

# Parton-Medium Interactions via Two Particle Correlations

**Michael P. McCumber**  
for the PHENIX Collaboration

**RHIC & AGS Users Meeting**  
2 June 2009

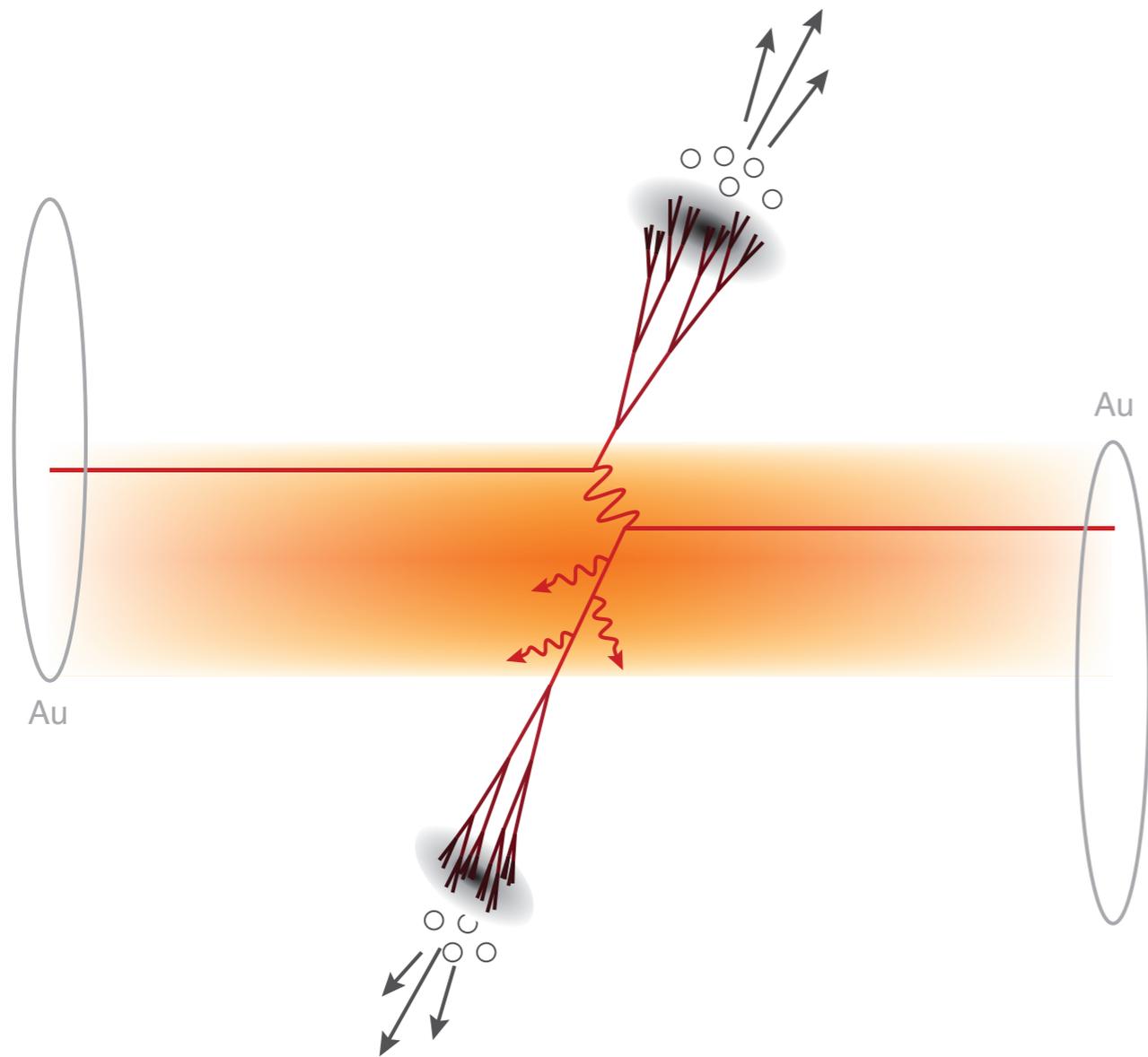
**BROOKHAVEN**  
NATIONAL LABORATORY



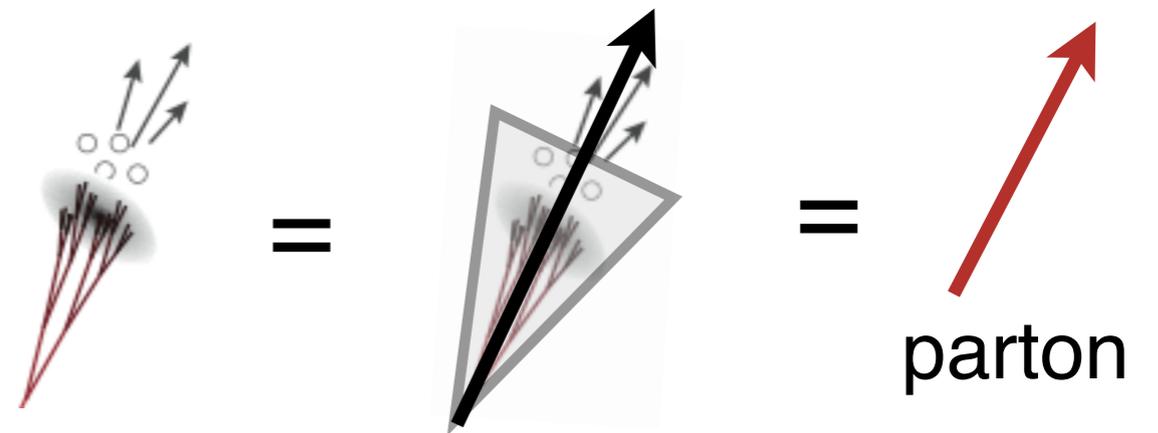
users'center

## Physics Motivation:

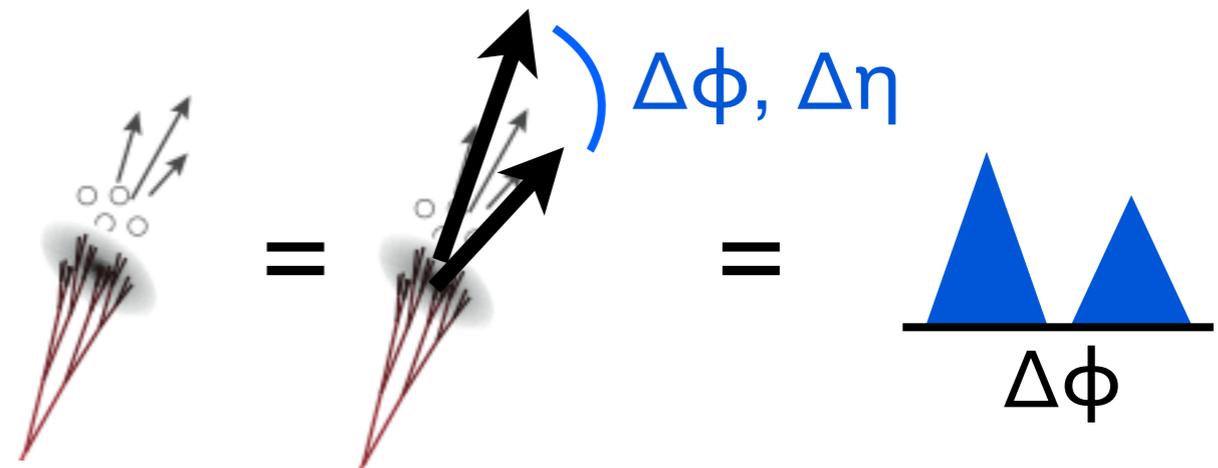
- Energy loss
- Production geometry
- Medium excitations



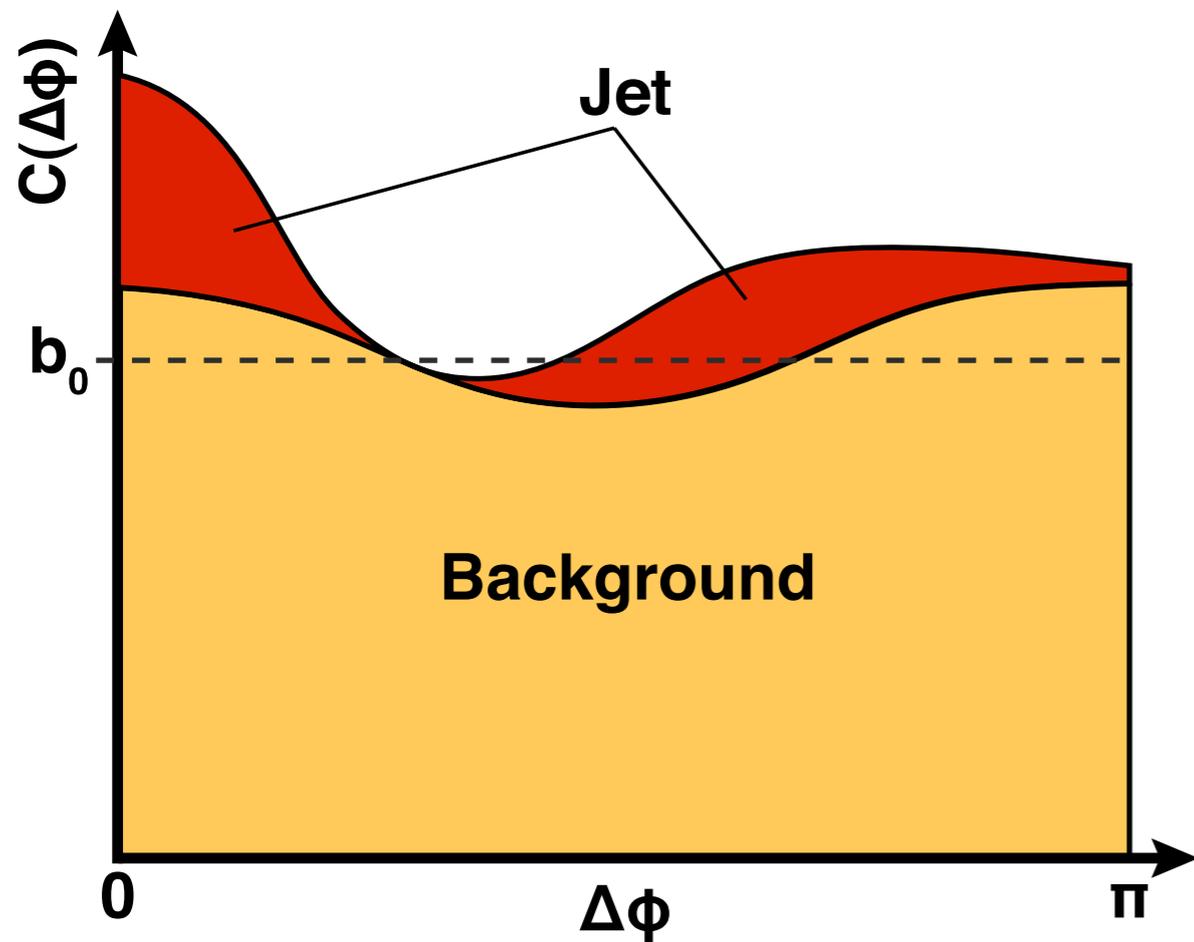
## Jet Reconstruction



## Two Particle Correlation

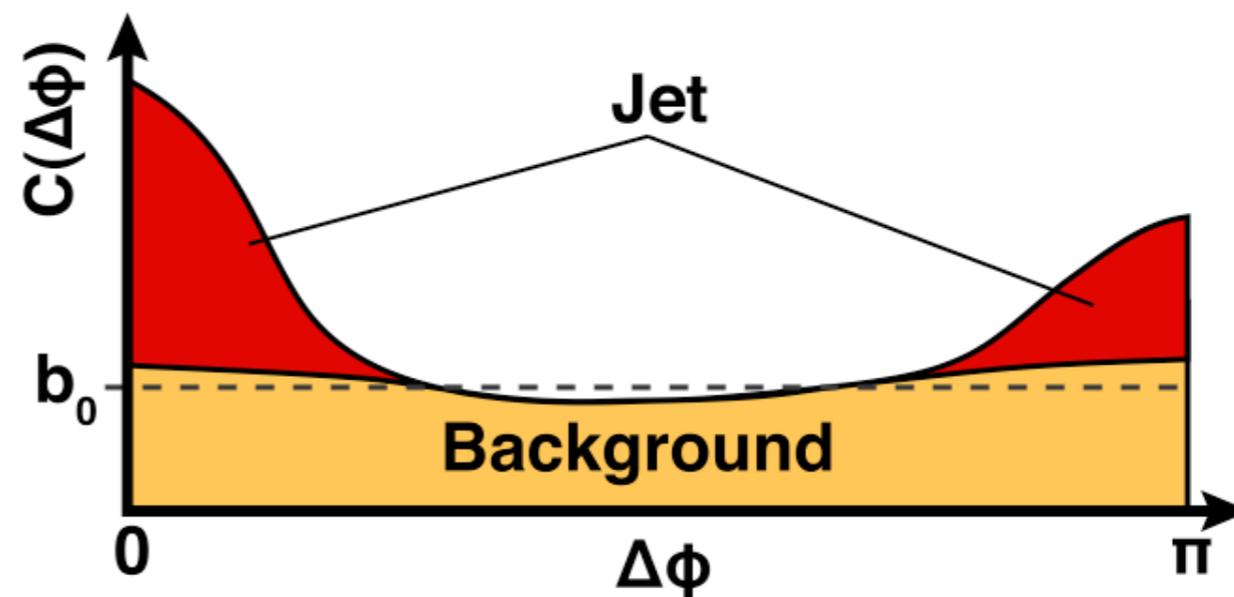


## Modification



“intermediate”  
 $\sim 1 - 4 \text{ GeV}/c$

## Suppression



“high”  
 $\gtrsim 4 \text{ GeV}/c$

$p_T^{A,B}$

# Two Source Assumption

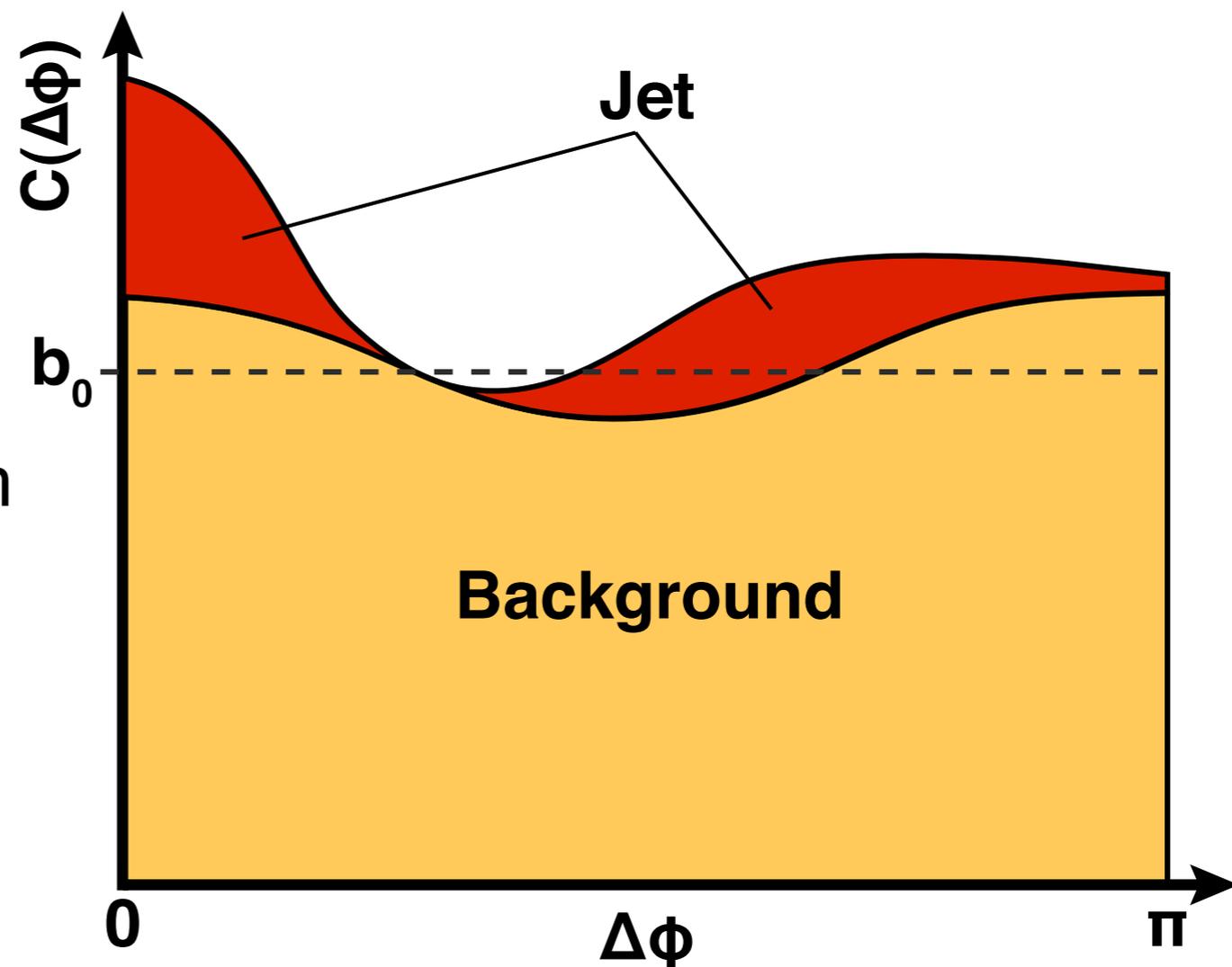
Pairs correlate via the **same hard scattering** or via trivial participation in the **same event**

Some correlation sources (HBT, decay) are small

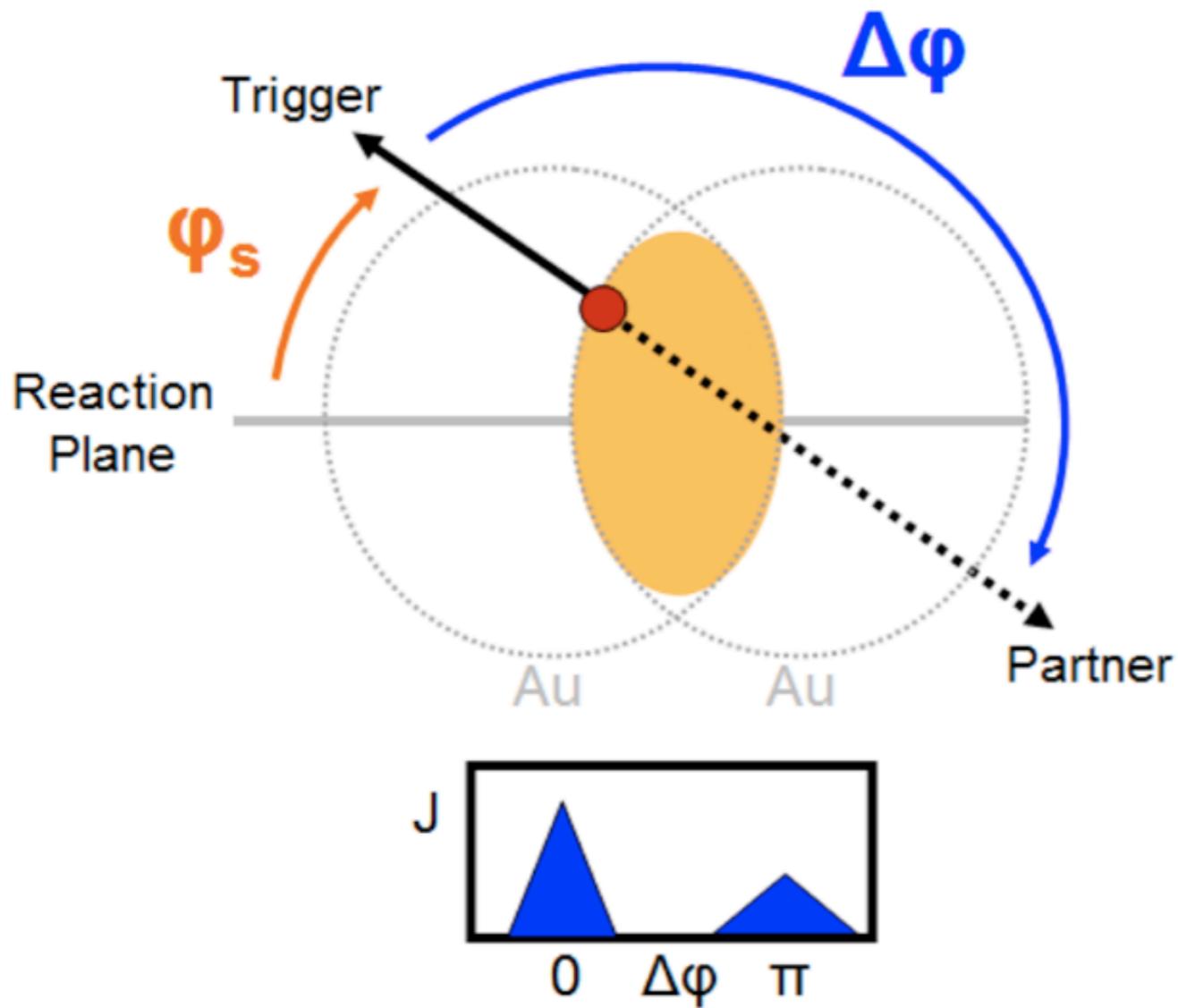
Others (recombination) may not be...

## Background Contribution:

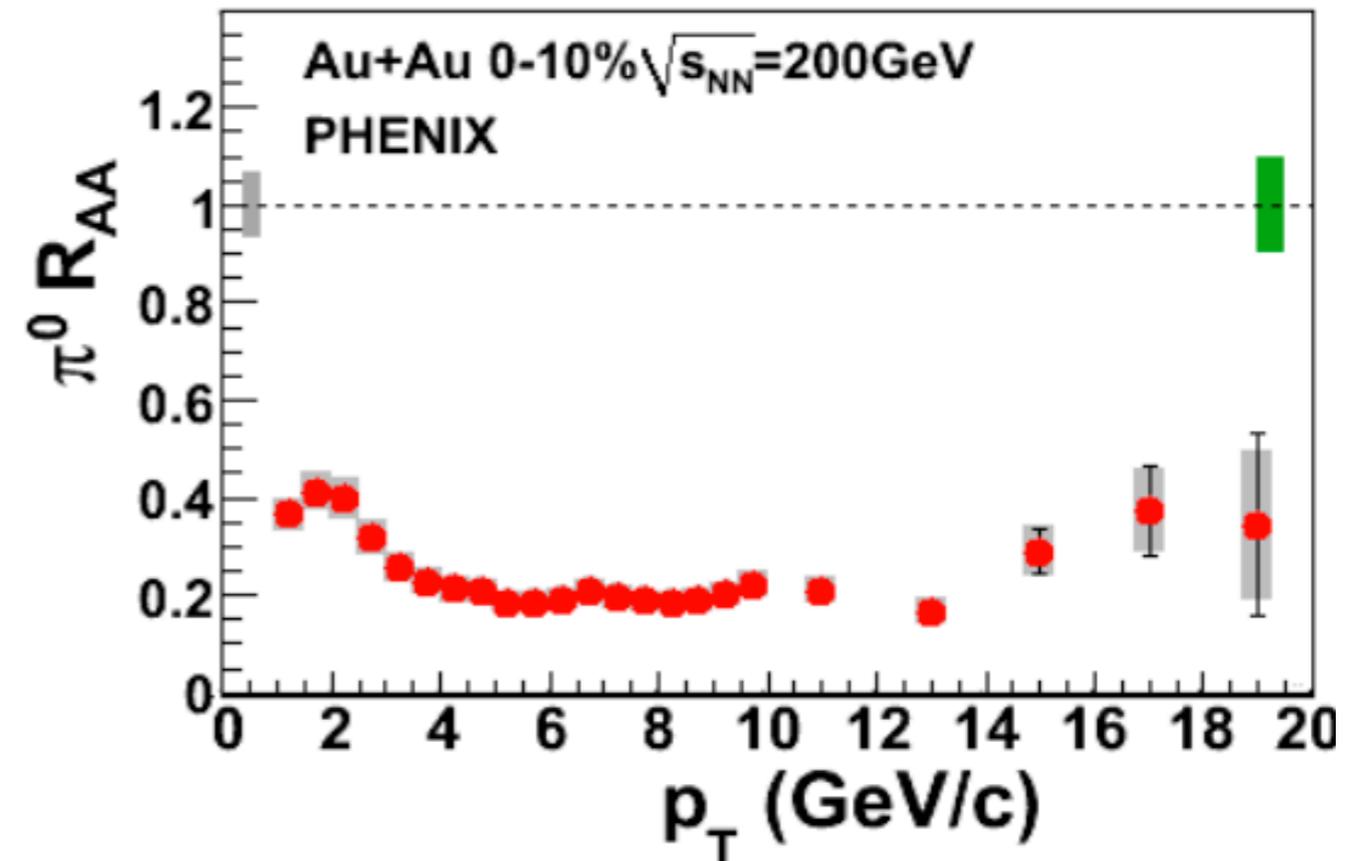
- collective event shape,  $v_2$
  - normalization,  $b_0$
- assume no jet signal at minimum
- or calculate combinatorial rate



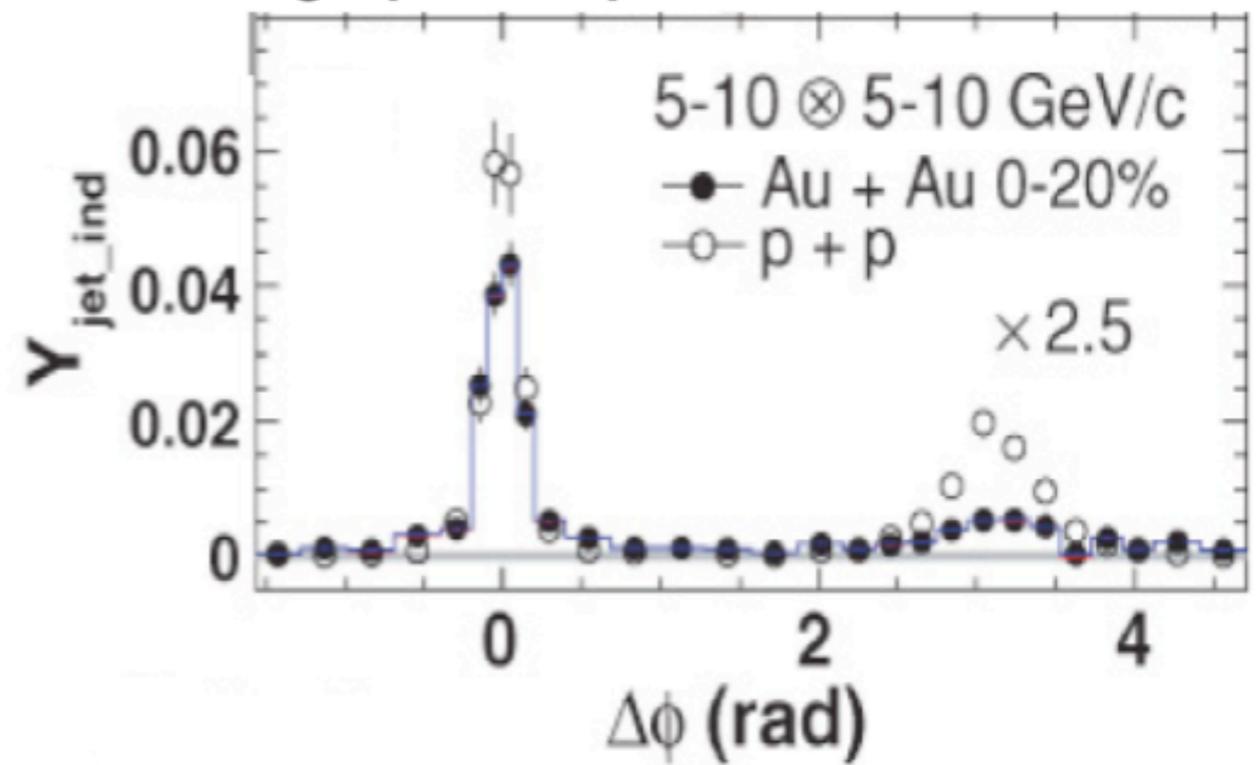
# High $p_T$ Energy Loss



### Single particle measurement

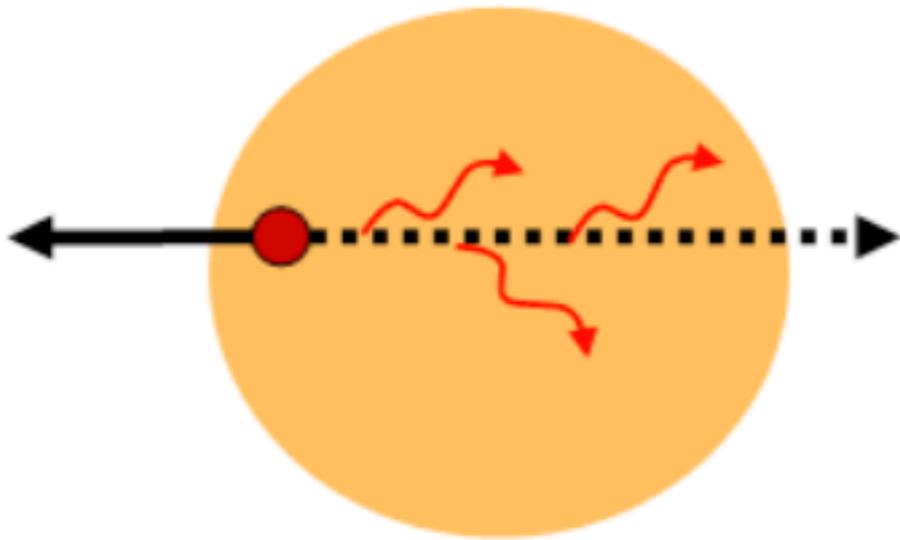


### High $p_T$ two particle measurement

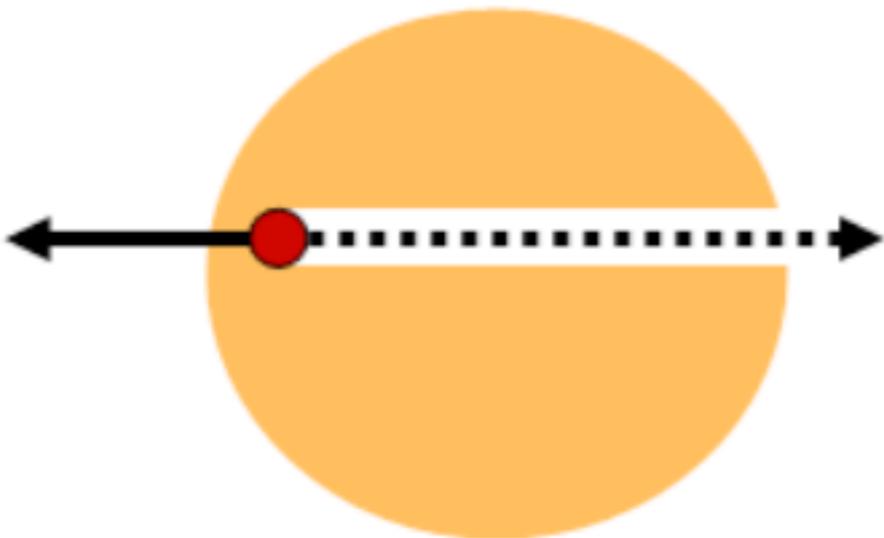


## Nuclear Overlap Crossing

“punch-through”

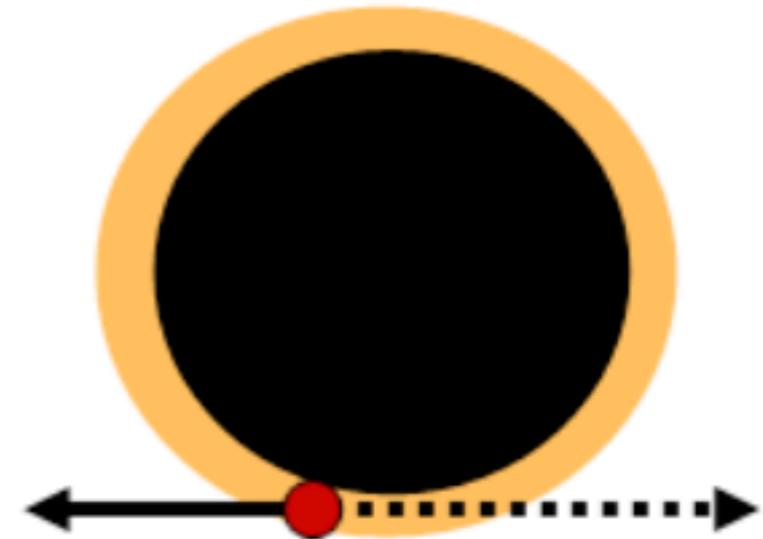


“skip-through”



## Nuclear Overlap Tangential

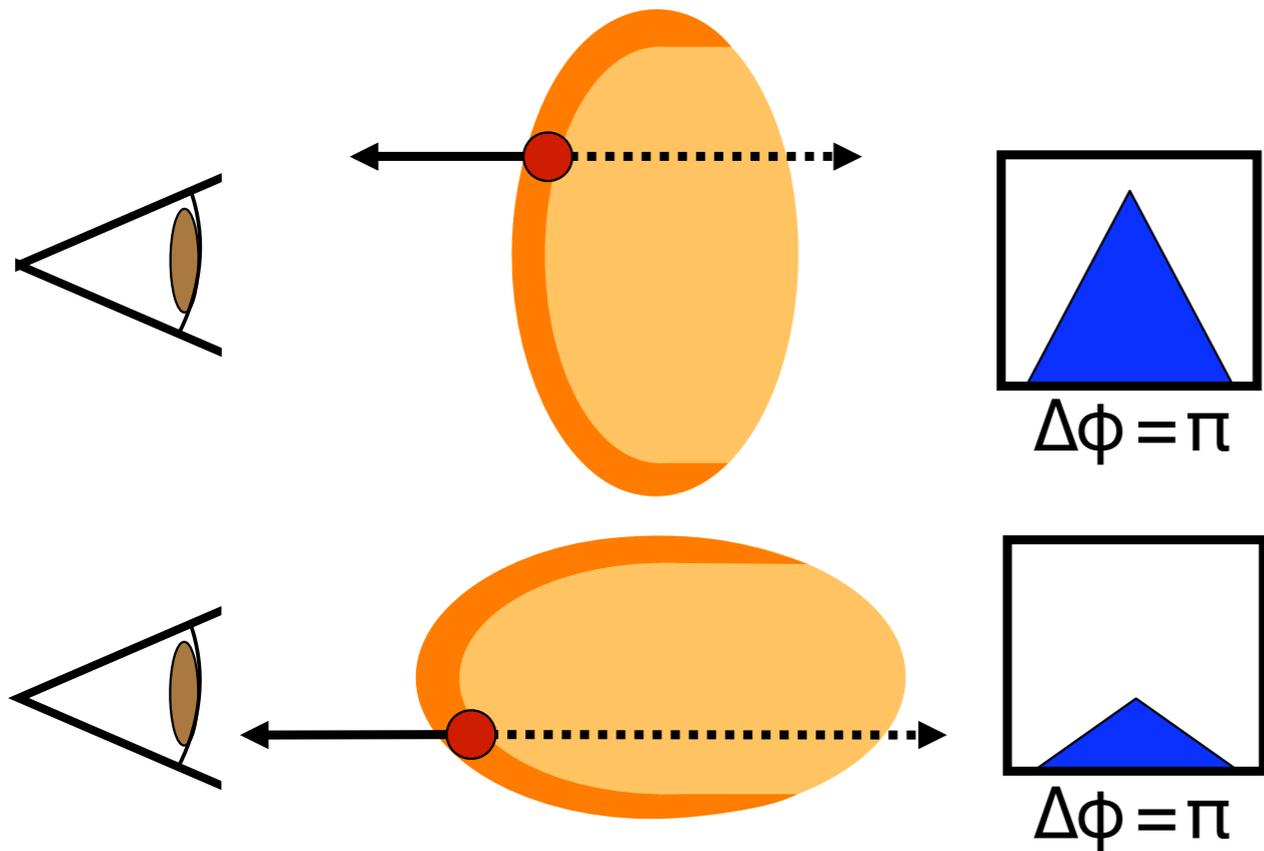
“corona”



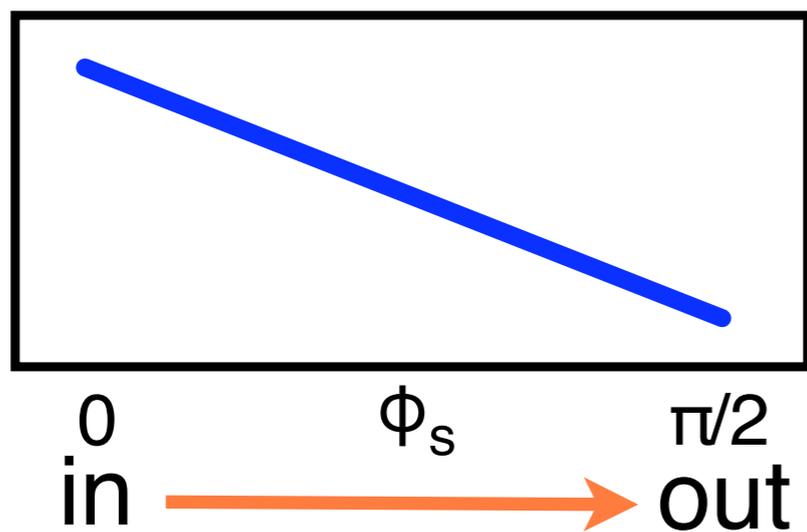
**Q: Can a fast parton enter the nuclear overlap and survive?**

# Variation with Reaction Plane

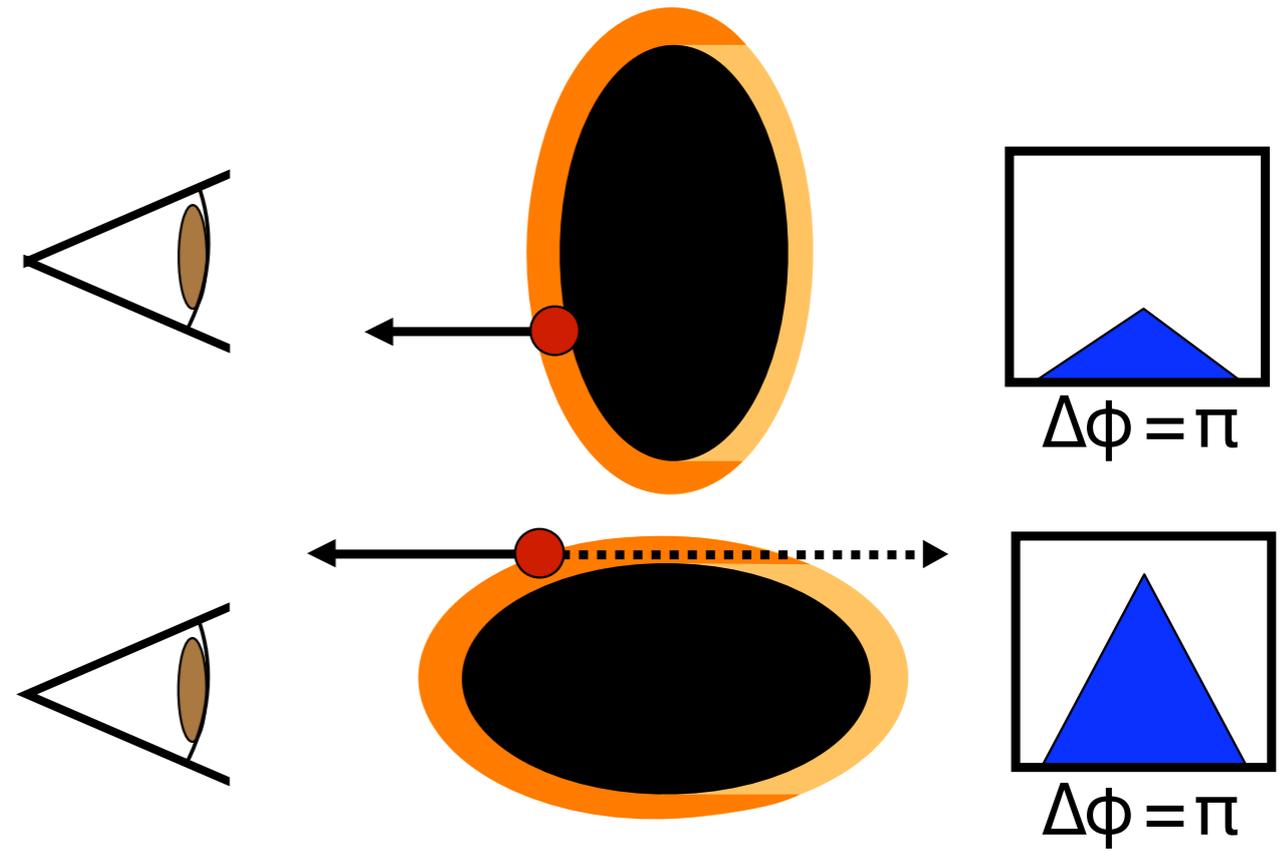
## Nuclear Overlap Crossing



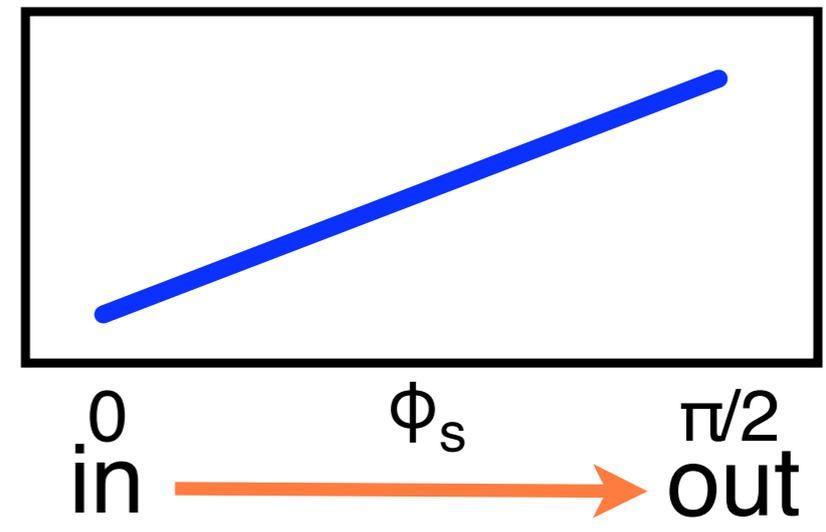
Away  
PTY



## Nuclear Overlap Tangential

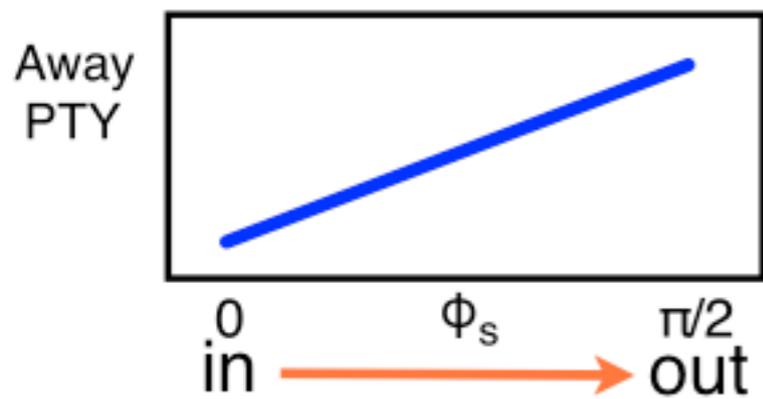


Away  
PTY



The dependence of away-side PTY can discriminate between models.

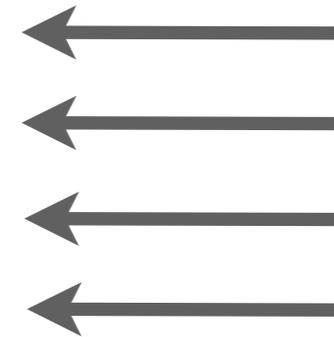
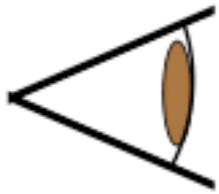
# Tangential Rising PTYs



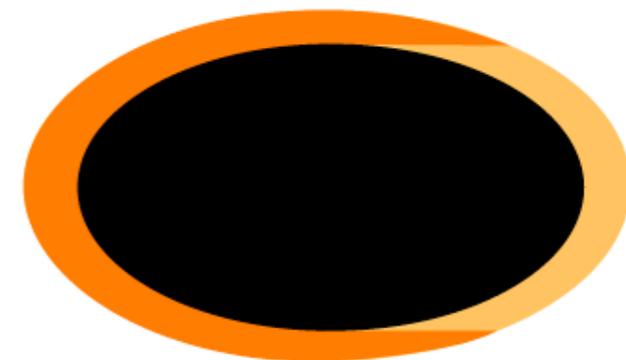
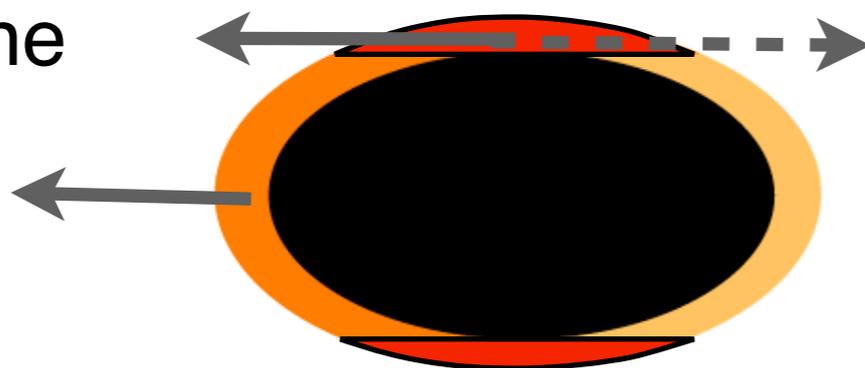
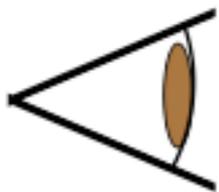
Integrated Column Density

Trigger Multiplicity

in-plane



out-of-plane



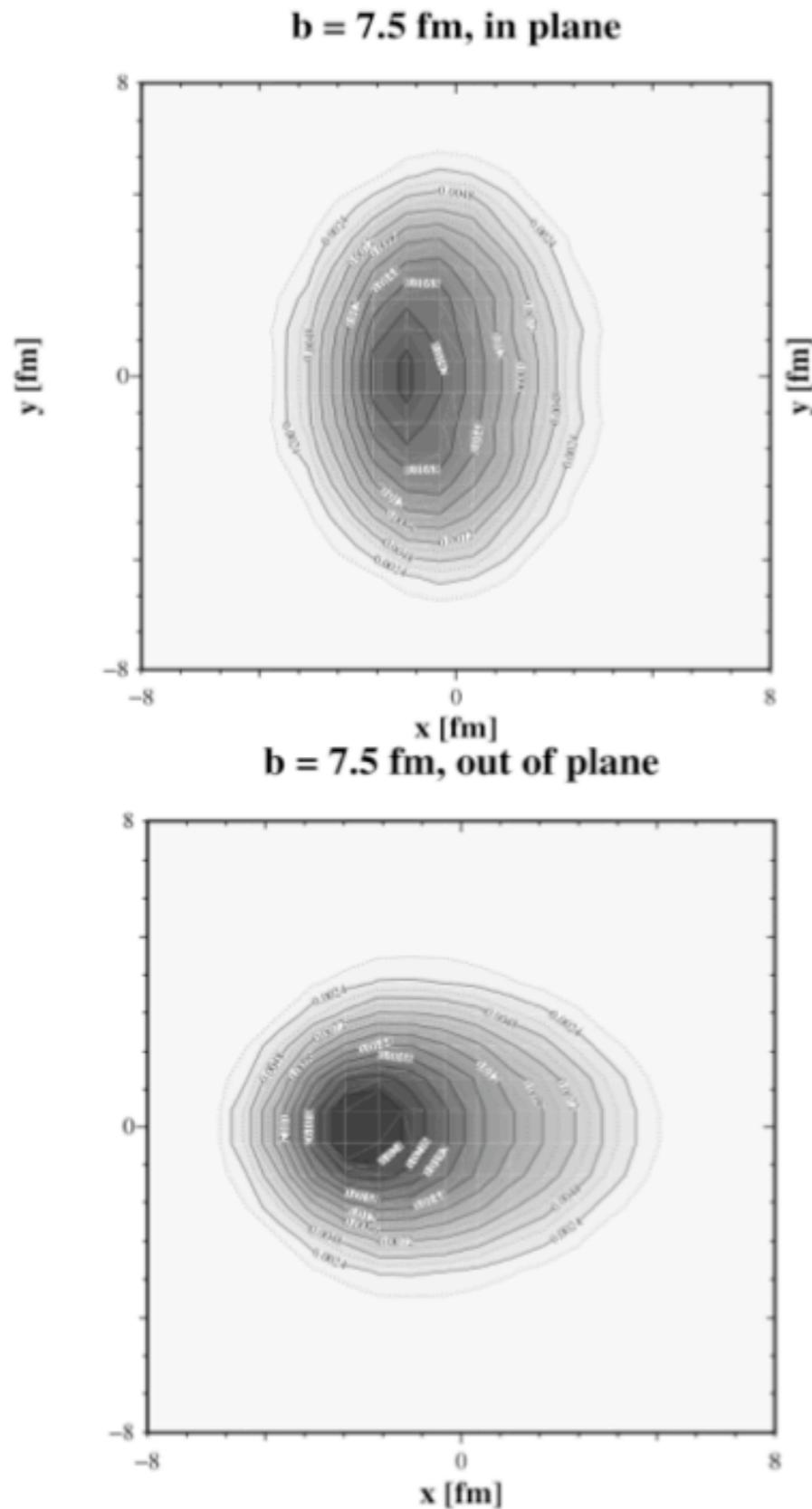
# Predicitions: Renk

Angular variation of hard back-to-back hadron suppression in heavy-ion collisions

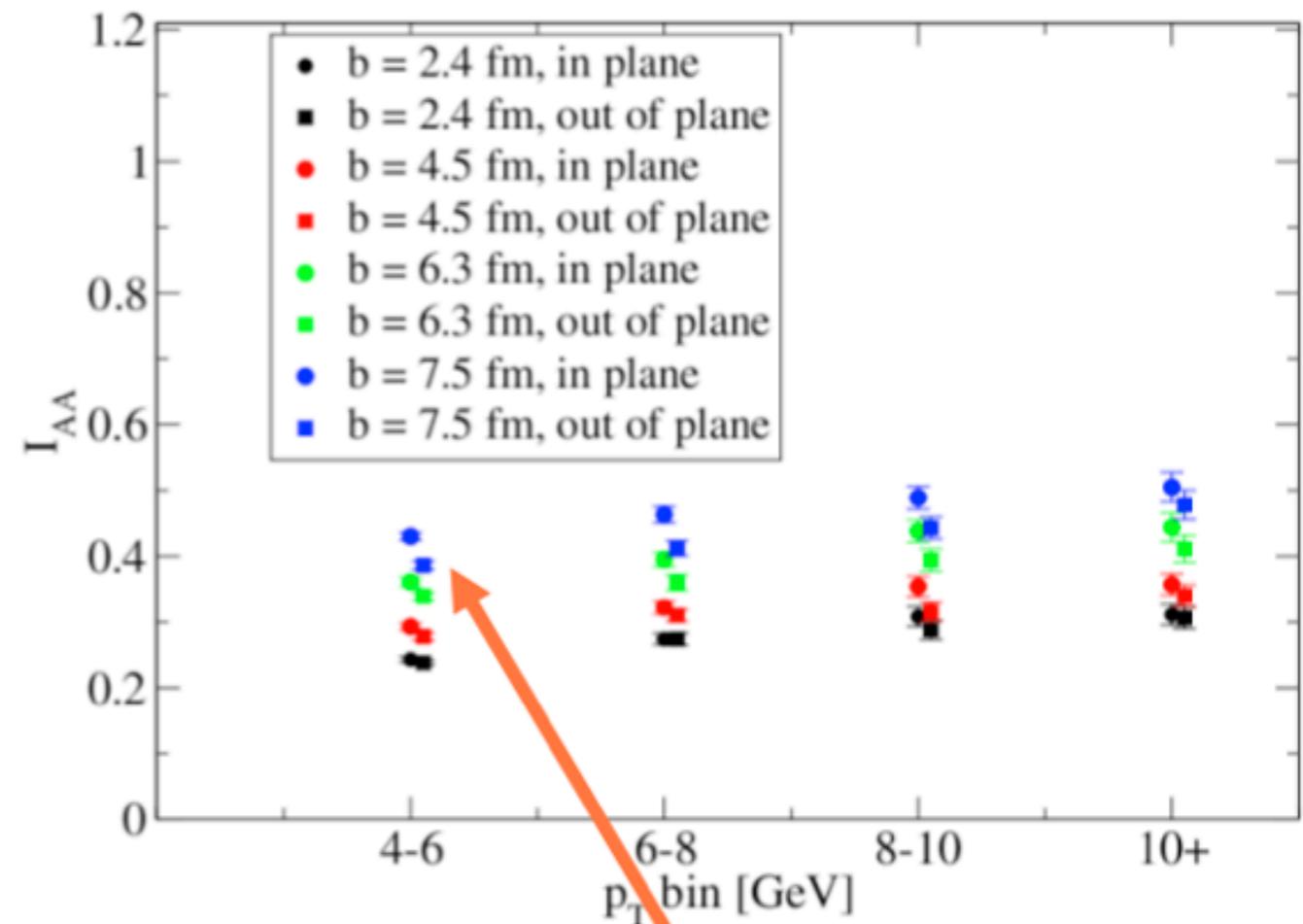
arXiv:0803.0218v2

Thorsten Renk\*

Box 35 FI-40014 University of Jyväskylä, Finland and  
P.O. Box 64 FI-00014, University of Helsinki, Finland



Trigger 12 - 20 GeV



falling with increasing  $rp$ -angle  
max  $\sim 12\%$  variation in mid-central

# Predicitions: Renk

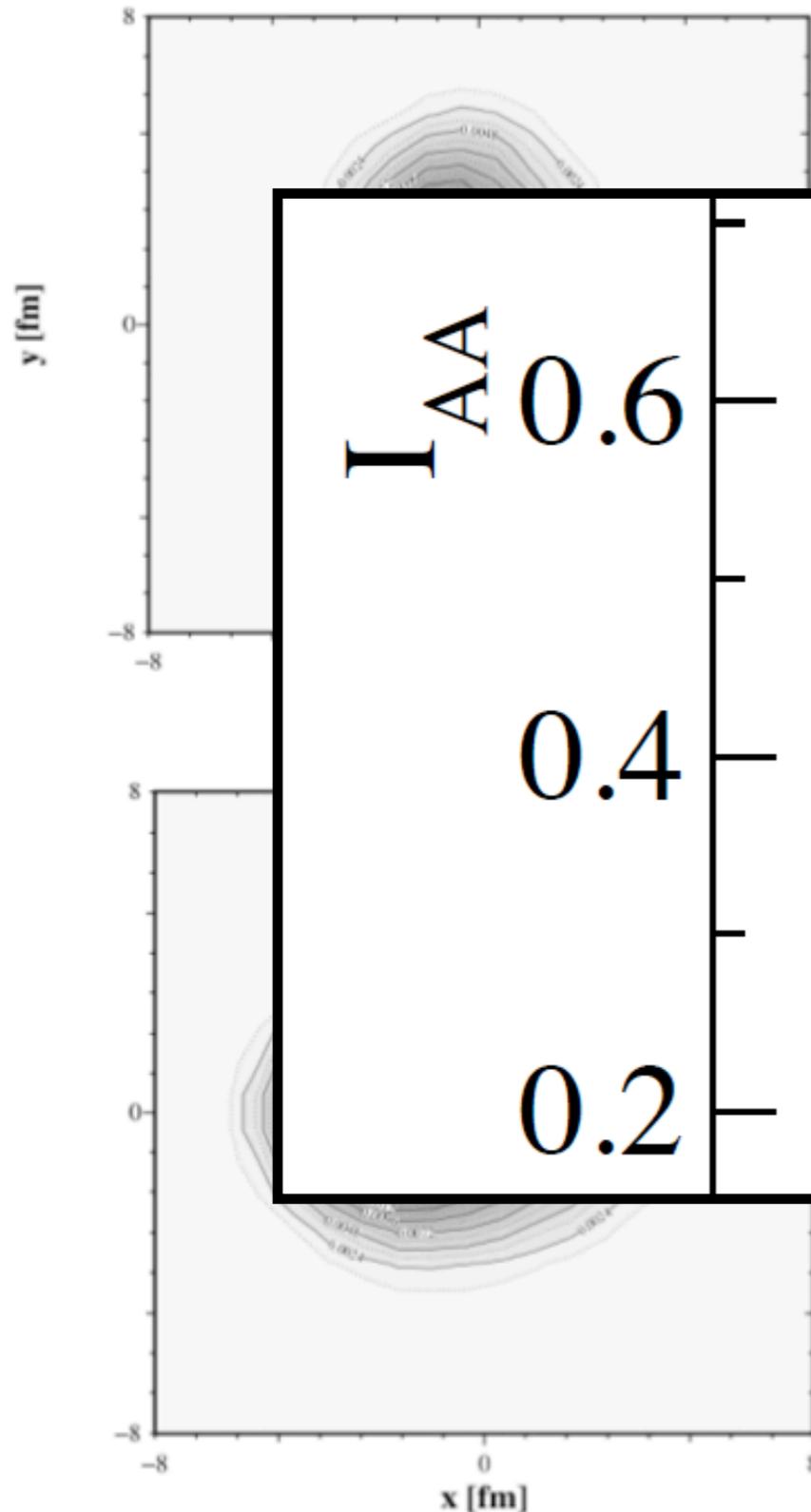
Angular variation of hard back-to-back hadron suppression in heavy-ion collisions

$b = 7.5$  fm, in plane

arXiv:0803.0218v2

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$I_{AA}$

0.6

0.4

0.2

- $b = 7.5$  fm, in plane
- $b = 7.5$  fm, out of plane

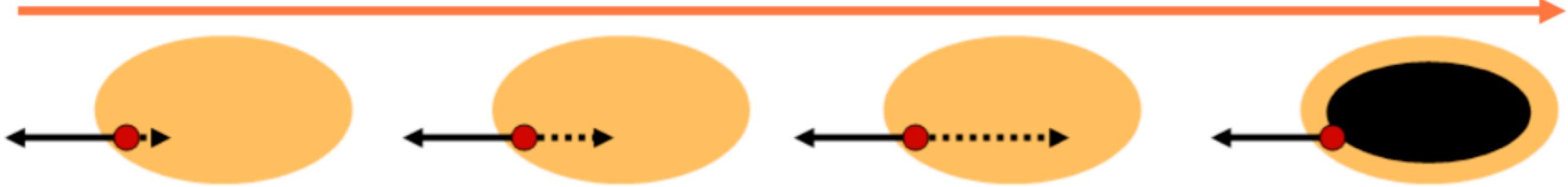


falling with increasing  $\varphi$ -angle  
max  $\sim 12\%$  variation in mid-central

# Predictions: Pantuev

Vlad Pantuev - nucl-ex/0610002

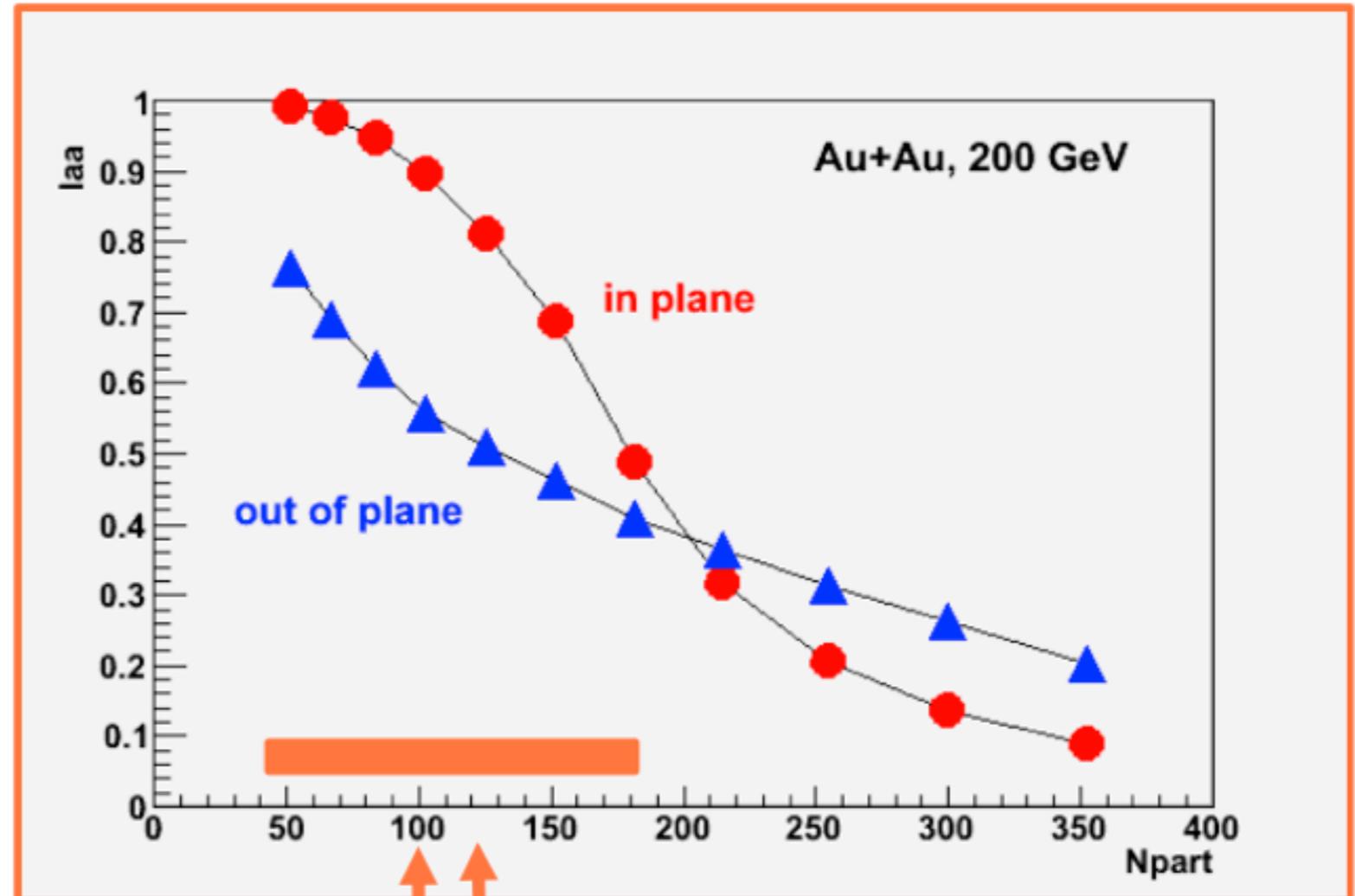
time



Tangential-dominance only  
in more central collisions

Transition driven by  
formation time of black  
core

Large falling variation  
in mid-central bin  
~45%

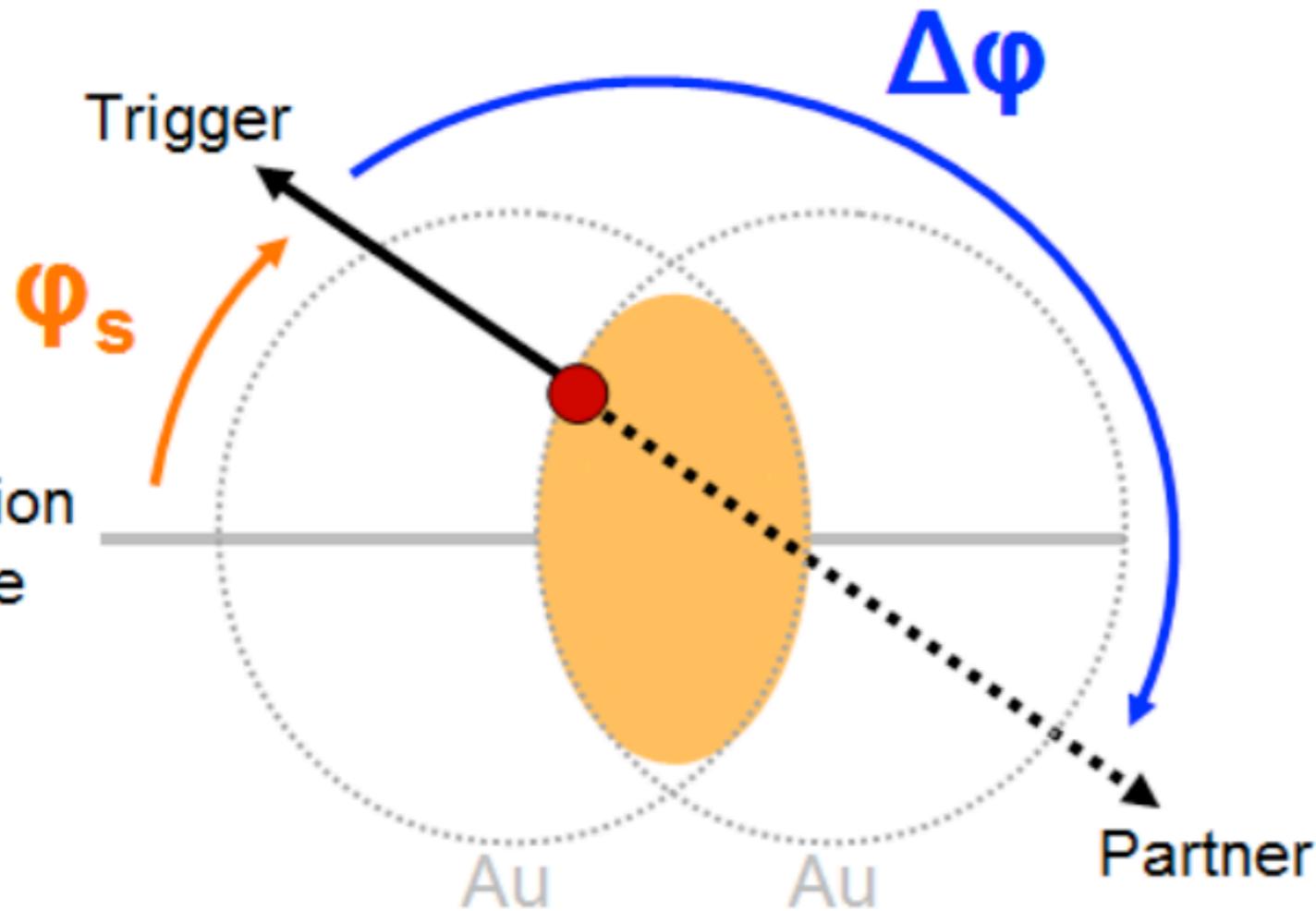


Npart 20-60% = 100

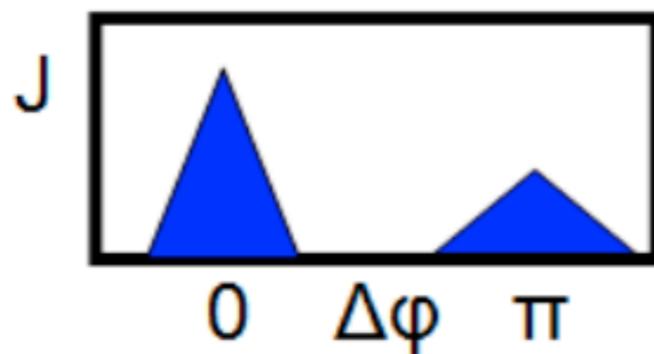
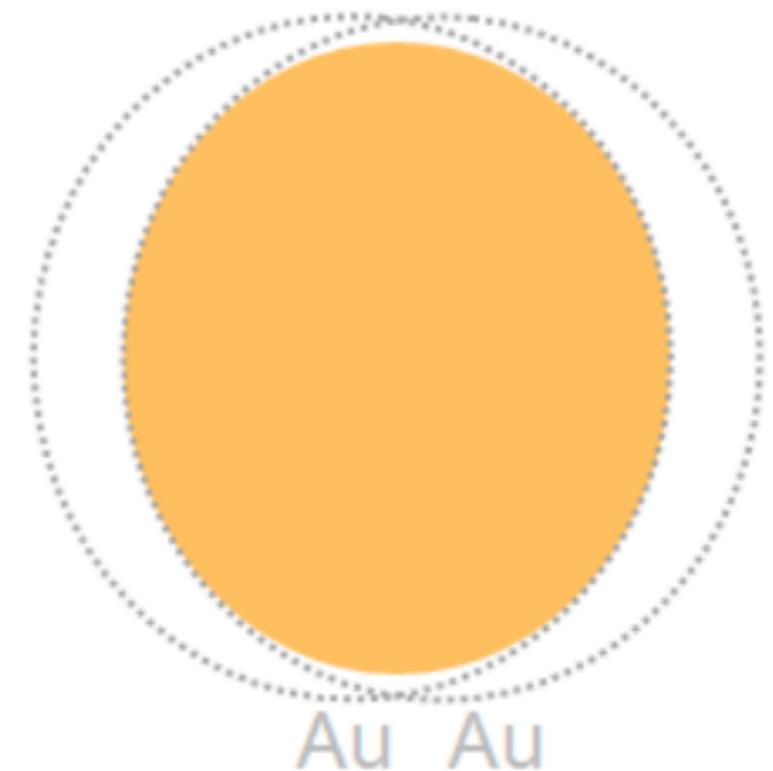
Trigger Weighted  
Npart 20-60% ~ 125

# High $\pi^0$ - $h^\pm$ by Reaction Plane Analysis

“Measurement” Bin  
20-60% Centrality



“Control” Bin  
0-20% Centrality



Less anisotropy  
Higher backgrounds

# Method

Two source model:

$$C(\Delta\phi) = J(\Delta\phi) + b_0^{ZYAM} \left( 1 + \frac{\beta}{\alpha} \cos(2\Delta\phi) + \frac{\gamma}{\alpha} \cos(4\Delta\phi) \right)$$

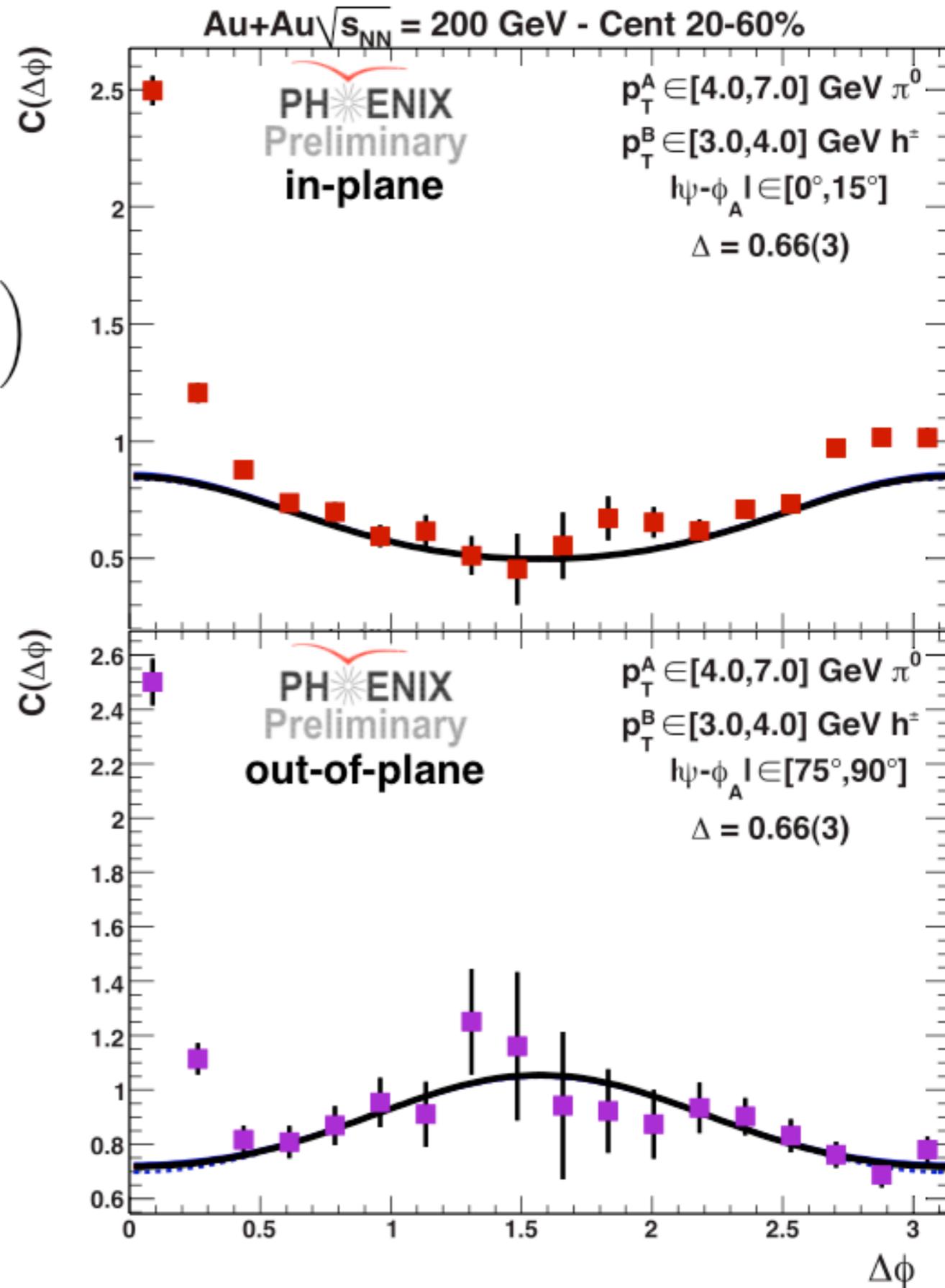
and rxpn-binning requires:

$$\alpha = 1 + 2v_2^A \cos(2\phi_s) \frac{\sin(2c)}{2c} \Delta + 2v_2^A \cos(4\phi_s) \Delta_4$$

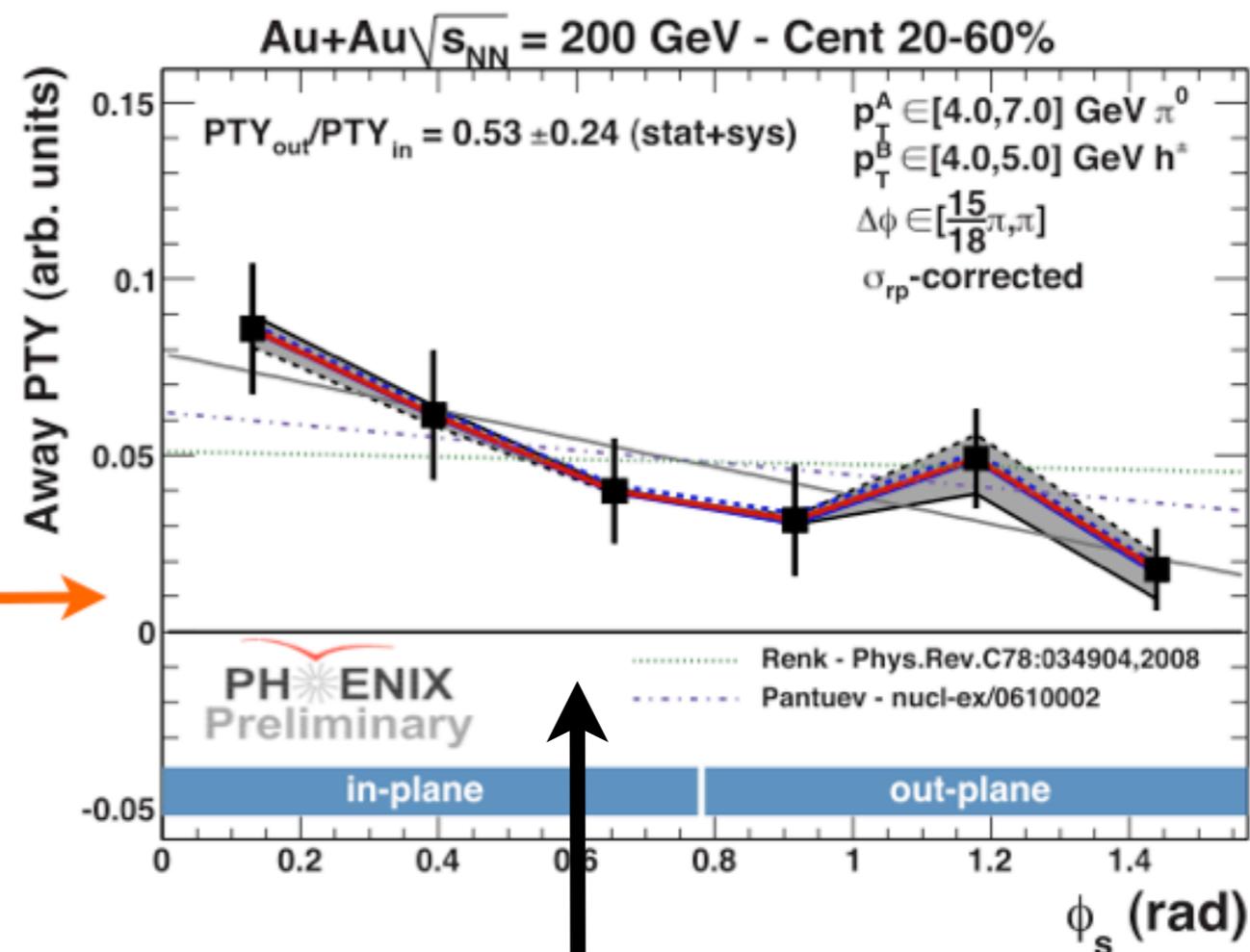
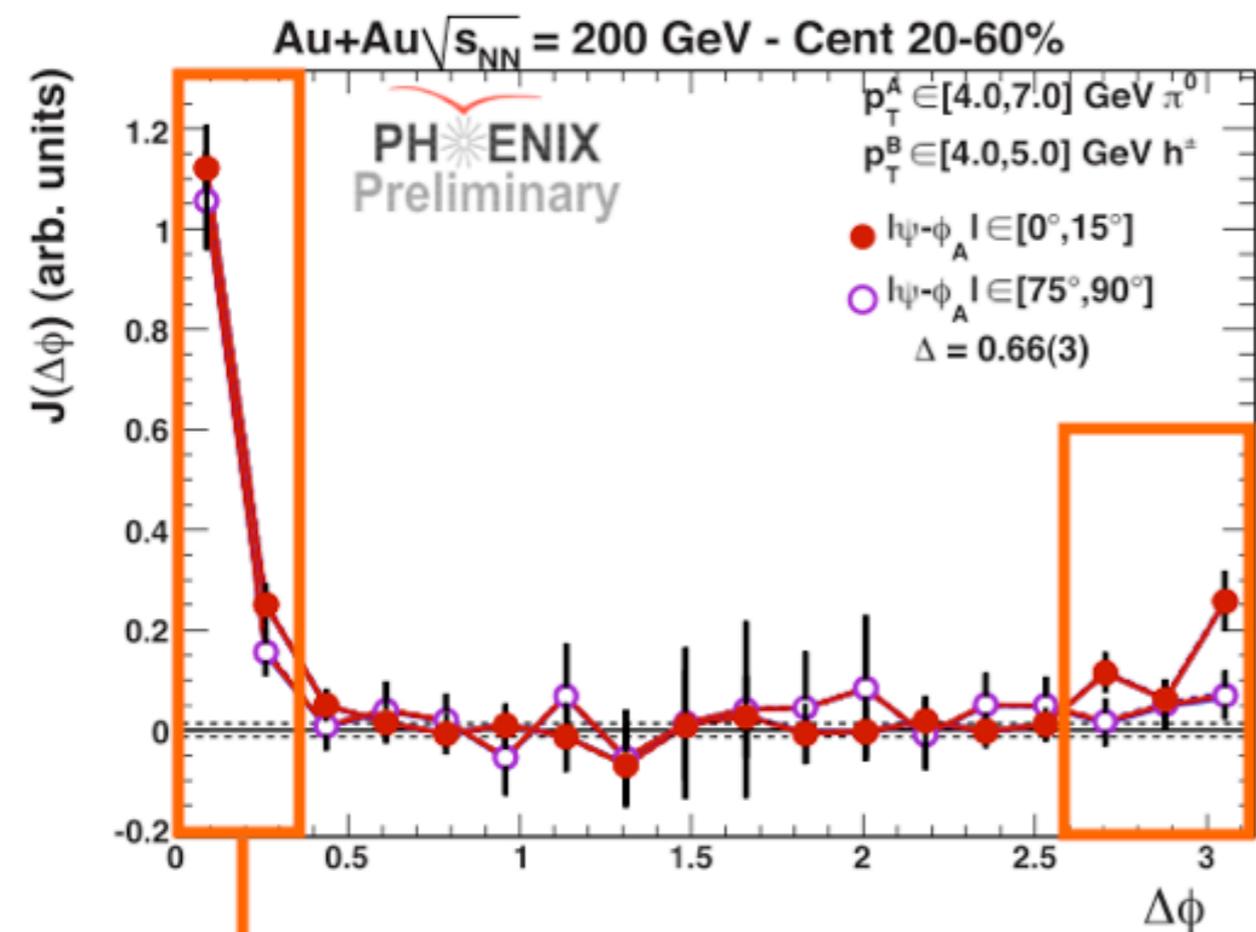
$$\beta = 2v_2^A v_2^B + 2v_2^B (1 + v_4^A) \cos(2\phi_s) \frac{\sin(2c)}{2c} \Delta + 2v_2^A v_2^B \cos(4\phi_s) \frac{\sin(4c)}{4c} \Delta_4 + 2v_2^B v_4^A \cos(6\phi_s) \frac{\sin(6c)}{6c} \Delta_6$$

$$\gamma = 2v_4^A v_4^B + 2v_4^B (1 + v_2^A) \cos(4\phi_s) \frac{\sin(4c)}{4c} \Delta_4 + 2v_2^A v_4^B \left( \cos(2\phi_s) \frac{\sin(2c)}{2c} \Delta + \cos(6\phi_s) \frac{\sin(6c)}{6c} \Delta_6 \right) + 2v_4^A v_4^B \cos(8\phi_s) \frac{\sin(8c)}{8c} \Delta_8$$

high order

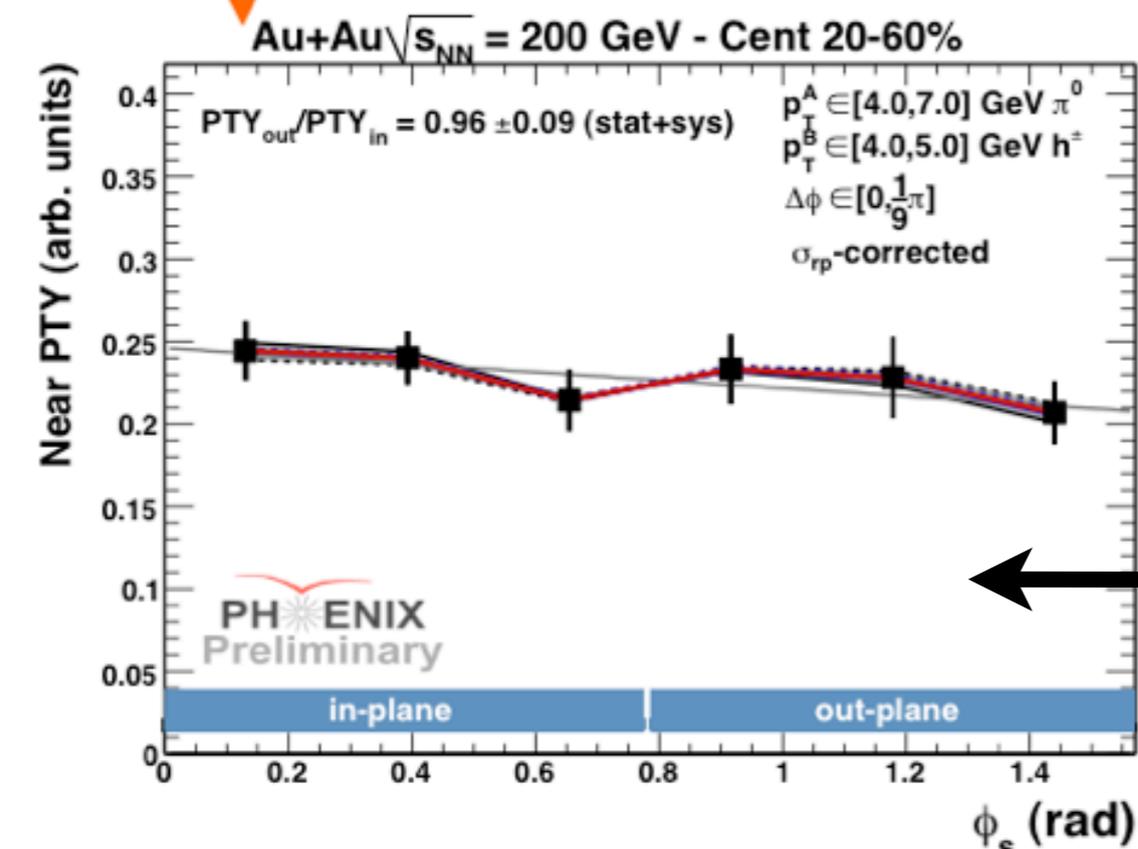


# Partners 4-5 GeV/c

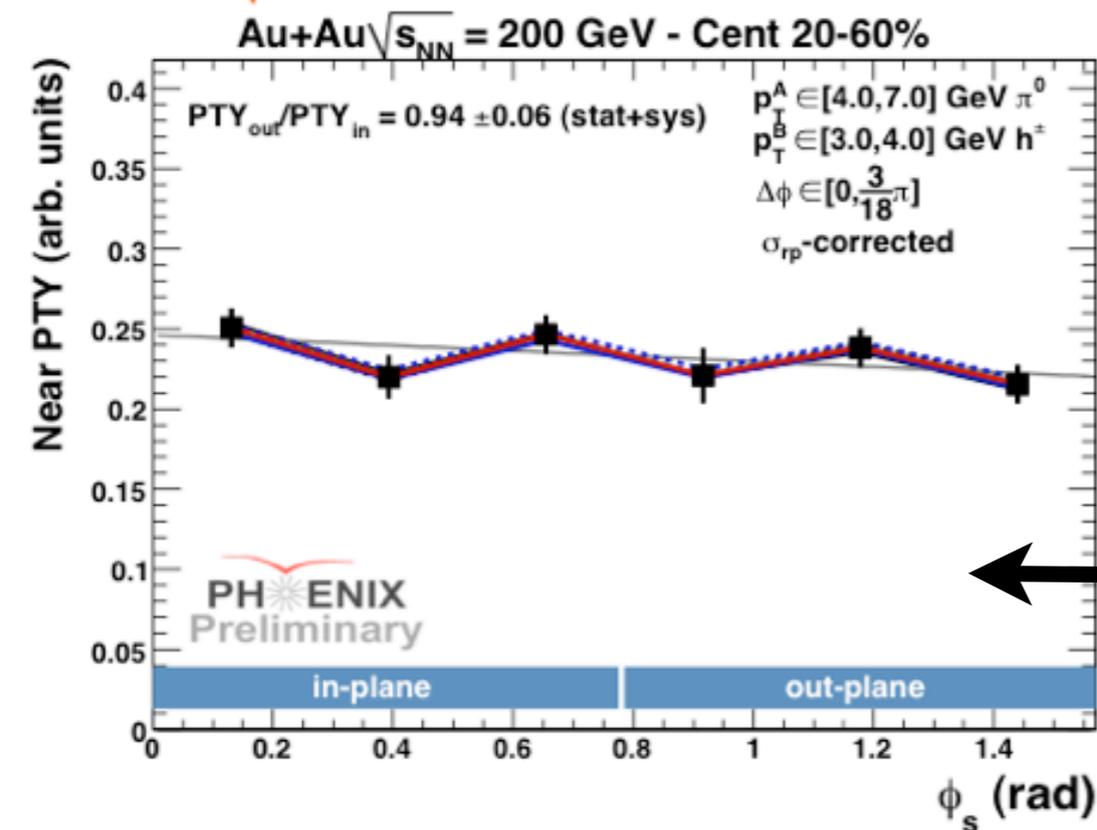
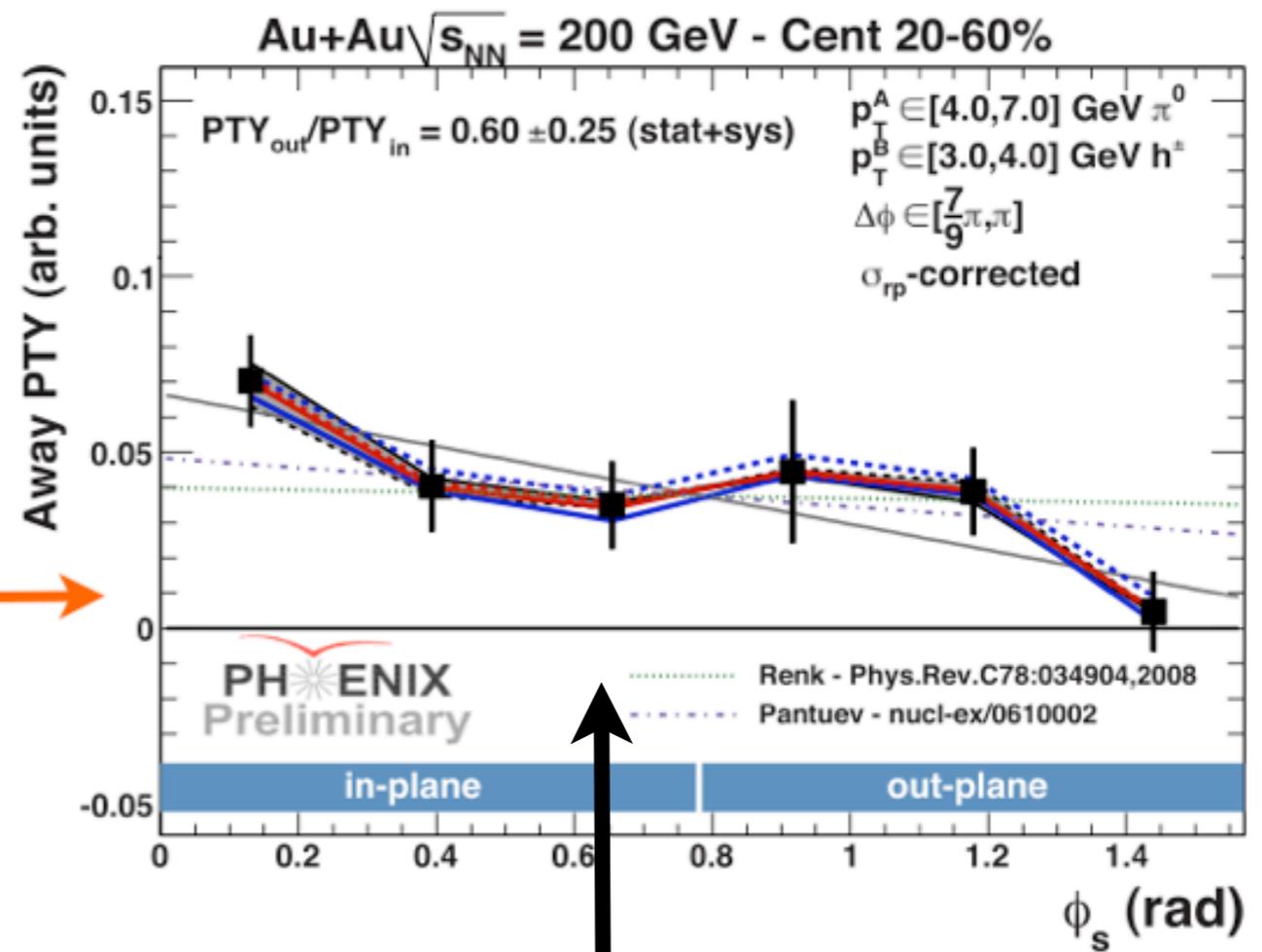
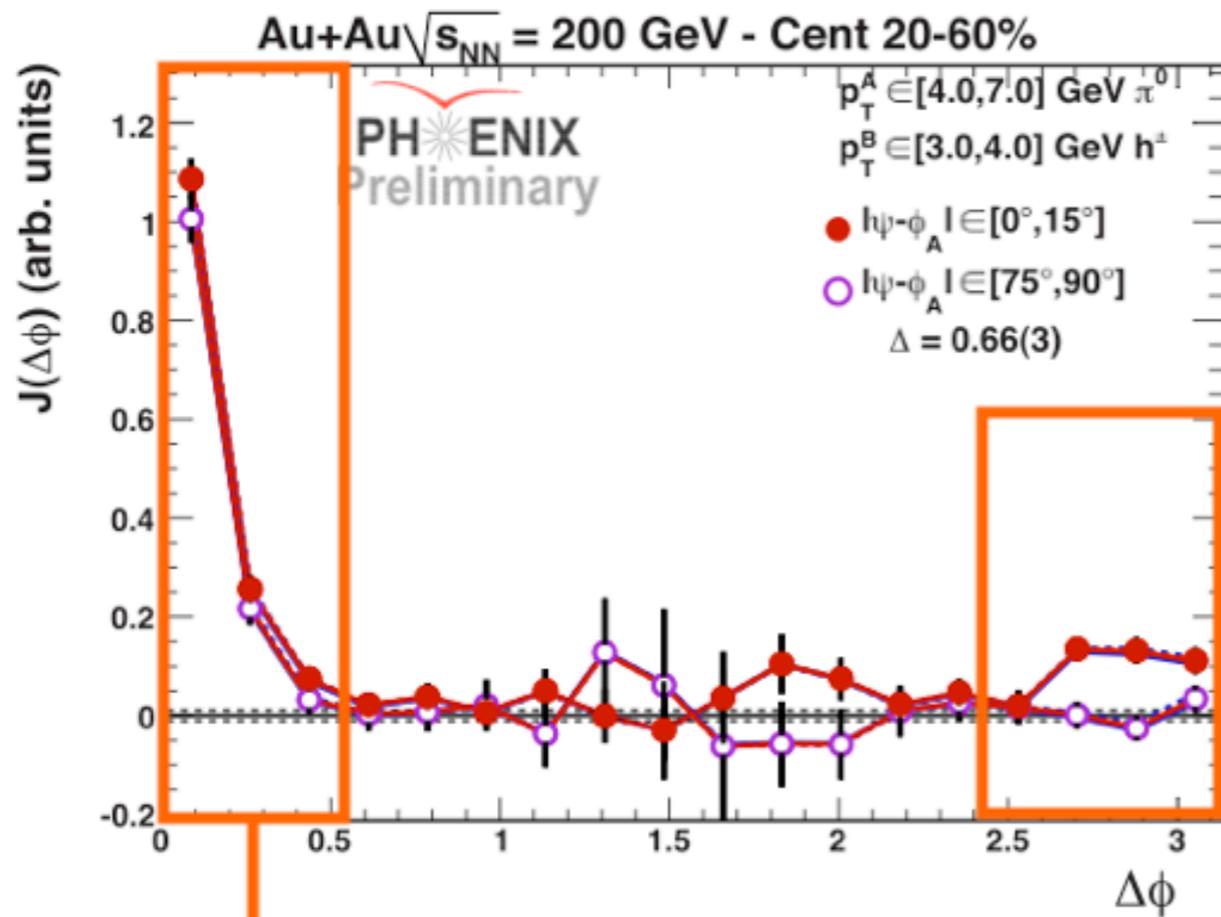


falling away-side trend

insignificant near-side trend



# Partners 3-4 GeV/c

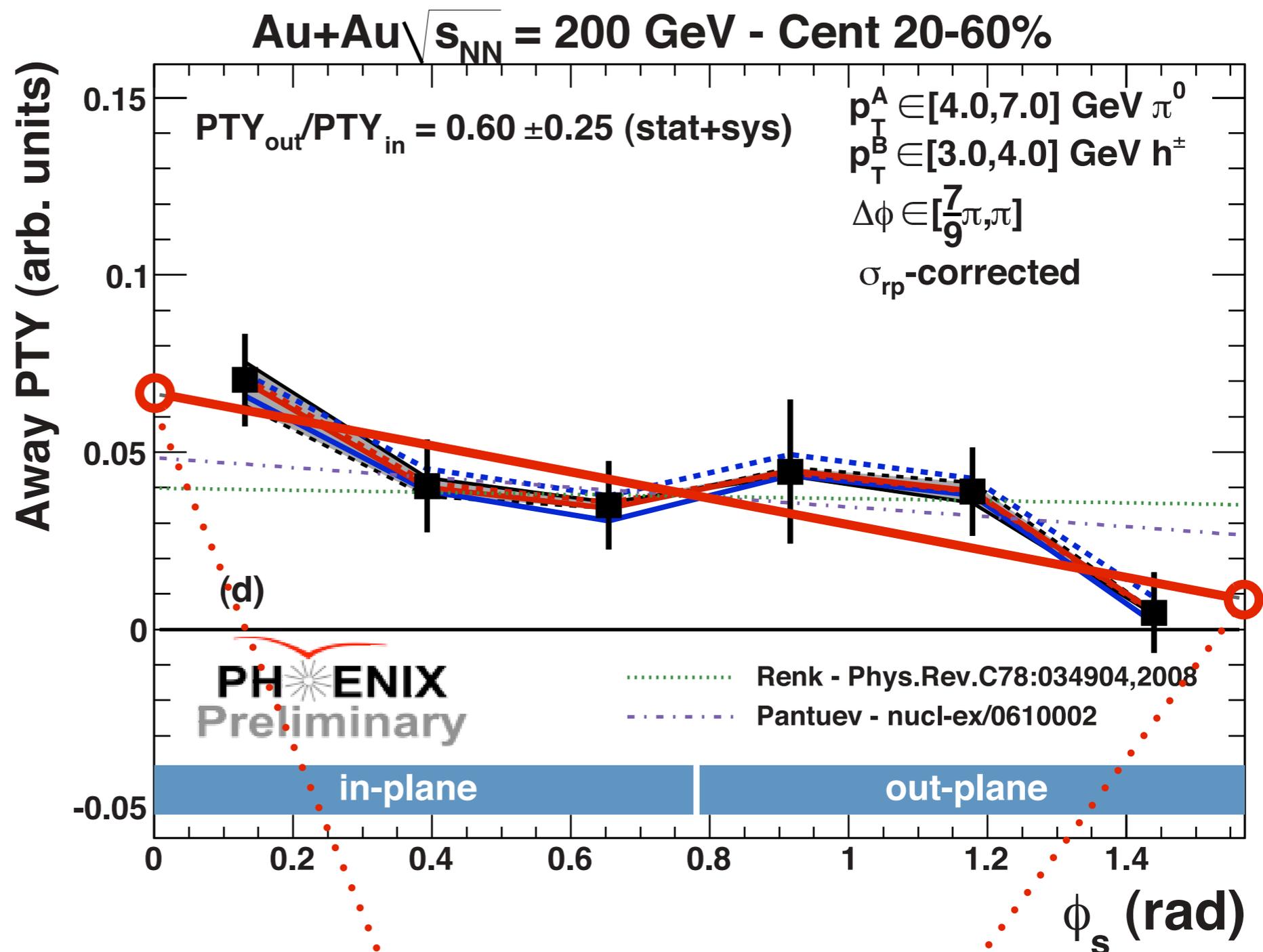


same trends as before

# Away-side $\phi_S$ Dependence

## Both partner bins:

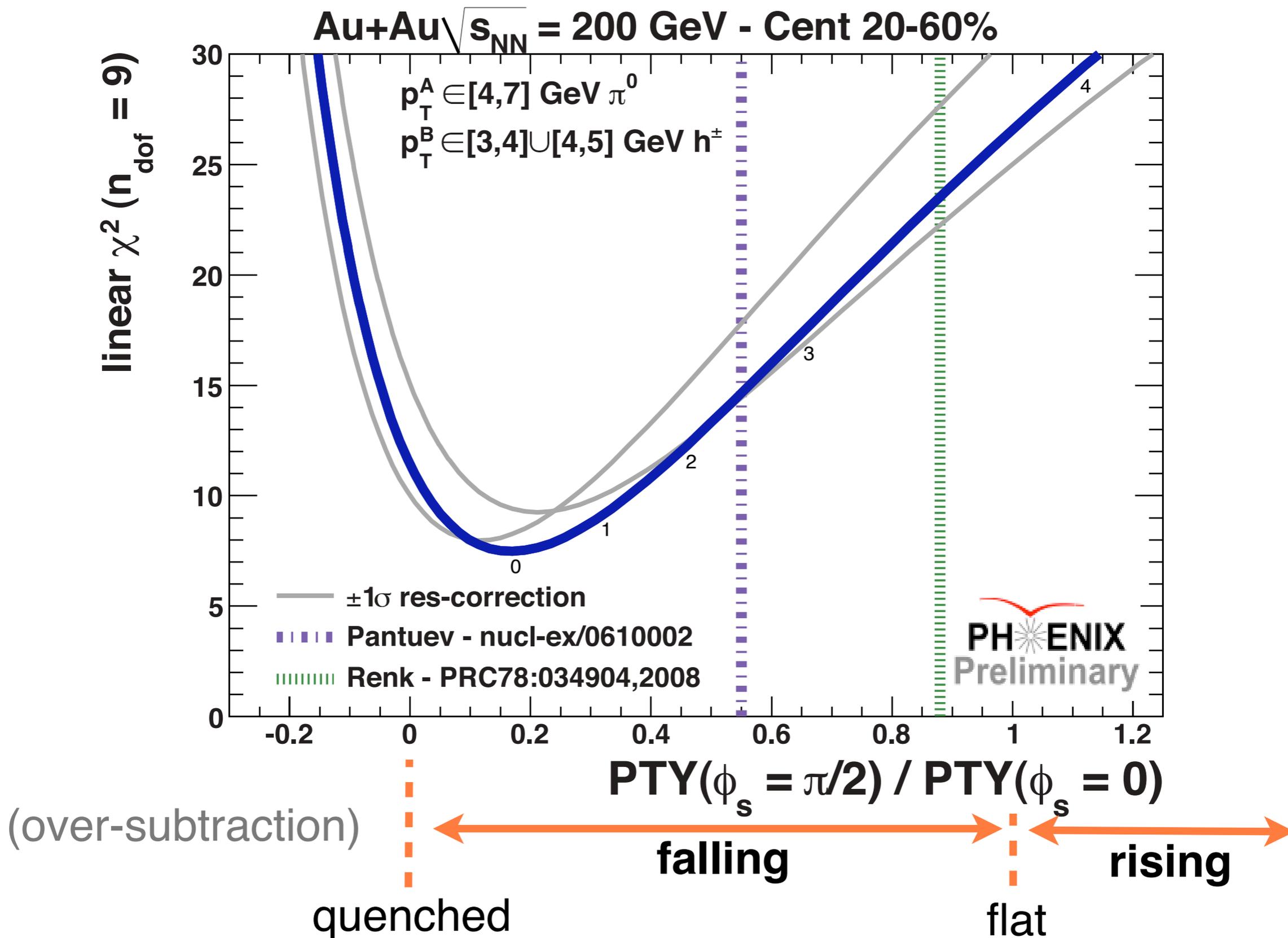
- Consistent with a linear falling function
- Steeper than predictions



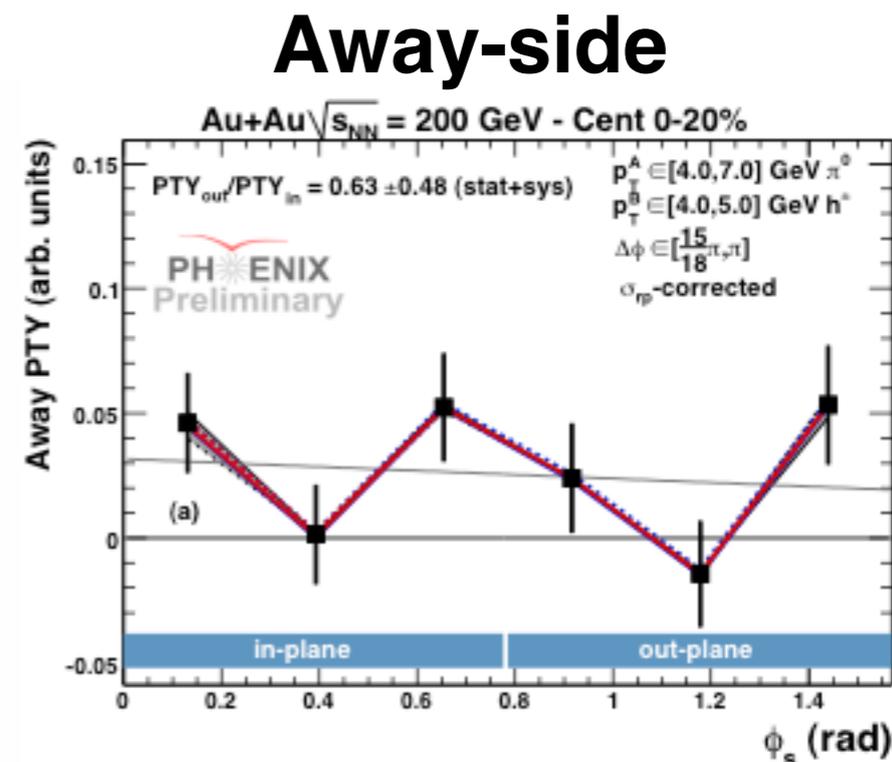
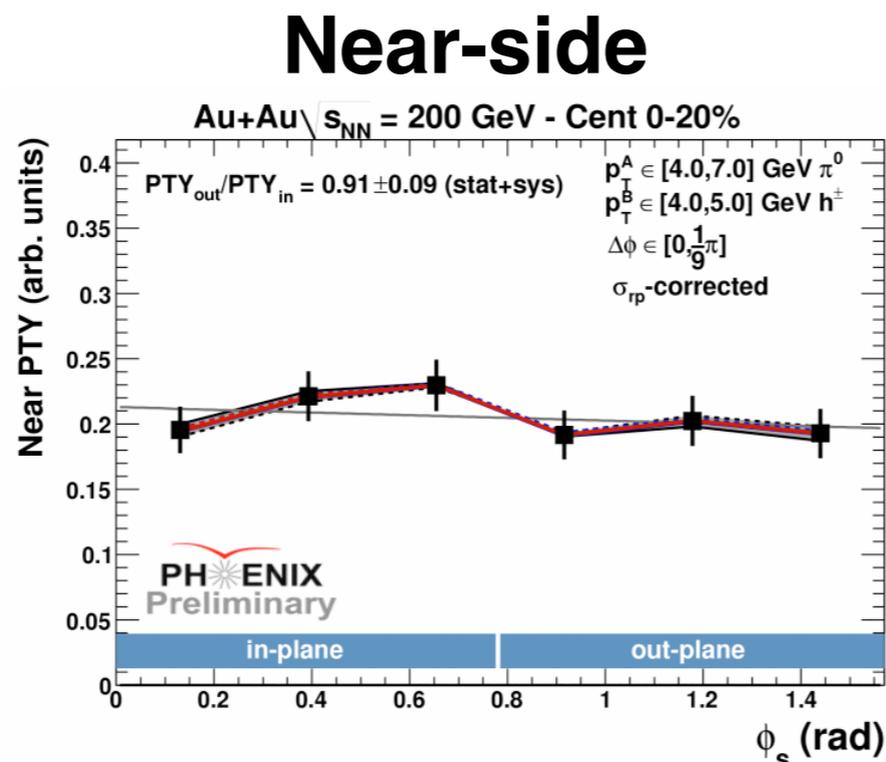
**Trend Characterization:**  
ratio of extrema yields

$$\frac{PTY(\phi_S = \pi/2)}{PTY(\phi_S = 0)}$$

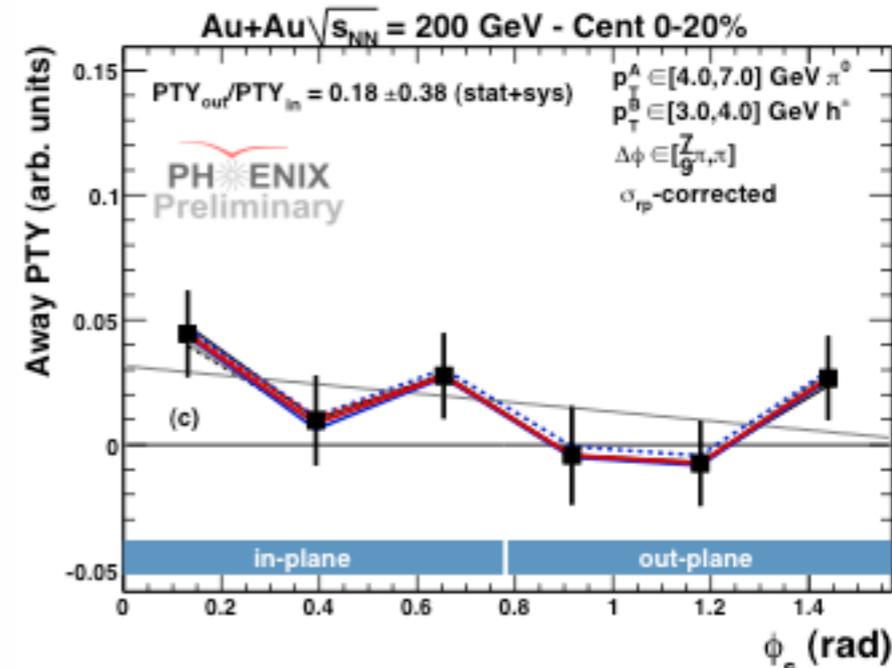
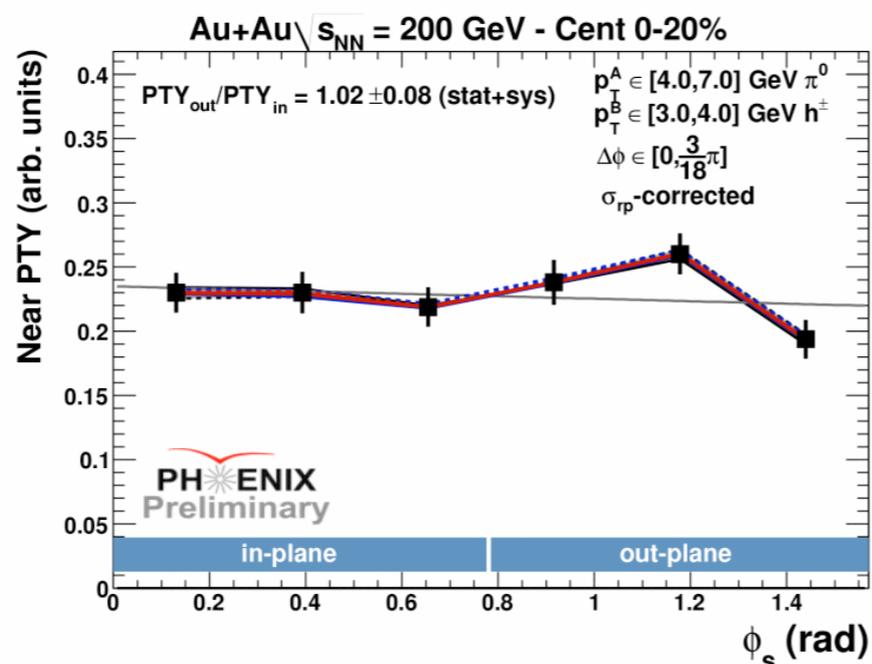
# Variations by Reaction Plane



**Partners:**  
**4-5 GeV/c**

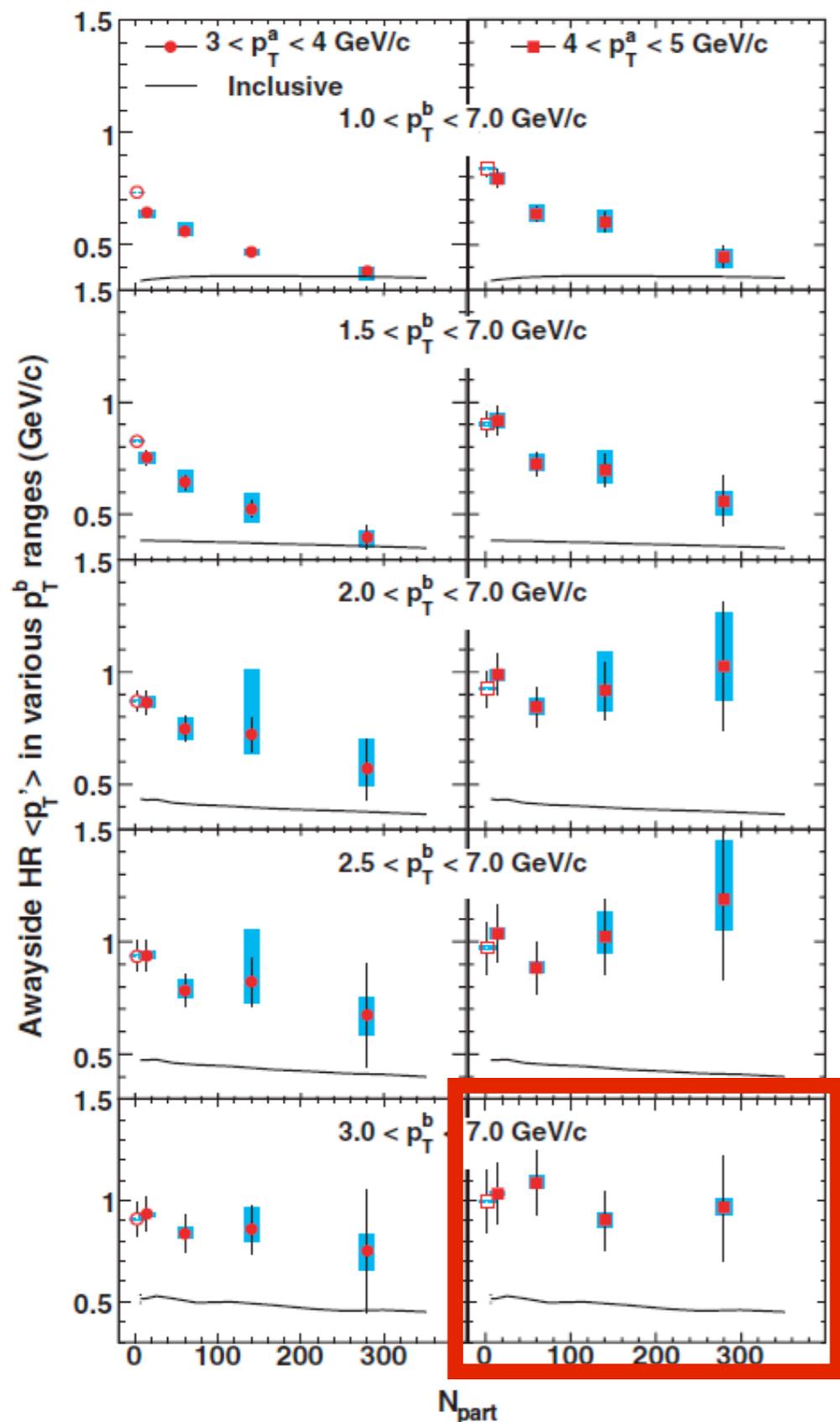


**3-4 GeV/c**



No significant trends, nearly complete away-side suppression

# Away-side $p_T$ Spectra



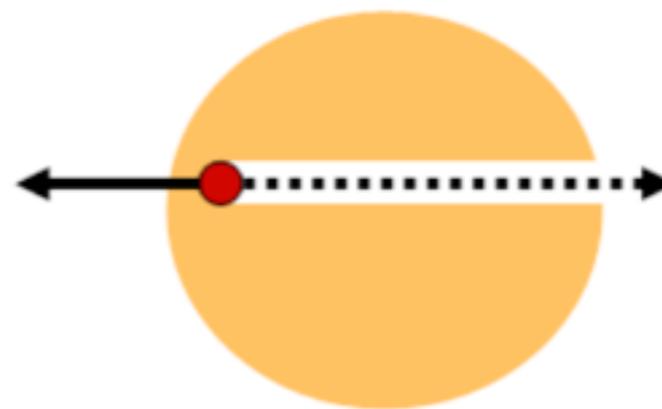
Reaction-plane dependence prefers crossing production

Spectral centrality dependence shows consistent slopes at high  $p_T$

## Surviving Partons:

- cross the nuclear overlap
- lose little energy

“skip-through” production indicated for mid-central collisions



# Summarizing...

## High $p_T$ - Energy Loss

Overlap Geometry:

- possibly more anisotropic than expected in models

Surviving partons:

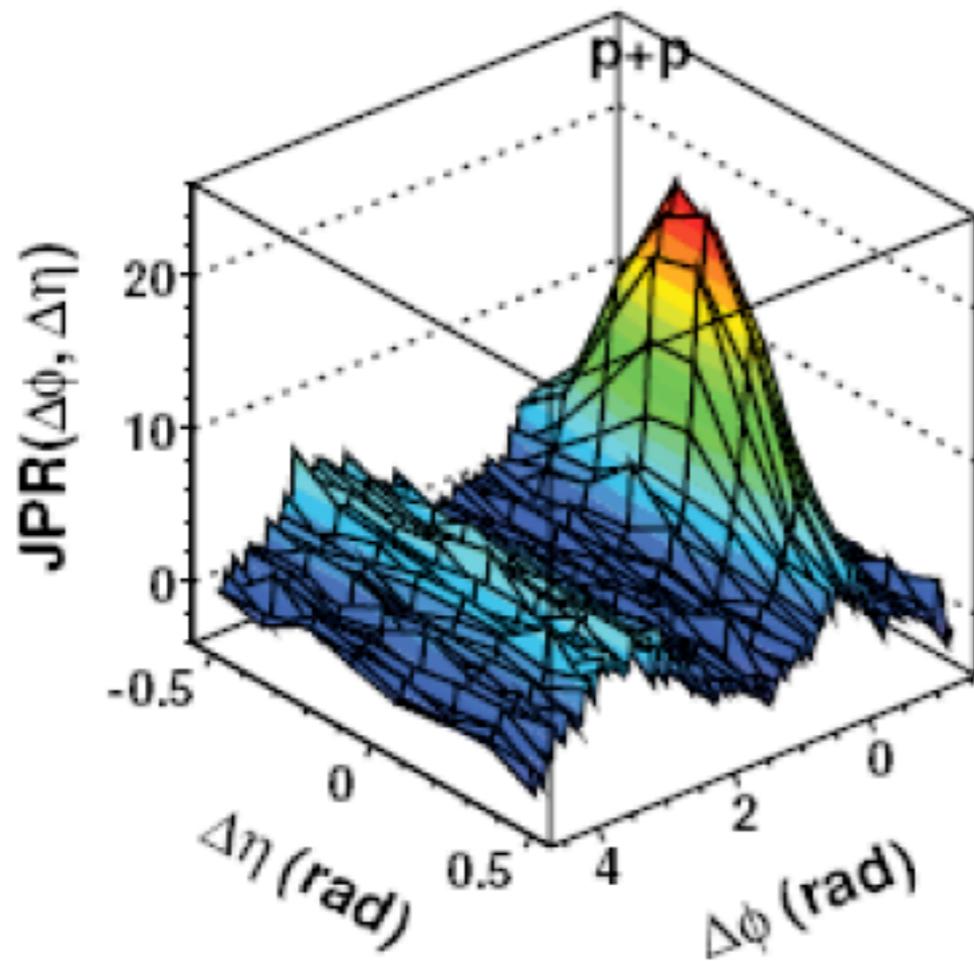
- cross the overlap
- lose little energy

## Intermediate $p_T$ - Medium Response

*But where does the energy go?*

# Intermediate $p_T$ Medium Response

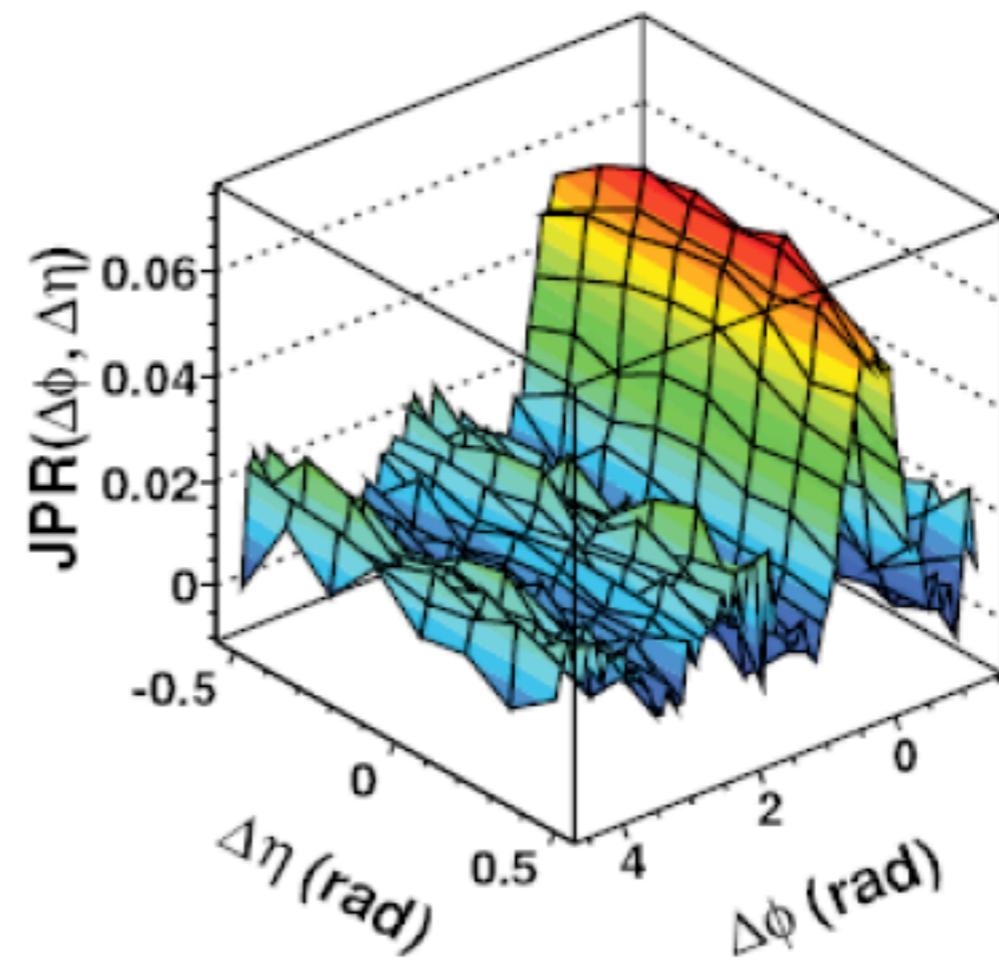
**p+p (similar in peripheral Au+Au)**



**Typical:**

- Near-side Jet
- Away-side Jet - "Head"

**central Au+Au**



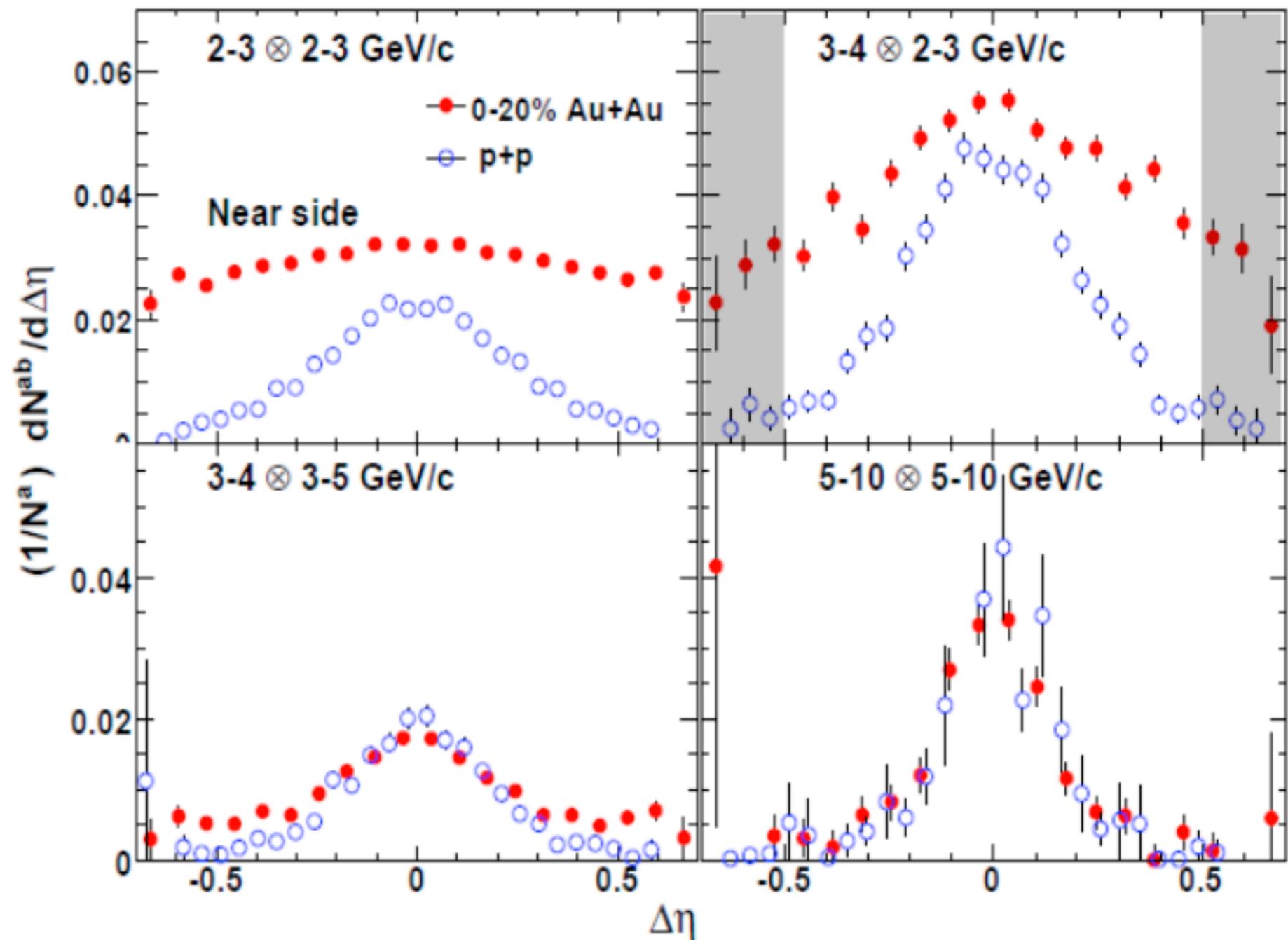
**New:**

- Near-side Modification- "Ridge"
- Away-side Modification - "Shoulder"

- Broad  $\Delta\eta$  near-side enhancement measured in Au+Au collisions at intermediate  $p_T$

- High  $p_T$  near-sides are similar

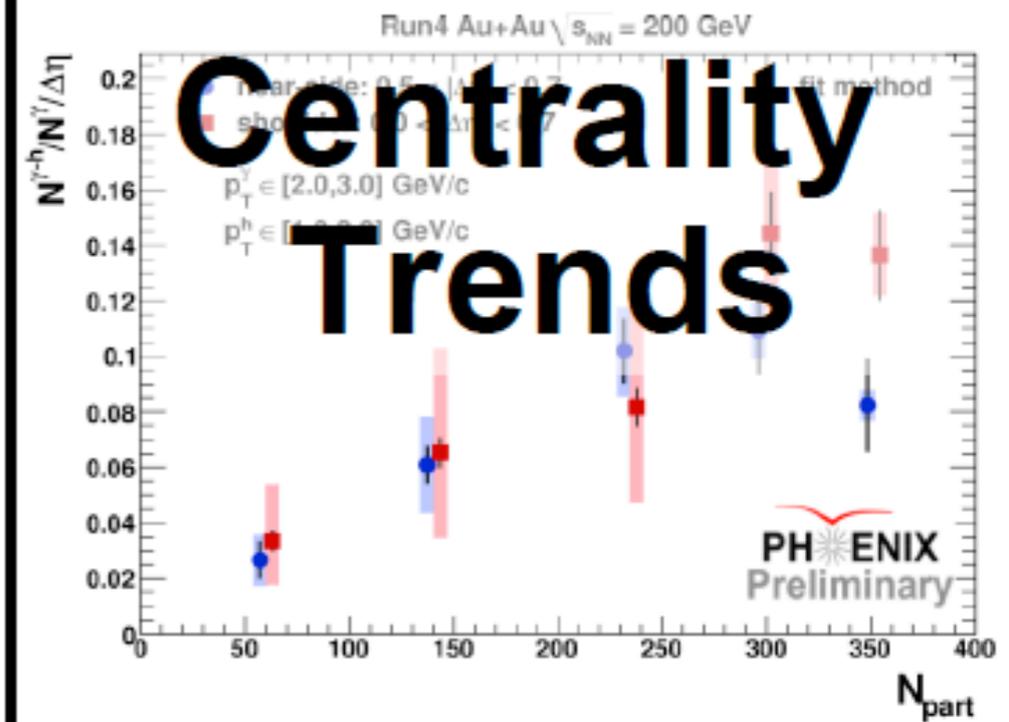
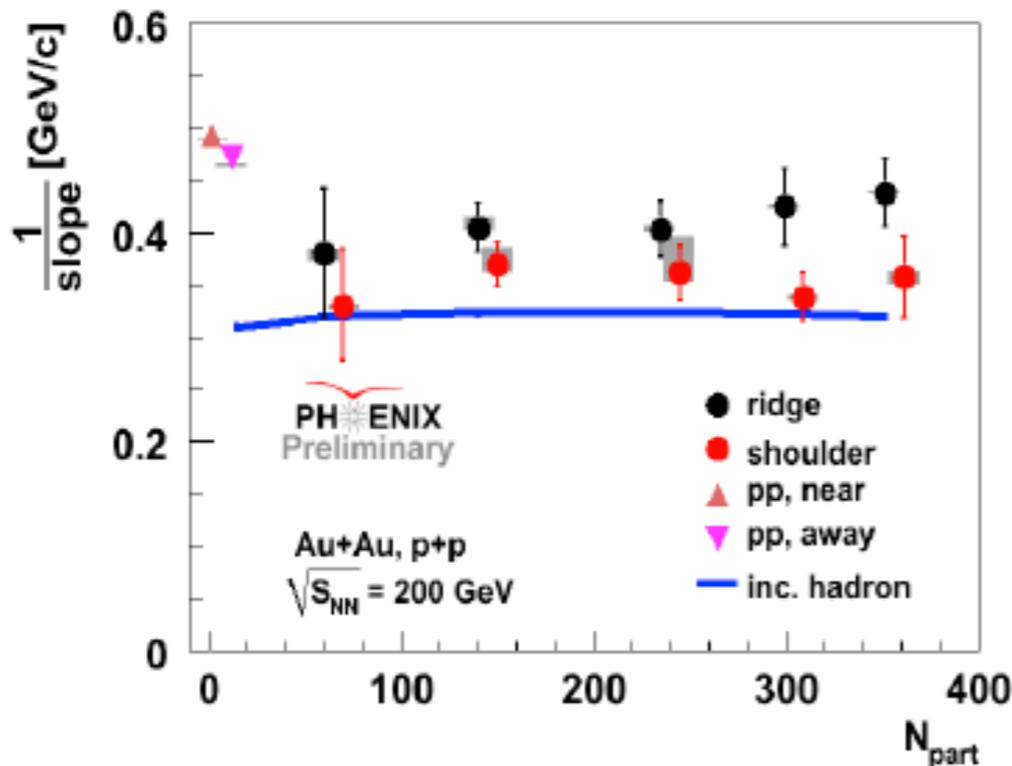
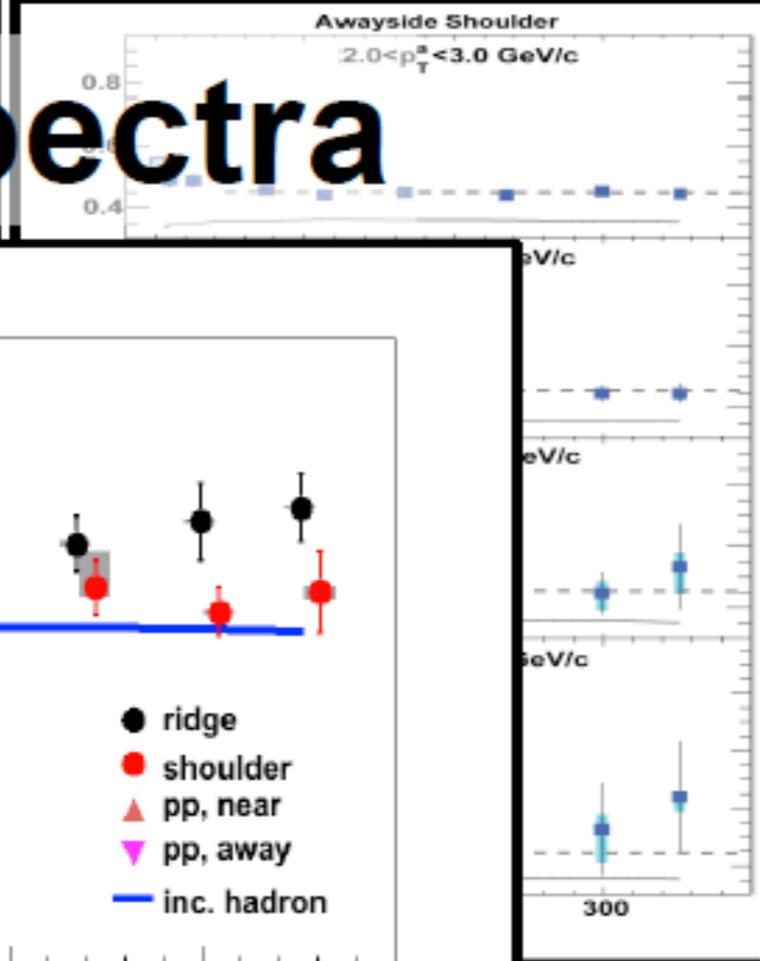
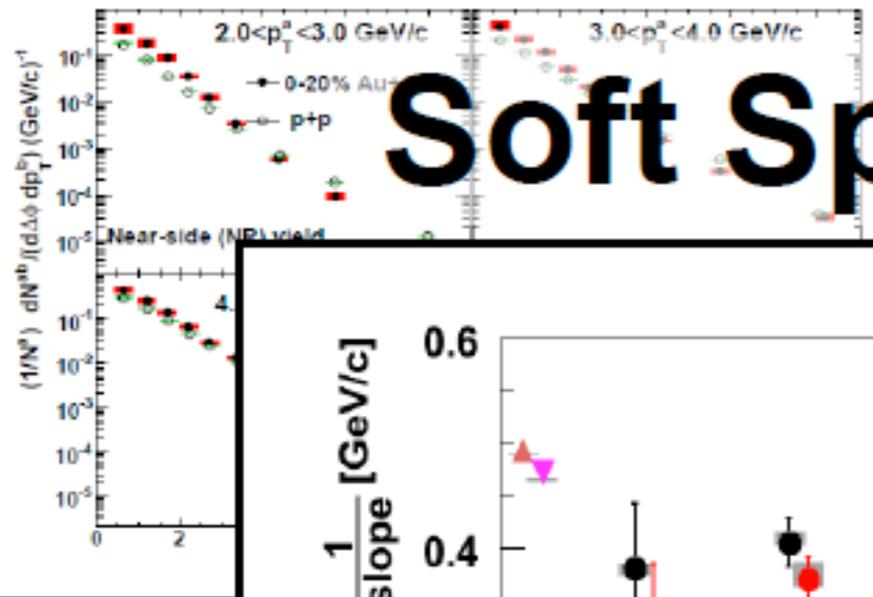
- Intermediate  $p_T$  p+p near-side is narrower in  $\Delta\eta$  than central collisions



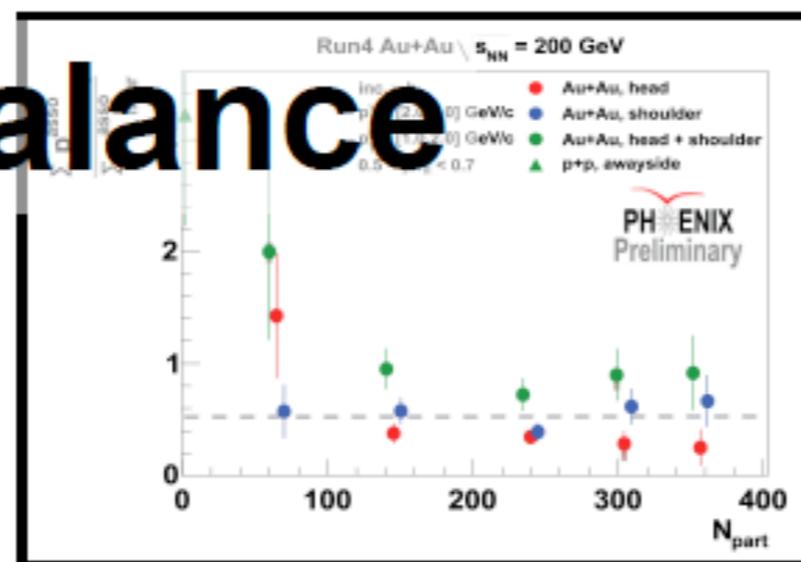
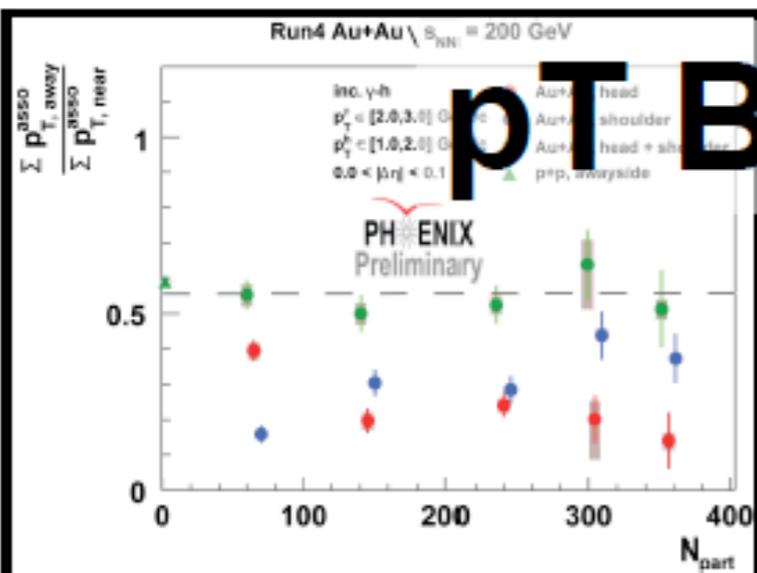
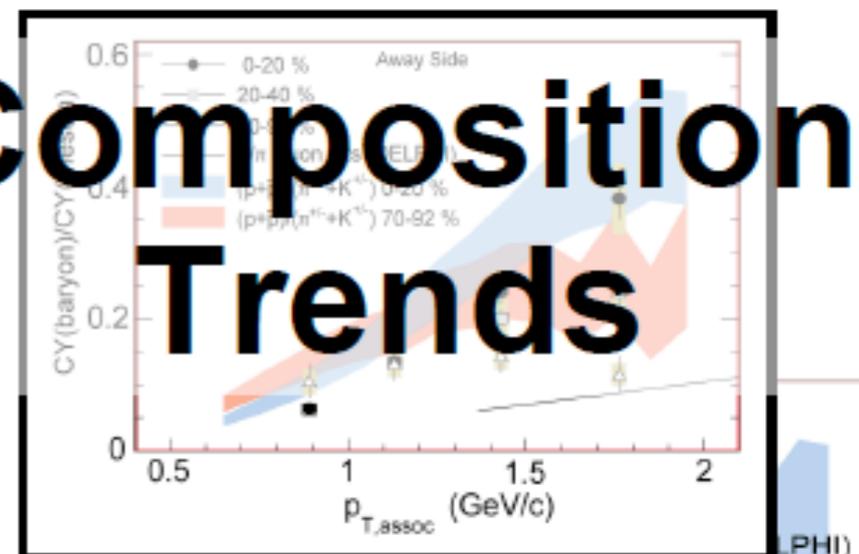
- At intermediate  $p_T$ , little p-p jet beyond  $\Delta\eta > 0.5$

# Many Similarities

## Soft Spectra



## Composition Trends



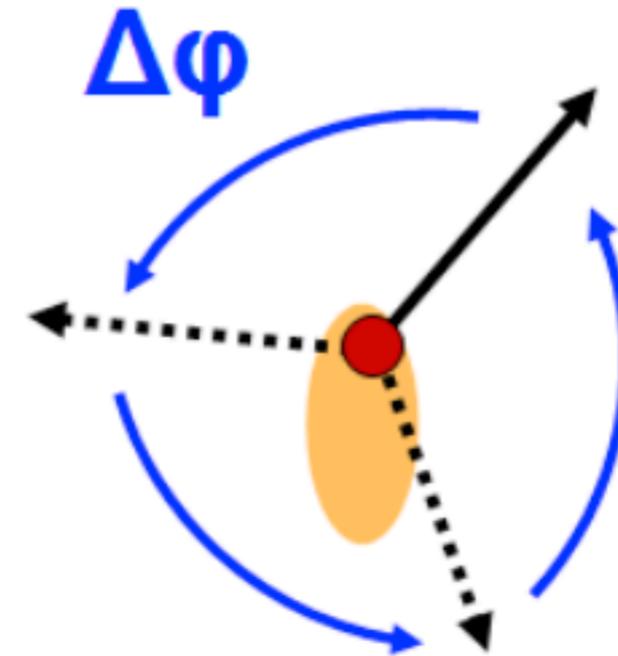
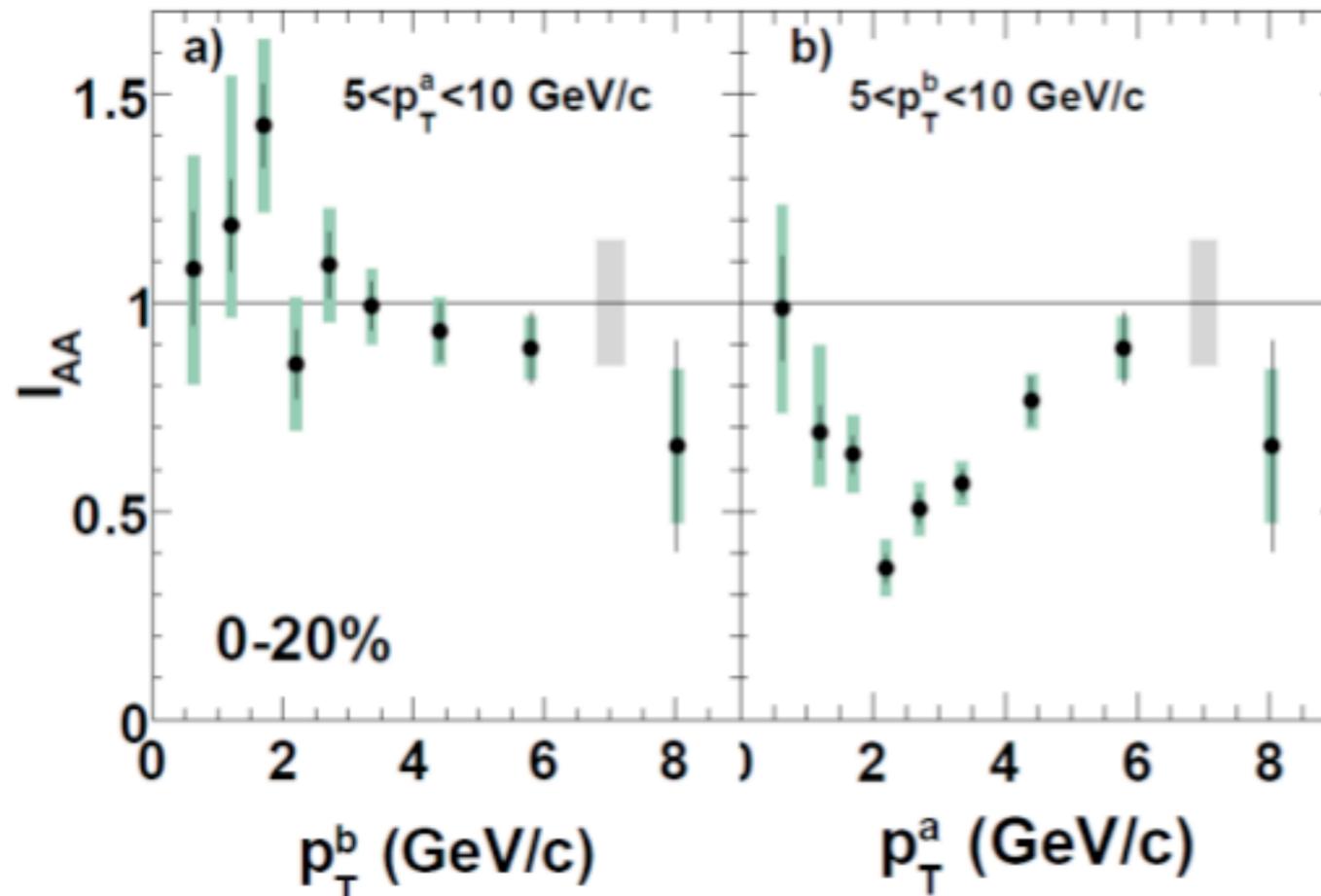
McCumber, QM08

Chen, HP08

# Intermediate $p_T$ Triggers

-  $I_{AA}$  trigger-partner anti-symmetry indicates not all triggers at intermediate  $p_T$  are jet fragments

- Some could be from the medium response itself



- 120 deg is a special angle
- Two-sided shoulder mechanisms could create structures at  $\Delta\phi = 0$  and  $\Delta\phi = \pi \pm 1.1$

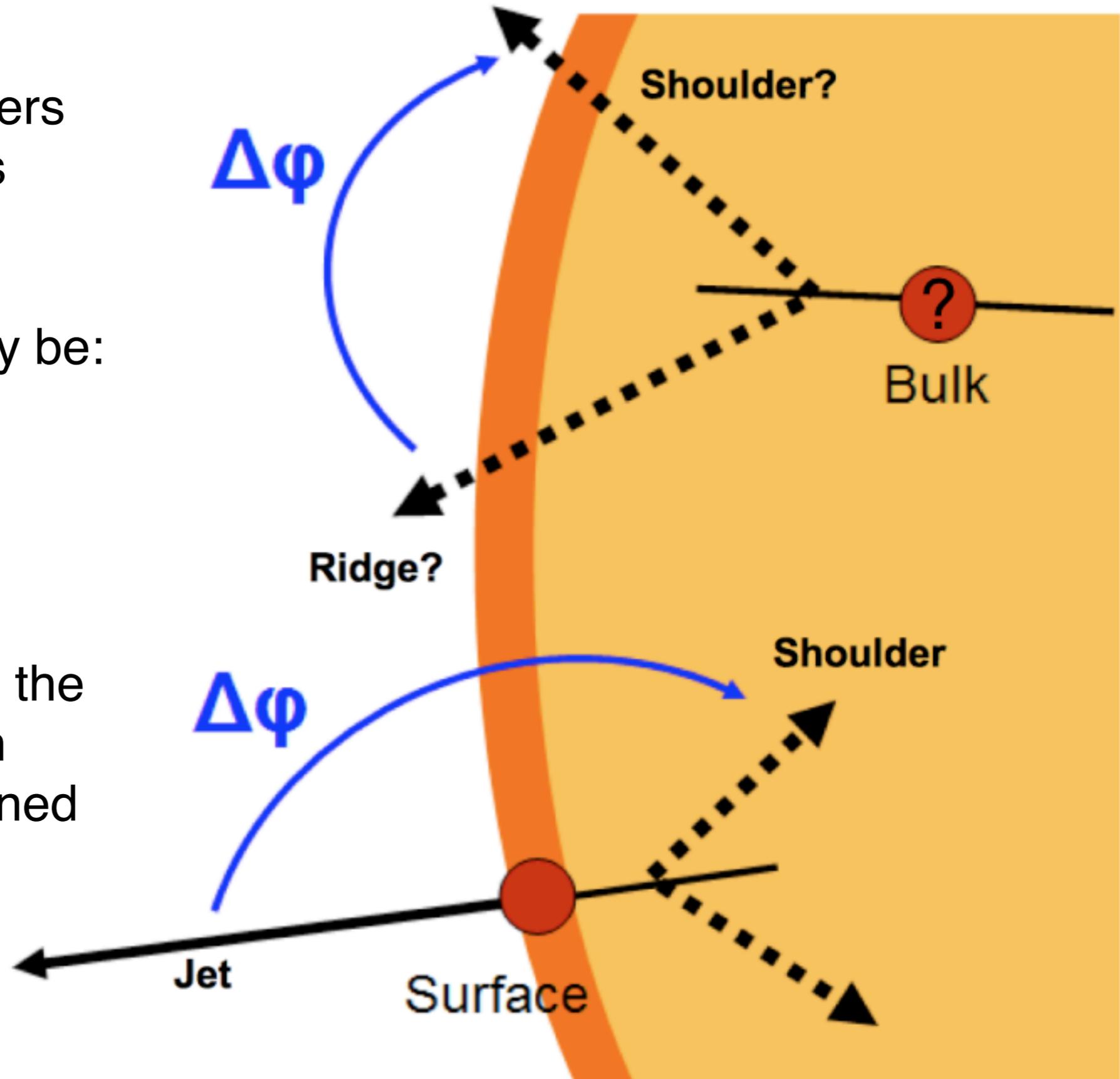
# Medium Response Triggers

Non-fragmentation triggers significantly complicates interpretation

Ridge and Shoulder may be:

- jet-correlated
- self-correlated

Medium Response from the bulk and Recombination effects should be examined



## High $p_T$ - Energy Loss

Away-side partons:

- additional path length = more suppression

Surviving partons have:

- crossed the overlap
- lost little energy

## Intermediate $p_T$ - Medium Response

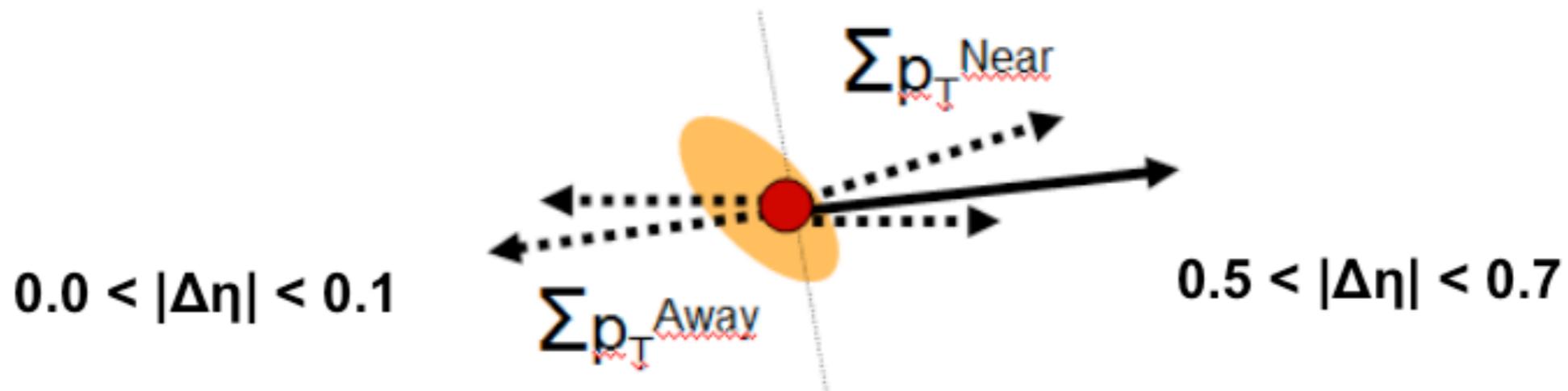
Ridge and Shoulder share many properties  
and possibly a production mechanism

May not be jet correlated

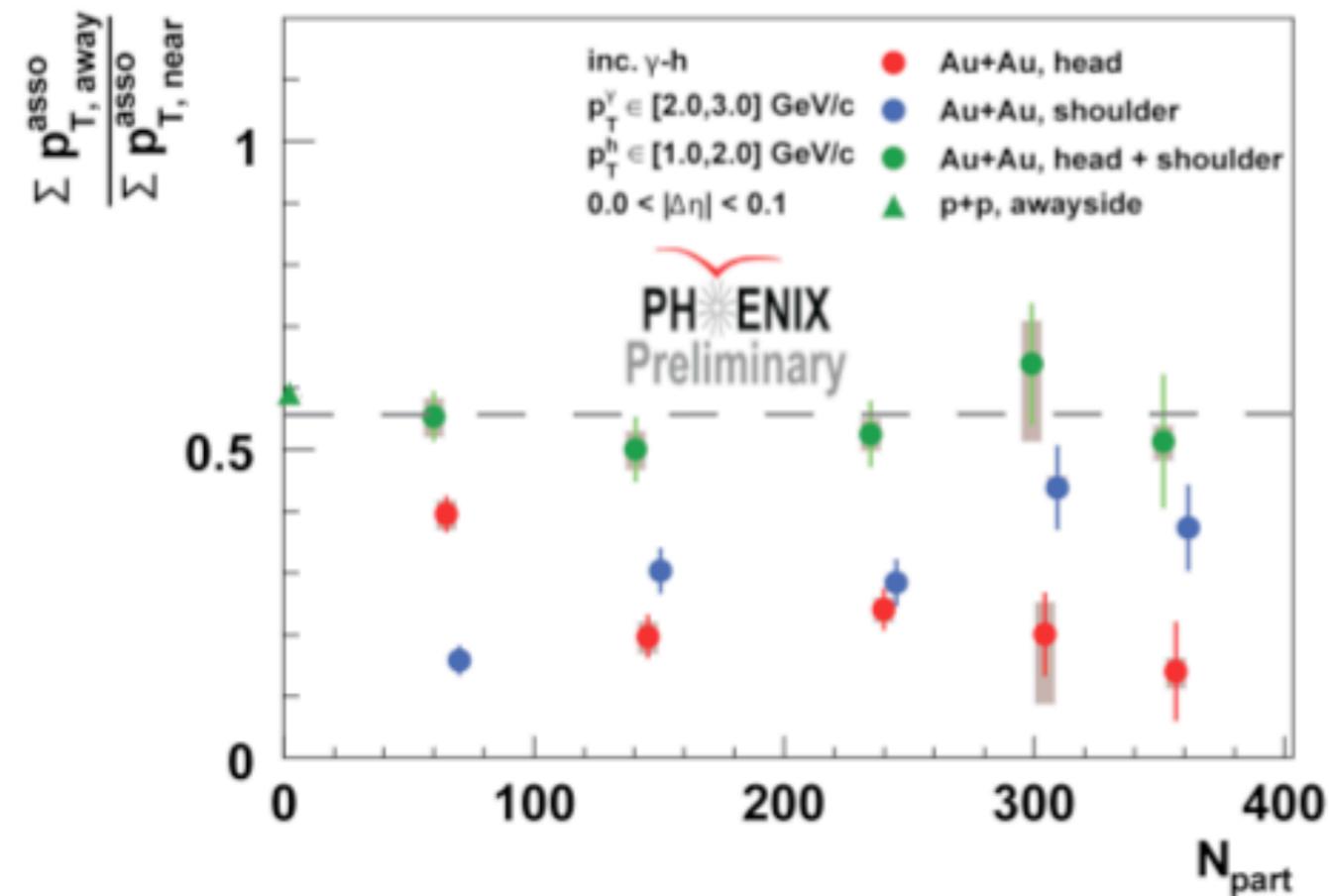
An aerial photograph of a forested landscape. The image shows a large, irregularly shaped clearing or field in the center, surrounded by dense forest. The clearing is lighter in color, possibly due to a different vegetation type or a field. The forest is dark green and covers the majority of the area. The text "Extra Slides" is overlaid in the center of the image.

# Extra Slides

# Ridge & Shoulder Balance

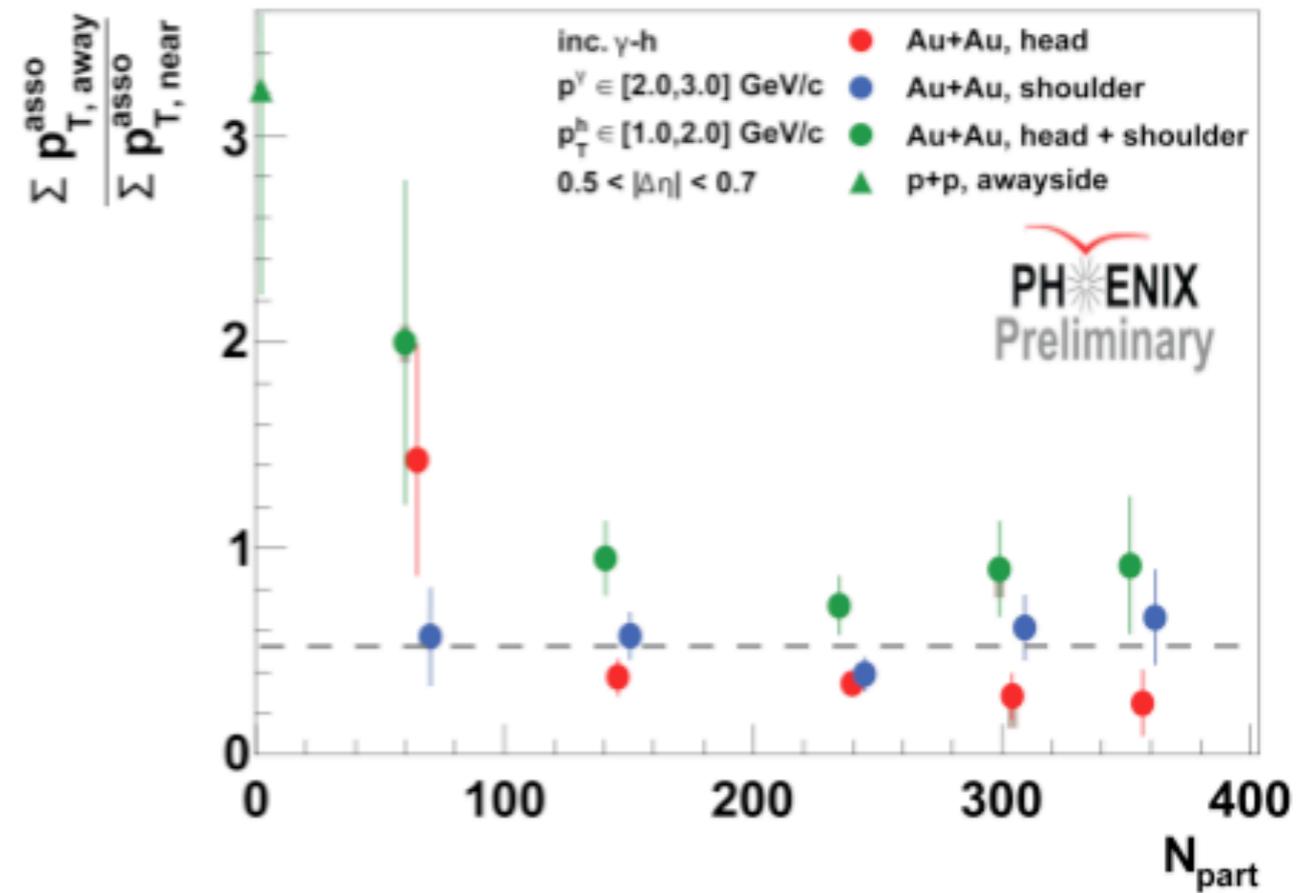


Run4 Au+Au  $\sqrt{s_{NN}} = 200$  GeV



Jet + Ridge balances Shoulder + Head

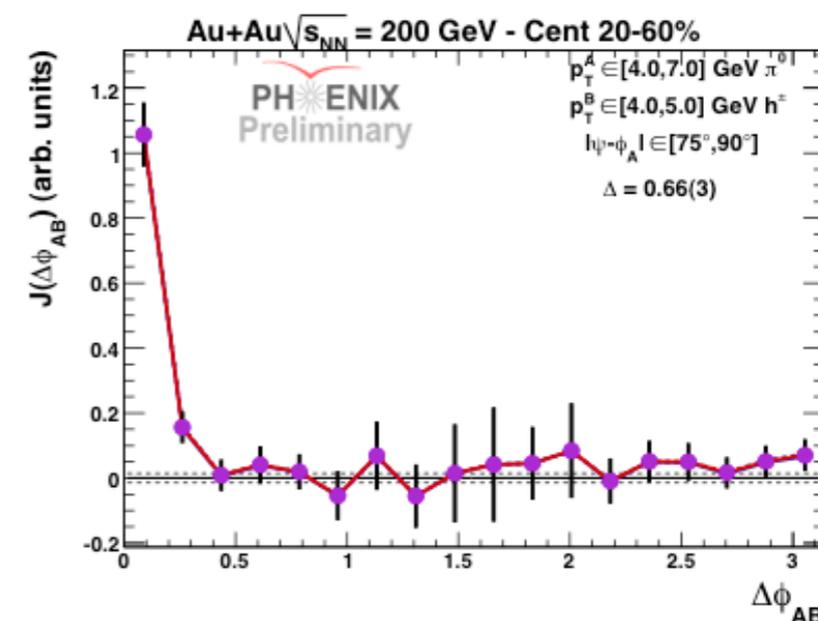
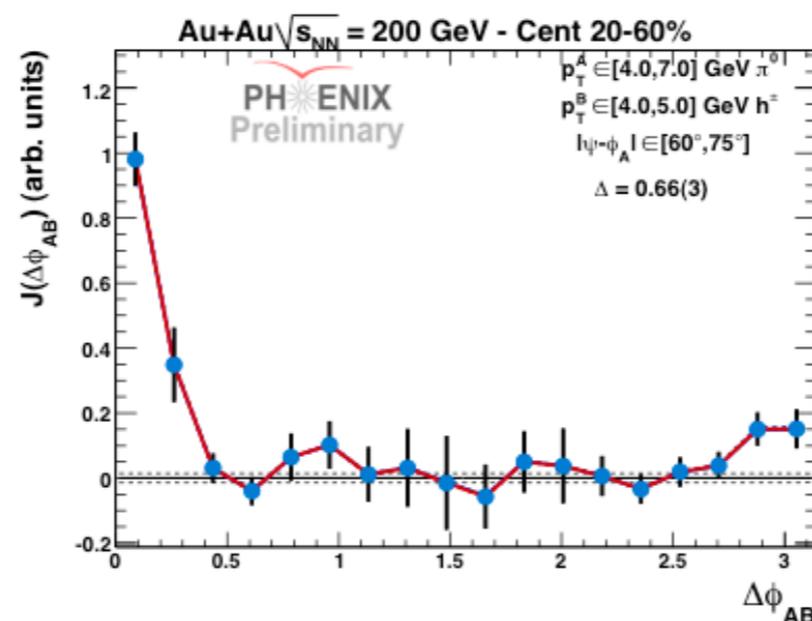
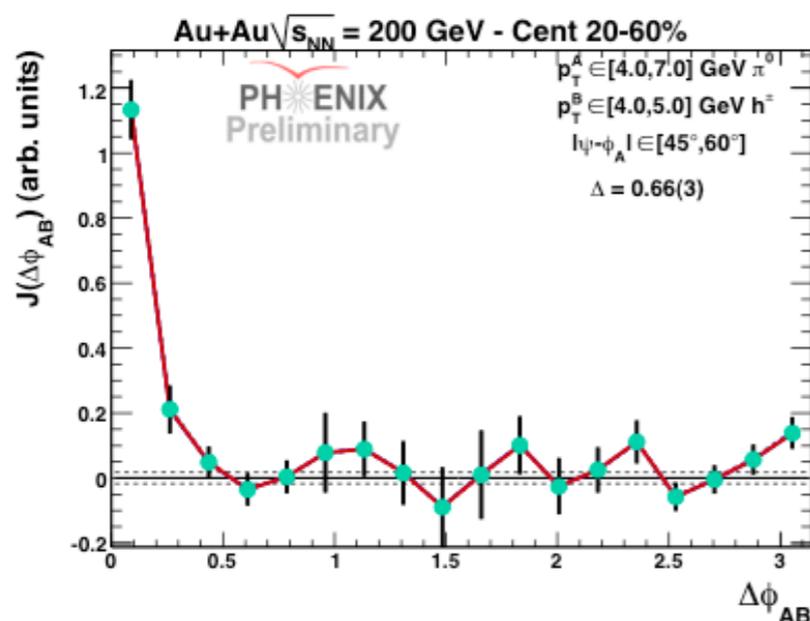
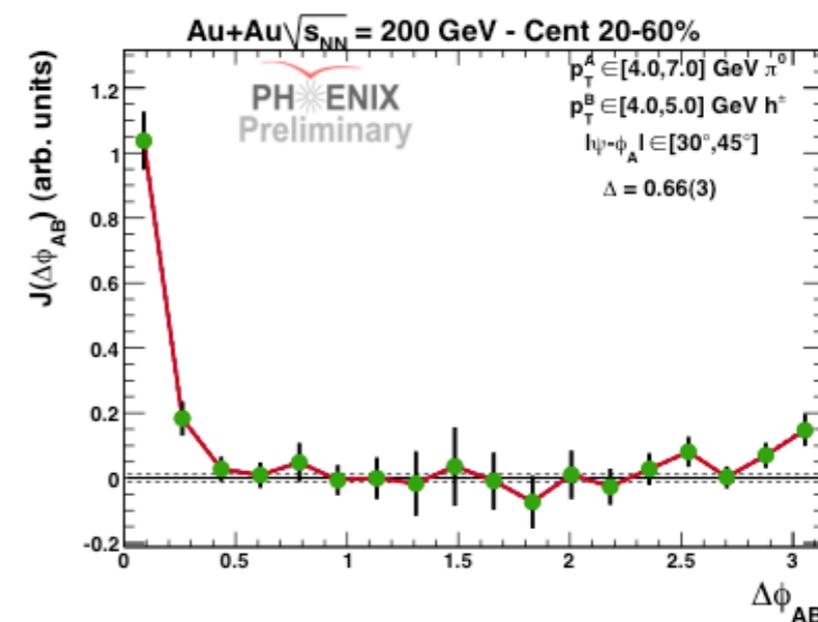
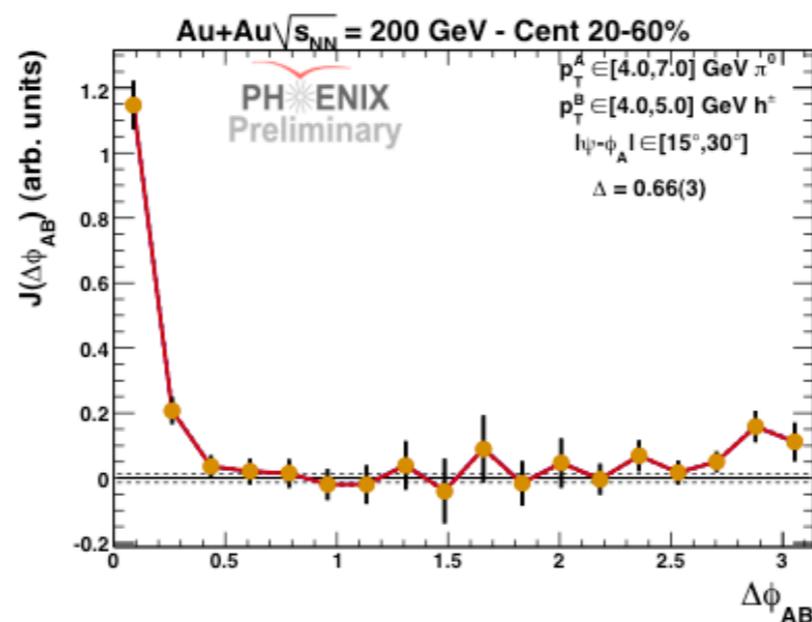
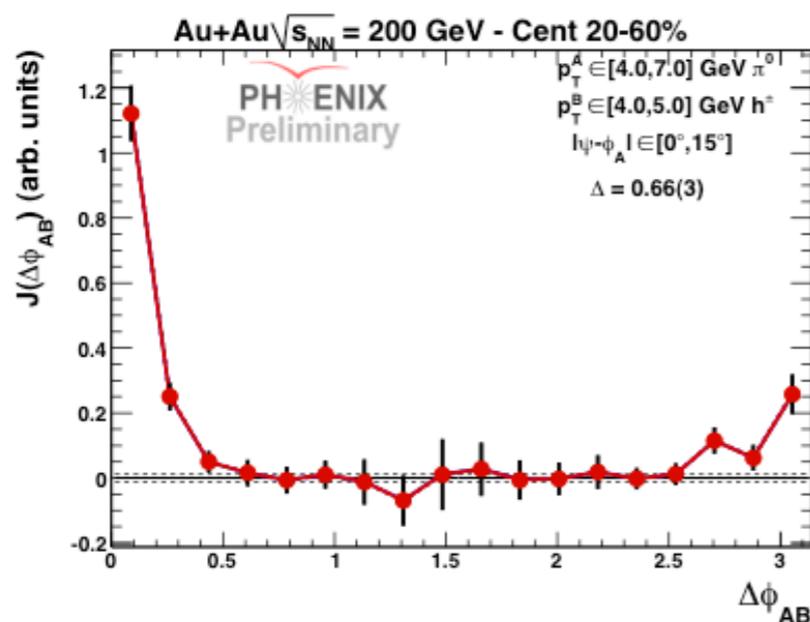
Run4 Au+Au  $\sqrt{s_{NN}} = 200$  GeV



Ridge balances Shoulder!

# Jet Functions - Full Set @ 4-5 GeV/c

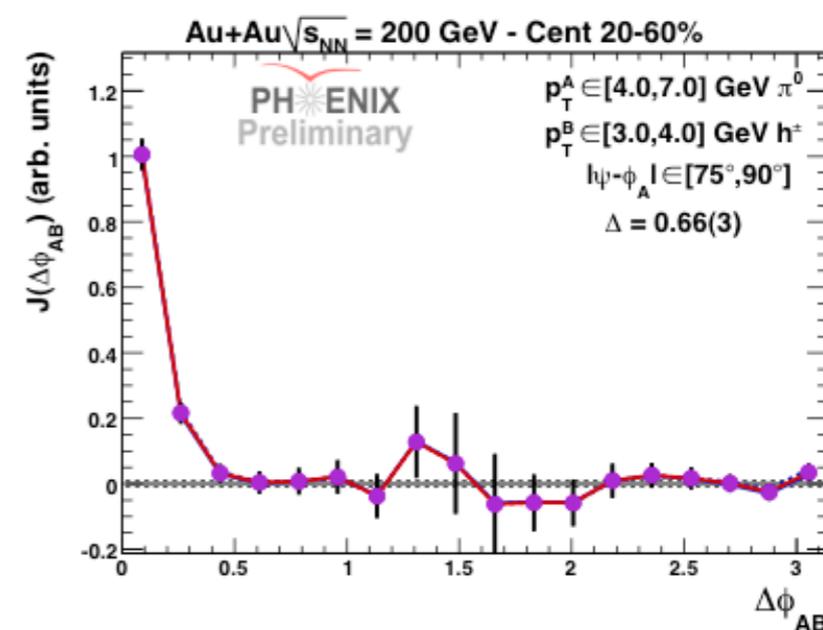
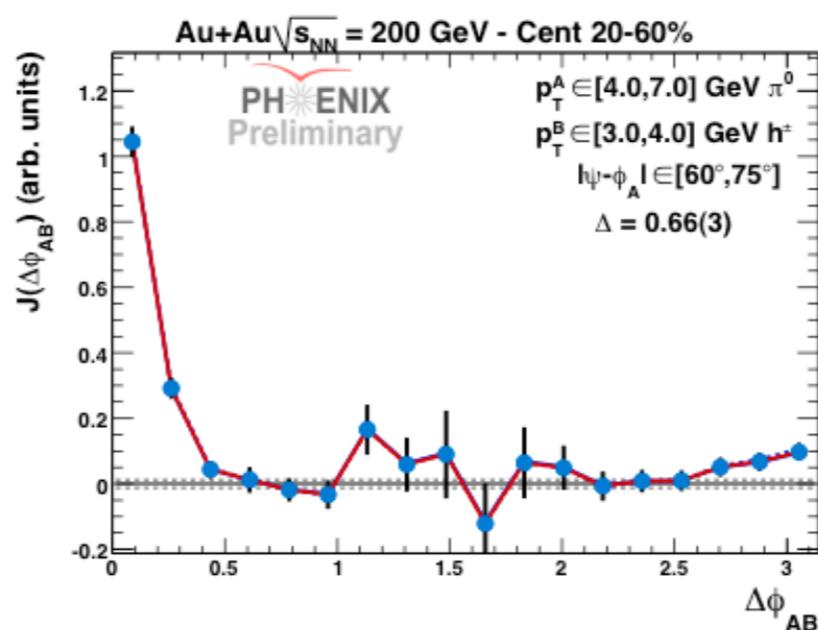
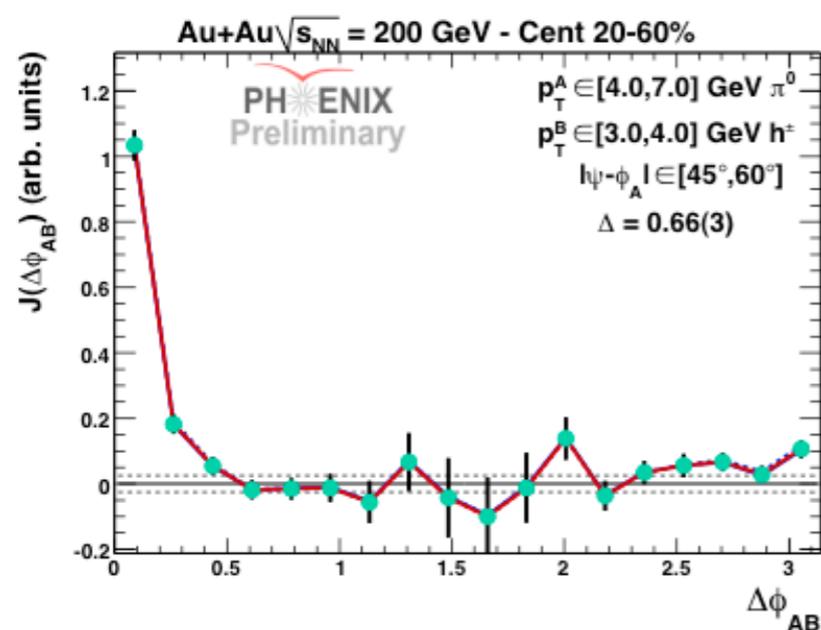
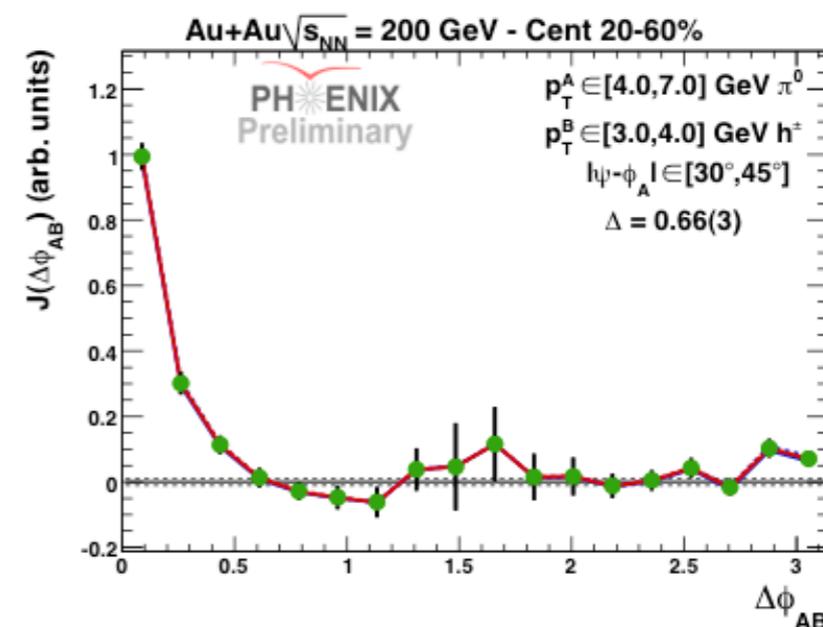
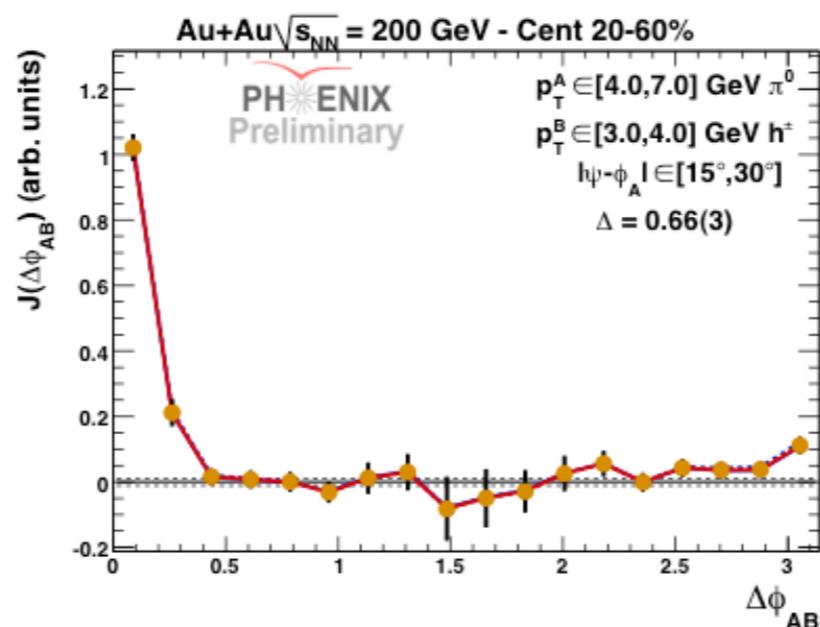
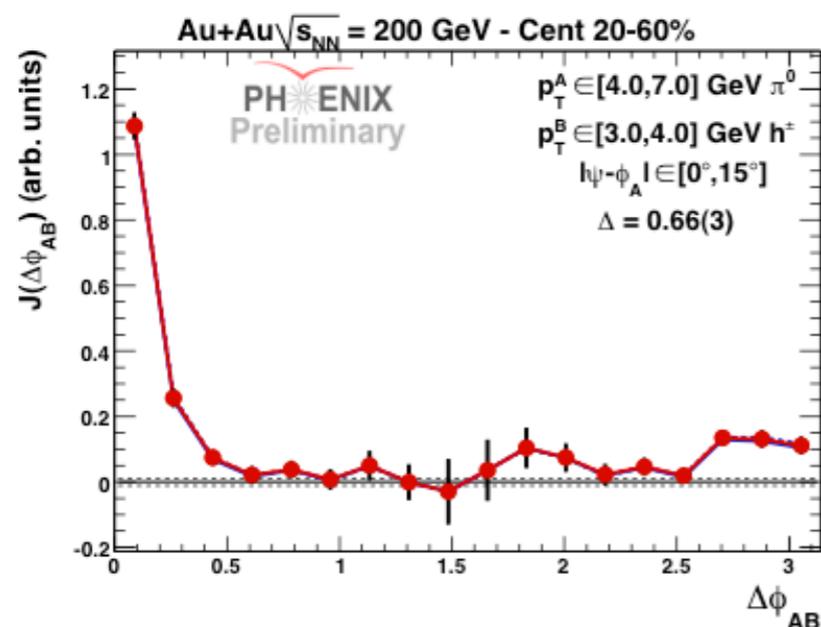
most  
in-plane



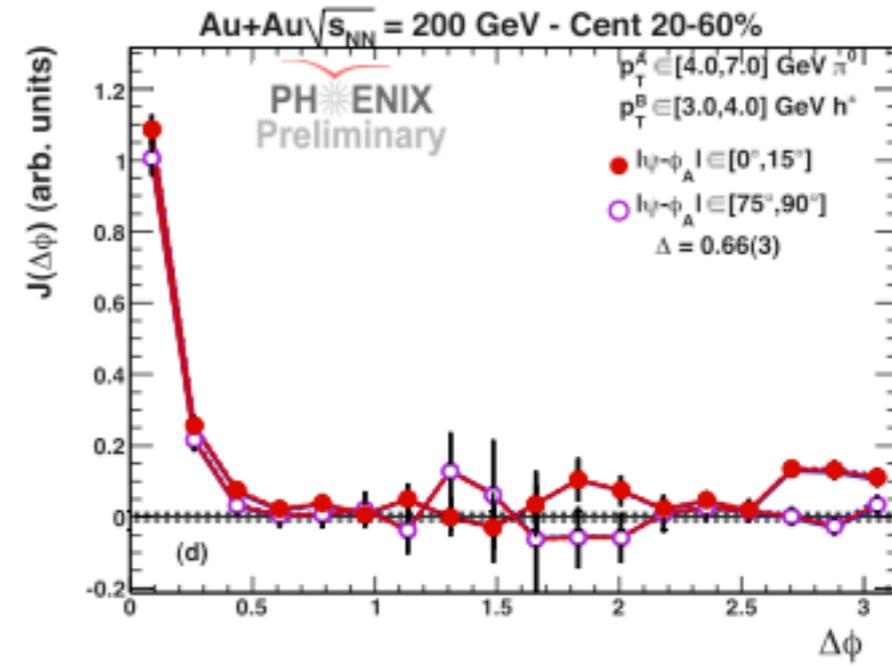
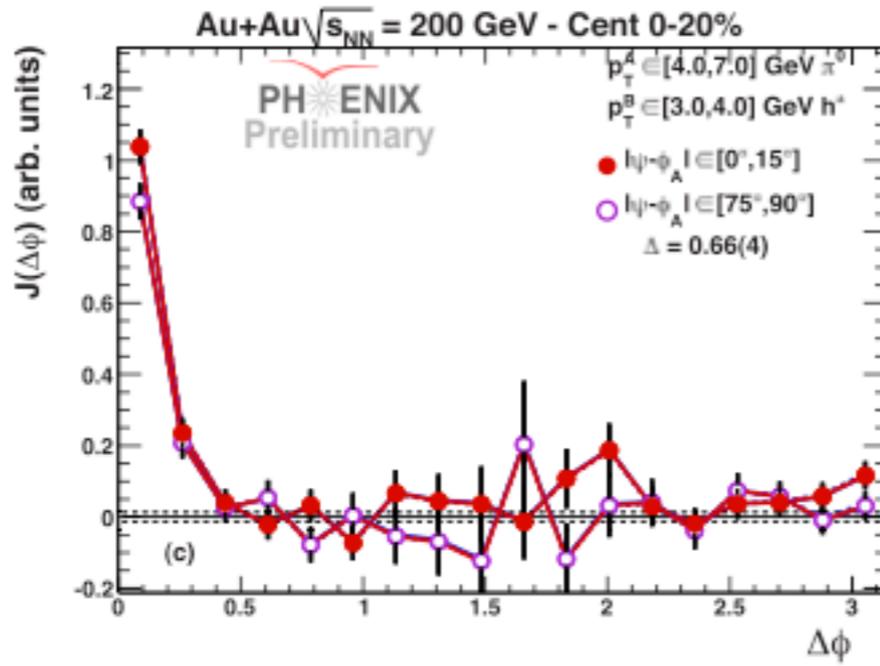
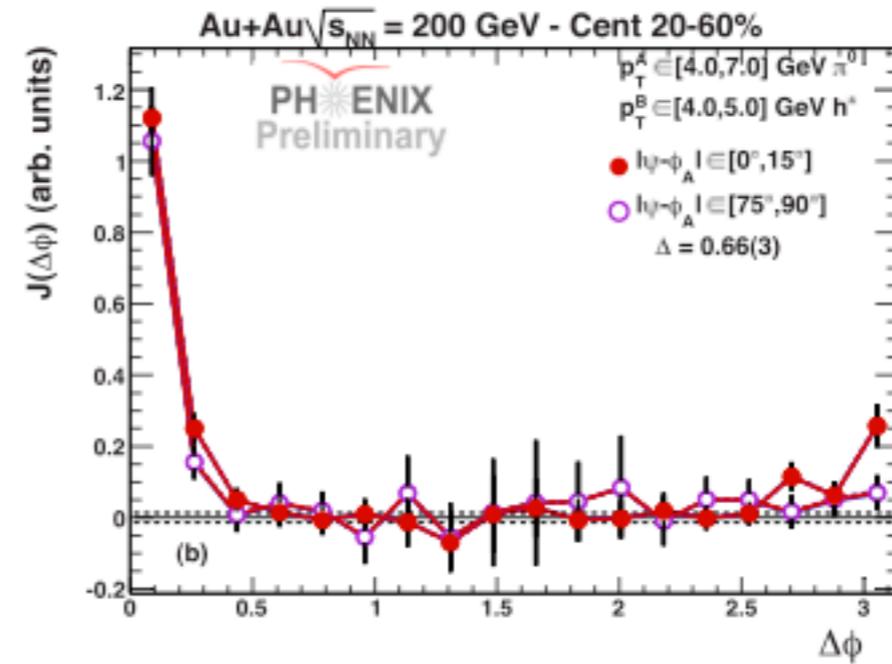
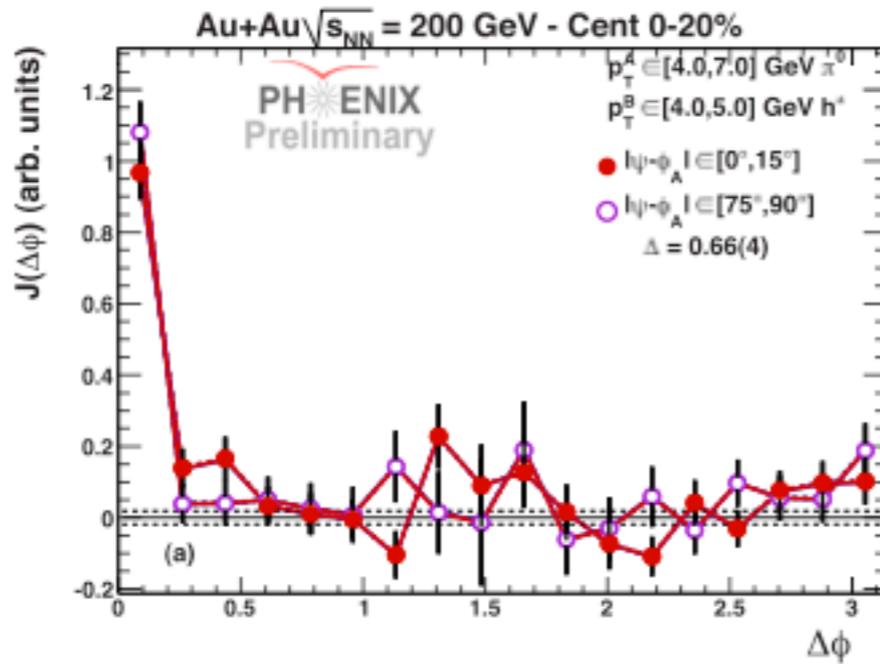
most  
out-of-plane

# Jet Functions - Full Set @ 3-4 GeV/c

most  
in-plane



most  
out-of-plane



# Arb. Scale Definition

