Probing QCD matter with hard scattering processes in PHENIX: High p_T in Au+Au, d+Au and p+p at $\sqrt{s}$ = 200 GeV

"INT-03-1: The first three years of heavy-ion physics at RHIC"

Seattle, June 03, 2003

David d'Enterria
Nevis Labs, COLUMBIA University, NY
(PHENIX Collaboration)

Overview

- PHENIX high p_T measurements :
  - Charged hadrons, π^0, and p,pbar in Au+Au, d+Au, p+p.
- Au+Au *vs* p+p — "hot & dense medium" vis-à-vis "vacuum"
  - 2 most significant "discoveries" at RHIC:

    "High p_T hadron suppression" & "anomalous" baryon/meson ratio
  - $\sqrt{s_{NN}}$ dependence of suppression
  - Magnitude and p_T (and x_T) dependence
  - Centrality dependence
  - Particle species dependence
- d+Au *vs* p+p — "cold" medium vis-à-vis "vacuum"
  - Role of "conventional" nuclear effects: Cronin, shadowing.
- Data *vs* theory — properties of underlying QCD matter:
  - Dense partonic medium (FSI): Parton energy loss + recombination.
  - Dense partonic medium (ISI): Gluon saturation.
  - Dense hadronic medium (FSI): Hadronic energy loss.
- Summary & conclusions

High p_T particles @ RHIC. Motivation

- Products of parton fragmentation (jet "leading particle").
- Early production in parton-parton scatterings with large Q^2.
- Direct probes of partonic phases of the reaction ⇒ Sensitive to dense medium properties: QGP energy loss, saturated CGC ...
- Info on medium effects accessible through comparison to nuclear- geometry scaled "vacuum" (*pp*) yields:

Small hard cross-sections + factorization → "collision" scaling

$$\sigma_{AB}^{hard} = \int d^2b \left[1 - e^{-\sigma_{NN}^{hard} T_{AB}(b)}\right] \approx \int d^2b\, \sigma_{NN}^{hard}\, T_{AB}(b) \propto \langle N_{coll}\rangle(b)$$

$$\langle N_{coll}\rangle(b) = \sigma_{NN} \cdot T_{AB}(b)$$

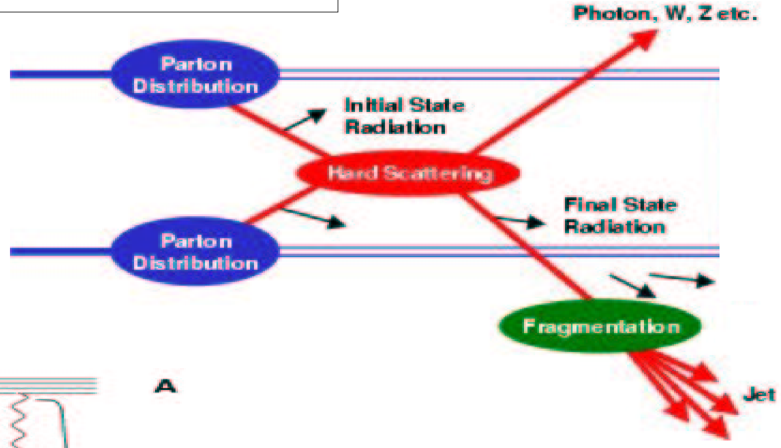
- Production yields calculable theoretically (next slide) ...

High p_T particles @ RHIC. Motivation (cont'd)

- Production yields calculable via pQCD:

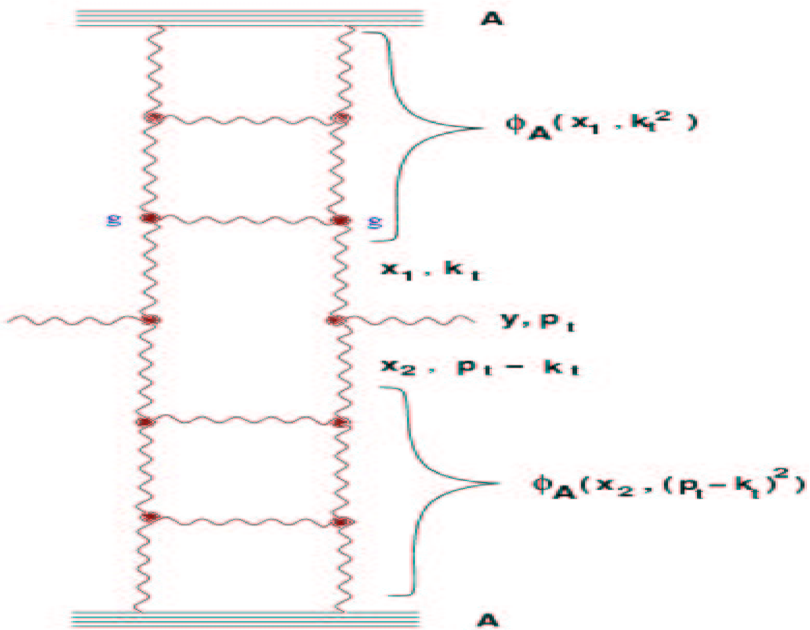
$$\sigma_{AB\to hX}^{hard} \propto f_{a/A}(x_a,Q^2_a) \otimes f_{b/B}(x_b,Q^2_b) \otimes \sigma_{a\,b\to cd} \otimes D_{h/c}(z_c,Q^2_c)$$

“Factorization theorem”



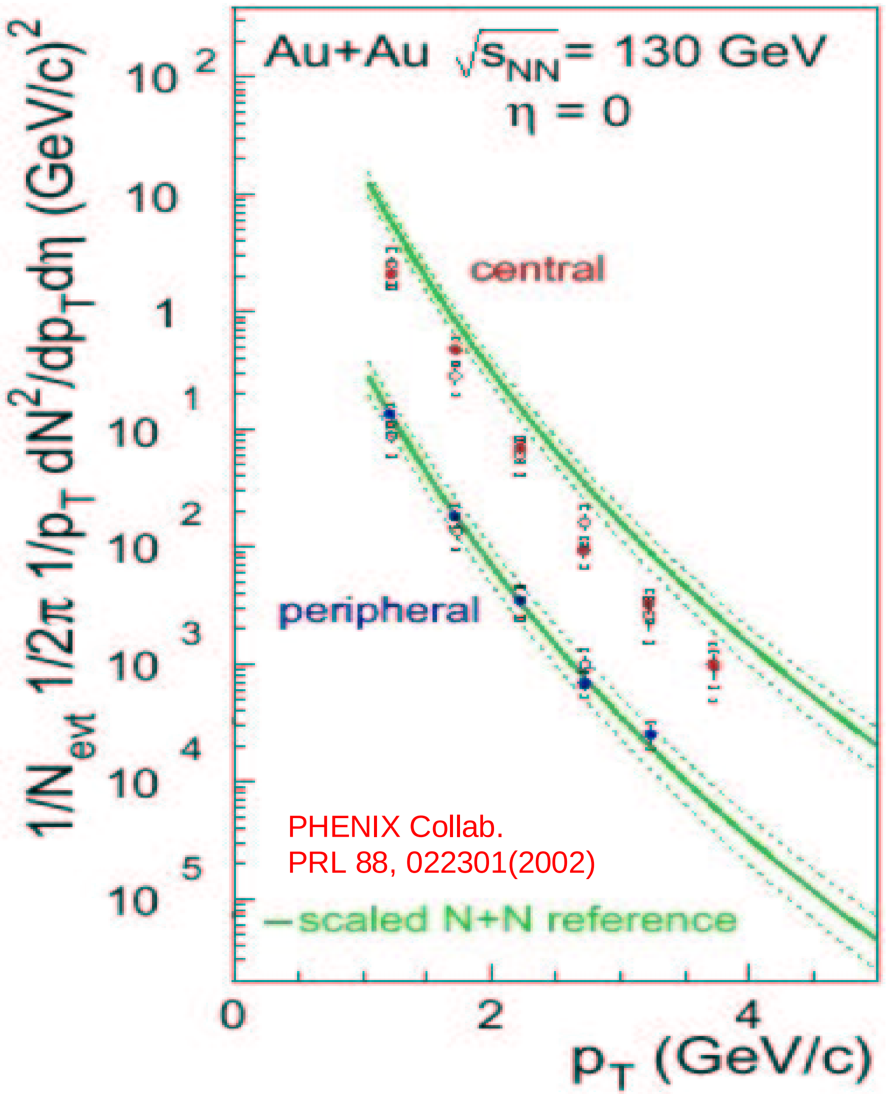
- ... or via “classical” CD:

“Mueller diagram for classical glue radiation”

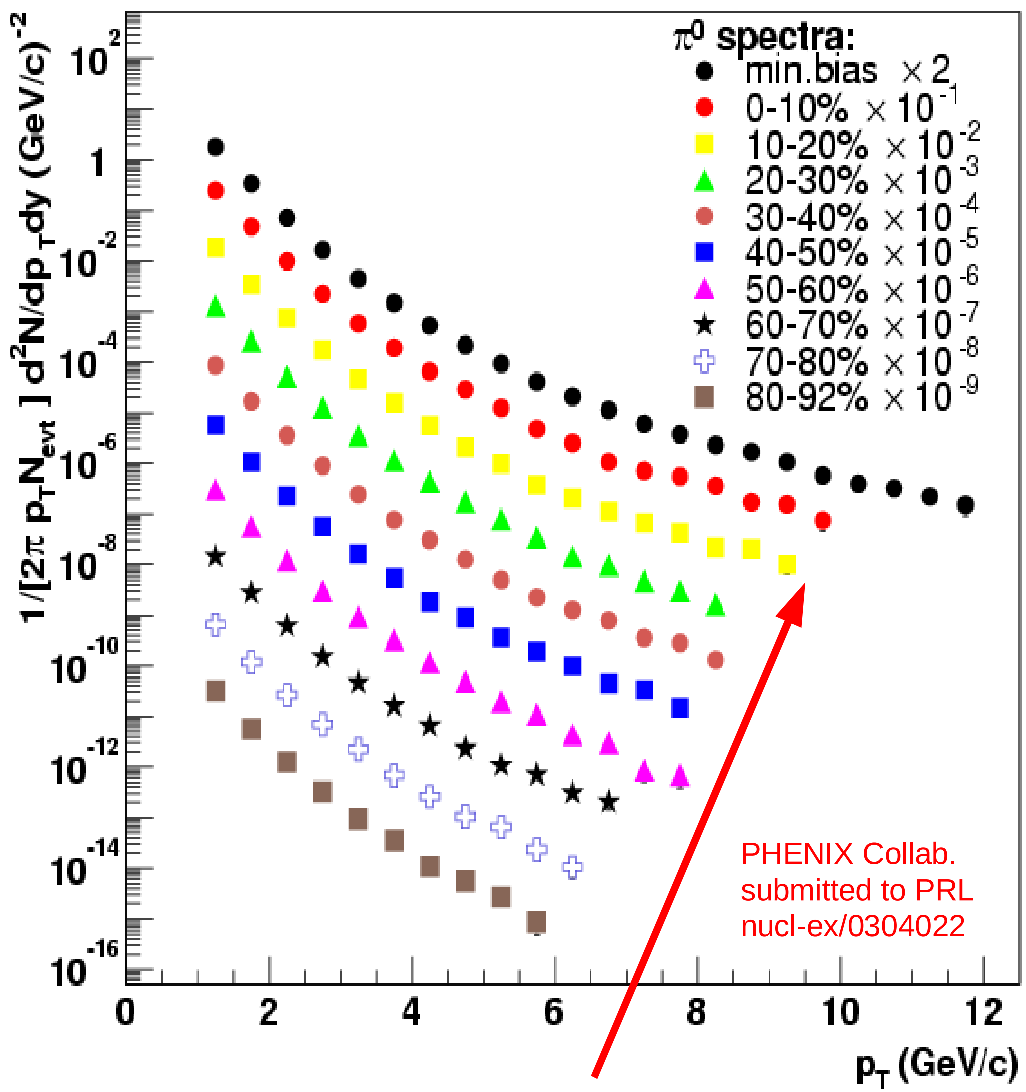


Data (1): high p_T neutral pions (Au+Au)

Au+Au $\sqrt{s_{NN}}$ = 130 GeV



Au+Au $\sqrt{s_{NN}}$ = 200 GeV

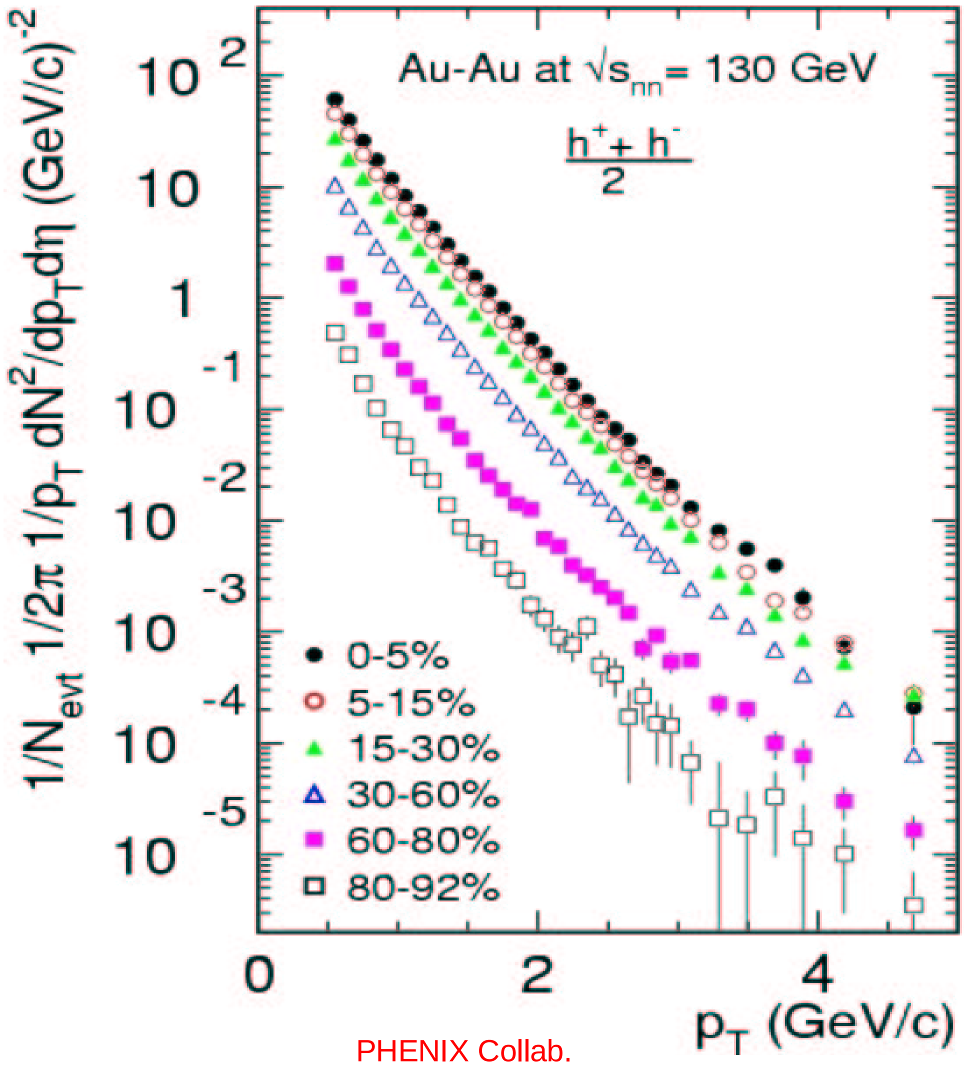


- central spectra up to ~10. GeV/c

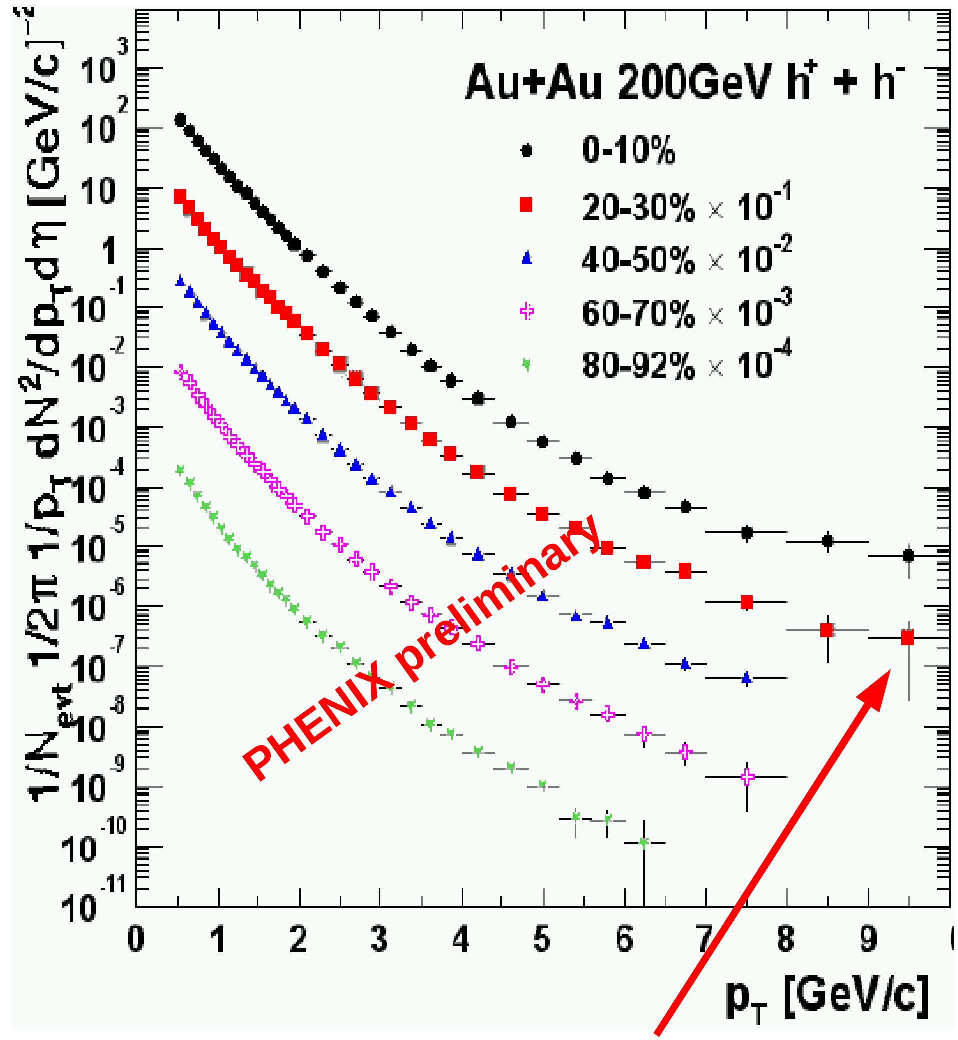
Data (2): inclusive charged hadrons (Au+Au)

Au+Au $\sqrt{s_{NN}}$ = 130 GeV

Au+Au $\sqrt{s_{NN}}$ = 200 GeV



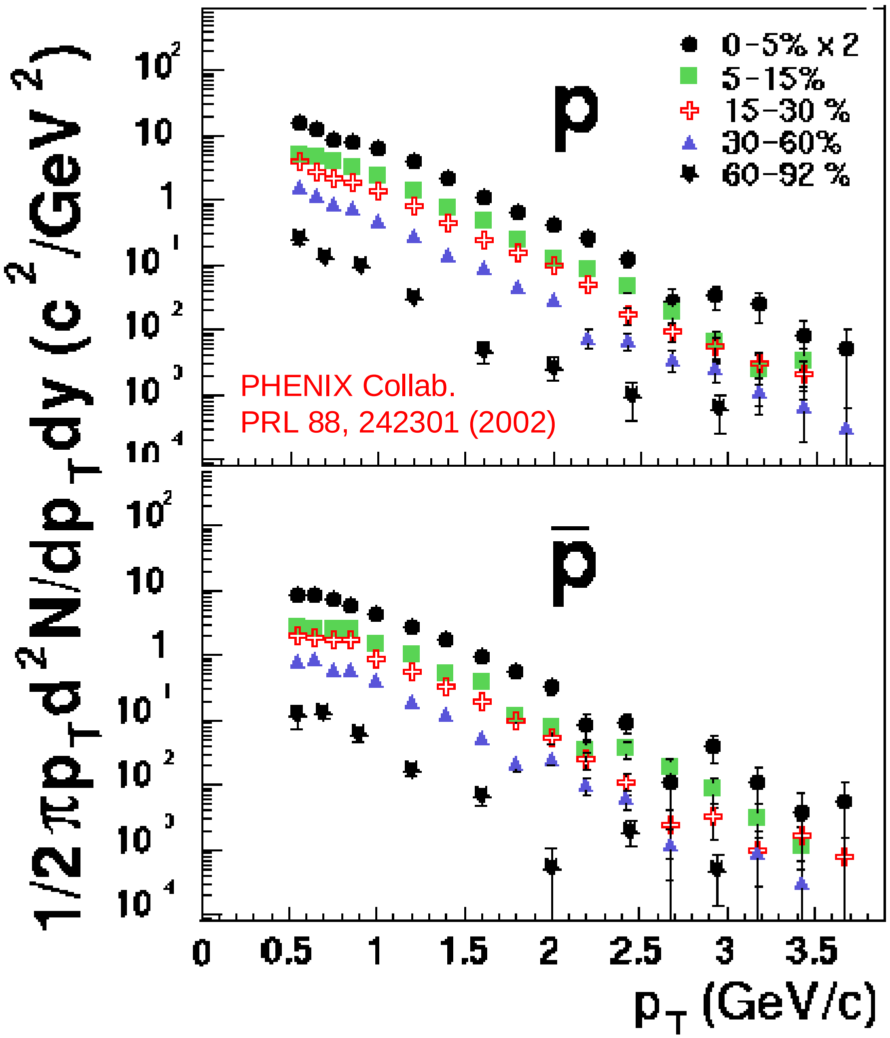
PHENIX Collab.
PLB 561, 82 (2003)



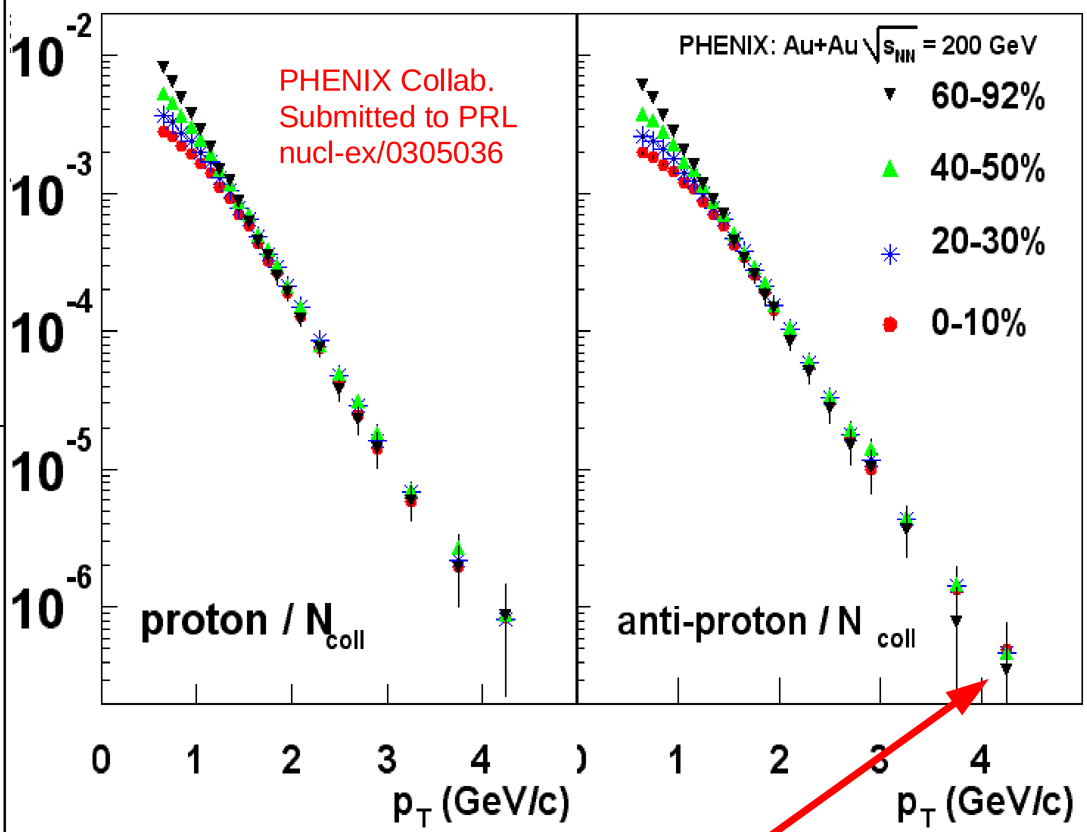
- central spectra up to ~9. GeV/c

Data (3): identified p,pbar (Au+Au)

Au+Au $\sqrt{s_{NN}}$ = 130 GeV

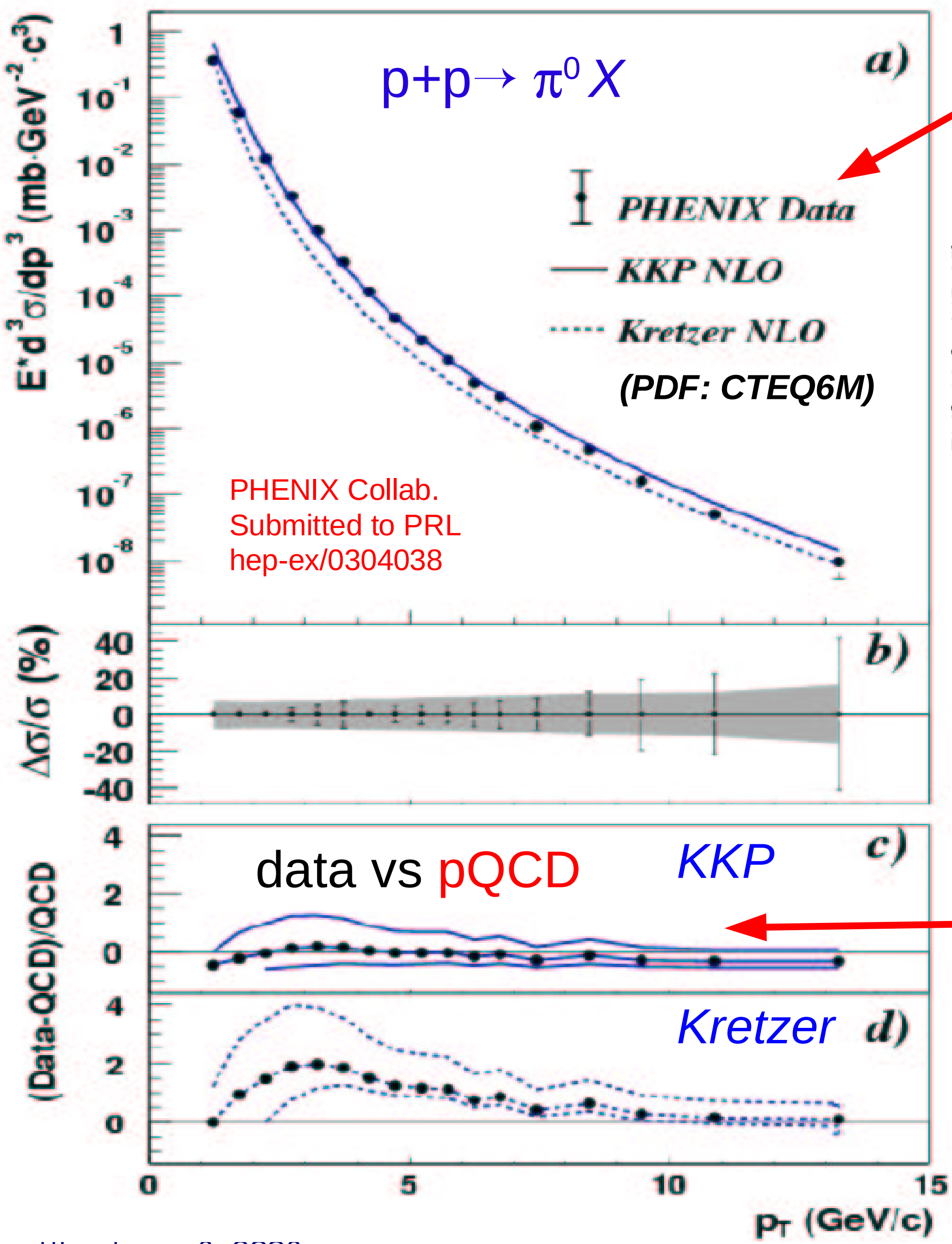


Au+Au $\sqrt{s_{NN}}$ = 200 GeV

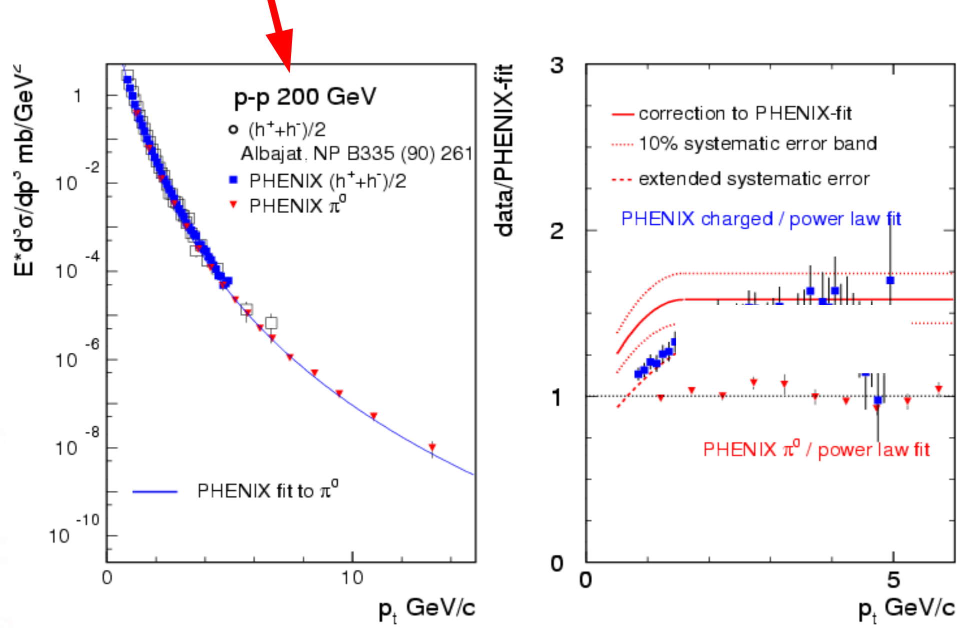


- spectra up to ~4.5 GeV/c

Data (4): high-p_T neutral pions (p+p @ 200 GeV)



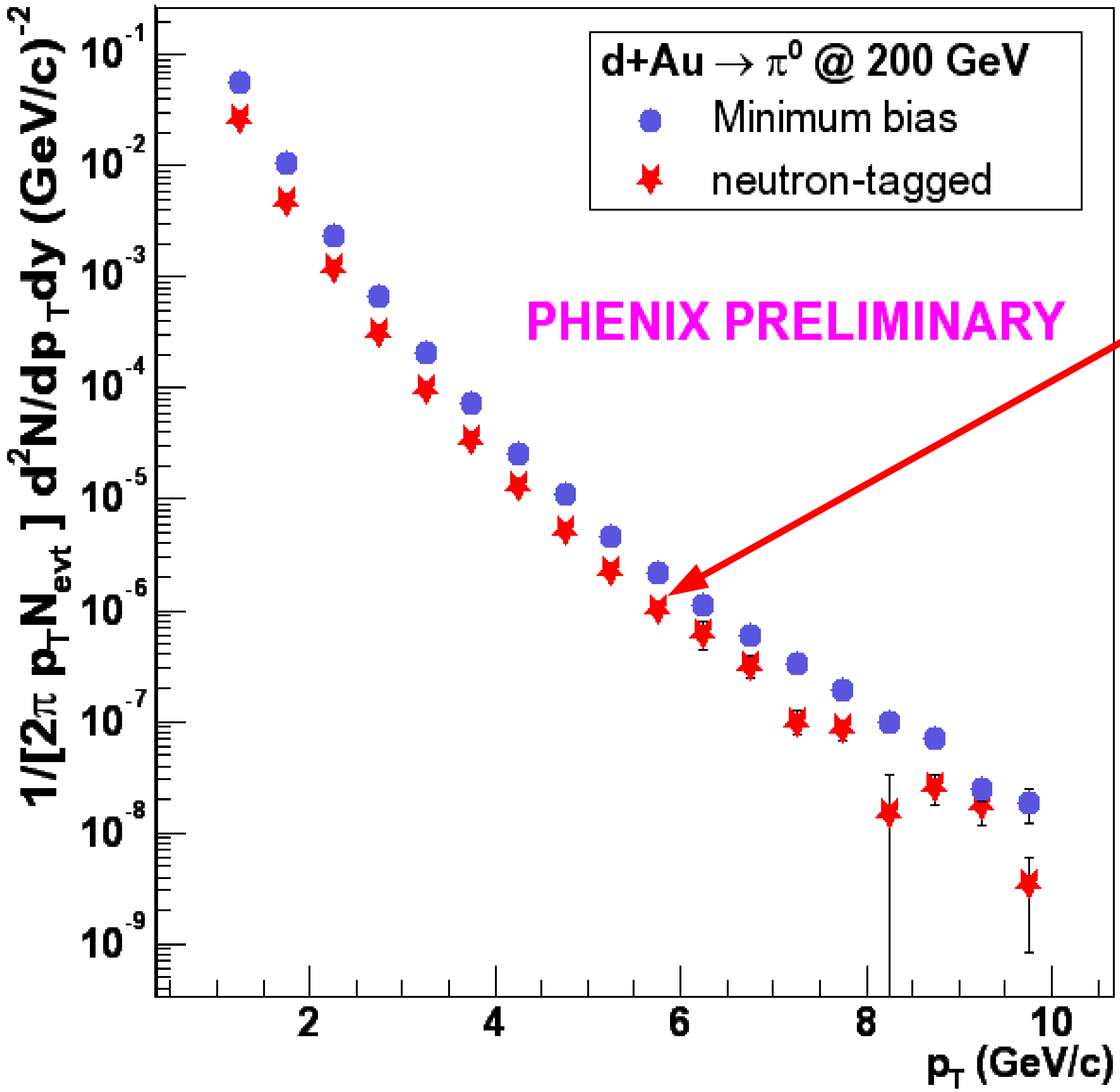
- "Unbiased" ref. for Au+Au → π^0
- "Auxiliary" ref. for Au+Au → $h^{\pm}$



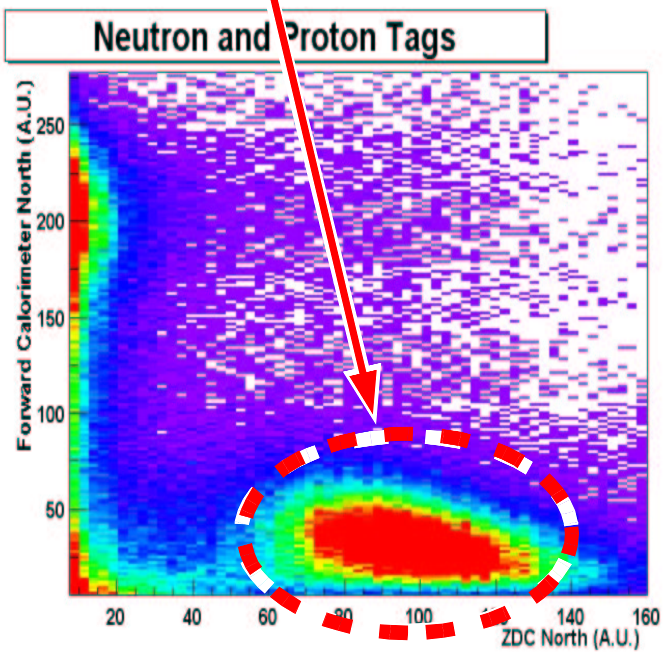
- Good NLO pQCD description

(down to p_T~ 1 GeV/c,
no intrinsic k_T needed,
sensitivity to gluon→π^0 FF)

Data (5): neutral pions, d(p)+Au @ 200 GeV

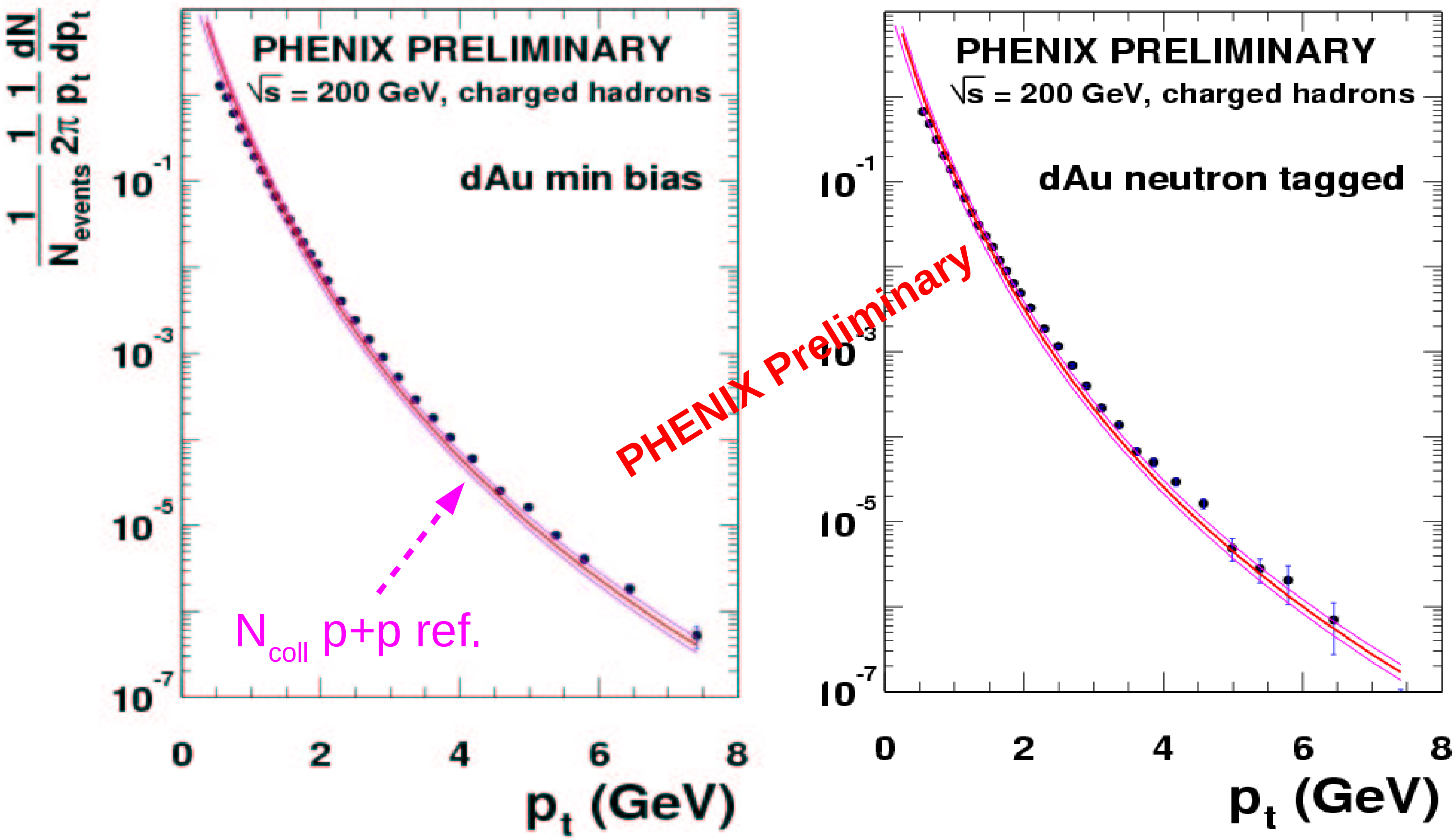


p+Au→ $\pi^0 X$ from neutron-tagged evts. (FCAL vs ZDC correlation)



Data (6): charged hadrons, d(p)+Au @ 200 GeV

d+Au→ h± *X*   p+Au→ h± *X*

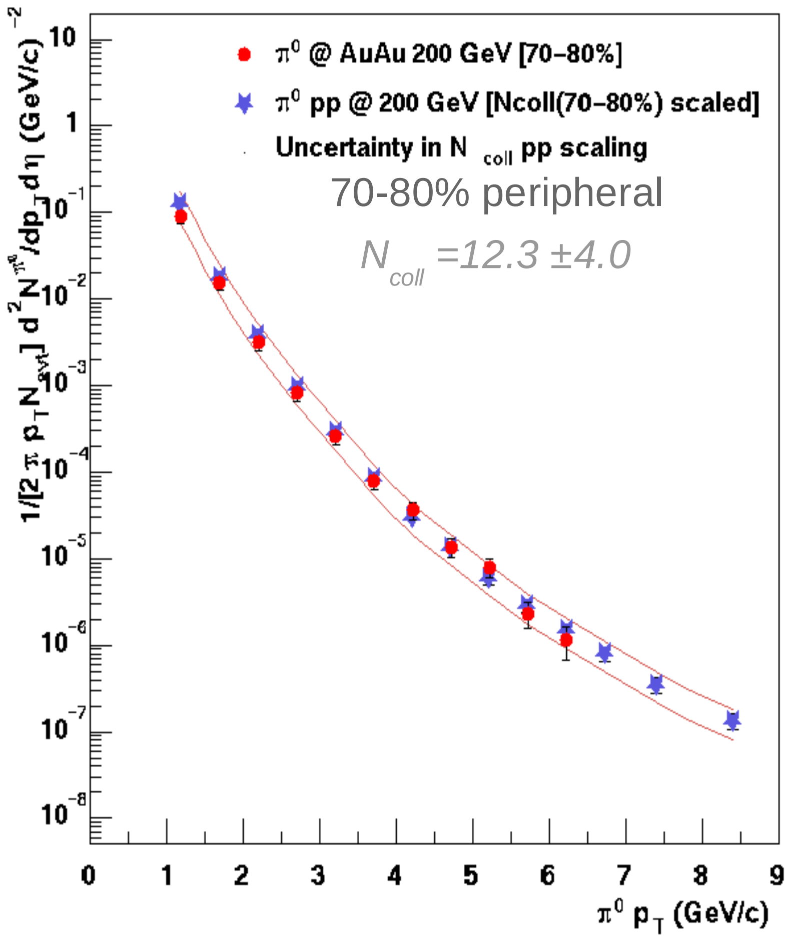


High p_T: AuAu *versus* pp

"hot & dense" QCD medium vis-à-vis QCD "vacuum" ...

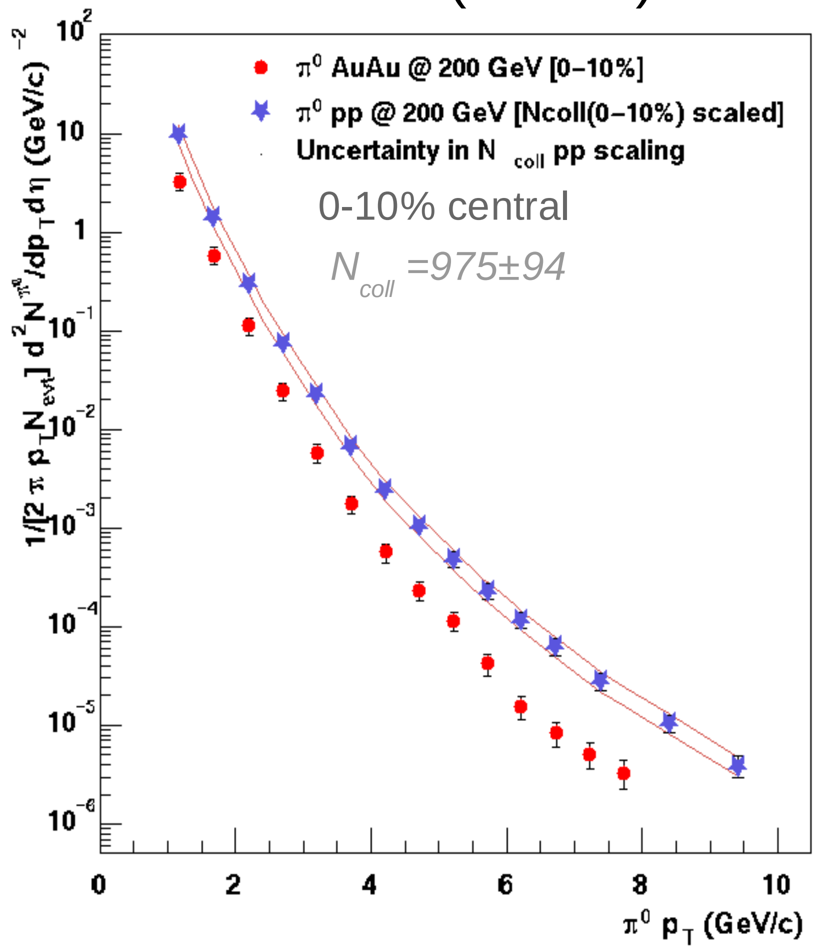
AuAu *vs* pp (neutral pions)

Au+Au→ $\pi^0 X$ (periph)



Peripheral data agree with pp plus collision scaling

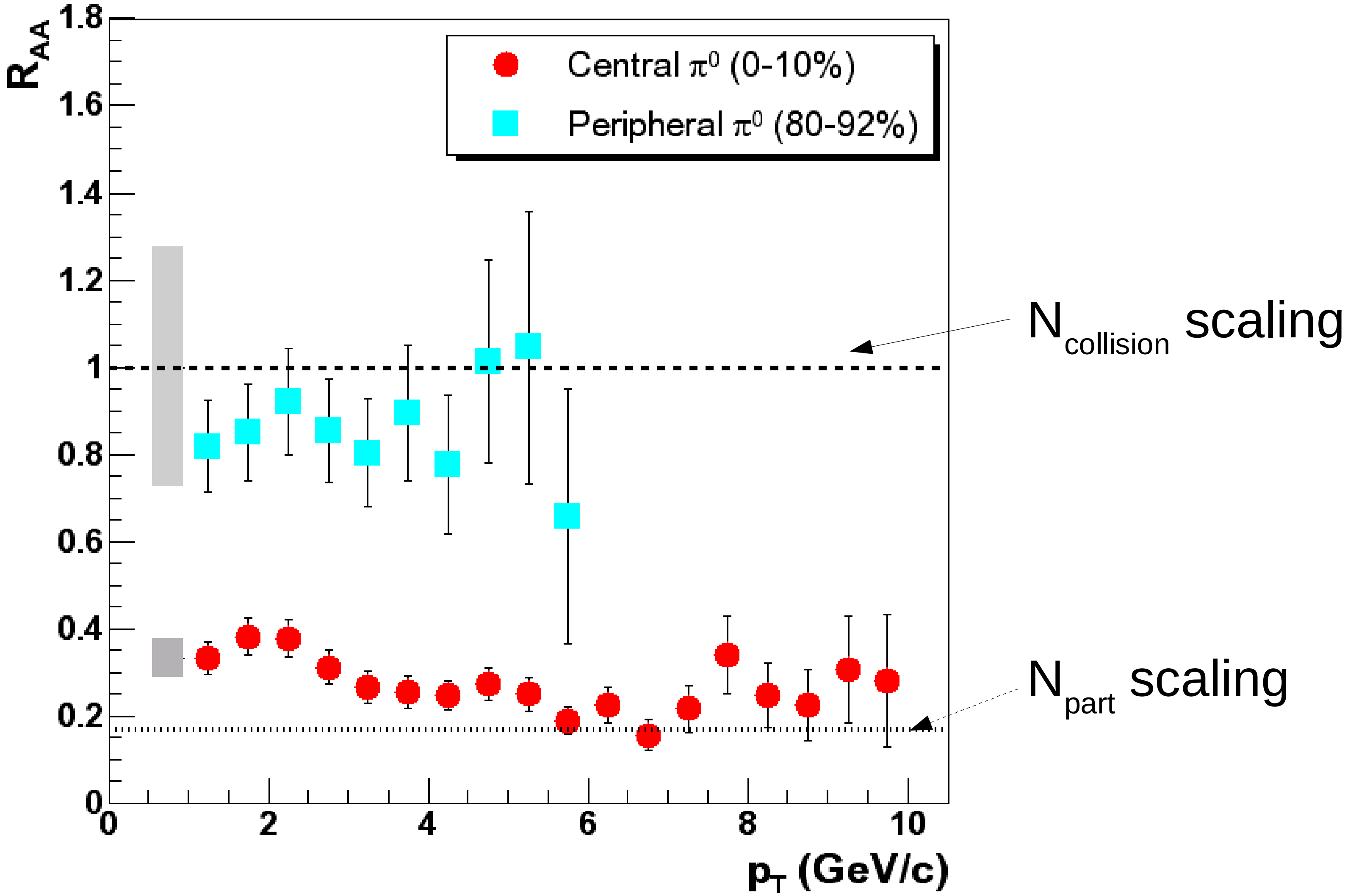
Au+Au→ $\pi^0 X$ (central)



Strong suppression in central AuAu collisions

Nuclear modification factor (π^0): central & periph.

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

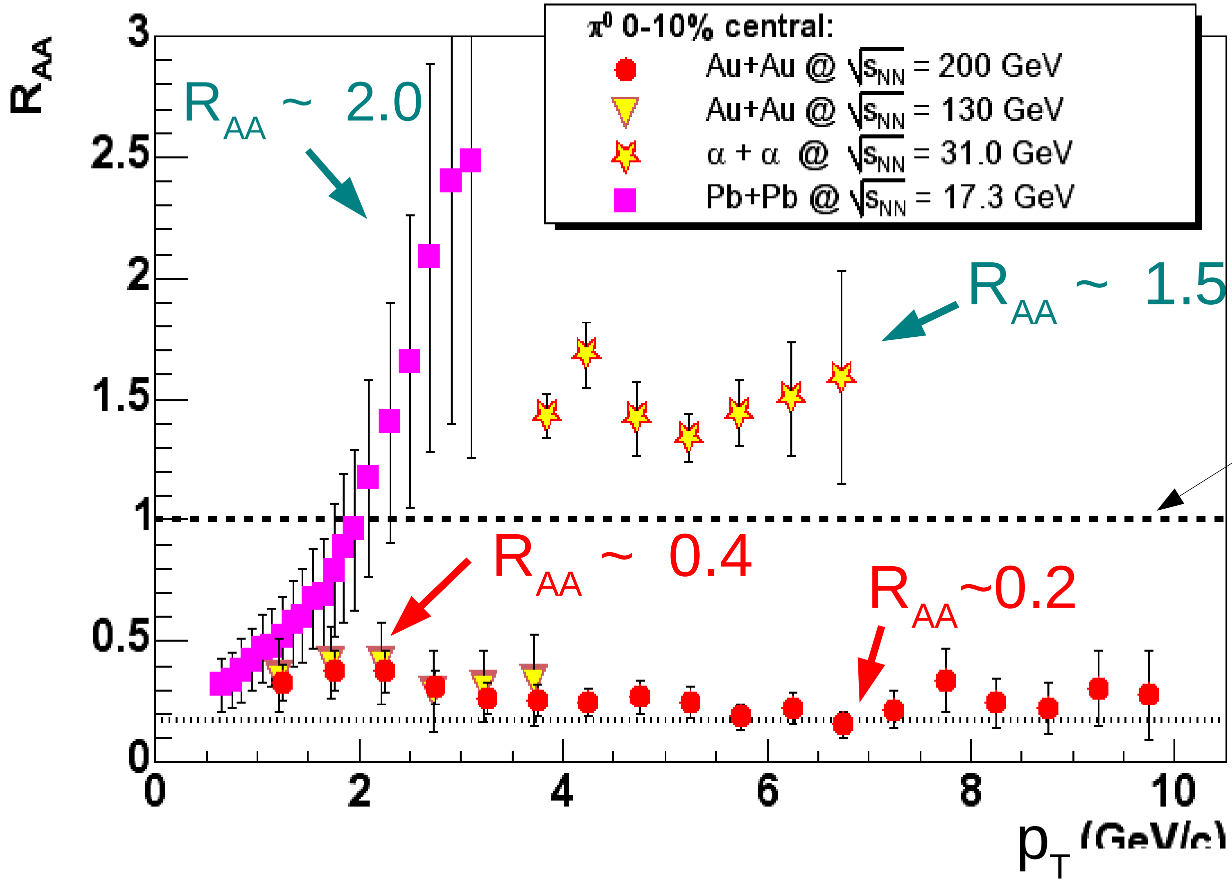


PHENIX Collab.
submitted to PRL,
nucl-ex/0304022

Nuclear modification factor: $\sqrt{s_{NN}}$ dependence

R_{AA} compilation for π^0 in central A+A:

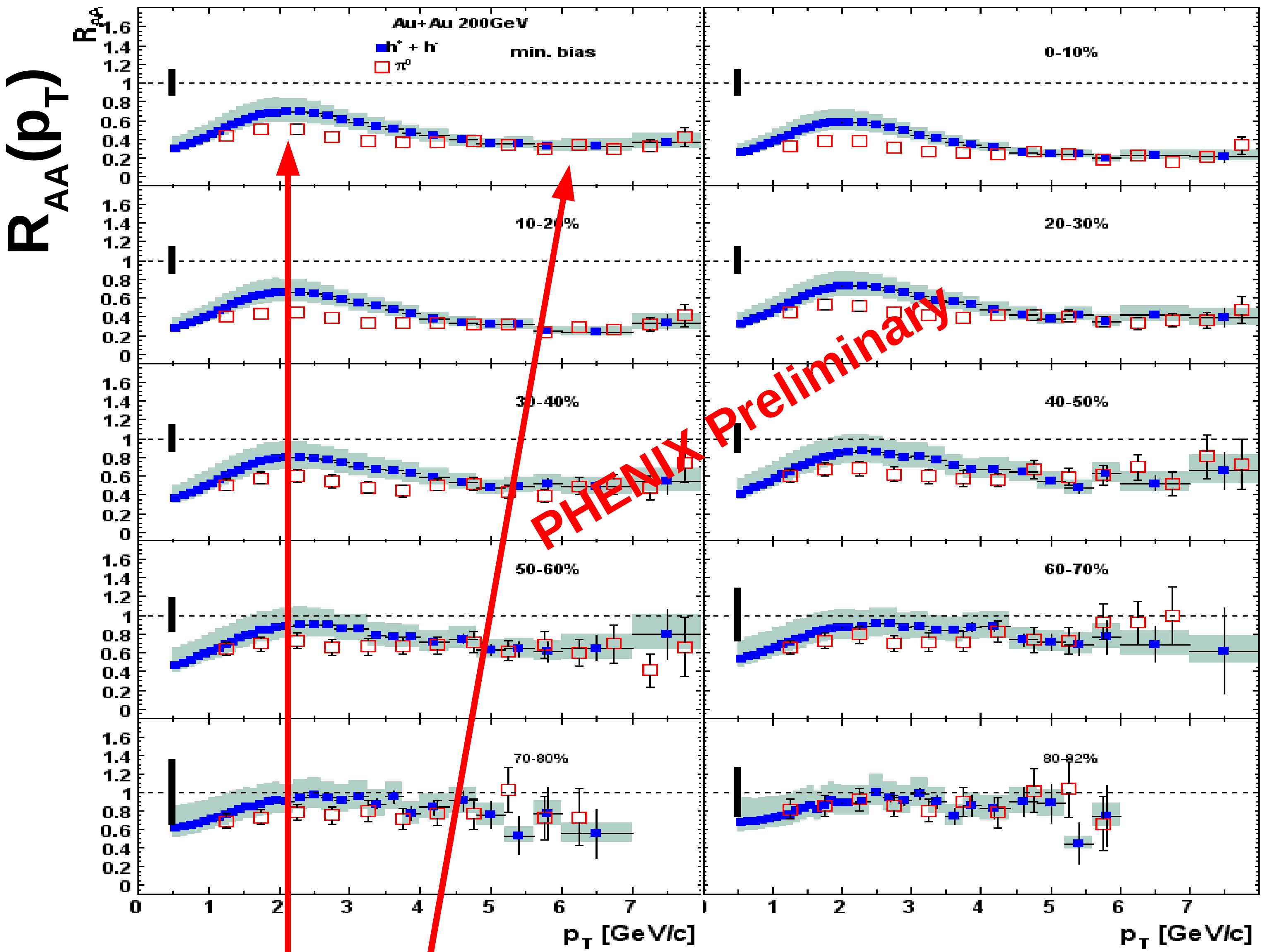
- CERN: Pb+Pb ($\sqrt{s_{NN}}$ ~ 17 GeV), $\alpha+\alpha$ ($\sqrt{s_{NN}}$ ~31 GeV): Cronin enhancement
- RHIC: Au+Au ($\sqrt{s_{NN}}$ ~ 130, 200 GeV): x4-5 suppression with respect to N_{coll}



A.L.S.Angelis PLB 185, 213 (1987)
WA98, EPJ C 23, 225 (2002)
PHENIX, PRL 88 022301 (2002)
PHENIX submitted to PRL, nucl-ex/0304022

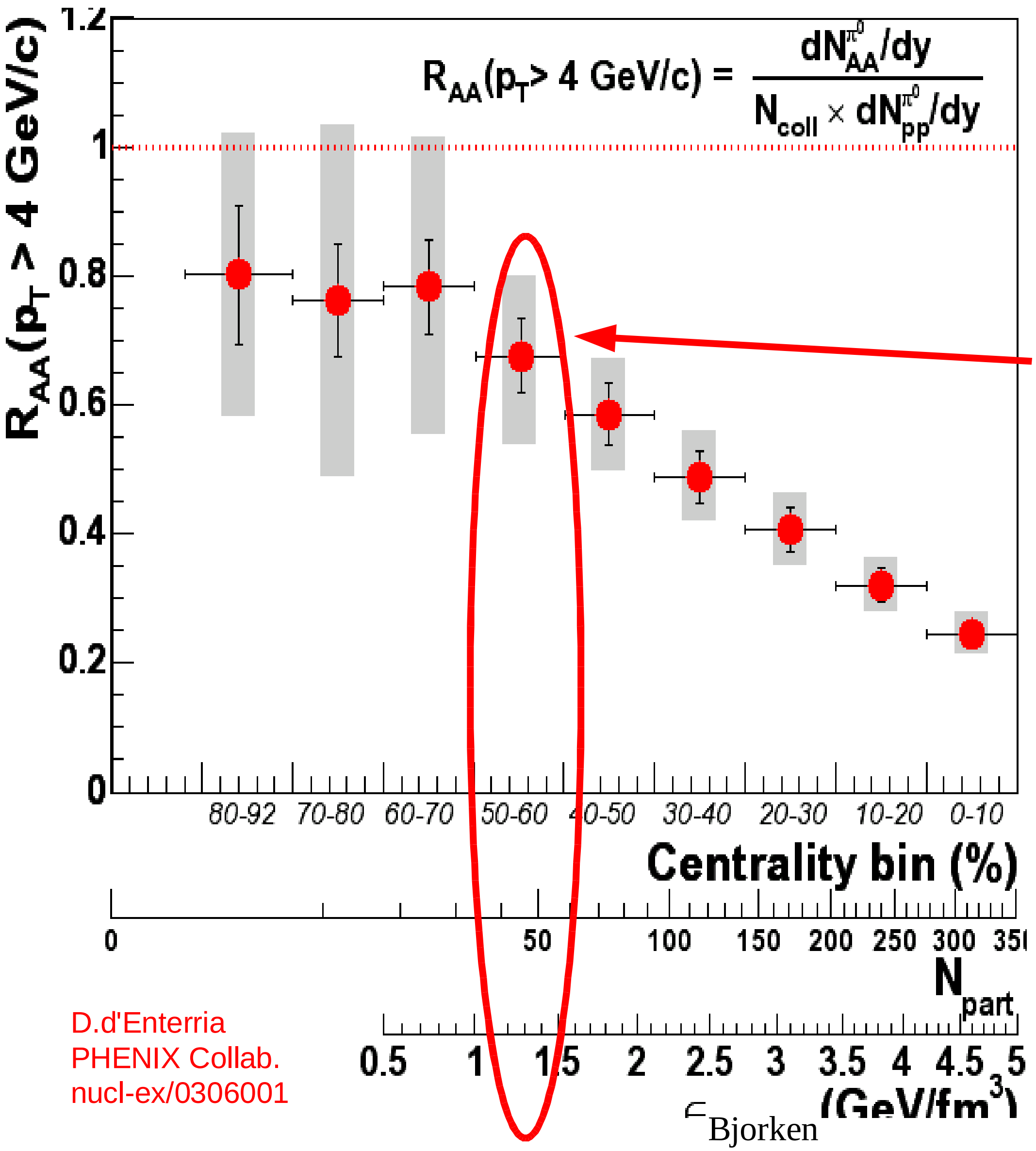
$N_{collision}$ scaling

Nuclear modification factor: charged hadrons vs π^0



- Less suppression for $h^{\pm}$ than for π^0 around p_T ~ 2. GeV/c
- Equal suppression (R_{AA}~ 0.2) above p_T ~ 4-5 GeV/c

Centrality dependence of suppression (1)



D.d'Enterria
PHENIX Collab.
nucl-ex/0306001

π^0 suppression vs N_{part}:

- Peripheral (60-92%) consistent with collision scaling.
- Gradual or abrupt suppression pattern not conclusive at this point.
- $R_{AA} < 1$ (2sigma) for 50-60% centrality: $N_{part} \sim 50 \pm 15$
  (ball-park of parton percolation predictions ?)

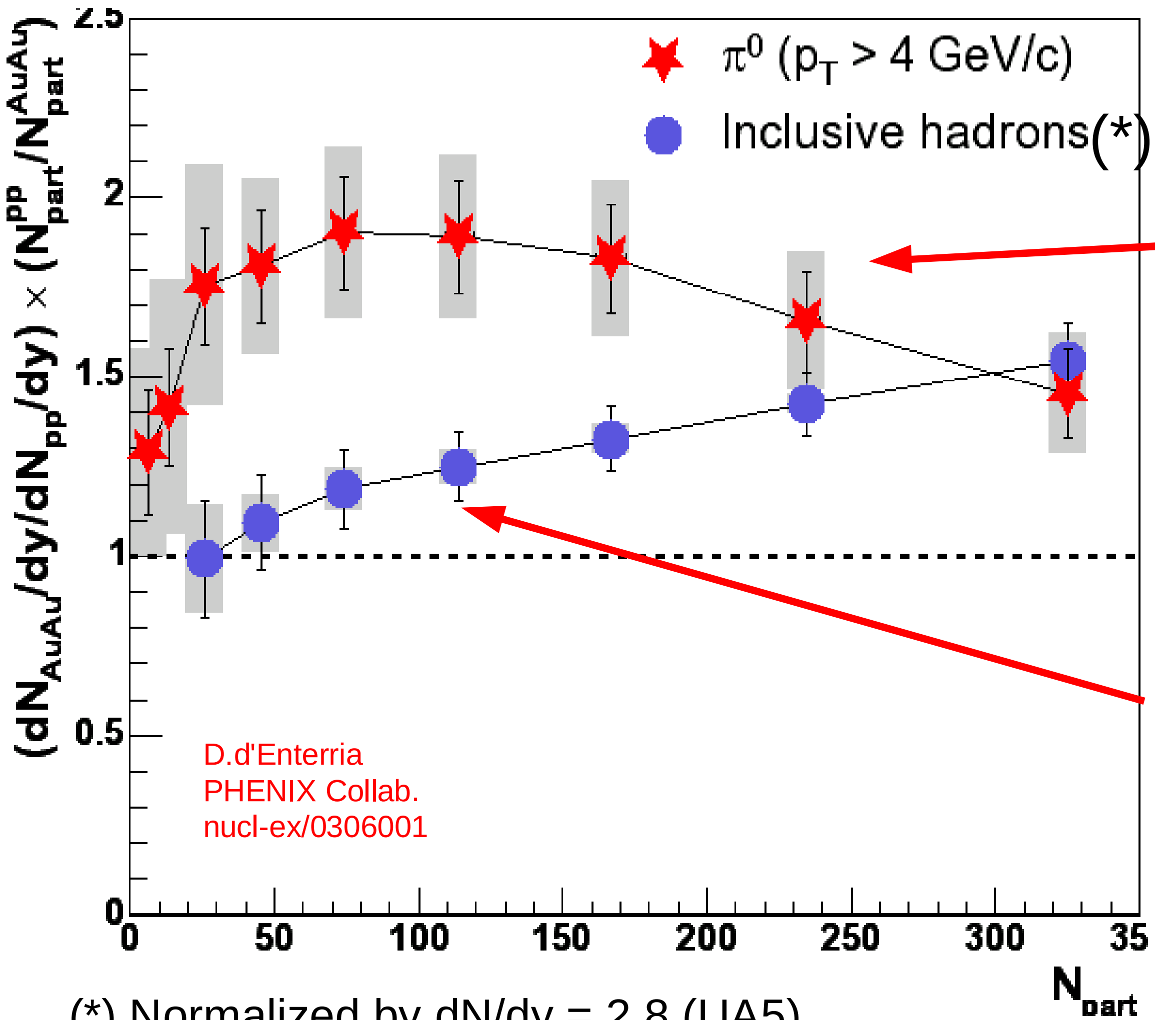
π^0 suppression vs $\varepsilon_{Bjorken}$:

$$\epsilon_{Bj} = \frac{dE_T}{dy}\frac{1}{\tau_0\,\pi R^2}$$ (τ_0 = 1 fm/c)

- E_T measured in EMCal. Overlap area from Glauber.
- Suppression at 50-60% centrality:
  $\varepsilon_{Bjorken} \sim 1.2\ GeV/fm^3$

Centrality dependence of suppression (2): N_{part} scaling ?

- Does high p_T production show N_{part} scaling ?
- If yes, is it the same N_{part} scaling as observed in soft particle production ?



(*) Normalized by dN/dy = 2.8 (UA5)

High p_T π^0 yields vs N_{part}:

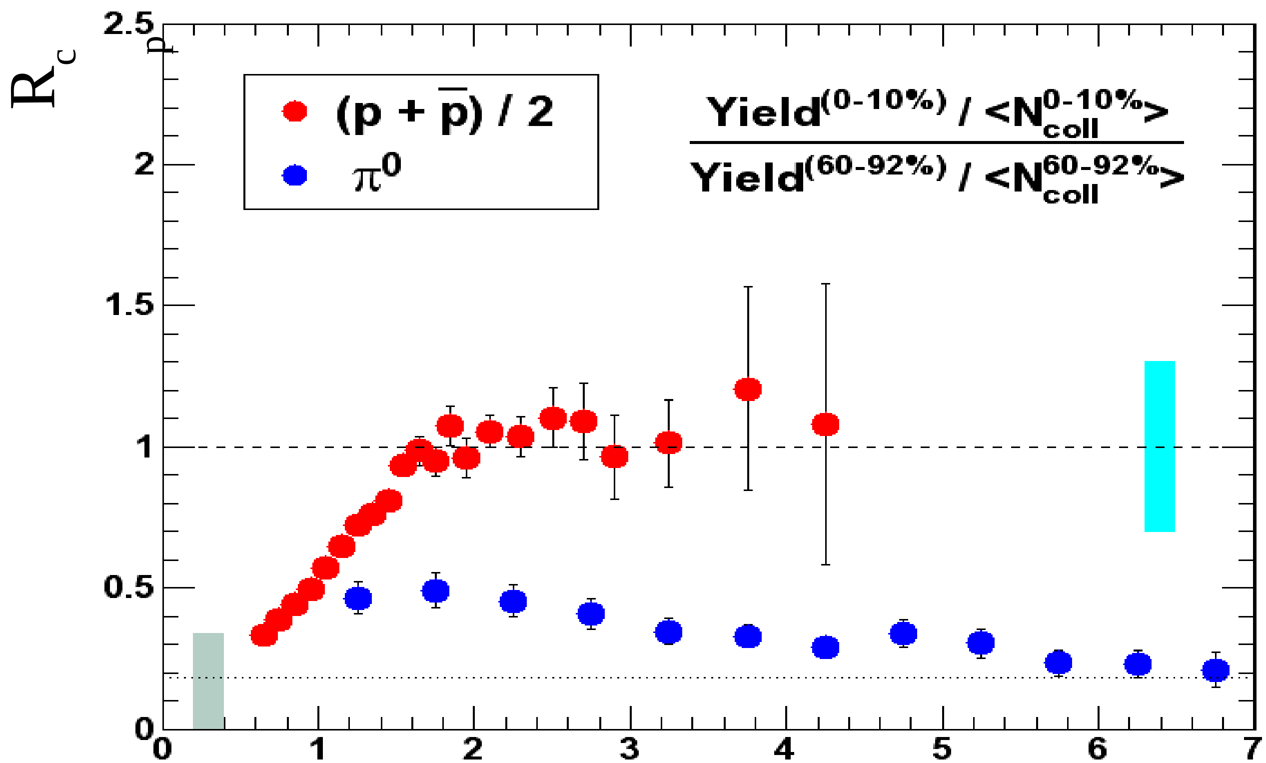
- No true N_{part} scaling: R_{AA}^{Npart} >1
- Fast increase with centrality, then gradual decrease.

Inclusive hadron mult. vs N_{part}:

- Very approx. N_{part} scaling.
- Steady increase with centrality

Hadron composition at high-p_T (1): R_{AA} (p) vs $R_{AA}(\pi)$

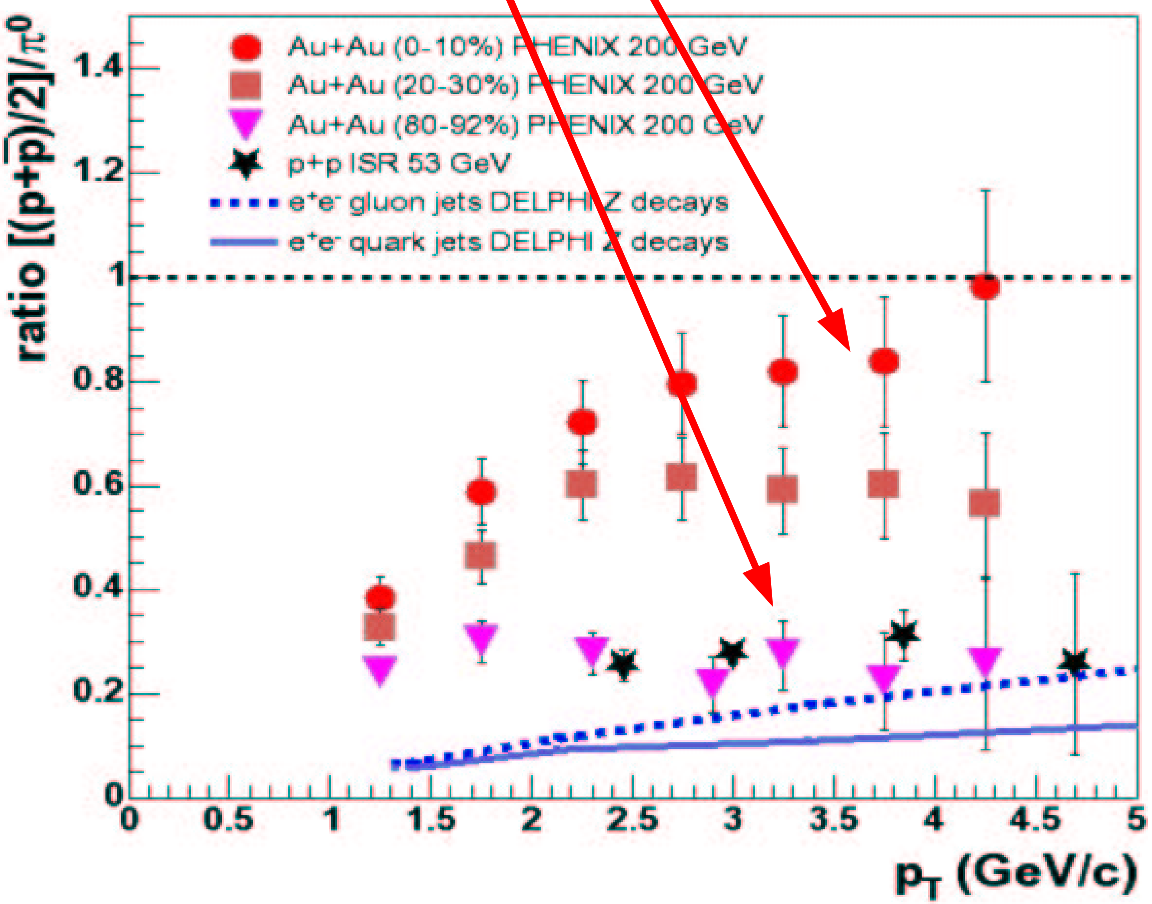
- Protons (antiprotons) not suppressed in central Au+Au for p_T < 4.5 GeV/c
- Ratio central/periph ~ $R_{AA} \approx 1$ (N_{coll} scaling holds for baryons).
  - *(consistent with observed larger R_{AA} for $h^{\pm}$ than for π^0 in the same p_T range).*
  - Different production mechanisms for baryons and mesons in the intermediate p_T range ...



PHENIX Collab.
Submitted to PRL
nucl-ex/0305036

Hadron composition at high-p_T (2): p/π ratio

- Pronounced centrality dependence of p/π ratio.
- Central colls.: baryon/meson ~ 0.8 for p_T > 2 GeV/c at variance with perturbative production mechanisms (favour lightest meson).
- Periph. colls. baryon/meson ~ 0.3 as in p+p,pbar (ISR,FNAL) and in e+e- jet fragmentation

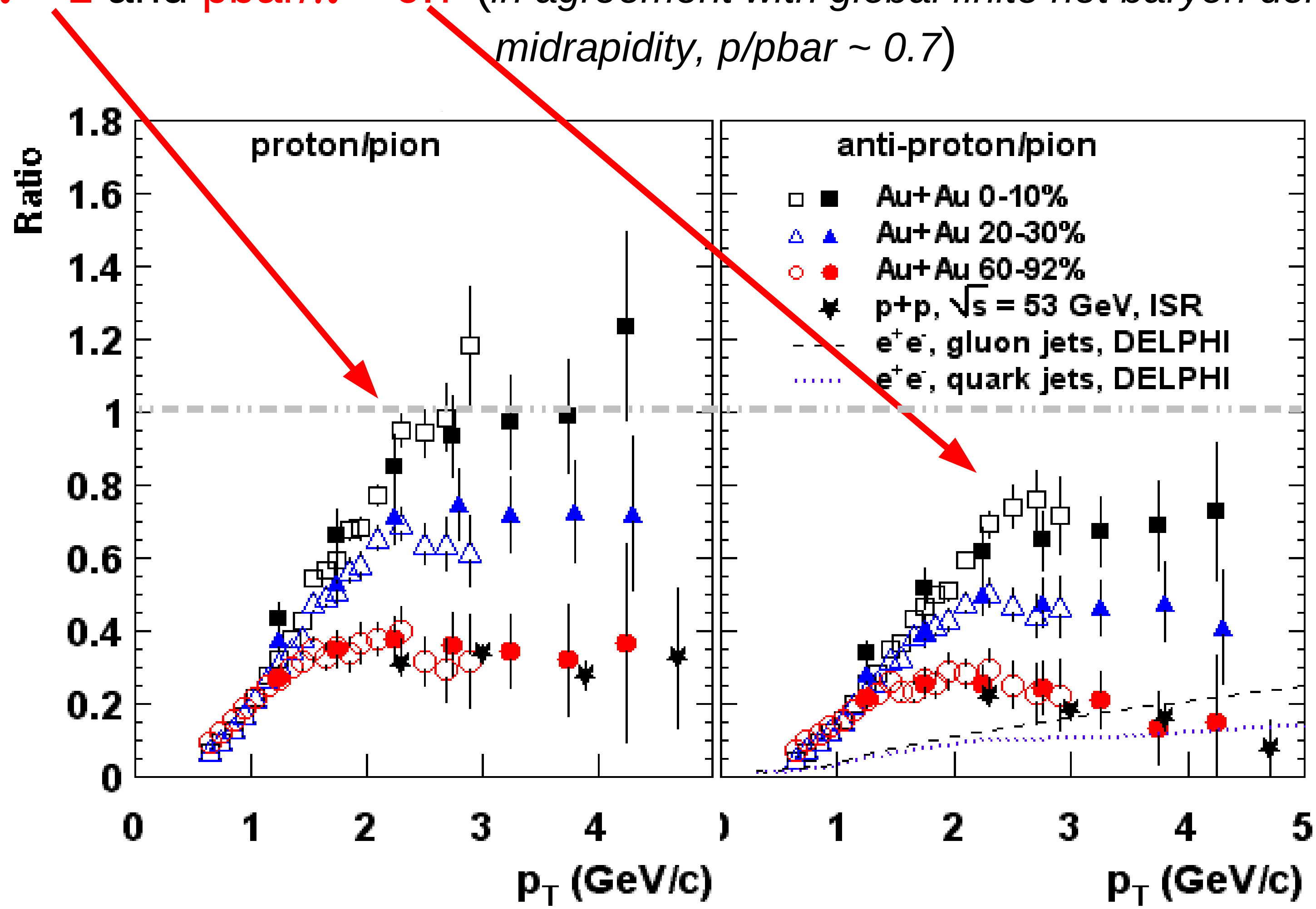


PHENIX Collab.
Submitted to PRL
nucl-ex/0305036

Hadron composition at high-p_T (3): p,pbar/π ratios

- Same info as former slide but now individually for p and pbar ...
- Enhanced baryon production in central Au+Au:

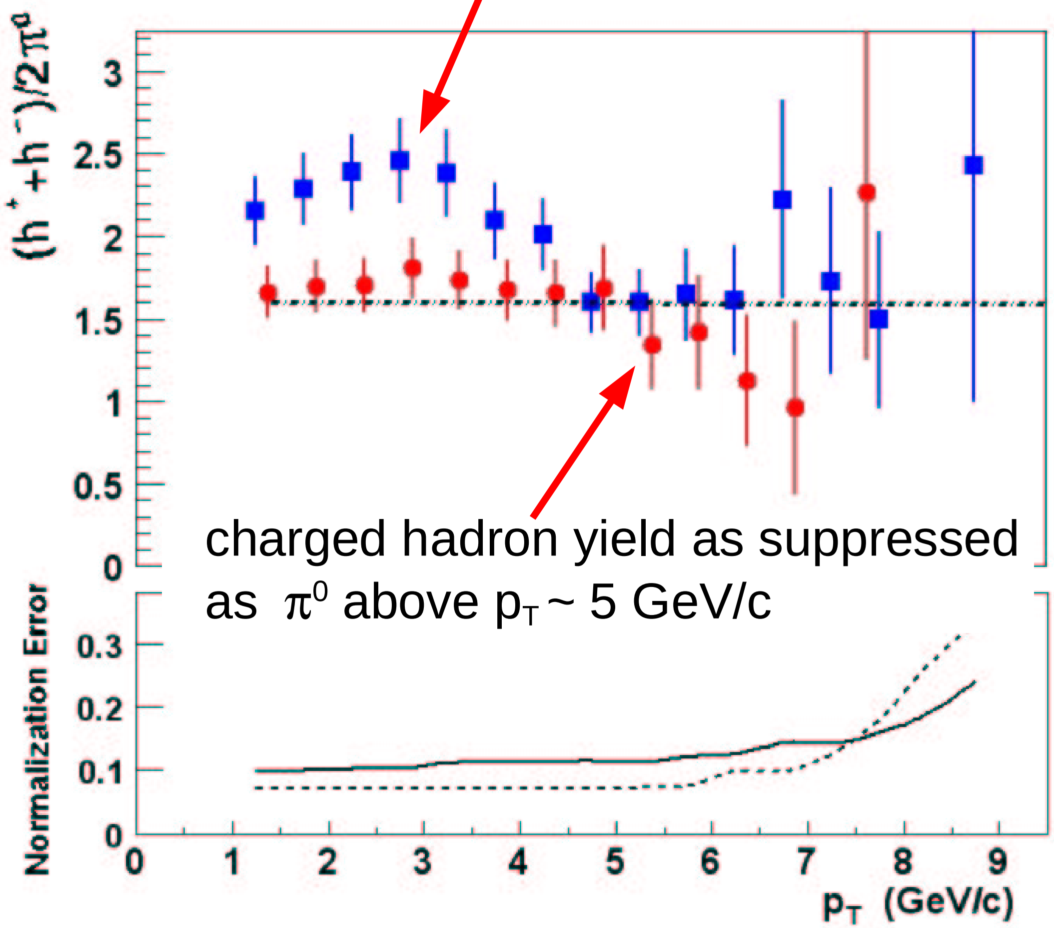
  p/π ~ 1 and pbar/π ~ 0.7 (*in agreement with global finite net baryon density at midrapidity, p/pbar ~ 0.7*)

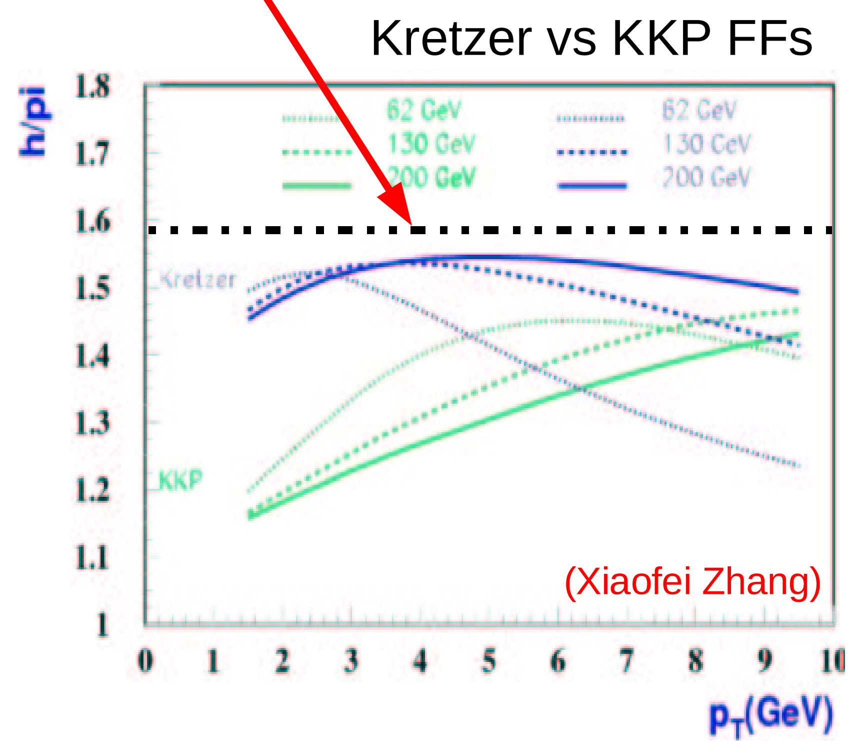


PHENIX Collab.
Submitted to PRL
nucl-ex/0305036

Hadron composition at high-p_T (4): h/π ratio

- Central colls.: h/p ~ 2.5 at intermediate p_T's (enhanced baryon production)
- Peripheral colls.: h/p ~ 1.6 as in p+p (perturbative ratio)

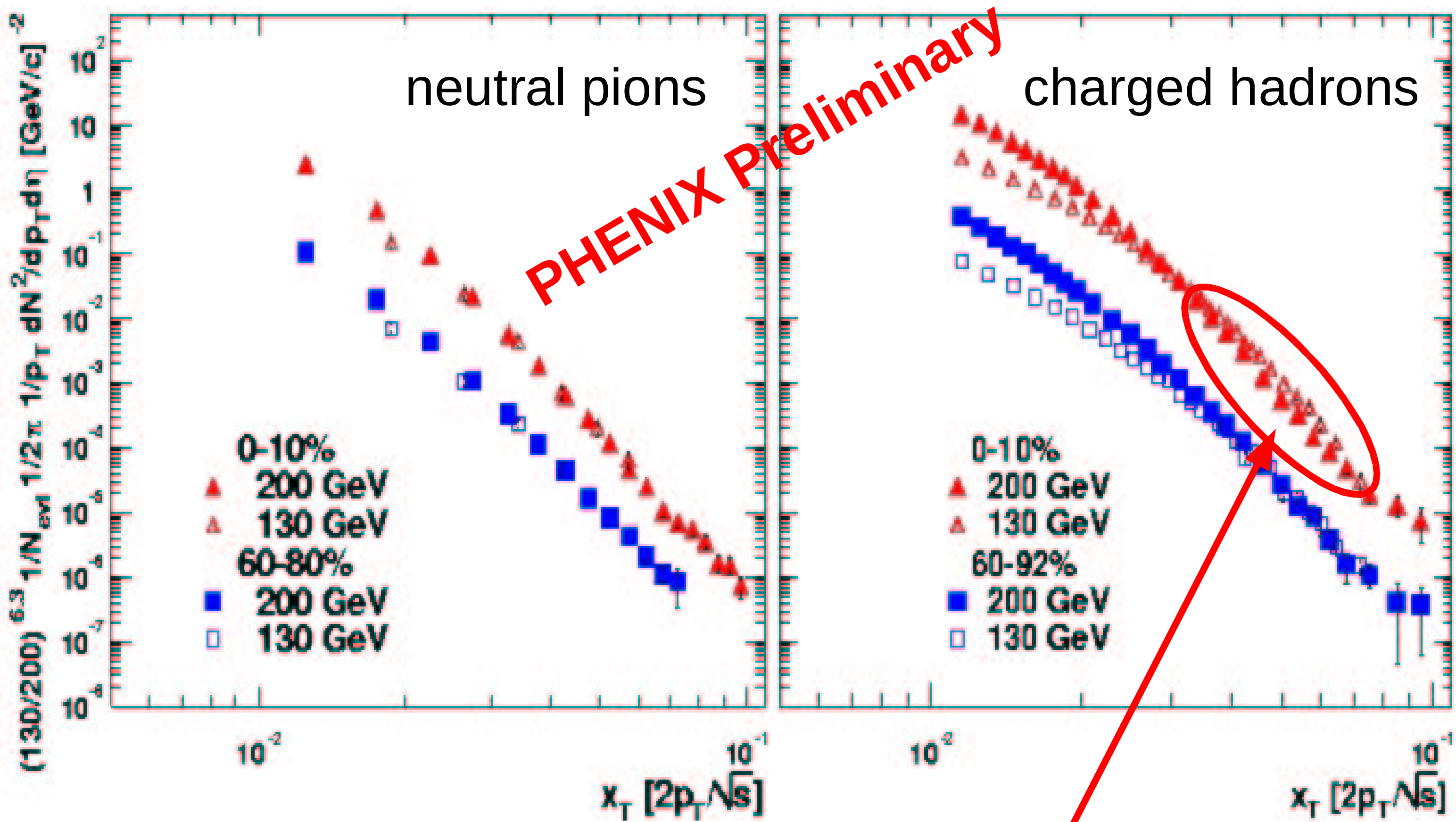




PHENIX Collab.
Submitted to PRL
nucl-ex/0305036

- Since $h^\pm = \pi^\pm$ + p(pbar) + $K^\pm$ ⇒ proton (antiproton) non perturbative enhancement limited to p_T < 5 GeV/c

x_T scaling in Au+Au collisions

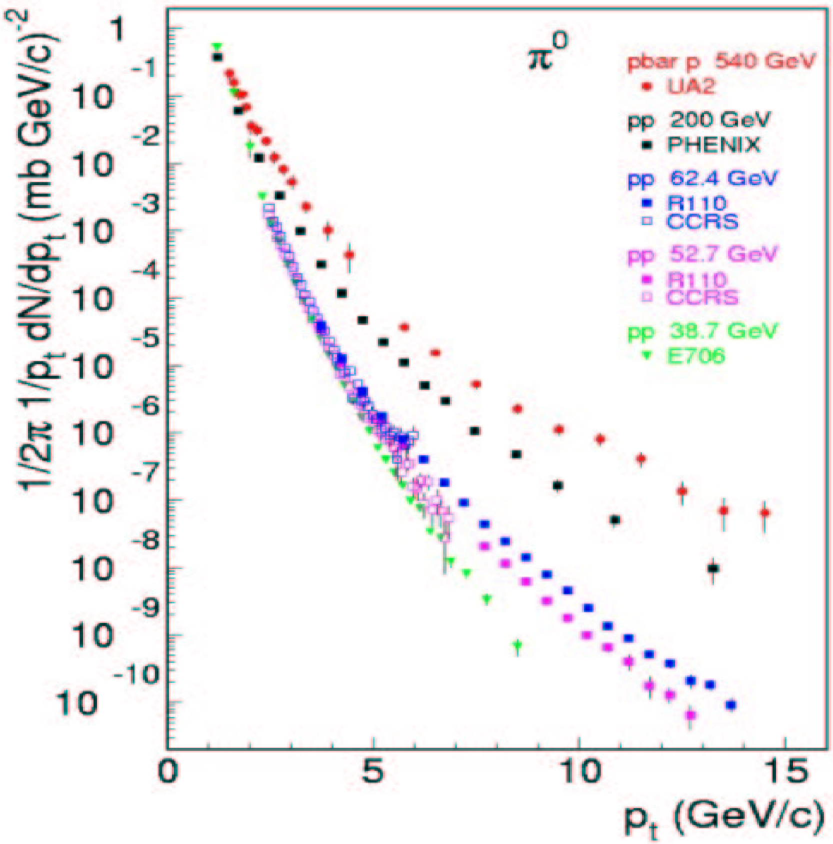


From pQCD: $\sqrt{s}^{\,n(x_T,\sqrt{s})} \times E\dfrac{d^3\sigma}{dp^3} = G(x_T)$, with n(√s) = 6.3 (as in p+p data)

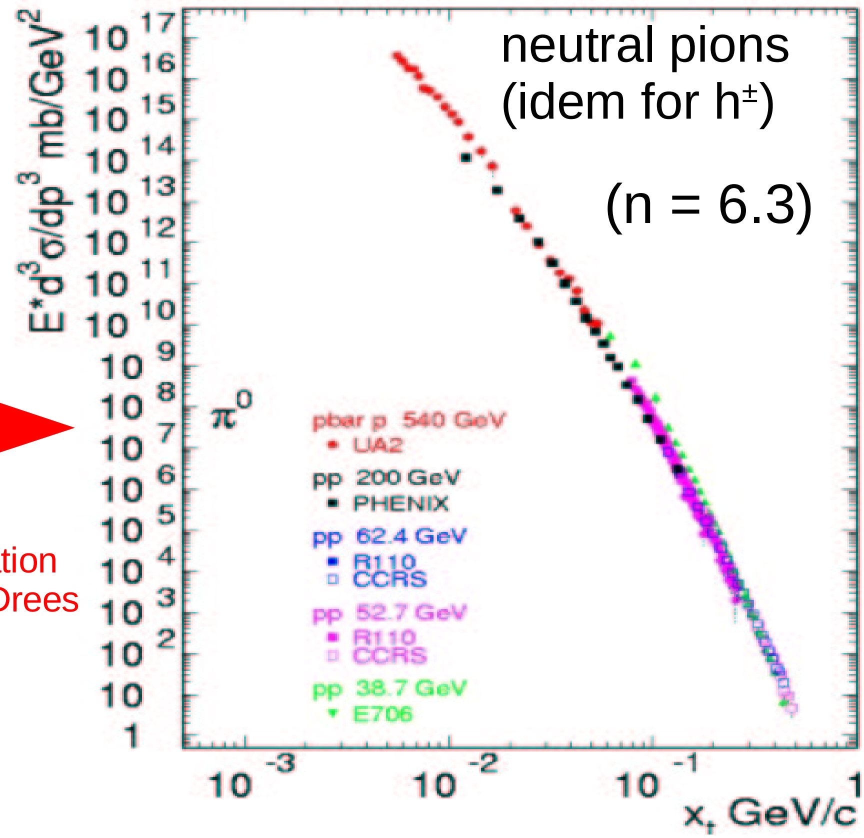
- x_T scaling holds (for x_T>0.03, with same power-law as p+p data) for π^0 (central & peripheral) and for $h^\pm$ (peripheral): hard-scattering-like √s dependence of yields
- x_T scaling does not seem to hold for $h^\pm$ (central) → non-perturbative effects

(x_T scaling in hadronic collisions)

- Hard scattering cross-sections can be factorized in 2 terms: f(√s) x g(x_T)



Compilation by Axel Drees



$$E\frac{d^3\sigma}{dp^3} = \frac{1}{p_T^n}F(x_T) \quad \text{where} \quad x_T = 2p_T/\sqrt{s}$$

PDF & FF effects which scale as the ratio of p_T at diff. √s are all included in F(x_T)

Power-law exponent: n(√s) = 4-- 8

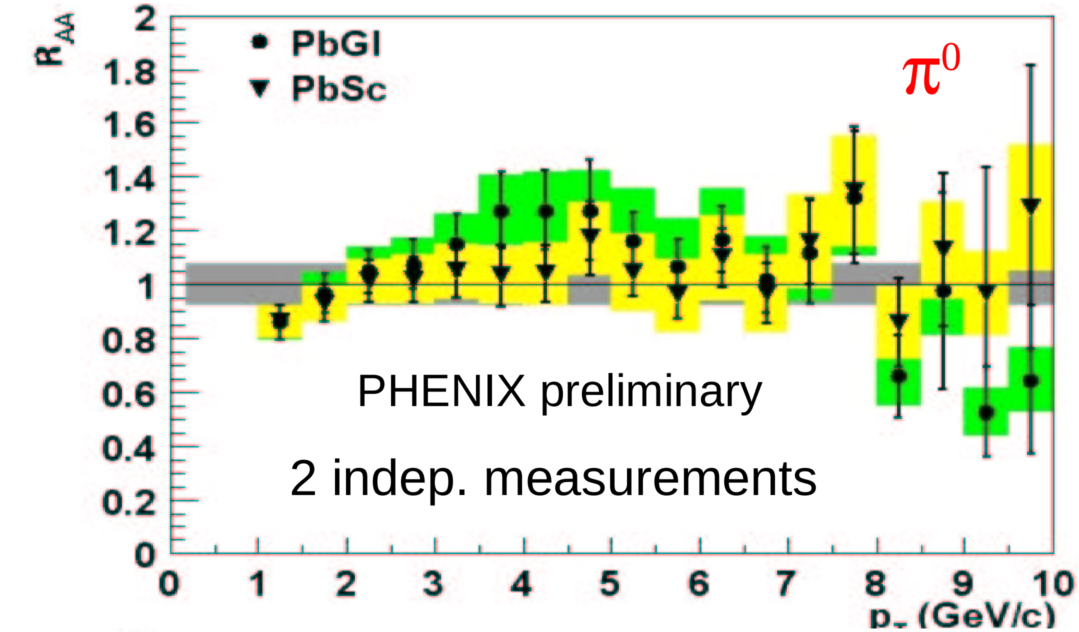
$$E\frac{d^3\sigma}{dp^3} = \frac{1}{\sqrt{s}^{\,n(x_T,\sqrt{s})}}G(x_T) \quad \Rightarrow \quad \sqrt{s}^{\,n(x_T,\sqrt{s})} \times E\frac{d^3\sigma}{dp^3} = G(x_T)$$

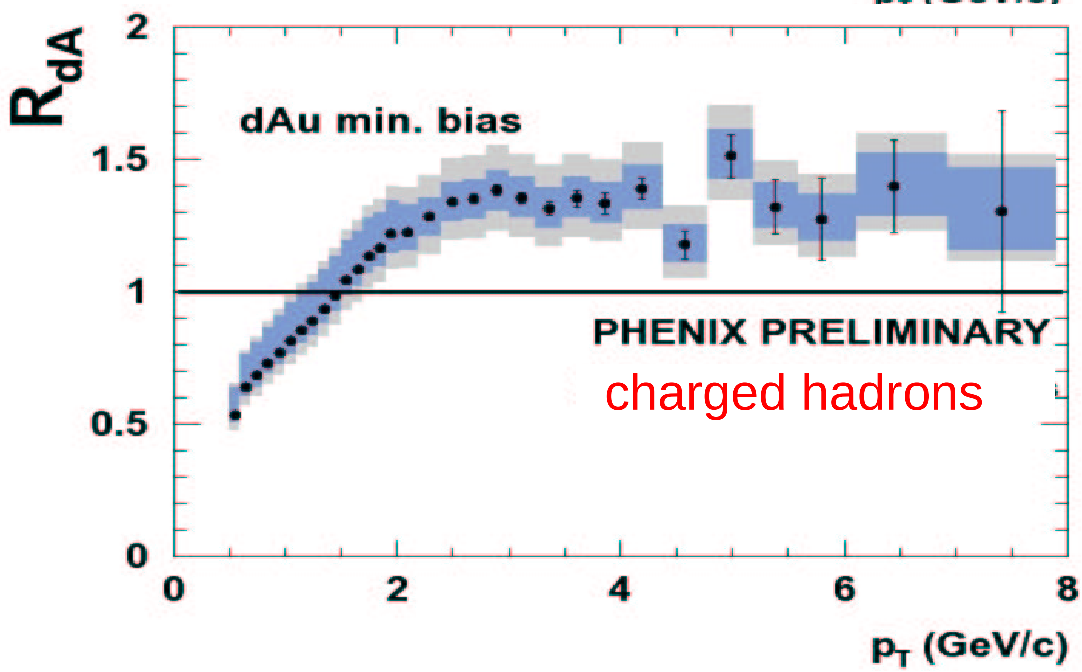
all √s dependence here

high p_T: d+Au *versus* p+p

"cold" QCD medium vis-à-vis QCD "vacuum" ...

d+Au (min. bias) nuclear modification factor (I)





No suppression observed in min. bias d+Au reactions (N_{coll}= 8.4±0.4)

- Neutral pions: R_{dAu} ~ 1.1
  (Slight enhancement with respect to collision scaling)

  Apparent decreasing trend above 8 GeV/c

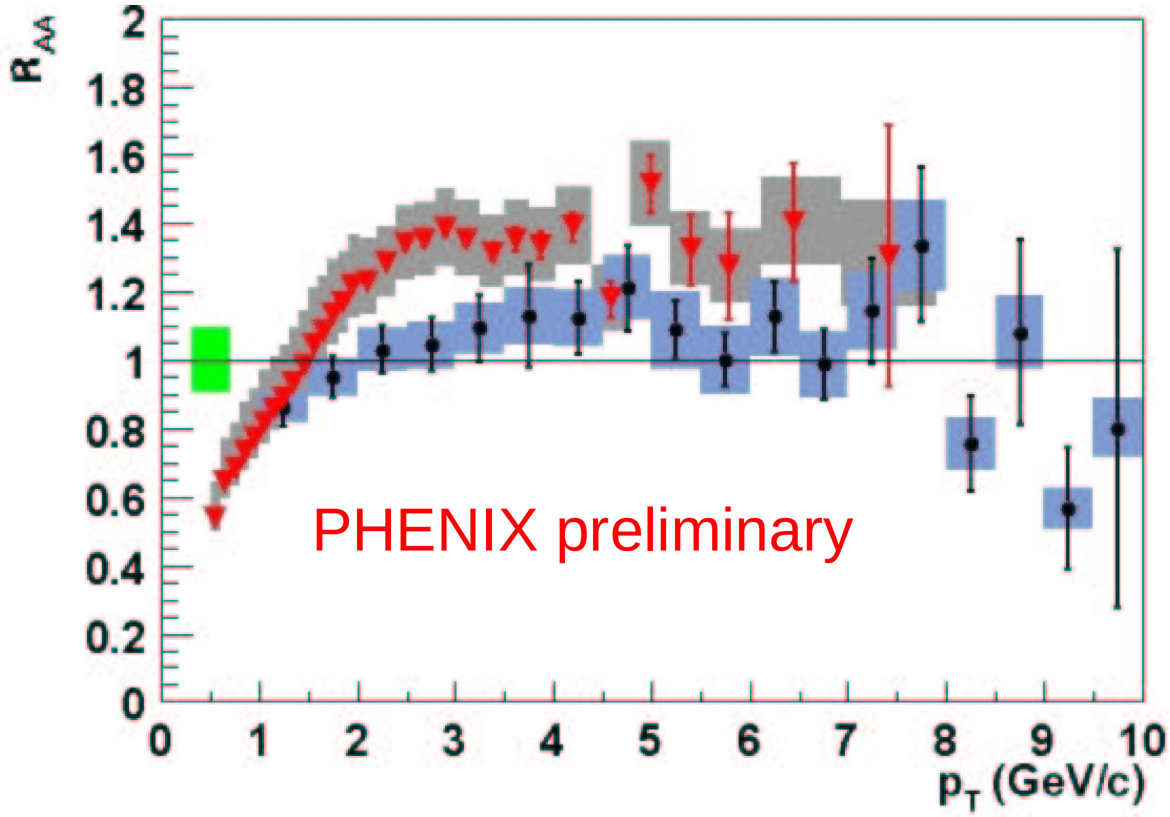
- Charged hadrons: R_{dAu} ~ 1.4
  (Larger enhancement)

  ~ flat between 3 – 8 GeV/c

(All errors are 1-sigma)

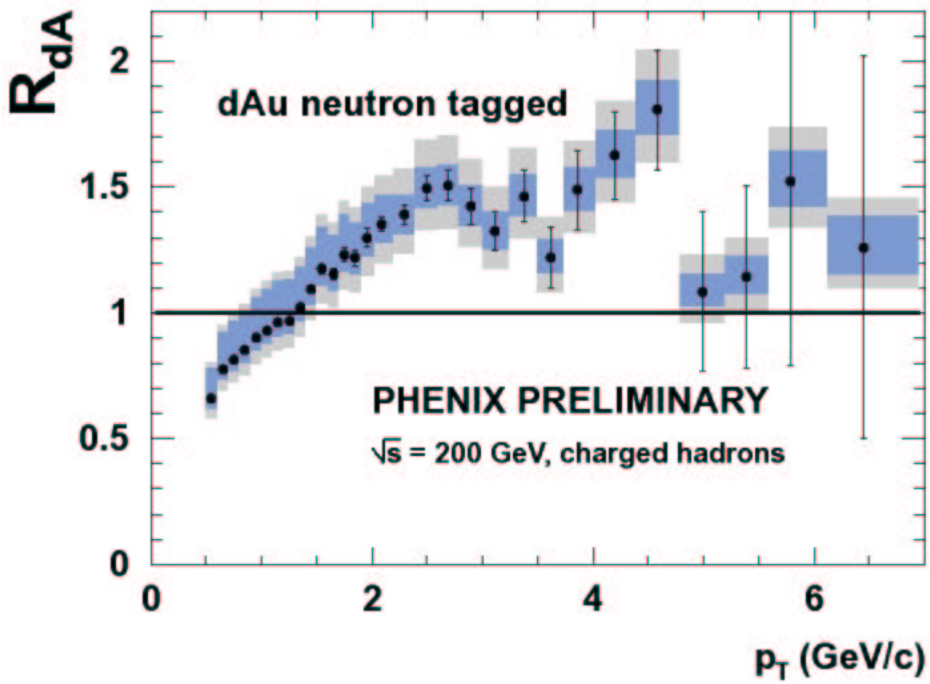
d+Au (min.bias) nuclear modification factor (II)

- Combined R_{dAu} for charged hadrons and π^0 :

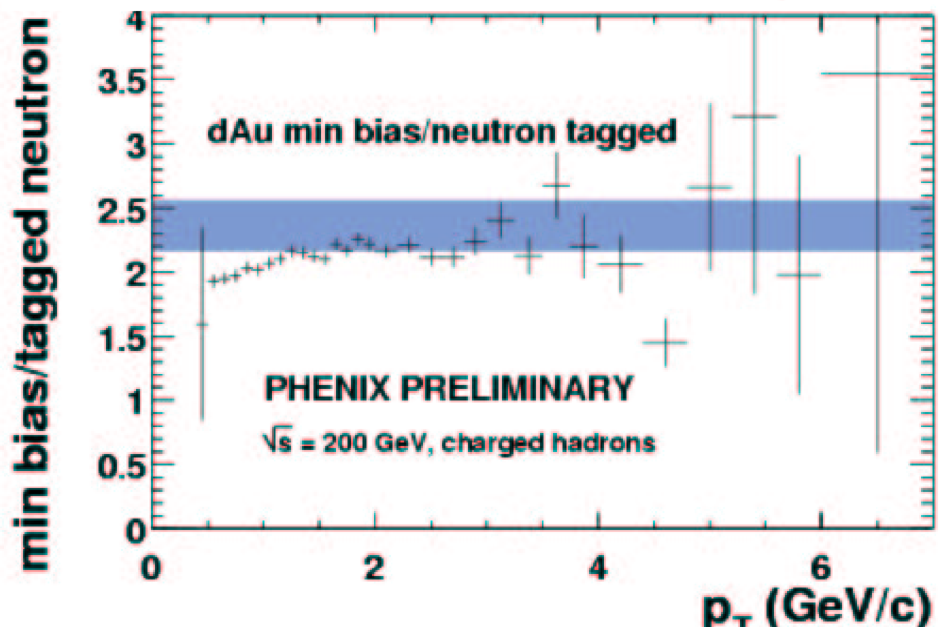


- d+Au results at RHIC clearly reminiscent of p+A Cronin effect
- No shadowing or strong saturation of Au PDF.

p+Au nuclear modification factor



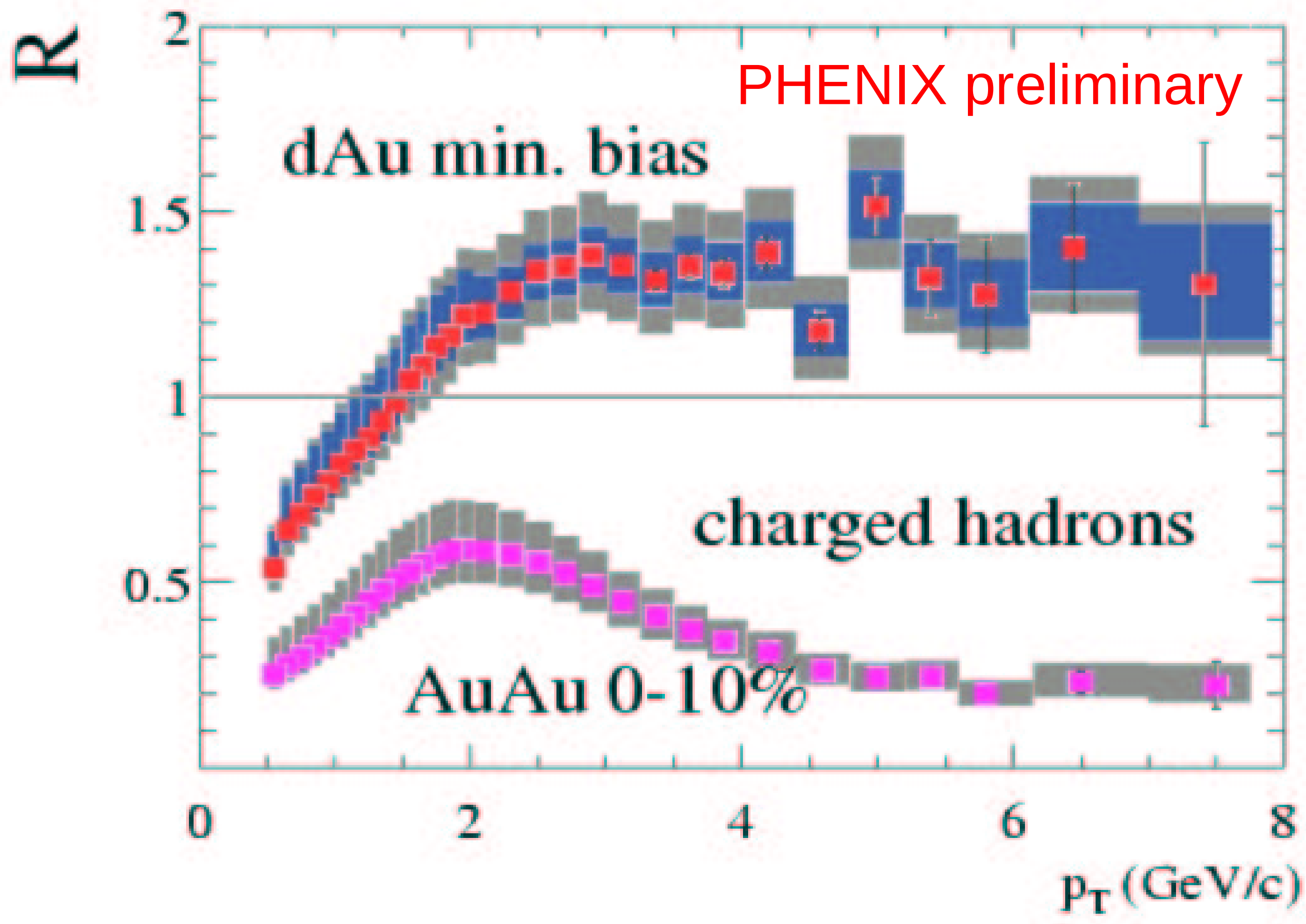
- No suppression observed either in p+Au reactions (N_{coll}= 3.6±0.25)



- Apparent small centrality dependence of nuclear effects:

d+Au / p+Au ~ N_{coll}(d+Au)/N_{coll}(p+Au) ~ 2.4

Nuclear modification: d+Au(min.bias) vs Au+Au(central)



- Conclusion: Au+Au suppression not due to a “cold” nuclear matter effect.

High-p_T @ RHIC: theory confronting data

- **APPROACH "A"** (pQCD, factorization theorem):

Step 1: pQCD *(NLO or LO+K-factor) = PDFs + scatt. matrix + FFs*
Step 2: pQCD + nPDF (shadowing) + p_T broadening (Cronin)

✔ *Peripheral data explained*

Step 3: pQCD + initial-state nuclear effects + Parton energy loss

- Energy loss 1: BDMPS (LPM, thick plasma)
- Energy loss 2: GLV (LPM, thin plasma)
- Energy loss 3: HSW (modified FFs), (*g* radiation + absorption)

✔ *Goal: explain central colls. (magnitude of quench, p_T dependence)*

Step 4: pQCD + IS nuc. effects + Energy loss + parton recombination

✔ *Goal: explain baryon-meson diff. in central colls.*

- **APPROACH "B"** ("classical" CD):

- Step 1: CGC (gluon saturated nuclear wave function: MLV, "evolved")
- Step 2: glue + glue collisions: gg $\rightarrow$ g
- Step 3: Gluon fragmentation (FFs)

✔ *Goal: explain deficit, N_{part} scaling ...*

"QGP" models (FSI parton energy loss) vs. data (I)

✔ Foreword: Jet quenching is a true prediction of QGP models.

✔ Magnitude of Au+Au suppression → properties of dense medium:

- High opacities: <n> = $L/\lambda \approx 3 - 4$
- Large initial gluon densities: $dN^g/dy \sim 800\text{-}1200$
- Transport coefficients: $\langle q_0 \rangle \sim 3.5$ GeV/fm^2
- Radiative energy losses: $dE/dx \approx 0.25$ GeV/fm (expand.) ≈ 14 GeV/fm (static)

✔ Centrality dependence of Au+Au suppression (detailed comparison of quenching vs N_{part} needed).

✔ x_T dependence of Au+Au yields → indication of perturbative (hard) mechanisms (modulo baryons in central reactions).

✔ No suppression in d+Au collisions.

"QGP" models (FSI parton energy loss) vs. data (II)

- p_T dependence of Au+Au suppression → not described in 1st instance:
  - Additional nuclear effects needed to "flatten" LPM R_{AA} (though they are probably justified given the d+Au results)
- √s dependence of Au+Au suppression clear ?
  - Why there is no jet quenching observed in Pb+Pb @ SPS if $dN^g/dy \sim 500$?
- Particle species dependence of Au+Au suppression → not described in 1st instance:
  - Additional non-perturbative final state effects (quark recomb., baryon junctions, others ?) needed.

ISI gluon saturation ("CGC") models vs. data

✗ Caveat: High p_T at midrapidity at RHIC is above Q_s ~ 1-2 GeV/c (straight application of CGC questionable in first instance).

✔ Magnitude of Au+Au suppression → saturated Au wave function (Kharzeev *et al.*). But: no suppression expected by Baier *et al.*

✔ Centrality dependence of Au+Au suppression → N_{part} scaling -like observed (modulo quantitative details).

✗ Some deficit expected in d+Au collisions (Kharzeev *et al.*).

✔ d+Au Cronin enhancement built in the initial wave function (Baier *et al.*). Similar conclusions by J.Jalilian too (though no calculations at y = 0).

- Somewhat confusing interpretation of Au+Au, d+Au results. More converging agreement needed ...

FSI hadronic reinteractions model vs. data

✗ Caveat 1: Very dense hadronic medium scenarios should result in partonic scenarios by definition.

✗ Caveat 2: Really quantitative calculations non-existent (more realistic description of hadronic expanding medium needed).

✔ Magnitude of Au+Au suppression → dense hadronic medium:

- High opacities: $\langle n \rangle = L/\lambda \approx 2$

- p_T dependence of Au+Au suppression → apparently described **but** with counter-intuitive arguments (due to the assumed formation time ansatz).

- Possible "control" calculations (not observed in data but expected in hadronic medium description): charm meson energy loss, suppressed near-side jet correlation, ...

High p_T @ PHENIX: Summary (I)

- A wealth of experimental measurements:

1. Identified mesons – π^0:
   - Au+Au @ 130 GeV (2 centralities, $p_T^{max} \approx$ 3.5 GeV/c), PRL 2001
   - Au+Au @ 200 GeV (10 centralities, $p_T^{max} \approx$ 10. GeV/c), submitted to PRL
   - p+p @ 200 GeV ($p_T^{max} \approx$ 14. GeV/c), submitted to PRL
   - d+Au @ 200 GeV (p+Au via n-tagged too, $p_T^{max} \approx$ 10. GeV/c), preliminary
2. Inclusive charged hadrons – $h^{\pm}$:
   - Au+Au @ 130 GeV (6 centralities, $p_T^{max} \approx$ 5. GeV/c), PRL 2002
   - Au+Au @ 200 GeV (10 centralities, $p_T^{max} \approx$ 10. GeV/c), submitted to PRL
   - d+Au @ 200 GeV (p+Au via n-tagged too, $p_T^{max} \approx$ 8. GeV/c), preliminary
3. Identified baryons – p, pbar:
   - Au+Au @ 130 GeV (2 centralities, $p_T^{max} \approx$ 3.5 GeV/c), PRL 2002
   - Au+Au @ 200 GeV (10 centralities, $p_T^{max} \approx$ 4.5 GeV/c), submitted to PRL

4. Electrons: 130, 200 GeV ($p_T^{max} \approx$ 4. GeV/c): PRL 2002, QM2002

High p_T @ PHENIX: Summary (II)

- Central Au+Au collisions:
  - Strong suppression (factor ~ 4-5) of π^0 and $h^\pm$ (with respect to N_{coll} scaling) above p_T~ 4 GeV/c.
  - Flat p_T dependence of suppression above ~4 GeV/c.
  - Very different behaviour than at lower $\sqrt{s}$ (high p_T enhancement).
  - Suppression pattern seemingly gradual with centrality (not yet settled).
  - Departure from N_{coll} scaling at a 2-sigma level over 50-60% centrality class: N_{part} ~ 50, $\varepsilon_{Bjorken}$ ~ 1.2 GeV/fm^3.
  - No true N_{part} scaling.
  - No apparent suppression of (anti)protons up to ~4 GeV/c: "anomalous" p/π ~ 0.8 ratio >> than in p+p and e+e- jet fragmentation.
  - Hadron/meson ~ 1.6 above p_T~ 5 GeV/c as in p+p (baryon enhancement limited to p_T<5 GeV/c).
  - x_T scaling holds for π^0 not for hadrons (in limited x_T range).

High p_T @ PHENIX: Summary (III)

- Peripheral Au+Au collisions:
  - Behave effectively as p+p collisions plus N_{coll} scaling (expected pQCD behaviour) for all species and for all observables !

- d+Au collisions:
  - No suppression observed in min. bias d+Au (and p+Au) reactions.
  - Cronin-like enhancement for π^0 (small) and $h^{\pm}$ (larger).
  - No "cold" nuclear matter effects (shadowing, strong modification of nuclear PDFs) seem to explain high p_T Au+Au suppression.

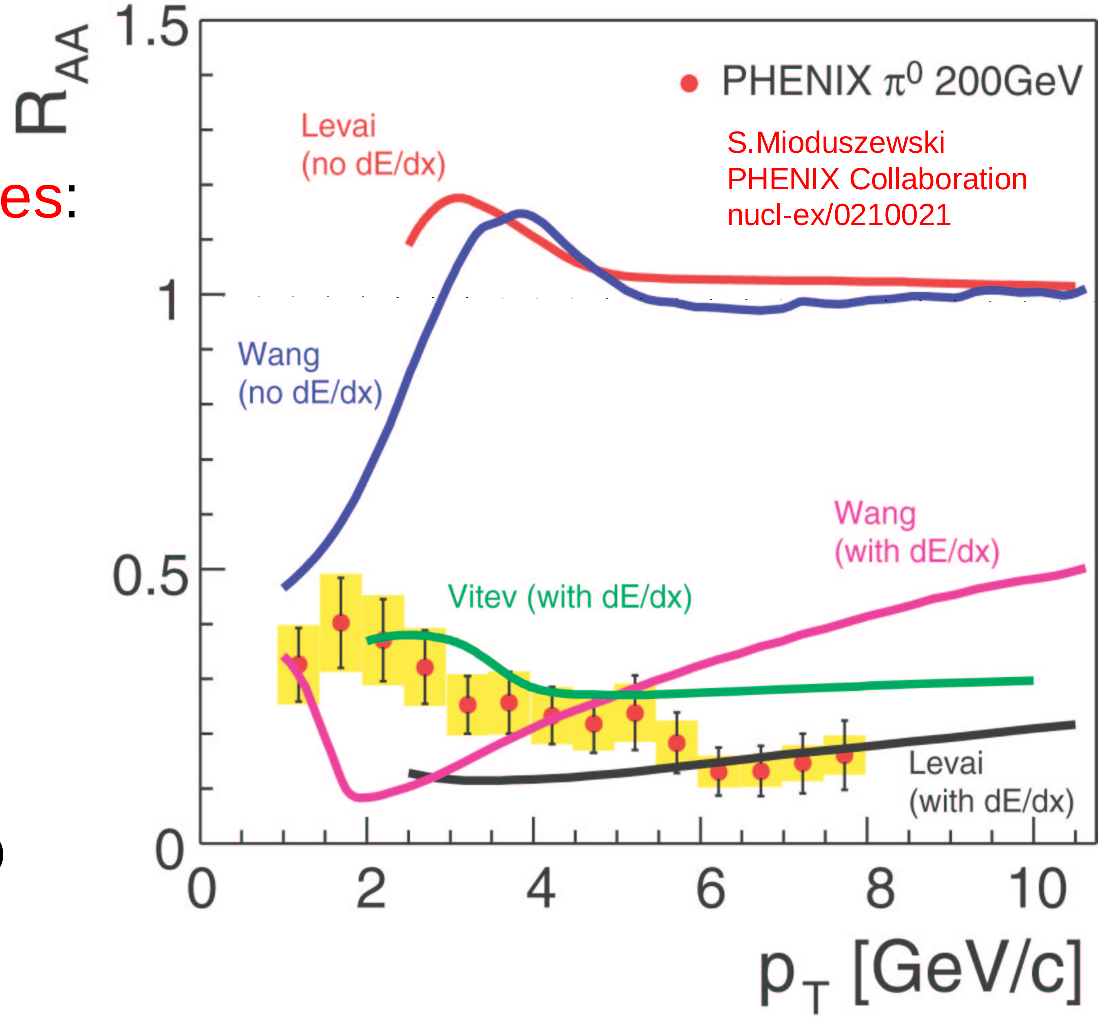
- Data vs. theory:
  - pQCD-based final-state parton energy loss models reproduce more aspects of the data (Au+Au, d+Au) than other approaches.
  - Non negligible "leftovers" lacking consistent explanation.

Backup slides

“Jet quenching” models: Magnitude of suppression

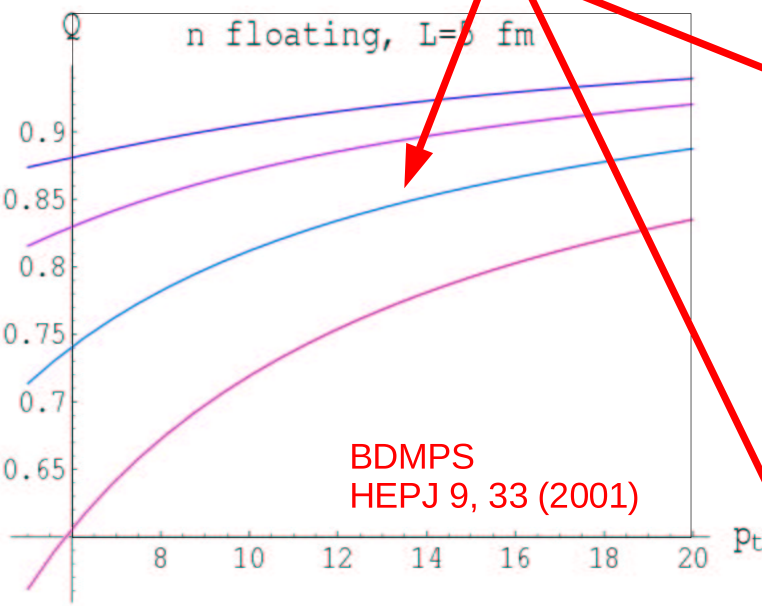
- Dense medium properties according to “jet quenching” models:
  - High opacities:
    $\langle n \rangle = L/\lambda \approx 3 - 4$
  - Large initial gluon densities:
    $dN^g/dy \sim 800\text{-}1200$
  - Transport coefficients:
    $\langle q_0 \rangle \sim 3.5$ GeV/fm^2
  - Medium-induced gluon radiative energy losses:

$dE/dx \approx 0.25$ GeV/fm (expanding)
$dE/dx|_{eff} \approx 14$ GeV/fm (static source)

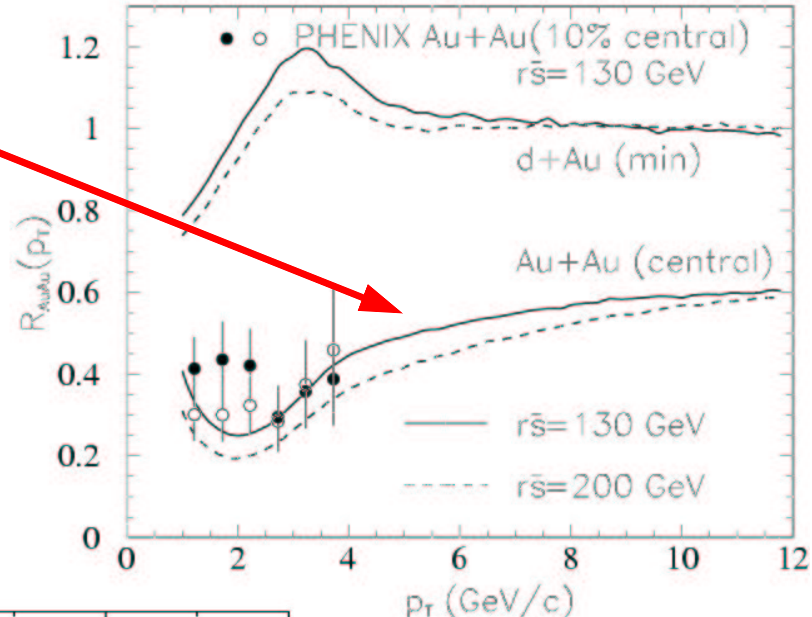


"Jet quenching" models: p_T depend. of suppression (I)

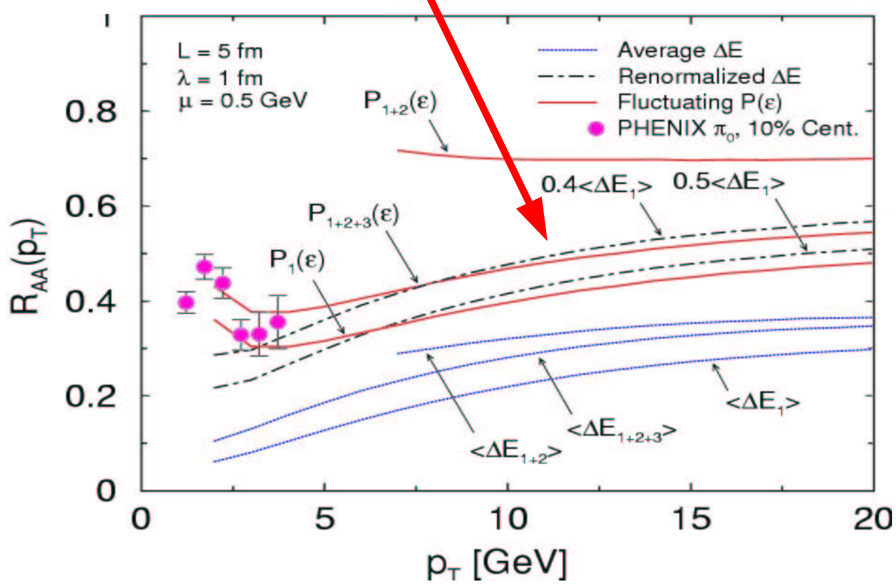
- All medium-induced (LPM) energy-loss models predict a smooth decrease of suppression ($\propto \sqrt{p_T}$) not seen in the data ...



BDMPS
HEPJ 9, 33 (2001)



E. Wang & X.N.Wang
PRL 89 162301 (2002)



GLV
PLB538, 282(2002)

"Jet quenching" models: p_T depend. of suppression (II)

- Energy loss with LPM interference effect: (1) gives too much suppression at moderate p_T, (2) does not give the observed flat p_T dependence of R_{AA}
- Alternative 1: Test the Bethe-Heitler limit ...

Jeon, Jalilian-Marian, Sarcevic: hep-ph/0207120

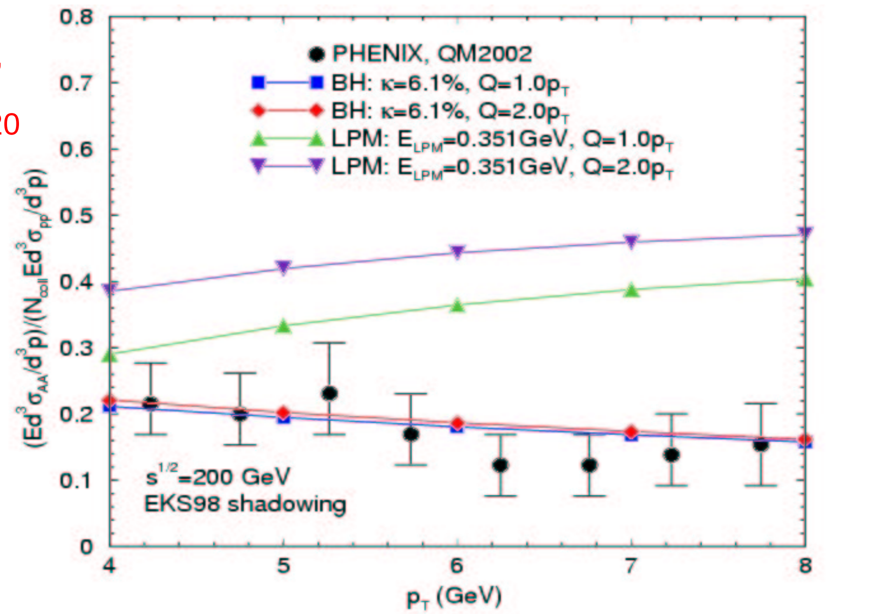
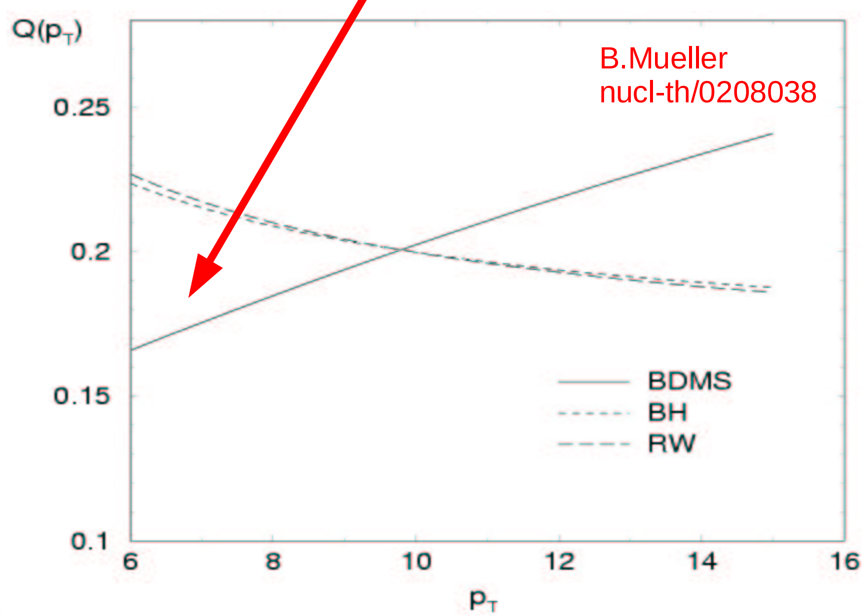


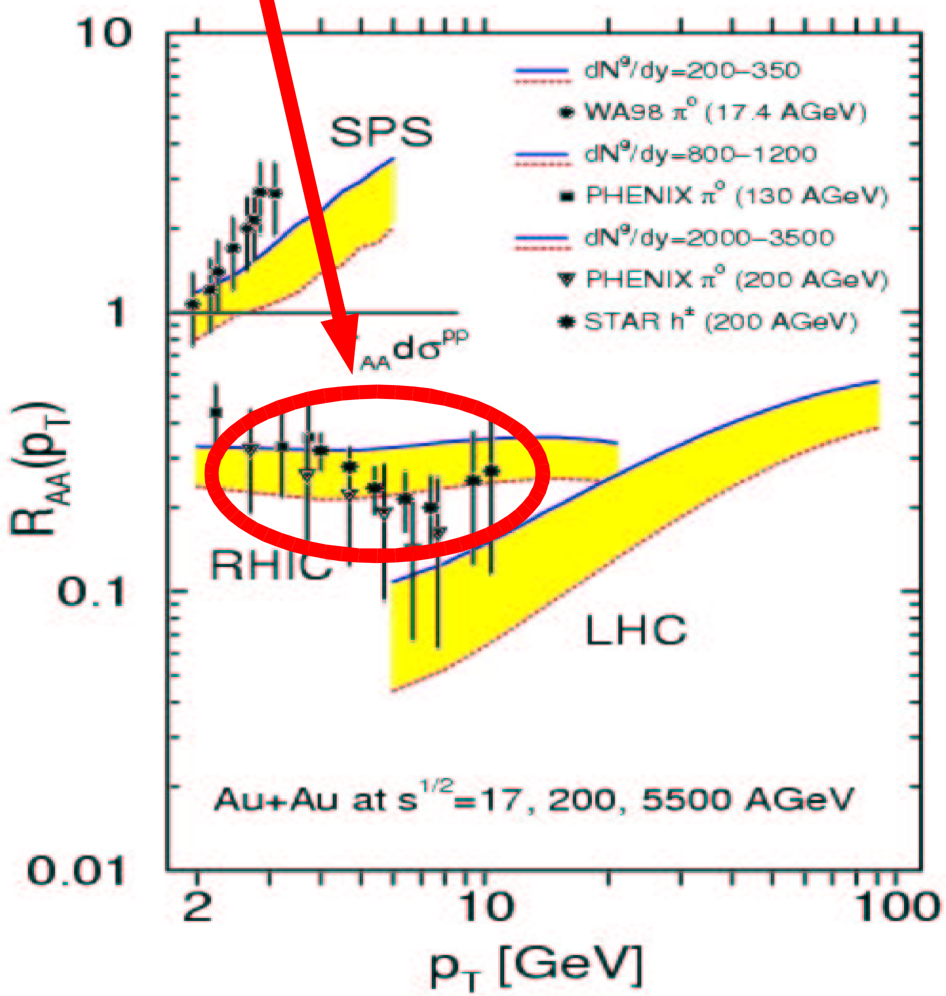
FIG. 8. Ratio of inclusive π^0 cross sections in heavy ion and p-p collisions at $\sqrt{s} = 200$ GeV, compared with PHENIX



- Alternative 2: Add all other relevant nuclear effects ...
  - ✔ Modified nuclear PDFs (aka "shadowing")
  - ✔ Initial-state p_T broadening (aka "Cronin effect")

"Jet quenching" models: parton en. loss + shadowing + Cronin = flat R_{AA}

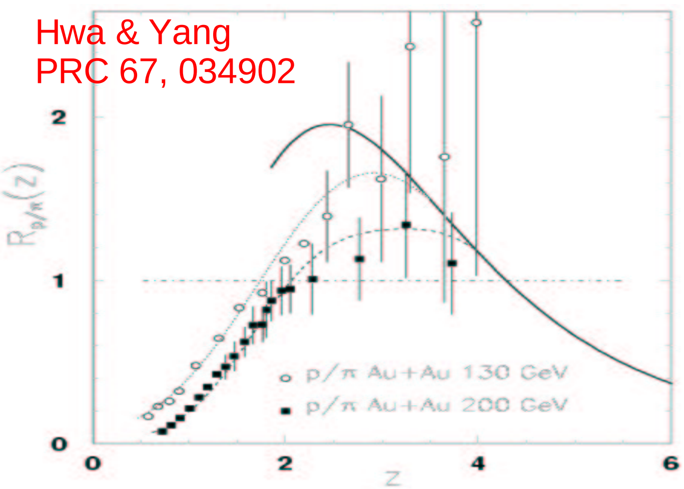
- Initial state p_T broadening provides: (1) the needed enhancement at intermediate p_T , (2) the small decrease at higher p_T so as to compensate for the p_T dependence of energy loss and give the observed ~flat R_{AA} (p_T)

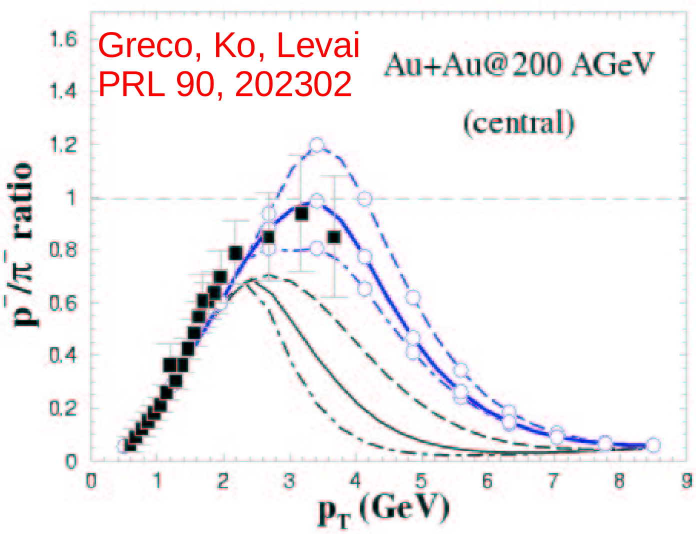


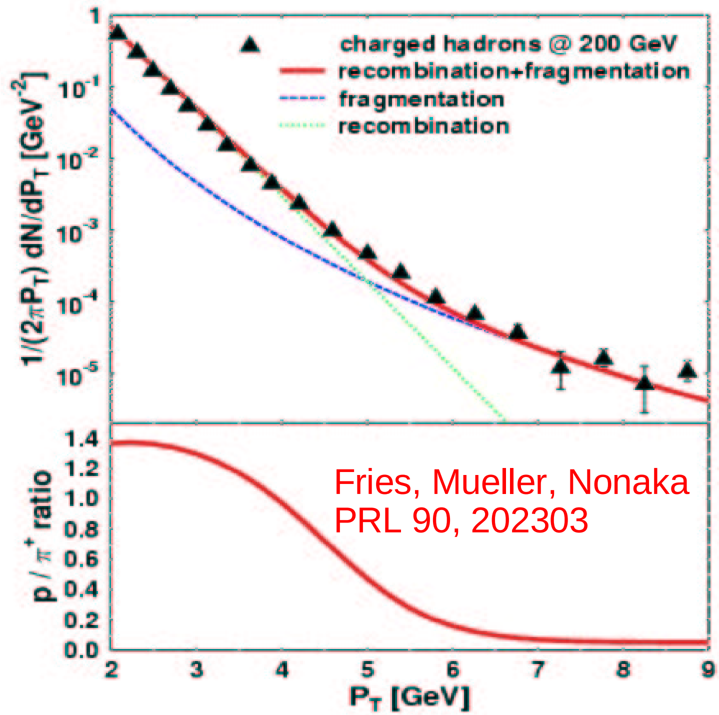
I.Vitev, M.Gyulassy PRL 89 252301 (2002)

"Jet quenching" models: final-state quark recombination

- Recombination/coalescence models and high p_T "chemistry"



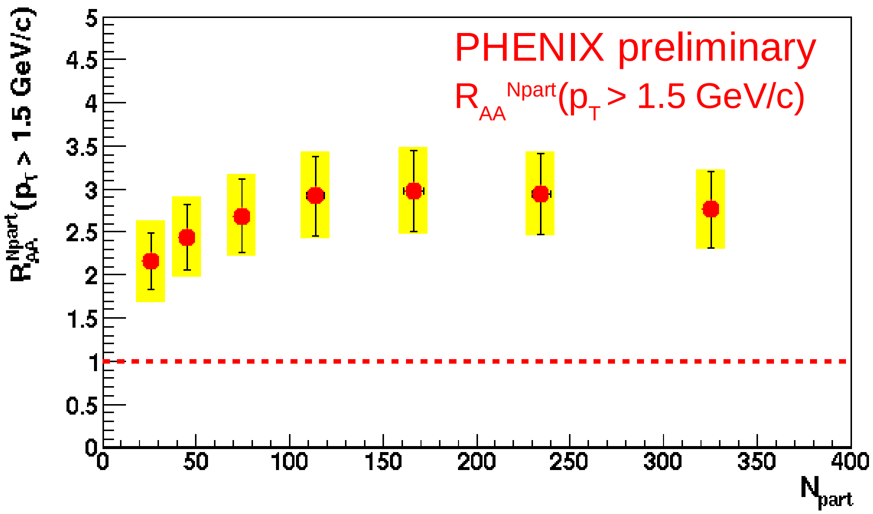


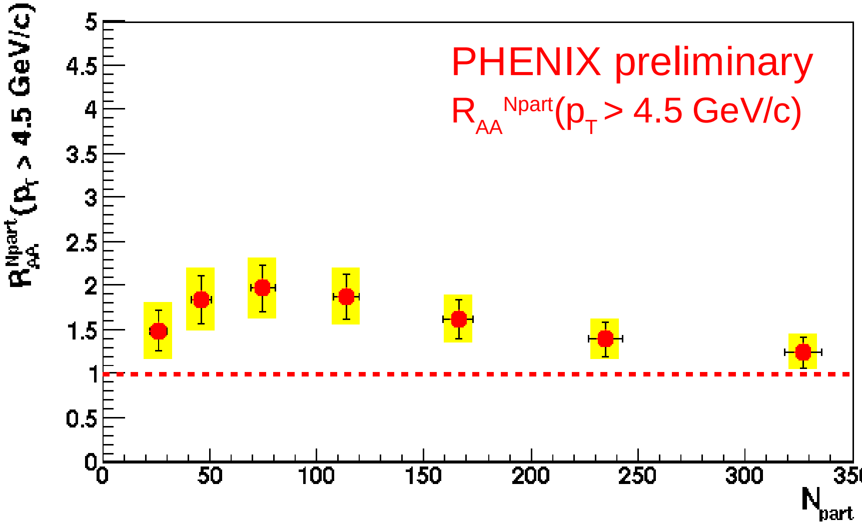


- Recombination dominates for p_T ~ 1- 4 GeV/c:
  ⟨p_T(baryons)⟩ > ⟨p_T(mesons)⟩ > ⟨p_T(quarks)⟩
  (coalescence, thermal quark distribution ...)
- Fragmentation dominates for p_T > 5 GeV/c:
  p_T(hadrons)= z p_T(partons) , with z<1

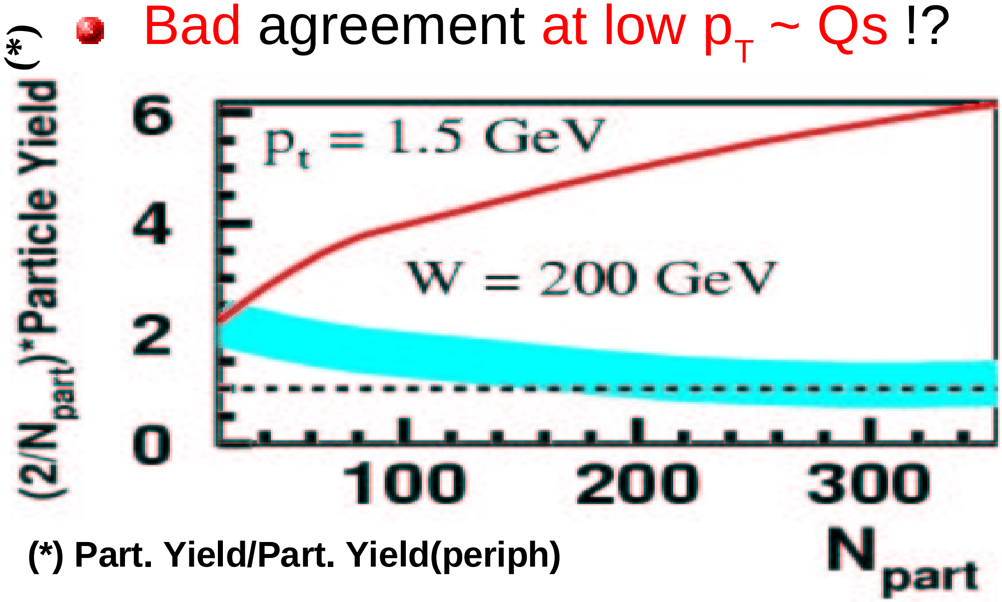
Gluon saturation models: Centrality-dependence of π^0 suppression

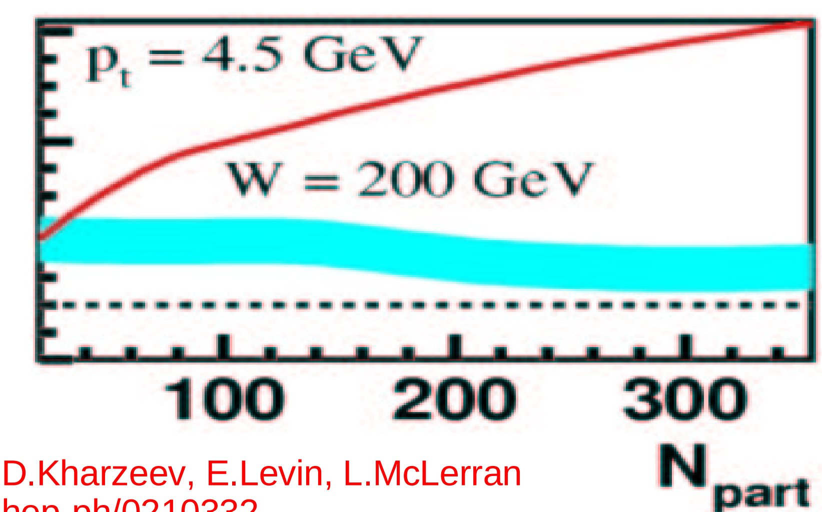
- Integrated R_{AA}^{Npart} above a given p_T (1.5 GeV/c, 4.5 GeV/c) vs. N_{part} compared to gluon saturation predictions:





- Bad agreement at low $p_T \sim Qs$!? Reasonable agreement at high p_T



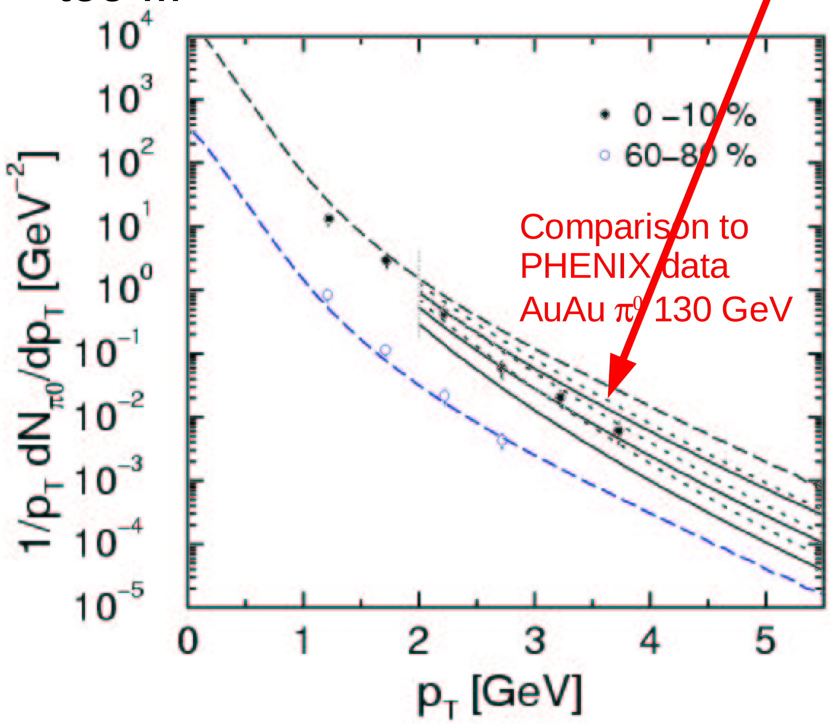


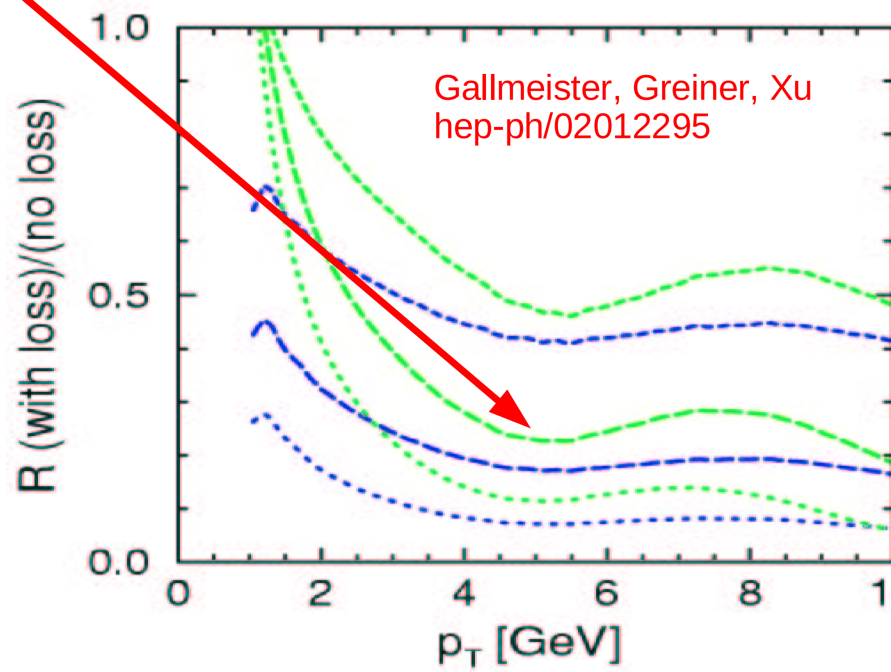
(*) Part. Yield/Part. Yield(periph)

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

Hadronic models: energy loss due to final-state hadron interactions

- Dense hadronic medium ($\langle L/\lambda \rangle \sim$ 2-3) seems to provide a flat suppression too ...





- Main justification: fast parton hadronization time (i.e. inside expanding fireball)
  [But, do τ_{had} estimates in pp (vacuum) apply to hadroniz. in (colored) medium ?]
- Description of scattering in the hadronic phase realistic enough ? ("... *our calculations are at best semiquantitative* ...").

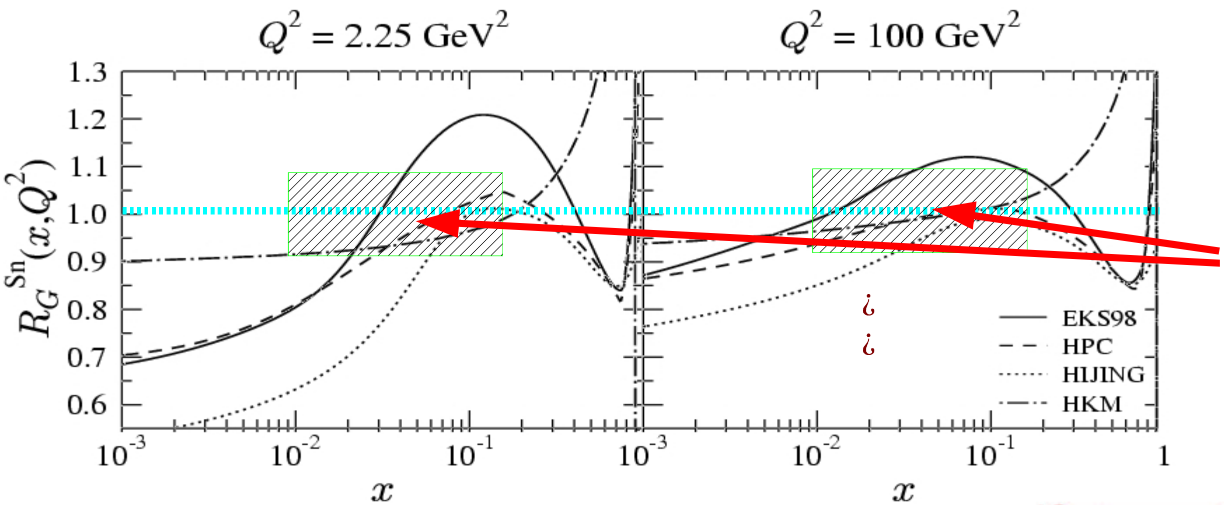
(even more) Backup slides from other presentations

Parton shadowing does not seem to play a role (?)

- (x,Q^2) kinematical range relevant for RHIC ($p_T \sim$ 2-10 GeV/c, $y \approx 0$):

$x_{i,j} = (p_T/\sqrt{s})\cdot(e^{\pm y1}+e^{\pm y2}) \approx 2p_T/\sqrt{s} \approx 0.01\text{-}0.2$ (gluons dominant !)

$Q^2 \approx p_T^2 \approx 4 - 100$ GeV^2



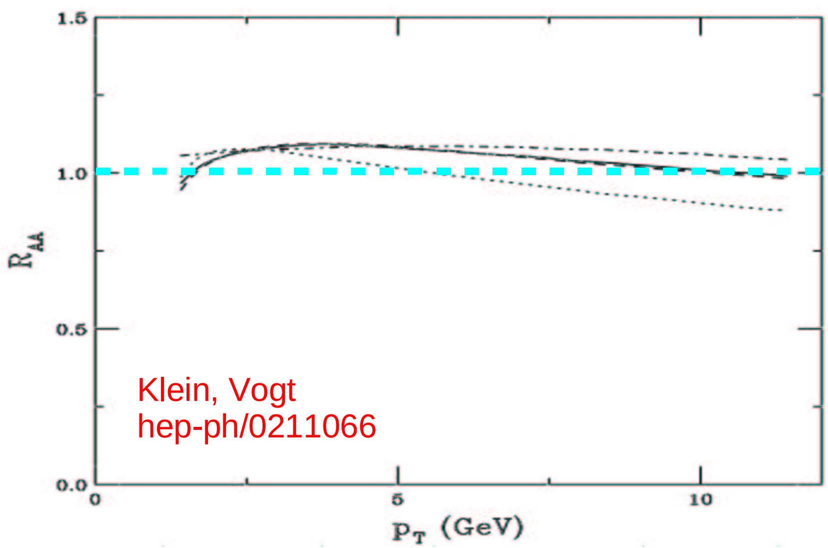
EKS98 ("state-of-the-art" nuclear PDFs):

$R_{gluon} \sim 1.0$ @ RHIC:

EKS hep-ph/0201256

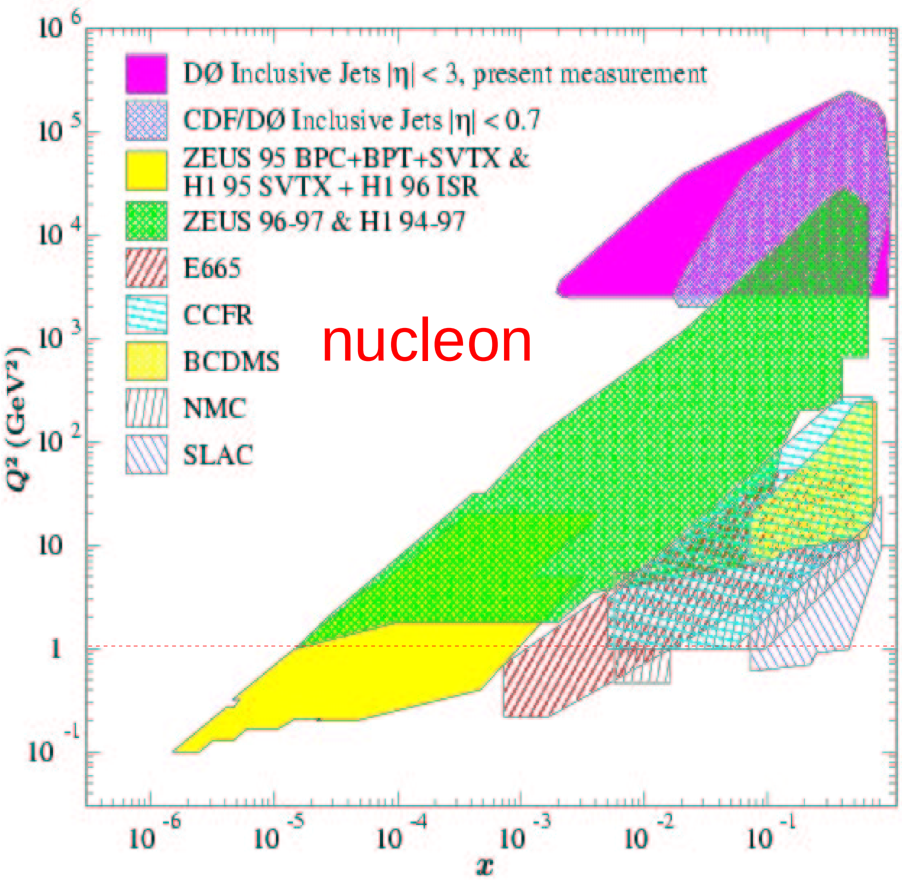
R_{AA} vs p_T due to shadowing: ~ 1

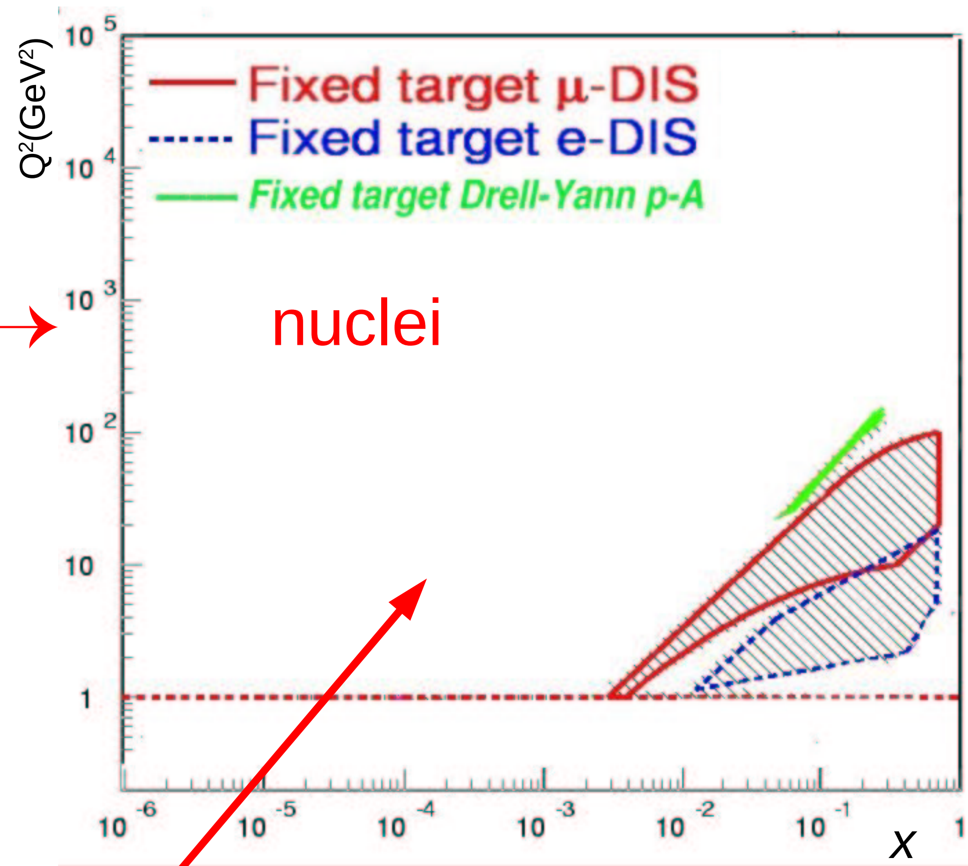
"Shadowing is a small effect at mid-rapidity"



but ... what do we <u>really know</u>(*) about gluon shadowing ?

(*) = *measured in lepton-A experiments*

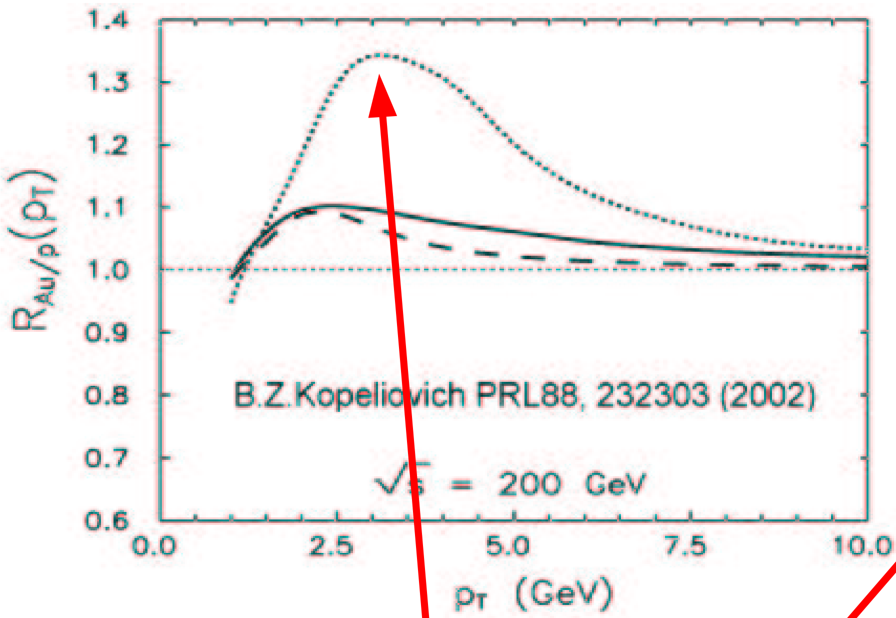


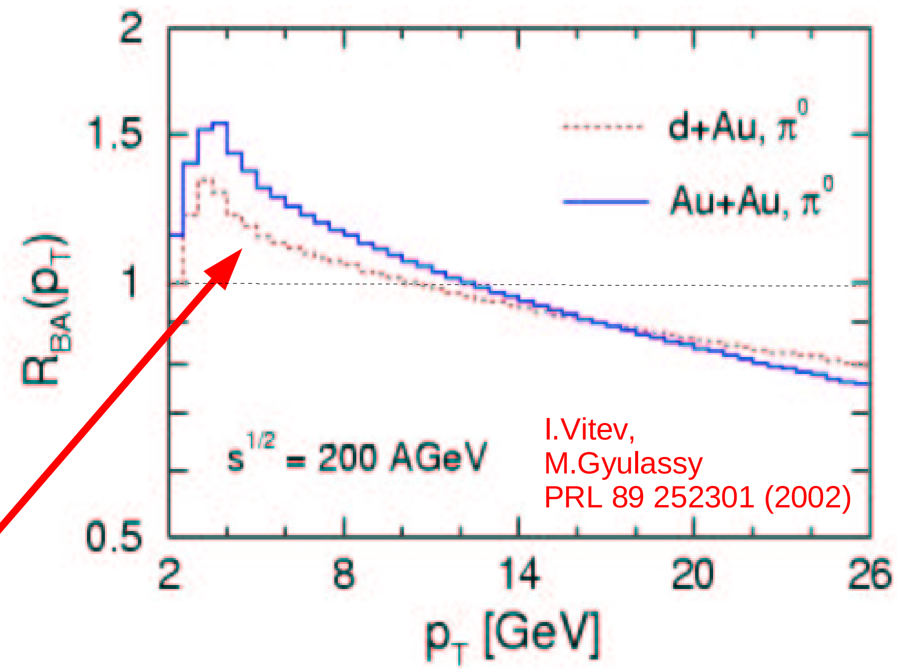


“propaganda”-plot for dA run (and for eRHIC) ...

Nuclear (x,Q^2,A) plane is “terra incognita” compared to nucleon (x,Q^2) !

Cronin enhancement does seem to play a role

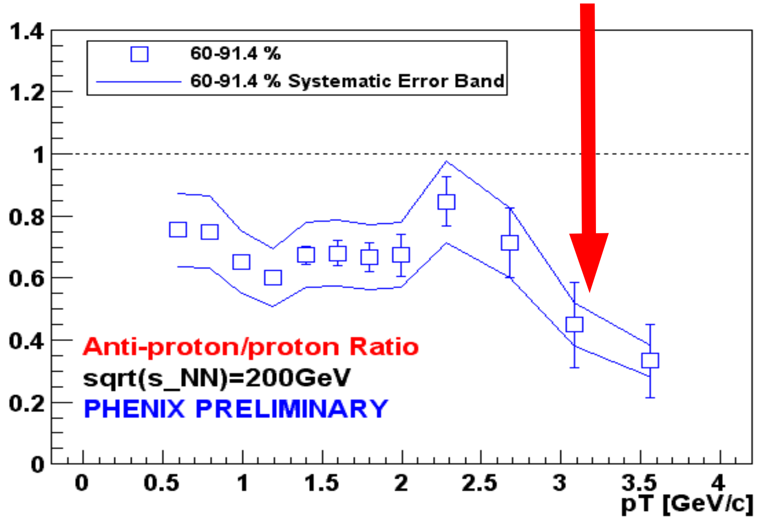


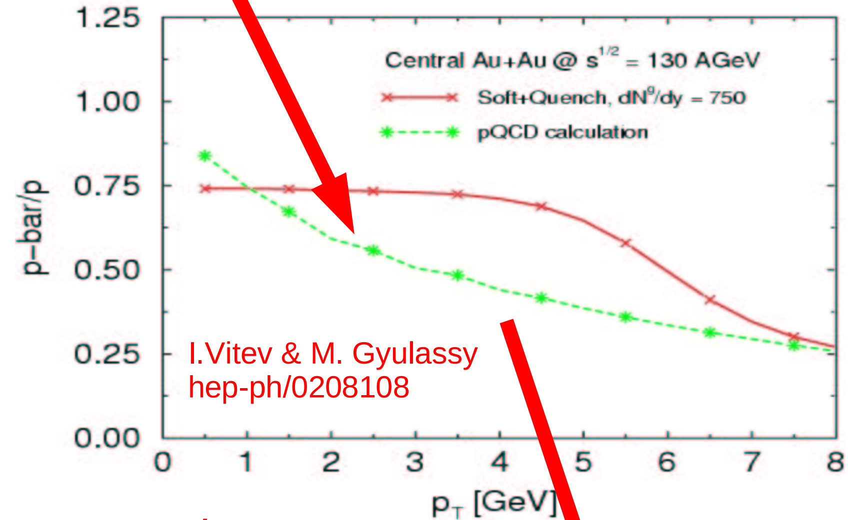


Expected k_T broadening @ RHIC

Hadron composition at high-p_T : $\bar{p}/p$ ratios

- Peripheral pbar/p: Decreases with p_T (perturbative behaviour)





- Central pbar/p: ~ 0.7 constant up to 3.5 GeV/c

(as found in pp data)