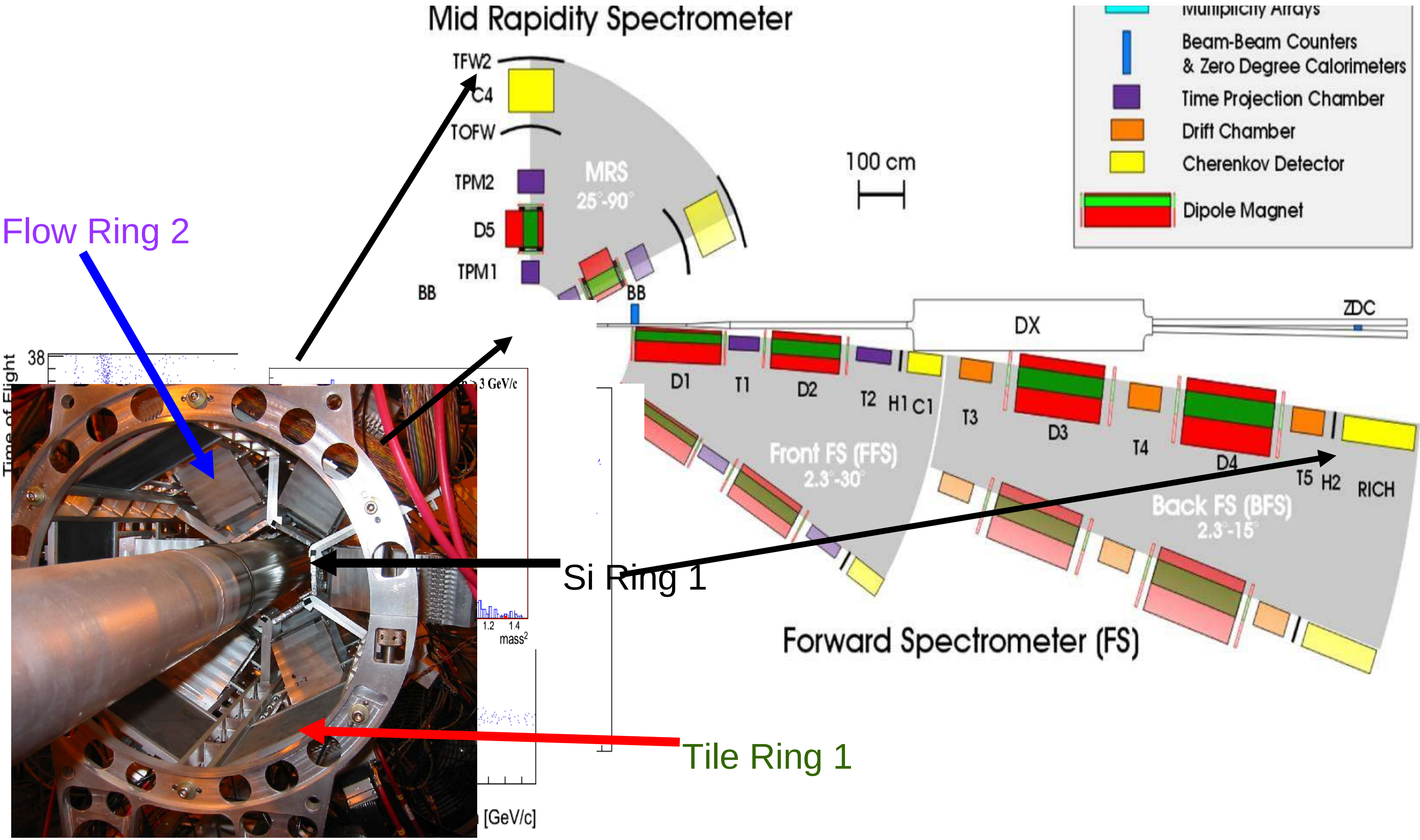
$\sqrt{s_{NN}}$=62GeV



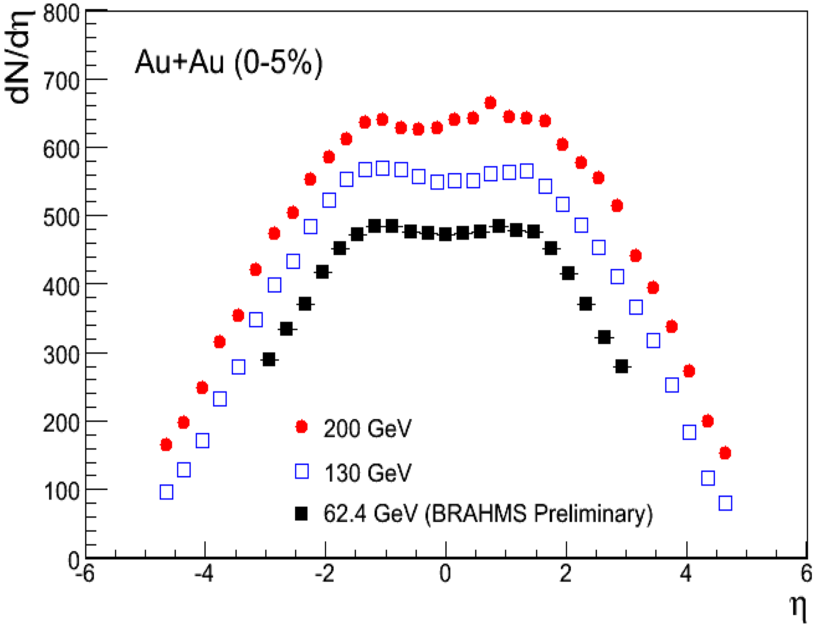
Outline

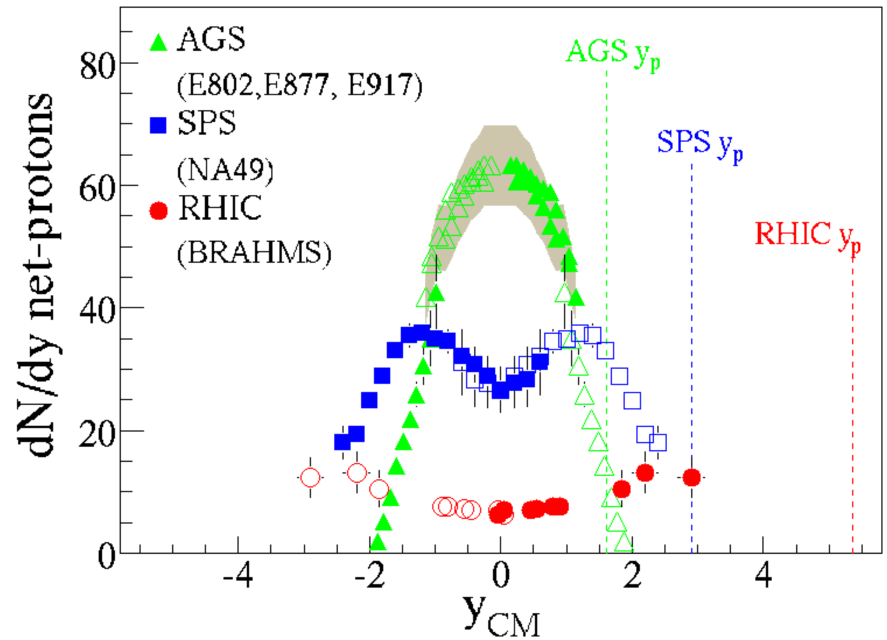
1. Detector setup.
2. General (bulk) characteristics of nucleus-nucleus reactions.
3. Nuclear modification at mid-rapidity
4. Nuclear modification at forward rapidity
5. Elliptic Flow
6. Summary.

Broad Range Hadron Magnetic Spectrometers



Particle production and energy loss





<u>Energy density:</u> Bjorken 1983

$$e_{BJ} = 3/2 \times (\langle E_t \rangle / \pi R^2 \tau_0)\, dN_{ch}/d\eta$$

assuming formation time t_0=1fm/c:

>5.0 GeV/fm³ for AuAu @ 200 GeV

>4.4 GeV/fm³ for AuAu @ 130 GeV

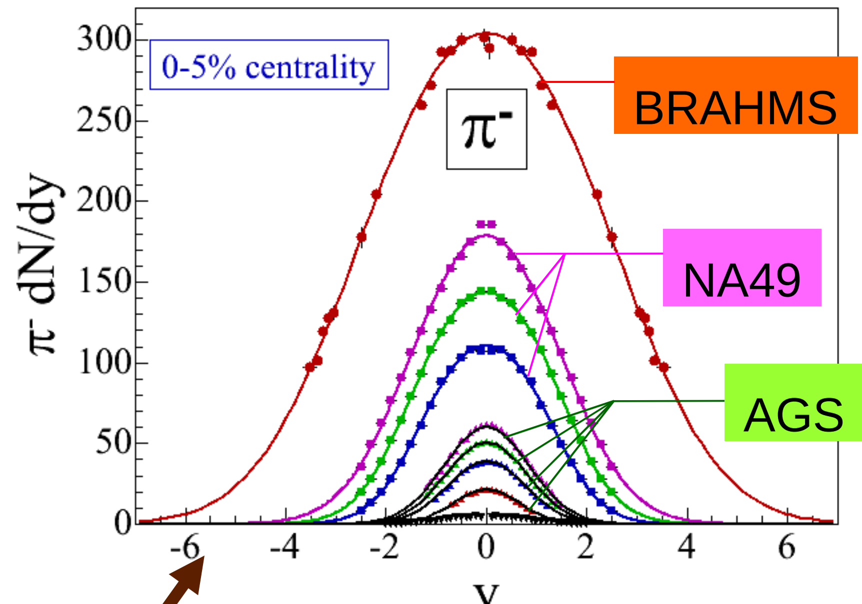
>3.7 GeV/fm³ for AuAu @ 62.4 GeV

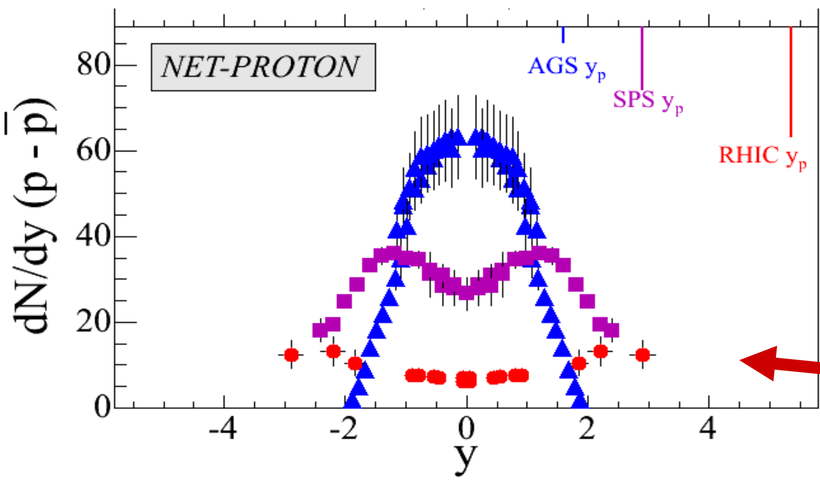
$$\int_{-y_p}^{y_p} \langle m_T \rangle_y \frac{dN_{(B-\bar{B})}}{dy} \cosh y \, dy$$

Total ΔE=25.7±2.1TeV

72GeV per participant

Primary versus produced matter





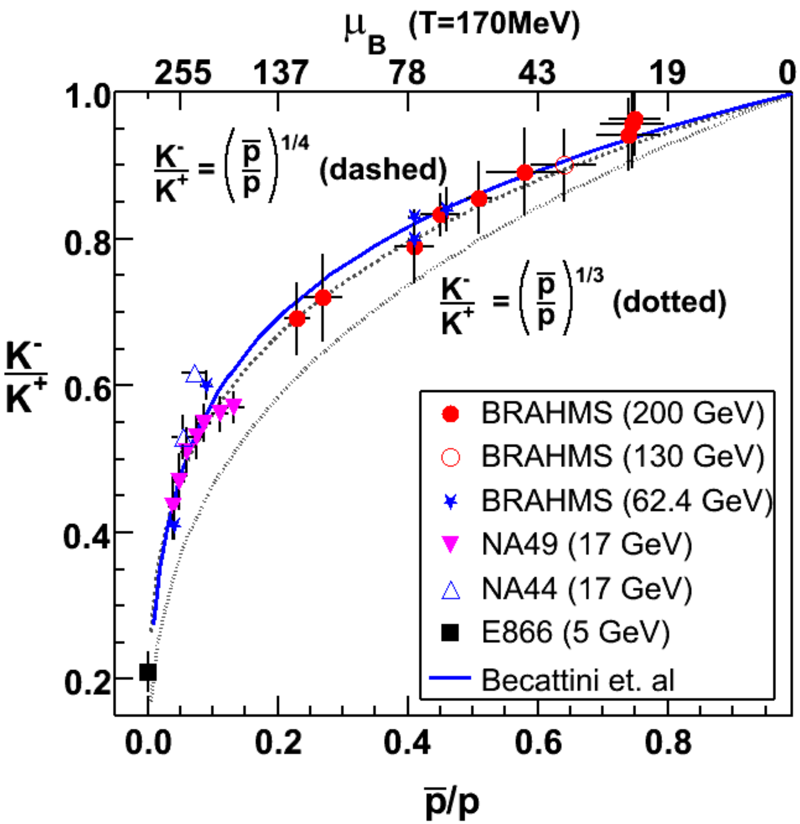
At 200GeV

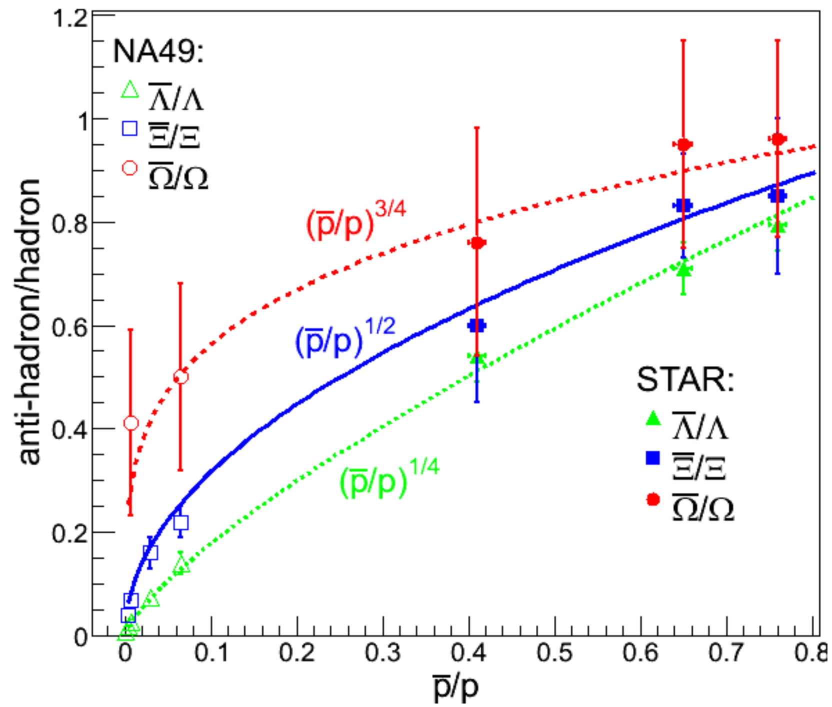
created matter is at picked at y=0

primary matter is concentrated around y≈3 (δy≈2.0)

- longitudinal net-kaon evolution similar as net-proton in |y|< 3 at RHIC (AuAu @ 200 GeV)
- strong “association”: net-kaon / net-lambda /net-proton?

K^-/K^+ and antihyperon/hyperon





$K^-/K^+ = \exp((2\mu_s - 2\mu_{u,d})/T)$

$\text{pbar}/p = \exp(-6\mu_{u,d}/T)$

$\mu_s = 0 \Rightarrow K^-/K^+ = (\text{pbar}/p)^{1/3}$

Fit shows that $K^-/K^+ = (\text{pbar}/p)^{1/4}$

$\Rightarrow \mu_s = \frac{1}{4}\mu_{u,d}$

How $\mu_s = \frac{1}{4}\mu_{u,d}$ will work for hyperons?

Hbar/H $= (\text{pbar}/p)^{3/4}$ for Lambdas

$= (\text{pbar}/p)^{1/2}$ for Xis

$= (\text{pbar}/p)^{1/4}$ for Omegas

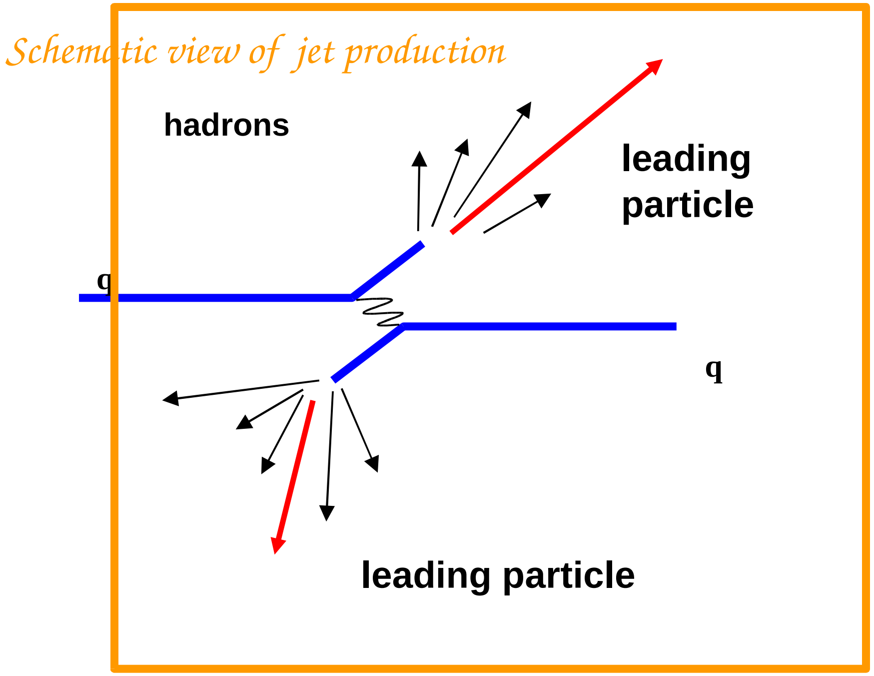
High p_t suppression & jet quenching

Particles with high p_t's (above ~2GeV/c) are primarily produced in hard scattering processes early in the collision

p+p experiments → hard scattered partons fragment into jets of hadrons

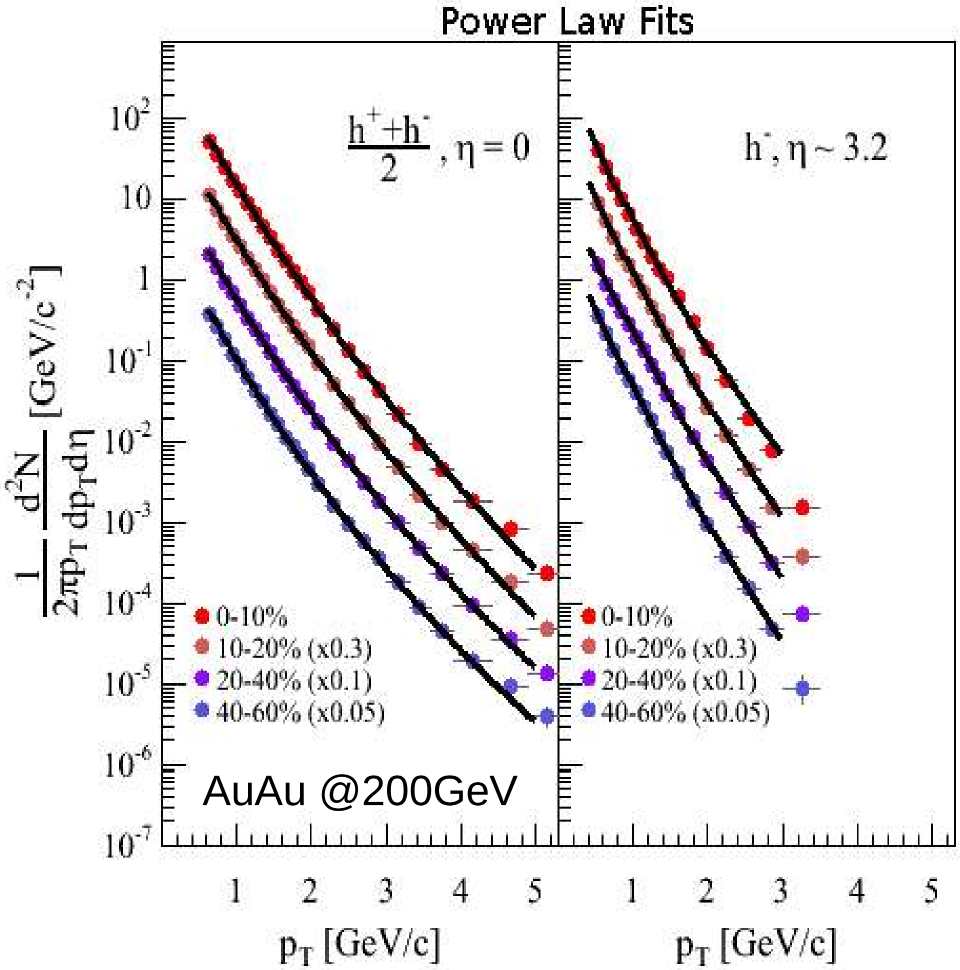
In A-A, partons traverse the medium
→ Probe of the dense and hot stage

If QGP → partons will lose a large part of their energy (induced gluon radiation)
→ suppression of jet production
↔ Jet Quenching



Experimentally → depletion of the high p_t region in hadron spectra

Charged hadron invariant spectra



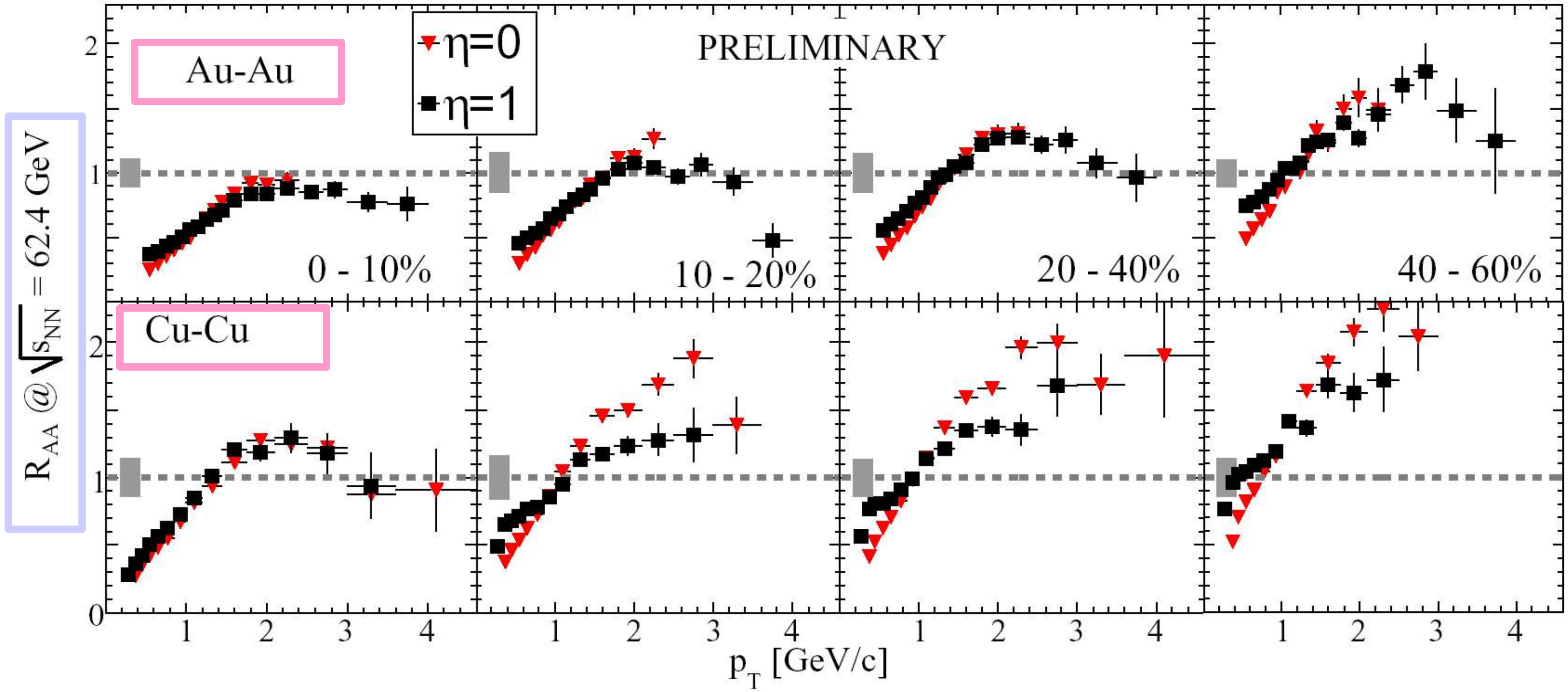
Nuclear Modification Factor

$$R_{AA} = \frac{\text{Yield(AA)}}{N_{COLL}(AA) \times \text{Yield(NN)}}$$

Scaled N+N reference

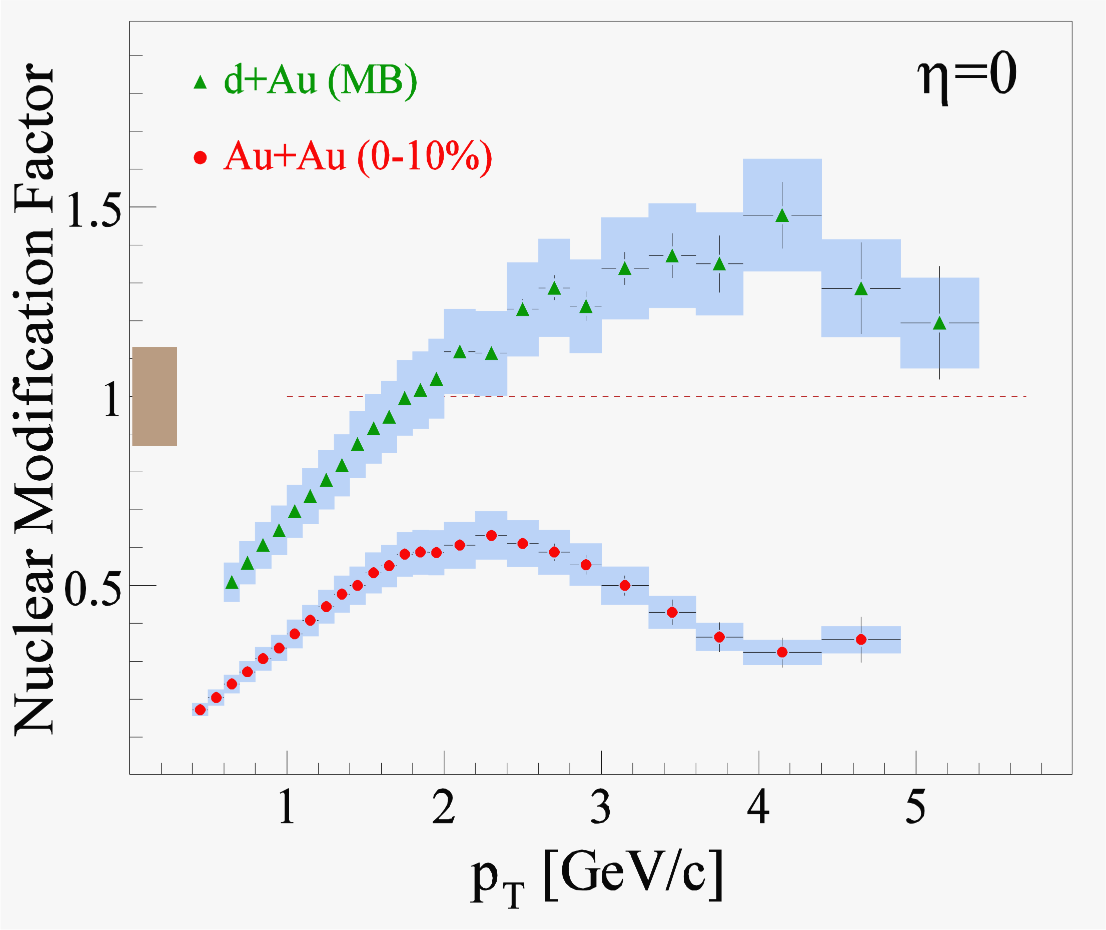
$R_{AA}<1$ ↔ **Suppression relative to scaled NN reference**

Energy and system dependent nuclear modification factors at h~0 and 1



- R_{AuAu} (200 GeV) < R_{AuAu}(63 GeV) < R_{CuCu}(63 GeV) for charged hadrons
- p+p at 63 GeV is ISR Data (NPB100), RHIC-Run6 will provide better reference

Control measurement: d+Au @ $\sqrt{s_{NN}}$=200

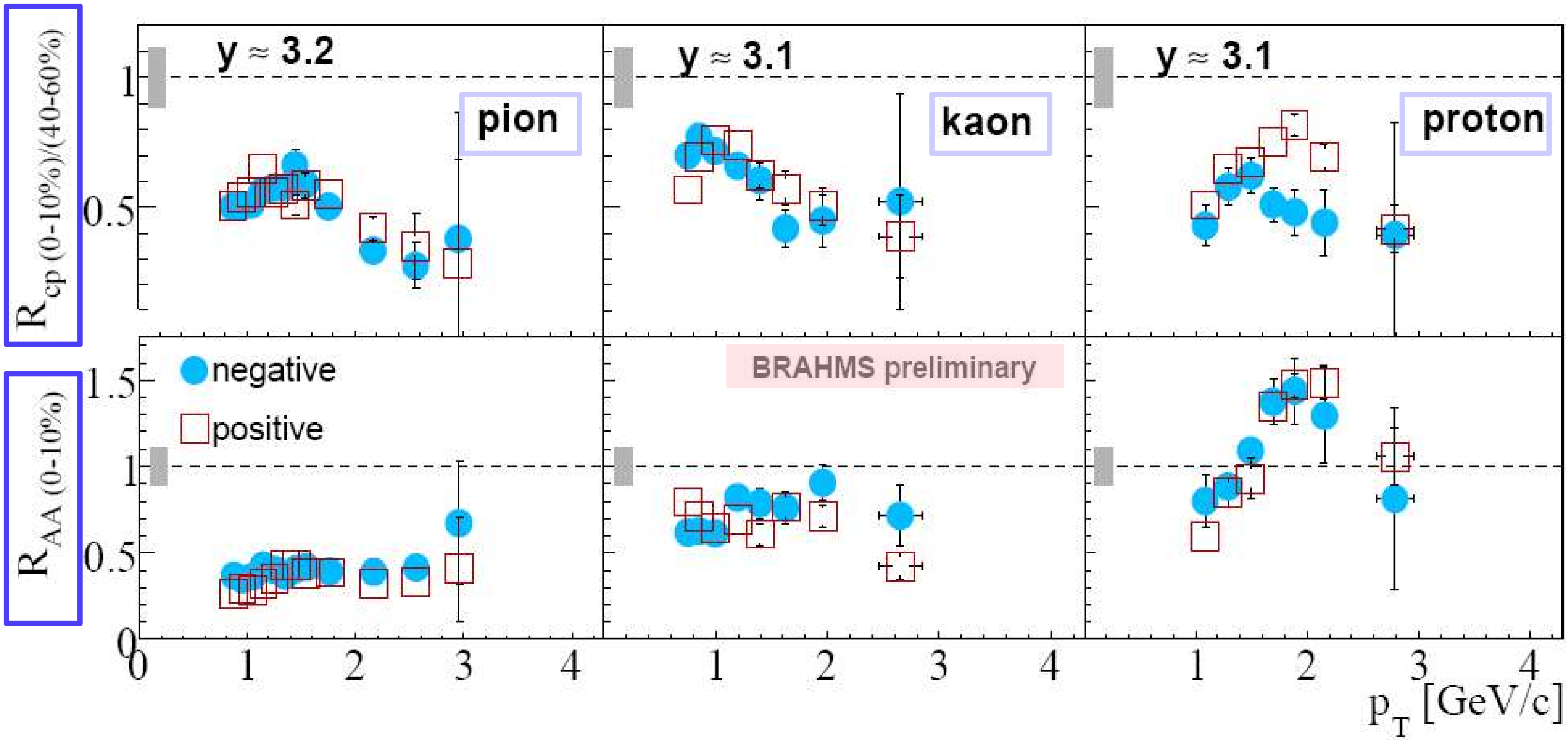


Excludes alternative interpretation in terms of Initial State Effects

→ Supports the Jet Quenching for central Au+Au collisions

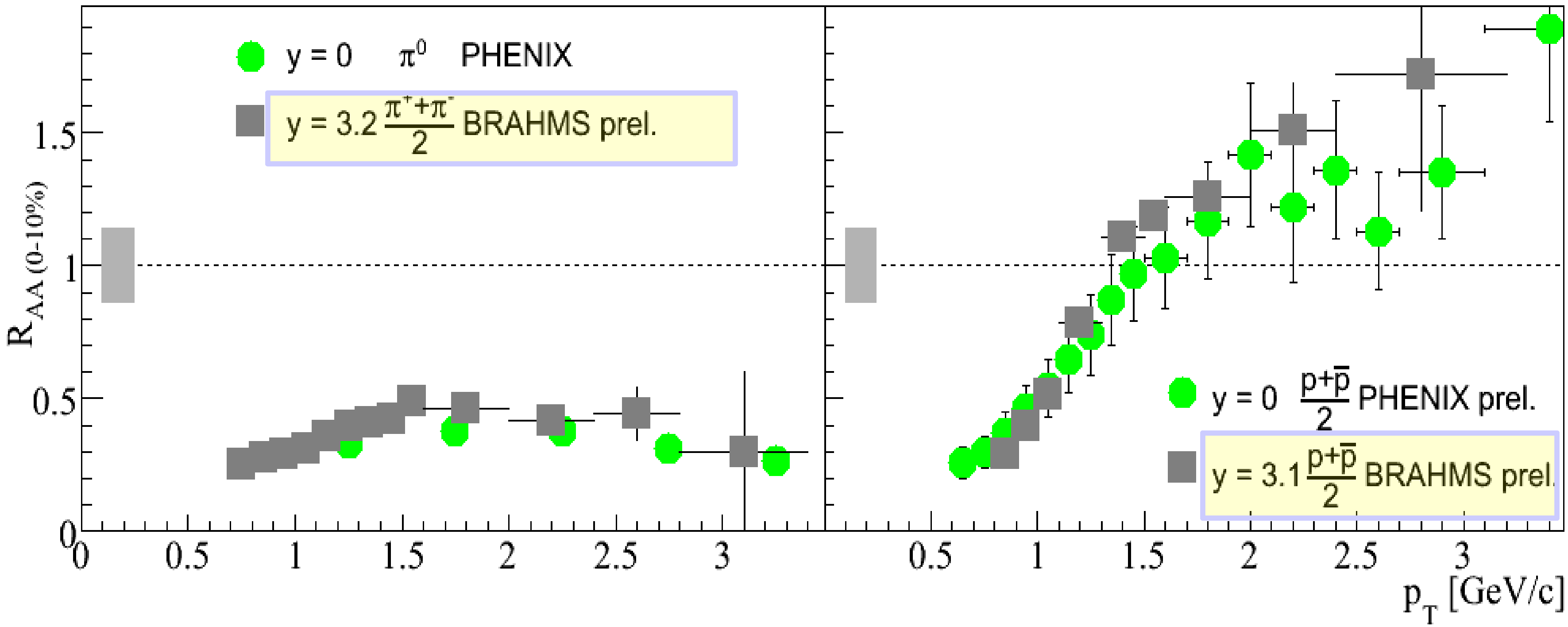
+ back-to-back azimuthal correlation and jet structure by STAR and PHENIX

Nuclear modification factors (R_{CP}, R_{AuAu}) for p,K,p at y~3.1



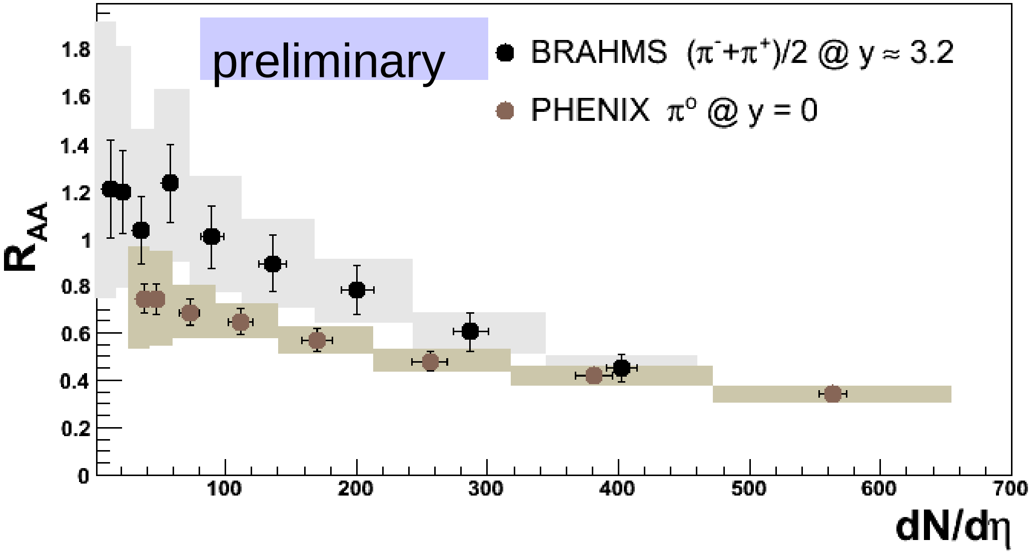
- Suppression for pions and kaons: R_{AuAu}: $\pi < K < p$
- $R_{AuAu} \neq$ Rcp (<Ncoll>,<Npart> for 40-60% ~ 70,56)

$R_{AuAu}(Y=0) \sim R_{AuAu}(y\sim3)$ for central Au+Au at $\sqrt{s}$ = 200 GeV



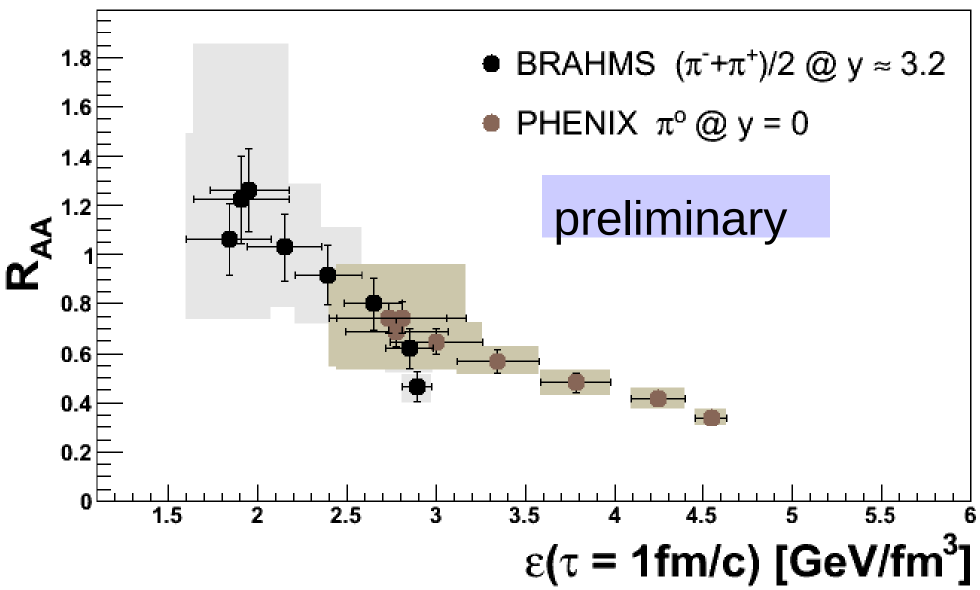
- R_{AuAu} (Y=0) ~ R_{AuAu}(y~3) for pions and protons: accidental?
- Rapidity dependent interplay of Medium effect + Hydro + baryon transport

... more on R_{AA} rapidity dependence



- Similar level of suppresion for central collisions
- At forward rapidity R_{AA} shows stronger rise towards peripheral coll.
  (surface -> volume emmission)

Looking for scaling: dN/dη ?



BE: ε **= 3/2** $\times$**(<E$_t$>/ Sτ_0) dN$_{ch}$/dη**

S is transwers area of overlaping region

<E$_t$> dirived from π and K spectra

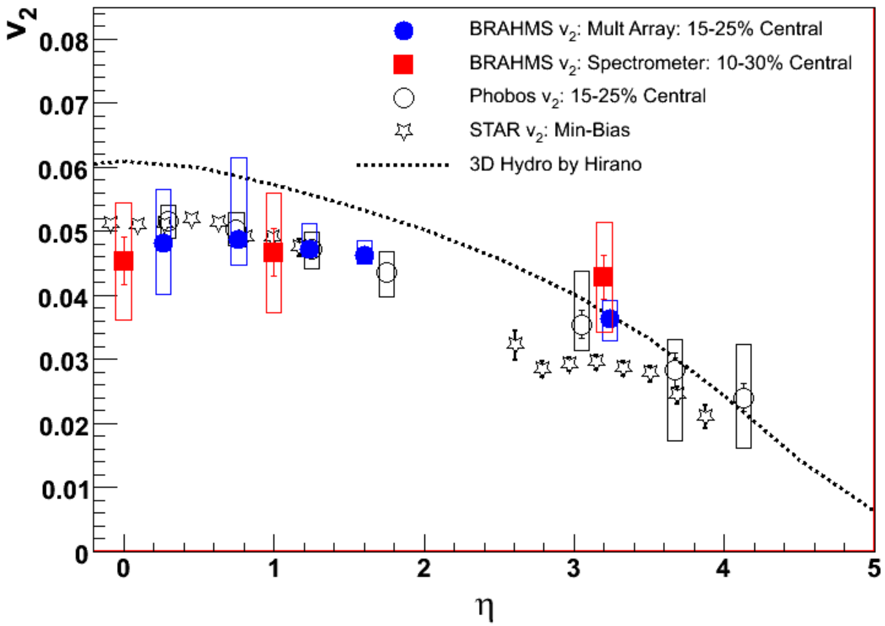
Is the energy density the only parameter that controls R_{AA}?

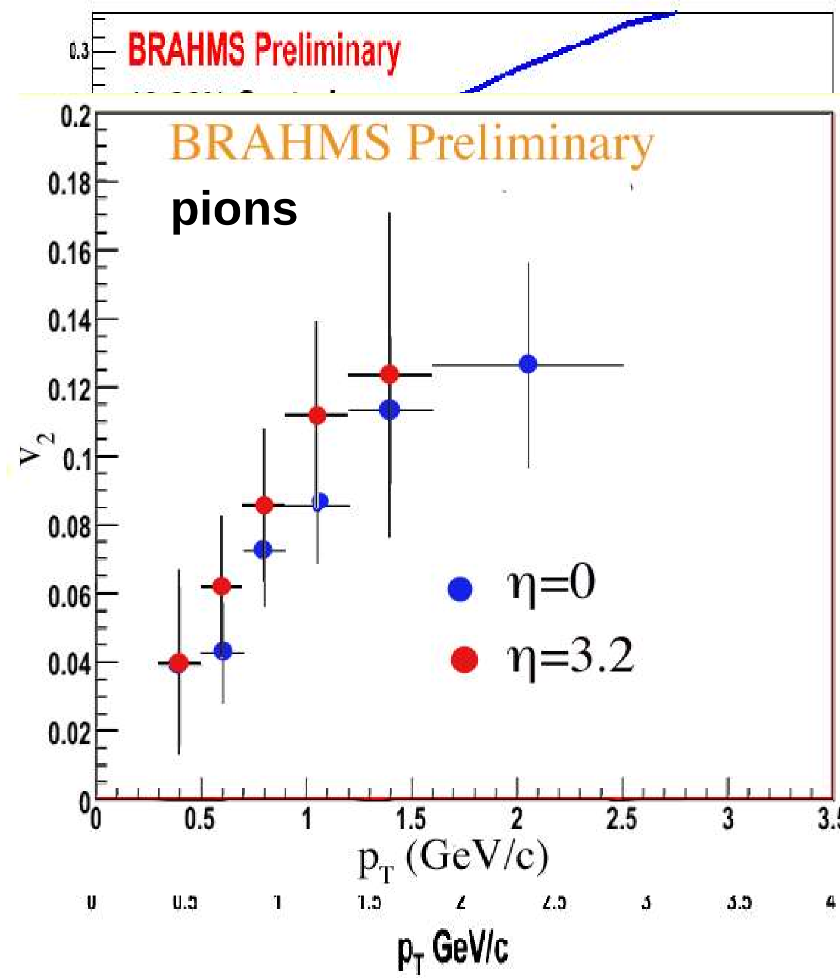
New pp data @62GeV will allow for various comparisions at the same rapidities

Flowing at forward

$$\frac{dN}{d\eta\, dp_t\, d\varphi} = \frac{dN}{d\eta\, dp_t}\frac{1}{2\pi}\left(1 + 2v_1\cos\varphi + 2v_2(\eta,p_t)\cos 2\varphi\right)$$

η Dependence of v_2: Charged Hadrons

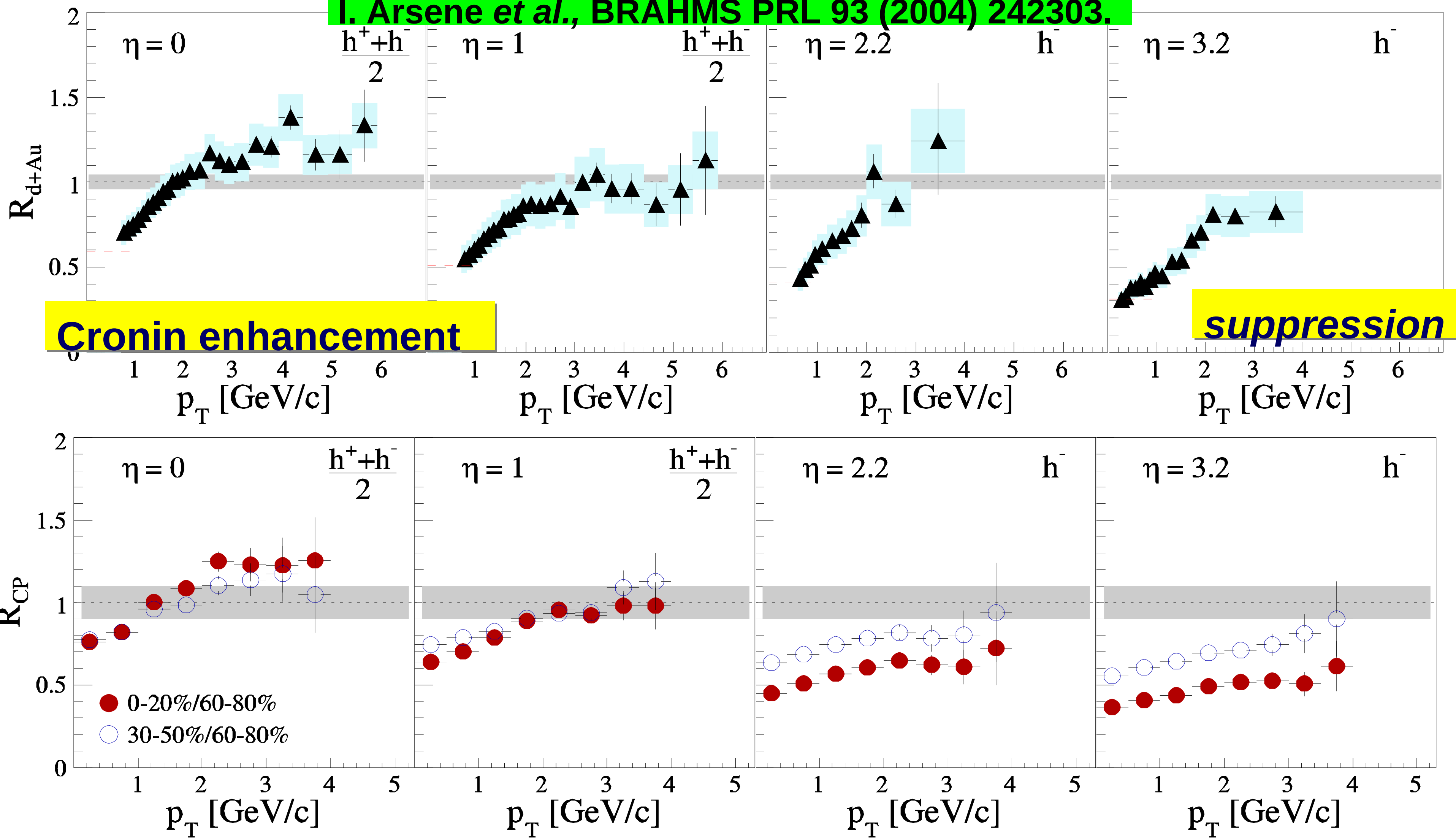




- Understanding missing low-pt fraction is important for integrated v2 from FS
- Kaon and proton v2 will come: Statistically Challenging
- $v2(y\sim0) \sim v2(y\sim3)$ for $0.5<p_T<2$ GeV/c

Examine d+Au at all rapidities

I. Arsene *et al.*, BRAHMS PRL 93 (2004) 242303.

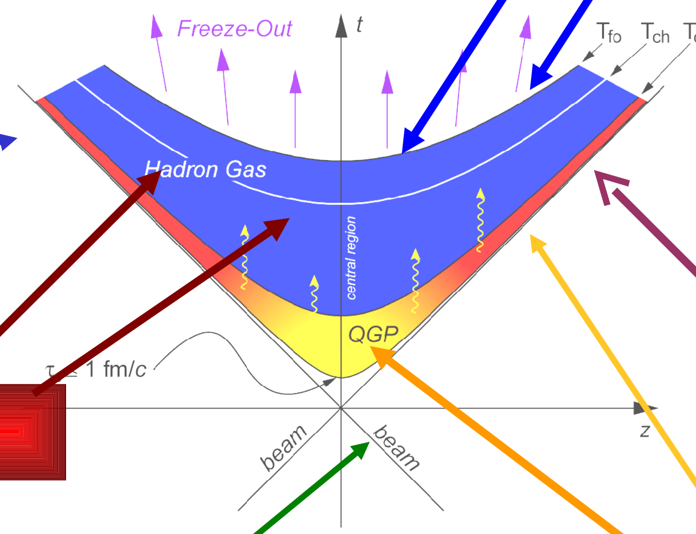


Summary

High energy density >> nuclear density

Strong transverse/elliptic flow in y<3

Limiting fragmentation



- ⟨δy⟩ ≈ 2
- 25 TeV left for particle production

(local) Chemical equilibration

Onset of gluon saturation?

Non-hadronic energy loss through the medium in |y|<3:

The BRAHMS Collaboration

I.Arsene[7], I.G. Bearden[6], D. Beavis[1], S. Bekele[6] , C. Besliu[9], B. Budick[5], H. Bøggild[6] , C. Chasman[1], C. H. Christensen[6], P. Christiansen[6], R. Clarke[9], R.Debbe[1], J. J. Gaardhøje[6], K. Hagel[7], H. Ito[10], A. Jipa[9], J. I. Jordre[9], F. Jundt[2], E.B. Johnson[10], C.E.Jørgensen[6], R. Karabowicz[3], N. Katrynska[3], E. J. Kim[4], T.M.Larsen[11], J. H. Lee[1], Y. K. Lee[4], S.Lindal[11], G. Løvhøjden[2], Z. Majka[3], M. Murray[10], J. Natowitz[7], B.S.Nielsen[6], D. Ouerdane[6], R.Planeta[3], F. Rami[2], C. Ristea[6], O. Ristea[9], D. Röhrich[8], B. H. Samset[11], D. Sandberg[6], S. J. Sanders[10], R.A.Sheetz[1], P. Staszel[3], T.S. Tveter[11], F.Videbæk[1], R. Wada[7], H. Yang[6], Z. Yin[8], and I. S. Zgura[9]

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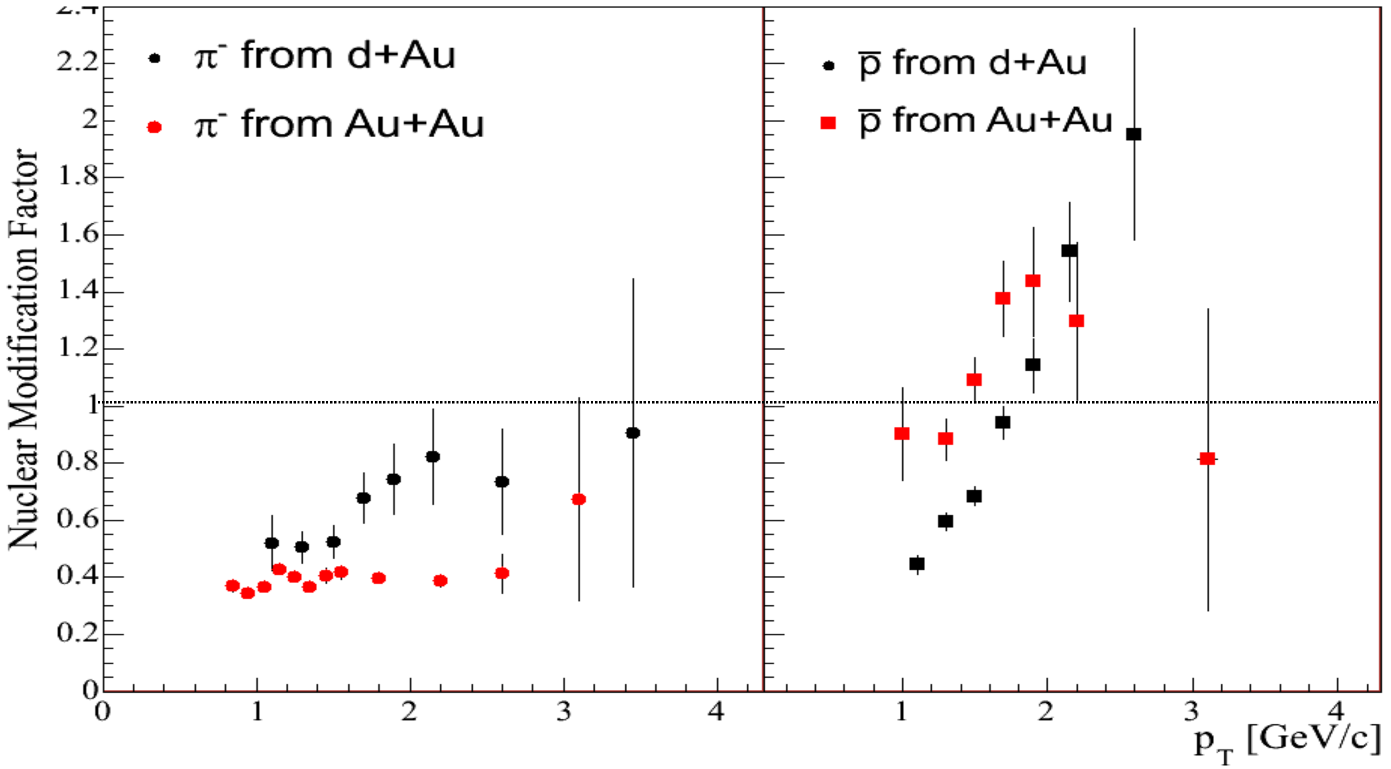
[9]University of Bucharest, Romania, [10]University of Kansas, Lawrence,USA
[11] University of Oslo Norway

48 physicists from 11 institutions

BACKUP SLIDES

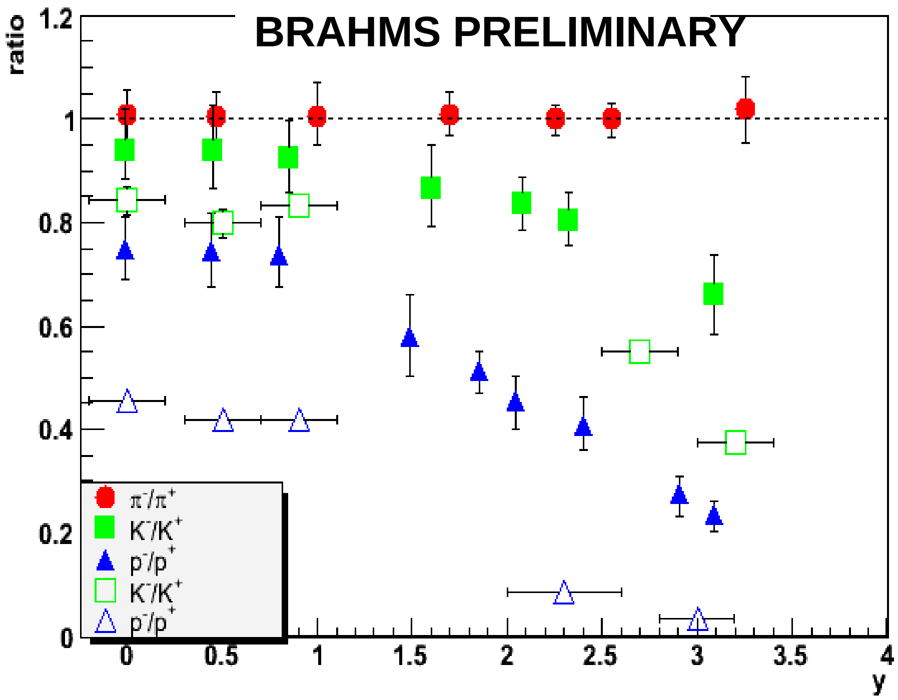
R_{dAu} and R_{AA} for anti-protons and pions @200

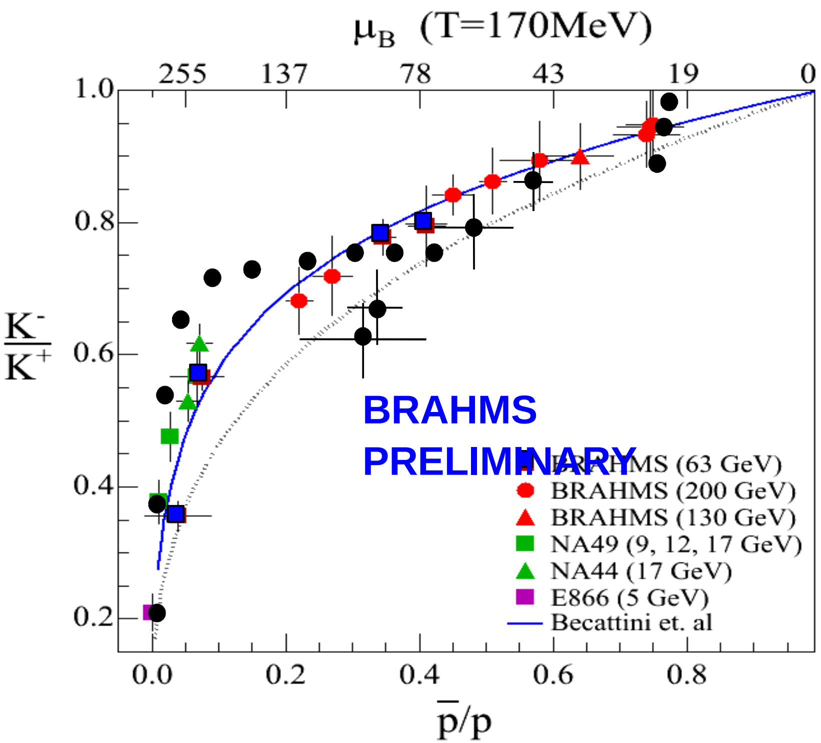
BRAHMS PRELIMINARY



- suppression for π^- but stronger for AuAu
- both R_{dA} and R_{AA} show enhancement for p-bar

Anti-particle to particle ratios ⇒ Chemical freeze-out



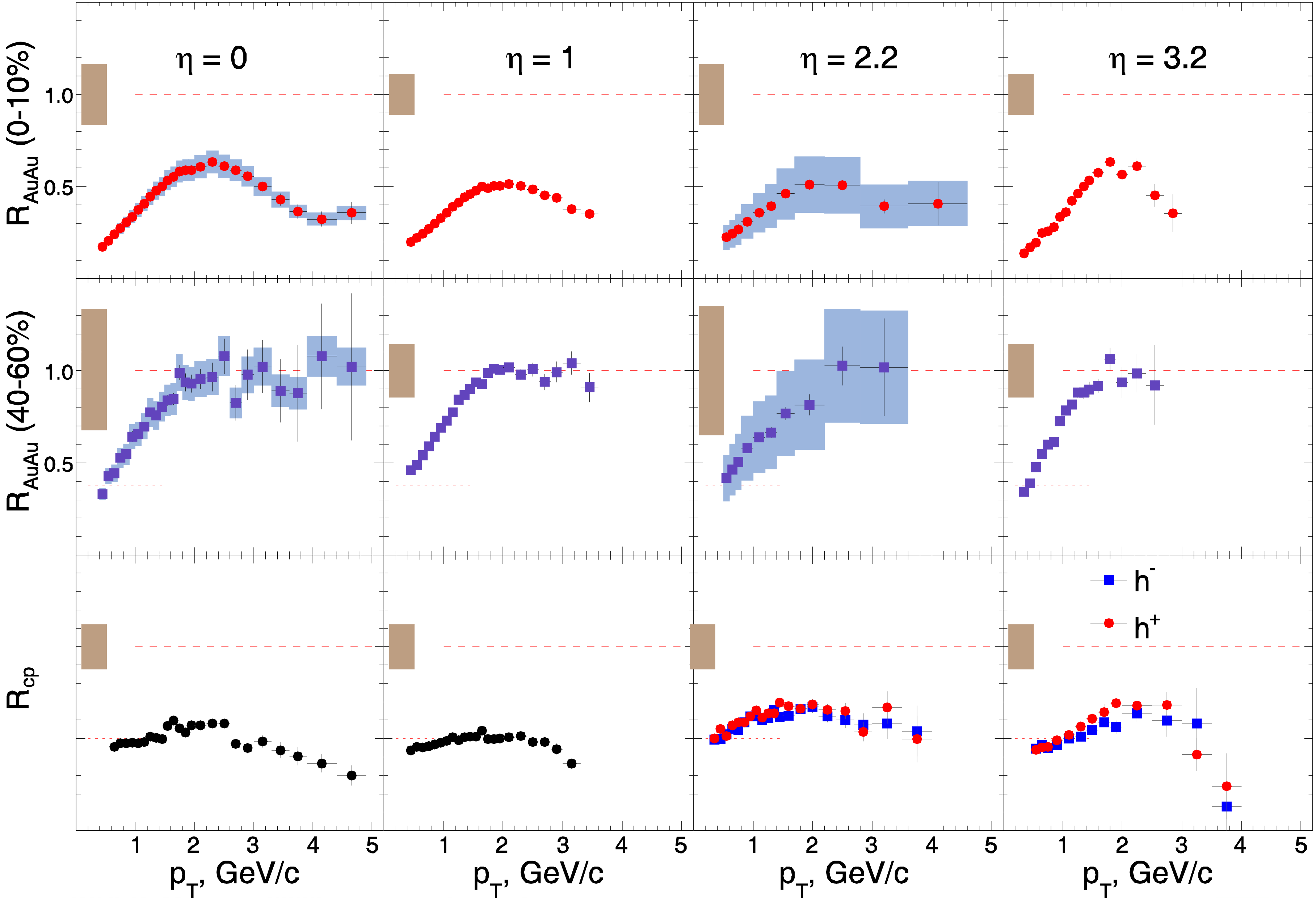


- **At 200 GeV: π^-/π^+ = 1.0, K^-/K^+ = 0.95, pbar/p = 0.75**
- **At 62 GeV: π^-/π^+ = 1.0, K^-/K^+ = 0.84, pbar/p = 0.45,**
- **At |y|<1 matter⇔antimatter**

- **pbar/p verus K^-/K^+ : good statistical model description with $\mu_B = \mu_B(y)$ with T~170MeV**
- **But this describes also energy depencency at y=0 ⇒ only μ_B controls the state of matter**
- **STAR and NA47 measures pbar/p versus Ξ^-/Ξ^+**

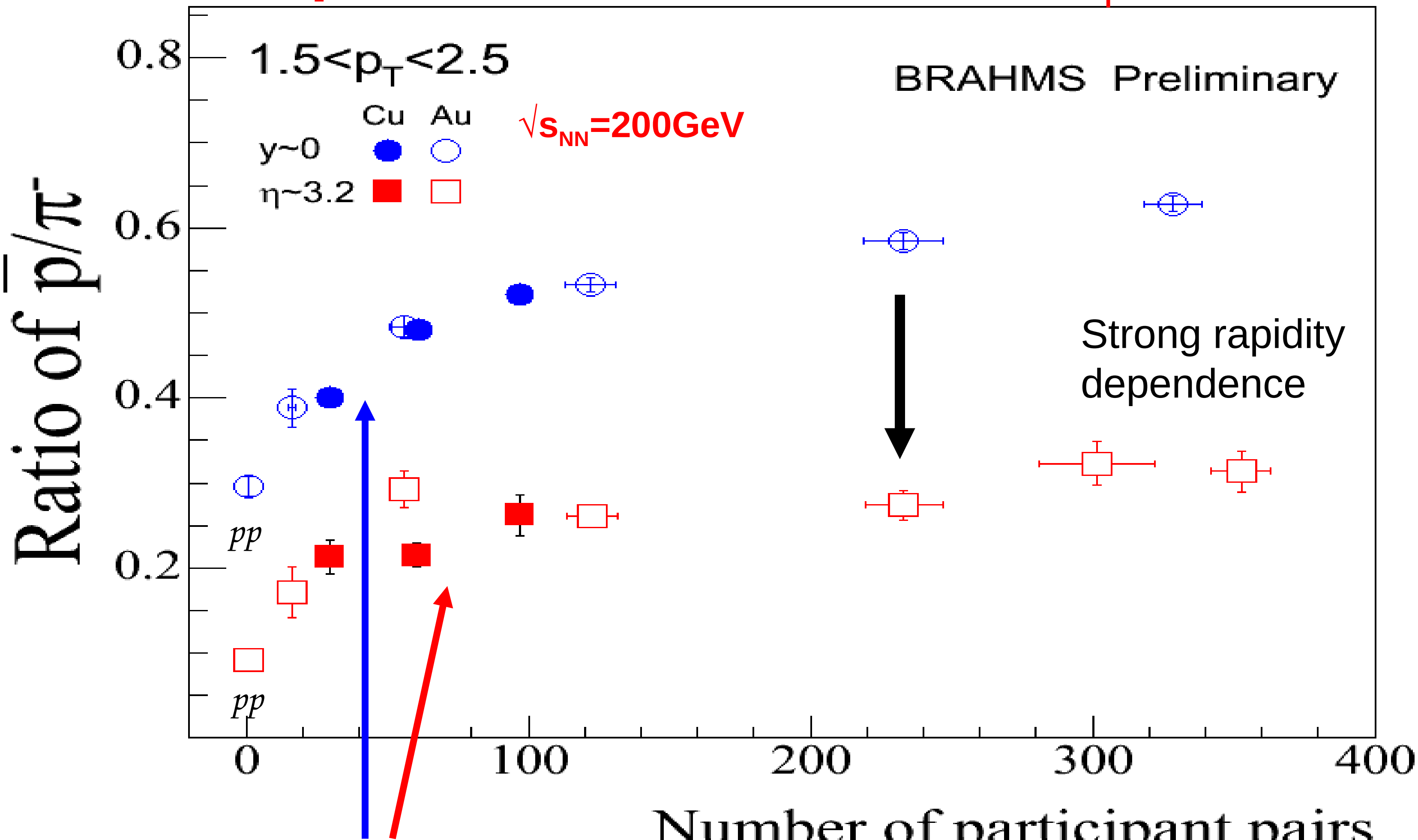
It is not true for p+p

R_{AuAu} 200 GeV



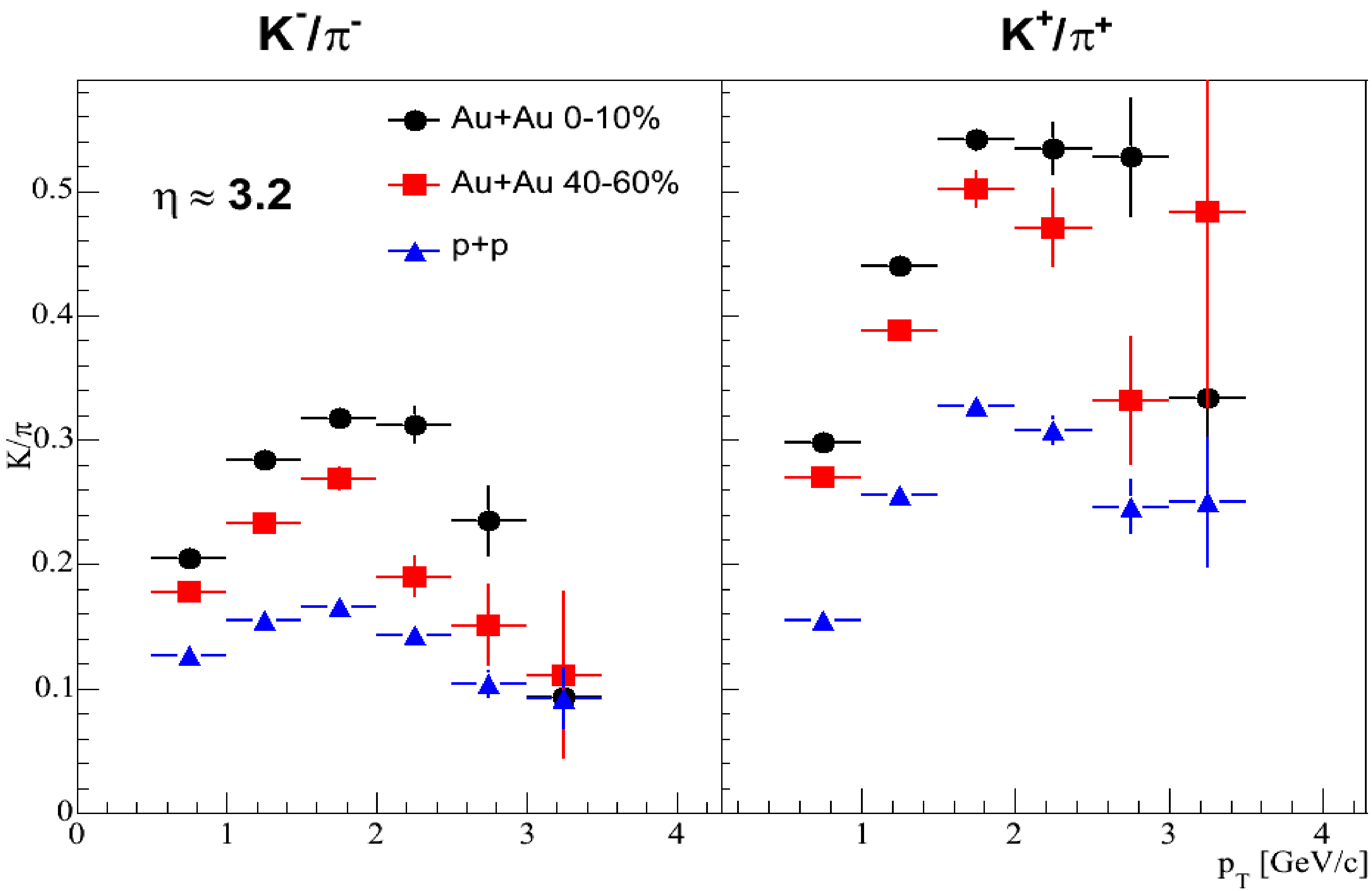
ICHEP, Moscow 2006

pbar/π^- scaling with N_{part}



CuCu data consistent with AuAu for the same N_{part}

K/π ratios at η=3.1, Au+Au @200GeV

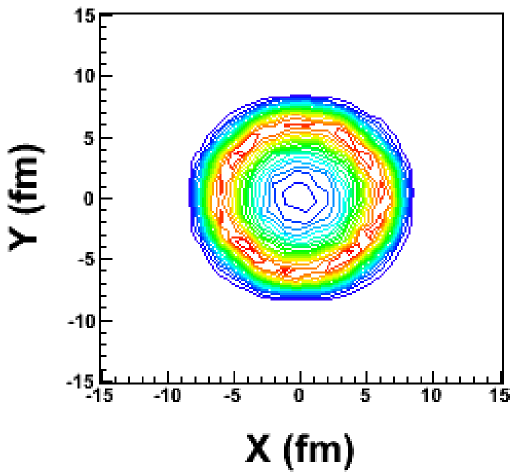


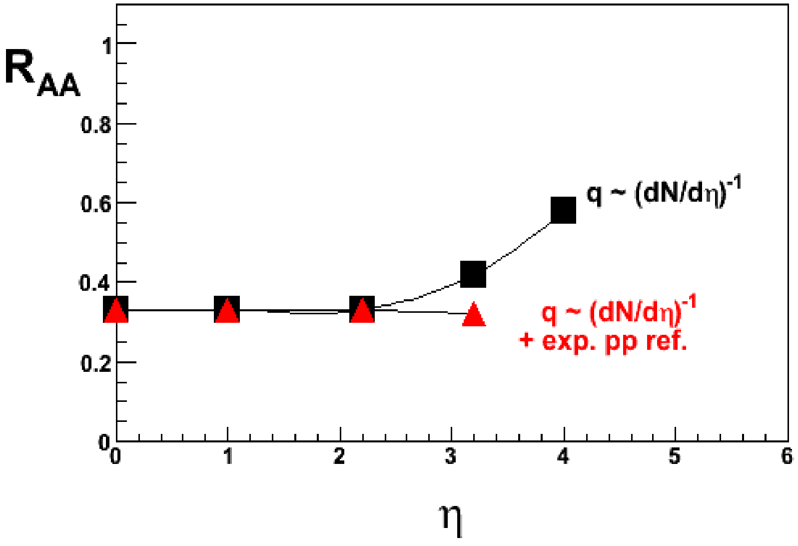
Strong energy absorption model from a static 2D matter source. (Insprired by A.Dainese (Eur.Phys.J C33,495) and A.Dainese , C.Loizides and G.Paic (hep-ph/0406201))

- Parton spectrum using pp reference spectrum
- Parton energy loss $\Delta E \sim q.L^{**}2$
- q adjusted to give observed R_{AA} at $\eta \sim 1$.

The change in $dN/d\eta$ will result in slowly rising R_{AA} .

The modification of reference pp spectrum causes the R_{AA} to be approximately constant as function of η .





Summary

Large hadron multiplicities

Almost a factor of 2 higher than at SPS energy($\leftrightarrow$ higher ε)
Much higher than pp scaled results($\leftrightarrow$ medium effects)

Identified hadron spectra

Good description by statistical model
Large transverse flow consistent with high initial density

v2(pt) is seem to not depend on rapidity

p/π

show strong η dependency
for given energy depend only on N_{par}

High-p_T

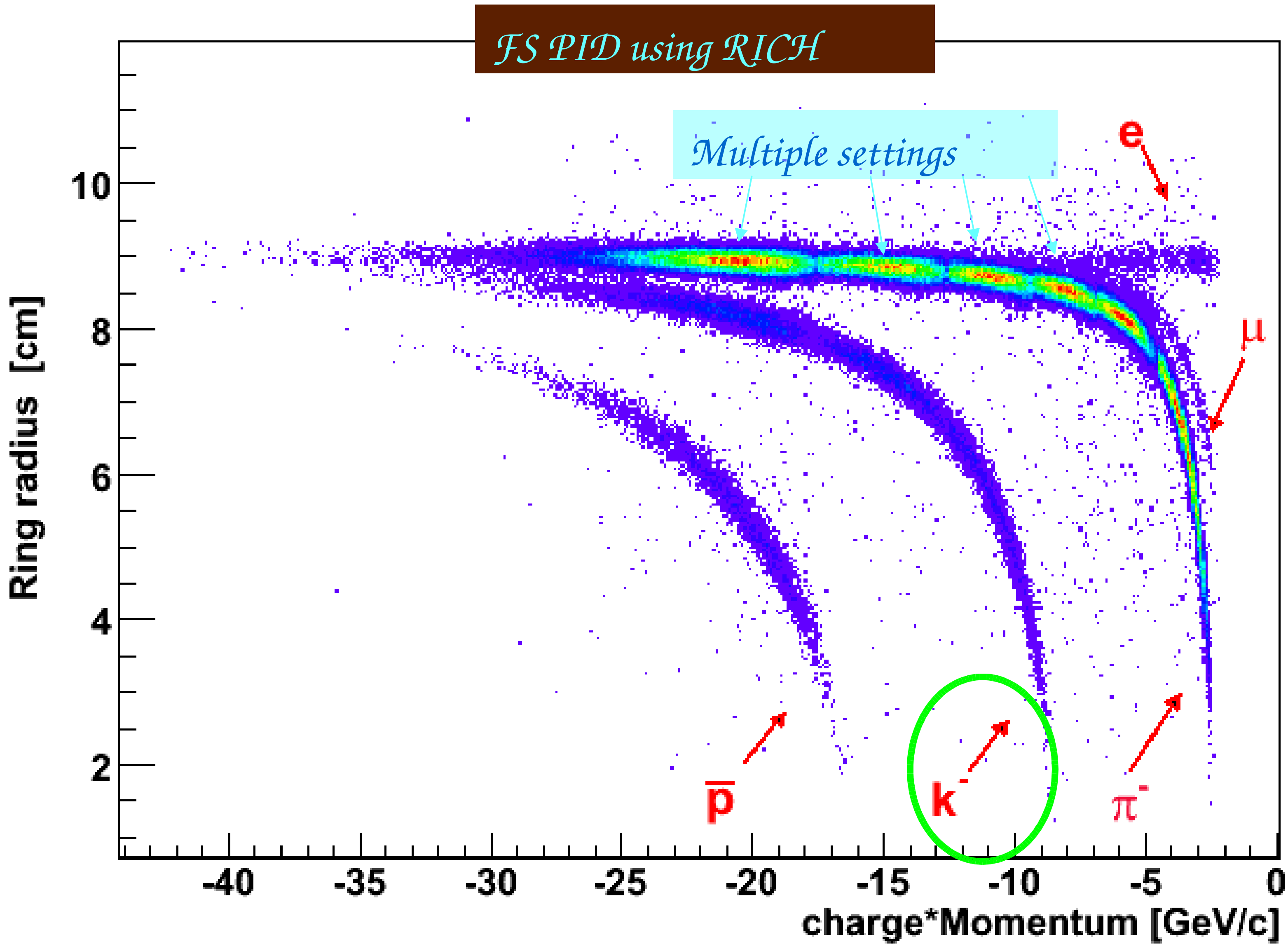
suppression increases with energy for given centrality bin

weak dependency on rapidity of R_{AA} which is consistent with surface jet emission

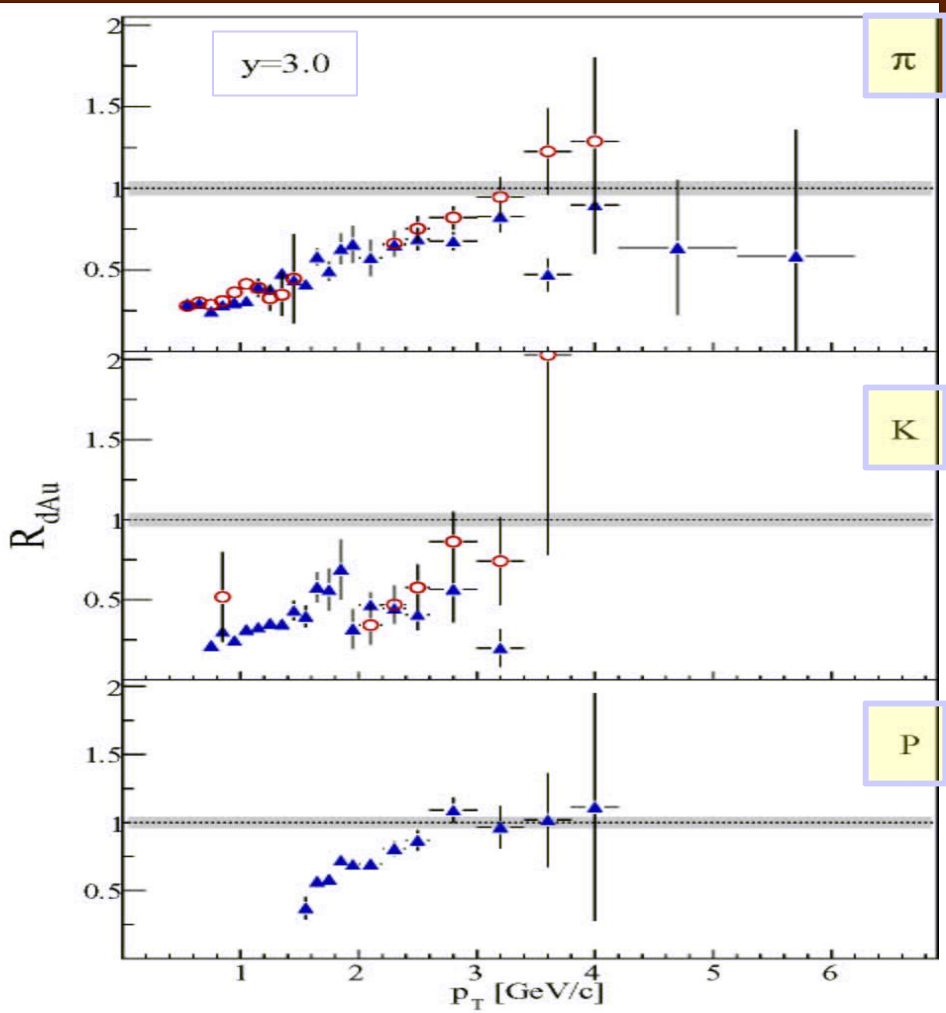
R_{CP} can hide or enhance nuclear effects

At y=3.2 R_{AA} shows larger suppression than R_{dA}

Ring radius vs p



RdAu Update: Identified Particle RdAu at



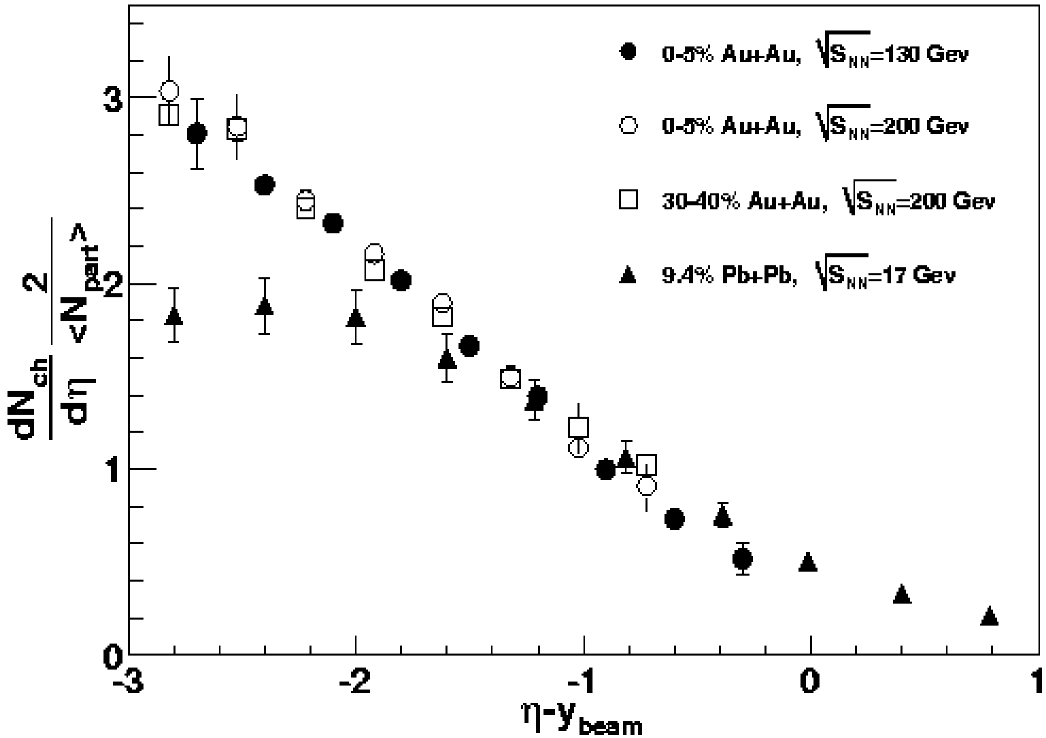
+ *blue*
- *red*

BRAHMS Preliminary

- *RdAu of identified particle consistent with published h- results*
- *dAu(π-)/dAu(π+): Valance quark isospin dominates in pp?*

Limiting Fragmentation

Shift the $dN_{ch}/d\eta$ distribution by the beam rapidity, and scale by $\langle N_{part} \rangle$.
Lines up with lower energy ⇒ limiting fragmentation



Au+Au $\sqrt{s_{NN}}$=200GeV (0-5% and 30-40%)
Au+Au $\sqrt{s_{NN}}$=130GeV (0-5%)
Pb+Pb $\sqrt{s_{NN}}$=17GeV (9.4%)