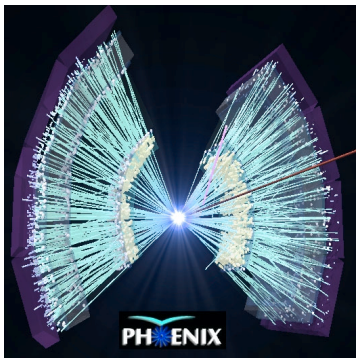
Can the QGP be found using only an ElectroMagnetic Calorimeter ?

M. J. Tannenbaum
Brookhaven National Laboratory
Upton, NY 11973 USA

PHENIX Collaboration



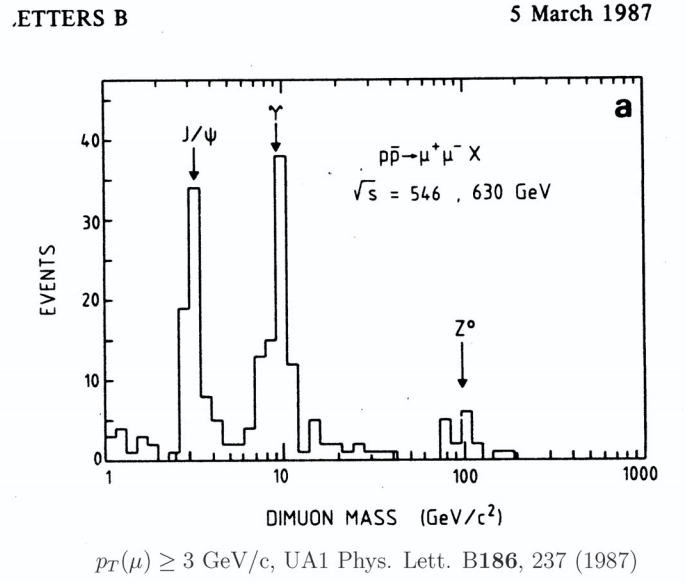
20th Nuclear Dynamics Workshop
Jamaica, March 14-20, 2004

The Short Answer is:
Almost.
Also need tracking to detect electrons...

How to discover the QGP

- The Classical road to success in RHI Physics: J/Ψ Suppression

The Road To Success in HEP

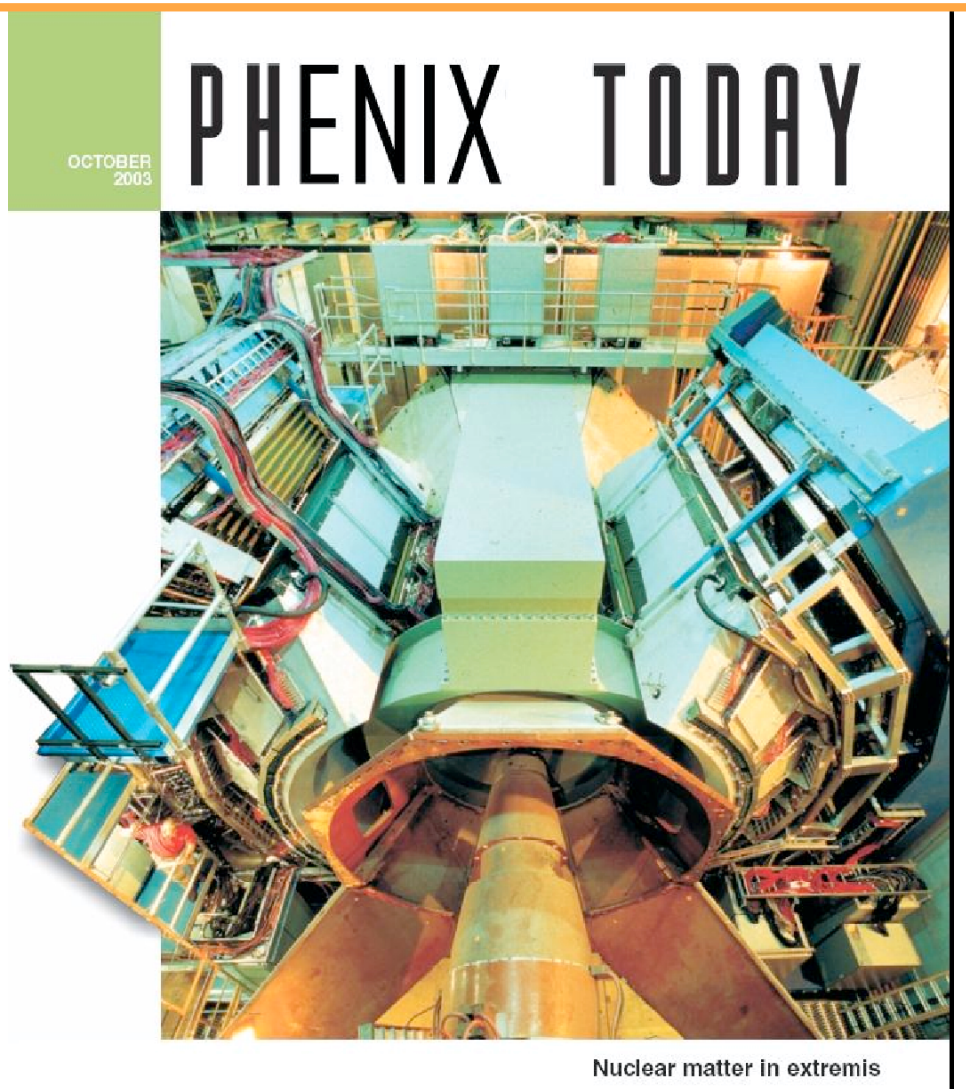


$p_T(\mu) \geq 3$ GeV/c, UA1 Phys. Lett. B**186**, 237 (1987)

The Road To Success in HIP

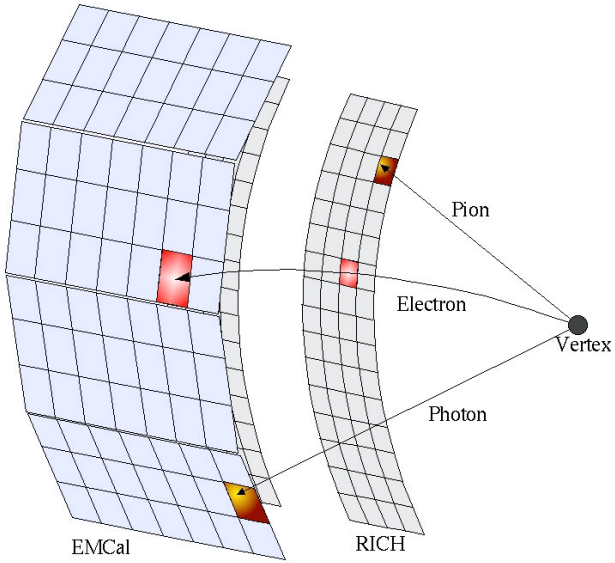
- Major background for $e^{\pm}$ detection is photons and conversions from π^0. but more importantly
- Need an electron trigger for full J/Ψ detection ⇒ EMCal plus electron ID at trigger level.
- High p_T π^0 and direct γ production and two-particle correlations are the way to measure hard-scattering in RHI collisions where jets can not be detected directly---> segmentation of EMCal must be sufficient to distinguish π^0 and direct γ up to 25 GeV/c (also vital for spin)
- Charm measurement via single $e^{\pm}$ (Discovered by CCRS experiment at CERN ISR)

"Mike, is there a `real collider detector' at RHIC?---J. Steinberger "

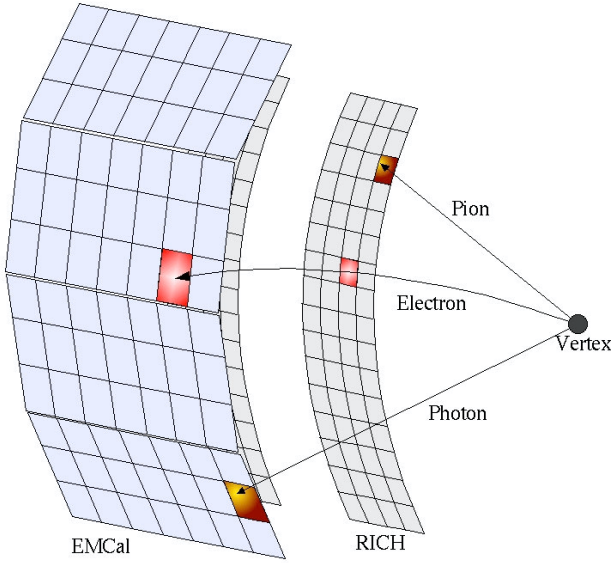


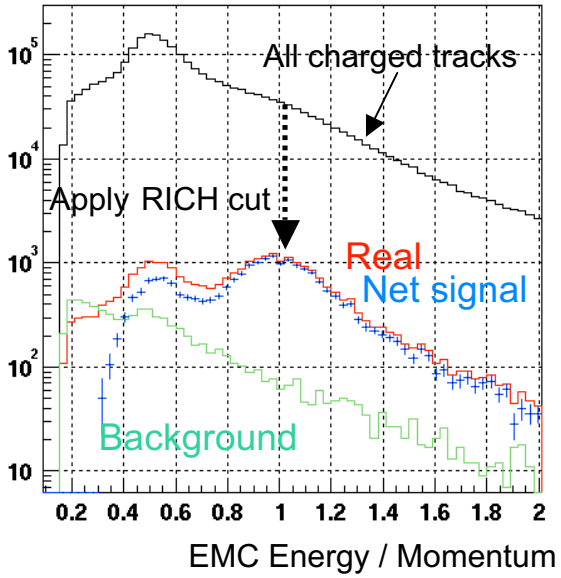
- **PHENIX is picturesque because it is not your father's solenoid collider detector**
- **Special purpose detector designed and built to measure *rare processes* involving *leptons and photons* at the *highest luminosities*.**

Detecting electrons means detecting all particles=PHENIX



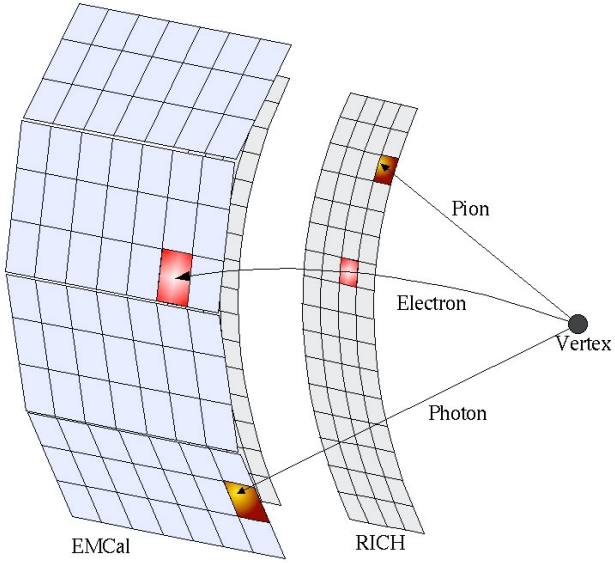
Detecting electrons means detecting all particles=PHENIX

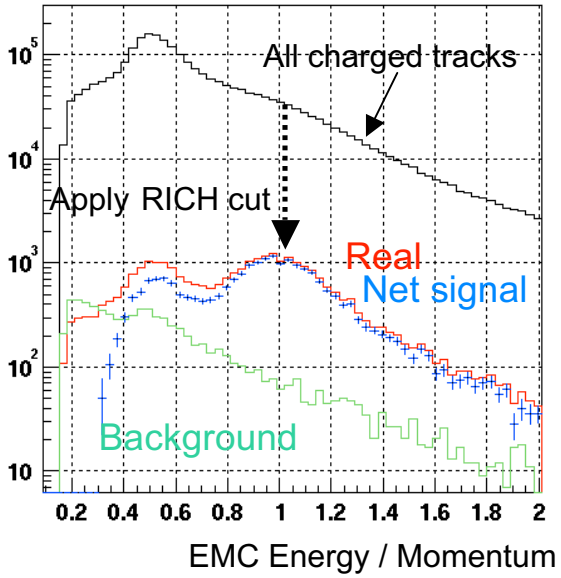


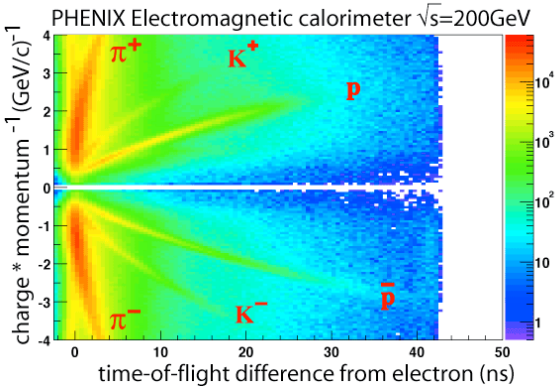


- **ElectroMagnetic Calorimeter** measures Energy of photons and electrons
  - reconstructs π^0 from 2 photons. Measures decent Time of Flight
  - hadrons deposit Minimum Ionization, or higher if they interact
- **For electron ID require RICH (cerenkov) and matching energy in EMCal**
  - Electron and photon energy can be matched to < 1%--No nonlinearity problem
- momentum +TOF=charged particle ID
- High Resolution TOF completes the picture giving excellent charged hadron PID

Detecting electrons means detecting all particles=PHENIX

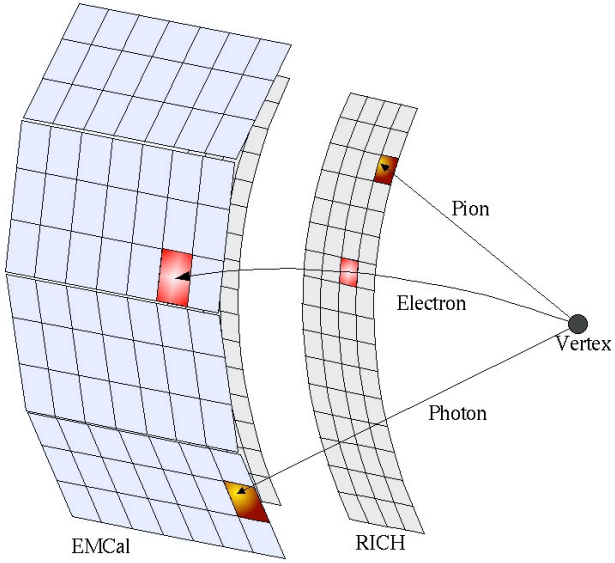


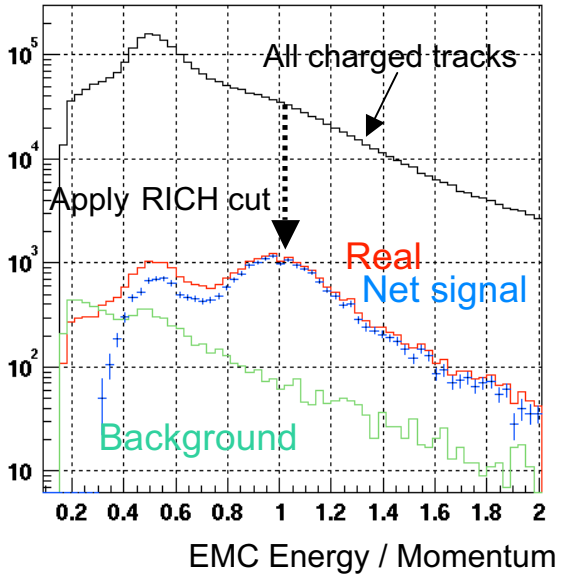


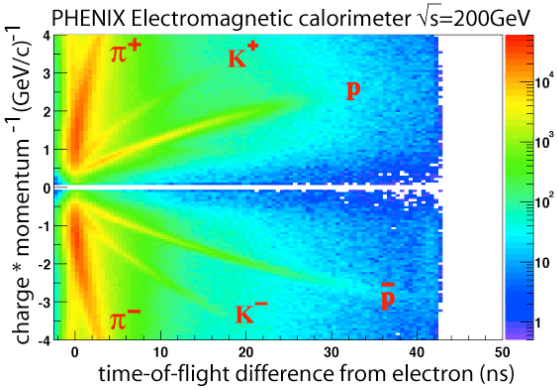


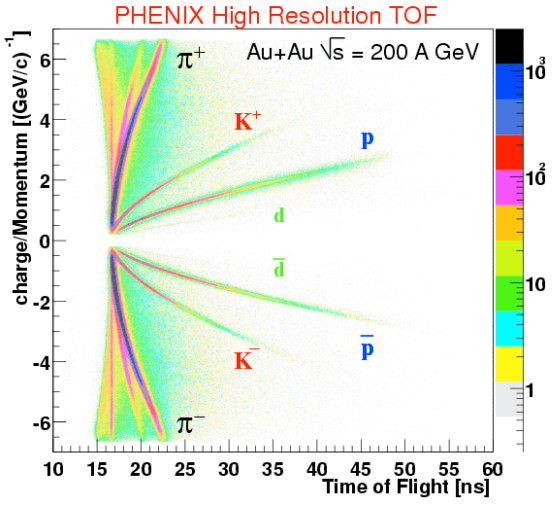
- **ElectroMagnetic Calorimeter** measures Energy of photons and electrons
  - reconstructs π^0 from 2 photons. Measures decent Time of Flight
  - hadrons deposit Minimum Ionization, or higher if they interact
- **For electron ID require RICH (cerenkov) and matching energy in EMCal**
  - Electron and photon energy can be matched to < 1%--No nonlinearity problem
- momentum +TOF=charged particle ID
- High Resolution TOF completes the picture giving excellent charged hadron PID

Detecting electrons means detecting all particles=PHENIX





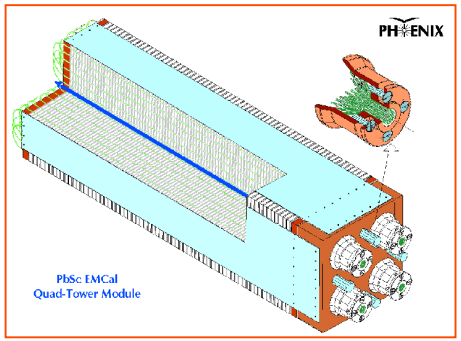




- **ElectroMagnetic Calorimeter** measures Energy of photons and electrons
  - reconstructs π^0 from 2 photons. Measures decent Time of Flight
  - hadrons deposit Minimum Ionization, or higher if they interact
- **For electron ID require RICH (cerenkov) and matching energy in EMCal**
  - Electron and photon energy can be matched to < 1%--No nonlinearity problem
- momentum +TOF=charged particle ID
- High Resolution TOF completes the picture giving excellent charged hadron PID

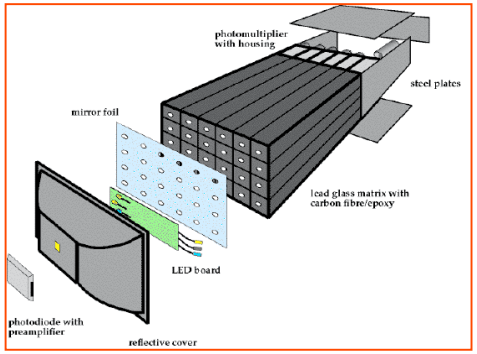
PHENIX EMCal

Lead-Scintillator (PbSc) Module



6 PbSc sectors (15,552 channels)
2 PbGl sectors (9,216 channels)
$\eta = \pm 0.38$ $\Delta\varphi = 8 \times 22.5^0 = 180^0$

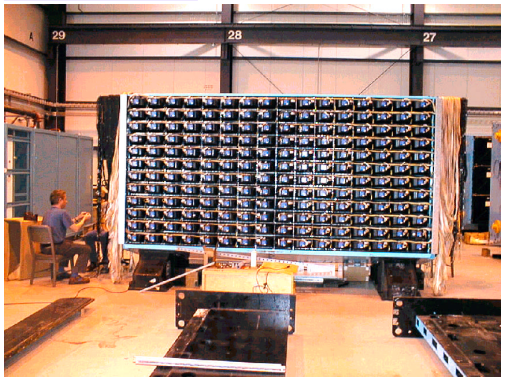
Lead-Glass (PbGl) Super Module



6 PbSc sectors	2 PbGl sectors
Granularity ($\delta\eta \times \delta\varphi$)	
0.011×0.011	0.008×0.008
System Energy resolution (%)	
$10/\sqrt{E} \oplus 6.5$	$8.5/\sqrt{E} \oplus 9$
Position resolution, orthog. imp. (mm)	
$5.7/\sqrt{E} + 1.6$	$\approx 6/\sqrt{E}$
Timing resolution σ_t	
340 ps	600ps

PbSc Sector

PbGl Sector

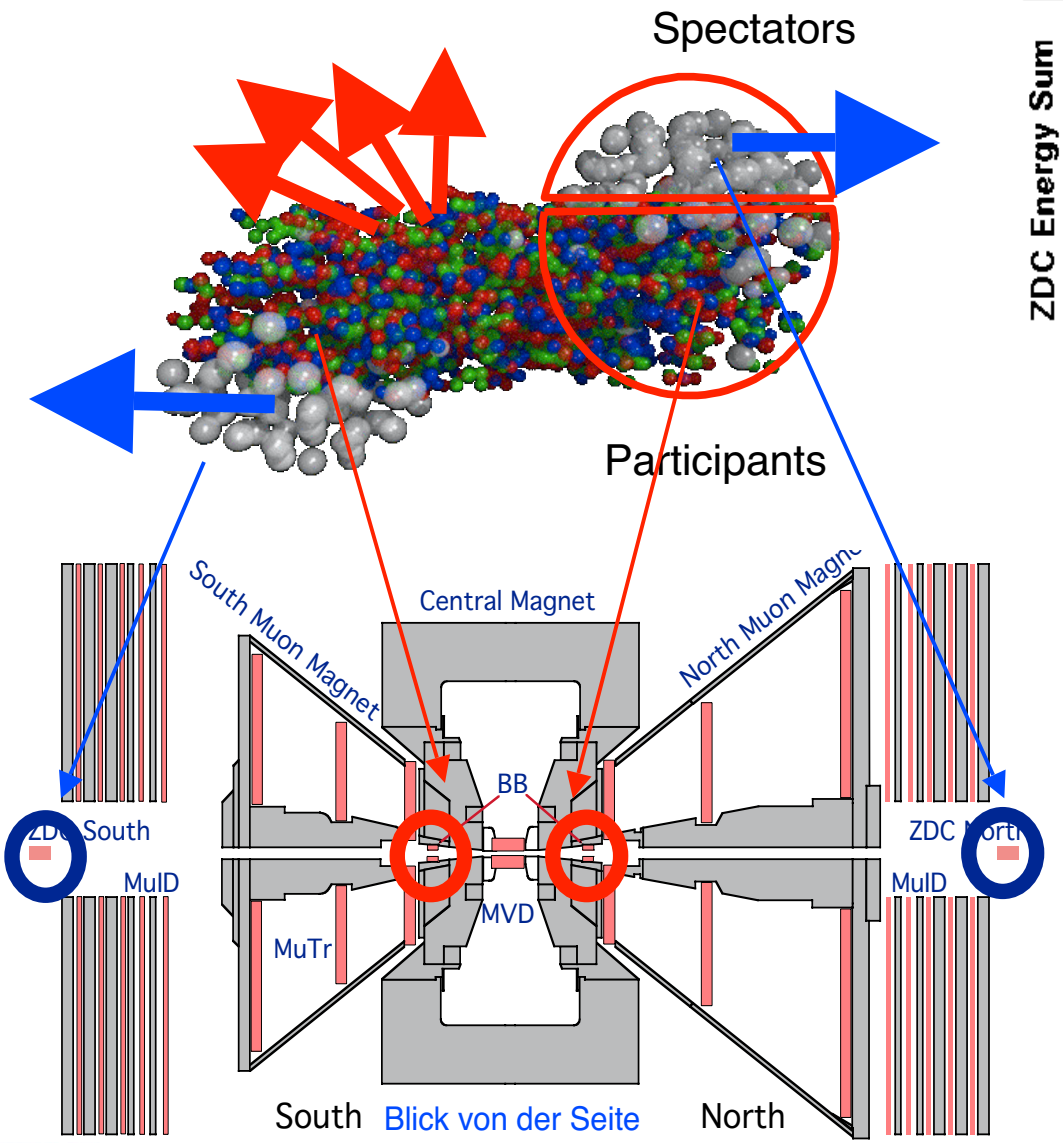


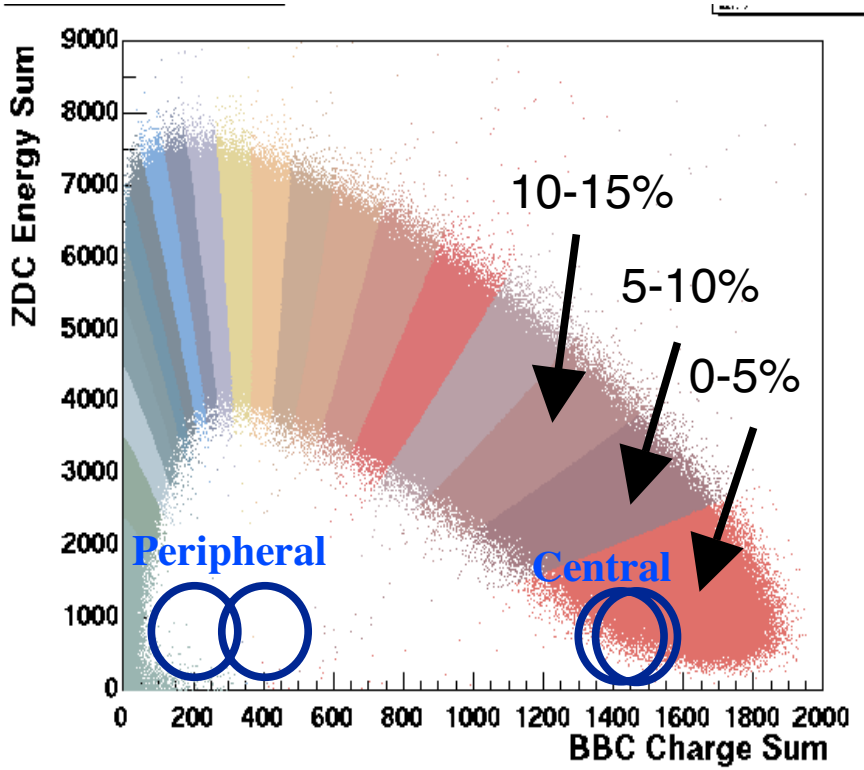
BNL/PHENIX

separates π^0 and direct γ up to >25 GeV/c

WA80/98

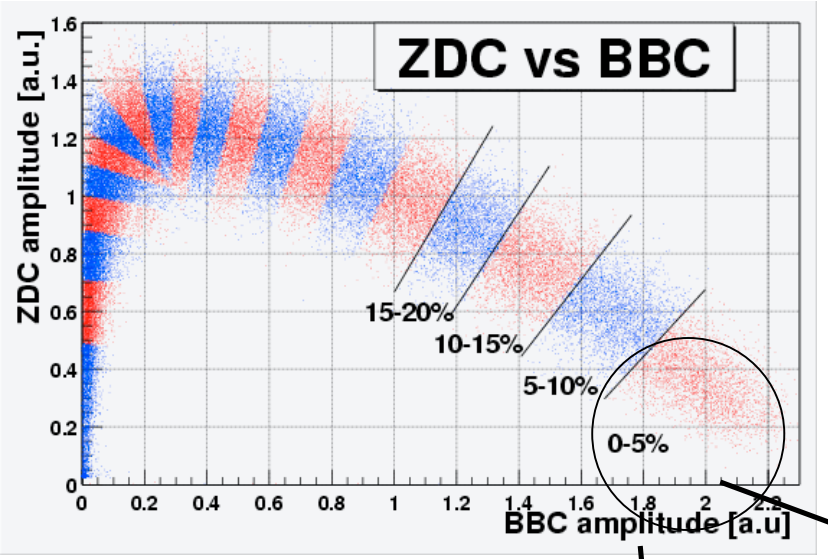
Collision Centrality Determination



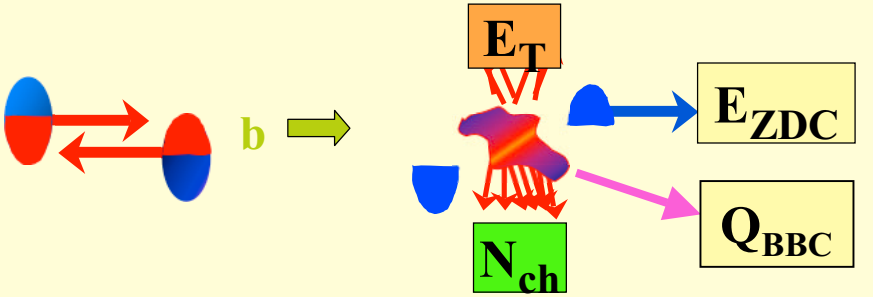


- **Centrality selection : Sum of Beam-Beam Counter (BBC, $|\eta|$=3~4) and energy of Zero-degree calorimeter (ZDC)**
- **Extracted N_{coll} and N_{part} based on Glauber model.**

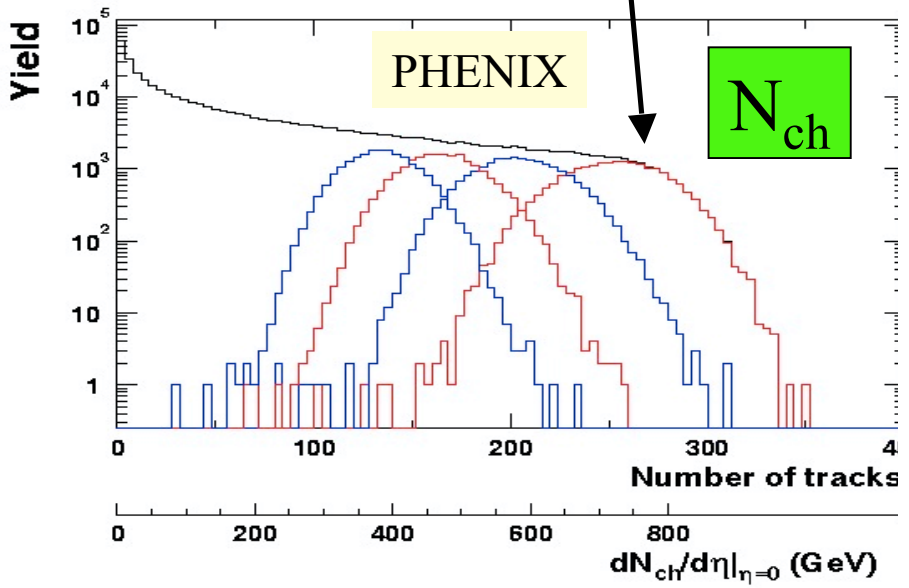
$N_{charged}$, E_T exhibit(&could determine) the Nuclear Geometry

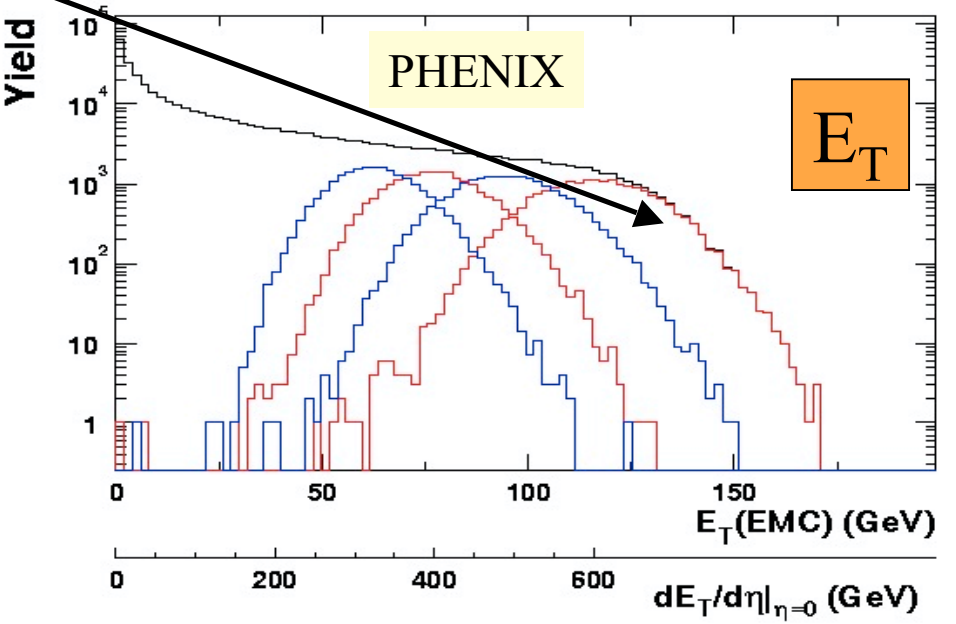


Define centrality classes: ZDC vs BBC



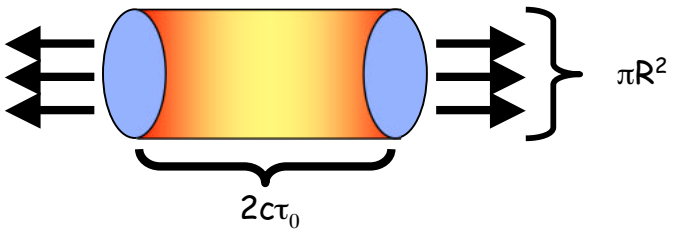
Extract N participants: Glauber model





Is the energy density high enough?

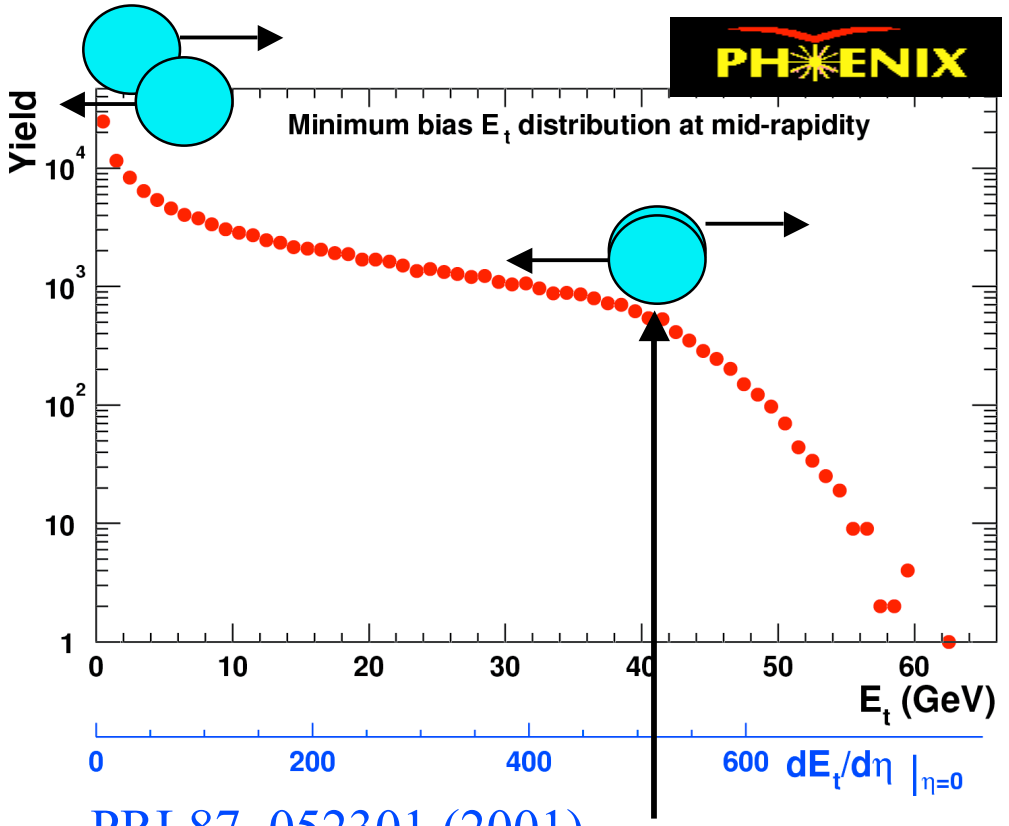
Colliding system expands:



Energy ⊥ to beam direction

$$\varepsilon_{Bj} = \frac{1}{\pi R^2}\frac{1}{2c\tau_0}\left(2\frac{dE_T}{dy}\right)$$

per unit velocity || to beam



PRL87, 052301 (2001)

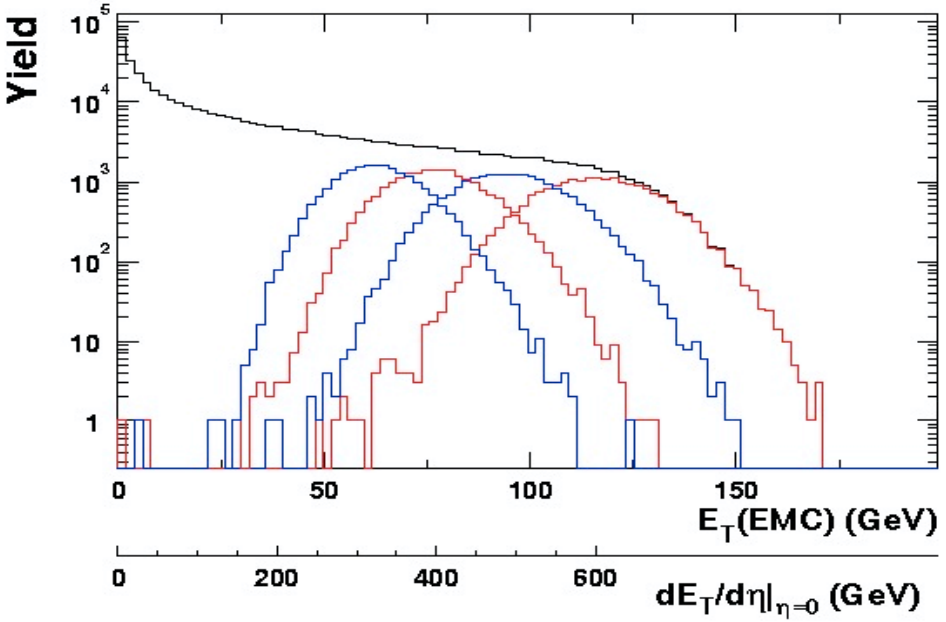
→ε ≥ *4.6 GeV/fm³* (130 GeV Au+Au)

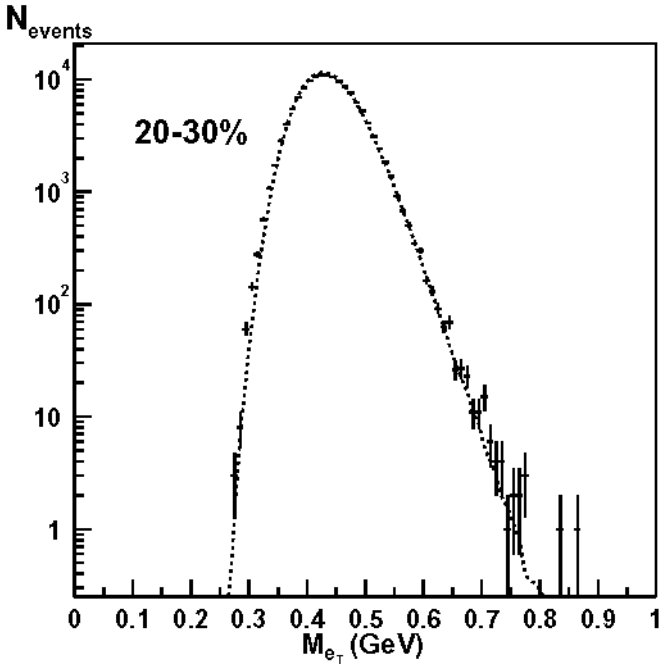
5.5 GeV/fm³ (200 GeV Au+Au)

well above predicted transition!

EMCal measures ε_{Bj}

Are upper edge fluctuations random?





- Event-by-event average p_T (M_{pT}) is closely related to E_T

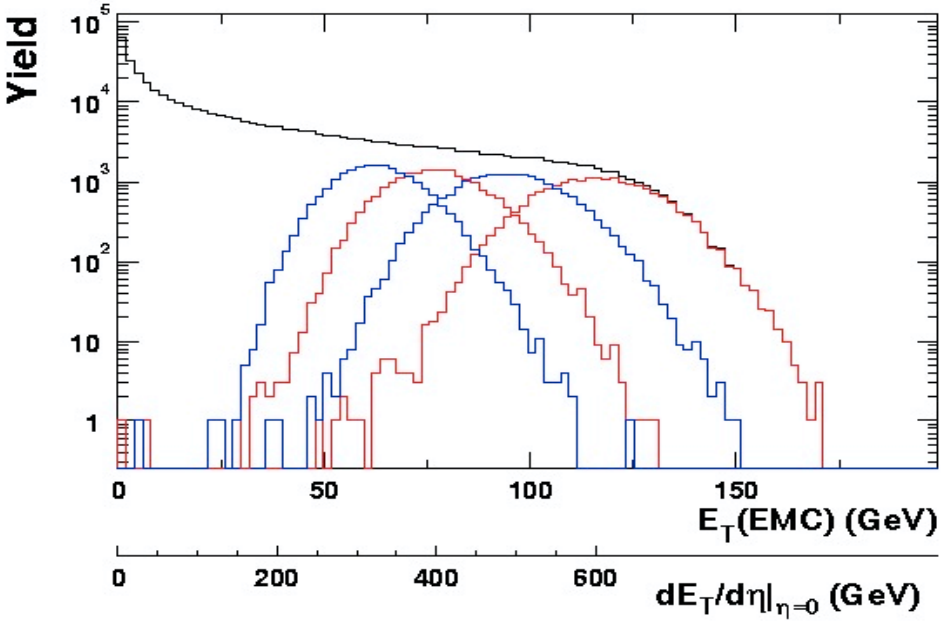
$$M_{p_T} = \overline{p_T}_{(n)} = \frac{1}{n}\sum_{i=1}^{n} p_{T_i} = \frac{1}{n} E_{Tc}$$

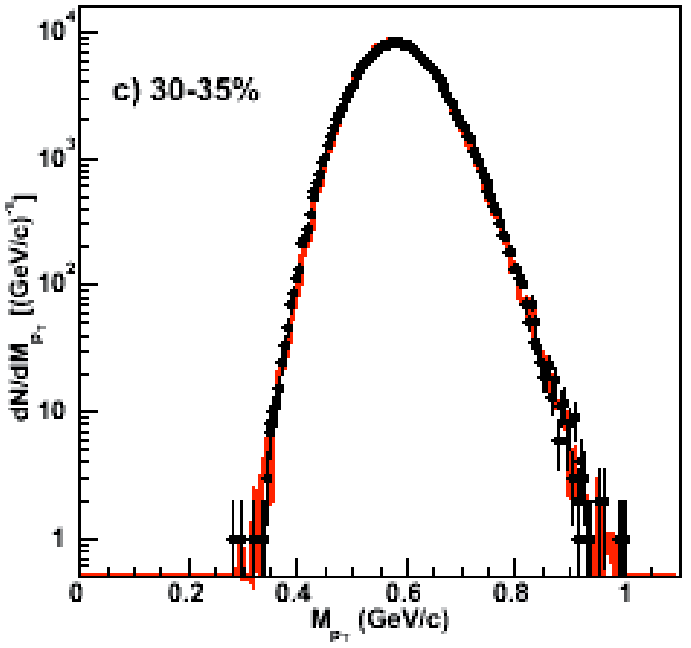
- compare Data to Mixed events for random.
- deviation expressed as:

$Fp_T = \sigma_{MpTdata} / \sigma_{MpTmixed} - 1$ ~ few %

- due to jets see nucl-ex/0310005

Are upper edge fluctuations random?





- Event-by-event average p_T (M_{pT}) is closely related to E_T

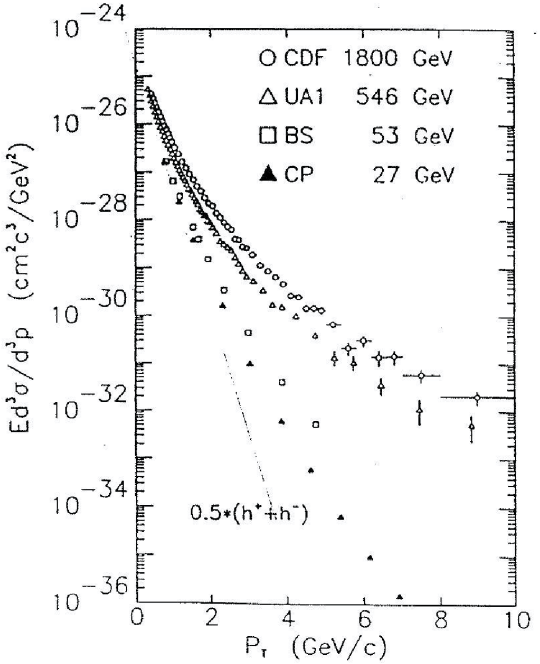
$$M_{p_T} = \overline{p_T}_{(n)} = \frac{1}{n}\sum_{i=1}^{n} p_{T_i} = \frac{1}{n} E_{Tc}$$

- compare Data to Mixed events for random.
- deviation expressed as:

$Fp_T = \sigma_{MpTdata} / \sigma_{MpTmixed} - 1 \sim$ few %

- due to jets see nucl-ex/0310005

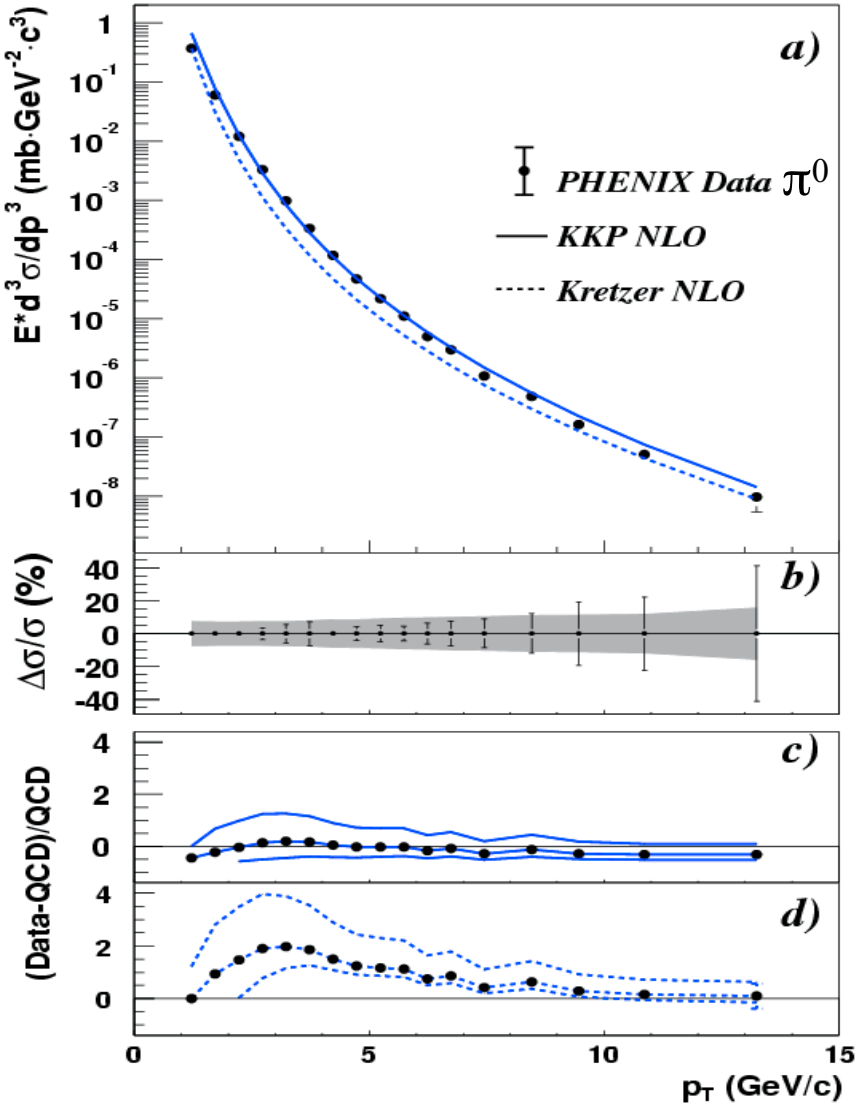
From 1998—My Best Bet on Discovering QGP
Utilizes semi-Inclusive π^0 or $\pi^{\pm}$ production



Invariant cross section for non-identified charged-averaged hadron production at 90° in the c.m. system as a function of the transverse momentum p_T tablulated by CDF for a range of C.M. energies $\sqrt{s}$. There is an exponential tail (e^{-6p_T}) at low p_T, which depends very little on $\sqrt{s}$. This is the soft physics region, where the hadrons are fragments of 'beam jets'. At higher p_T there is a power-law tail which depends very strongly on $\sqrt{s}$. This is the hard-scattering region, where the hadrons are fragments of the high p_T QCD jets from constituent-scattering. **My hope is that the QGP causes the high p_T quarks to lose all their energy and stop, so that the high p_T tail will 'vanish' for central Au+Au collisions**

In RHI central collisions, leading particles are the only way to find jets because in one unit of Δr there is $\pi \times \frac{1}{2\pi}\frac{dE_T}{d\eta} \sim 375$ GeV **!!!**.

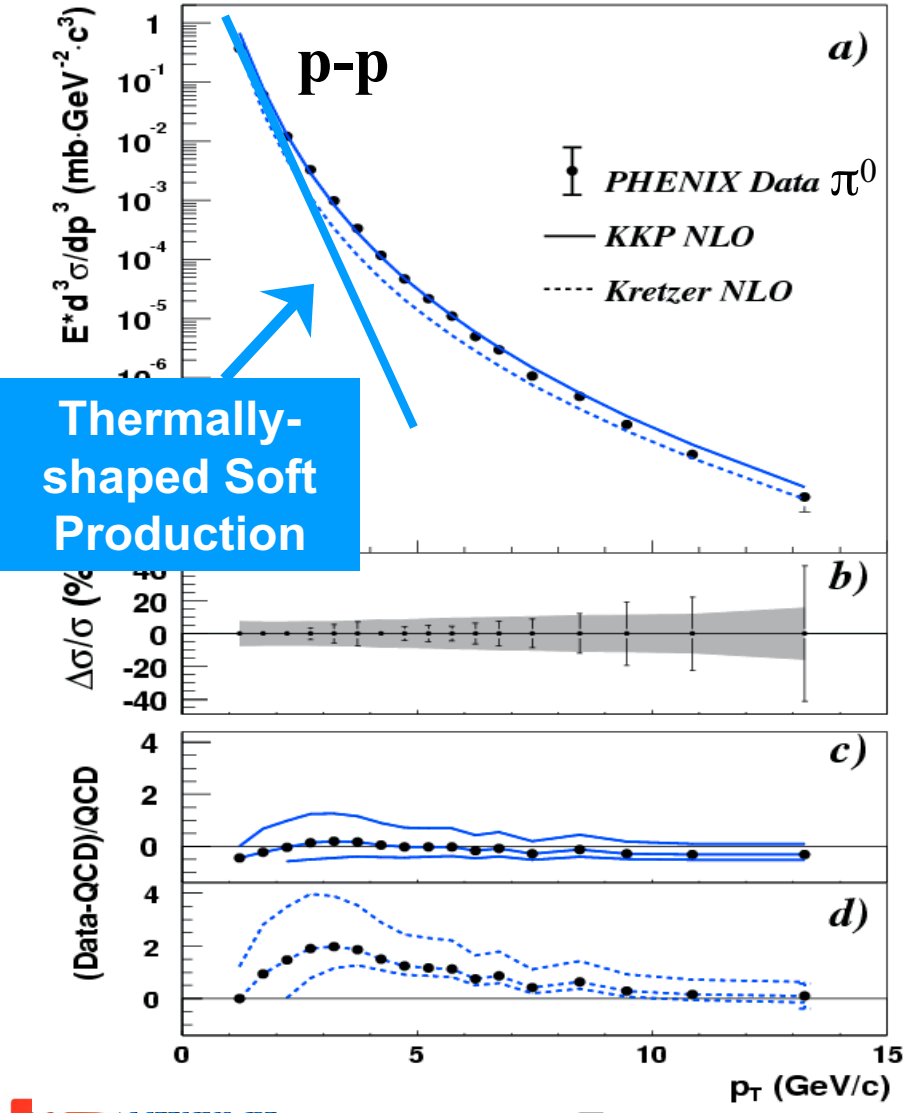
RHIC pp spectra √s=200 GeV nicely illustrate hard scattering phenomenology



- Good agreement with NLO pQCD
  - ✓ this is no surprise for `old timers' (like me) since as I just explained, single particle inclusive spectra were what proved QCD in the late 1970's before jets.
- **Reference for A+A and p+A spectra**
  - ✓ π^0 measurement in same experiment allows us the study of nuclear effect with less systematic uncertainties.

PHENIX (p+p) PRL 91, 241803 (2003)

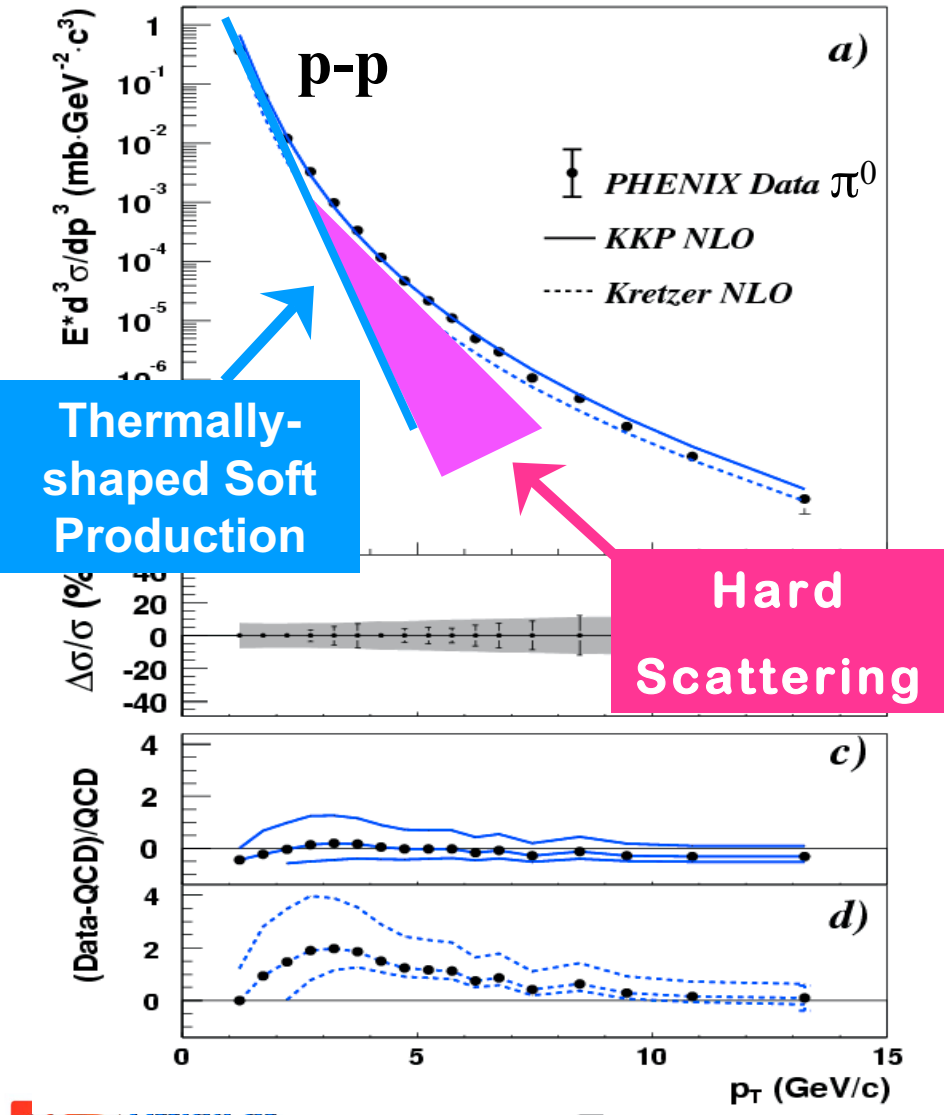
RHIC pp spectra √s=200 GeV nicely illustrate hard scattering phenomenology



- Good agreement with NLO pQCD
  - ✓ this is no surprise for `old timers' (like me) since as I just explained, single particle inclusive spectra were what proved QCD in the late 1970's before jets.
- **Reference for A+A and p+A spectra**
  - ✓ π^0 measurement in same experiment allows us the study of nuclear effect with less systematic uncertainties.

PHENIX (p+p) PRL 91, 241803 (2003)

RHIC pp spectra √s=200 GeV nicely illustrate hard scattering phenomenology



- Good agreement with NLO pQCD
  - ✓ this is no surprise for `old timers' (like me) since as I just explained, single particle inclusive spectra were what proved QCD in the late 1970's before jets.
- **Reference for A+A and p+A spectra**
  - ✓ π^0 measurement in same experiment allows us the study of nuclear effect with less systematic uncertainties.

PHENIX (p+p) PRL 91, 241803 (2003)

μ-A DIS at AGS (1973)--Hard-Scattering is pointlike

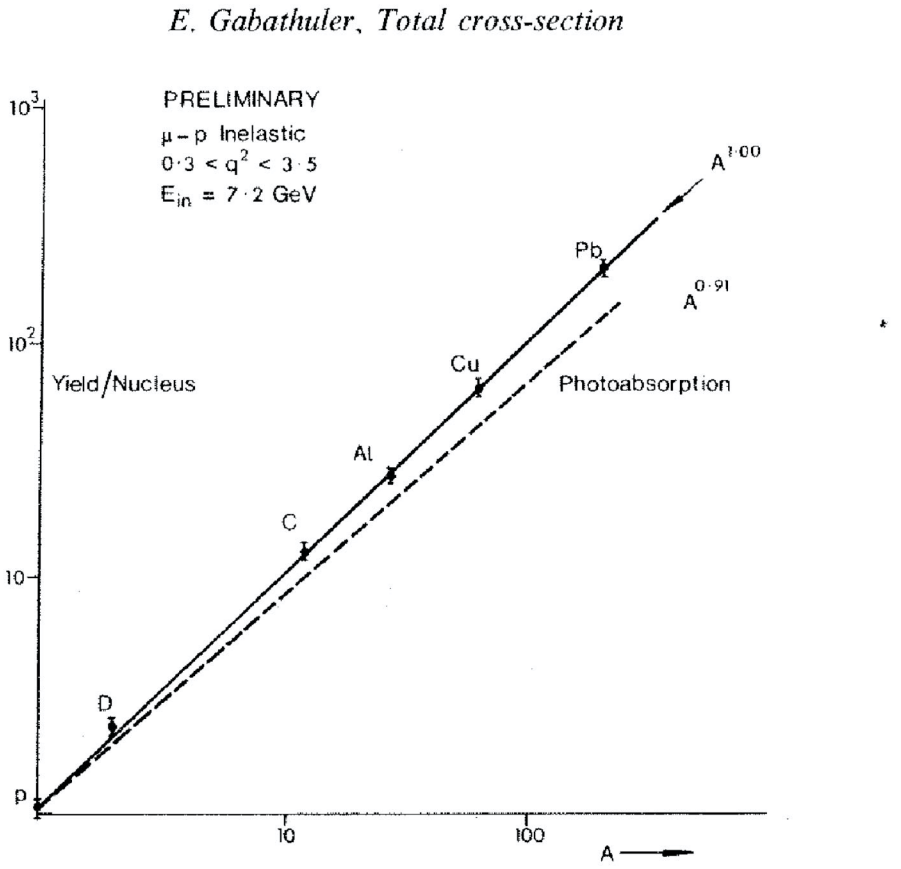
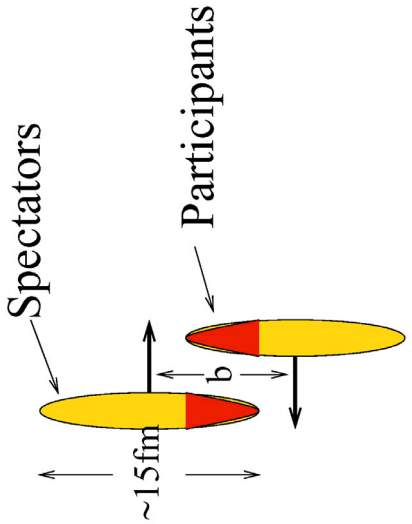


Fig. 14. The A dependence of the inelastic muon cross-section as presented by Tannenbaum (see discussion).

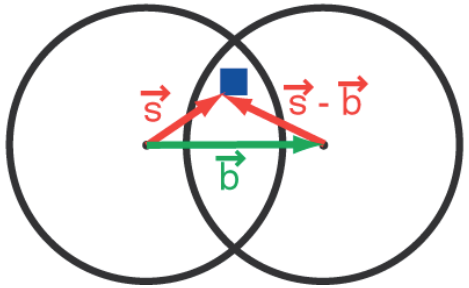
AGS $\mu - A$ scattering data, from E. Gabathuler's talk, [Proc. 6th Int. Symposium on Electron and Photon Interactions at High Energies, Bonn (1973)].

- ♡ DIS is pointlike $A^{1.00}$ even at modest q^2—no shadowing.
- ♡ Photoproduction is shadowed—$A^{0.91}$

High p_T in A+B collisions---T_{AB} Scaling



looking down



view along beam axis

- For point-like processes, the cross section in p+A or A+B collisions compared to p-p is simply proportional to the relative number of pointlike encounters

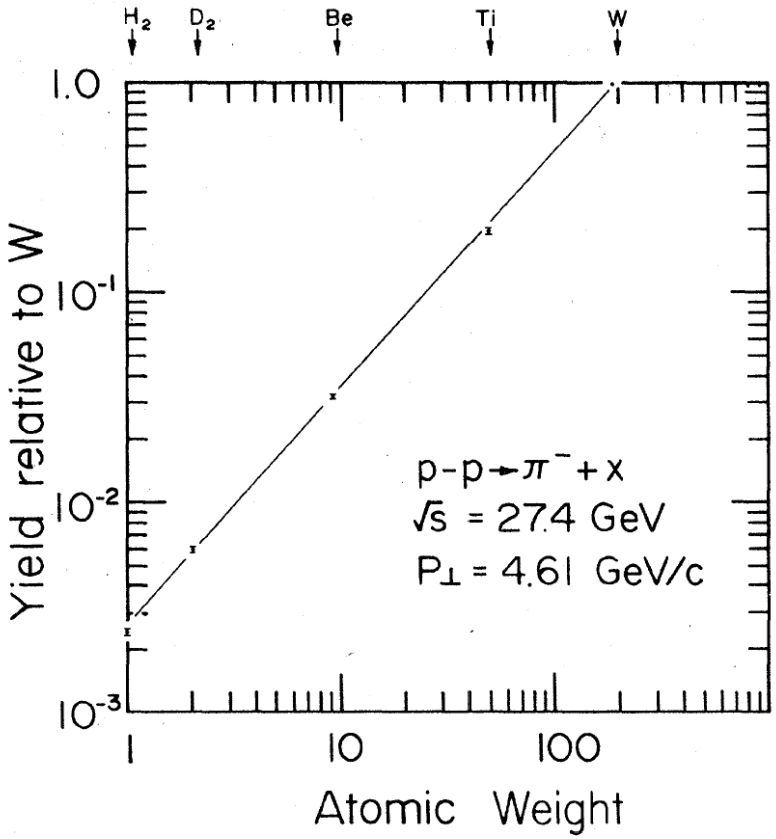
  - ✓ A for p+A, AB for A+B for the total rate

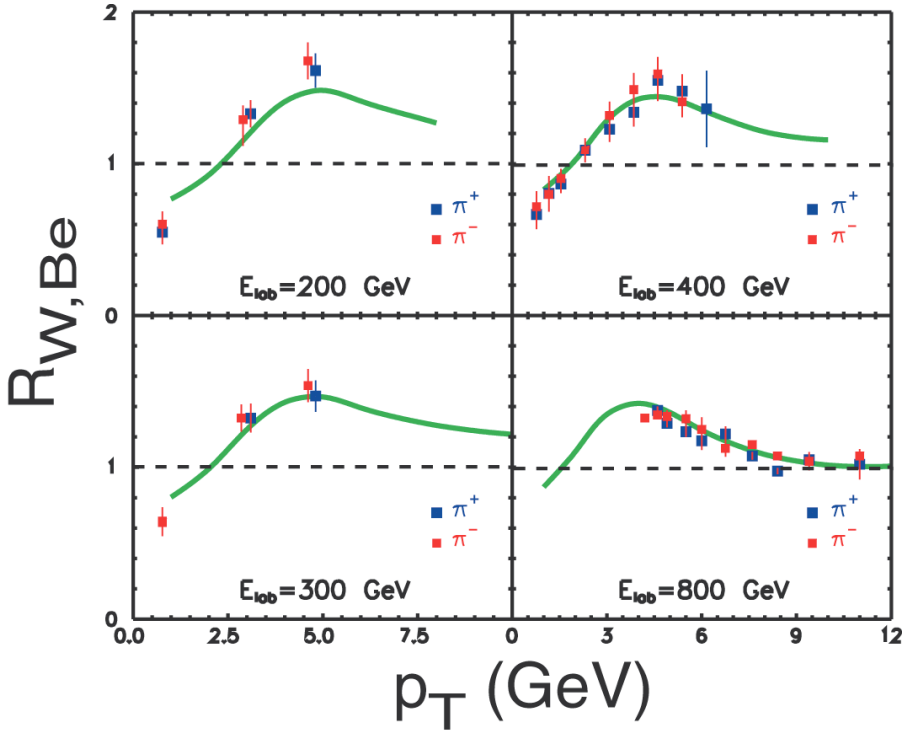
  - ✓ T_{AB} the overlap integral of the nuclear profile functions, as a function of impact parameter b

What really Happens for p+A: $R_A > 1$!

The anomalous nuclear enhancement a.k.a. the Cronin effect-- due to multiple scattering of initial nucleons (or constituents)

- Known since 1975 that yields increase as A^{α}, $\alpha > 1$





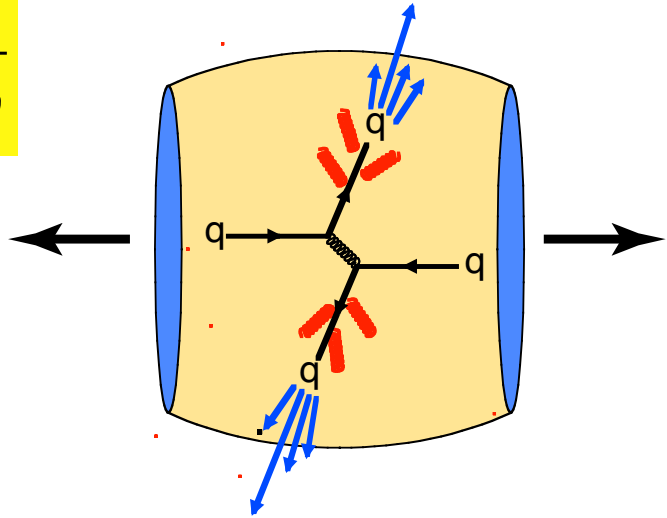
- J.W. Cronin et al., Phys. Rev. **D11**, 3105 (1975)
- D. Antreasyan et al., Phys. Rev. **D19**, 764 (1979)

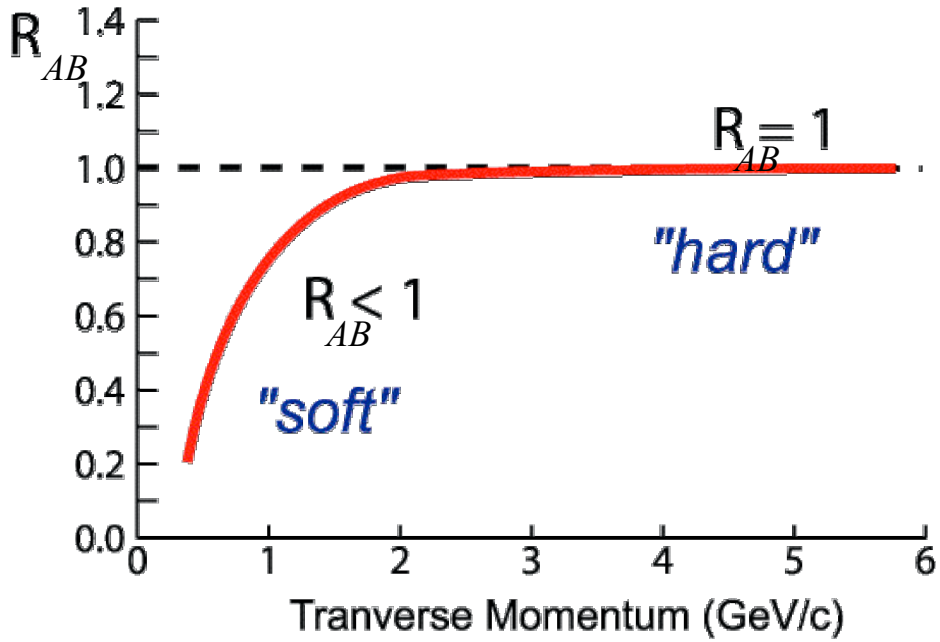
The Nuclear Modification Factor R_{AB} is the ratio of pointlike scaling of an A+B measurement to p-p

Nuclear Modification Factor:

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

Compare A+B to p-p cross sections



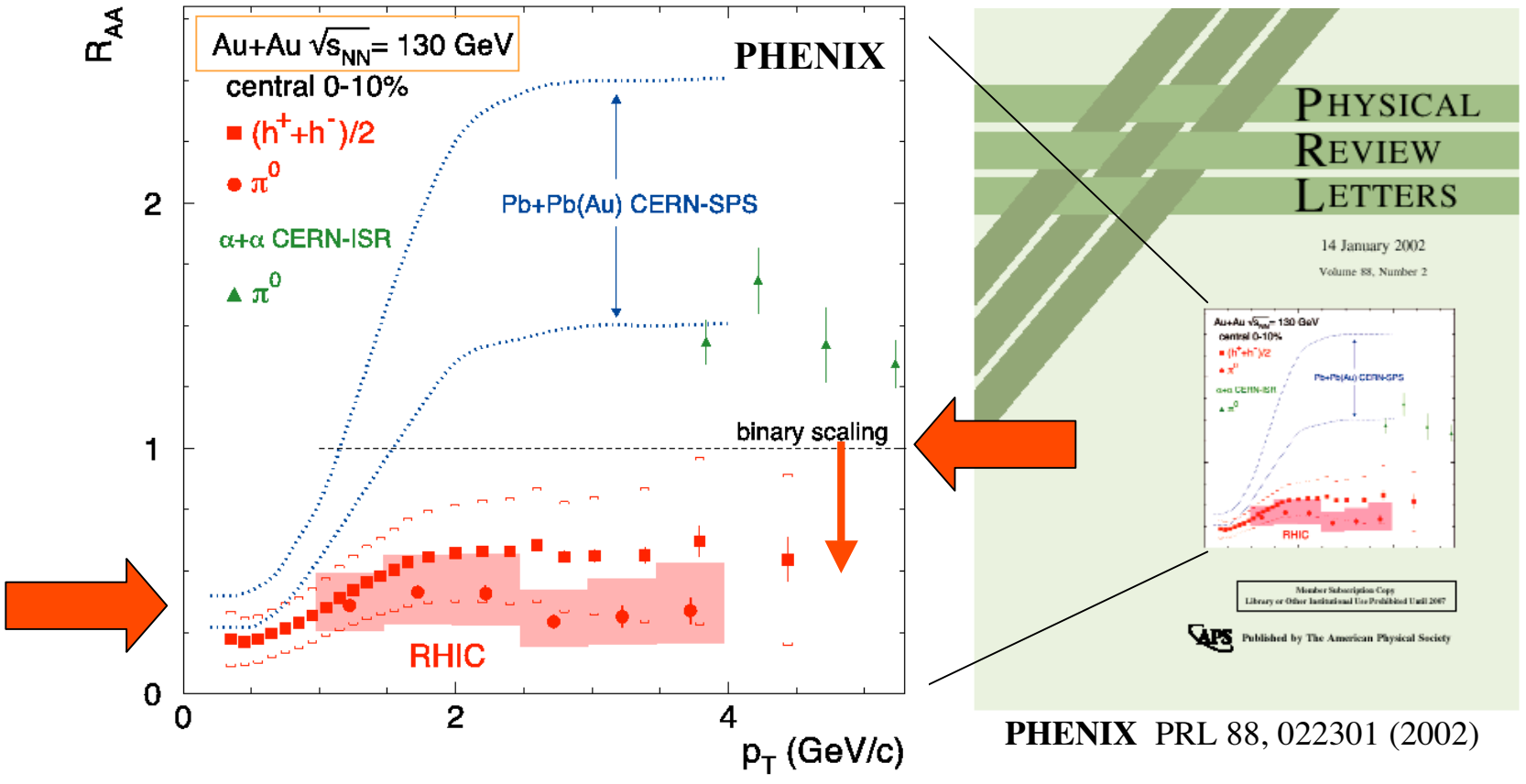


"Nominal effects":

$R_{AB} < 1$ in regime of soft physics

$R_{AB} = 1$ at high-p_T where hard scattering dominates

Run-1: RHIC Headline News … January 2002
THE major discovery at RHIC (so far)



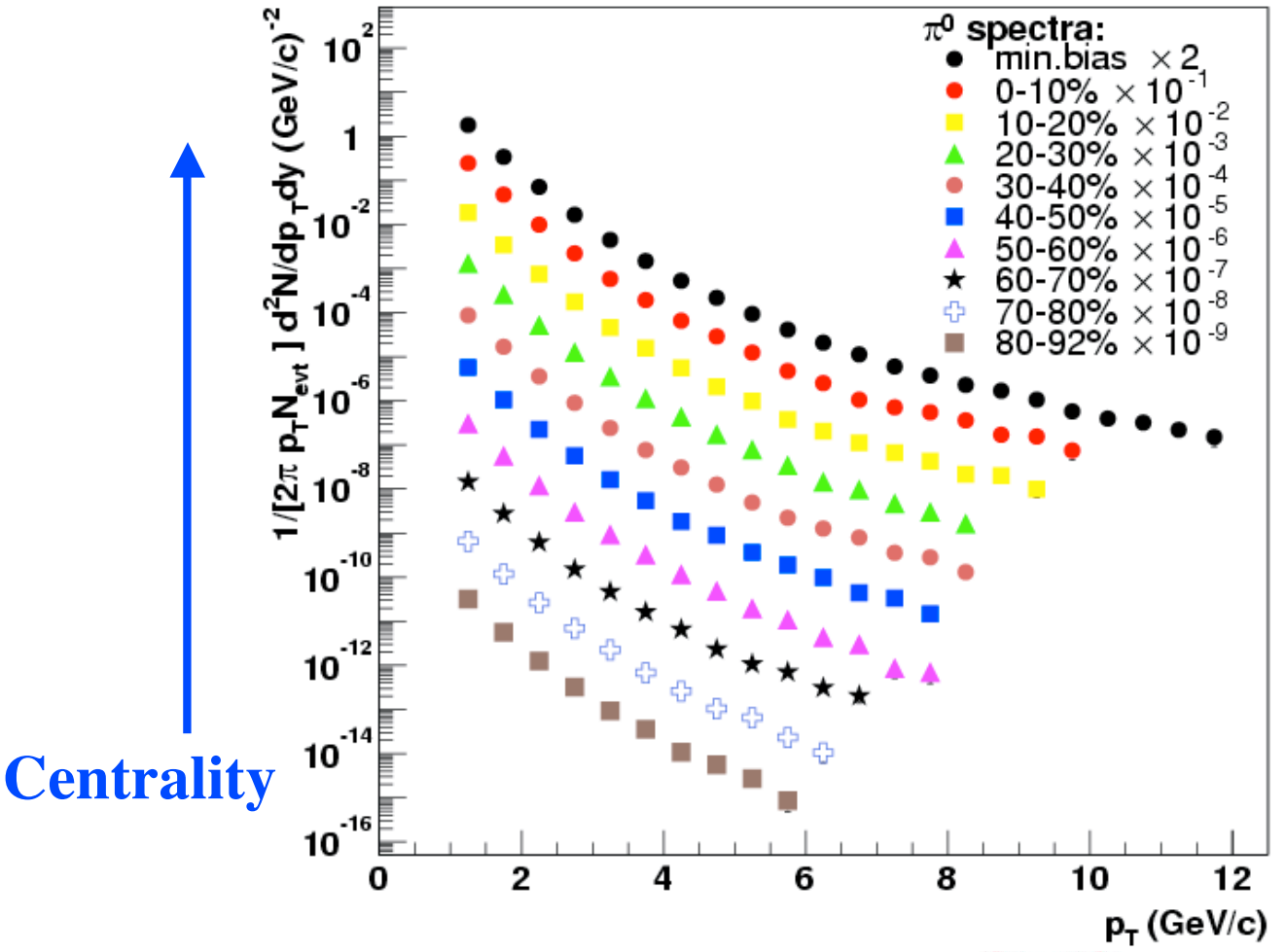
PHENIX PRL 88, 022301 (2002)

First observation of *large* suppression of high p_T hadron yields

"Jet Quenching''? == Quark Gluon Plasma?

RHIC Run 2 $\sqrt{s}$=200 GeV/c:1) π^0 extend to higher p_T in Au+Au collisions; 2) + π^0 reference in p-p

Au-Au nucl-ex/0304022 Phys. Rev. Letters **91**, 072301 (2003)

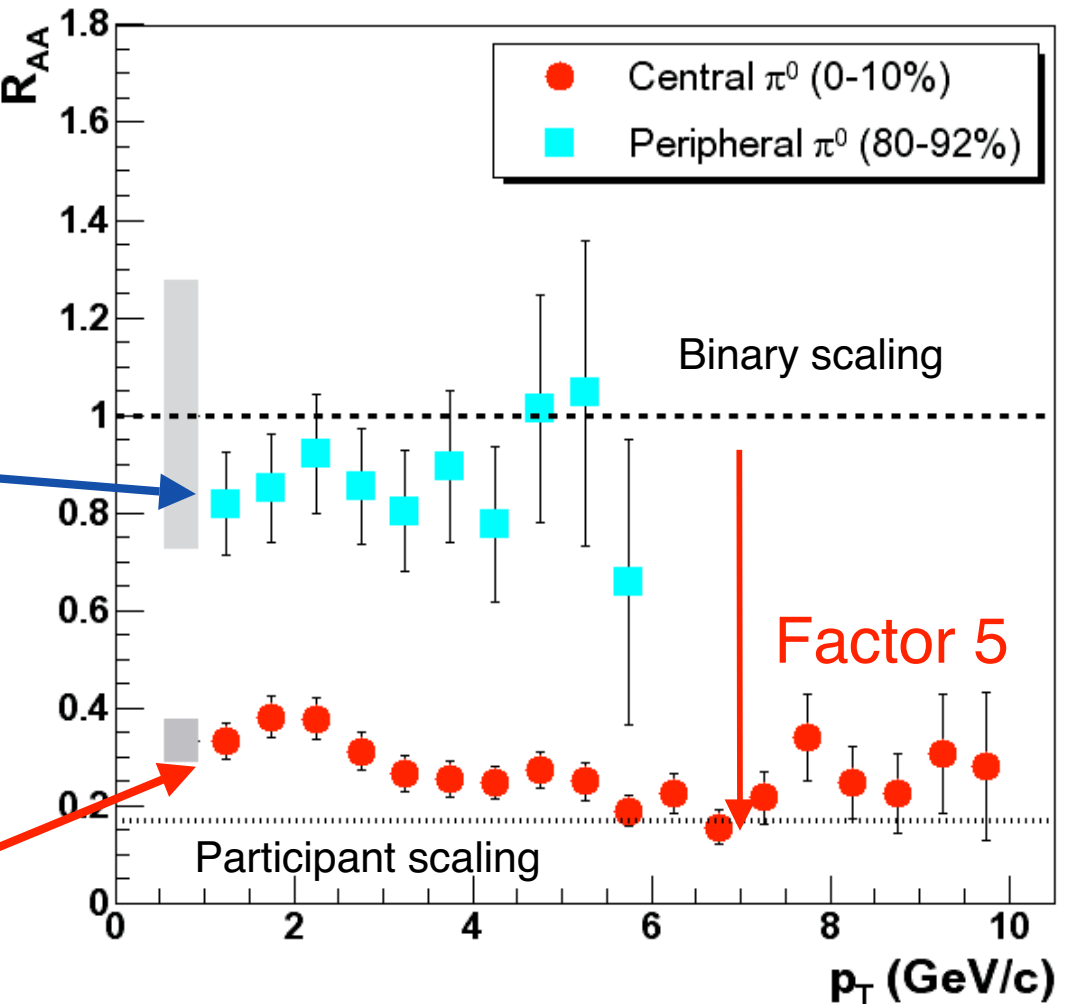


R_{AA} (π^0) AuAu:pp 200GeV
High p_T Suppression flat from 3 to 10 GeV/c !

$$R_{AA} = \frac{\text{Yield}_{AuAu}(p_T)}{\langle T_{AB} \rangle_{AuAu} \times \sigma_{pp}(p_T)}$$

Peripheral AuAu - consistent with N_{coll} scaling (large systematic error)

Large suppression in central AuAu - close to participant scaling at high P_T

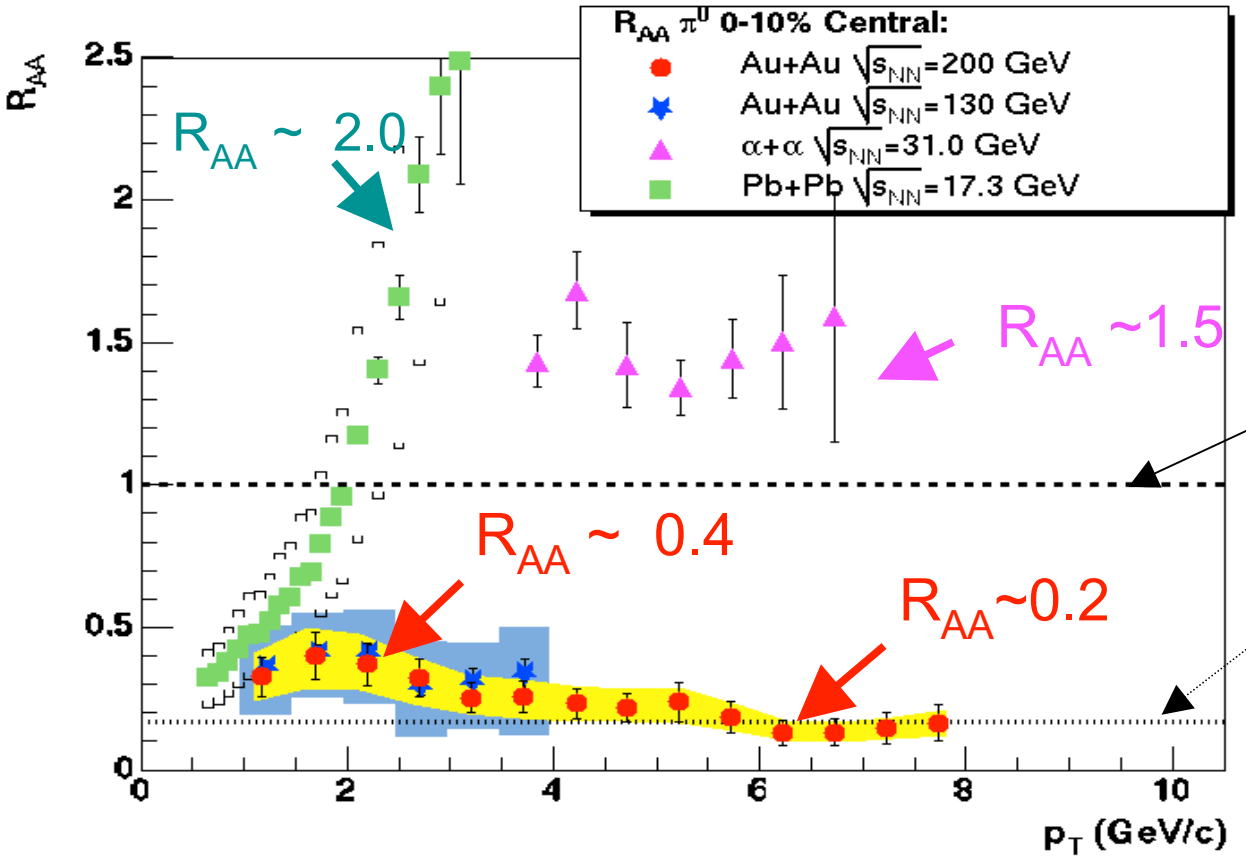


PRL 91, 072301 (2003)

Suppression at RHIC $\sqrt{s_{NN}}$=130 GeV is unique in A+A collisions--Enhancement at lower $\sqrt{s_{NN}}$

CERN: Pb+Pb ($\sqrt{s_{NN}}$ ~ 17 GeV), α+α ($\sqrt{s_{NN}}$ ~31 GeV)
plus all previous measurements in p+A in same x range

}Cronin Enhancement

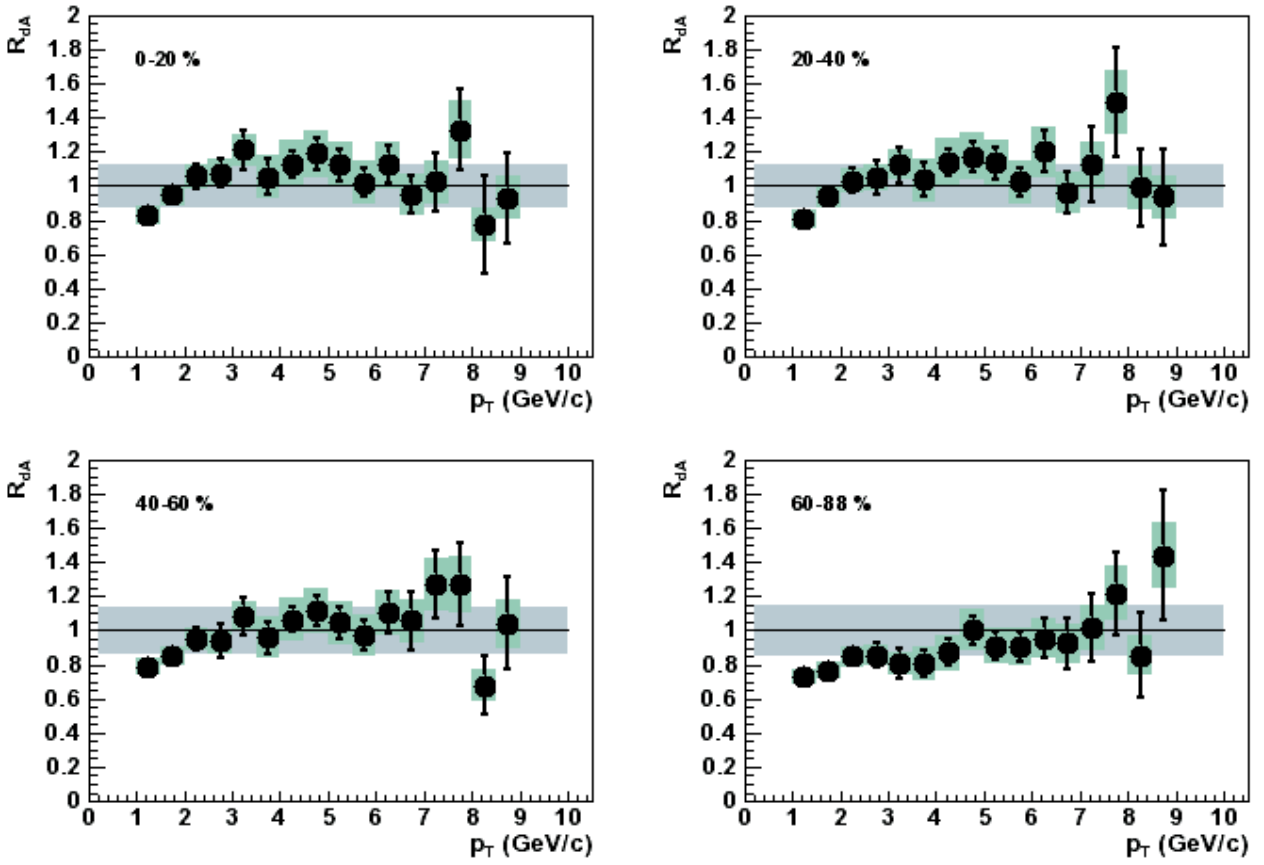


BCMOR Collab.

A.L.S.Angelis PLB 185, 213 (1987)
WA98, EPJ C 23, 225 (2002)
PHENIX, PRL 88 022301 (2002)
D.d'E. PHENIX Preliminary QM2002

Initial state effect (p+A) only depends on x, final state in A+A could depend on $\sqrt{s_{NN}}$ ⇐

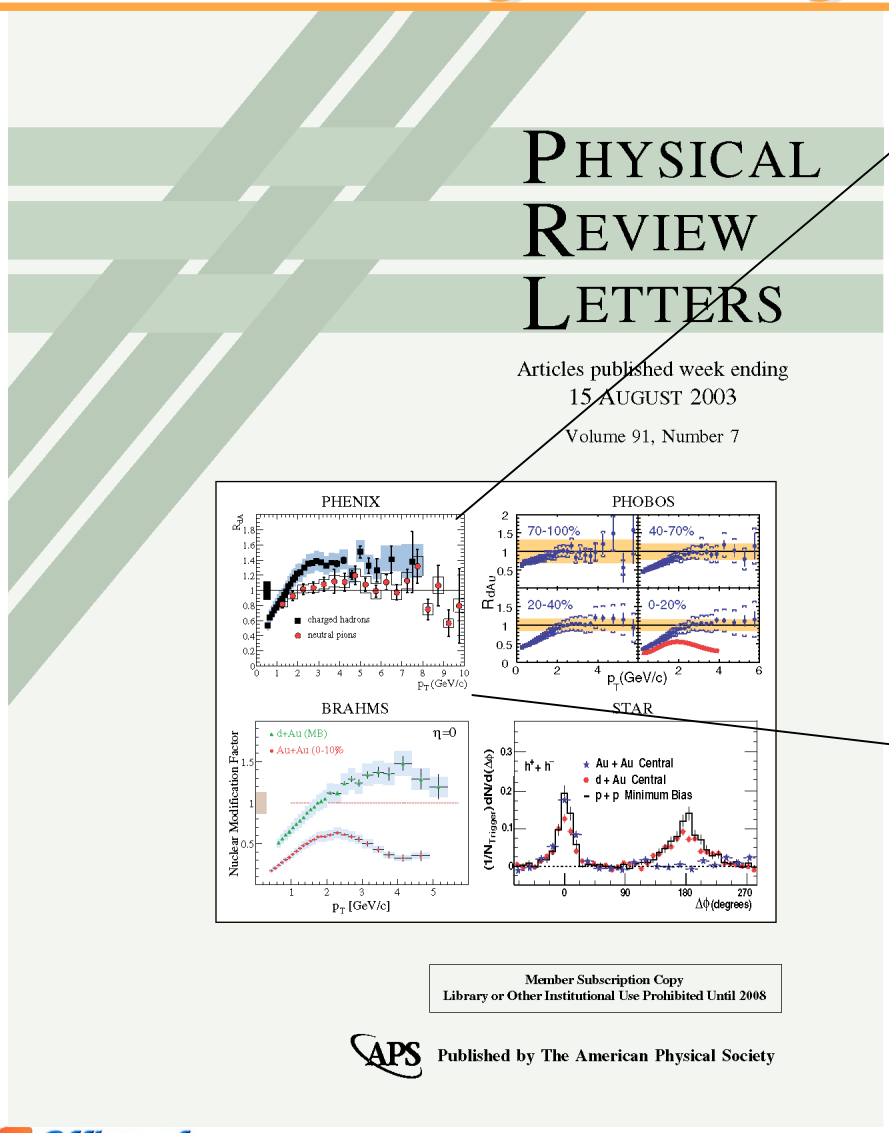
Cronin effect observed in d+Au at RHIC $\sqrt{s_{NN}}$=200 GeV, confirms x is a good variable

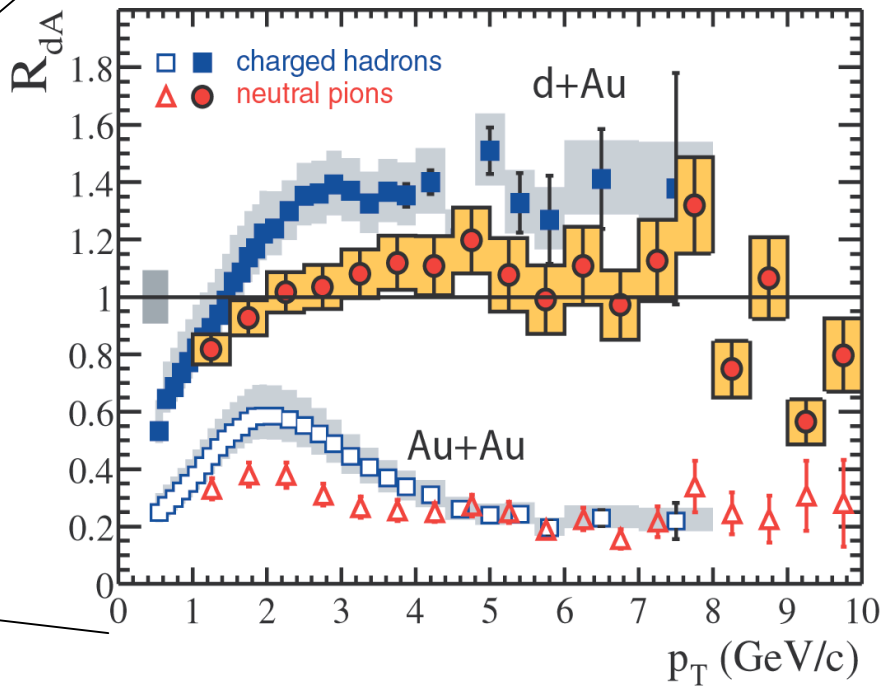


PHENIX preliminary π^0 d+Au vs centrality for DNP2003

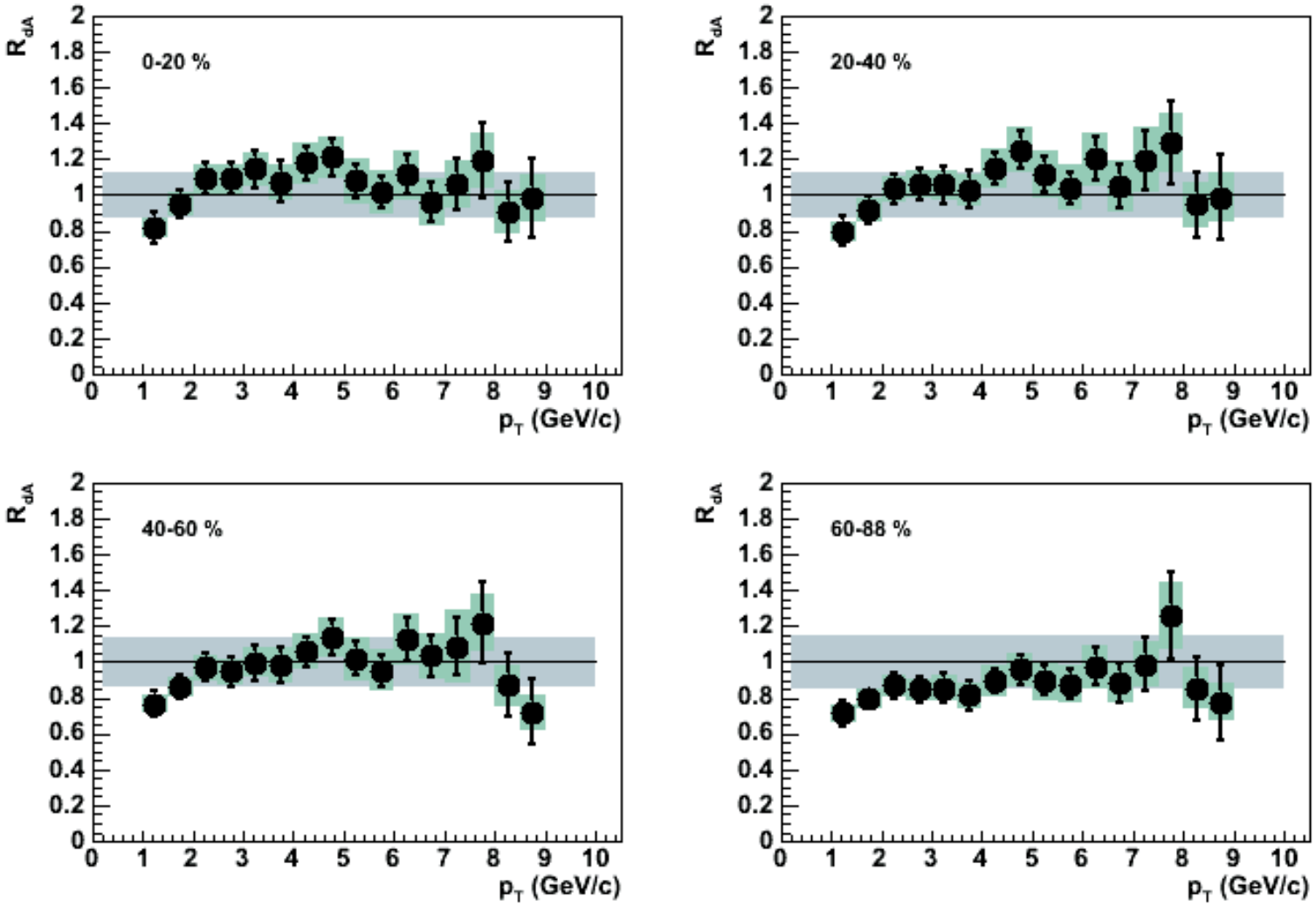
This leads to our second PRL cover, our first being the original Au+Au discovery

This leads to our second PRL cover, our first being the original Au+Au discovery

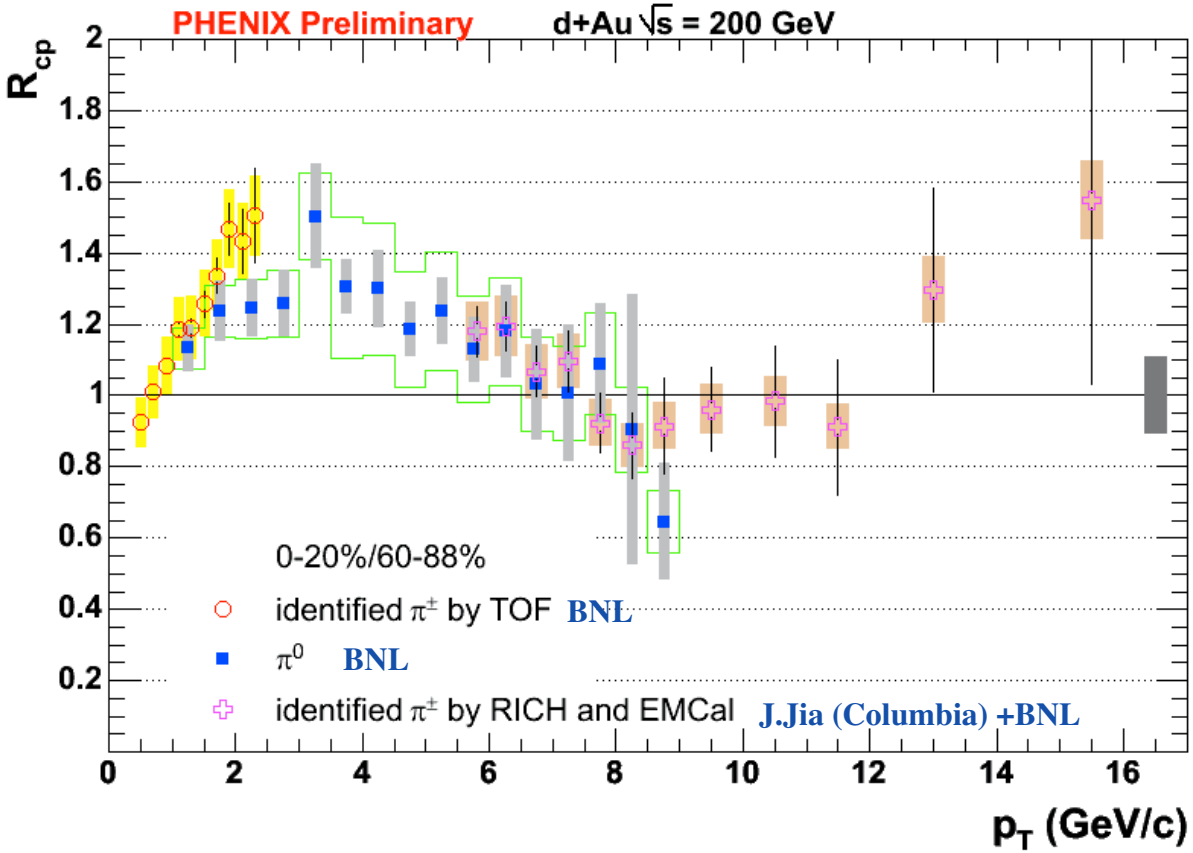




R_{dAu} Final 02/12/04



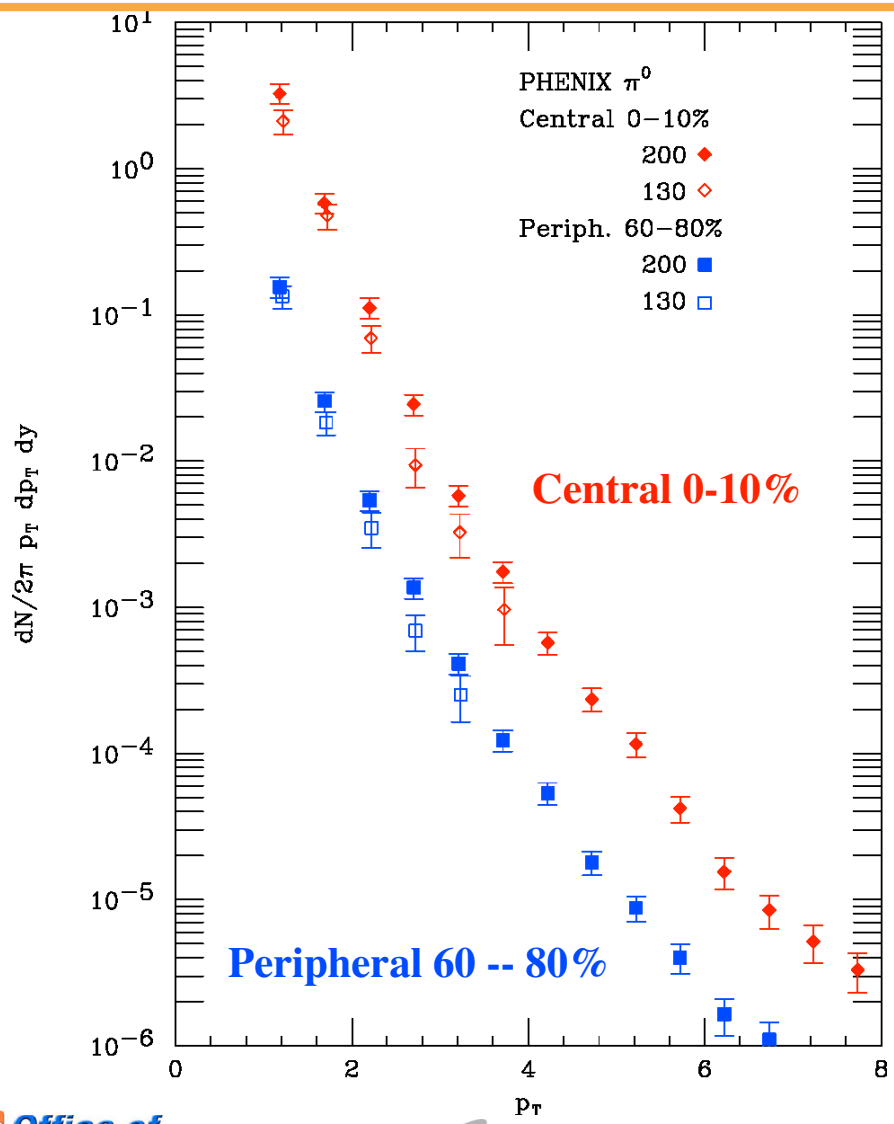
Does The Enhancement (R_{cp}) of pions Vanish At Higher p_T ??



- **R_{CP}**
  - ✓ Compares Yields in central and peripheral scaled by N_{coll}
  - ✓ Many systematics cancel
- **Different parts of PHENIX measure different p_T ranges of π**
- **Enhancement in central vanishes at high p_T**

Use EMCal to reject particles with E/p < 0.3
to eliminate fake high p_T particles from decays & conversions

Does the $\sqrt{s_{NN}}$=130, 200 GeV dependence of suppressed π^0 follow QCD--x_T scaling

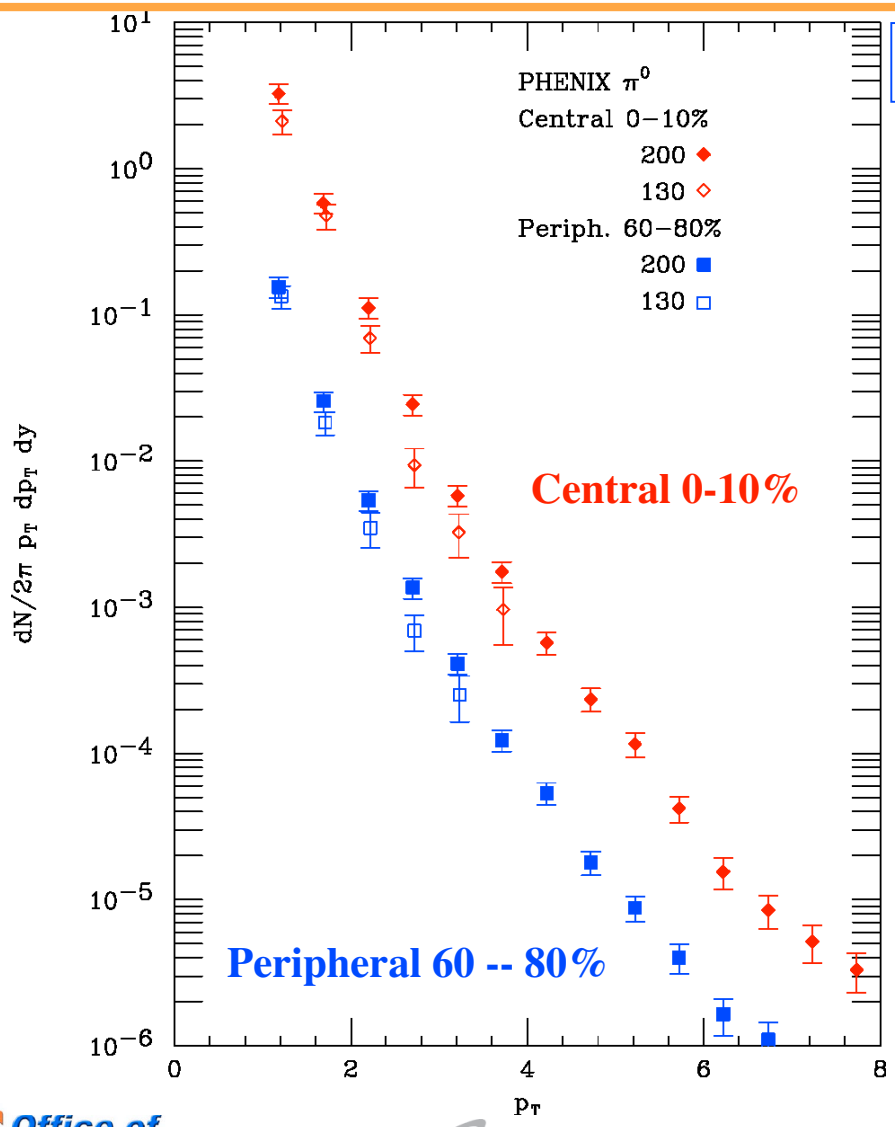


$$E\frac{d^3\sigma}{dp^3} = \frac{1}{p_T^n} F\left(\frac{2p_T}{\sqrt{s}}\right)$$

$x_T = 2p_T/\sqrt{s}$

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

Does the $\sqrt{s_{NN}}$=130, 200 GeV dependence of suppressed π^0 follow QCD--x_T scaling



Berman, Bjorken, Kogut, PR**D4**,3388(1971)

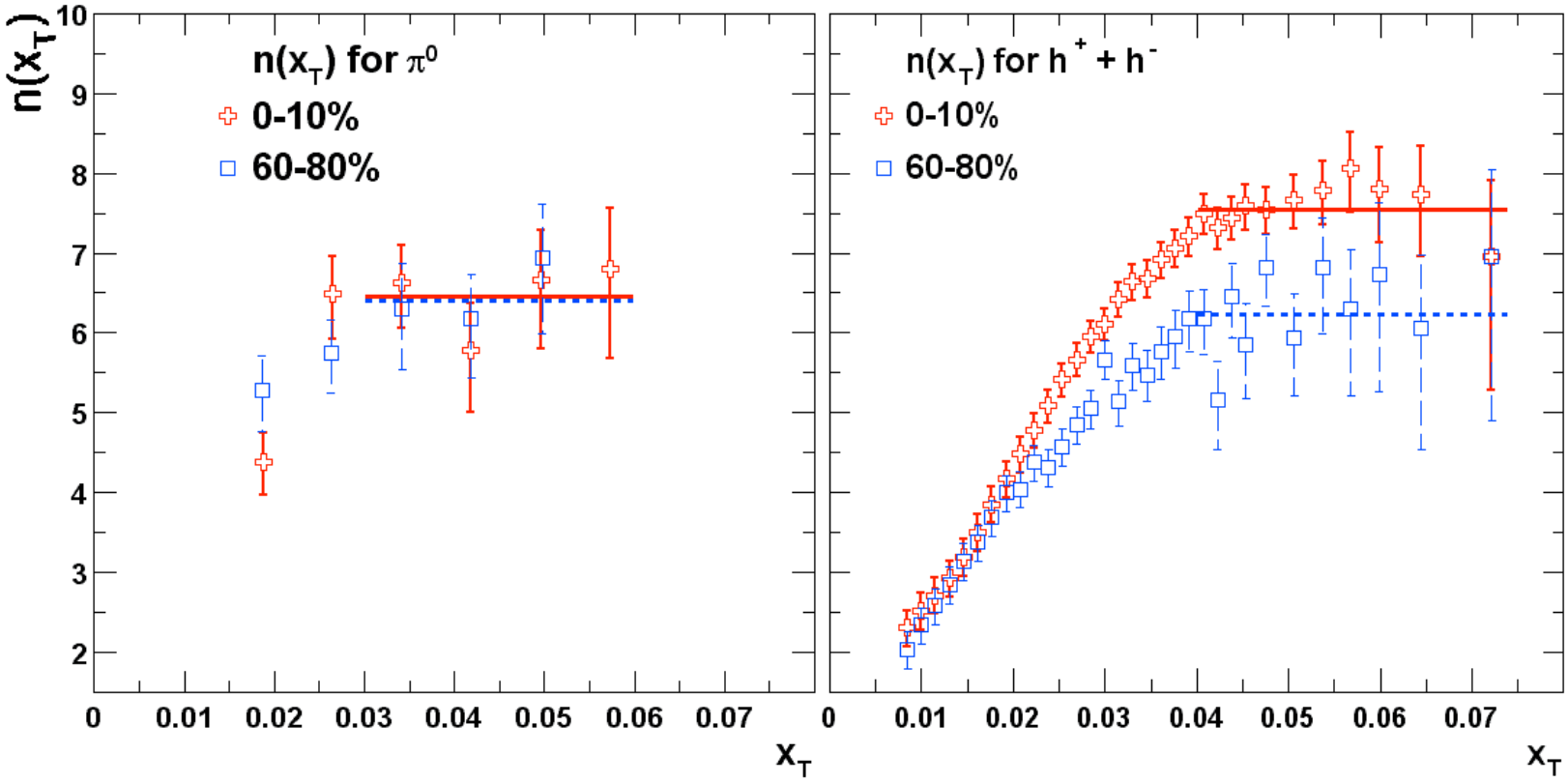
$$E\frac{d^3\sigma}{dp^3} = \frac{1}{p_T^n} F\left(\frac{2p_T}{\sqrt{s}}\right)$$

$x_T = 2p_T/\sqrt{s}$

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

QCD: Cahalan, Geer, Kogut, Susskind, PR**D11**, 1199 (1975)

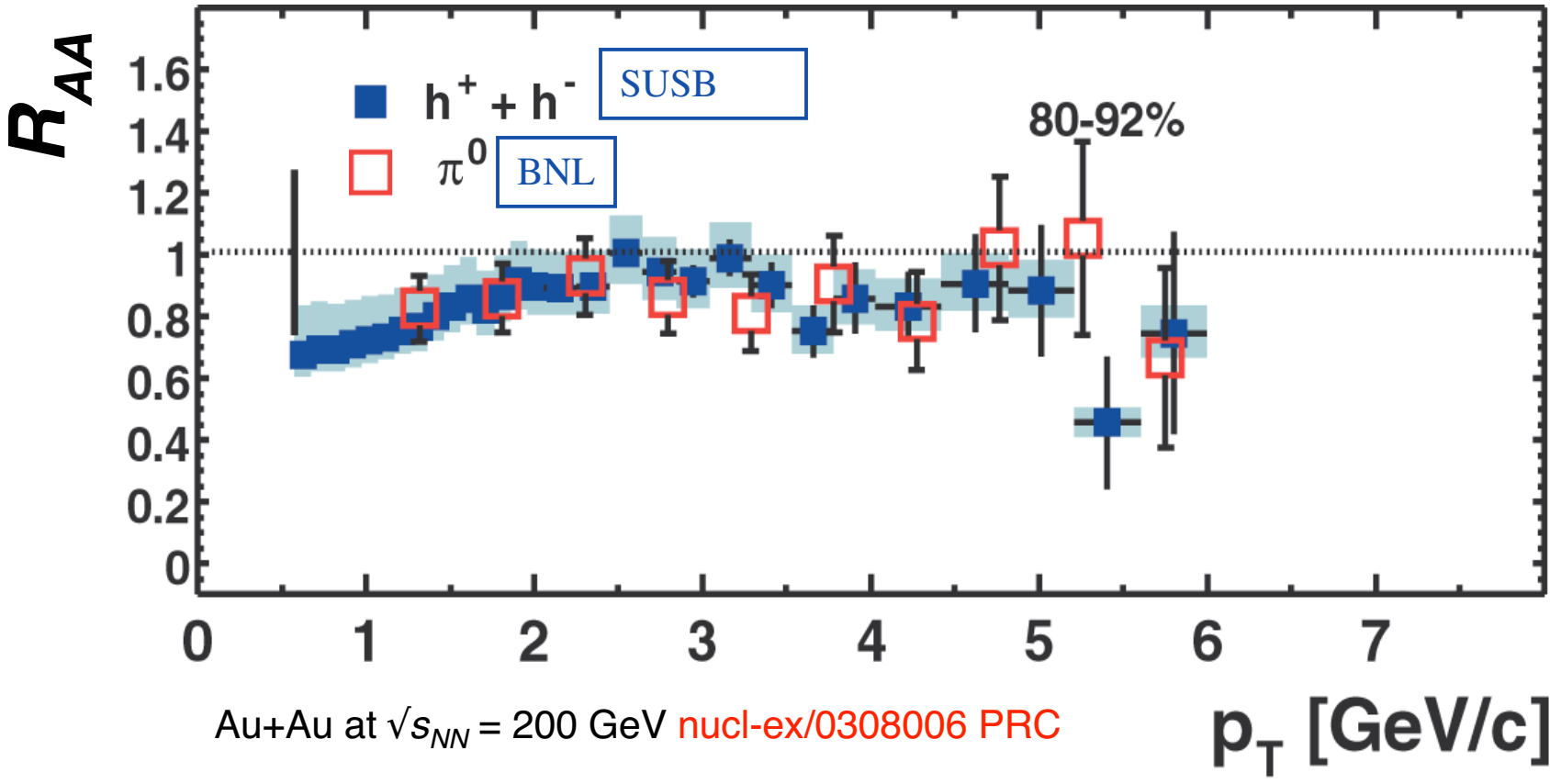
$n(x_T)$ point-by-point 200/130



$$\left(\frac{\sqrt{s_1}}{\sqrt{s_2}}\right)^{n(x_T,\sqrt{s})} = \frac{\frac{Ed^3\sigma}{dp^3}(x_T,\sqrt{s_2})}{\frac{Ed^3\sigma}{dp^3}(x_T,\sqrt{s_1})}$$

- π^0 x_T scales in both peripheral and central Au+Au with same value of n=6.3 as in p-p
- $(h^+ + h^-)/2$ x_T scales in peripheral same as p-p but difference between central and peripheral is significant

Charged Hadron excess $2.0<p_T<4.5$ GeV/c at 130 and 200, vanishes for $p_T>4.5$ GeV/c at 200

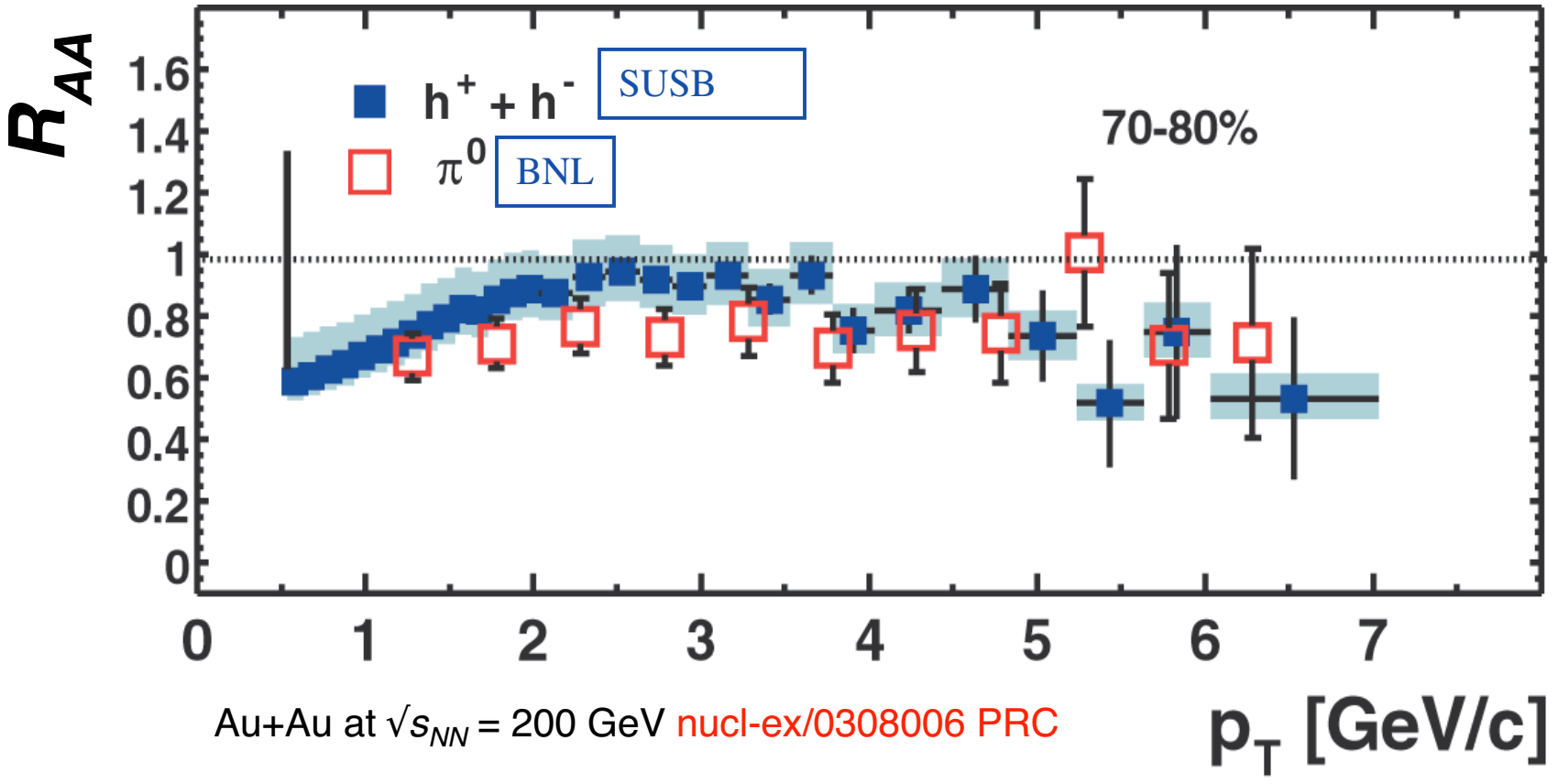


Au+Au at $\sqrt{s_{NN}}$ = 200 GeV nucl-ex/0308006 PRC

1) a clear violation of x_T scaling

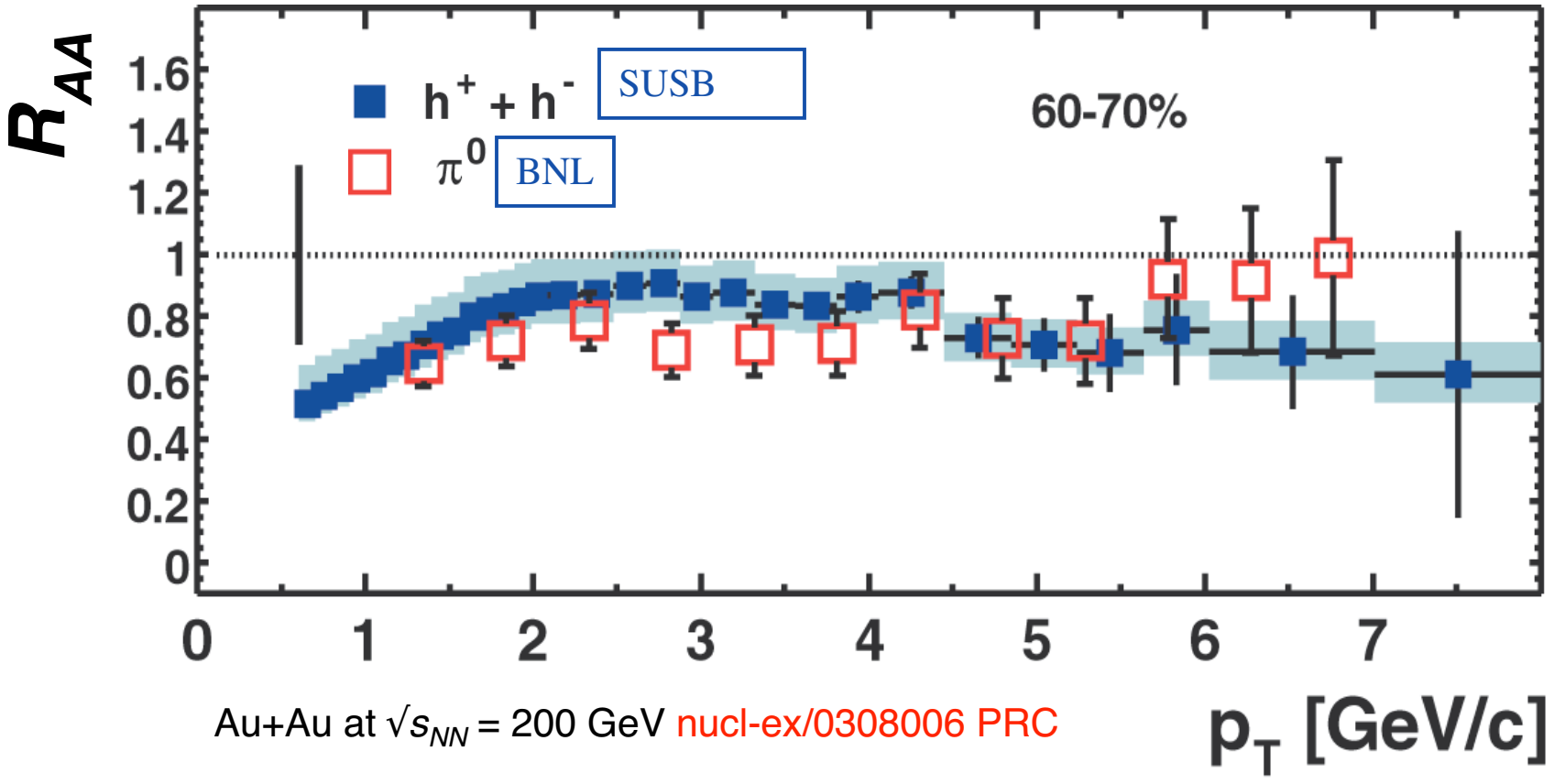
2) a measurement of ΔE vs centrality

Charged Hadron excess $2.0<p_T<4.5$ GeV/c at 130 and 200, vanishes for $p_T>4.5$ GeV/c at 200



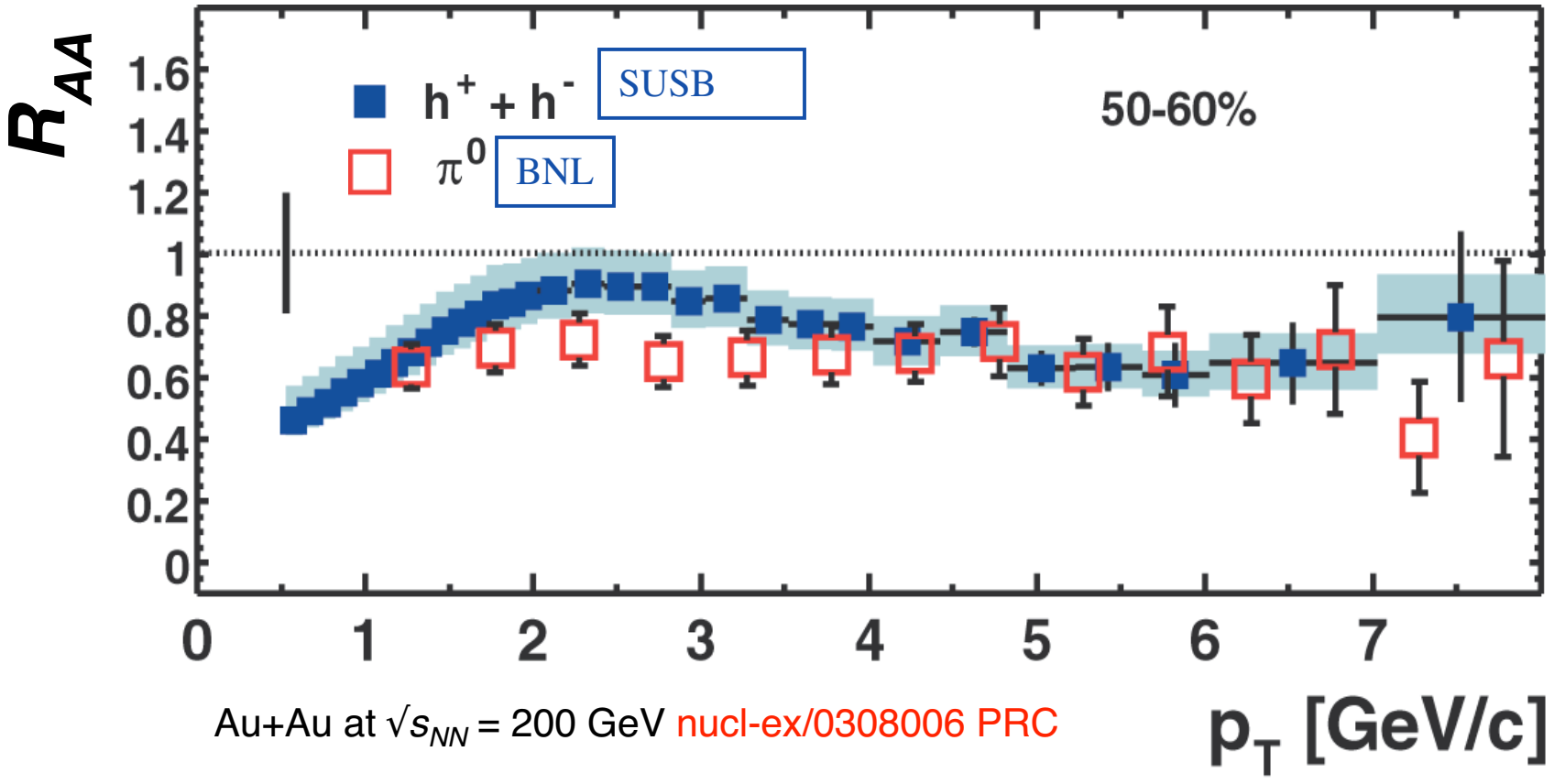
1) a clear violation of x_T scaling
2) a measurement of ΔE vs centrality

Charged Hadron excess $2.0<p_T<4.5$ GeV/c at 130 and 200, vanishes for $p_T>4.5$ GeV/c at 200



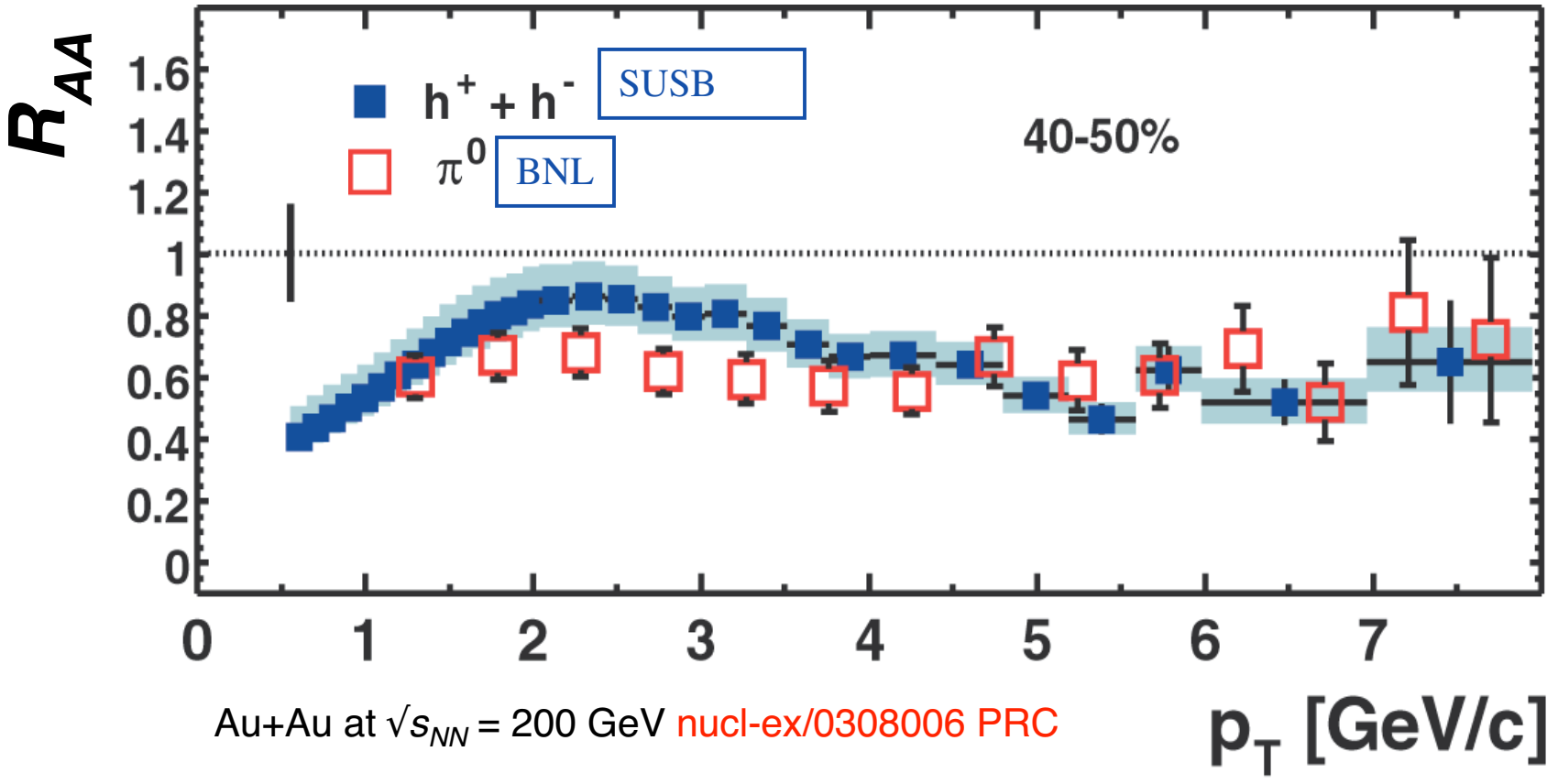
1) a clear violation of x_T scaling
2) a measurement of ΔE vs centrality

Charged Hadron excess $2.0<p_T<4.5$ GeV/c at 130 and 200, vanishes for $p_T>4.5$ GeV/c at 200



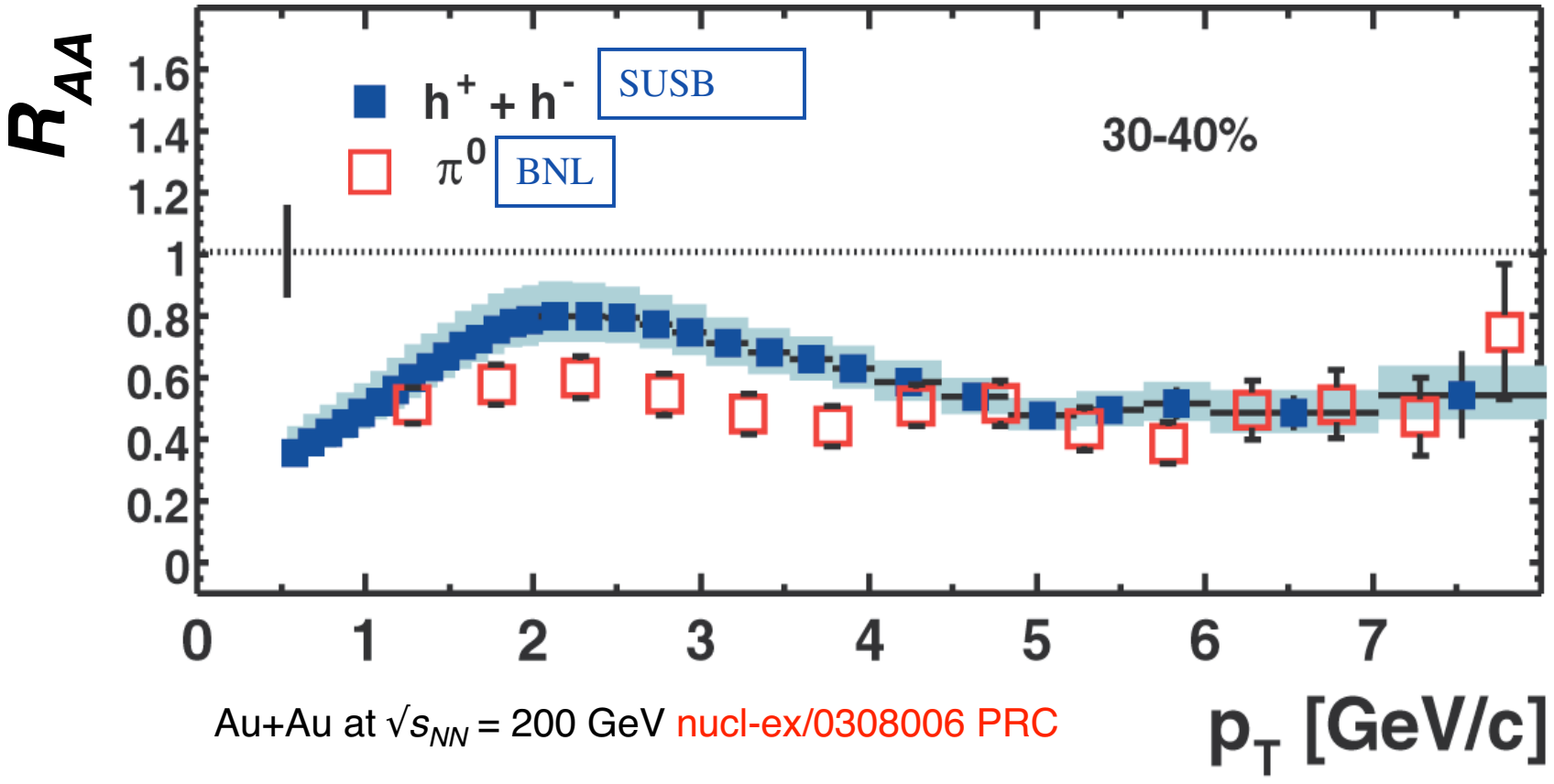
1) a clear violation of x_T scaling
2) a measurement of ΔE vs centrality

Charged Hadron excess $2.0<p_T<4.5$ GeV/c at 130 and 200, vanishes for $p_T>4.5$ GeV/c at 200



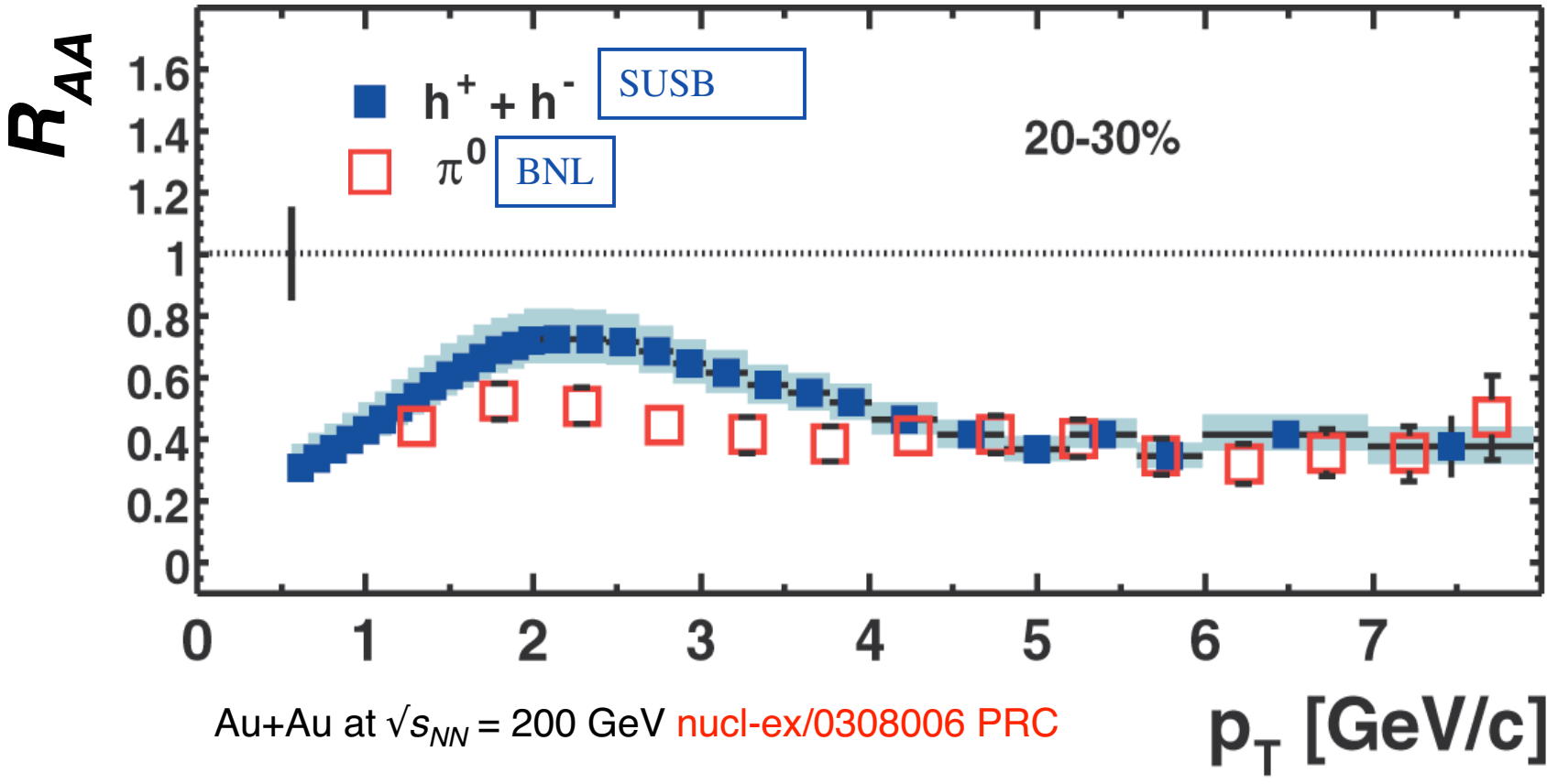
1) a clear violation of x_T scaling
2) a measurement of ΔE vs centrality

Charged Hadron excess $2.0<p_T<4.5$ GeV/c at 130 and 200, vanishes for $p_T>4.5$ GeV/c at 200



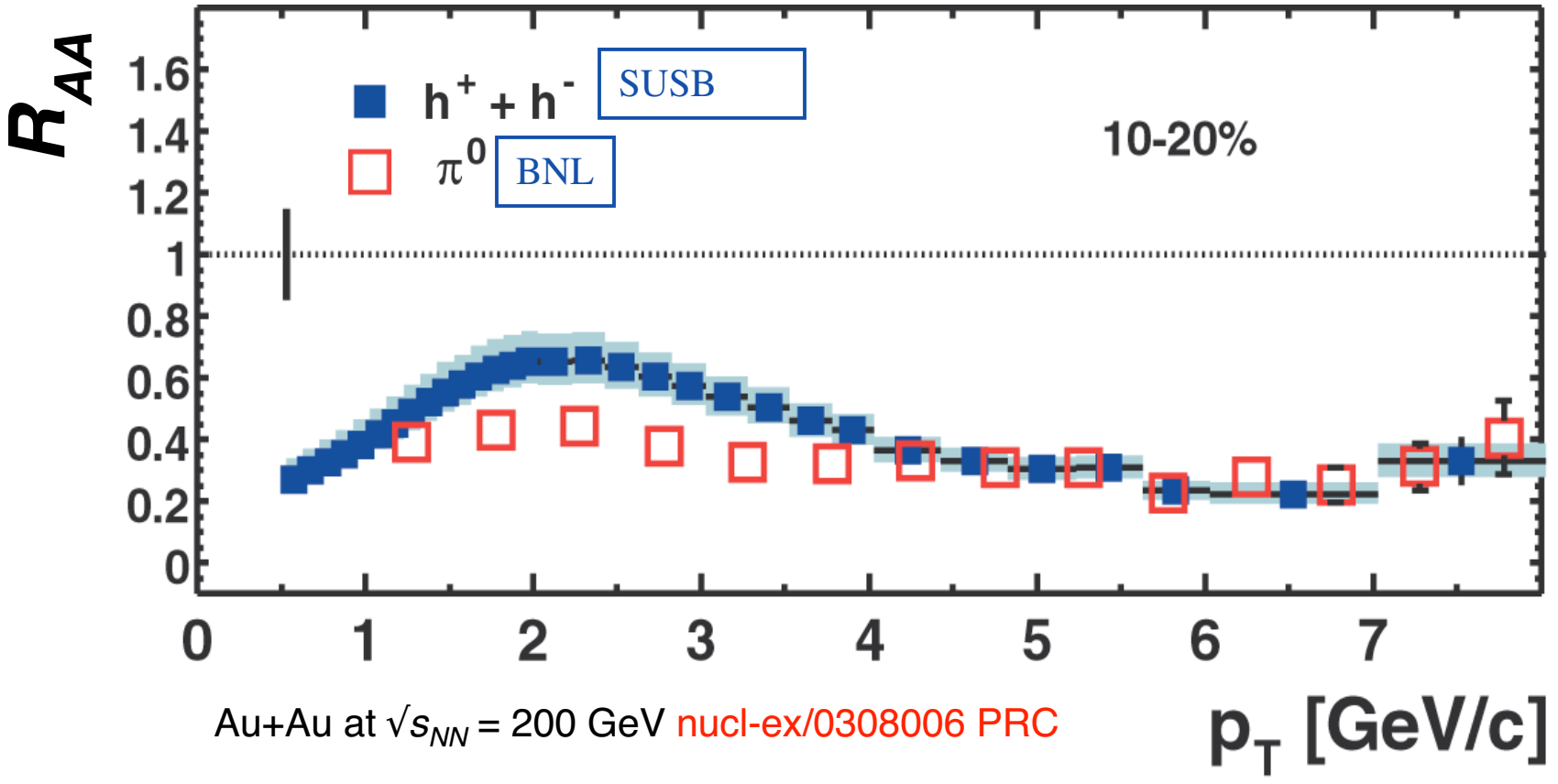
1) a clear violation of x_T scaling
2) a measurement of ΔE vs centrality

Charged Hadron excess $2.0<p_T<4.5$ GeV/c at 130 and 200, vanishes for $p_T>4.5$ GeV/c at 200



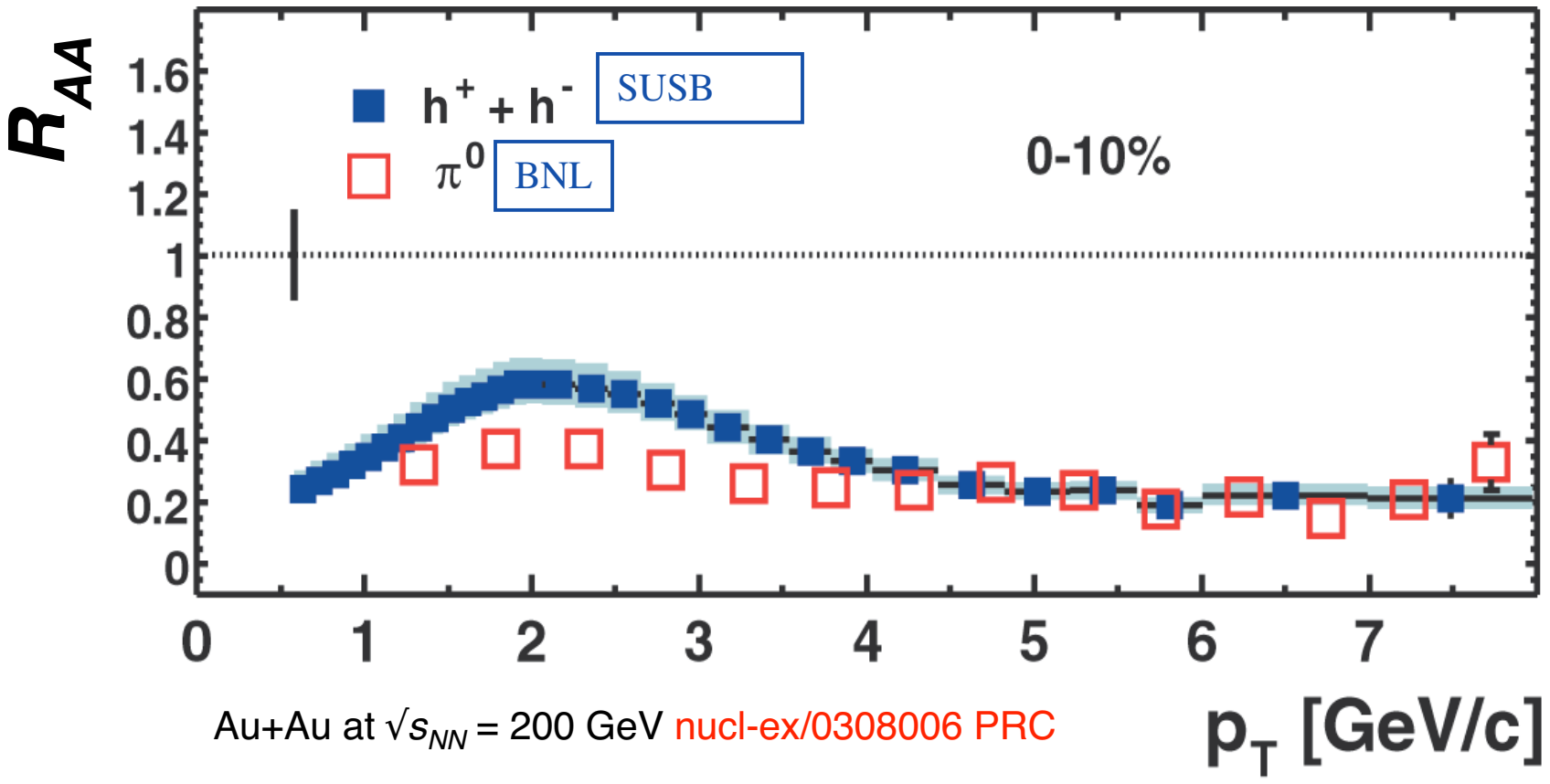
1) a clear violation of x_T scaling
2) a measurement of ΔE vs centrality

Charged Hadron excess $2.0<p_T<4.5$ GeV/c at 130 and 200, vanishes for $p_T>4.5$ GeV/c at 200



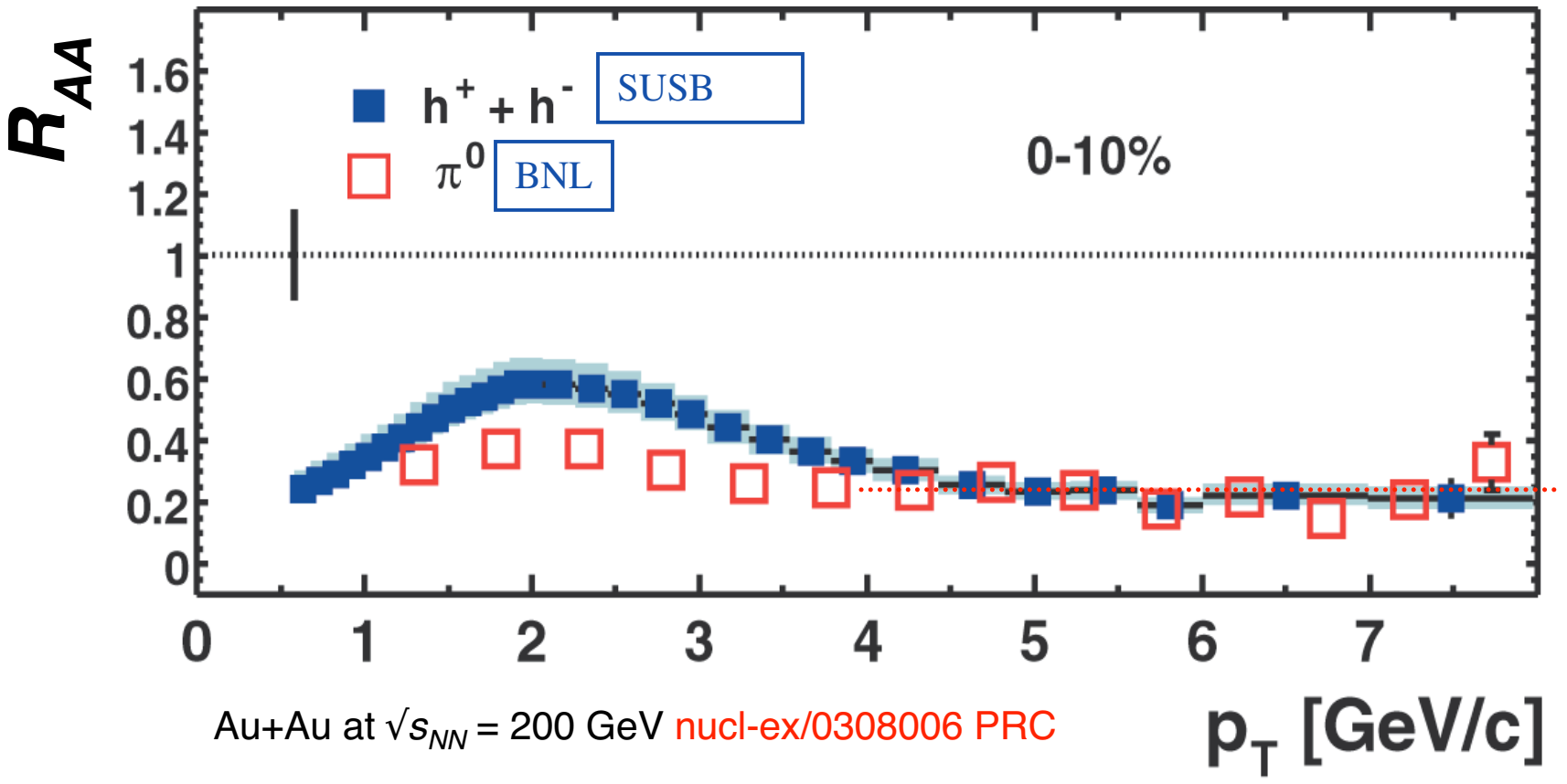
1) a clear violation of x_T scaling
2) a measurement of ΔE vs centrality

Charged Hadron excess $2.0<p_T<4.5$ GeV/c at 130 and 200, vanishes for $p_T>4.5$ GeV/c at 200



1) a clear violation of x_T scaling
2) a measurement of ΔE vs centrality

Charged Hadron excess $2.0<p_T<4.5$ GeV/c at 130 and 200, vanishes for $p_T>4.5$ GeV/c at 200

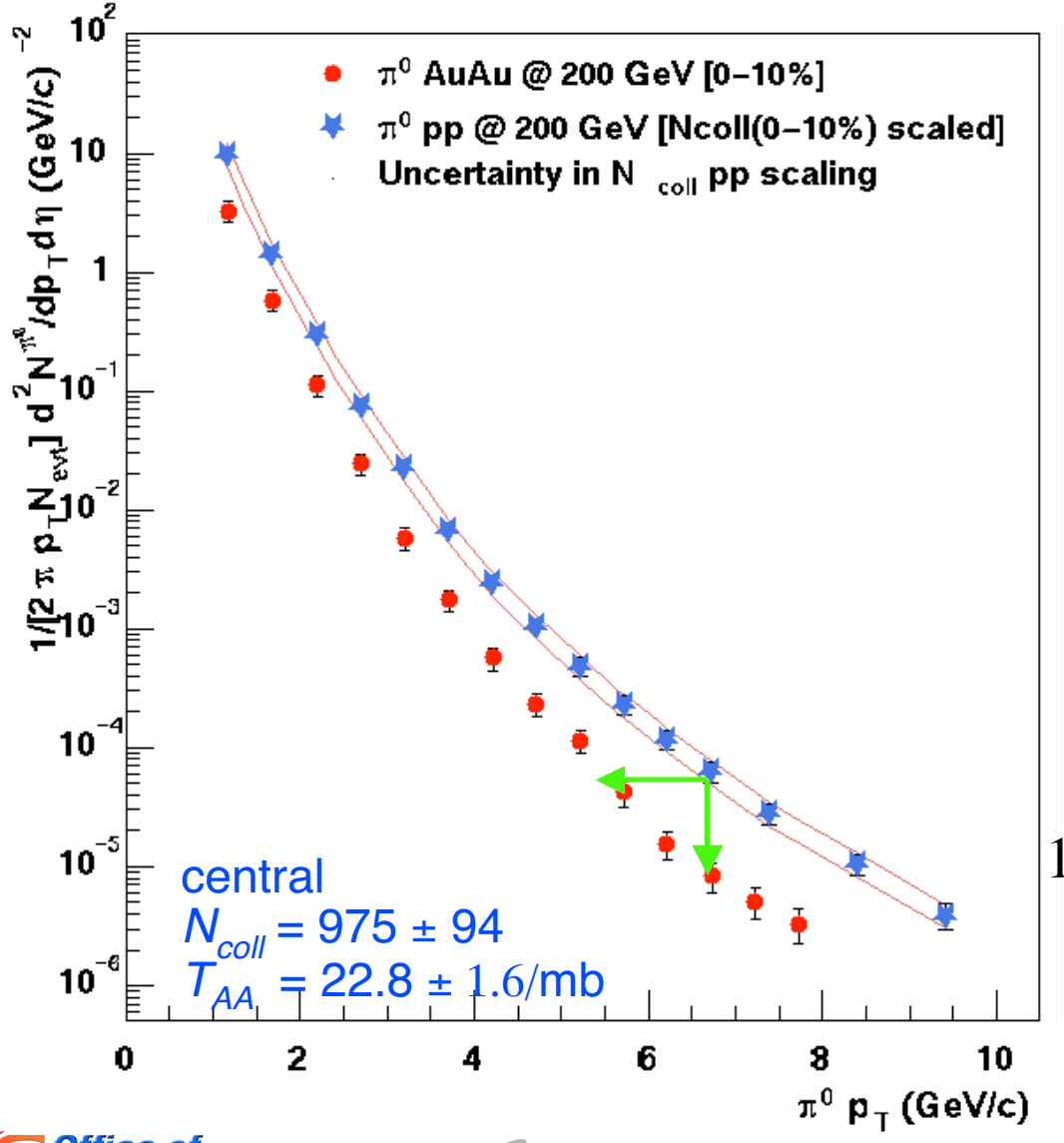


Au+Au at $\sqrt{s_{NN}}$ = 200 GeV nucl-ex/0308006 PRC

1) a clear violation of x_T scaling

2) a measurement of ΔE vs centrality $R_{AA}(p_T)$=constant for $p_T> 4$

Spectra are suppressed for more central collisions--- is this due to a shift caused by energy loss?

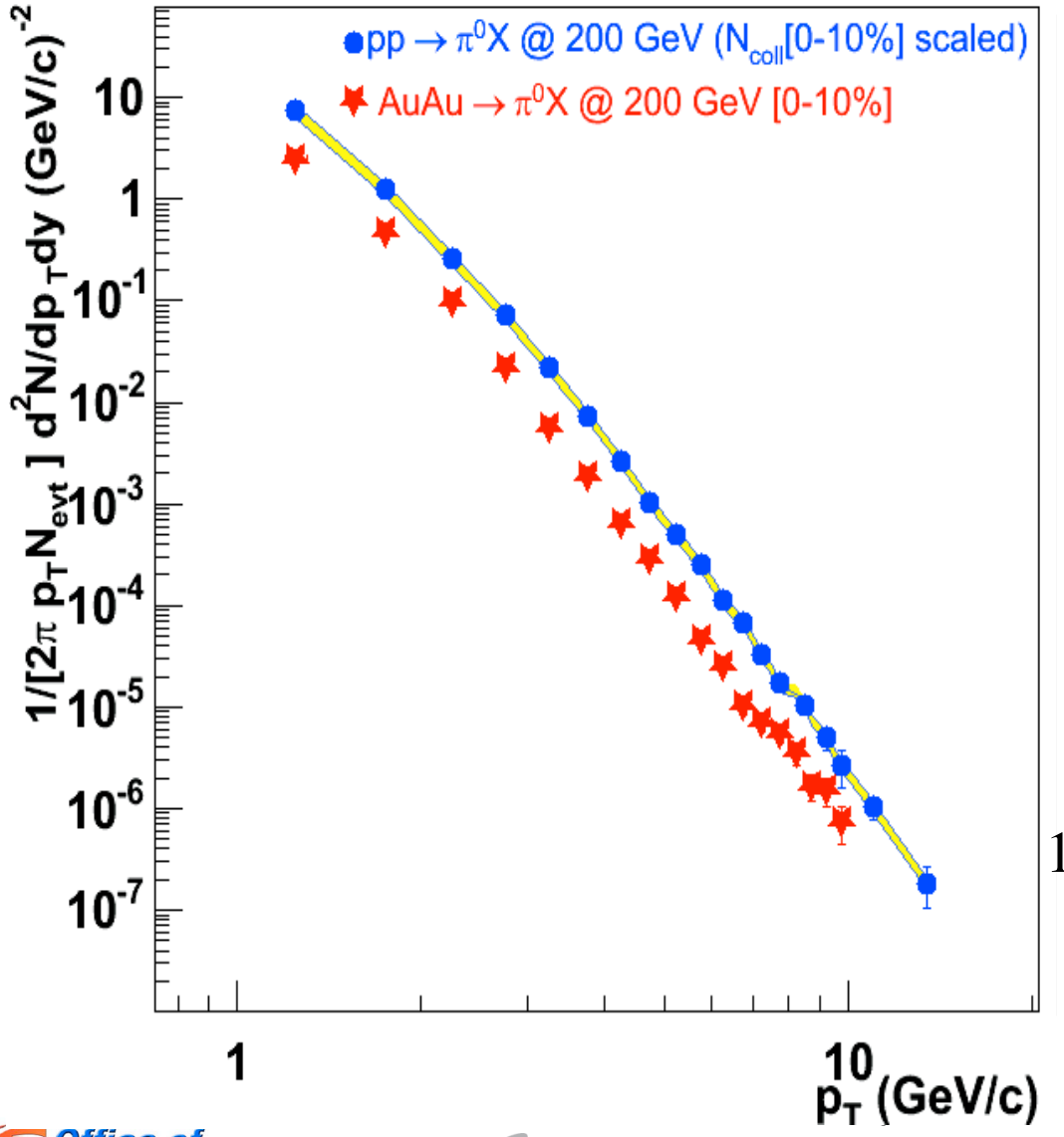


- $R_{AA}(p_T)$=constant for $p_T > 4$
- $d\sigma/p_T dp_T$ is $p_T^{-8.1}$
- Δp_T for $d\sigma/dp_T$

$$\left(1-\frac{\Delta E(p_T)}{p_T}\right)^{8.1-1} = R_{AA}(p_T)$$

$$1-R_{AA}(p_T)^{\frac{1}{8.1-1}} = \frac{\Delta E(p_T)}{p_T} = const$$

Spectra are suppressed for more central collisions--- is this due to a shift caused by energy loss?

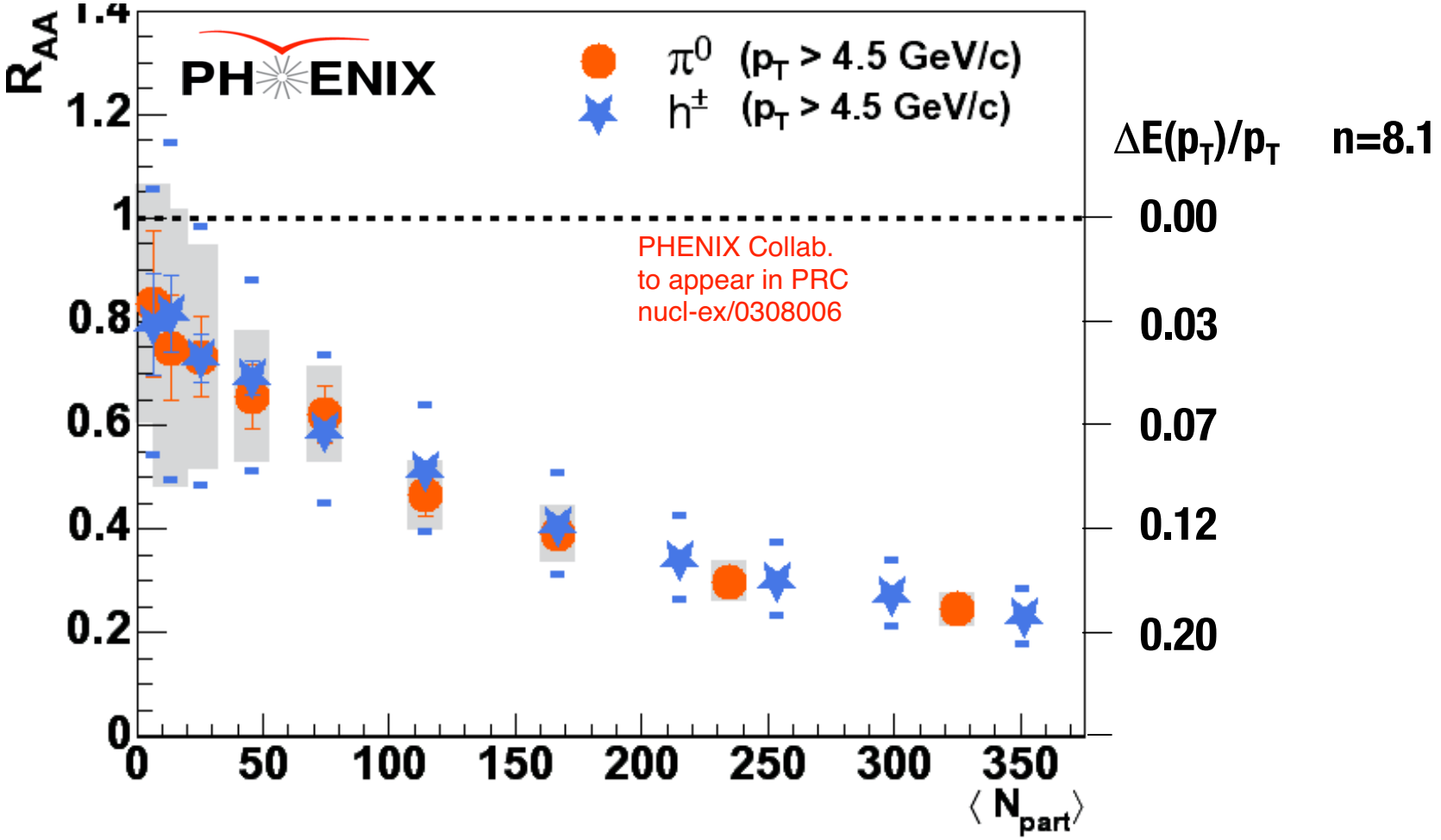


- $R_{AA}(p_T)$=constant for $p_T > 4$
- $d\sigma/p_T dp_T$ is $p_T^{-8.1}$
- Δp_T for $d\sigma/dp_T$

$$\left(1-\frac{\Delta E(p_T)}{p_T}\right)^{8.1-1} = R_{AA}(p_T)$$

$$1-R_{AA}(p_T)^{\frac{1}{8.1-1}} = \frac{\Delta E(p_T)}{p_T} = const$$

Estimate of $\Delta p_T / p_T$



DirectPhotons---$\pi^0(\eta)\rightarrow\gamma\gamma$ makes huge background- down a factor of 2/(n-1) due to falling spectrum

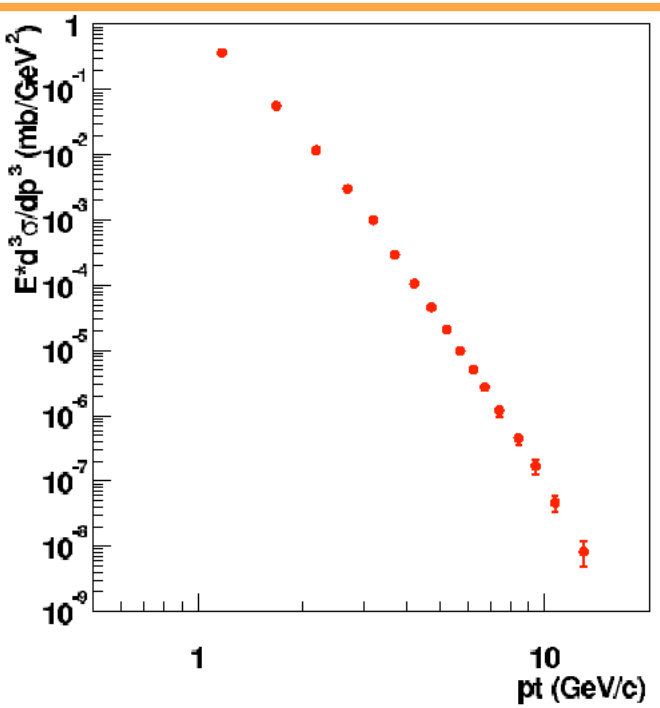


Figure 5: PHENIX π^0 spectrum for $\sqrt{s} = 200$ GeV p-p collisions

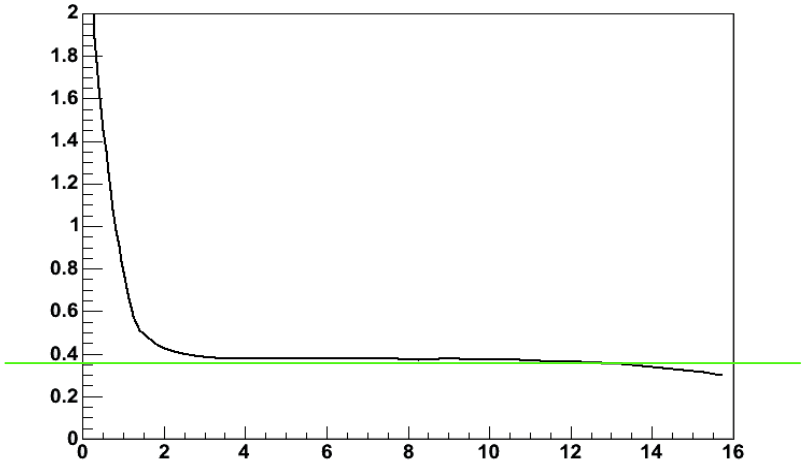
$$\frac{dn_{\pi^0}}{p_T dp_T} \propto p_T^{-n}$$

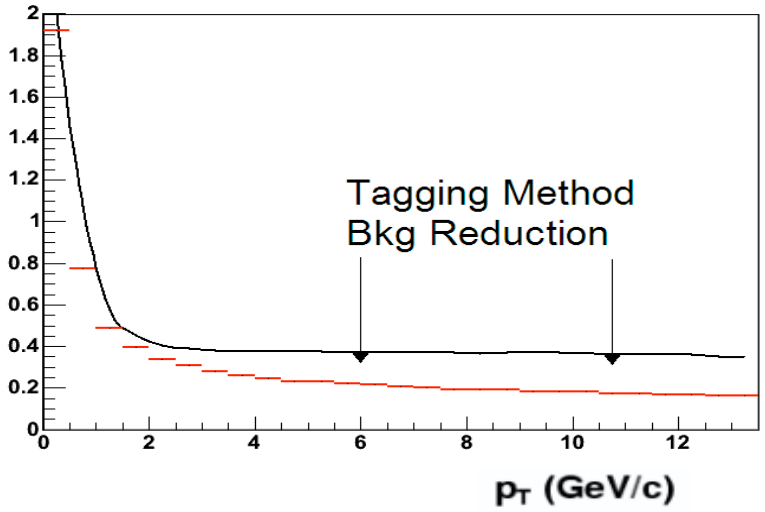
where $n \sim 8$, so $\gamma|_{\pi^0}/\pi^0 \sim 1.2 \times 2/7 = 0.34$ and the factor 1.2 includes $\eta \rightarrow \gamma + \gamma$ (estimated).

- This assumes that e.g. one 10 GeV photon and two 5 GeV photons (a 10 GeV π^0) measure at exactly the same energy $\Rightarrow$ **nonlinearity** is a big experimental issue for photons.

Actual calculated $\gamma|_{\pi 0 +...} / \pi^0$

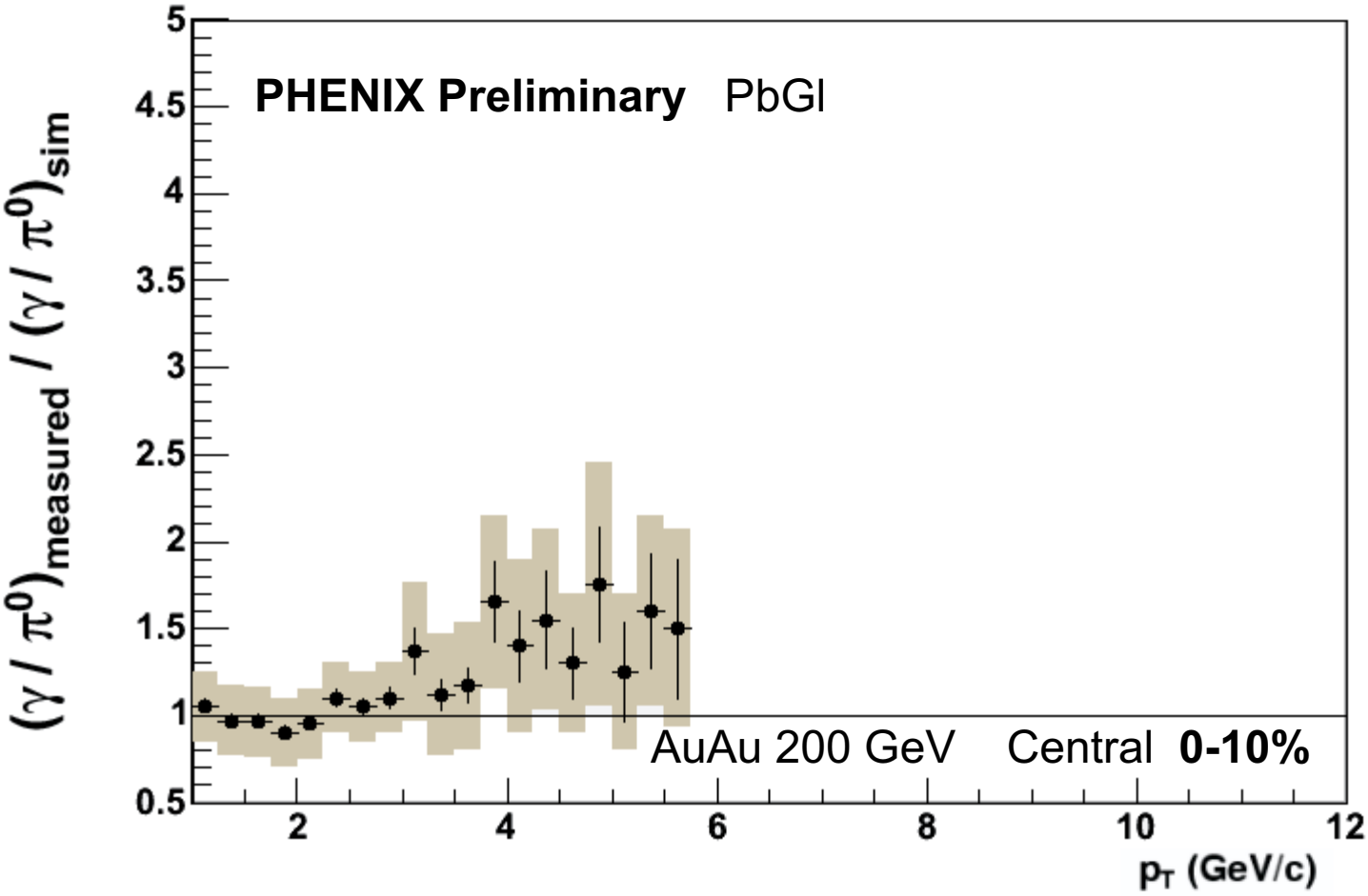
$\gamma_{\text{all decay background}} / \pi^0$





- We do this because doing the same with the actual point by point π^0 and inclusive γ measurements will cancel many systematics
- Variations: Tagging Methods (reject γ pairs in π^0 mass window), Isolation Methods Remove inherent background so smaller $(\gamma/\pi)_{\text{expected backgrd}}$
- Then we can compare measured γ/π with background γ/π …

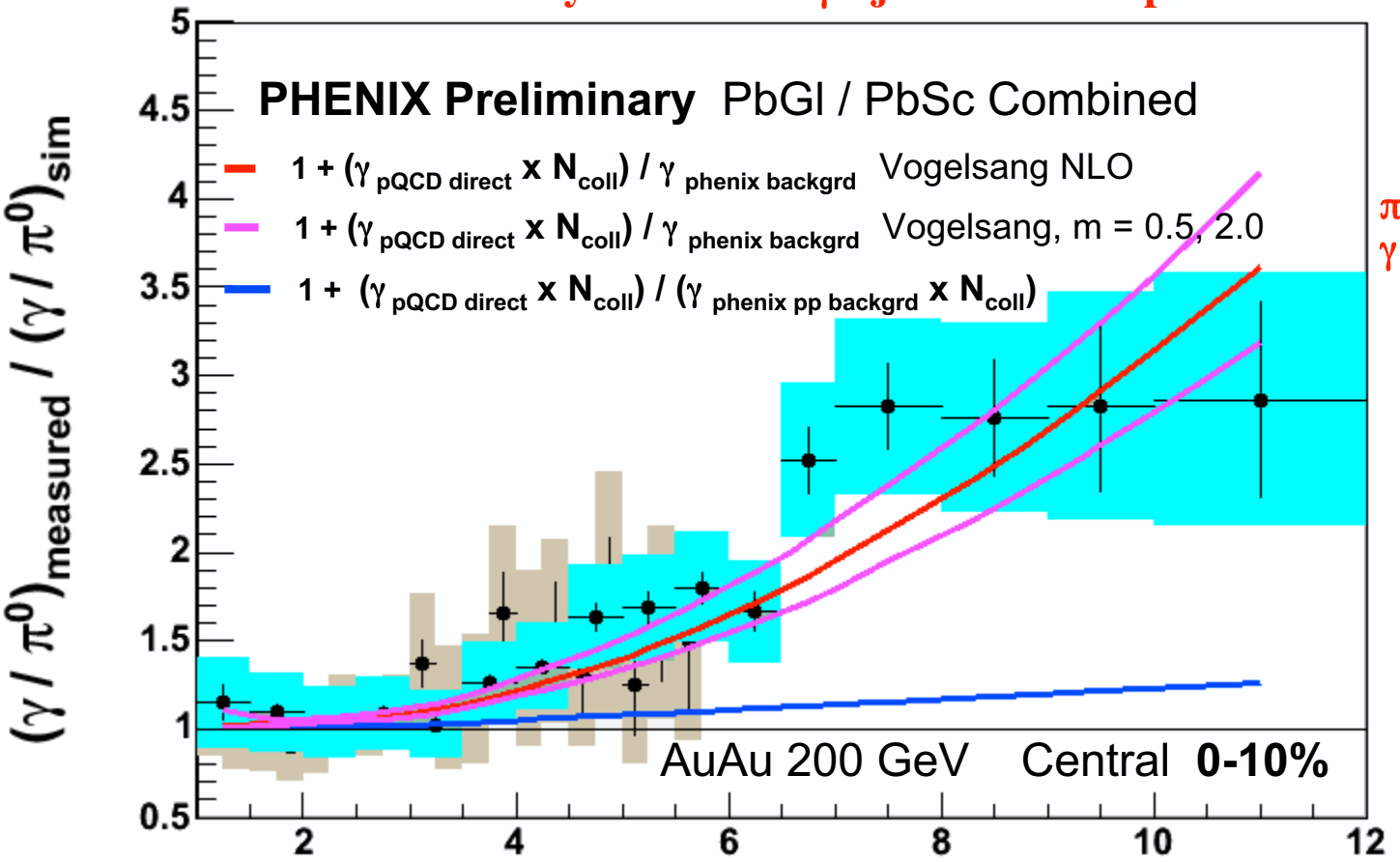
Direct γ-- QM02 Central 0-10%



$[\gamma/\pi^0]_{measured} / [\gamma/\pi^0]_{background} = \gamma_{measured}/\gamma_{background}$

QM04 Results Central 0-10% WoW

Need lots more statistics+systematics⇒γ-"jet"+thermal photons+...



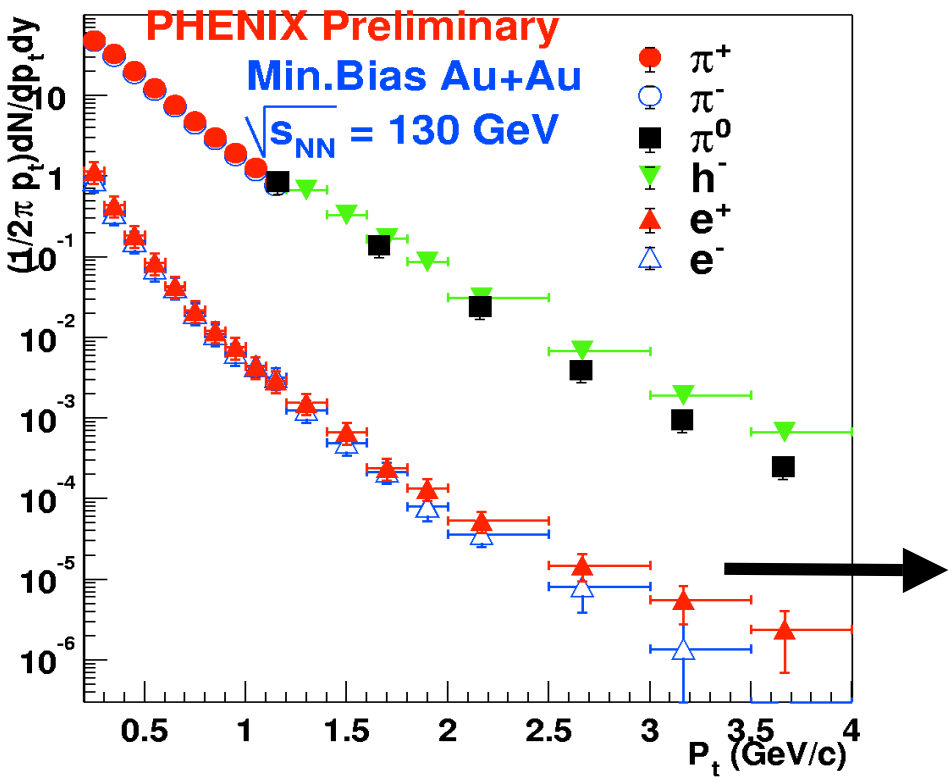
π^0 suppressed
γ not suppressed

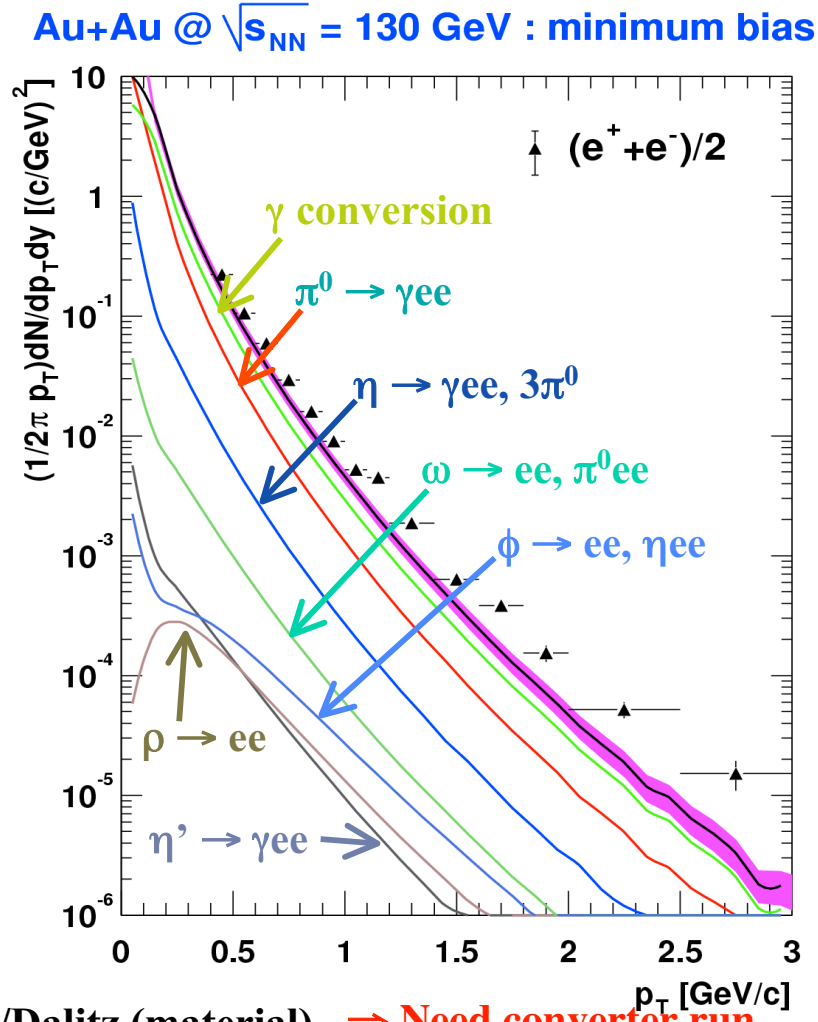
γ & π^0 both suppressed

Theory curves include PHENIX $\gamma_{\text{expected background}}$ calculation based on π^0:

$$(\gamma_{\text{direct}} + \gamma_{\text{exp. bkgd.}}) / \gamma_{\text{exp. bkgd.}} = 1 + (\gamma_{\text{direct}}/\gamma_{\text{exp. bkgd.}})$$

Open Charm (via single $e^{\pm}$) AuAu 130 GeV
A first in RHI collisions and very interesting



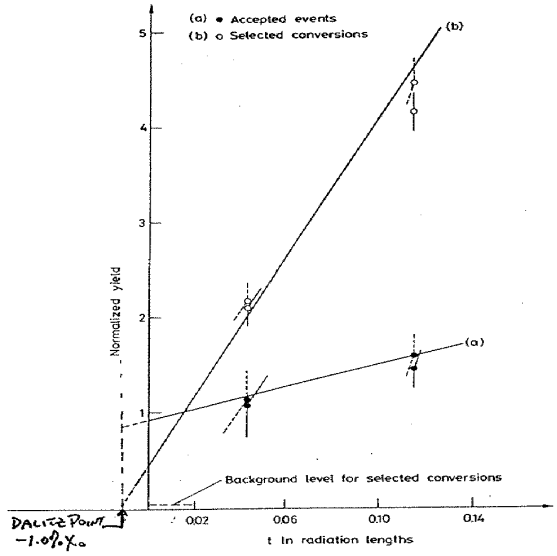


PRL 88, 192303 (2002)

- main systematic errors (band)
  - –pion spectra, ratio η/π^0, ratio conversion/Dalitz (material) ⇒ Need converter run

Converter run separates photonic from non-photonic $e^{\pm}$

From CCRS PL**B53**, 212 (1974)
Discovery of direct $e^{\pm}$ at the
CERN-ISR (S.N.White's thesis)



- Probability of internal and external conversion per γ

$$\frac{e^-|_\gamma}{\gamma} = \frac{e^+|_\gamma}{\gamma} = \frac{\delta_2}{2} + \frac{t}{\frac{9}{7}X_0} \equiv \delta_{eff}$$

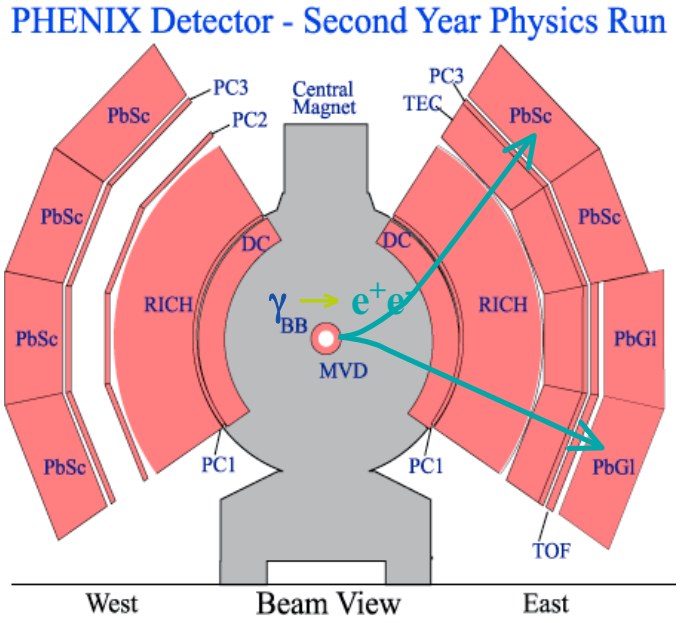
where $\delta_2/2$ = Dalitz (internal conversion) branching ratio per photon = 0.6% π^0, 0.8% for $\eta \to \gamma\gamma$.

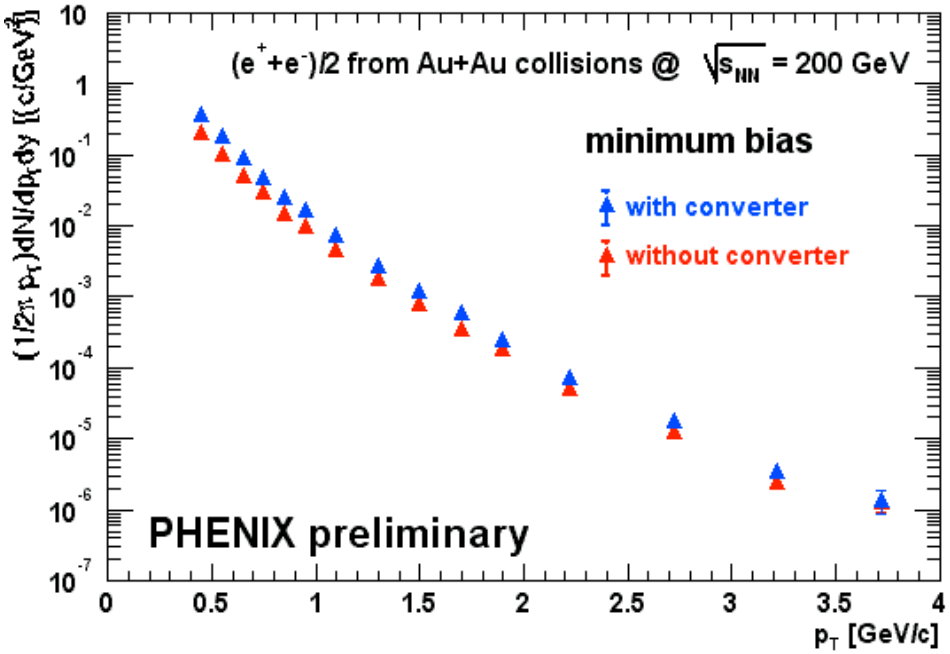
- Still assuming the p_T^{-n} power law for the π^0 and thus decay γ Spectra:

$$\left.\frac{e^-}{\pi^0}\right|_{\pi^0}(p_T) = \left.\frac{(e^- + e^+)}{2\pi^0}\right|_{\pi^0}(p_T) = \delta_{eff} \times \frac{2}{(n-1)^2} > 0.6\%/7^2 = 1.2 \times 10^{-4}$$

- Must keep external $t/\frac{9}{7}X_0$ comparable $\sim 0.6\%$ to avoid additional background from external conversions.
- But can add small external converter in test run to determine whether $e^-/\gamma \to 0$ at "Dalitz Point" $-\frac{9}{7}\delta_2/2 \sim 0.8 - 1.0\%$ in units of radiation lengths, **insensitve** to the η/π^0 ratio. Converter curve measures the photonic background!

QM02 PHENIX AuAu 200 GeV charm via $e^{\pm}$





- Some data with 1.7 % X_0 converter added
- converter only affects photonic component

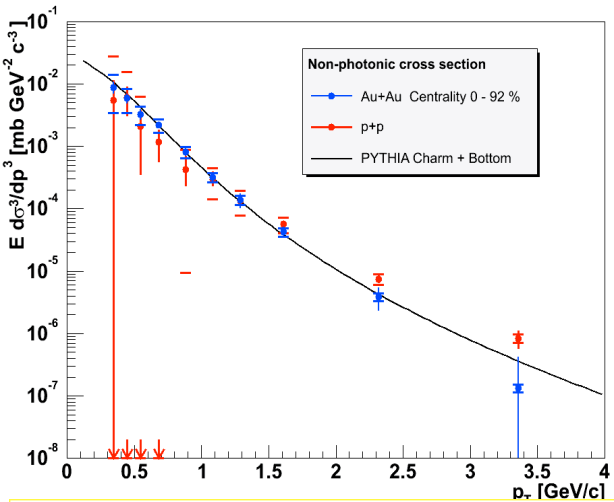
- converter effect is much greater at low p_T, indicating
  - ⇒ relatively much larger photonic component at low p_T
  - ⇒ relatively smaller phtonic (i.e. larger non-photonic) component at higher pT (i.e. charm)

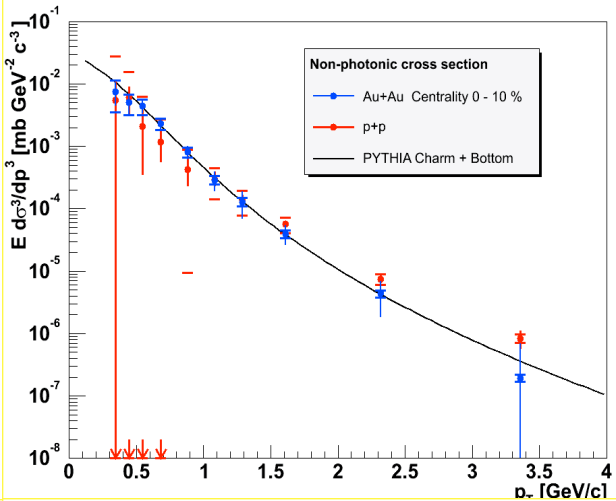
Reduced systematic erros.

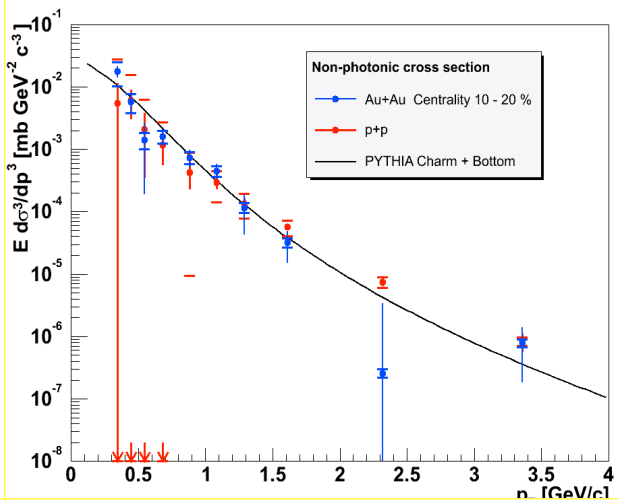
Single e p_T distribution vs Centrality 200 GeV AuAu data compared to pp data

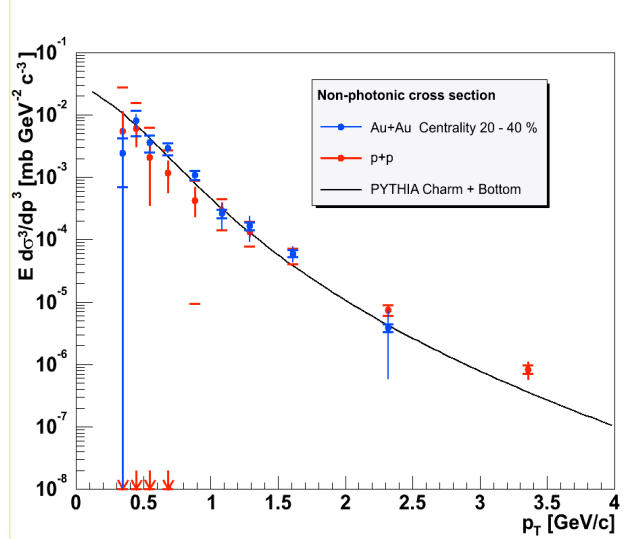
Consistent with binary (pointlike) scaling ⇒charm is not suppressed

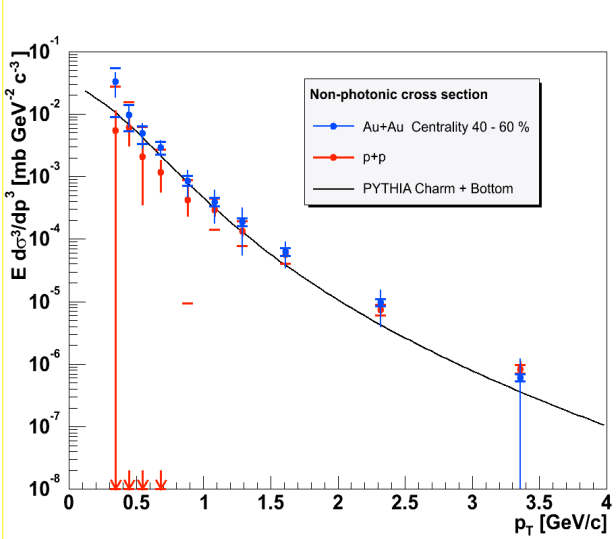
Consistent with our 130 GeV Measurement PRL 88, 192303 (2002)

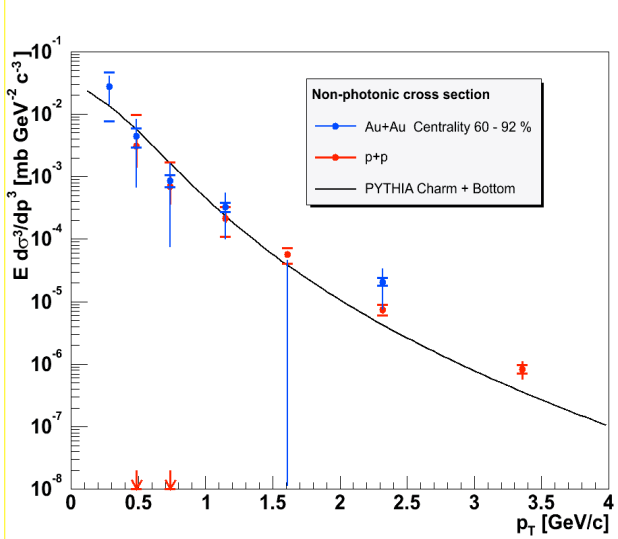




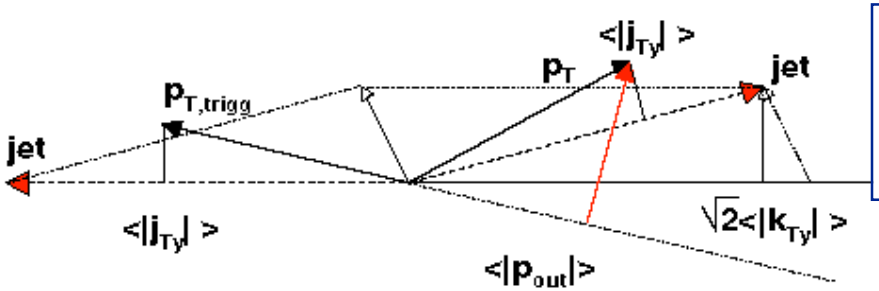




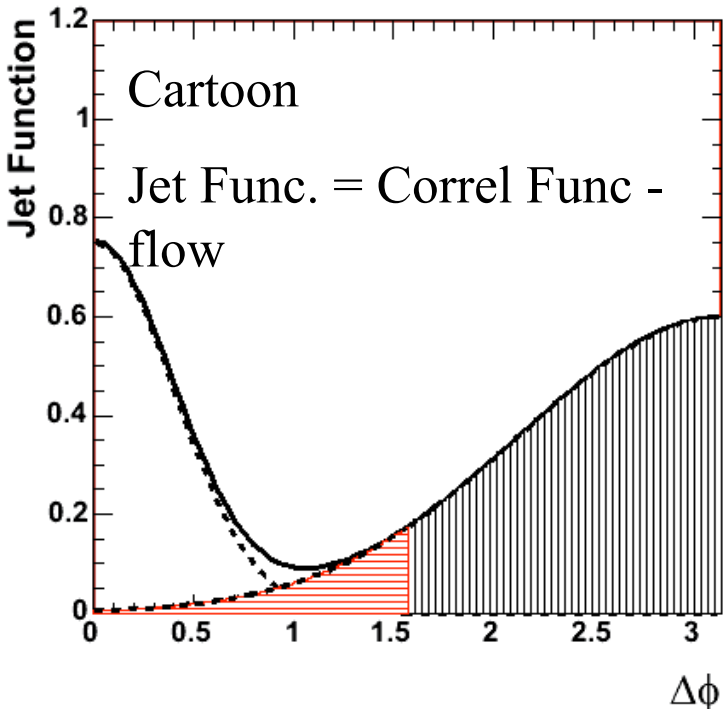




2-Particle correlations as the (only) way to measure jets in (Au+Au) collisions



from the CERN-ISR: CCOR PL**B97**, 163 (1980)
Jet properties given by widths and integrals of same and away-side peaks



CCOR--Feynman,Field,Fox-1978

$$\langle|p_{out}|\rangle^2 = x_E^2[2\langle|k_{Ty}|\rangle^2 + \langle|j_{Ty}|\rangle^2] + \langle|j_{Ty}|\rangle^2$$

$$x_E = p_T \cos(\pi-\Delta\phi)/p_{Ttrig}$$

$$p_{out} = p_T \sin(\pi-\Delta\phi)$$

PHENIX--Rak,Tannenbaum-2004

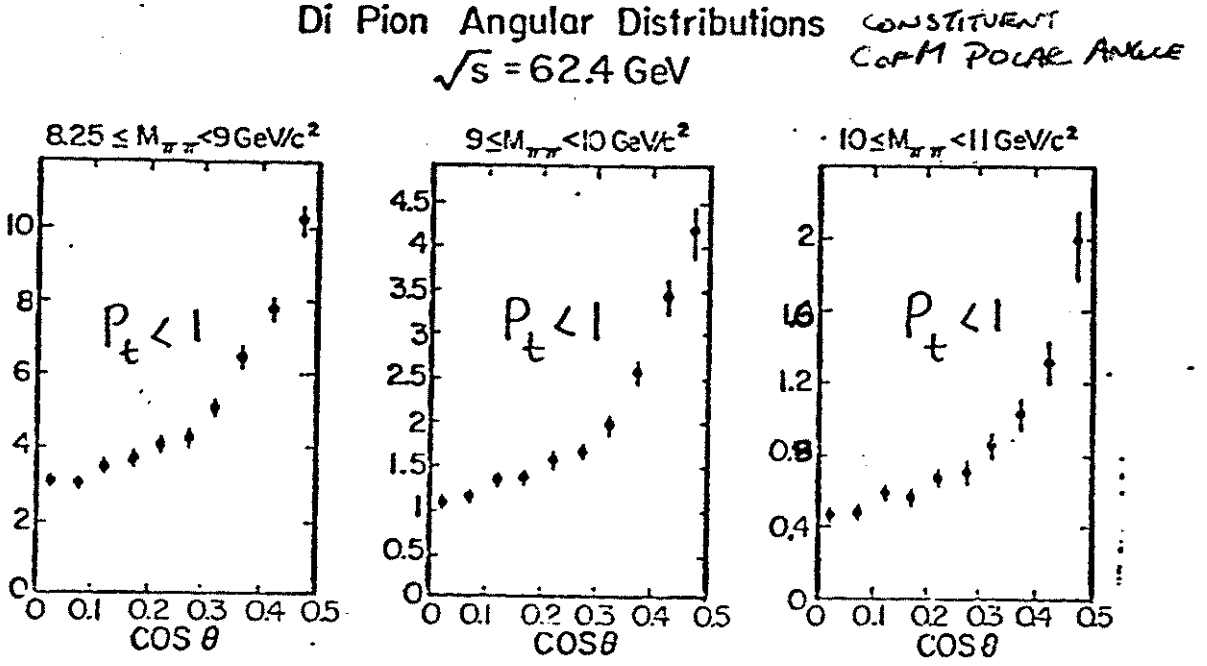
$$\langle|p_{out}|\rangle^2 = x_h^2[2\langle|k_{Ty}|\rangle^2\langle z_{trig}\rangle^2 + \langle|j_{Ty}|\rangle^2] + \langle|j_{Ty}|\rangle^2$$

$$x_h = p_T / p_{Ttrig}$$

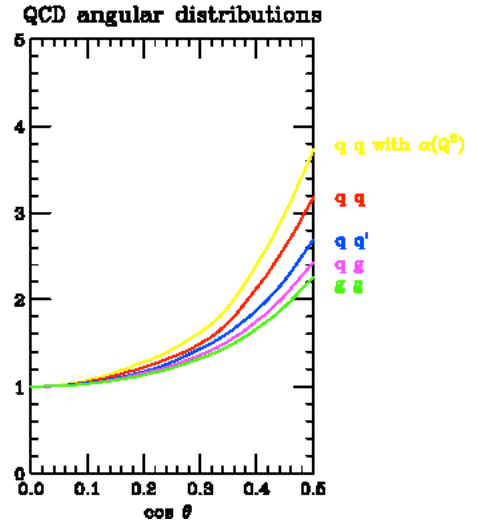
$$z_{trig} = p_{Ttrig} / p_{Tjet}$$

For everything you want to know about jet correlations using π^0-see Jan Rak's talk But here's my favorite correlation from CCOR

DATA: CCOR NP**B 209**, 284 (1982)



QCD



$$\frac{d^3\sigma}{dx_1 dx_2 d\cos\theta^*} = \frac{1}{s}\sum_{ab} a(x_1)b(x_2)\frac{\pi\alpha_s^2(Q^2)}{2x_1x_2}\Sigma^{ab}(\cos\theta^*)$$

$\Sigma^{ab}(\cos\theta^*)$, the characteristic subprocess angular distributions and $\alpha_s(Q^2) = \frac{12\pi}{25}\ln(Q^2/\Lambda^2)$ are predicted by QCD

Conclusions

- **It may very well be possible to find the QGP with only an EMCal**
- But it's better with electron id at the trigger (still better with muons too)
- Even better with full charged hadron identification
- **So the only remaining question is:**

Did we find the QGP at RHIC?