

High p_T Measurements from



Saskia Mioduszewski

for the PHENIX Collaboration

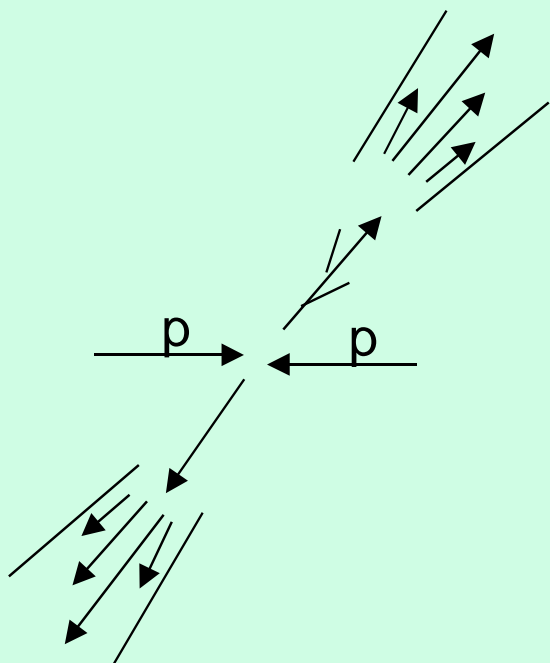
22 July 2002

Motivation

Effect of nuclear collision medium on hadron p_T spectra

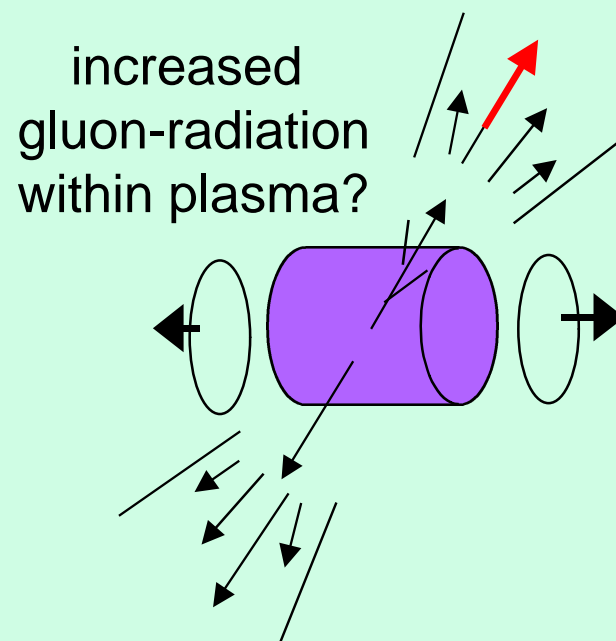
hard-scattered
parton from e.g. p+p

cone of hadrons “jet”



hard-scattered
parton during Au+Au

hadron distribution
softened, broadened?



Outline



- PHENIX overview

1. Assume high p_T hadrons from jets

- Particle Spectra
- Nuclear Modification Factor
- Particle Composition at high p_T

2. Investigate assumption

- Detecting jets

3. Make the connection

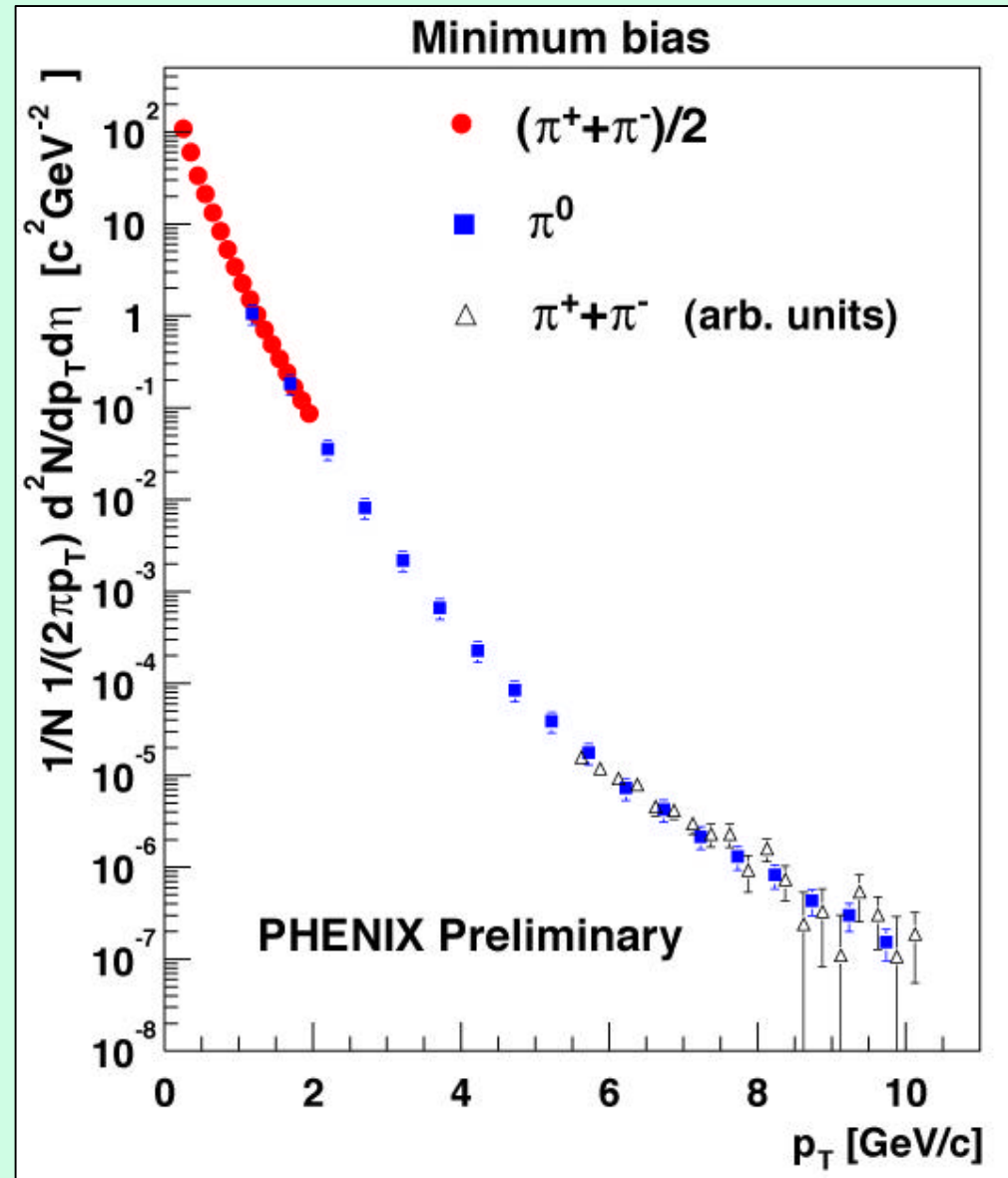
- Conclusions

PHENIX Overview



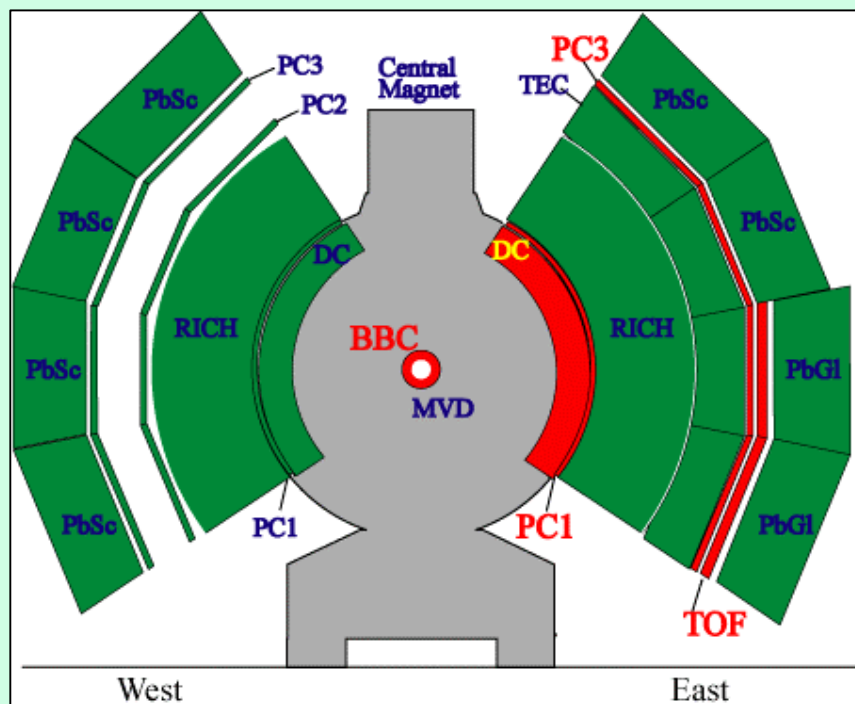
Versatile Detector

- Measurements extend to $p_T = 10 \text{ GeV}/c$
- Excellent PID coverage
- Different measurements provide cross-checks



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

PHENIX Overview

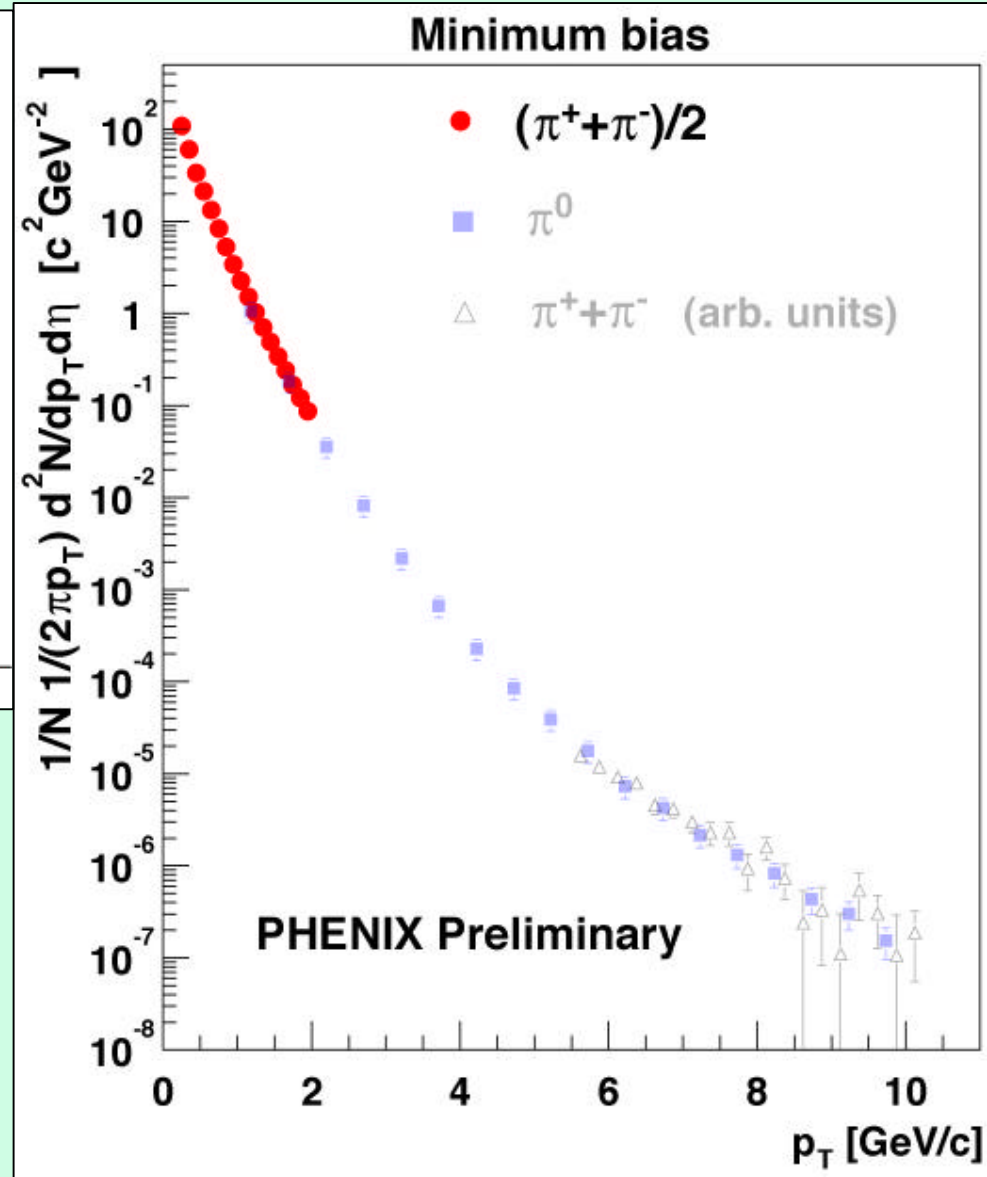


Charged pions at low p_T

-- Tracking +
Time-Of-Flight

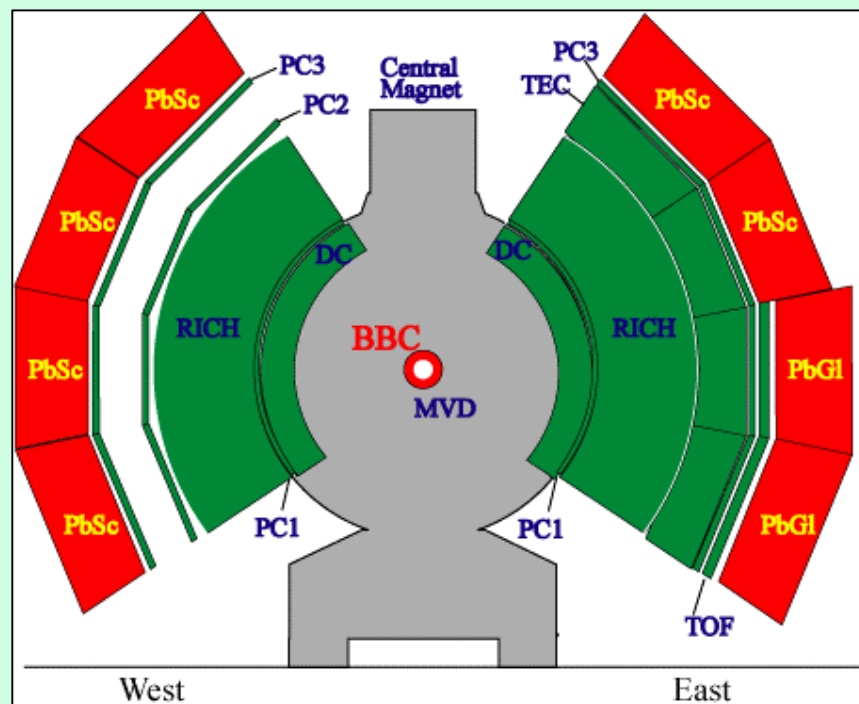
T. Chujo talk

J. Burward-Hoy talk



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

PHENIX Overview

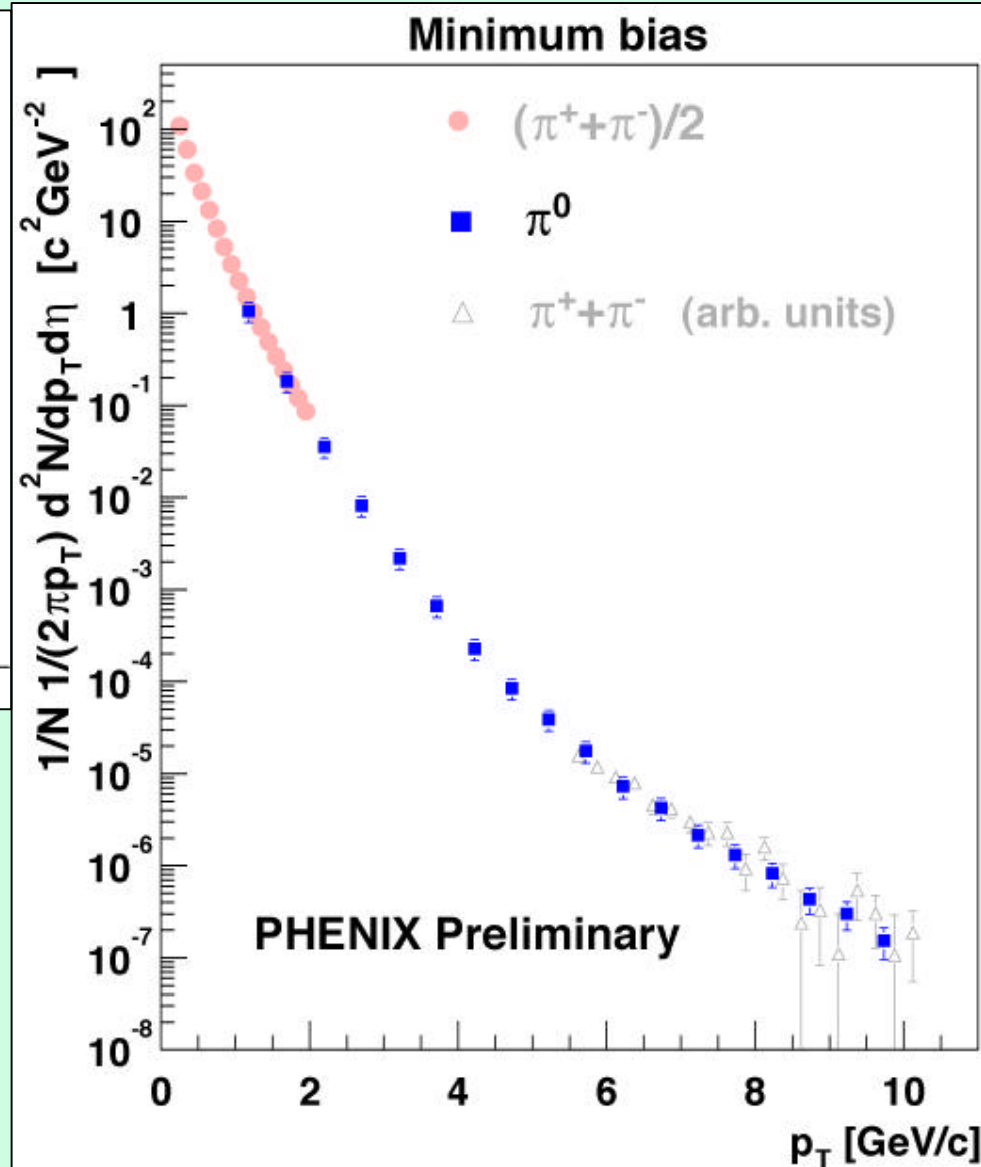


Neutral pions at mid to high p_T

-- E-M Calorimeters

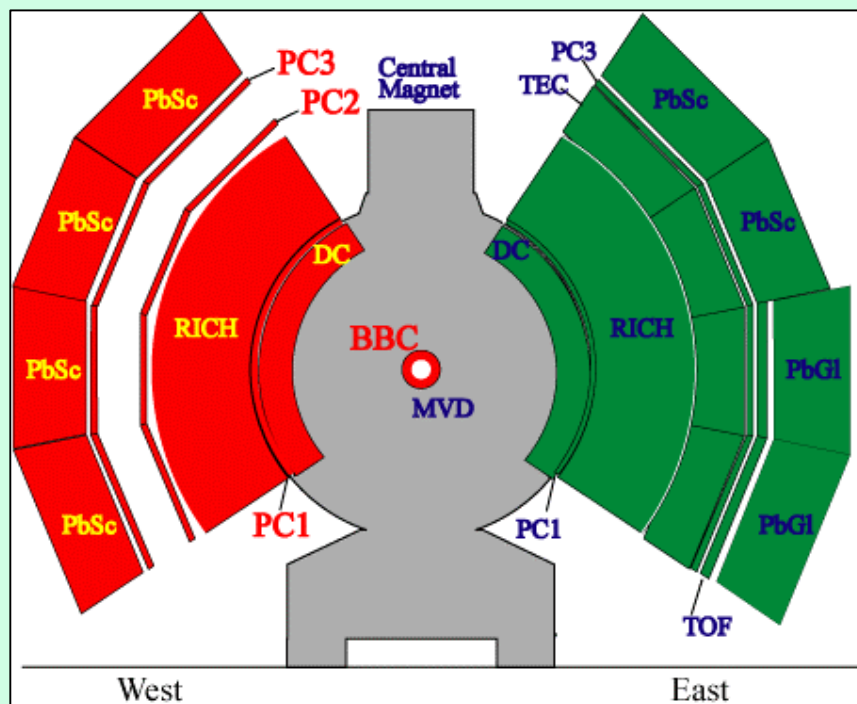
D. d'Enterria talk

C. Klein-Bösing poster



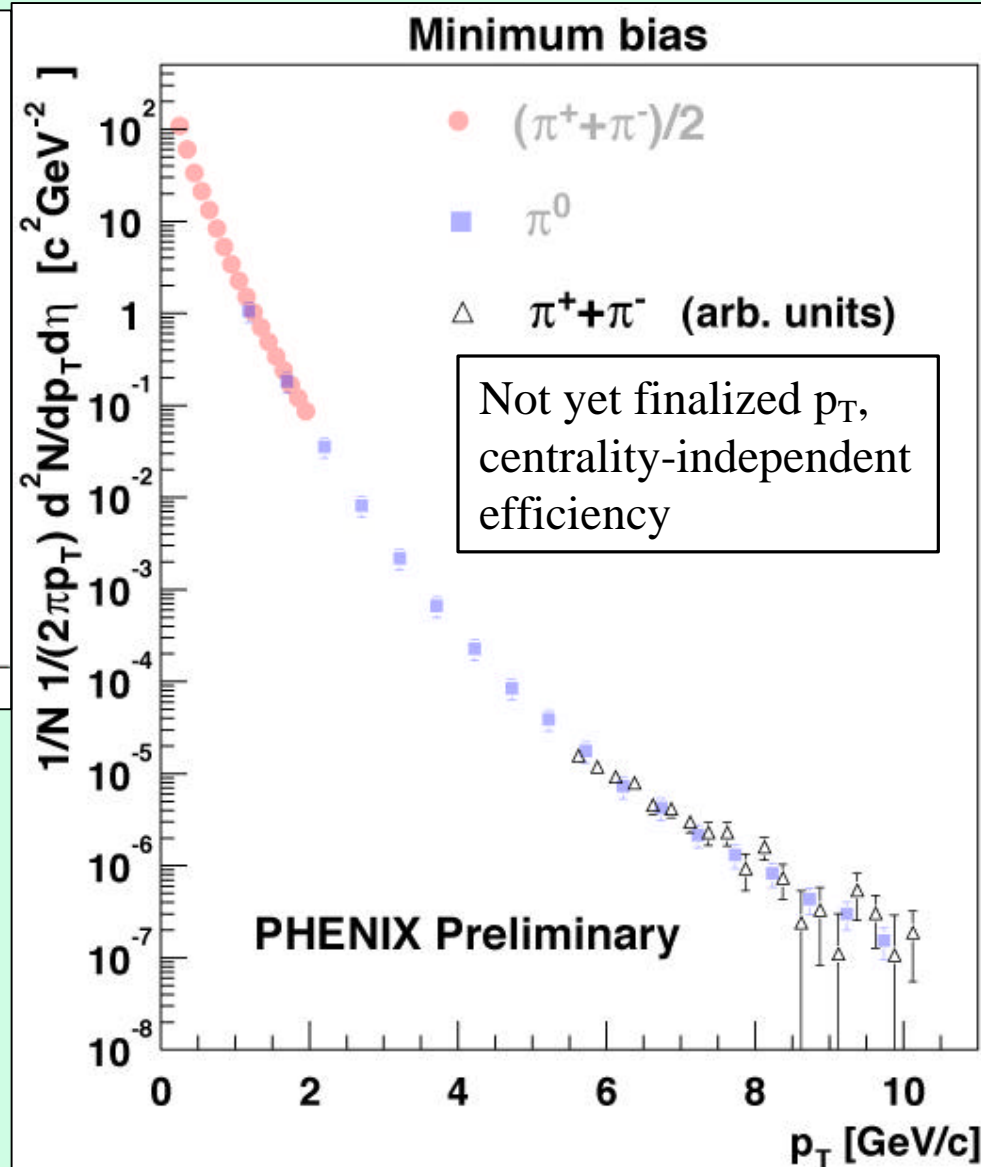
Au + Au $\sqrt{s_{NN}} = 200 \text{ GeV}$

PHENIX Overview



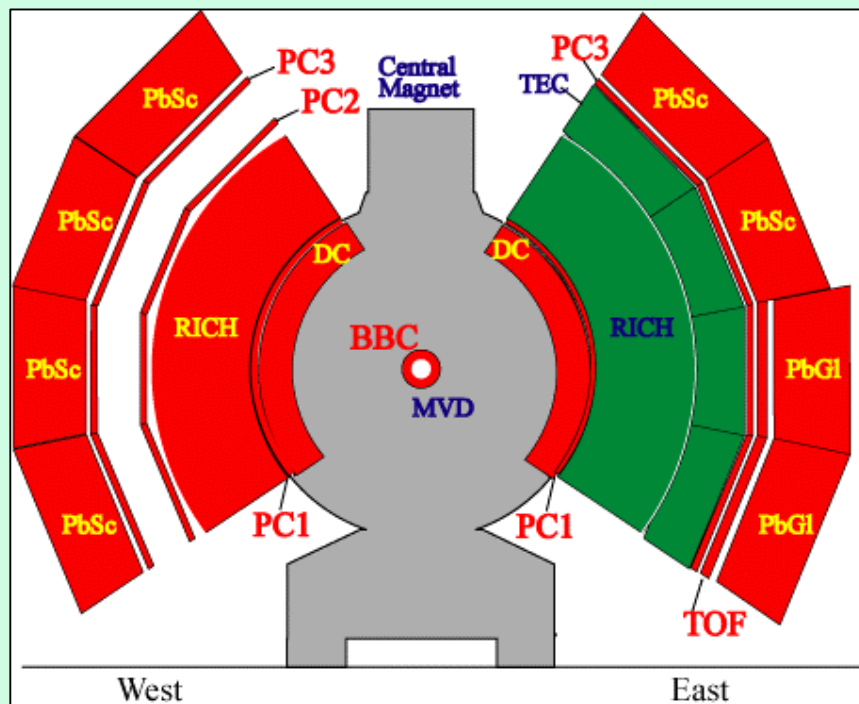
Charged pions at high p_T
 -- Tracking + Calorimeter
 erenkov (RICH)

F. Messer poster

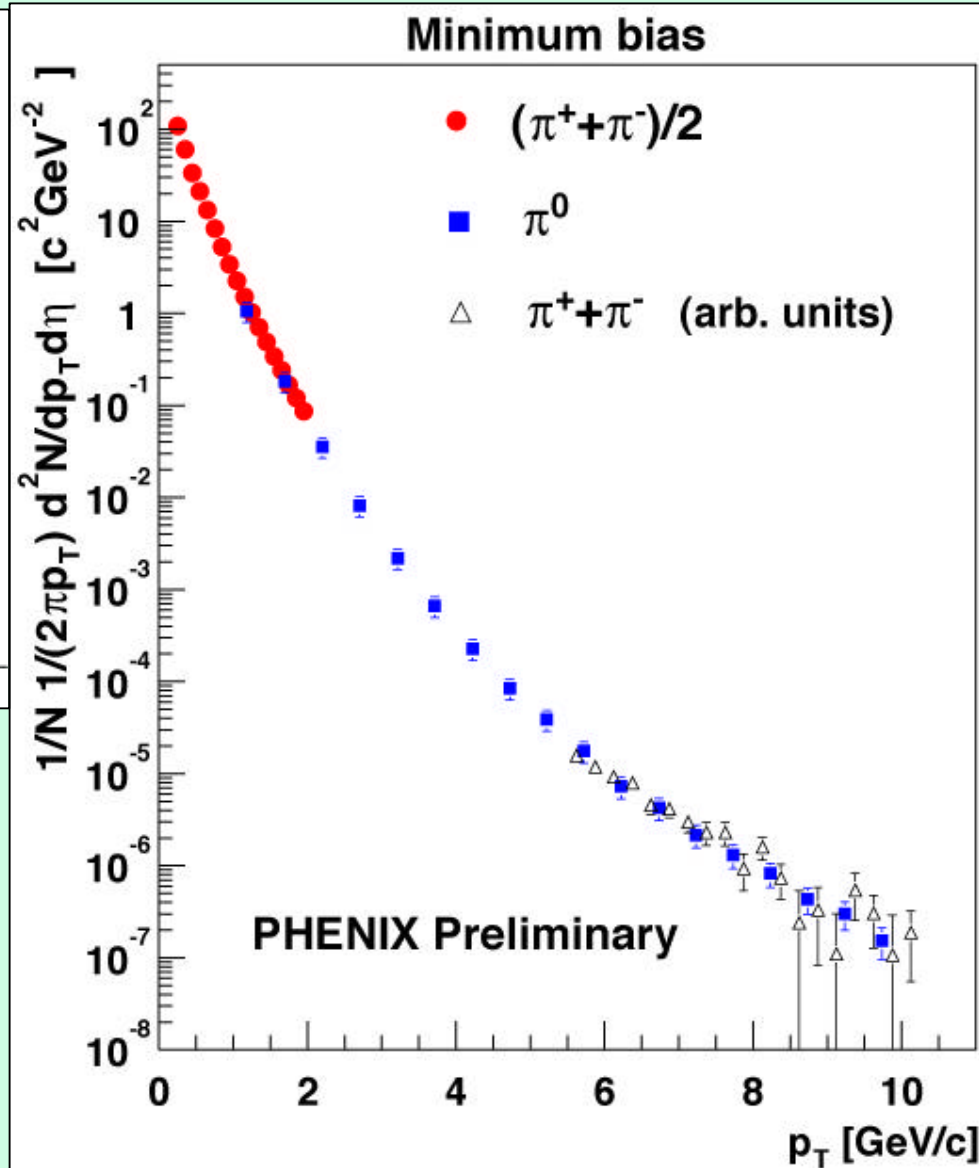


Au + Au $\sqrt{s_{NN}} = 200$ GeV

PHENIX Overview



- Most of central arms used to measure the pion spectrum
- Powerful cross-checks of results



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

1. Assume high p_T hadrons are leading particles of jets

- If hard-scattered partons lose energy in medium, expect suppression at high p_T in hadron spectra
- Suppression is quantified relative to p+p “baseline” scaled by N_{coll}
 - p+p
 - Central Au+Au
 - Ratios \rightarrow Suppression

p+p Collisions

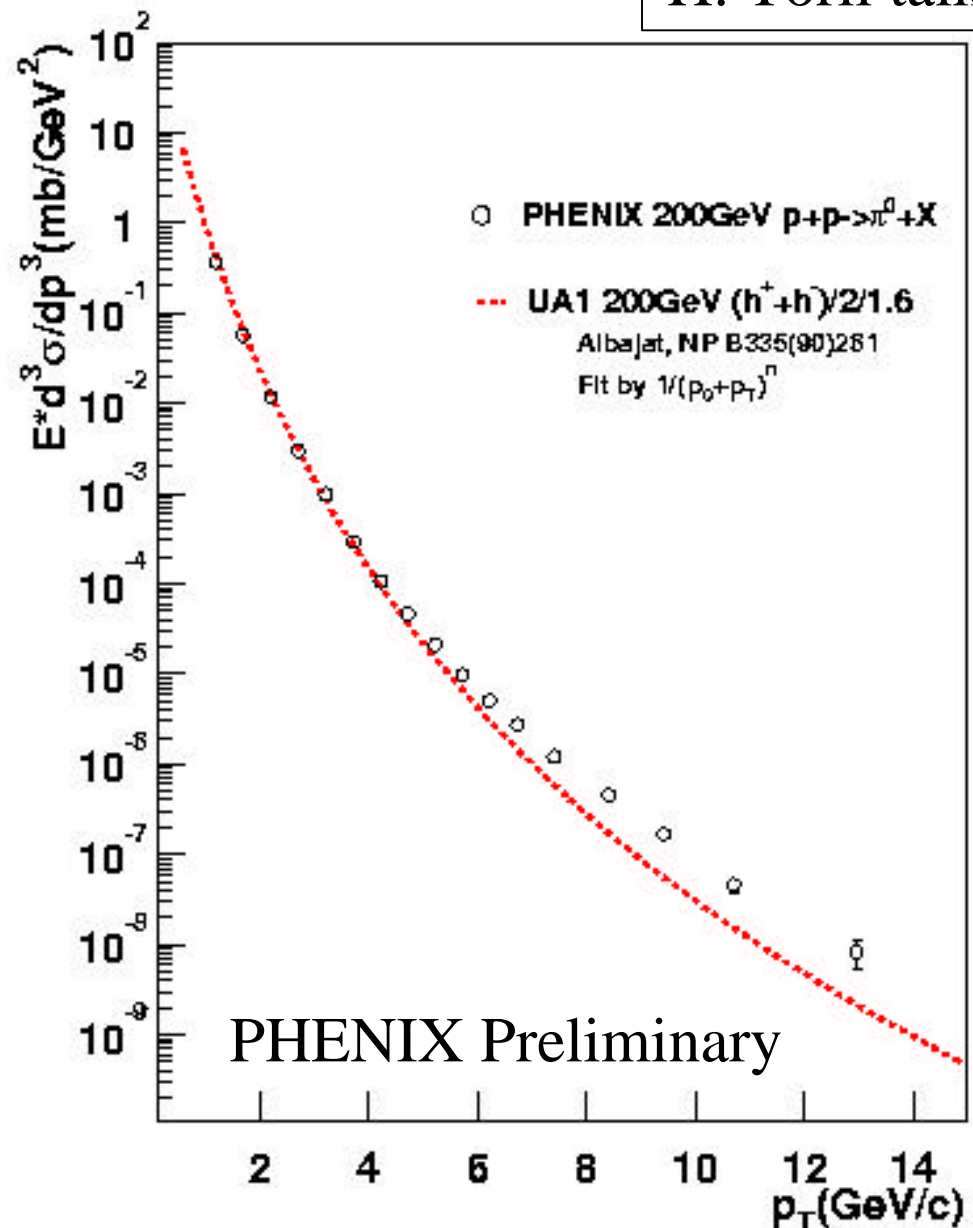
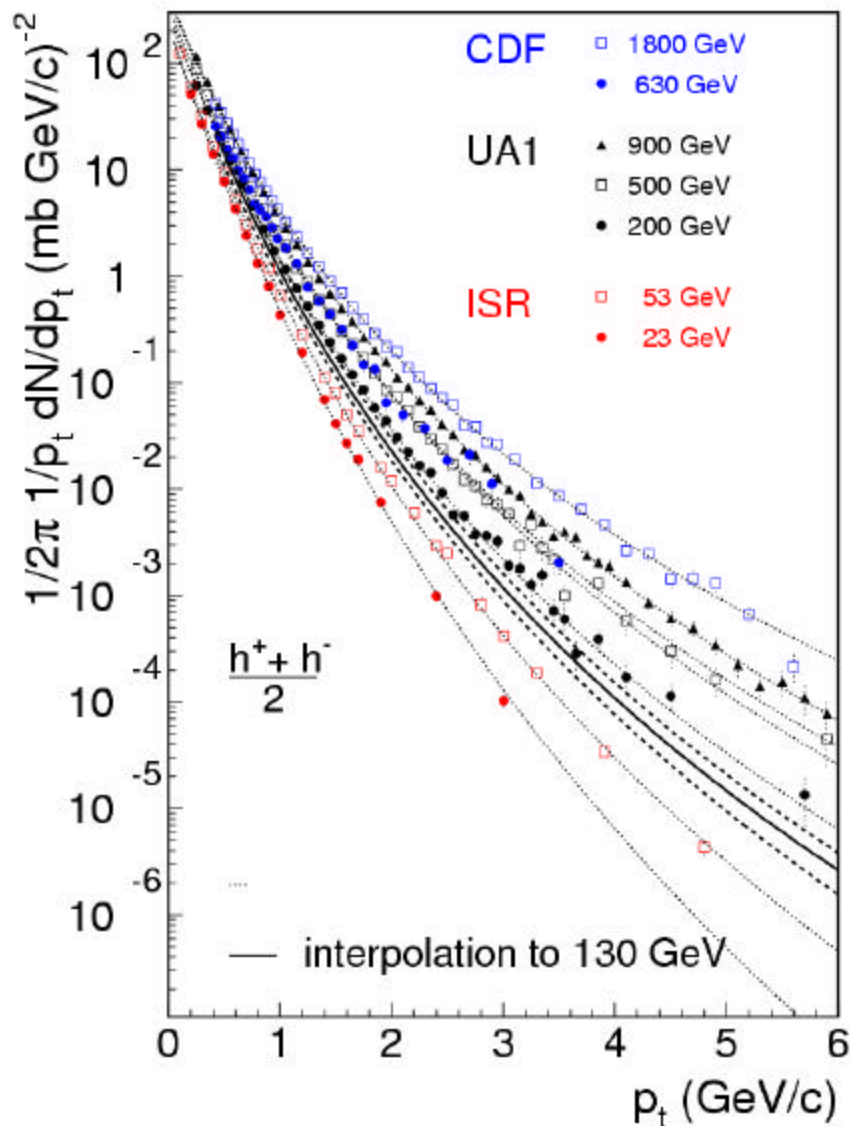
The Baseline

PHENIX

π^0 Measurement



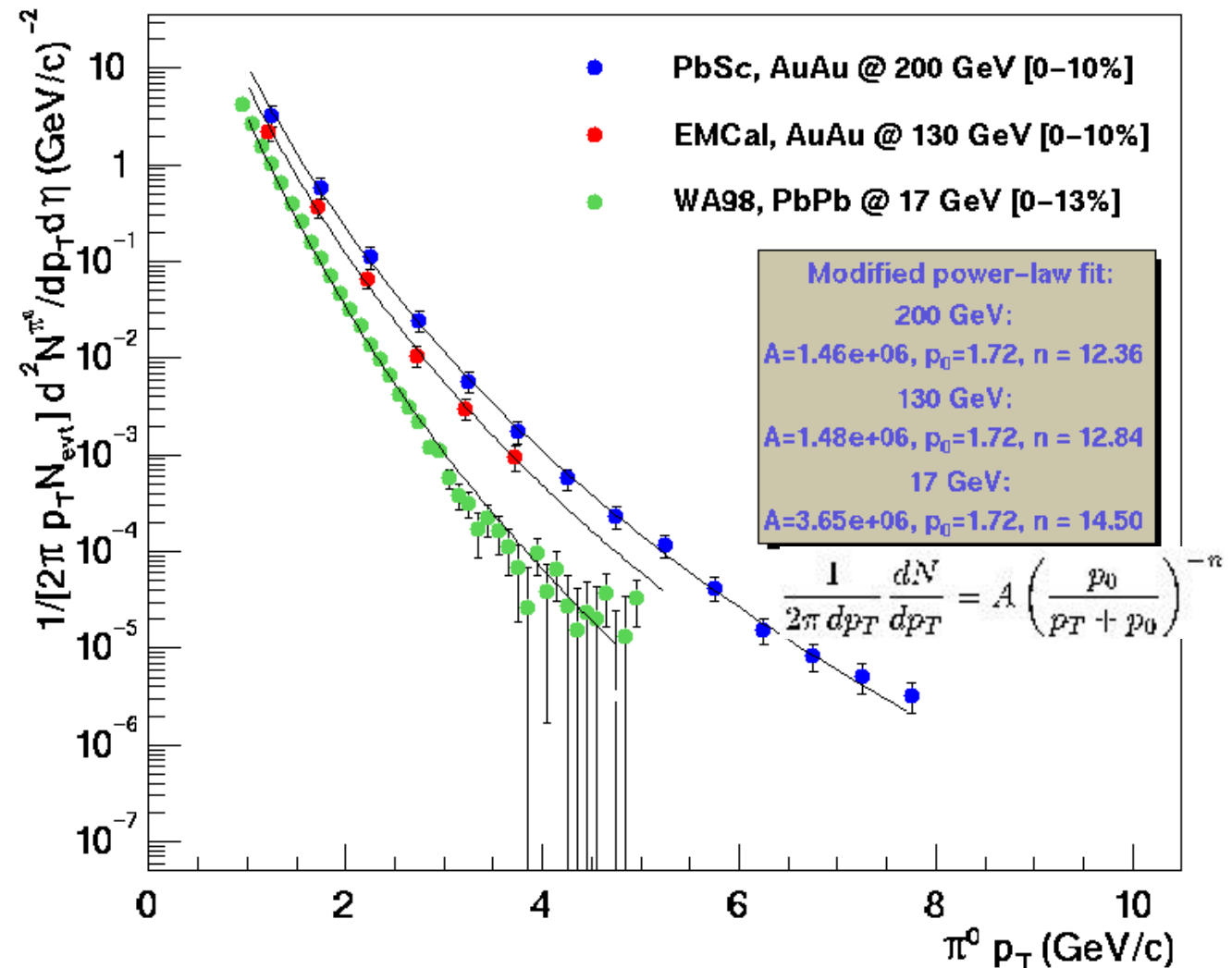
H. Torii talk



Central Au+Au Collisions – Effect of Dense Medium on π^0 Spectrum

D. d'Enterria talk

- Energy dependence of spectrum is shown
- Must be compared to p+p baseline to quantify suppression



Nuclear Modification Factor

$$R_{AA}(p_T) = \frac{1/N_{\text{events}} d^2N^{AA}/dp_T dh}{\langle N_{\text{binary}} \rangle (d^2s_{pp}/dp_T dh / s^{pp}_{\text{inelastic}})} =$$

D. d'Enterria talk

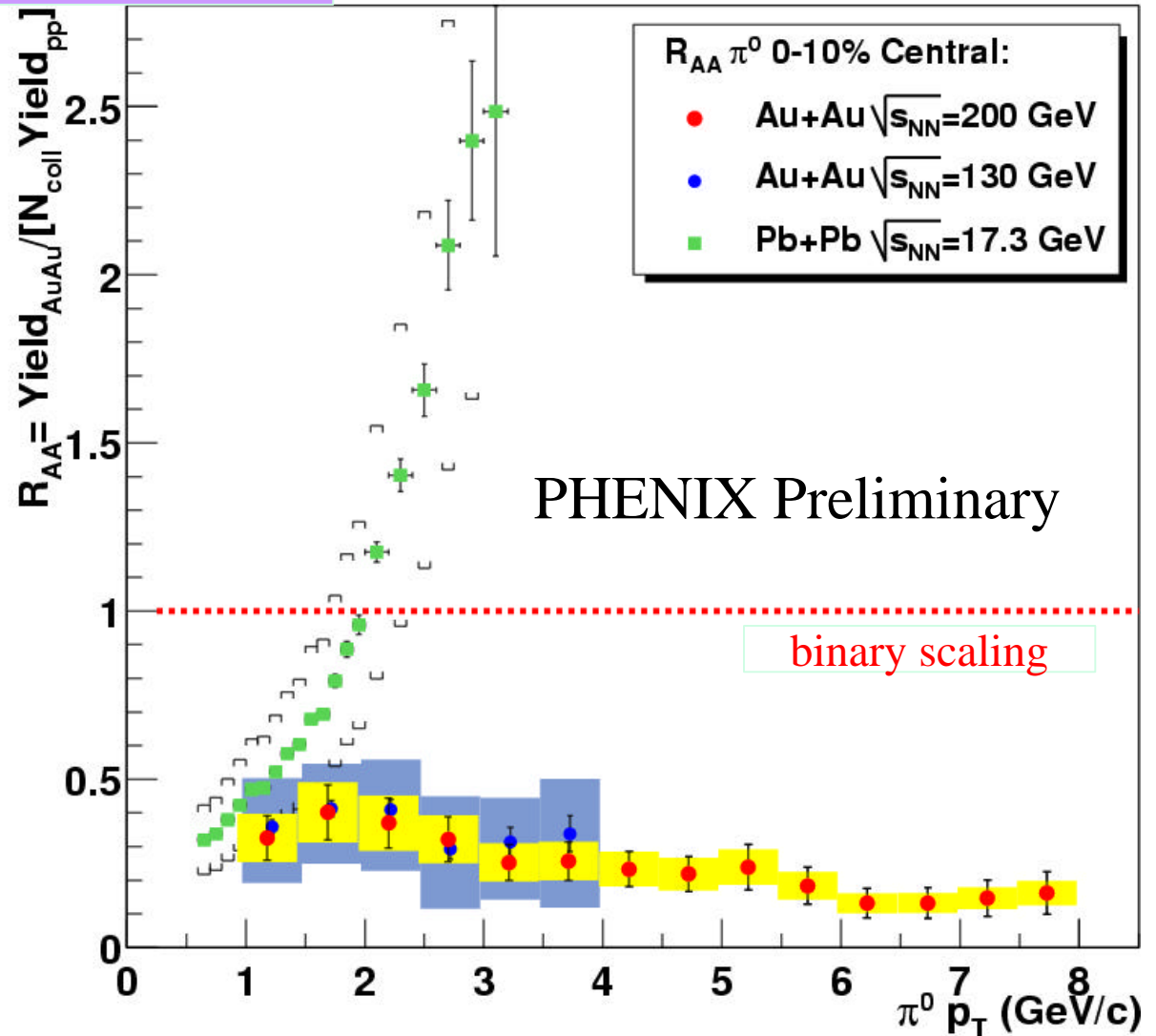
$$\frac{\text{Yield}_{\text{central}} / \langle N_{\text{binary}} \rangle_{\text{central}}}{\text{Yield}_{pp}}$$

→ Effect of nuclear medium on yields

SPS Cronin effect

RHIC - suppression

Our own measure of the p+p spectrum reduces the uncertainty!



Nuclear Modification Factor



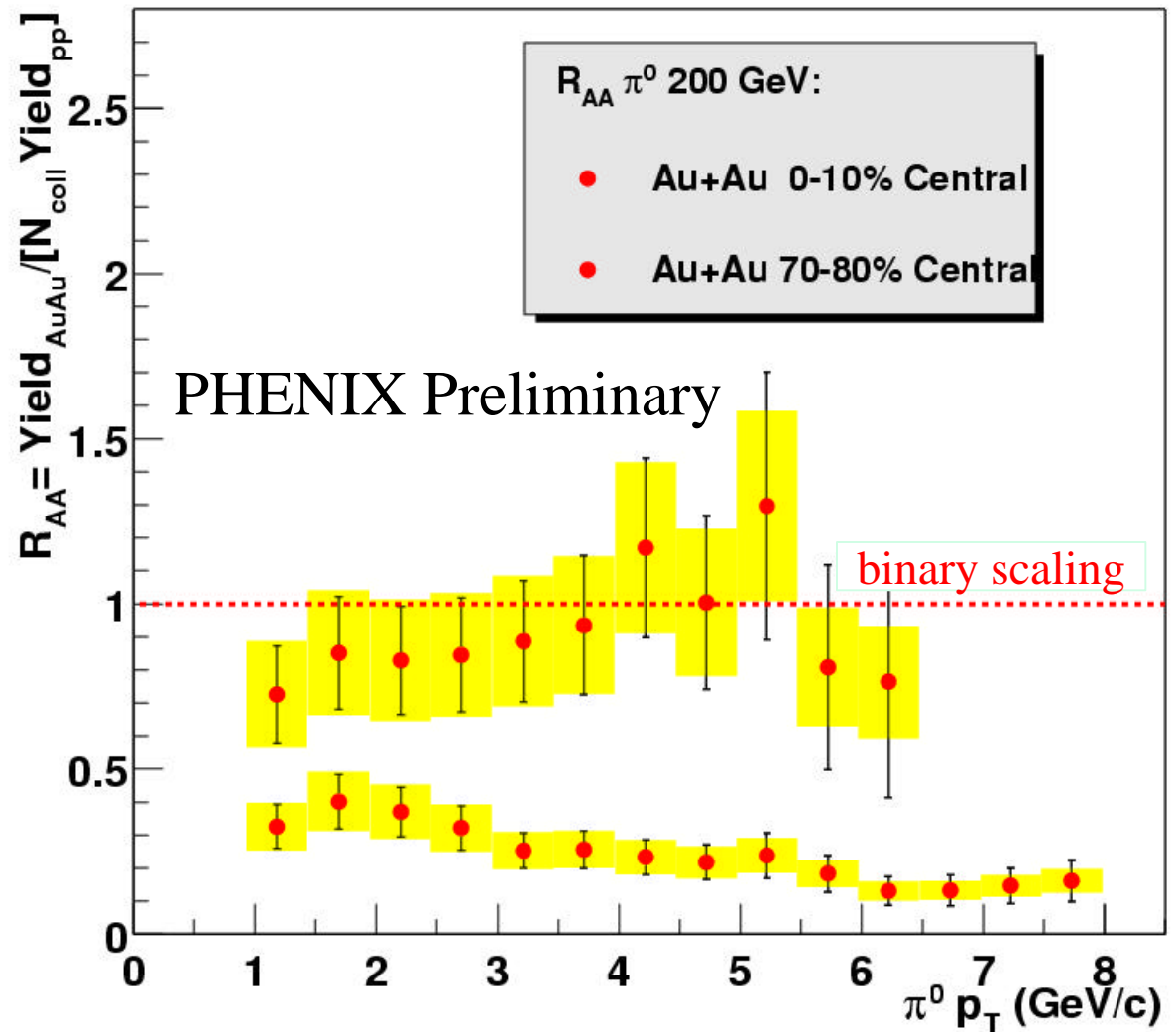
$$R_{AA}(p_T) = \frac{1/N_{\text{events}} d^2N^{AA}/dp_T dh}{\langle N_{\text{binary}} \rangle (d^2s_{pp}/dp_T dh / s^{pp}_{\text{inelastic}})} =$$

D. d'Enterria talk

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

→ Comparison of peripheral to central

RHIC 200 GeV
central -
Suppression
peripheral
 N_{coll} scaling



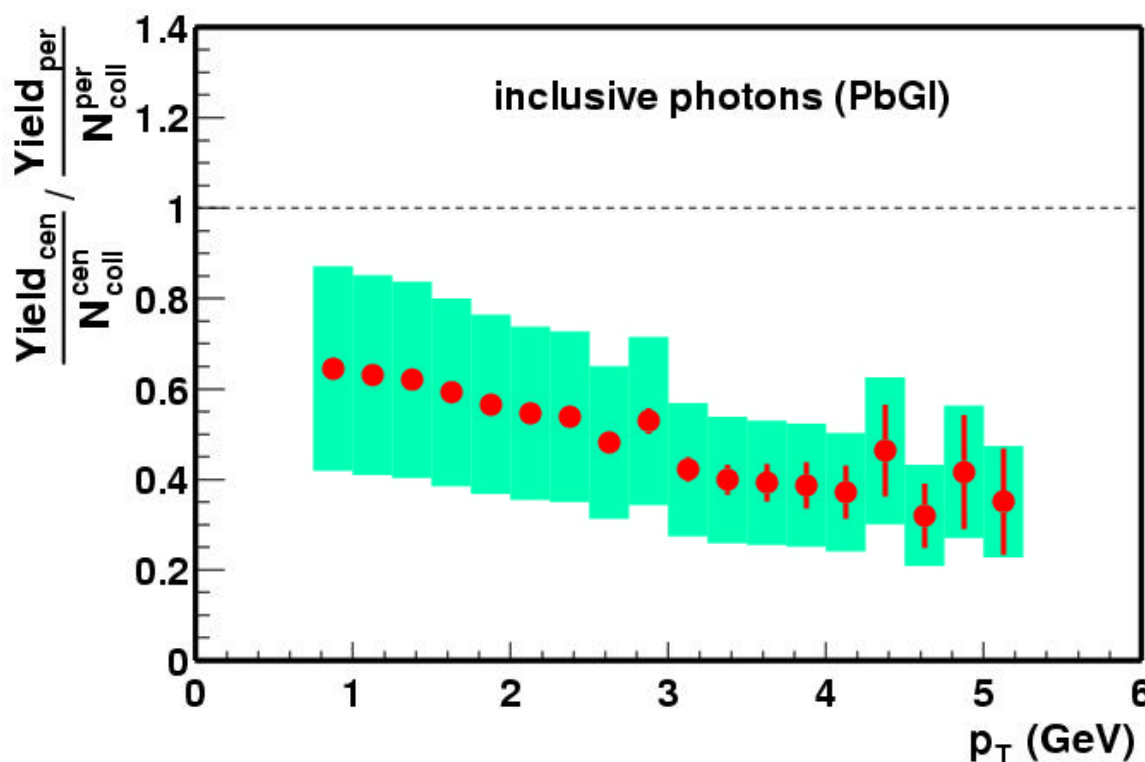
Suppression in Inclusive Photons

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

Photons (primarily
from π^0 decays)
also show
suppression

→ Not an artifact of
extraction of π^0
peak yield

Klaus Reygers talk



Theory Comparisons for R_{AA}

--- Wang $dE/dx = 0$

--- $dE/dx = 0.25 \text{ GeV/fm}$

Wang: X.N. Wang,
Phys. Rev. C61, 064910
(2000).

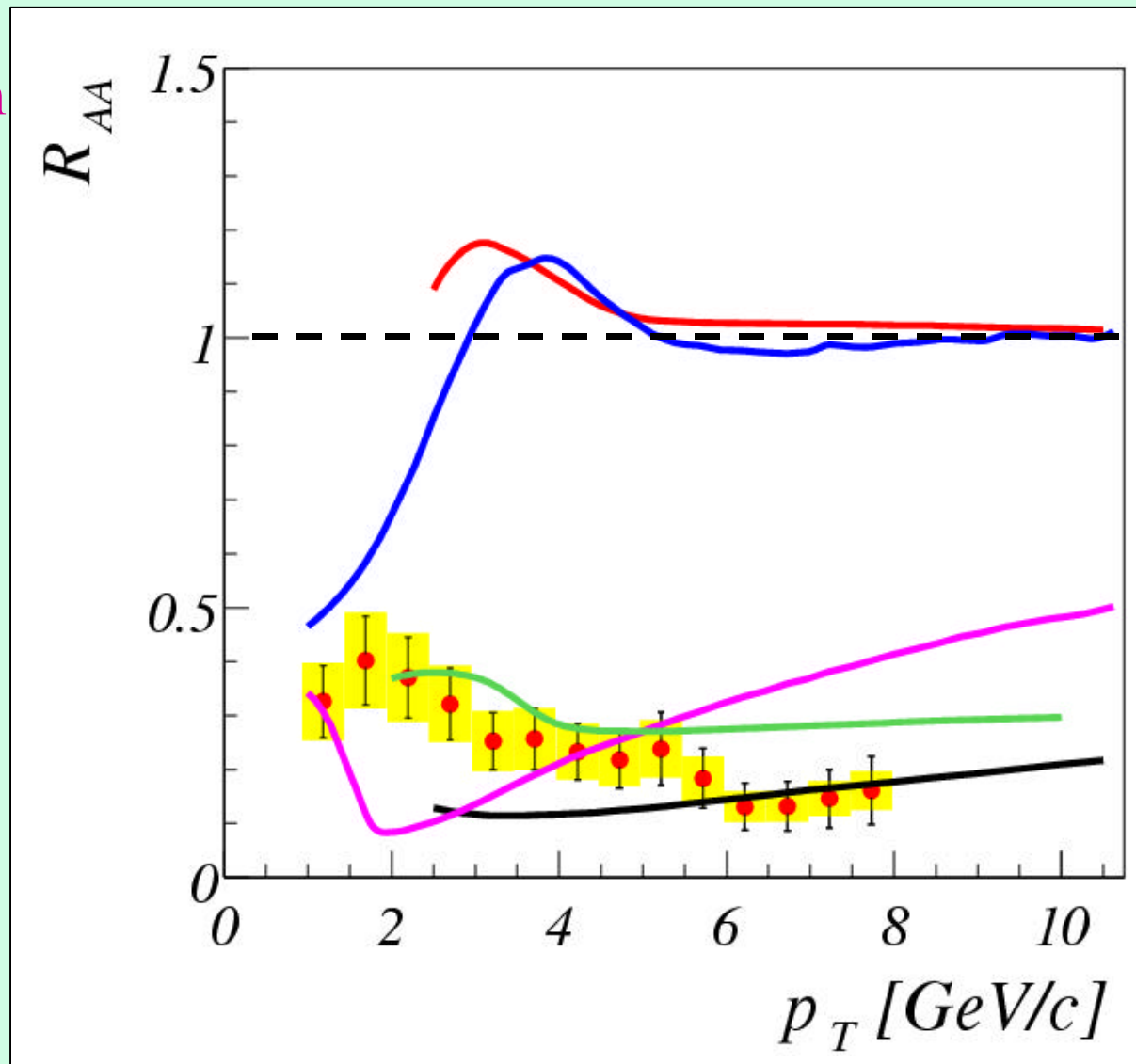
--- Levai $L/\lambda = 0$

--- $L/\lambda = 4$

Gyulassy, Levai, Vitev:
P.Levai, Nuclear Physics
A698 (2002) 631.

--- Vitev $dN^g/dy = 900$

• **GLV**, Nucl. Phys. B 594,
p. 371 (2001) + work in
preparation.

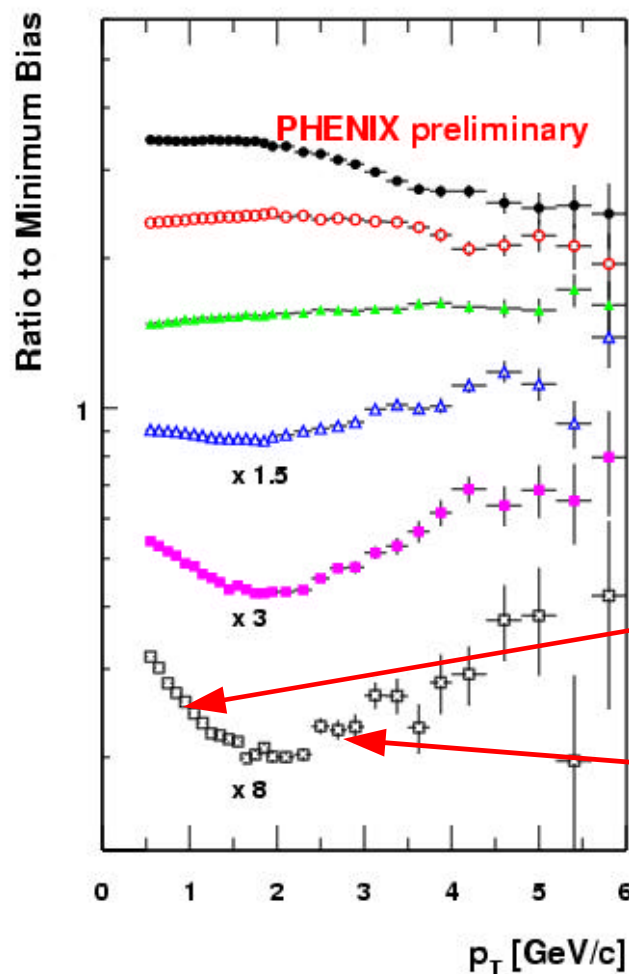
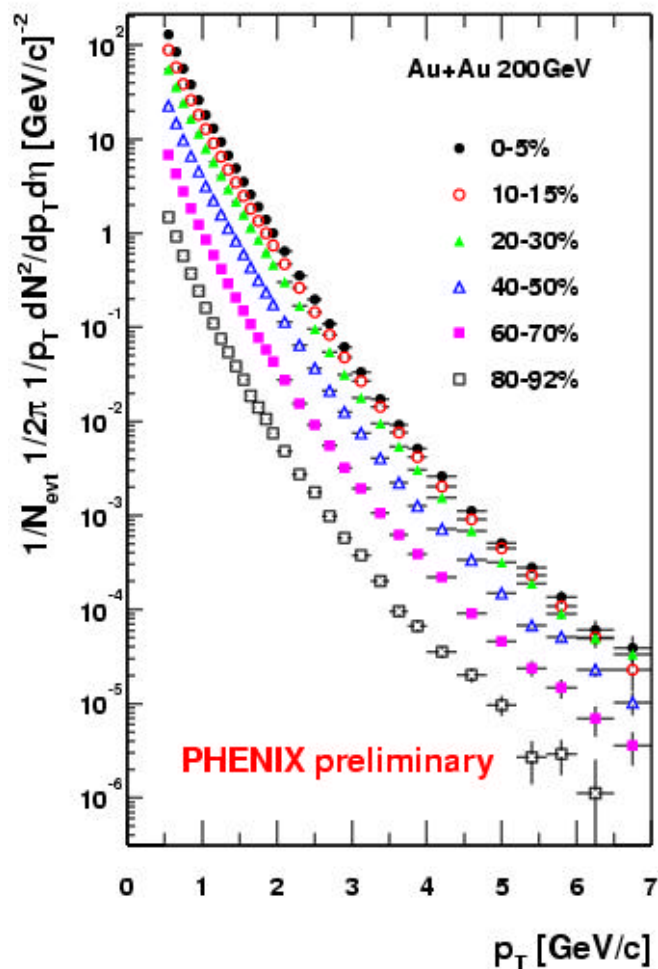


Charged Hadron spectra



Strong shape change with centrality

J. Jia talk



Ratios to
minimum bias
spectrum

Most Peripheral:
 $p_T < 2 \text{ GeV}/c$:
absence of flow
 $p_T > 2 \text{ GeV}/c$:
absence of
suppression

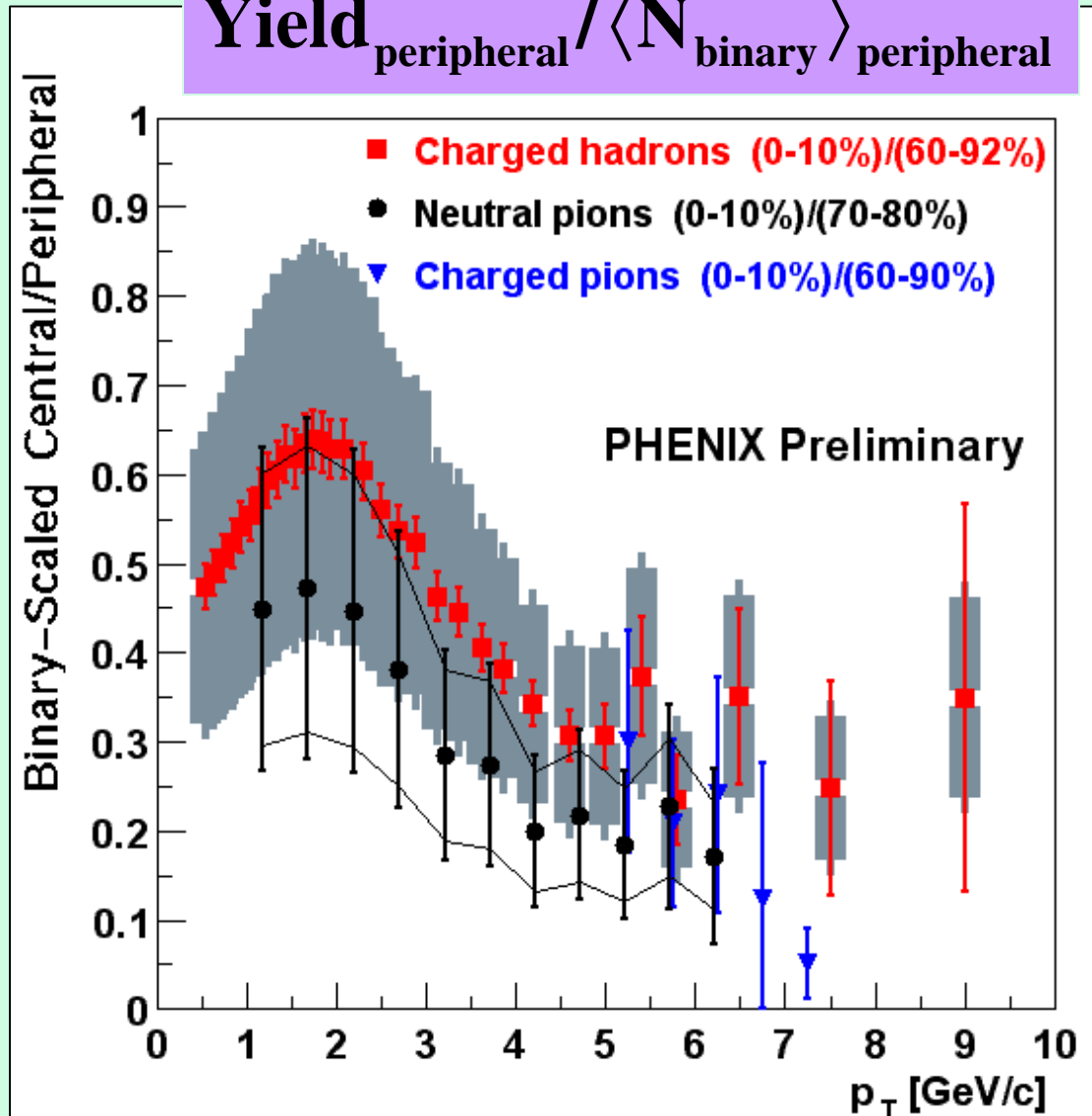
Central to Peripheral Ratio



(A variation on R_{AA})

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

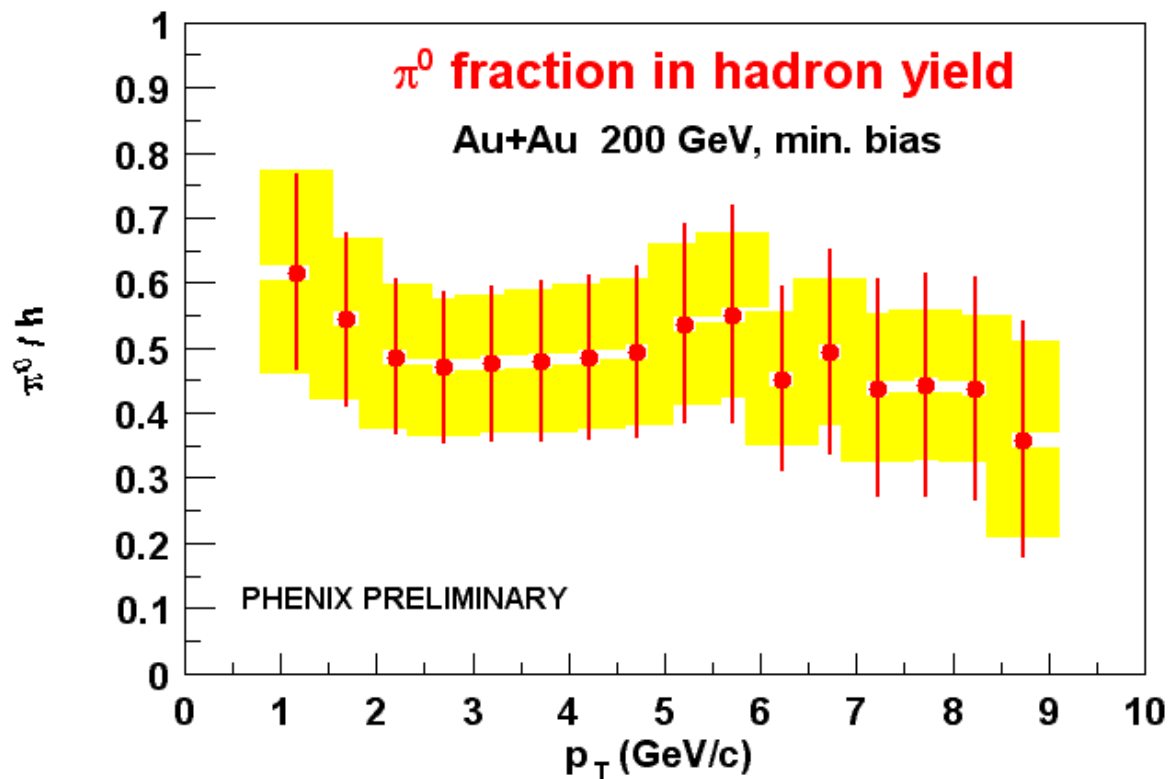
- Suppression seen in 3 independent measurements
- Difference in π^0 /charged h ratio \rightarrow particle composition



Particle Composition at high p_T

$\pi^0/(h^++h^-)/2$ ratio ~ 0.5 up to 9 GeV/c

→ do protons continue to make up a large fraction of charged hadron yield?

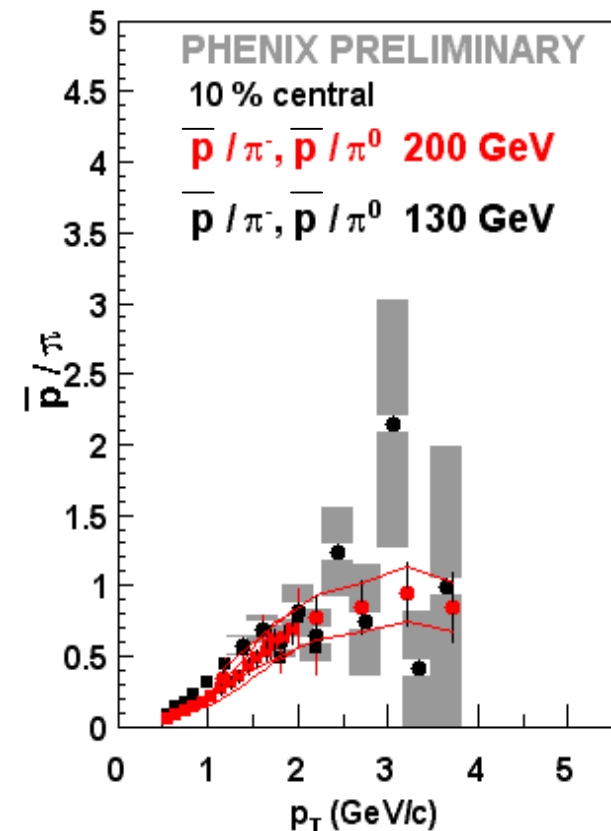
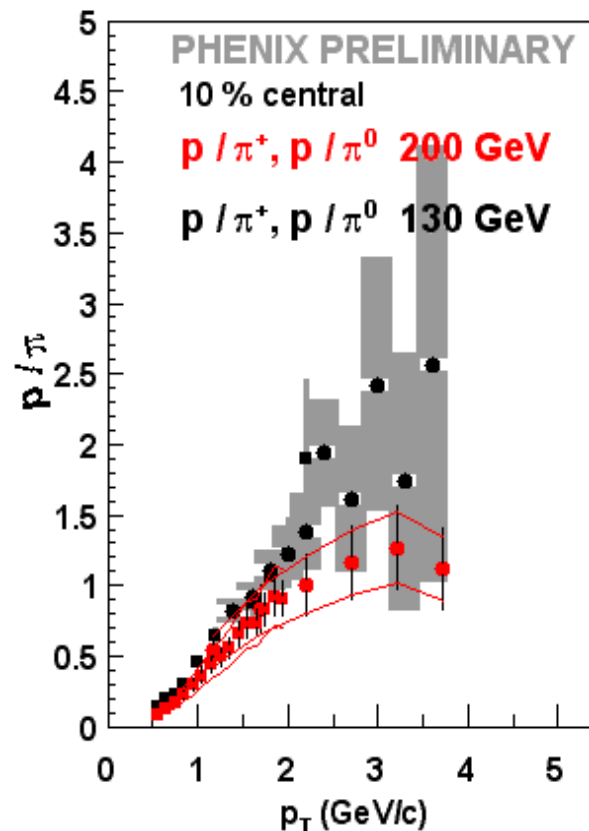


Particle composition at high p_T

- Proton/pion ~ 1 at high p_T for central collisions

T. Sakaguchi talk

- In peripheral collisions, ratio ~ 0.4



2. Identifying Jets via Particle Correlations

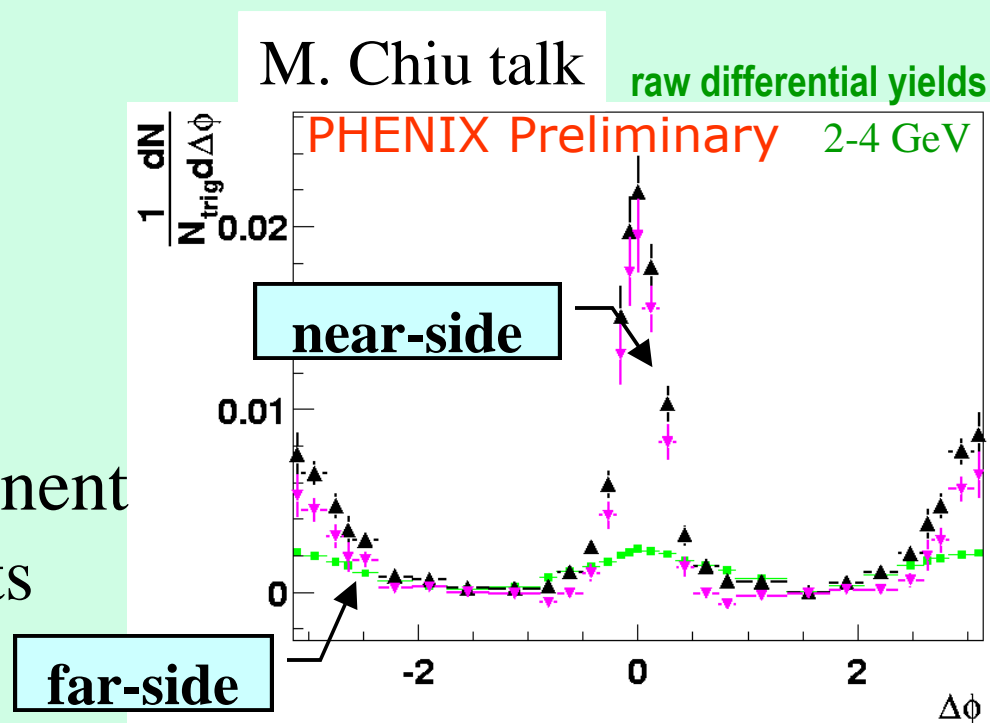


- Continued suppression in high p_T hadron spectra
- Expect that jet fragmentation dominates production at these p_T
- Do correlations demonstrate jet signal in Au+Au?
 - v_2 analysis (N. Ajitanand talk)
 - Multi-particle correlations (W. Holzmann poster)
 - Two particle correlations: v_2 + near angle term
 - Jet strength utilizing Pythia for correlation shape

Observing Jets via Angular Correlations



- Charged tracks associated with high energy leading photon (>2.5 GeV)
- Remove soft background by subtraction of mixed event distribution
- Fit remainder:
 - Jet correlation in $\Delta\phi$; shape taken from Pythia
 - In Au+Au, add v_2 component to account for flow effects



In p+p collisions



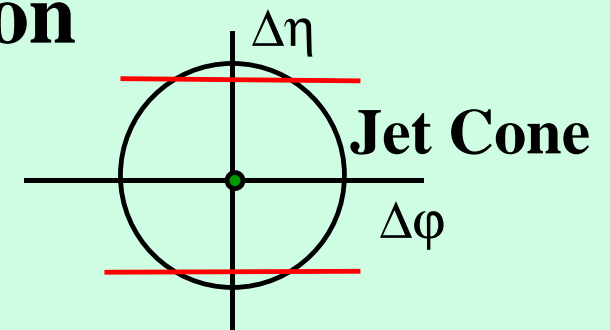
$\Delta\phi$ (leading photon $E > 2.5$ GeV & charged partner)

1-2 GeV partner

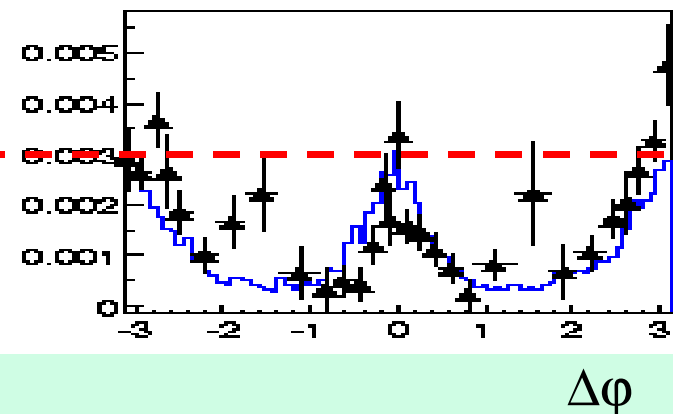
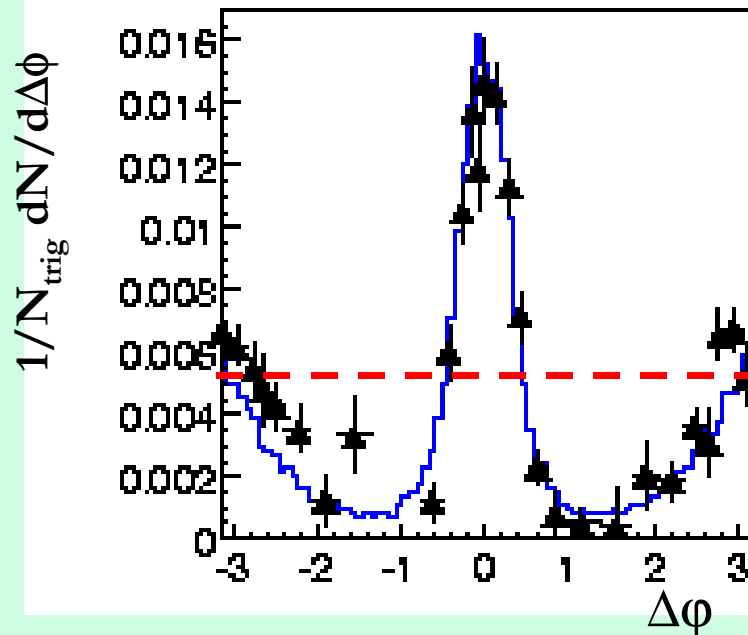
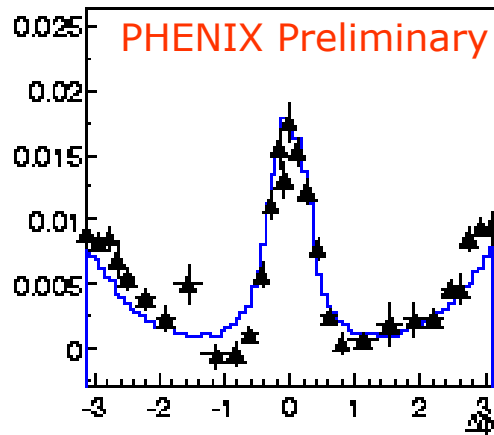
M. Chiu talk

Make cuts in $\Delta\eta$ to enhance
or suppress near-side
correlation

$|\Delta\eta| < 0.35$



$|\Delta\eta| > 0.35$



In Au+Au collisions



$\Delta\phi$ (leading photon $E > 2.5$ GeV & charged partner)

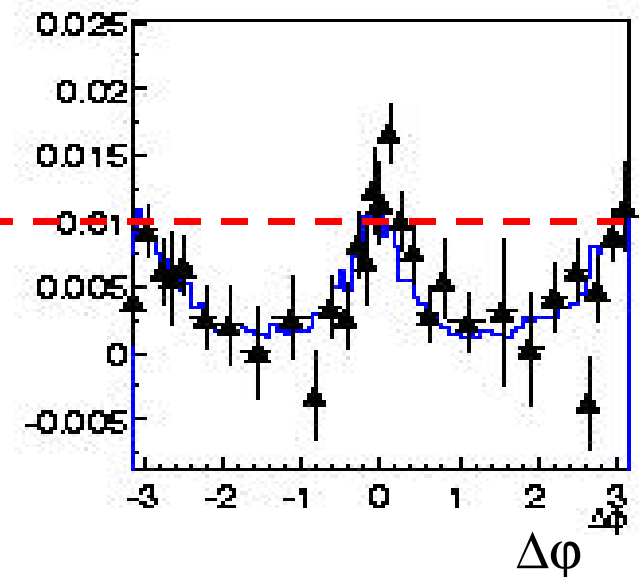
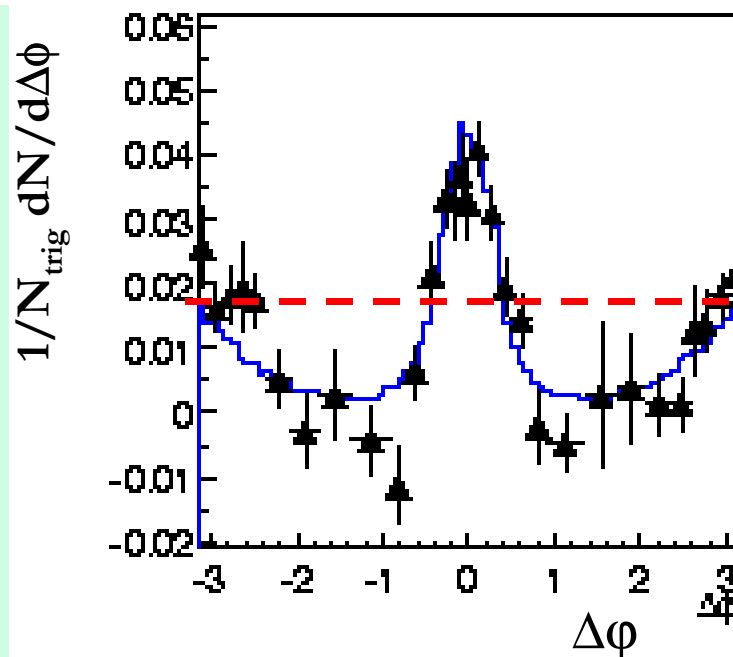
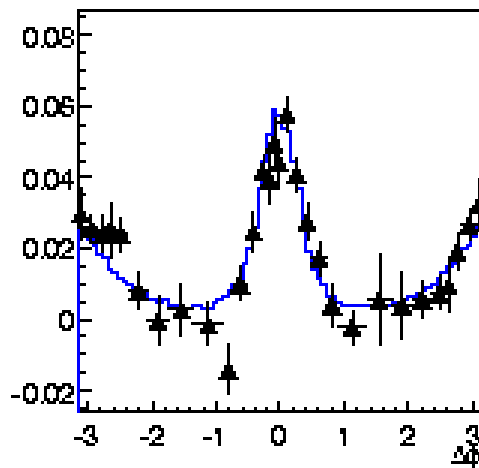
1-2 GeV partner

M. Chiu talk

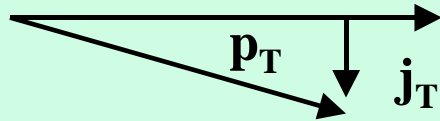
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or suppress near-side
correlation

$|\Delta\eta| < 0.35$

$|\Delta\eta| > 0.35$

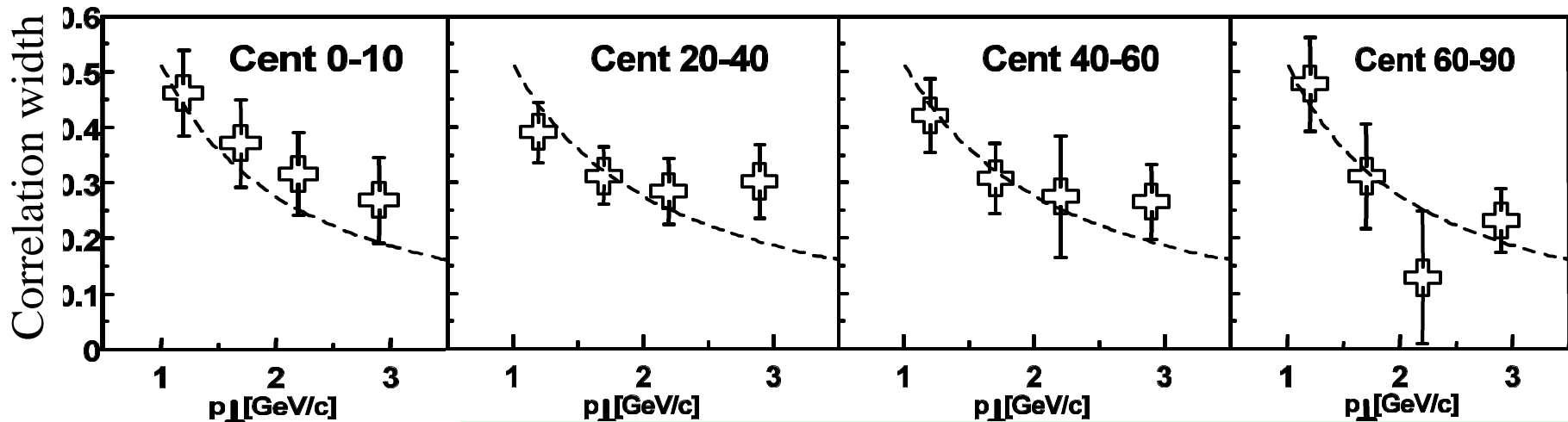


Fitting near-side correlation width



Correlation width $\propto j_T/p_T$

P. Constantin poster



- Near side correlation of two charged particles in fixed p_T bins
- Jet signal visible via correlation width

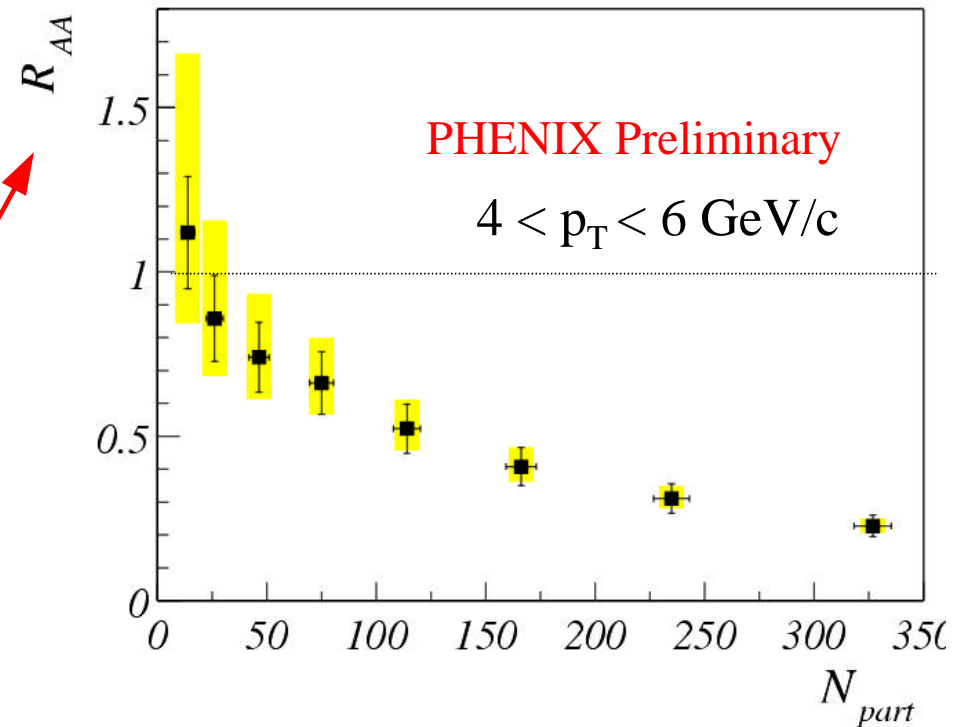
3. The Connection....

- Hadron spectra show suppression $\sim 3-8$ GeV/c
 - Photons with energy > 2.5 GeV (mostly from π^0) show strong evidence for jet contributions
- Suppression is occurring in a region where hadrons have contributions from jet fragmentation

Centrality Dependence of Suppression

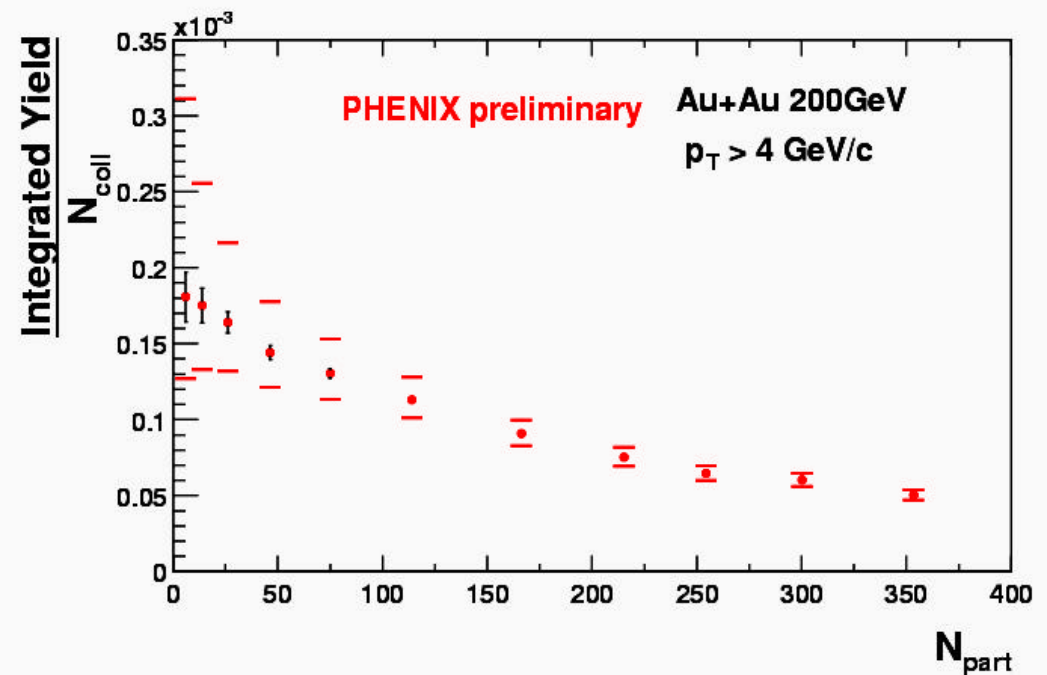
- Nuclear Modification Factor as a function of N_{part}

π^0



- Binary-scaled yield as a function of N_{part}

h^\pm



Conclusions

- h^\pm suppressed by factor 3-4 for $p_T > 4$ GeV/c
- π^0 suppressed by factor ~ 5 for $p_T > 4$ GeV/c
- Inclusive photons show similar suppression
- Strong evidence for jets
- In central collisions, $p/\pi \sim 1.2$ and $\bar{p}/\pi \sim 0.9$ at 3 GeV/c
- What is the particle composition at higher p_T ??!
- No significant “Cronin” effect at RHIC in peripheral collisions
- Suppression gradual with N_{part}

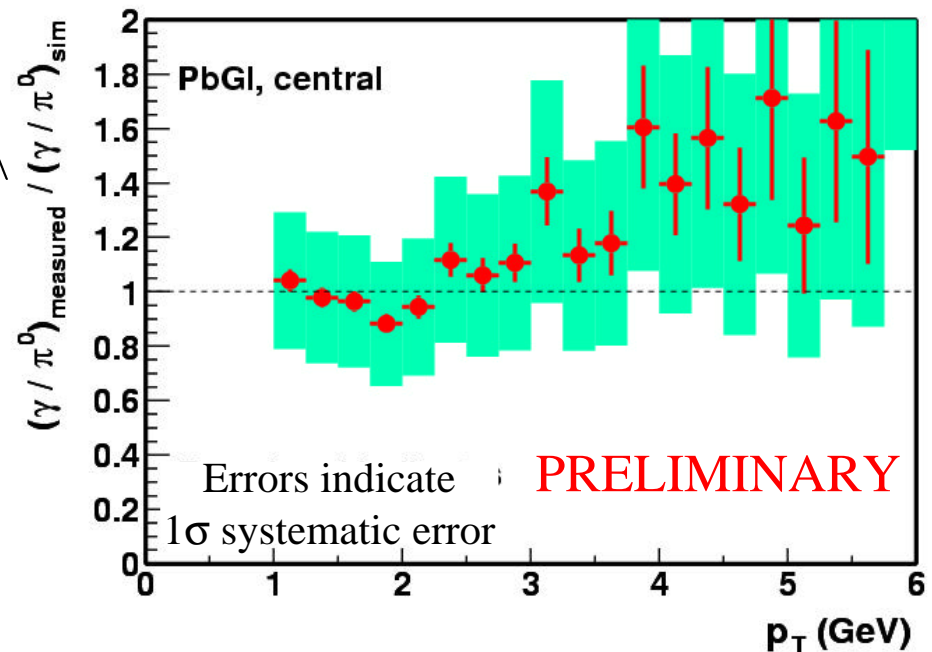
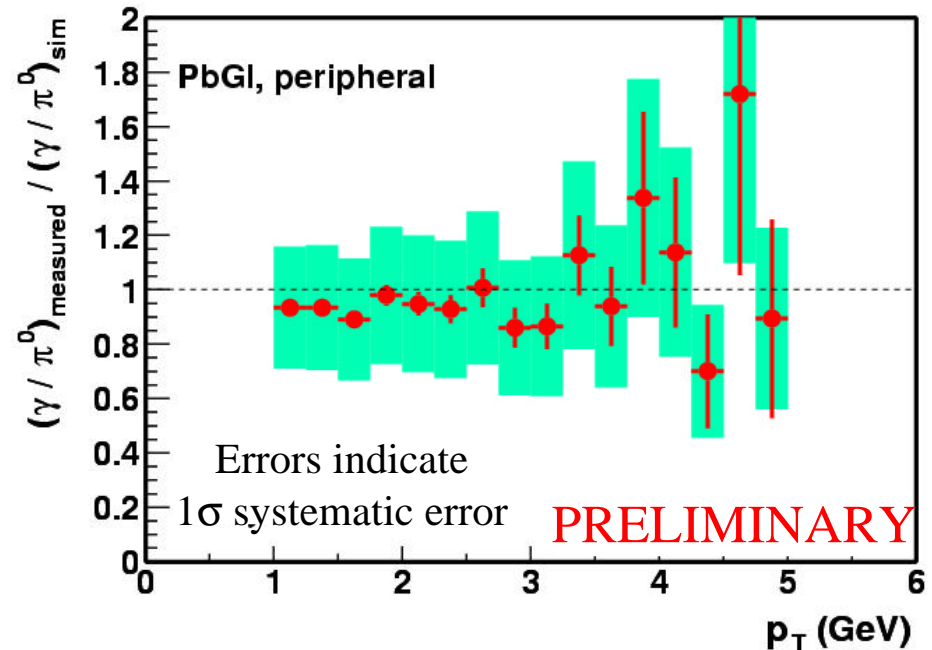
Direct Photon Limit

Klaus Reygers talk

Peripheral

Central

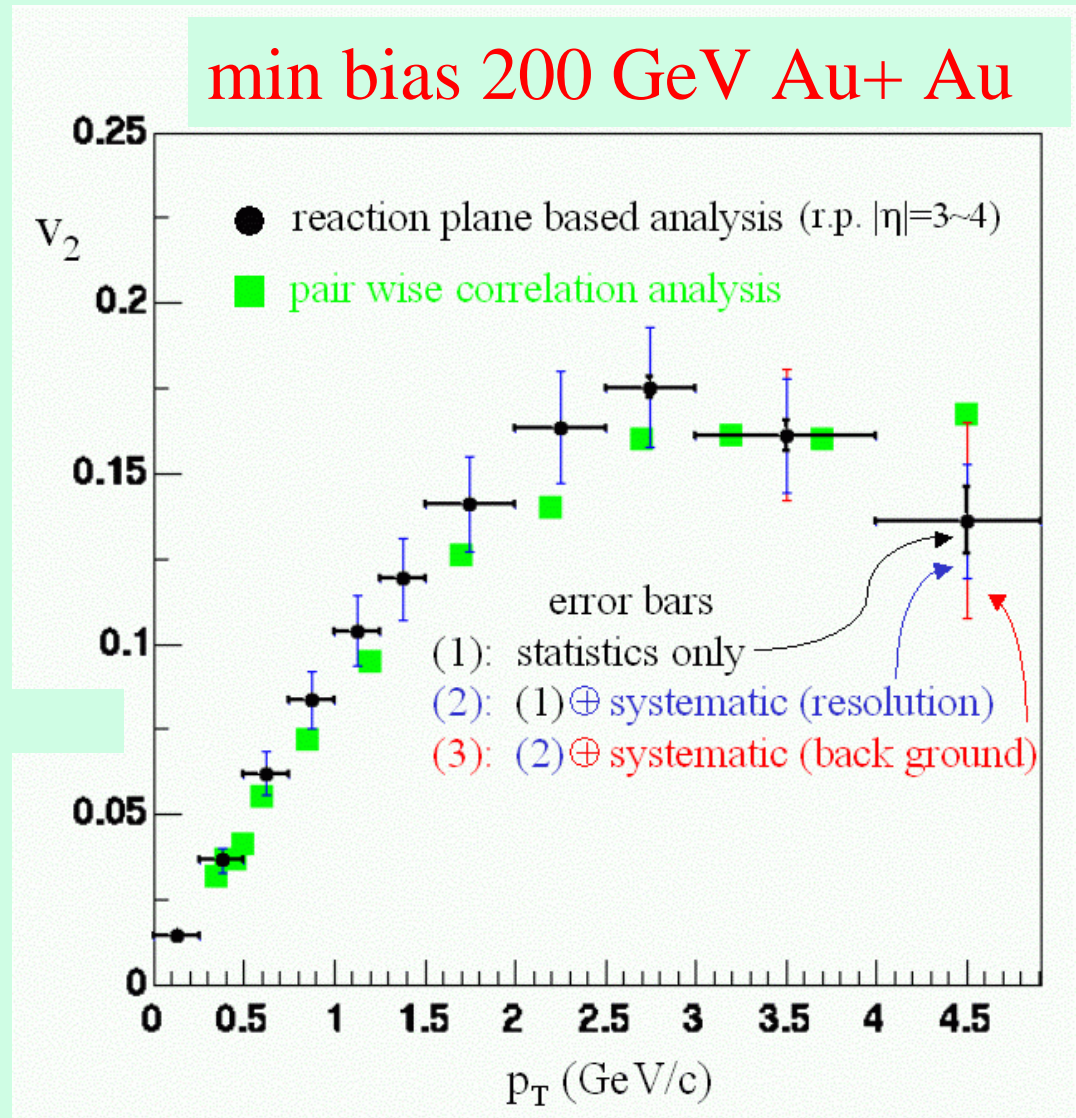
- No direct photon excess within 1σ systematic error
- Working to reduce systematic errors



V2 extended to high p_T

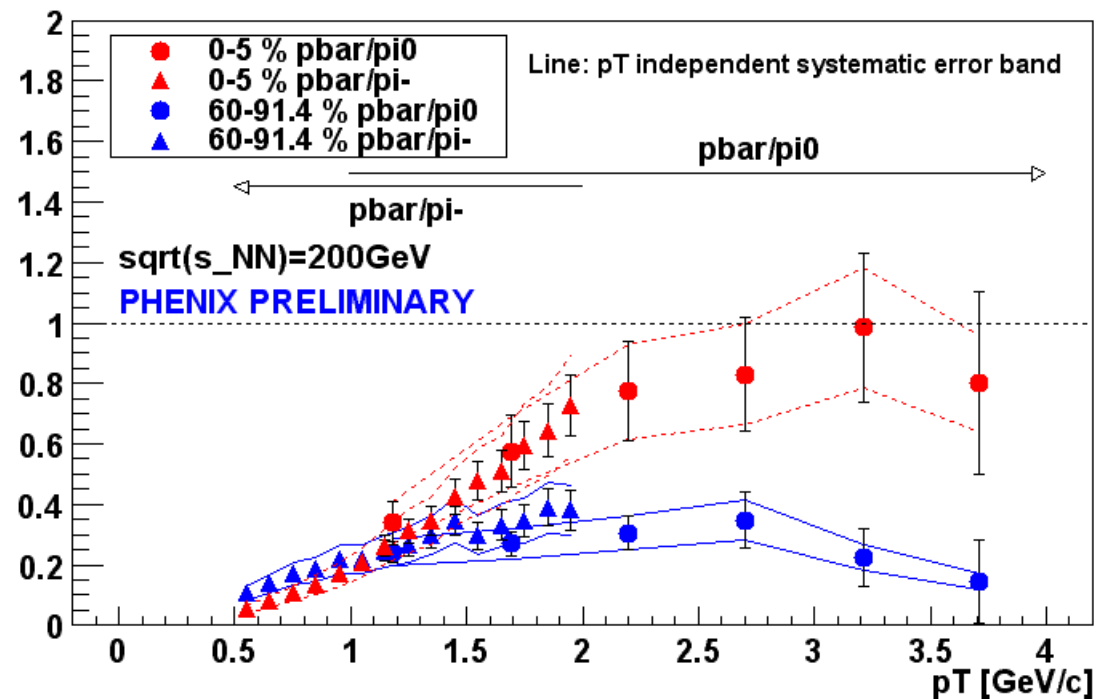
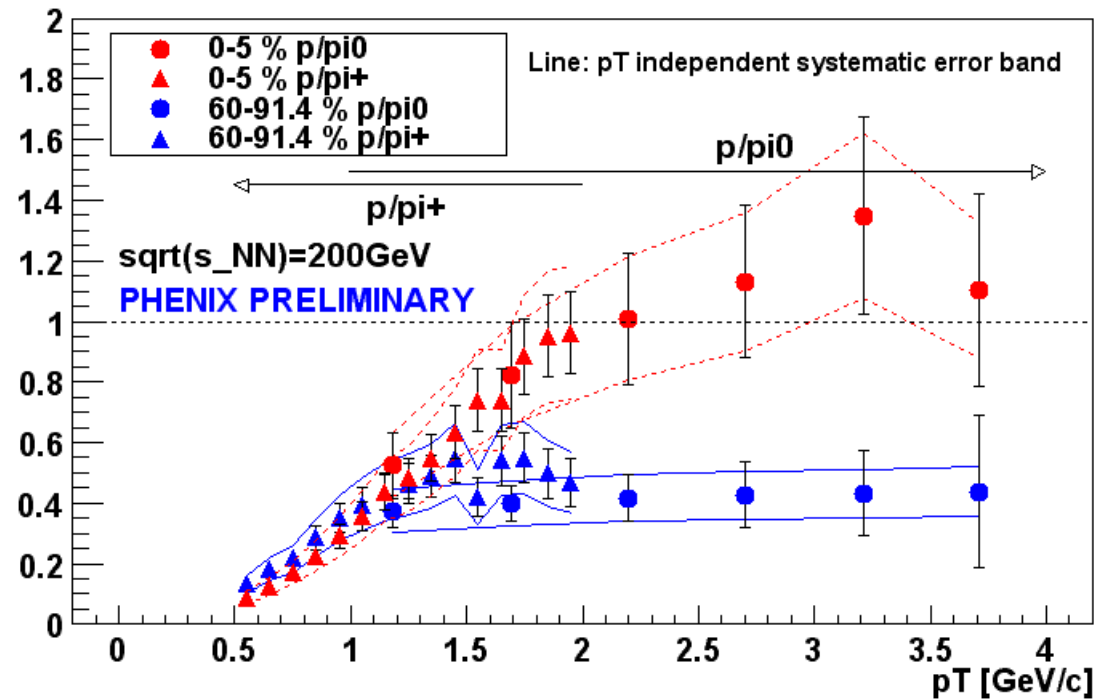
talk of S. Esumi

- V2 via reaction plane at $\eta=3-4$ and via 2-particle correlations agree
 - No jet contamination of reaction plane!
- Low p_T as expected from hydrodynamics
- V2 at high $p_T > 0.15$ – interpretation at $p_T > 3$ GeV/c??

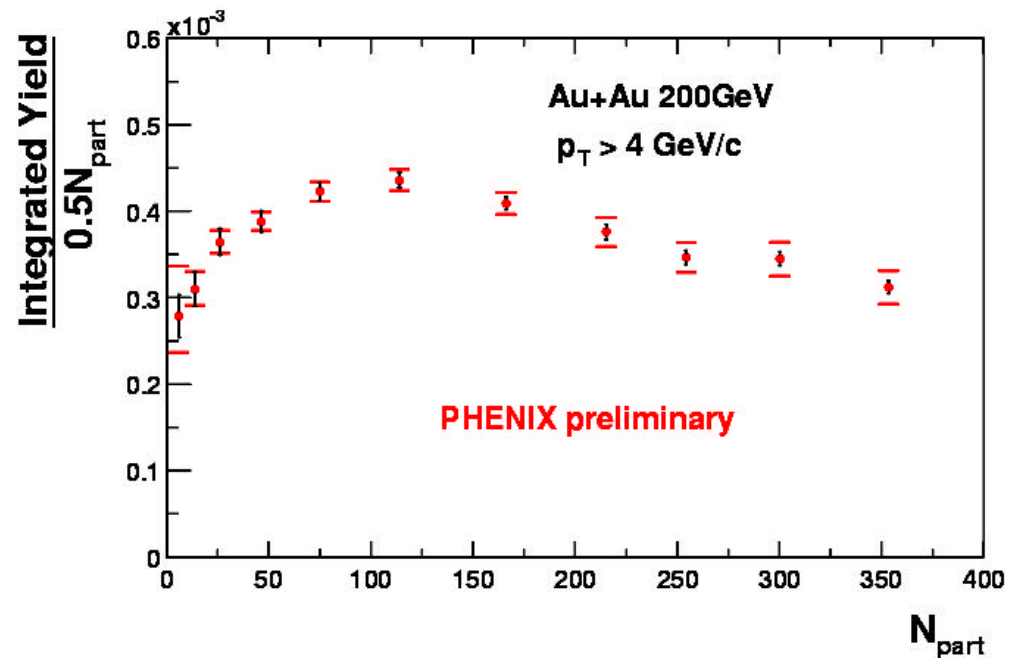
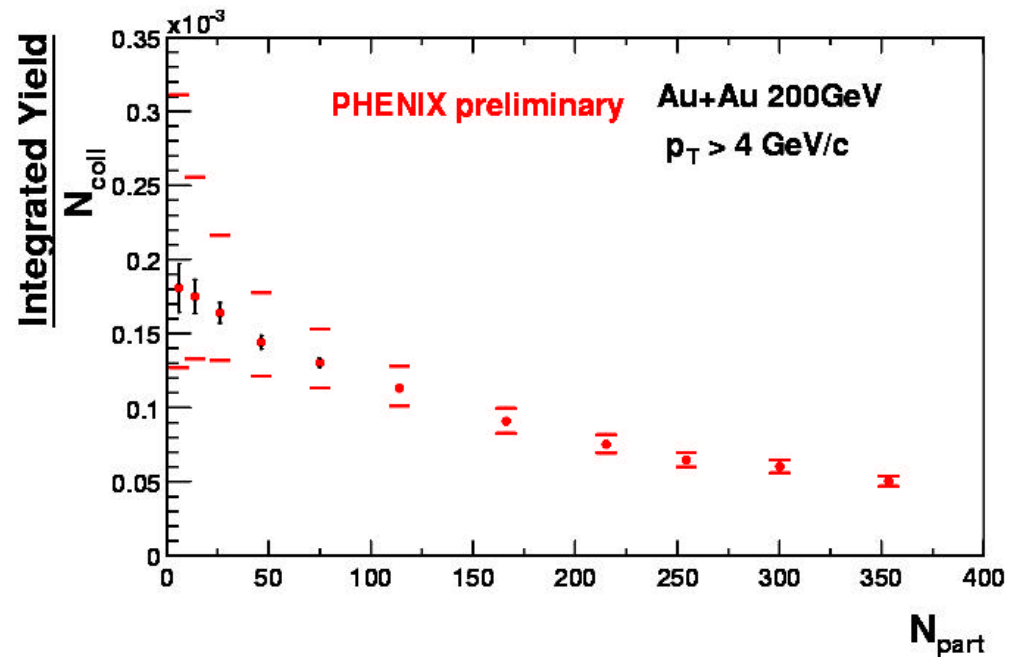


Ratios of p/π and \bar{p}/π for central vs. peripheral collisions

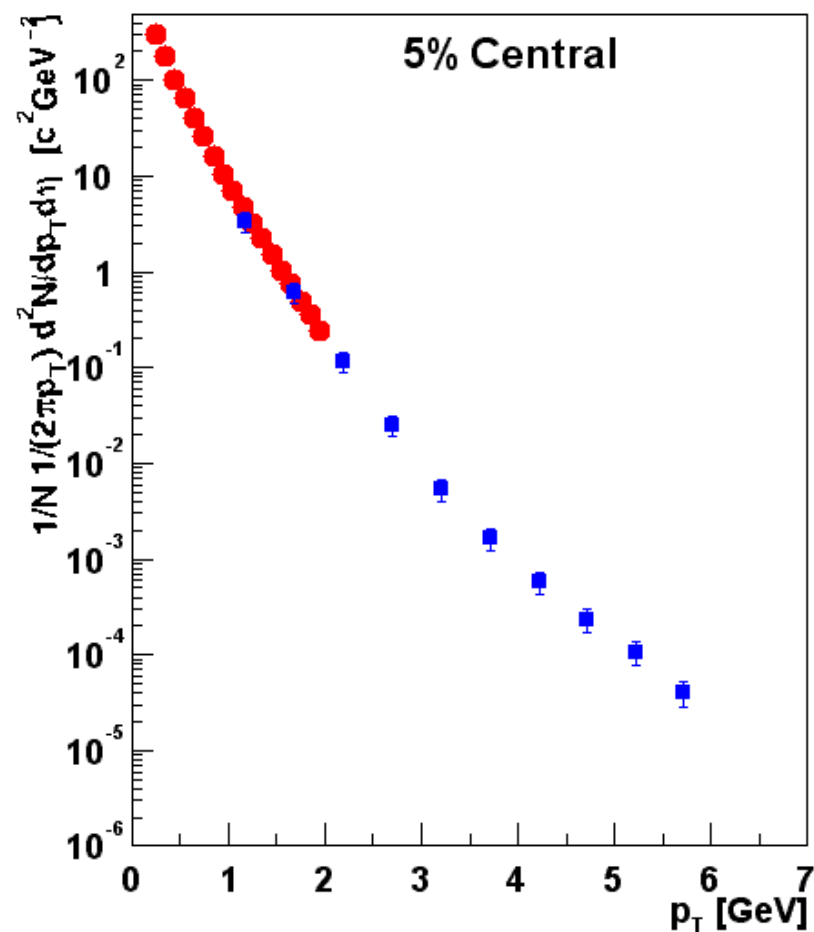
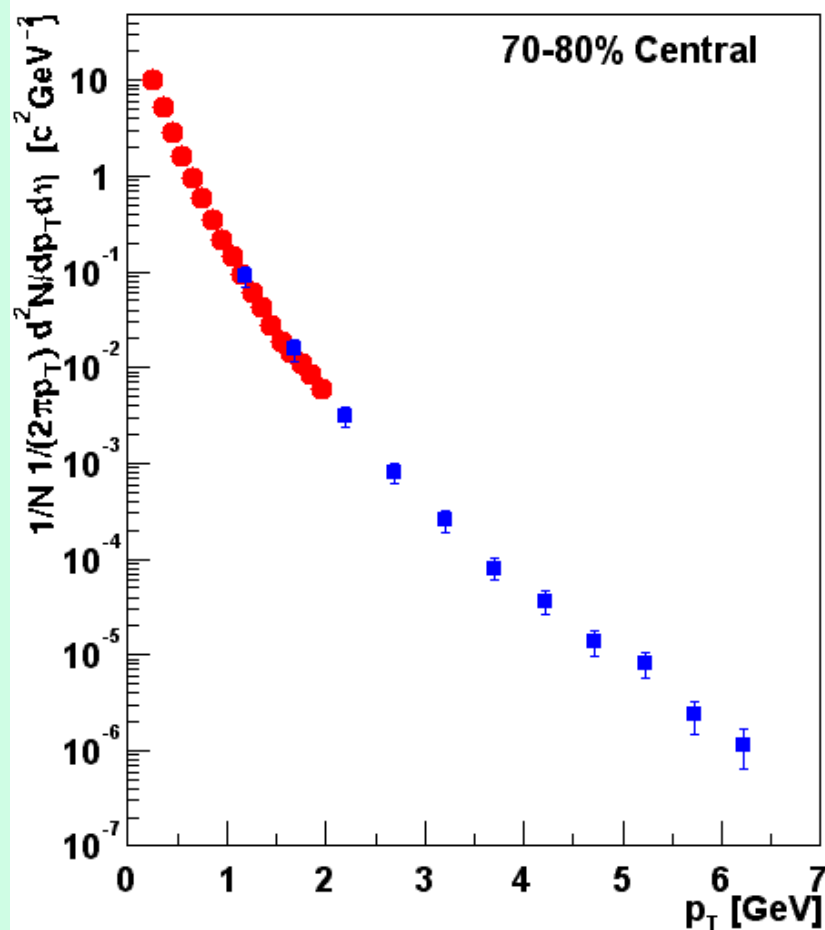
T. Sakaguchi talk



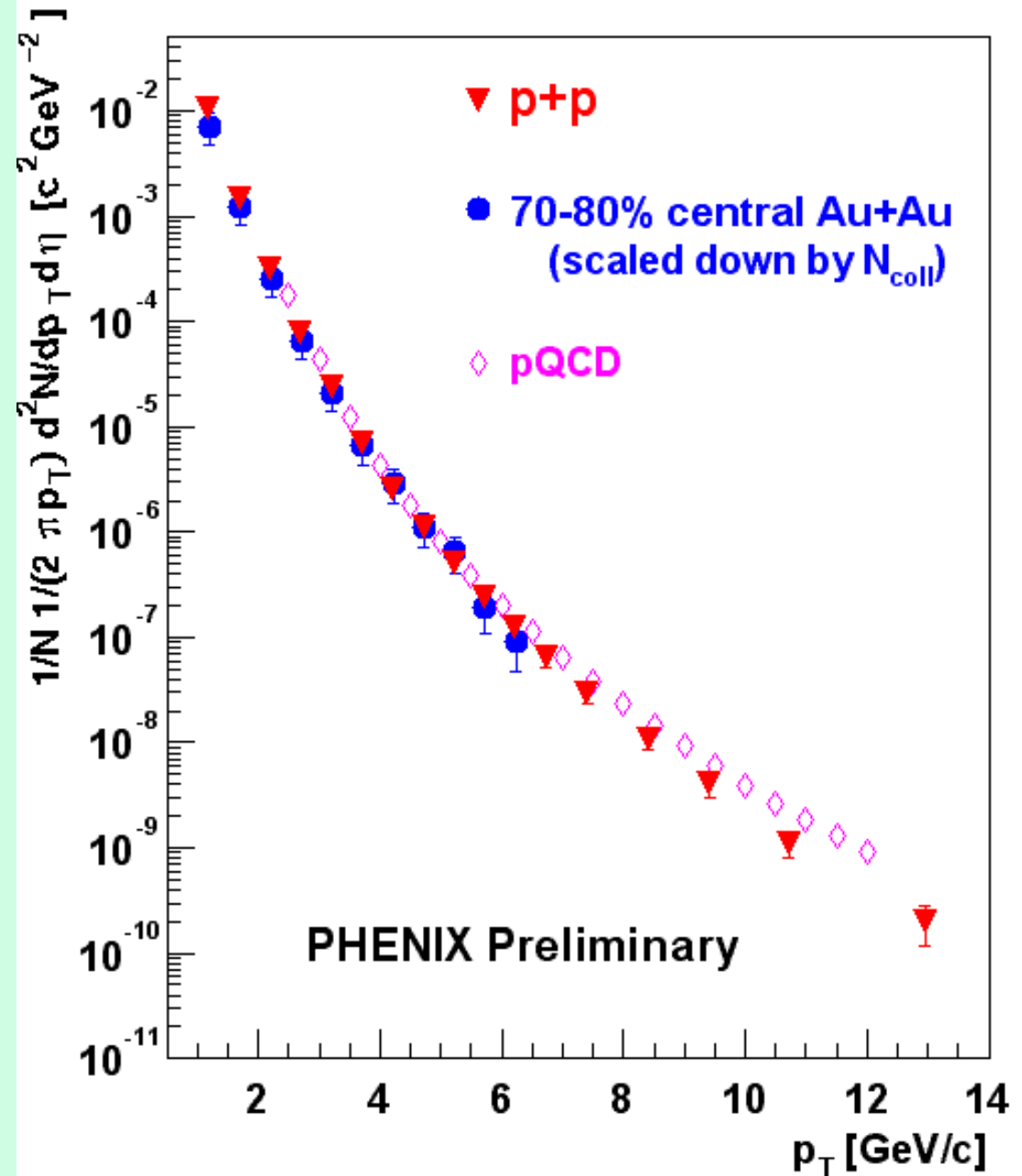
Charged hadron yields scaled by N_{coll} and N_{part}



Comparison of Pion Measurements in Central and Peripheral Events



p+p Comparison with peripheral



pQCD calculation

LEVAI et. al.,

Y. Zhang, ... PRC65:034903,2002

In Au+Au: fit pythia + $2v_2v_j\cos(2\phi)$



M. Chiu talk

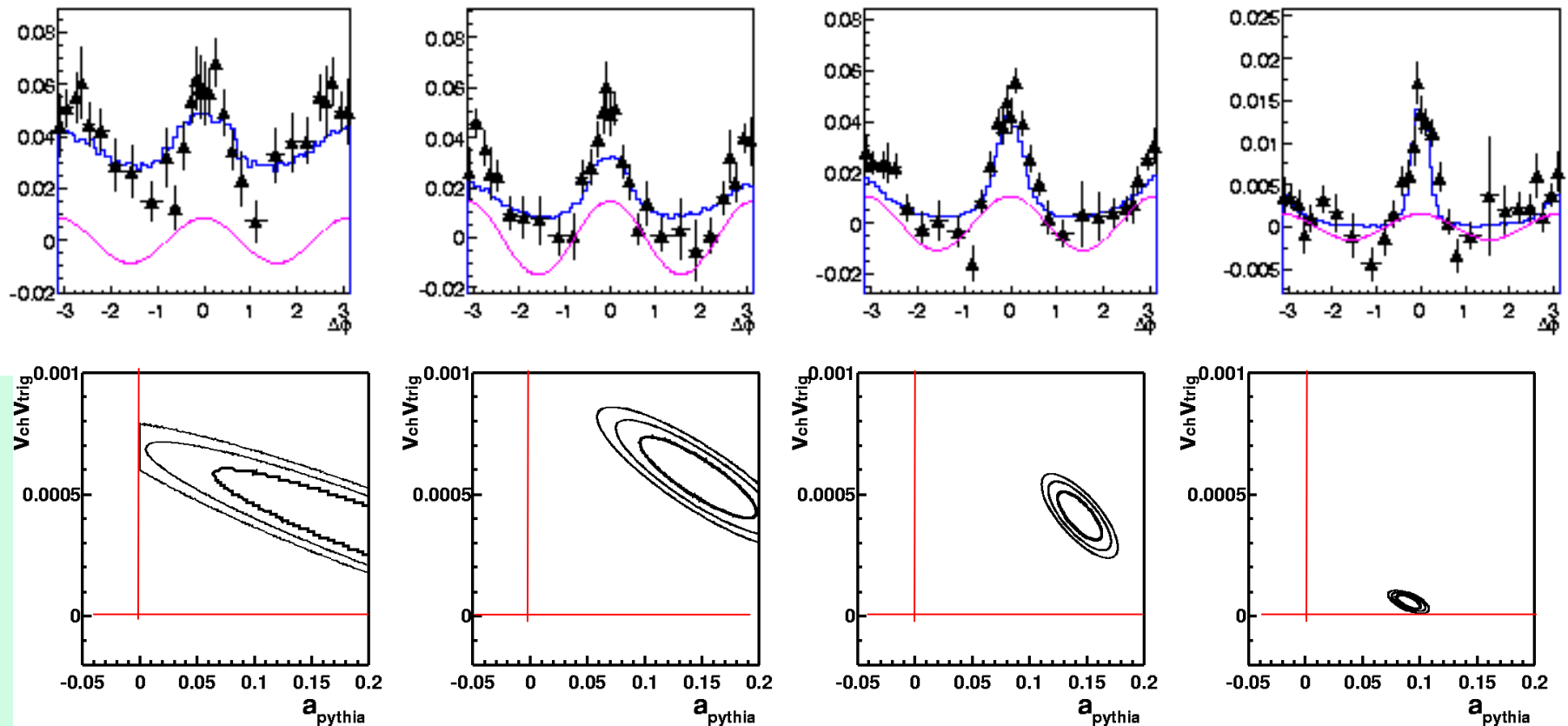
$\Delta\phi$

Partner p_T : 0.3-0.6 GeV/c

0.6-1.0 GeV/c

1-2 GeV/c

2-4 GeV/c



Jet strength

See non-zero jet strength as partner p_T increases!