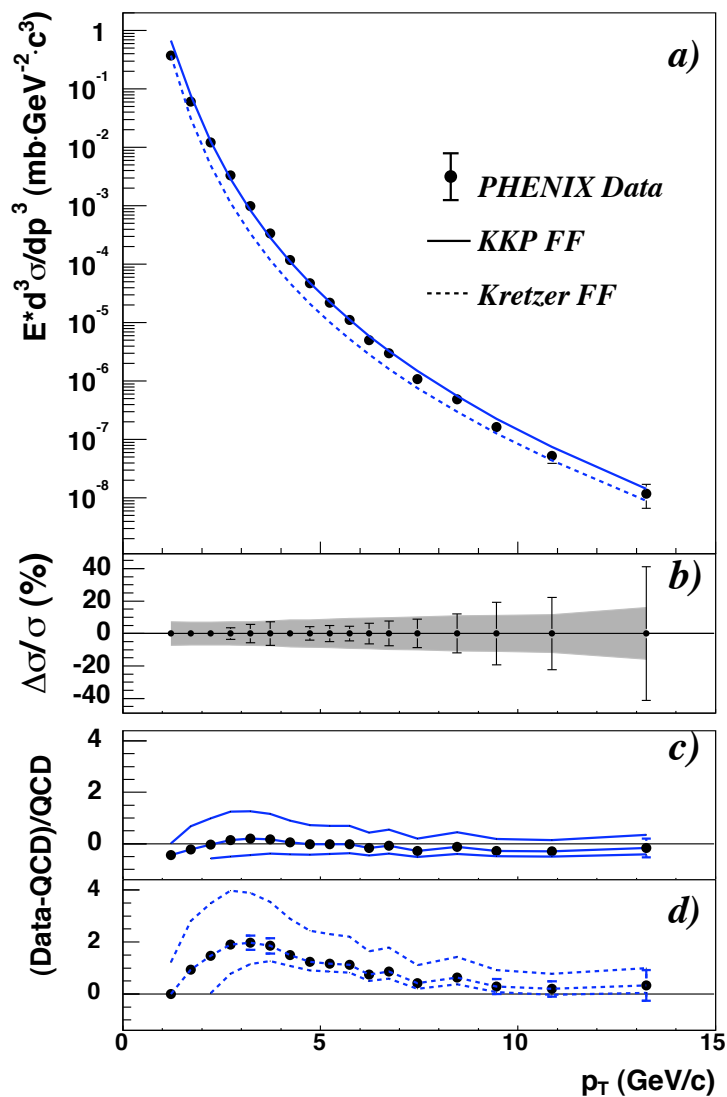


# Jets with Identified Particles at Intermediate $p_T$ at PHENIX

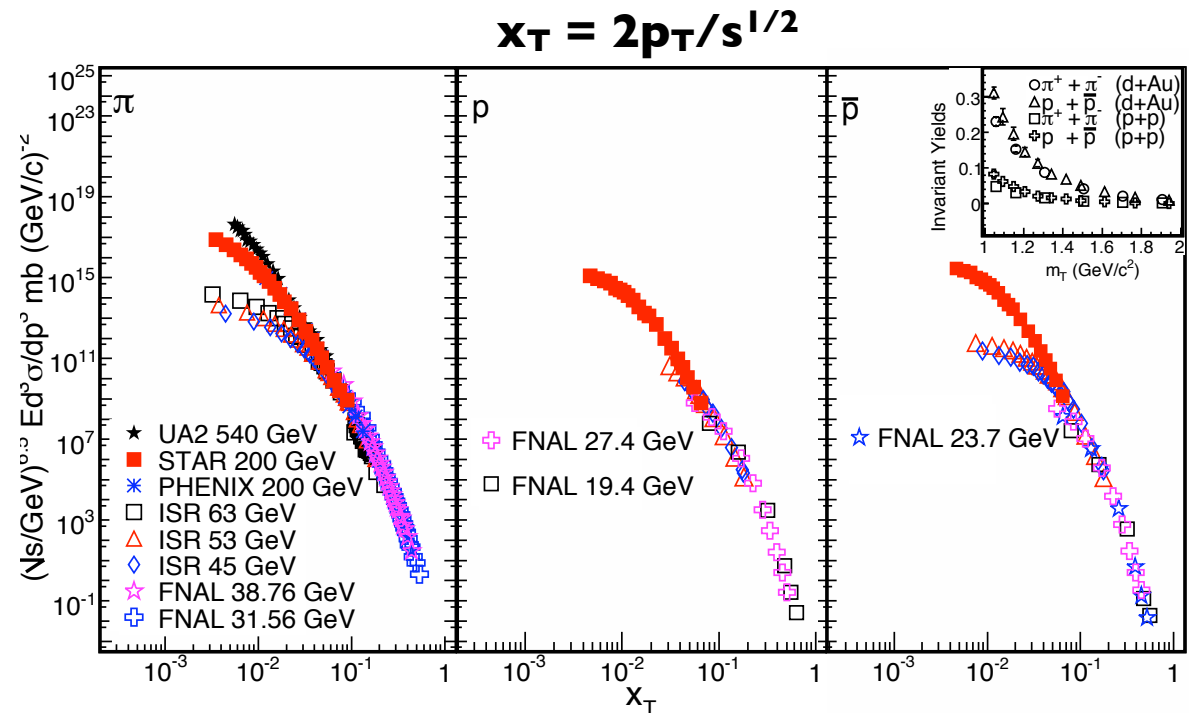
Anne Sickles

Brookhaven National Lab  
for the PHENIX Collaboration

# p+p: Limits of Hard Scattering Picture



**PHENIX PRL 91 241803 (2003)**



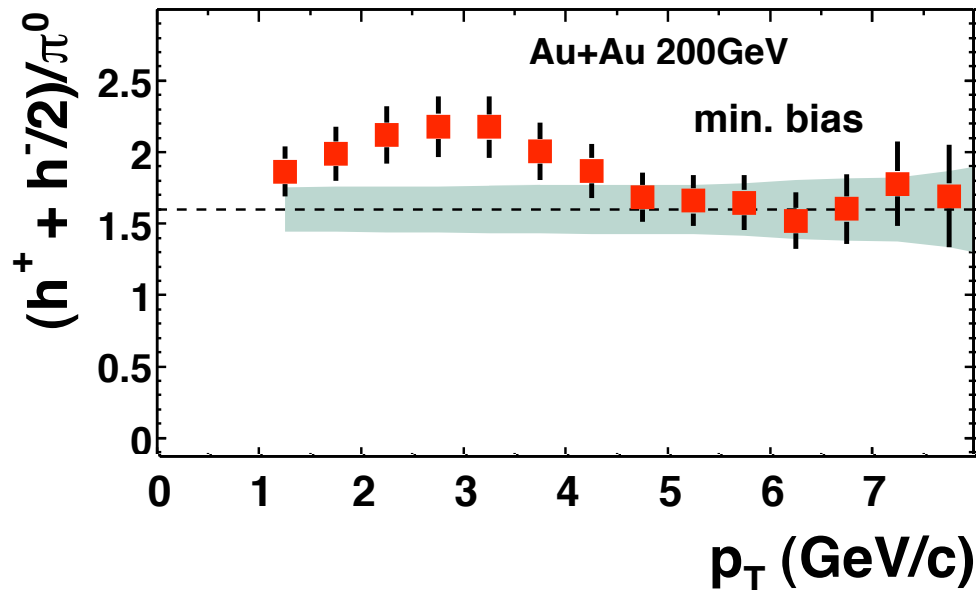
**STAR PLB 637 161 (2006)**

NLO pQCD and  $x_T$  scaling describe the p+p data down to  $p_T \sim 2\text{GeV}/c$

# Heavy Ions: Soft Physics @ Higher $p_T$ ?

---

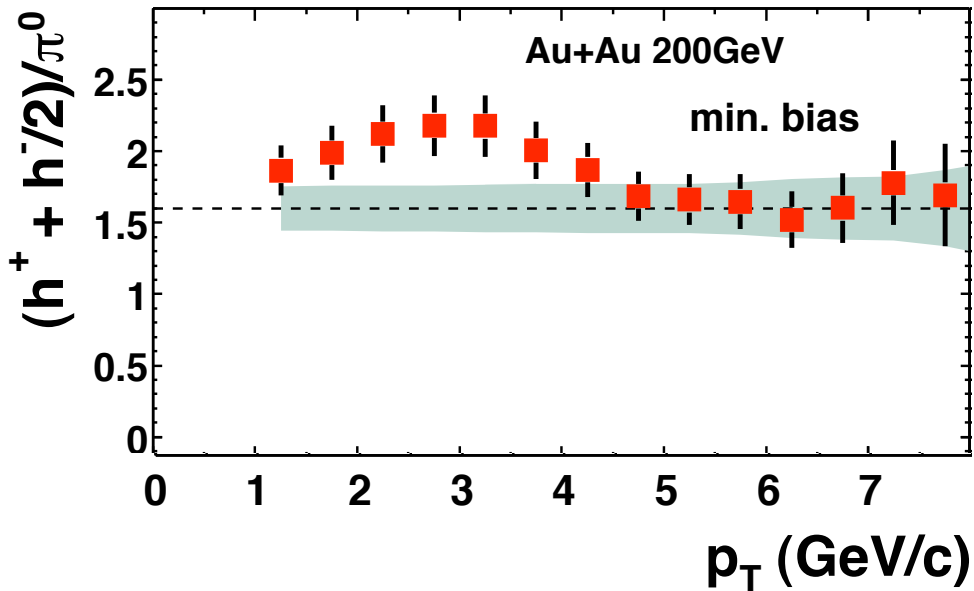
# Heavy Ions: Soft Physics @ Higher $p_T$ ?



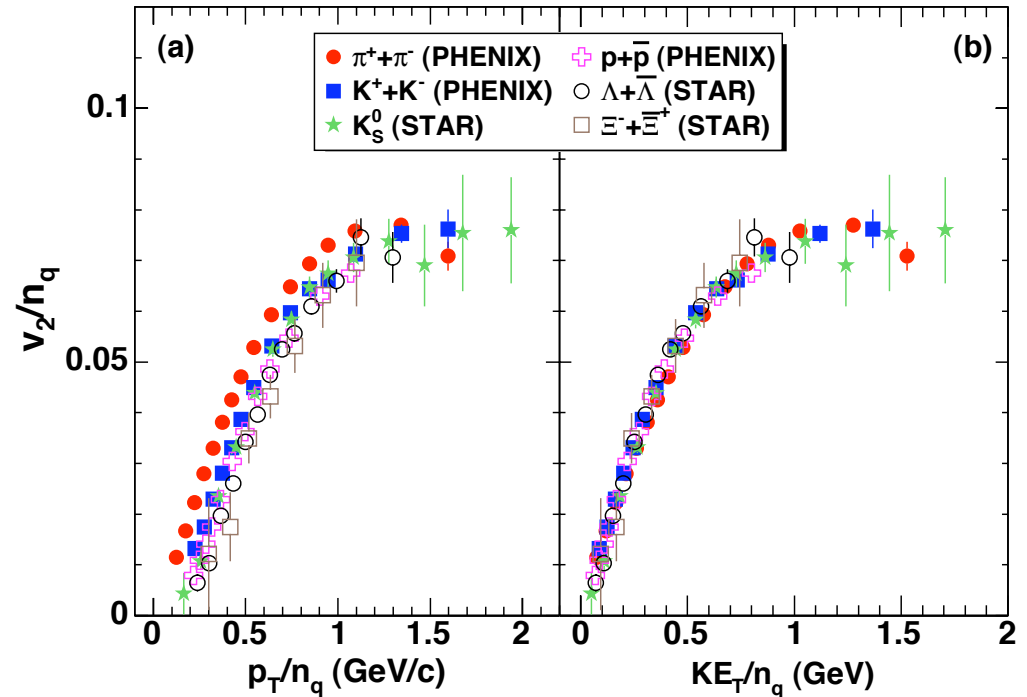
**Modification to  
fragmentation particle  
ratios extends to  $p_T \sim 5$   
GeV**

**PHENIX PRC 69 034910 (2004)**

# Heavy Ions: Soft Physics @ Higher $p_T$ ?



**Modification to fragmentation particle ratios extends to  $p_T \sim 5$  GeV**



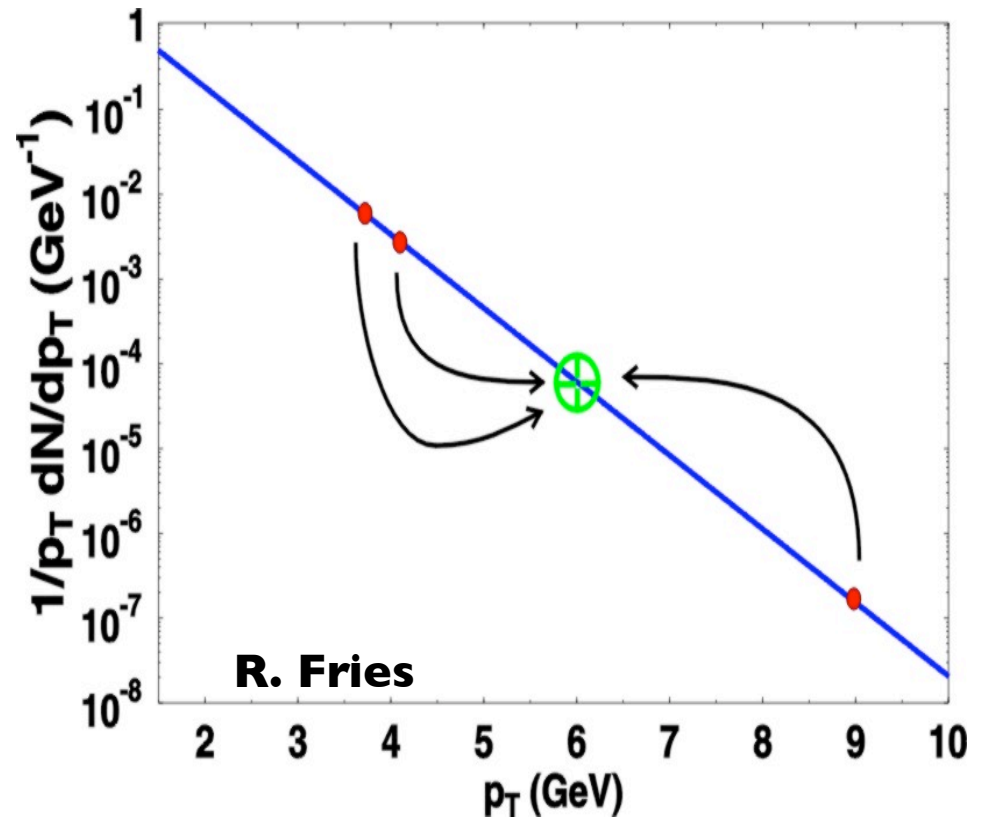
**Quark Number Scaling of  $v_2$  extends to  $p_T \sim 4-6$  GeV**

PHENIX PRC 69 034910 (2004)

PHENIX PRL 98 162301 (2007)

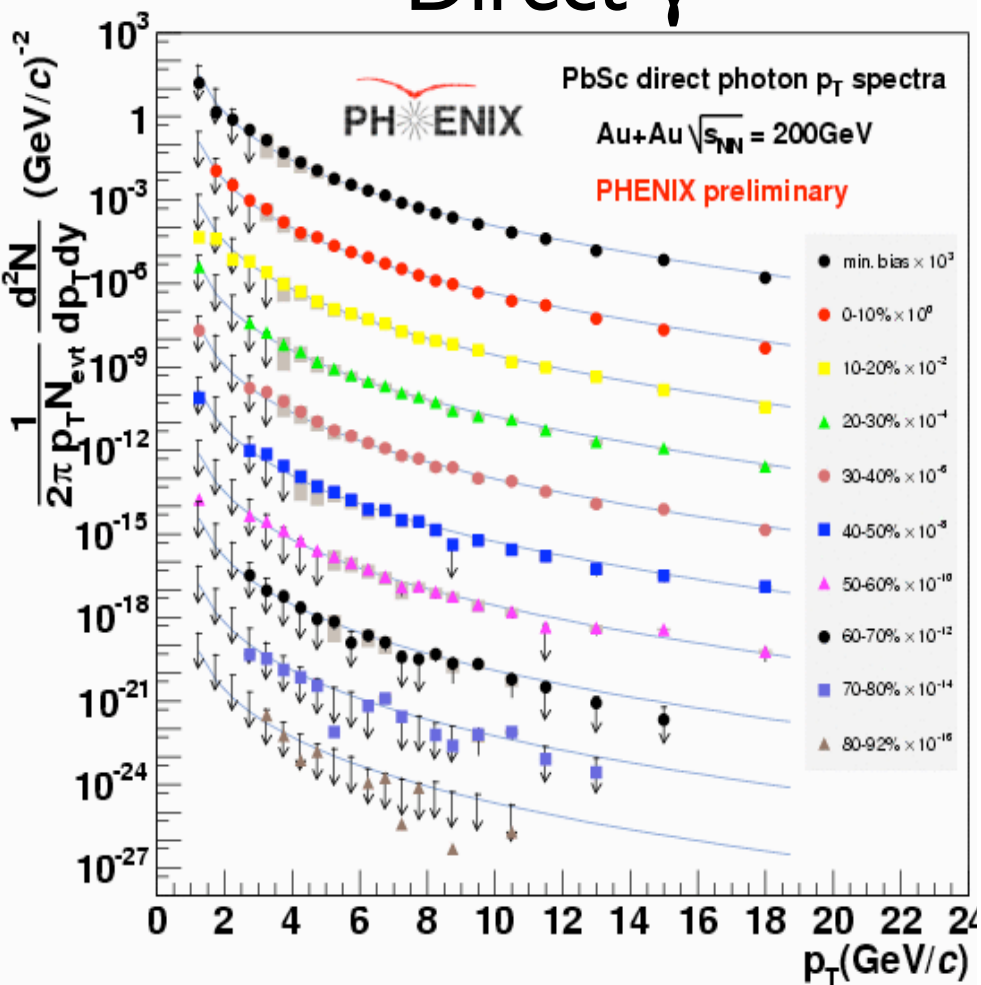
# Natural Explanation: Recombination Models

- quarks close together in phase space come together to form final state hadrons
- resulting hadron at higher  $p_T$  than parent partons, in contrast to fragmentation
- dominates for exponential parton  $p_T$  spectra
- implies partonic degrees of freedom and a QGP (Fries et al, PRL 90 202303 (2003))



# hard scattering still happens...

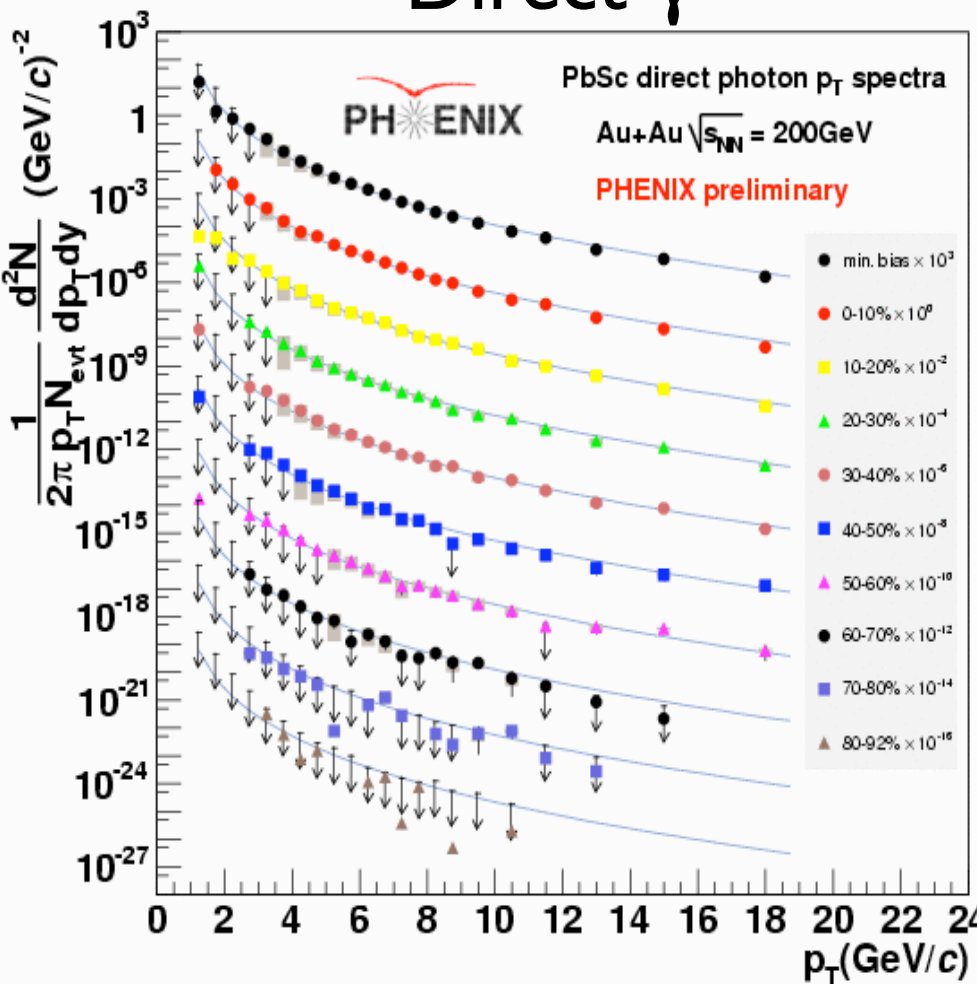
## Direct $\gamma$



**PHENIX PRL 94 232301 (2005)**

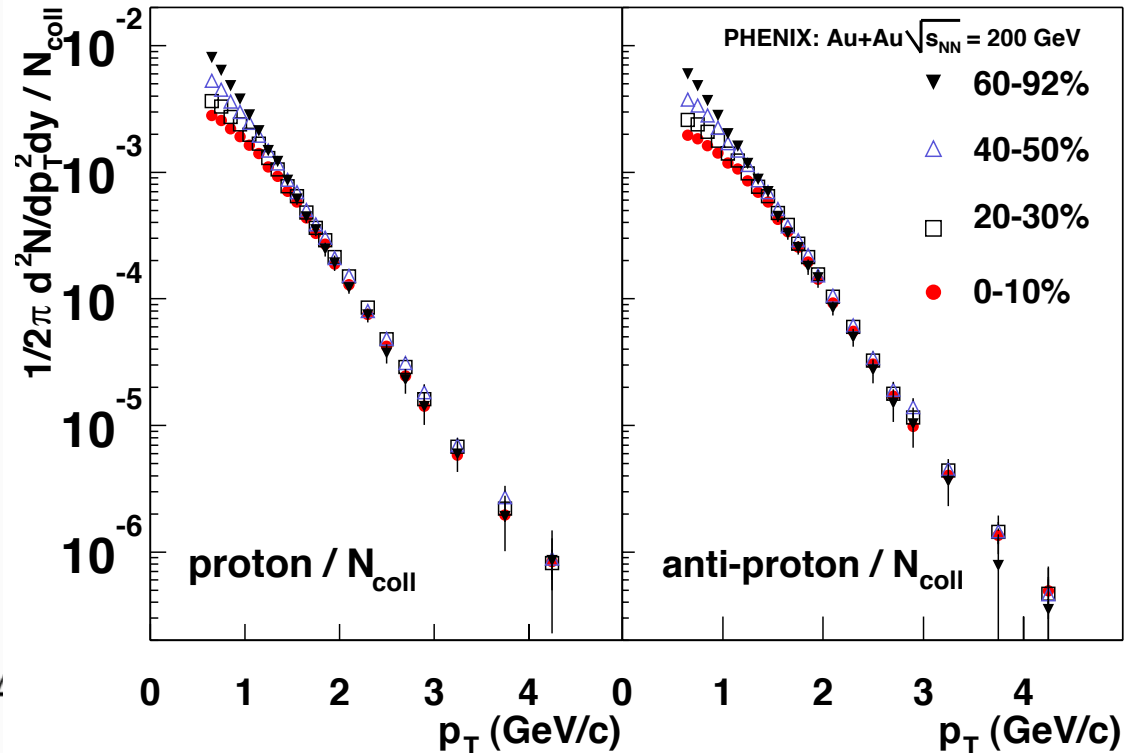
# hard scattering still happens...

## Direct $\gamma$



PHENIX PRL 94 232301 (2005)

...and even the baryons look hard at times...



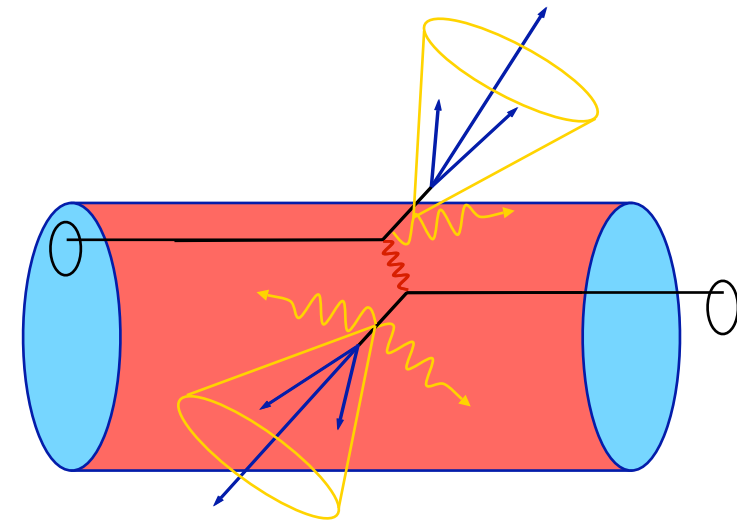
PHENIX PRL 91 172301 (2003)



# Looking at the Whole Picture

---

- single particles:
  - energy loss,
  - changes to particle ratios,
  - biased toward surface
- near side correlations:
  - changes to fragmentation,
  - different surface bias than single particles
- away side correlations:
  - biased toward long medium path lengths,
  - energy loss & changes to fragmentation

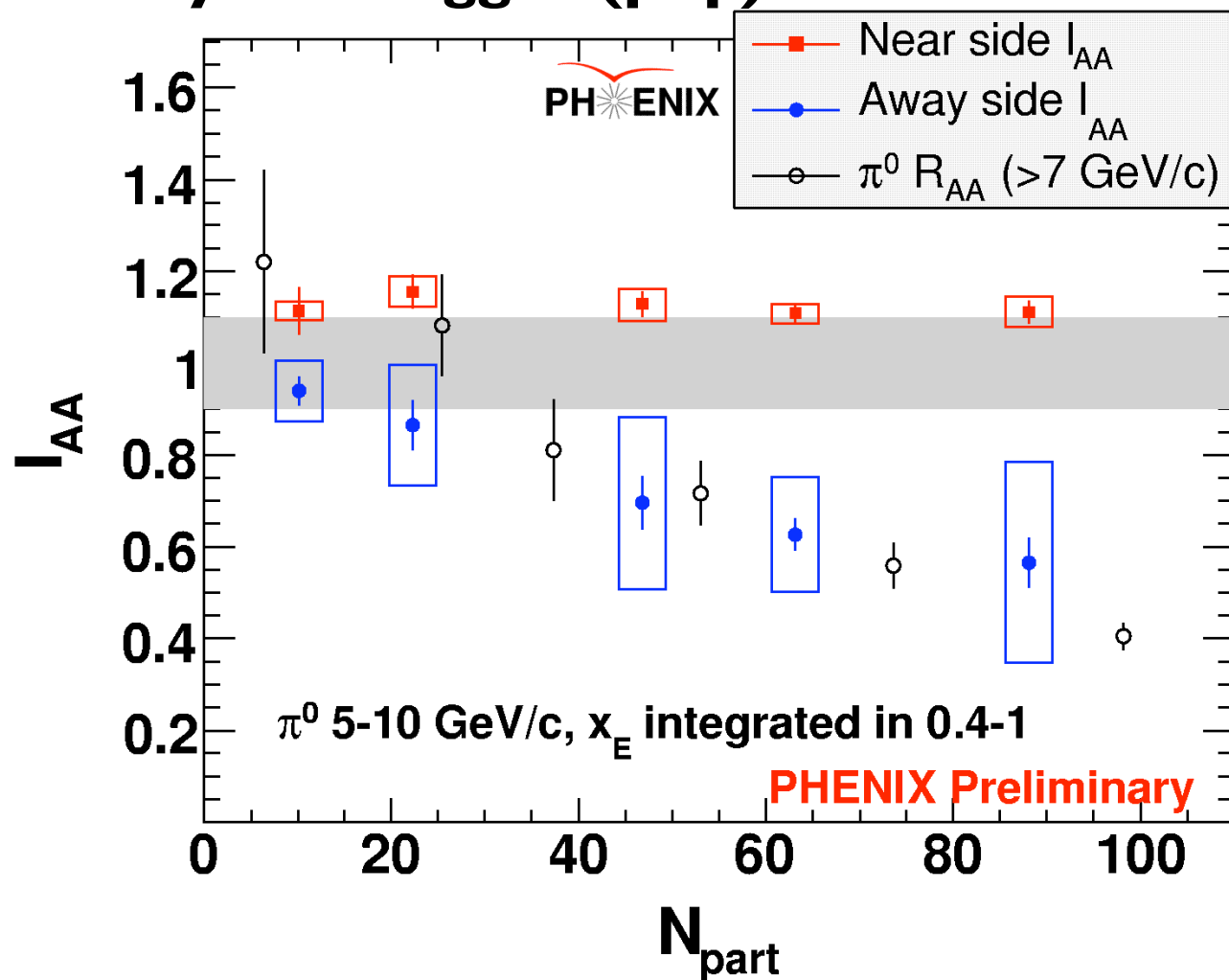


# Correlations Between High and Intermediate $p_T$ Hadrons

# High $p_T$ : Near Side Nearly Unmodified Fragmentation

$$I_{AA} = \frac{\text{yield/trigger (Cu+Cu)}}{\text{yield/trigger (p+p)}}$$

**Cu+Cu, 200GeV**

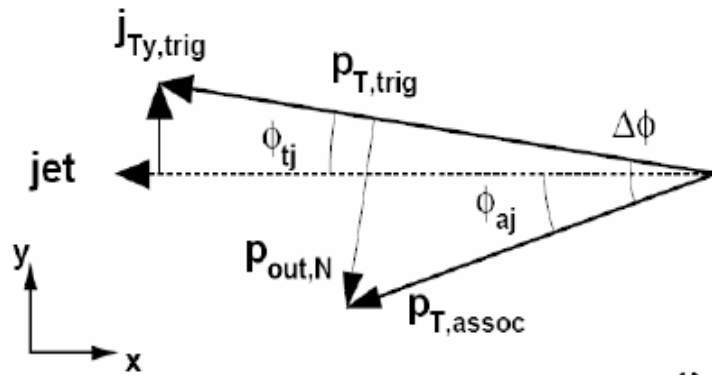


**conditional yields constant:  
vacuum fragmentation**

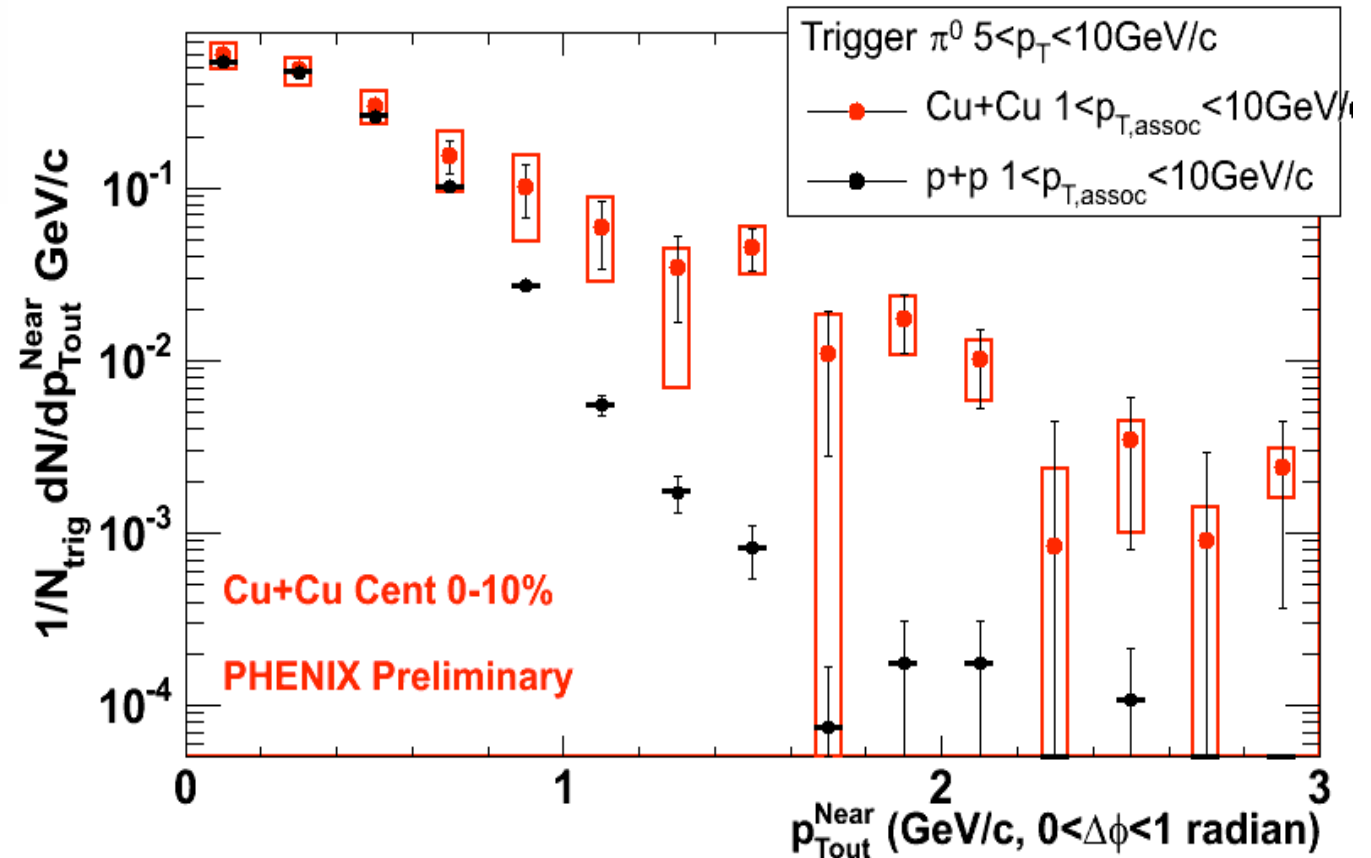
**single particle suppression:  
energy loss**

**J. Jia, QM2006**

# A Closer Look at Cu+Cu



$$p_{T,out} = p_{T,assoc} \sin(\Delta\phi)$$



H. Pei, QM2006

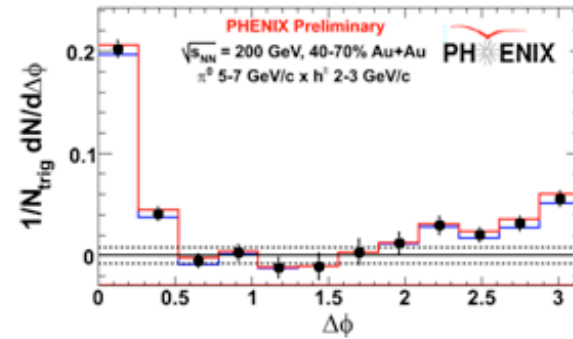
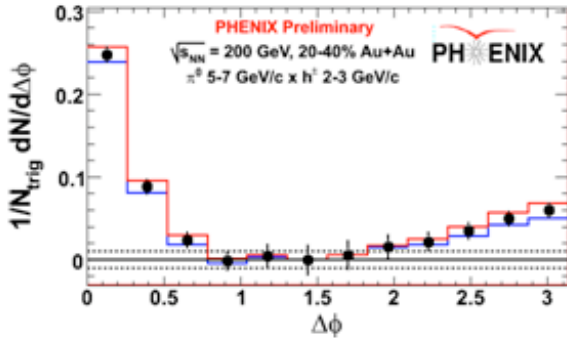
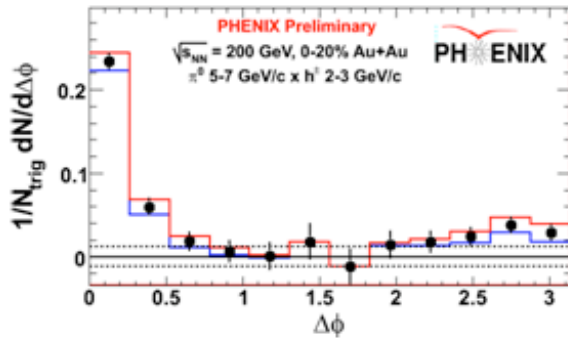
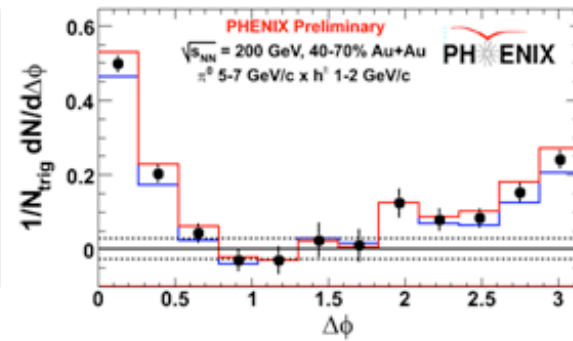
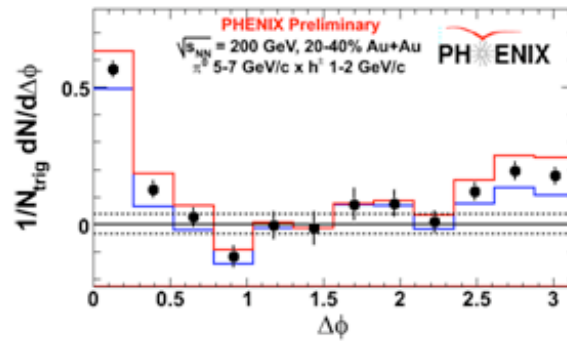
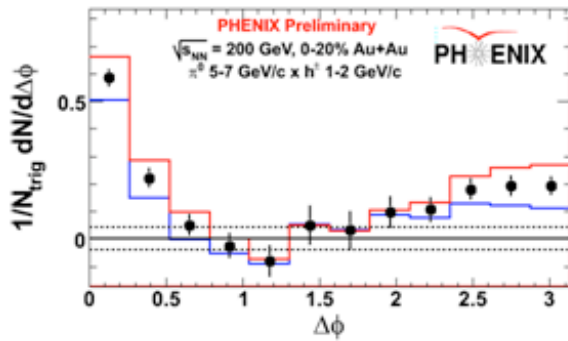
# Au+Au: High $p_T$

$5 < p_{T, \text{trig}} < 7 \text{ GeV}/c$

0-20%

20-40%

40-70%



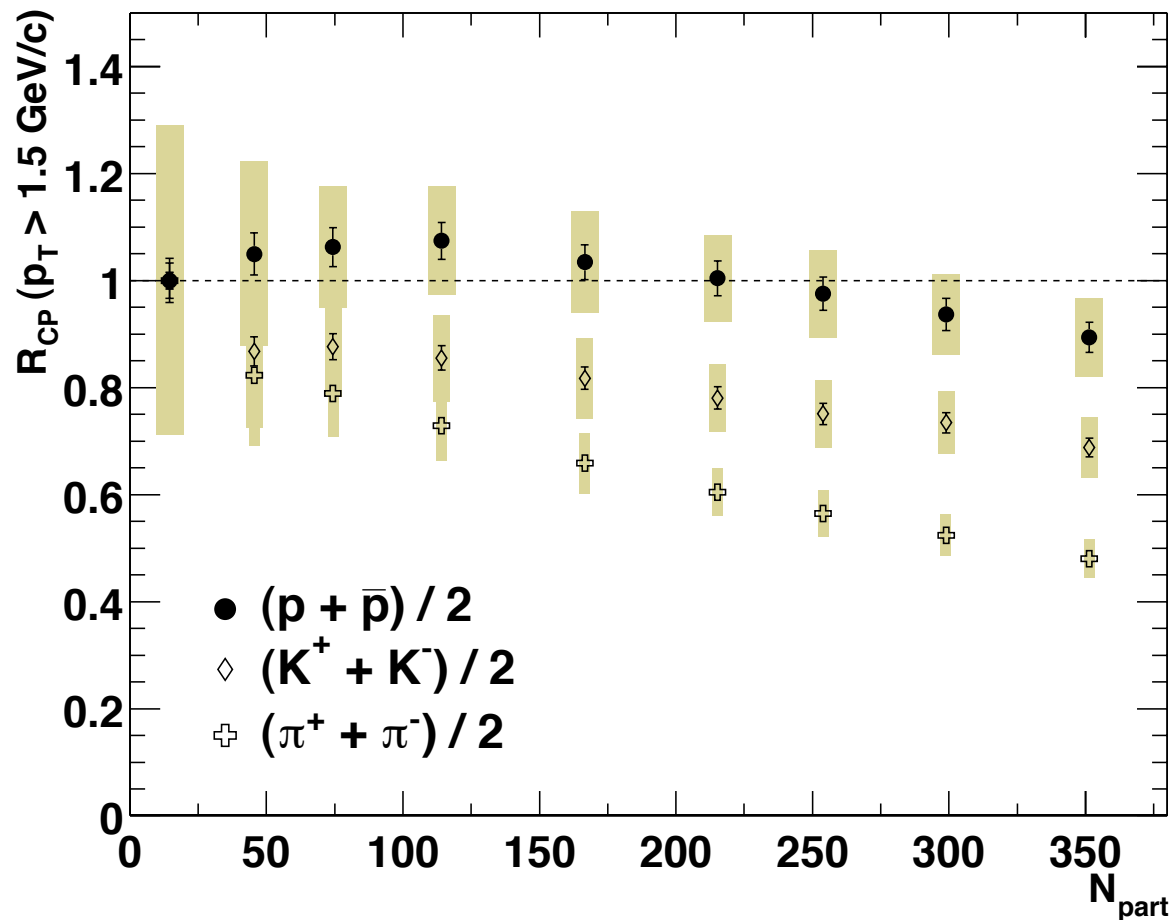
$1 < p_{T, \text{assoc}} < 2 \text{ GeV}/c$   
 $2 < p_{T, \text{assoc}} < 3 \text{ GeV}/c$

near side yields ~constant over wide centrality range

N. Grau, QM2006

# Correlations Between Hadrons @ Intermediate $p_T$

# Intermediate $p_T$ : Single Particles

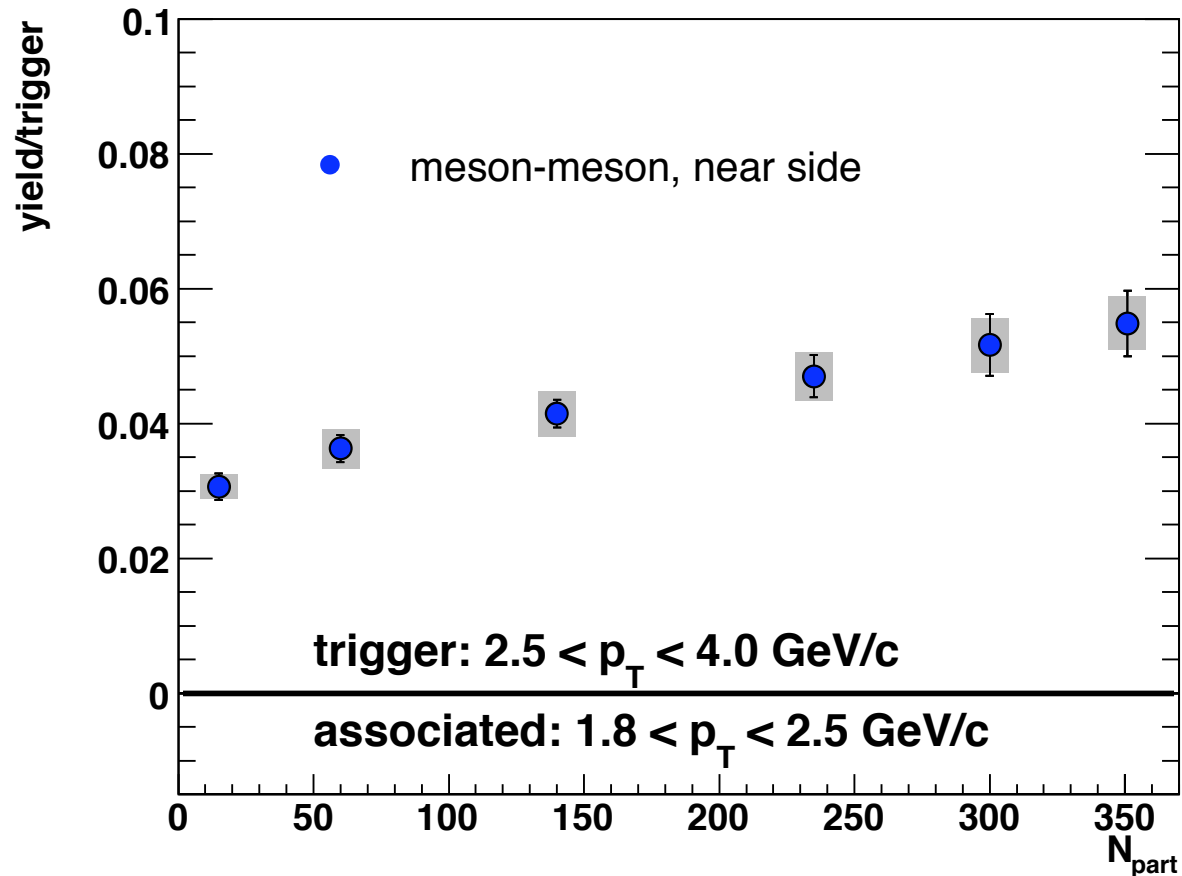


**baryons: ~unsuppressed**

**mesons: suppressed**

# Intermediate $p_T$ : Conditional Yield

mesons: yield suppressed, yield/trigger enhanced

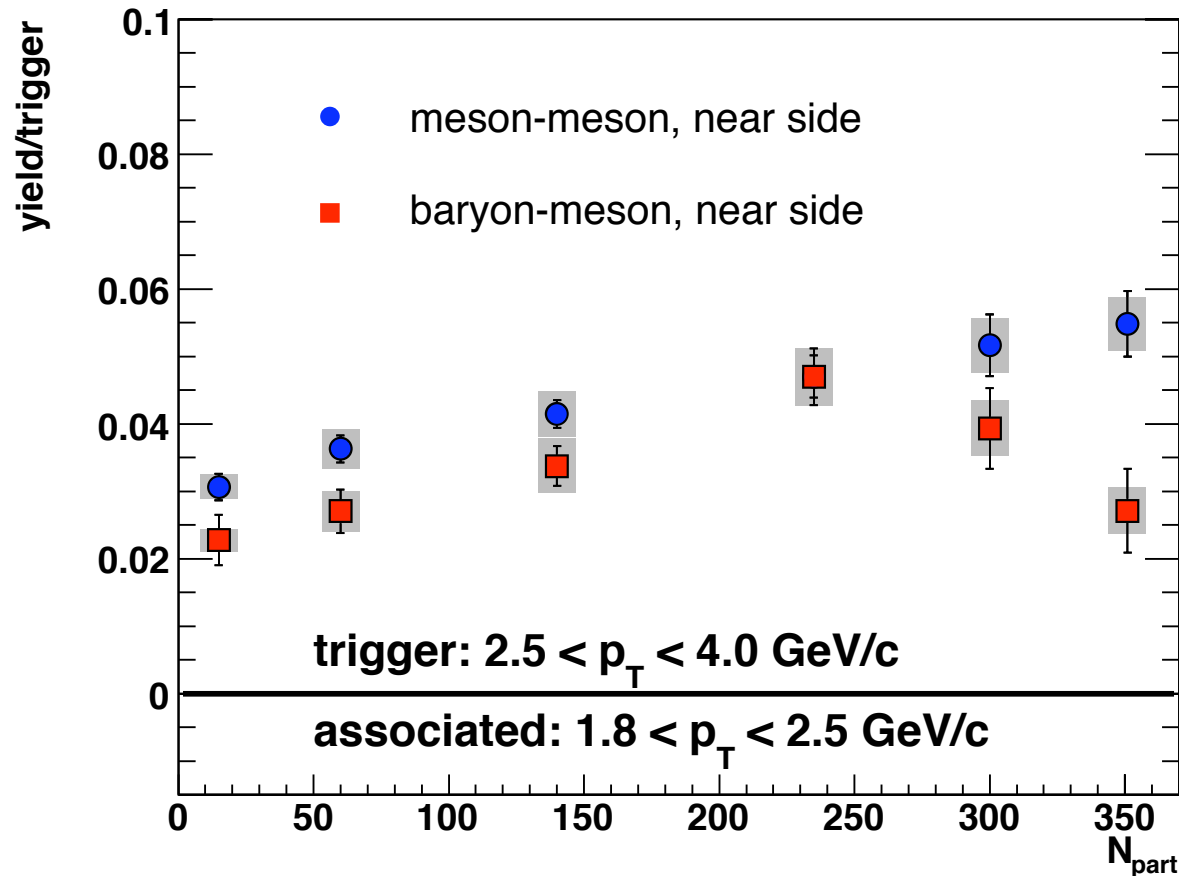




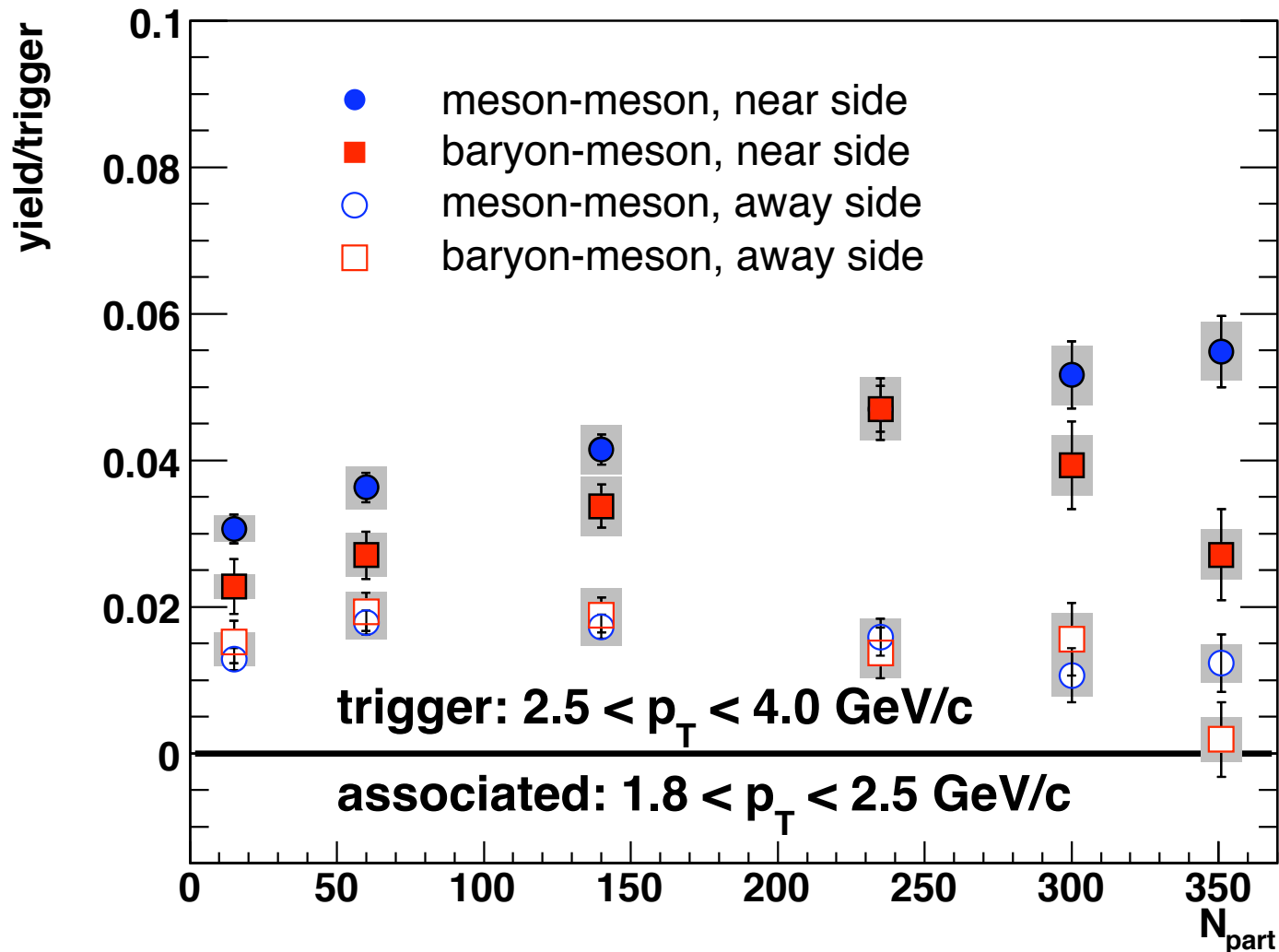
# Intermediate $p_T$ : Conditional Yield

**mesons: yield suppressed, yield/trigger enhanced**

**baryons: yield scales with  $N_{coll}$ , yield/trigger enhanced**



# Away Side Yields

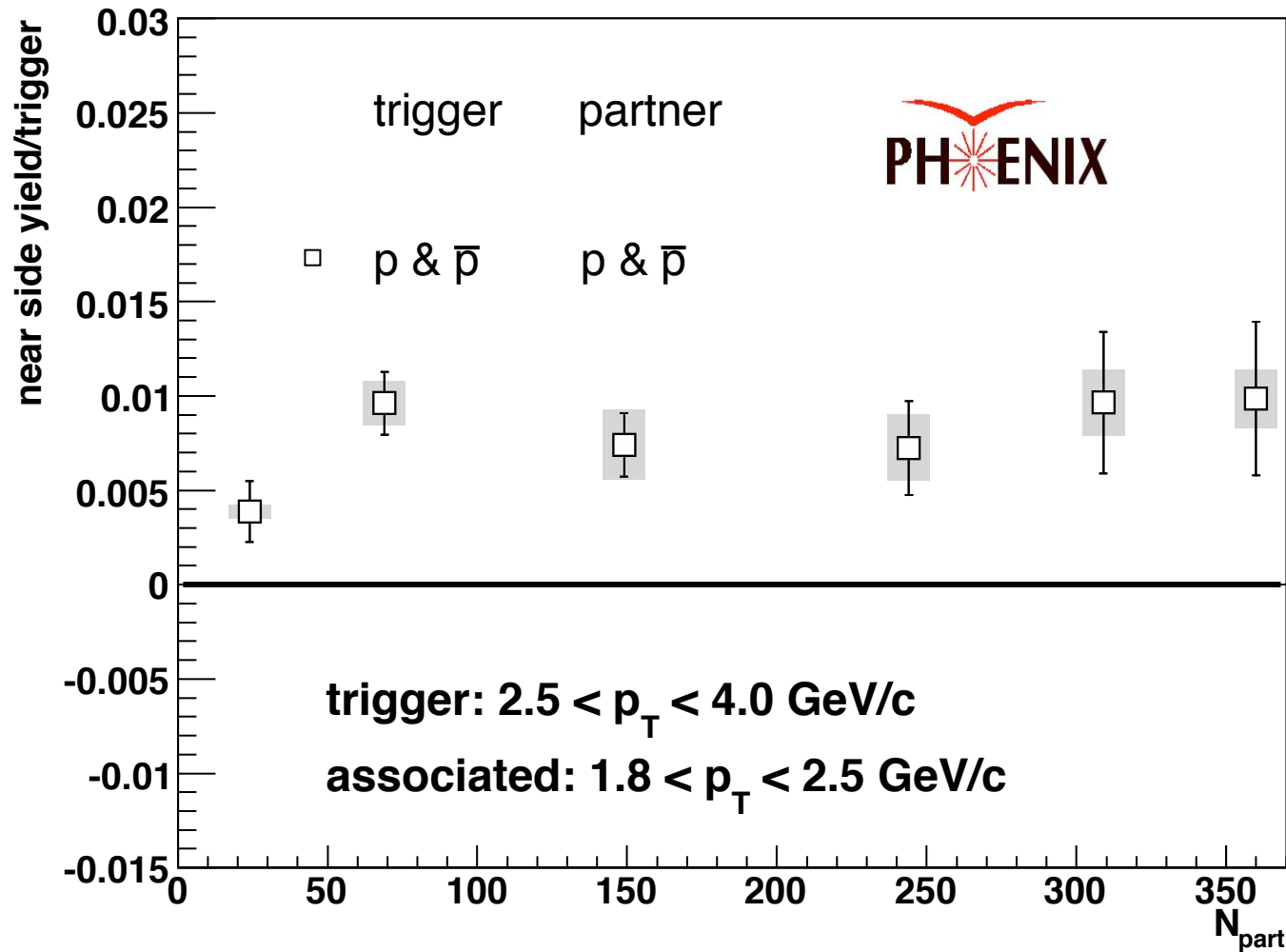


away side yields can't know what the near side looks like

PHENIX PLB 649 (2007) 359

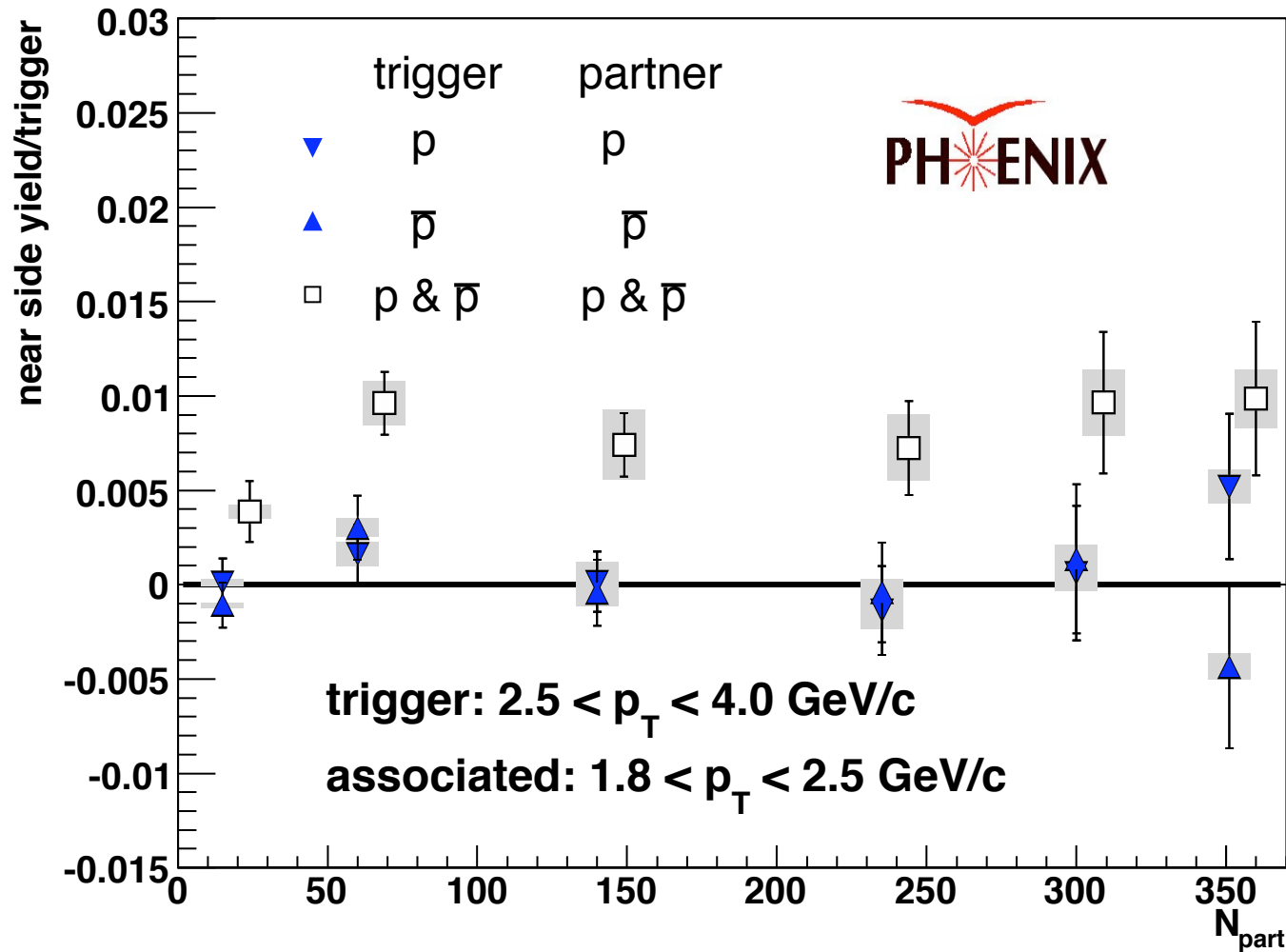
# What about the baryons?

PLB 649 (2007) 359-369



# What about the baryons?

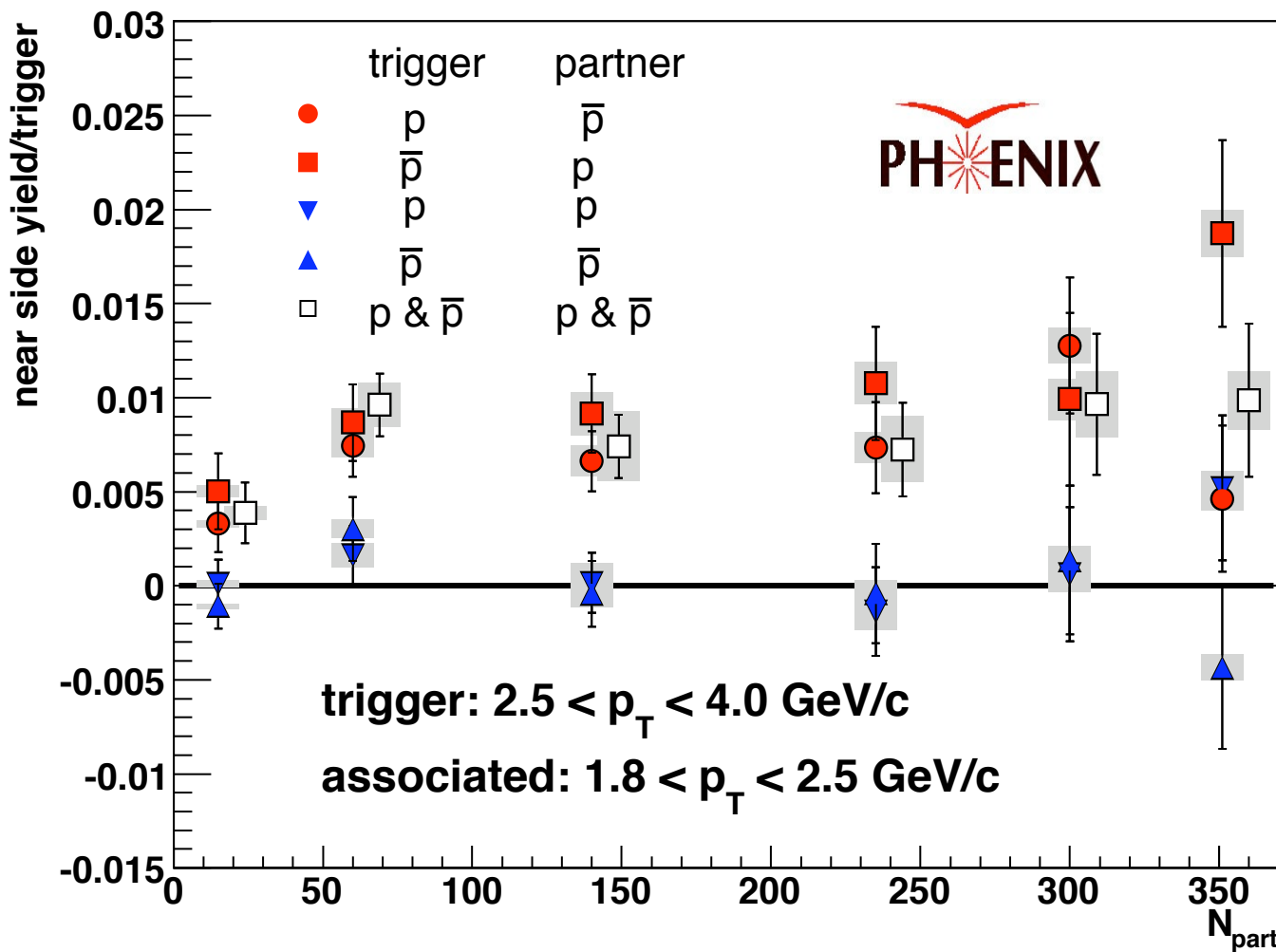
PLB 649 (2007) 359-369



same sign pairs:  
**NO CORRELATION**

# What about the baryons?

PLB 649 (2007) 359-369



**opposite sign pairs:  
CORRELATED**

**same sign pairs:  
NO CORRELATION**

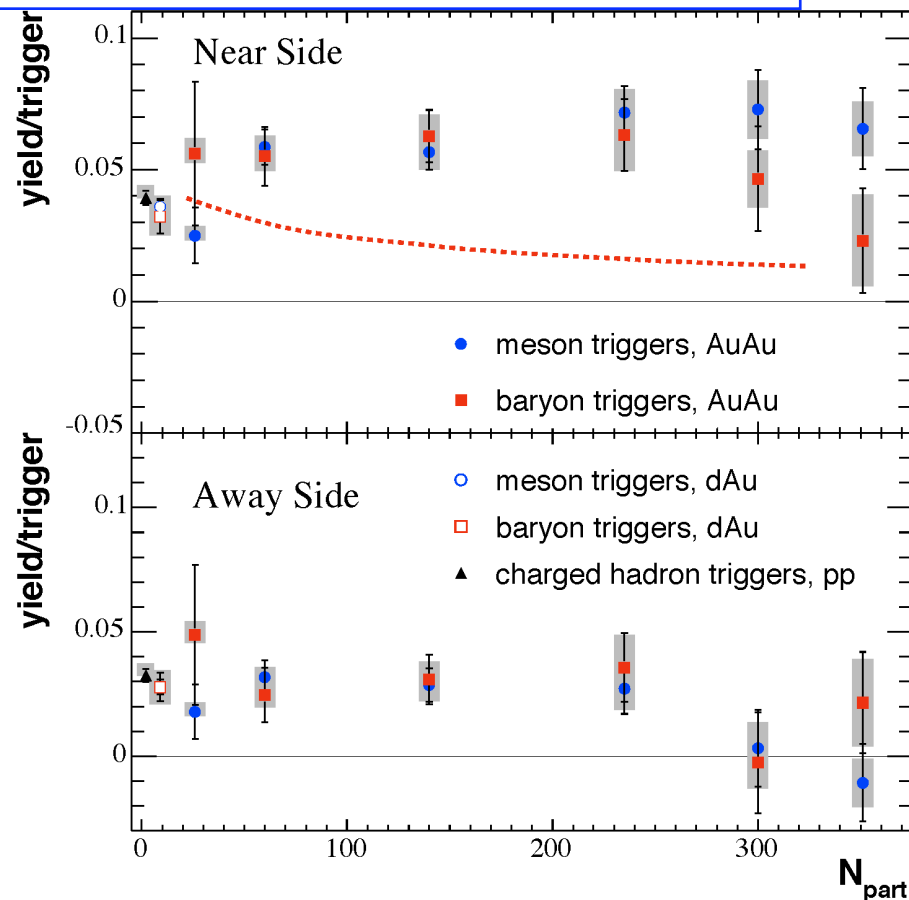
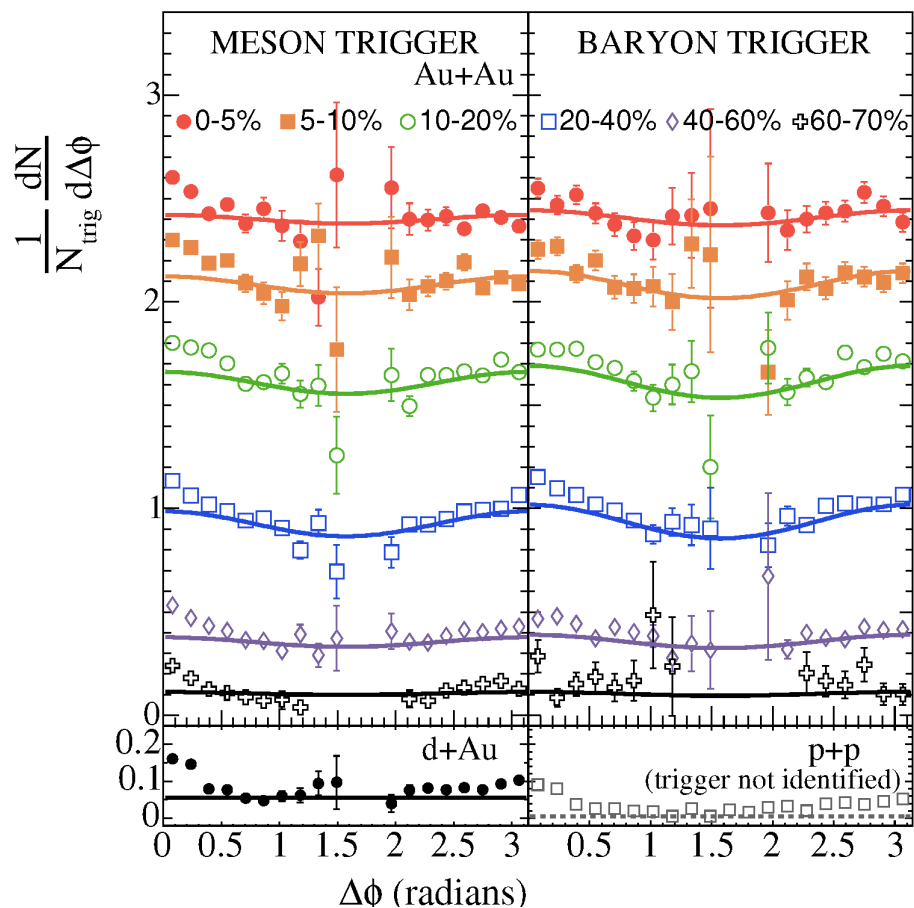
$\bar{p}/\pi=0.25$

$\bar{p}/\pi=0.8$

**$p$ - $\bar{p}$  pair correlations nearly independent of baryon excess**

# Correlations-one of the first definitive results

PHENIX PRC 71 051902  $2.4 < p_{Tt} < 4 \text{ GeV}/c$   $1.7 < p_{Ta} < 2.5 \text{ GeV}/c$



Trigger mesons and baryons in the region of the baryon anomaly both show the same trigger (near) side and away side jet structure. This 'kills' the elegant recombination model of the baryon anomaly

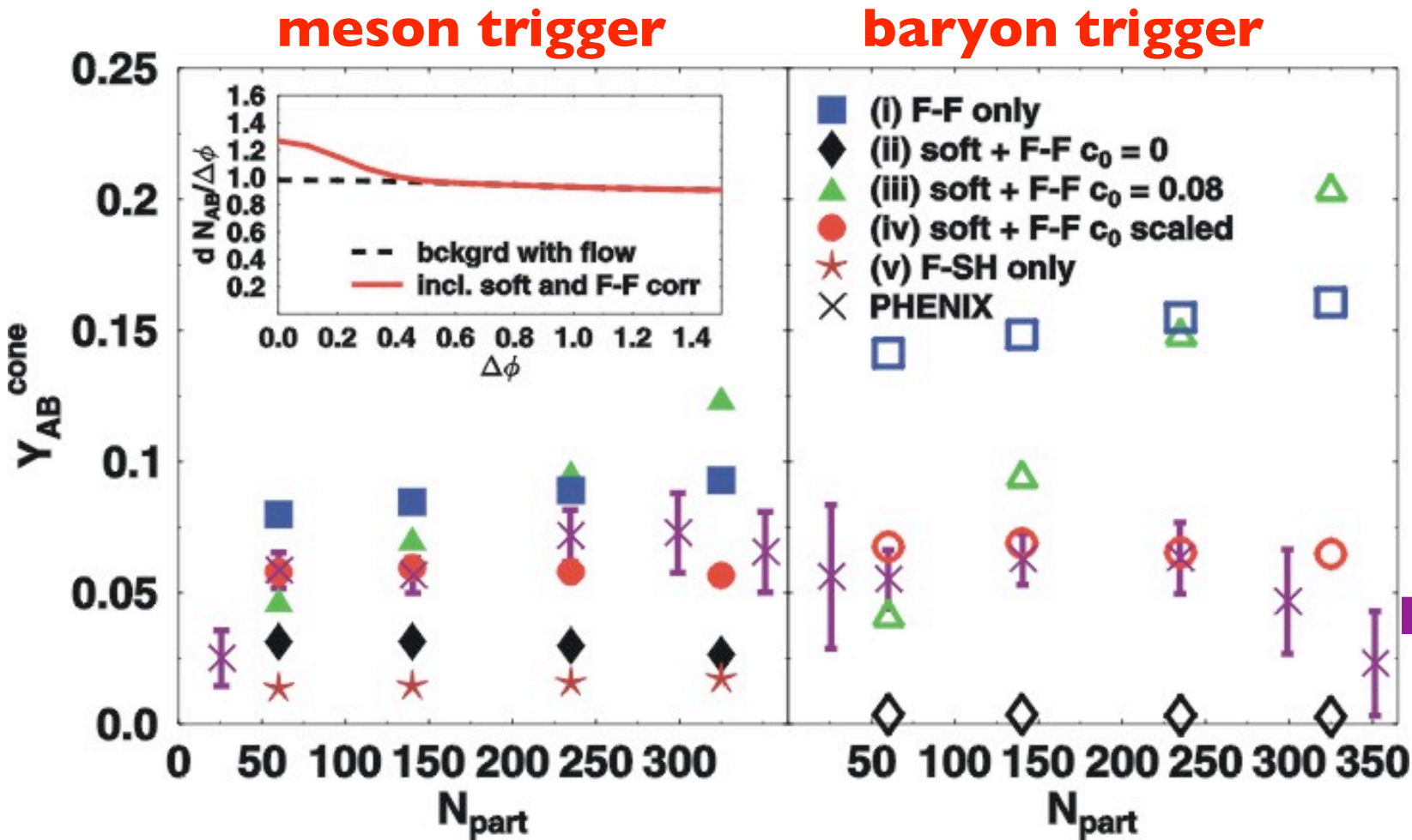
# Recombination & Jet Correlations

---

- incorporating hard physics into reco models: partons associated with a hard scattering recombine with medium partons (Ko et al, Fries et al & Hwa et al)
- wouldn't recombination wash out the charge ordering of the p/pbar correlations?
  - does the surface bias for near side correlations minimize sensitivity to recombination?
- what about the away side correlations? baryon & meson triggers are consistent
- do the correlations break the  $v_2$  scaling?
- are there other ideas which can explain the data?

**need calculations that explain all the data with one set of parameters**

# Recombination Models & Correlations



PHENIX, PRC  
71 05 1902

R. Fries, Hard Probes 2006

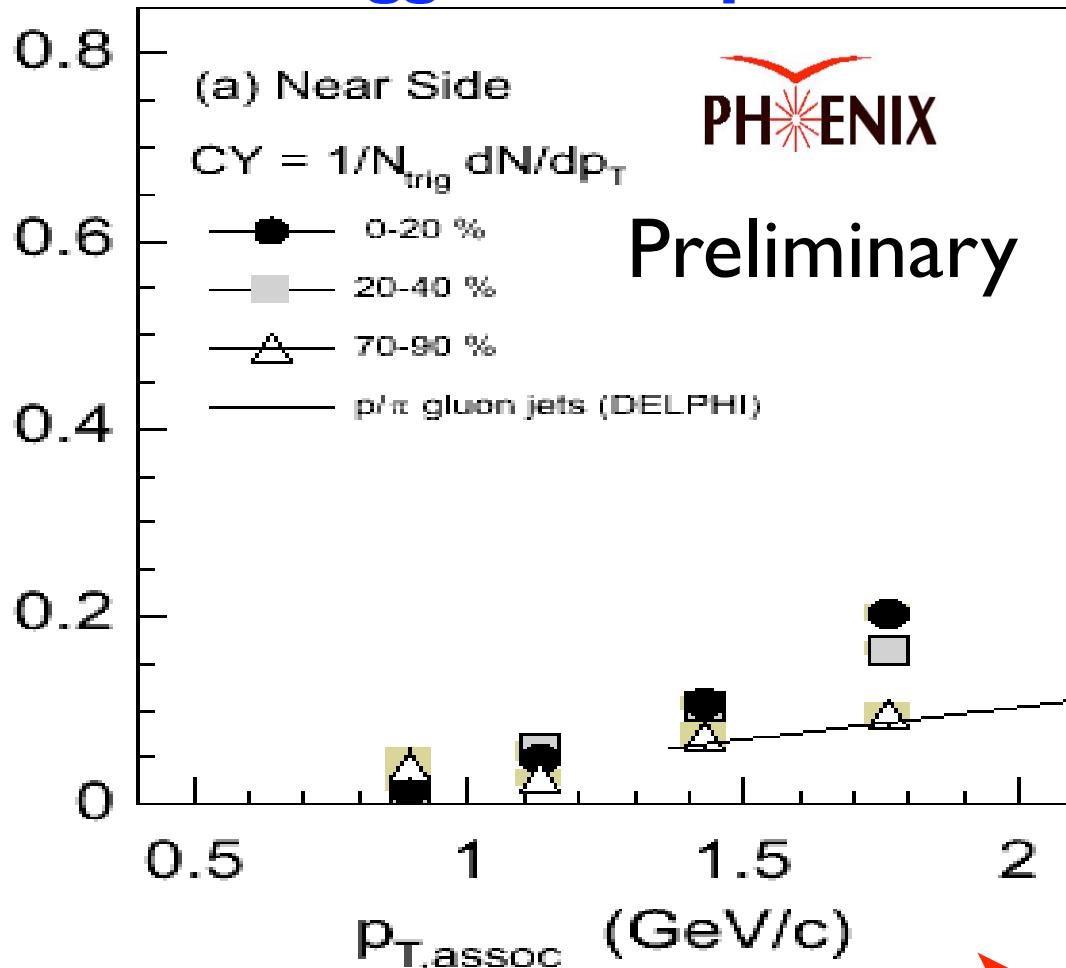


How are the Particle  
Ratios in Jet  
Correlations Modified?

# Extra Baryons in Near Side Jets

assoc. baryons/assoc. mesons

hadron trigger:  $2.5 < p_T < 4.0 \text{ GeV}/c$



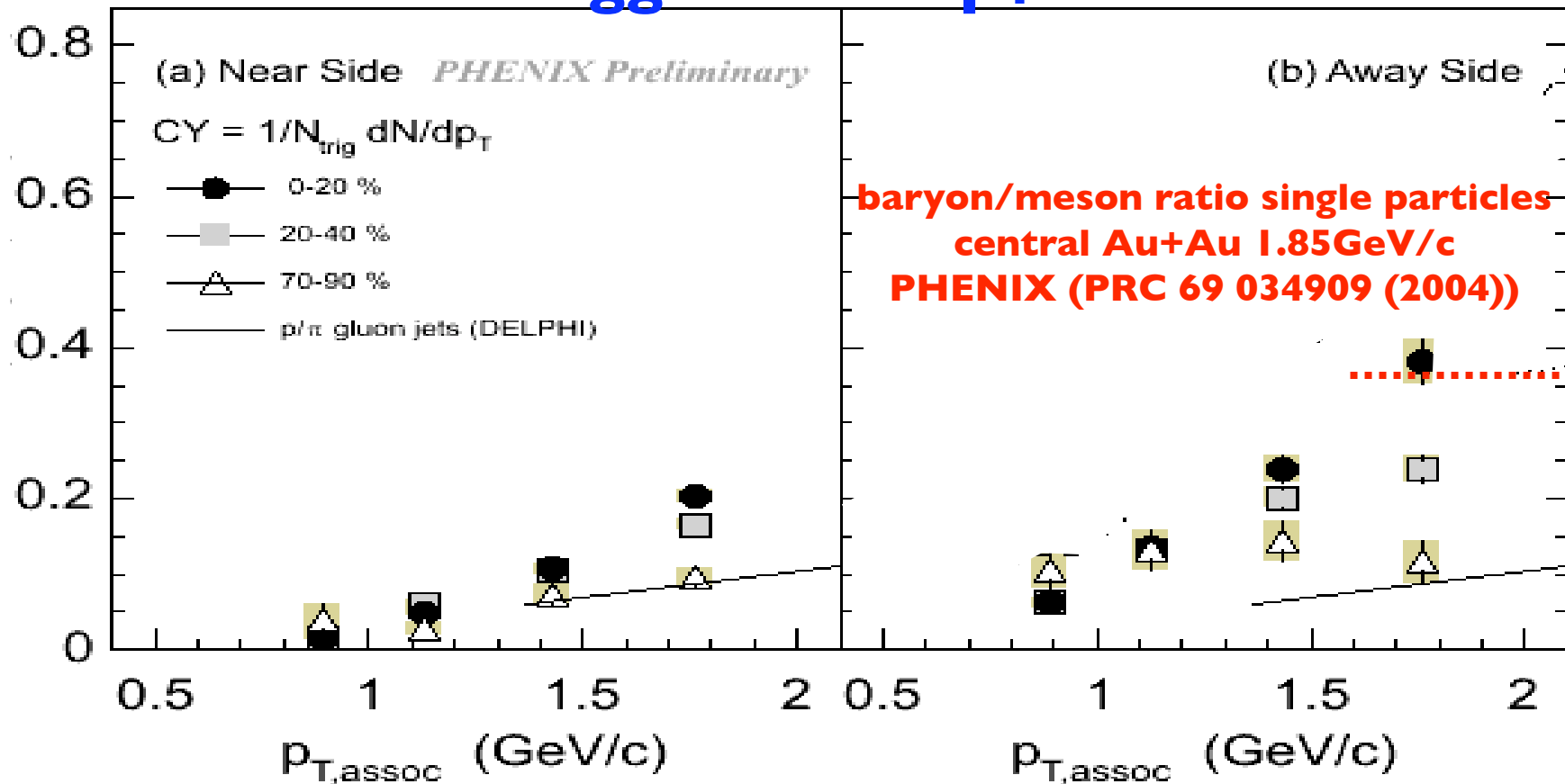
increasing p/π- ratio

increasing centrality

# And Even More Baryons in Away Side Jets

assoc. baryons/assoc. mesons

hadron trigger:  $2.5 < p_T < 4.0 \text{ GeV}/c$



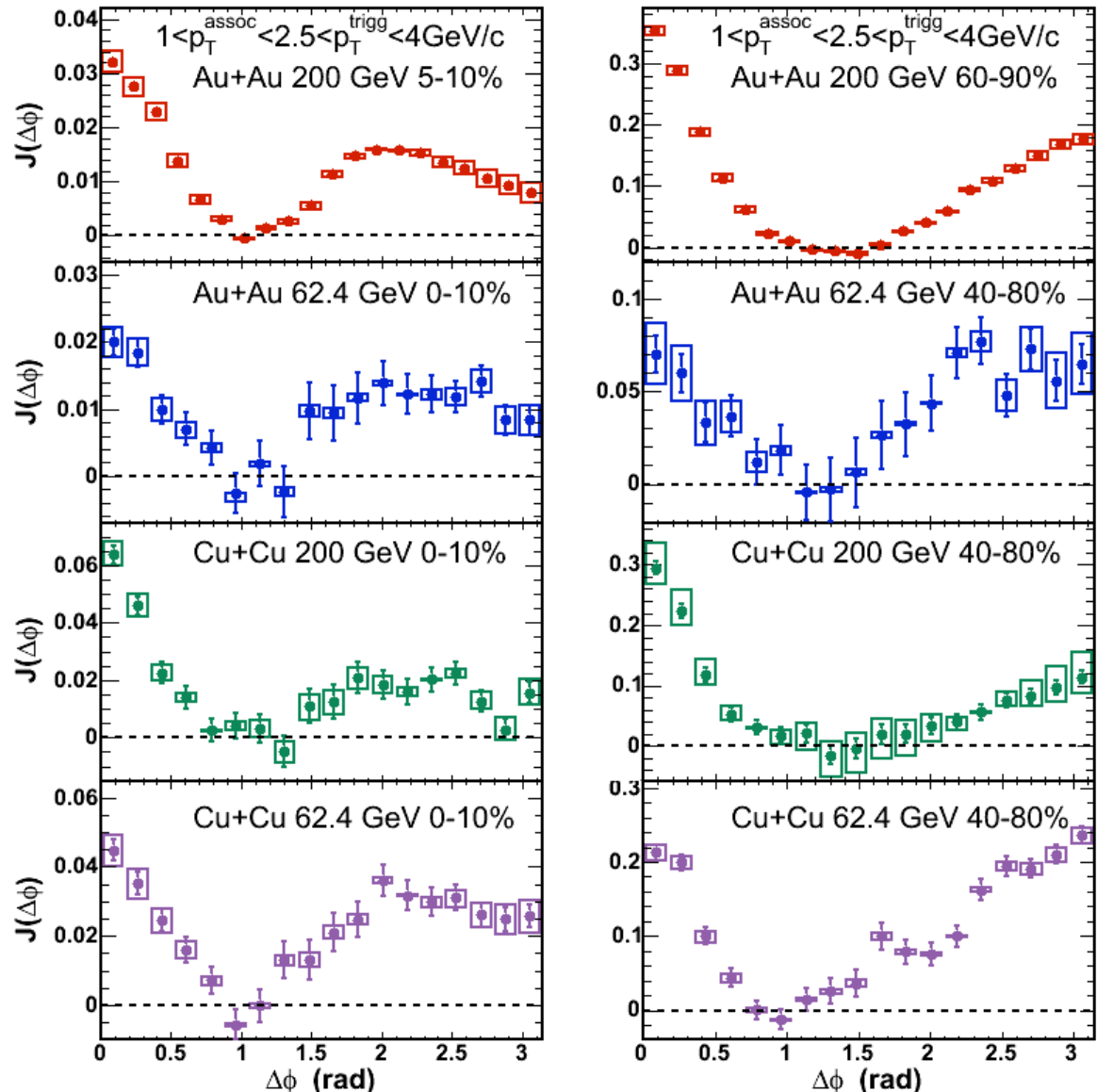
*do the away side particles hadronize with the medium?*

**What About the Jet  
Shapes?**

# Jet Shapes In h-h Correlations

away side region at  
intermediate  $p_T$   
hadron-hadron  
correlations has a  
modified shape  
(see J. Jia's talk)

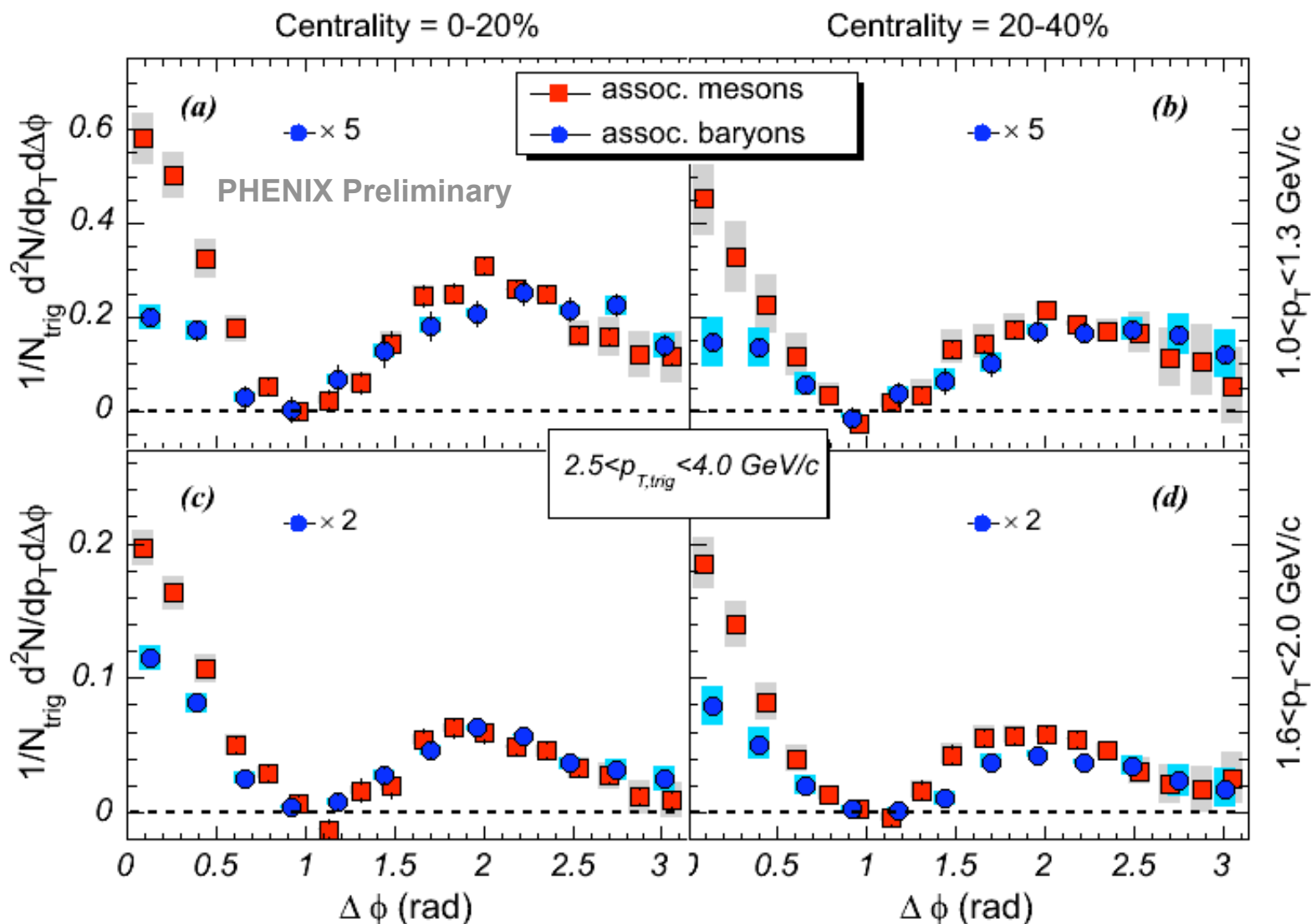
*what do we see with  
identified particles?*



**PRL 98 232202 (2007)**

# Shapes at Intermediate $p_T$

## non-identified hadron triggers



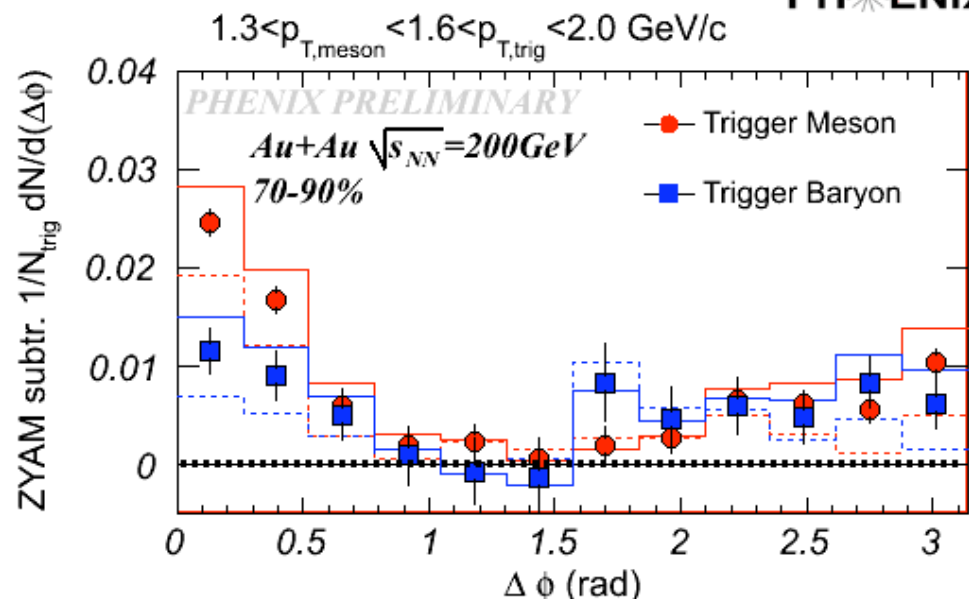
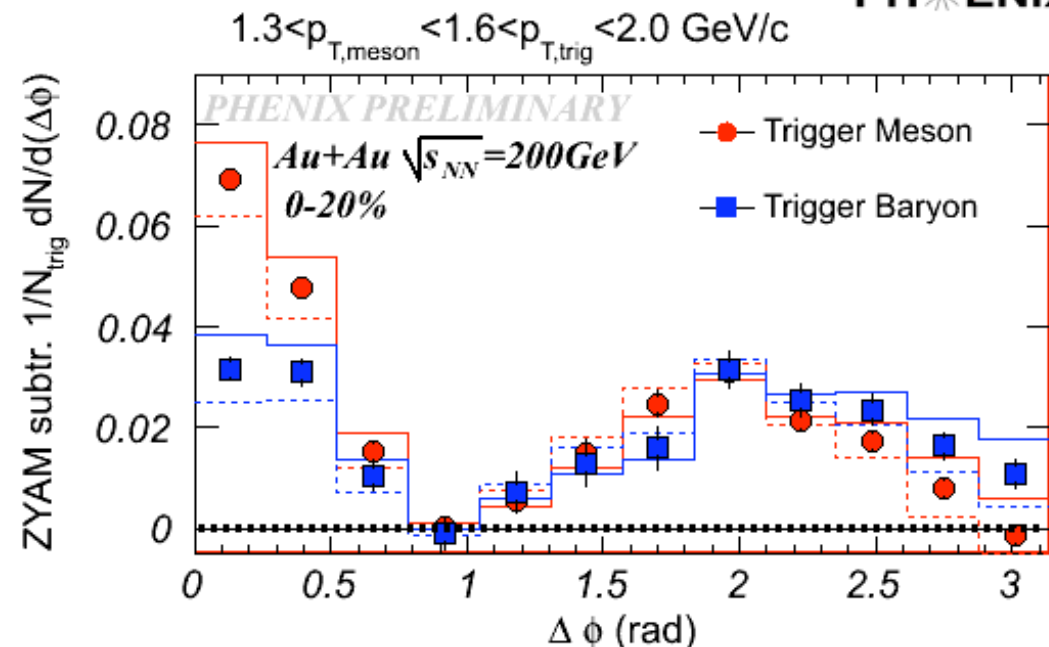
# Shapes at Low $p_T$

central

peripheral

PHENIX

PHENIX



**trigger:  $1.6 < p_T < 2.0 \text{ GeV/c}$**   
**partner:  $1.3 < p_T < 1.6 \text{ GeV/c}$ , mesons**

**Displaced peak about the same place as at higher  $p_T$**

# Conclusions

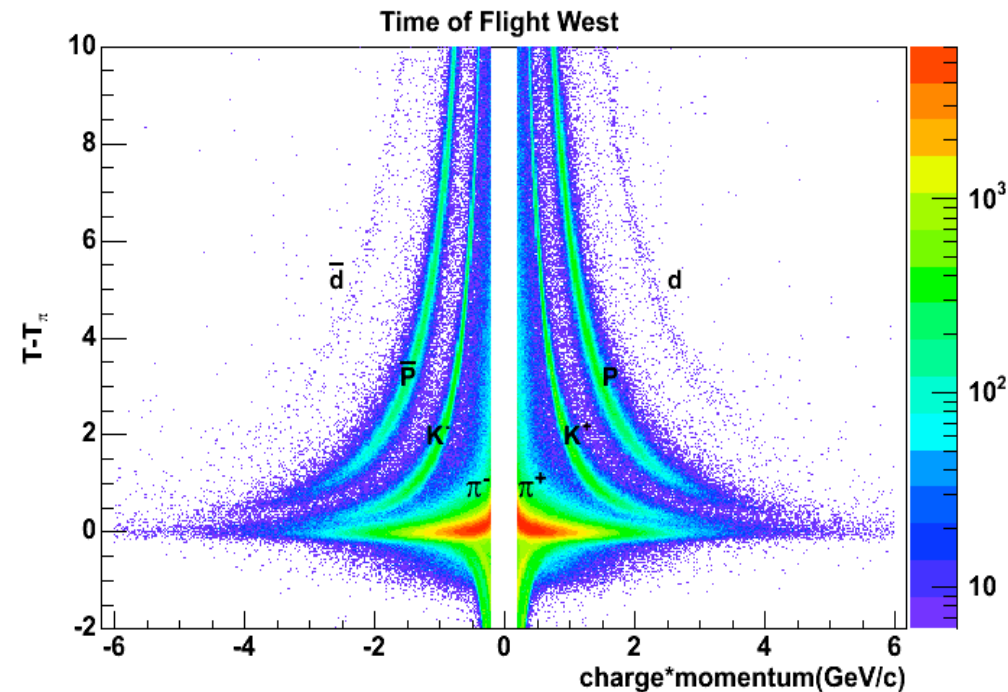
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- Yields: modified  $p_{out}$  distribution for high  $p_T$ -intermediate  $p_T$  correlations, strong centrality dependence when both particles are at intermediate  $p_T$
- Particle composition: extra baryons, especially in away side correlations
- Shape: extra peak for both associated baryons & mesons, Mach Cones?
- Ridge: associated with trigger hadron  $\rightarrow$  jet like?
- Do we have a model that can quantitatively explain all this physics?
- Are they modified beyond recognition as jets?
  - what are the limits of the two-source model?
  - need to characterize the correlations more differentially: widths, connections to higher  $p_T$ , jet variables



# The Future: Better Detectors and More Data

- Run 7 just completed
  - PHENIX took  $\sim 5\text{B}$  events, x3 more than Au+Au data shown here
  - TOF West Detector installed
    - 90ps timing resolution, charge particle PID at higher  $p_T$
    - doubles intermediate  $p_T$  PID acceptance
    - full azimuthal coverage for identified particle correlations
  - new reaction plane detector will allow more control over medium path length



**precision measurements of  
jet-medium interactions**

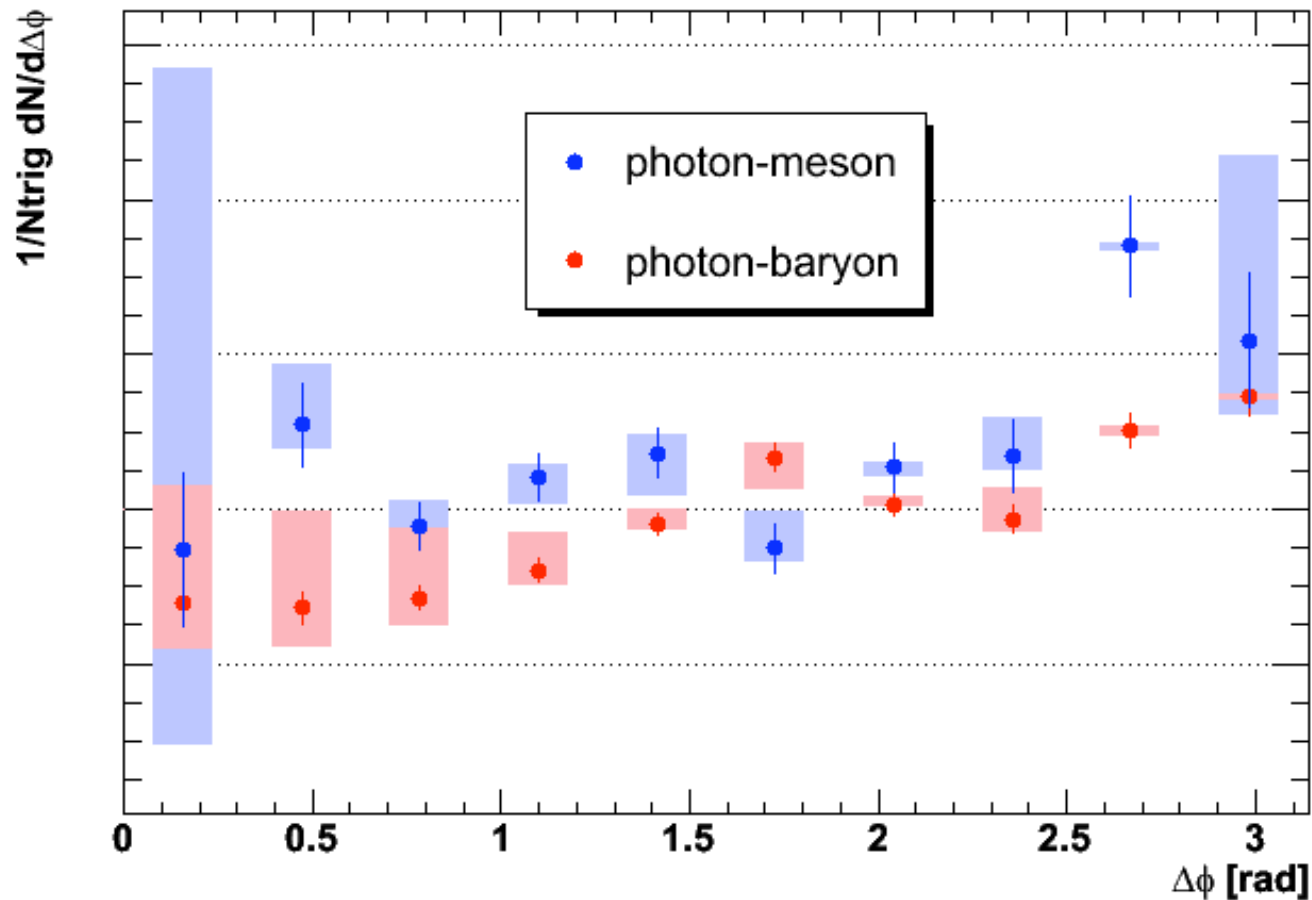
# Frontier Measurements

## Direct Photon-Identified Hadron Correlations

trigger:  $5 < p_T < 7 \text{ GeV}/c$

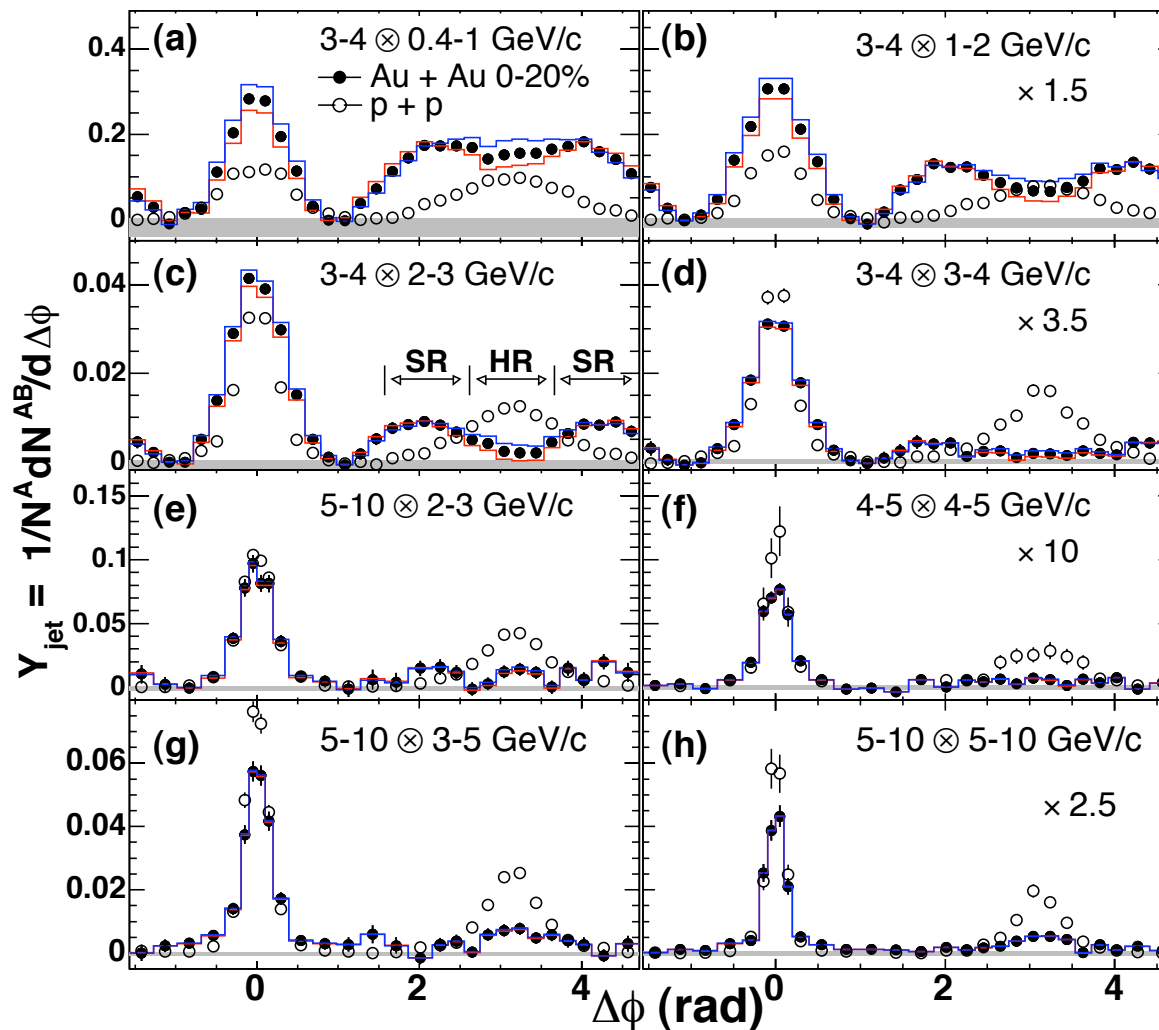
partner:  $1 < p_T < 2 \text{ GeV}/c$

PHENIX, M. Nguyen



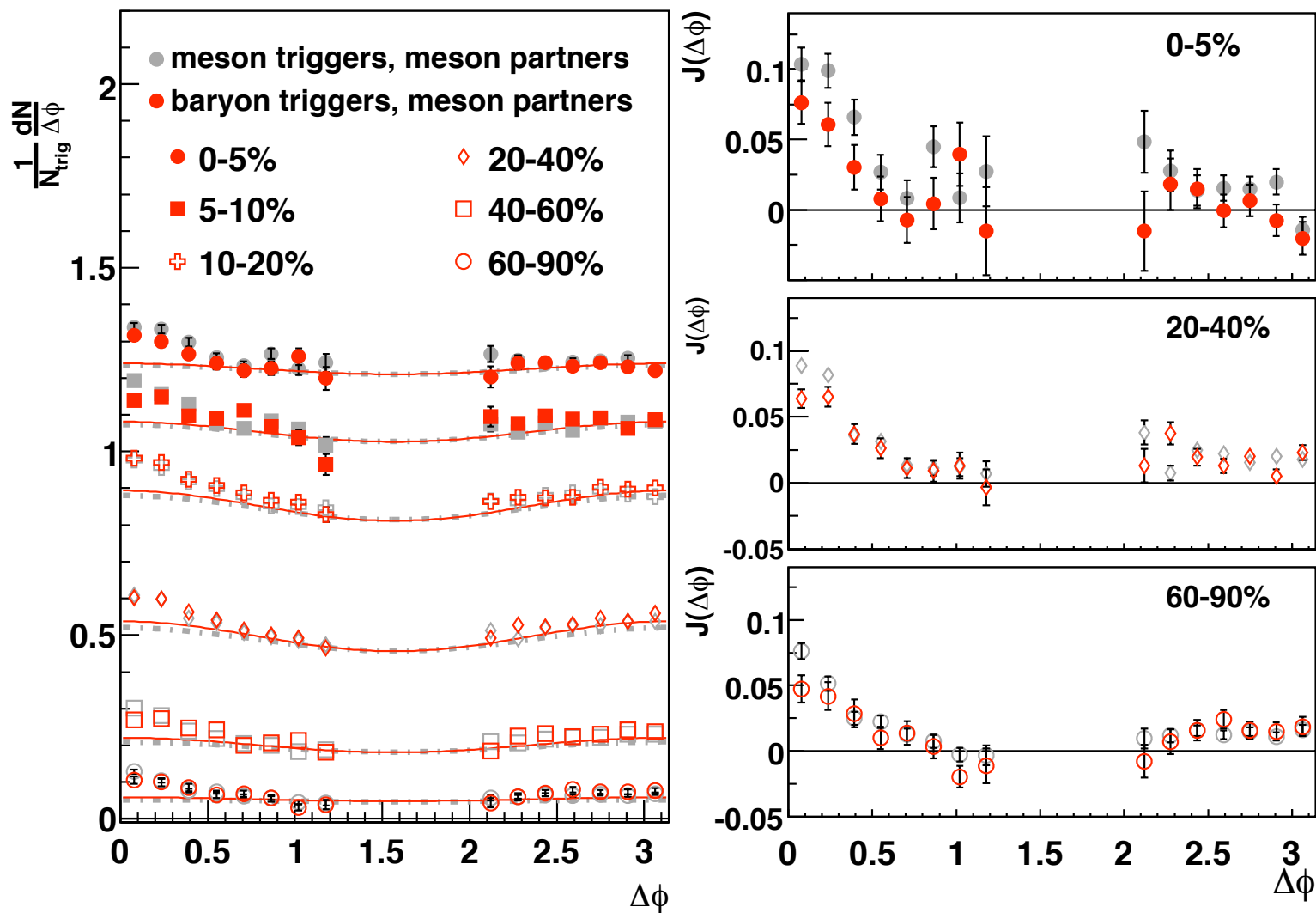
**backups**

# hadron-hadron correlations



**PHENIX 0705.3238 submitted to PRL**

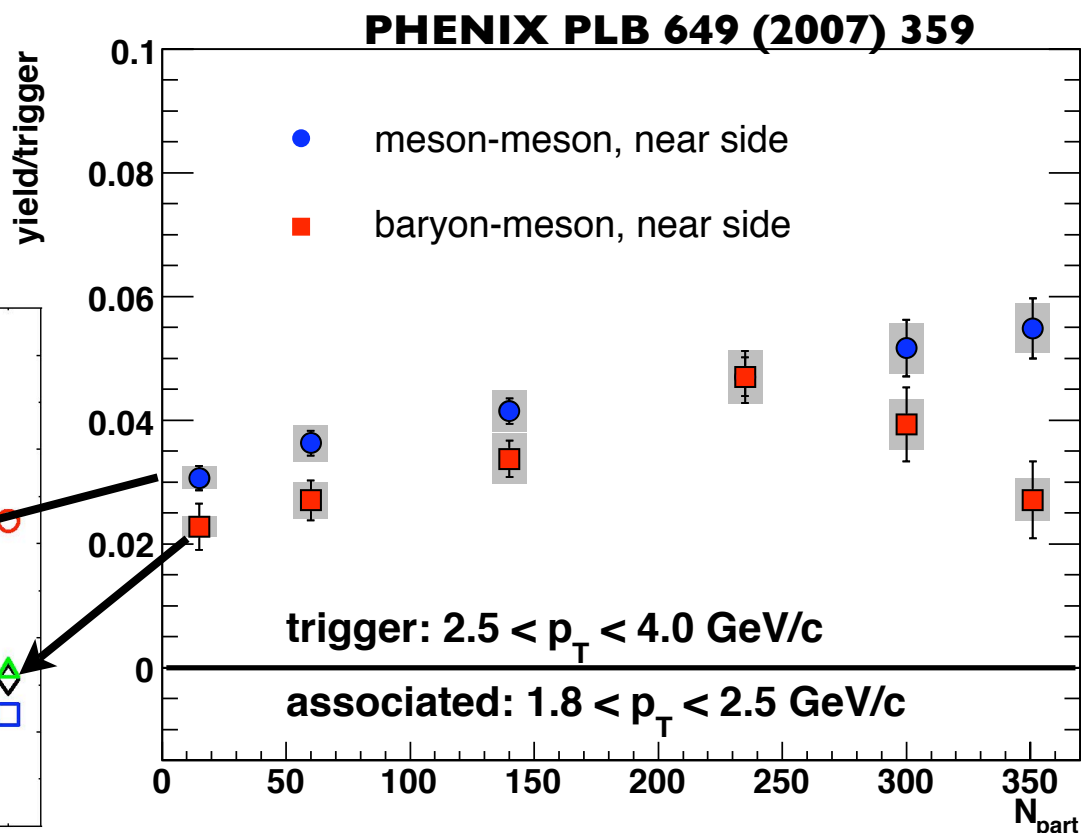
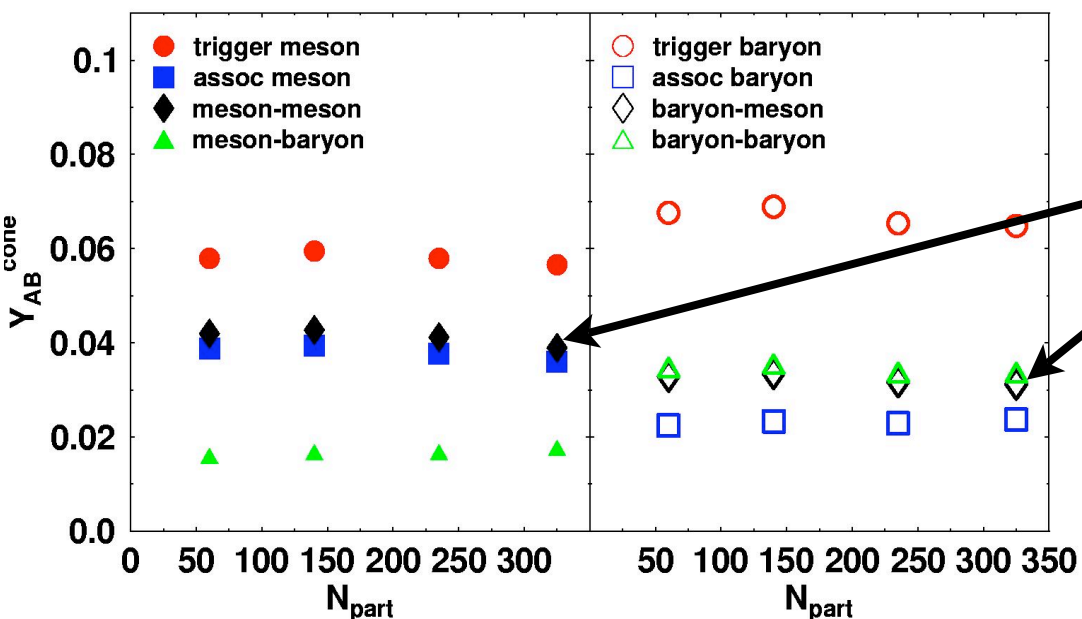
# Shapes



PHENIX PLB 649 (2007) 359

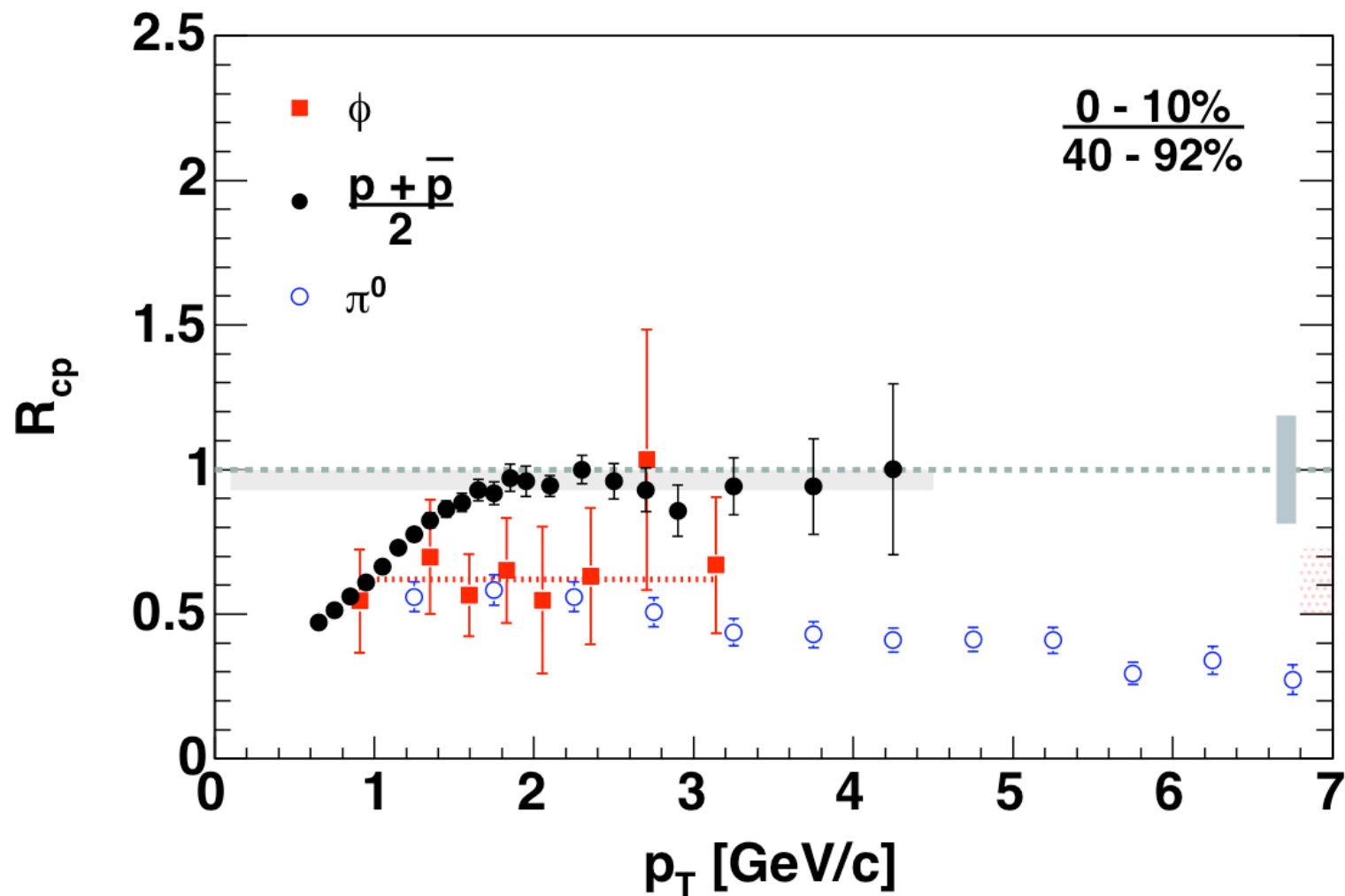
# Recombination & Correlations

stronger centrality dependence in the data than calculation



**R. Fries, Hard Probes 2006**

# Intermediate $p_T$ : Hadronization



PHENIX PRC 72 014903 (2005)