Experimental Overview of Two-Particle Correlations

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Questions of Interest

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  - Weak-coupling (pQCD)
  - Strong-coupling (AdS/CFT)
- What are the medium properties?
  - $\hat{q}$, so λ or σ
  - c_s, n, quasi-particle states

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- What is the mechanism of energy loss?
  - Study parton modification after traversing a colored medium
    - Study jets and their modification
    - Study jet fragments and their modification
- What are the medium properties?
  - Determine how the medium responds to the passage of a jet

Why Two-Particle Correlations?

- Jets are more ideal but difficult
  - You have to deal with the underlying event that flows, fluctuates, and is large.
  - We will hear how to deal with this at the end of the day.

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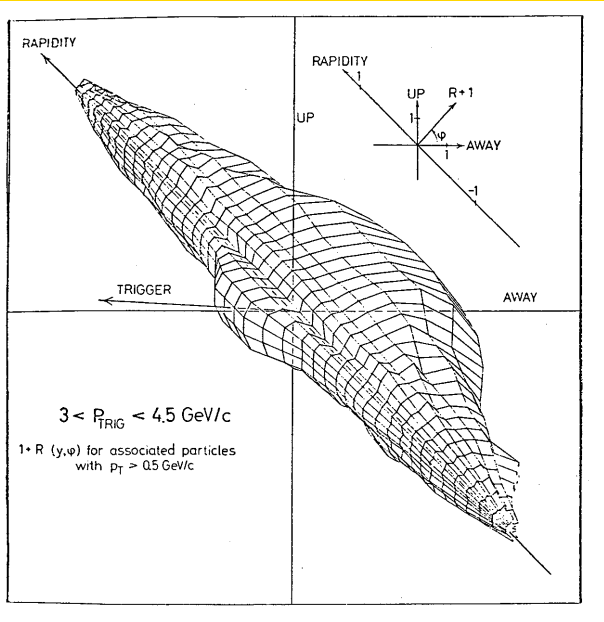
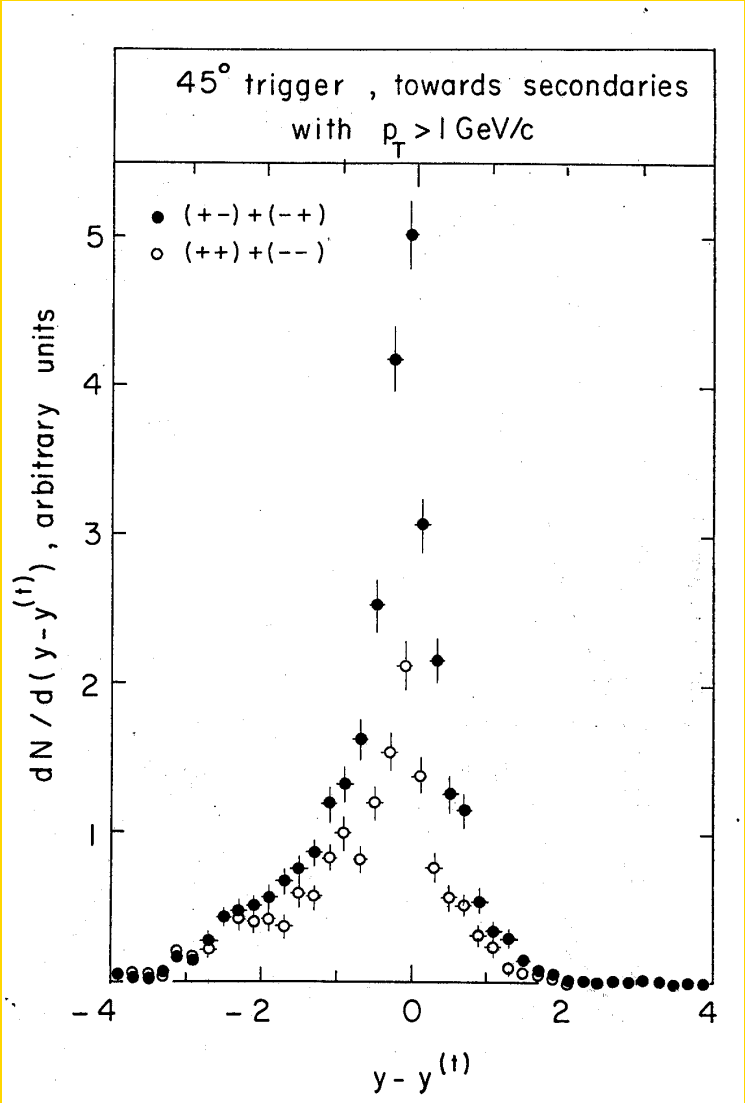
- Legacy
  - First jet-like measurements at RHIC
  - First jet-like measurement in the 1970's

Two-Particle Correlation Legacy

- Experiments at the CERN ISR used two particle to search for evidence of jets in hadronic collisions



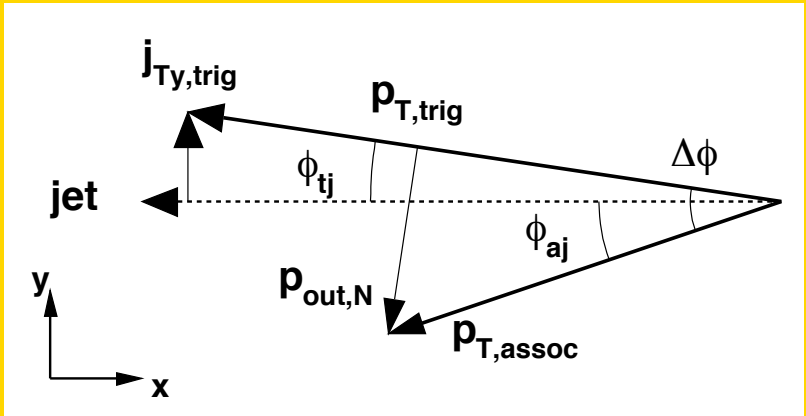
BFS Collaboration *Nucl. Phys.* **B145**, 305 (1978)

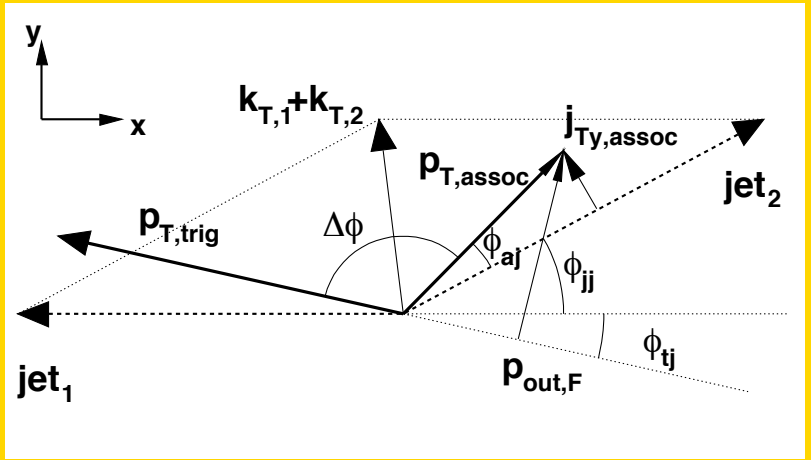


CCHK Collaboration *Nucl. Phys.* **B127**, 1 (1977)

Two-Particle Correlation Legacy

- Hadronic observables can be related to partonic observables...





$$\left\langle p_{out,N}^2 \right\rangle = \left\langle p_{T,assoc}^2 \sin^2(\Delta\phi) \right\rangle = \left\langle j_{Ty}^2 \right\rangle + \left\langle \frac{p_{T,assoc}^2}{p_{T,trig}^2} j_{Ty}^2 \right\rangle$$

$$\left\langle p_{out,F}^2 \right\rangle = \left\langle p_{T,assoc}^2 \sin^2(\Delta\phi^2) \right\rangle = \left\langle 2 z_{assoc}^2 k_{Ty}^2 \right\rangle + \left\langle j_{Ty}^2 \right\rangle$$

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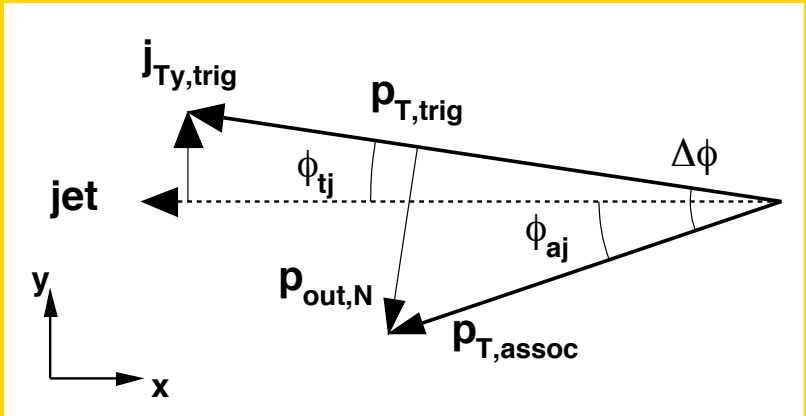

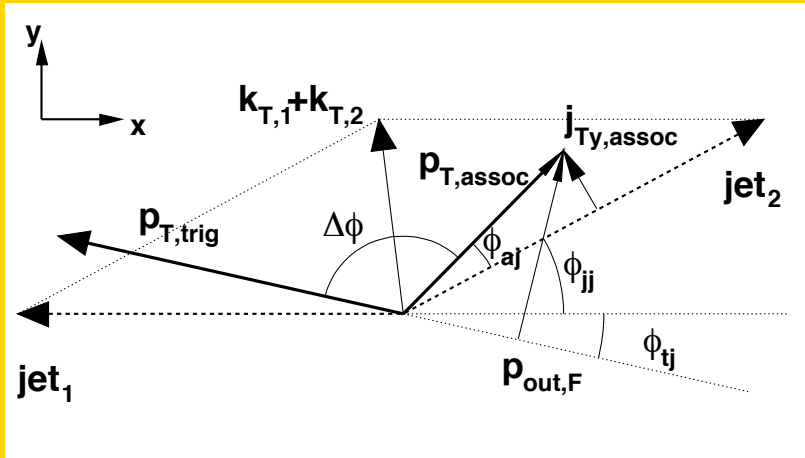

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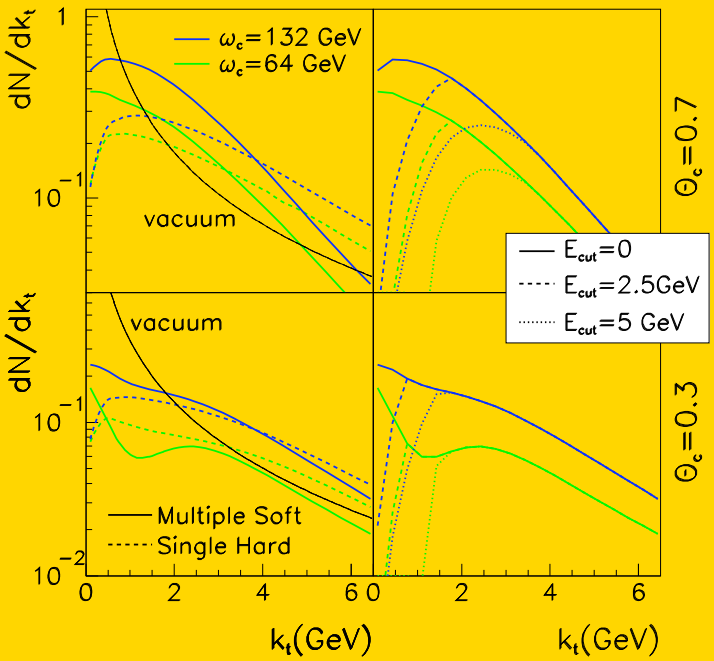
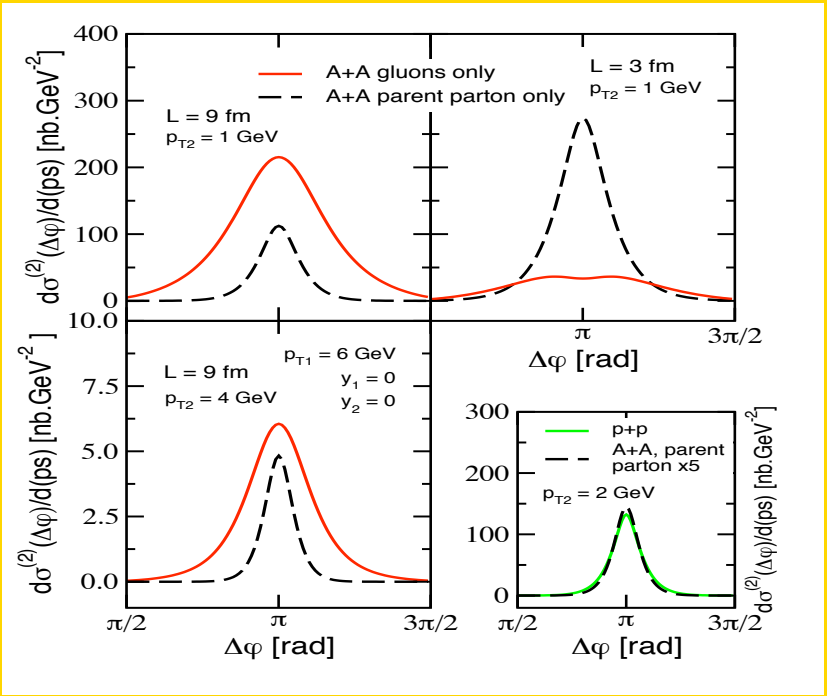
- But you have to average over events, and need to know z_{assoc} ...

Two-Particle Correlation Legacy

- The parton parameters are of interest in jet modification



Salgado, Wiedemann *Phys. Rev. Lett.* **93** 042301 (2004)



Vitev *Phys. Lett.* **B630** 78 (2005)

- Single jet broadening
  - $-dE/dx = \alpha_s N_c j_T^2/8$
  - BDMPS *Nucl. Phys.* **B484** 282 (1997)
- Di-jet broadening from multiple scattering
  - $\langle k_T^2 \rangle_{A+A} - \langle k_T^2 \rangle_{p+p} = \hat{q}L$
  - BDMS *Phys. Rev.* **C60** 064902 (1999)

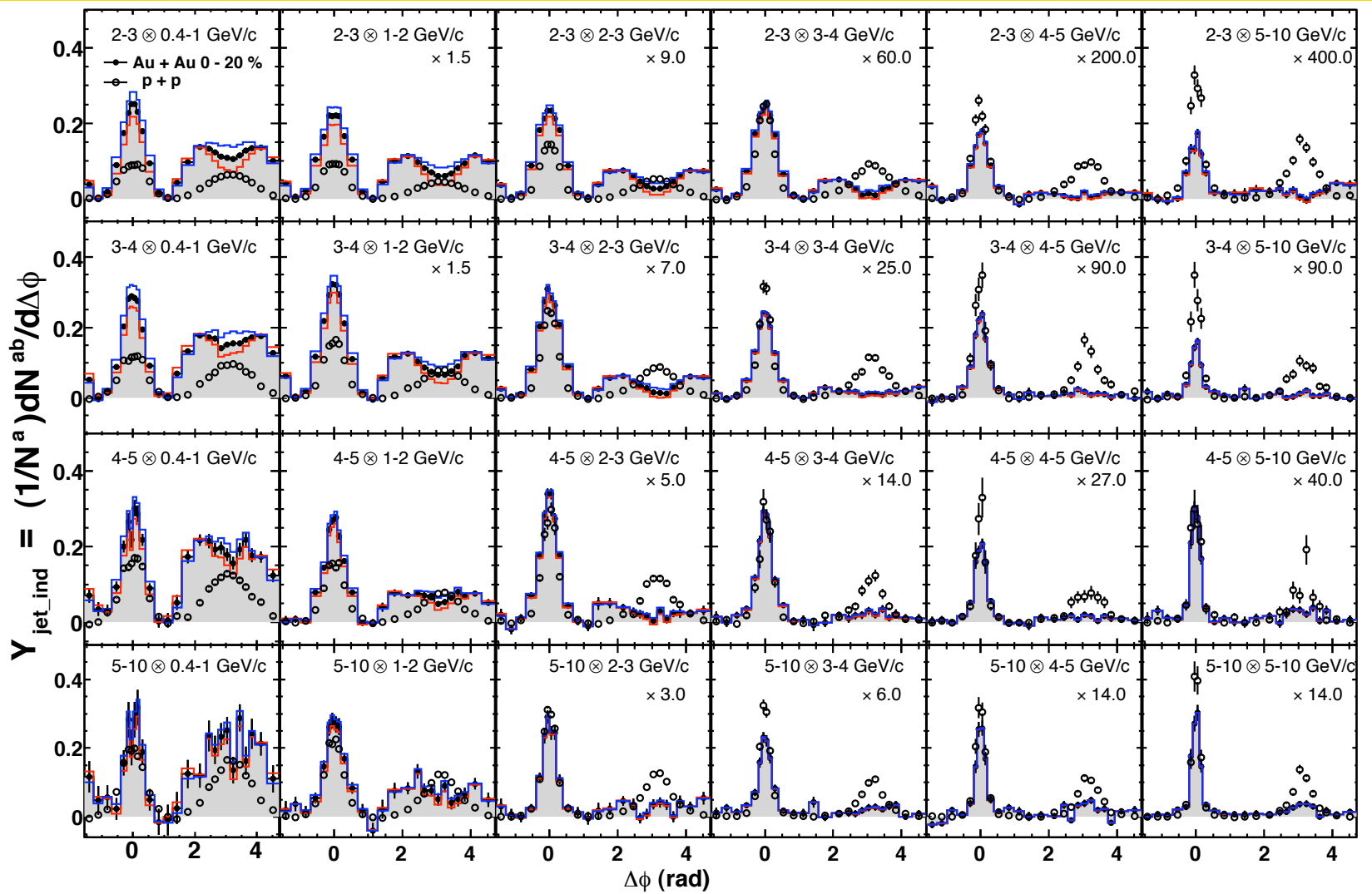
Summary of Unidentified Charged Hadron Correlations

00-20% Au+Au (closed) and p+p (open)

$p_{T,assoc} \rightarrow$

PHENIX *Phys. Rev.* **C78** 014901 (2008)

$\leftarrow p_{T,trig}$



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20-40% Au+Au (closed) and p+p (open)

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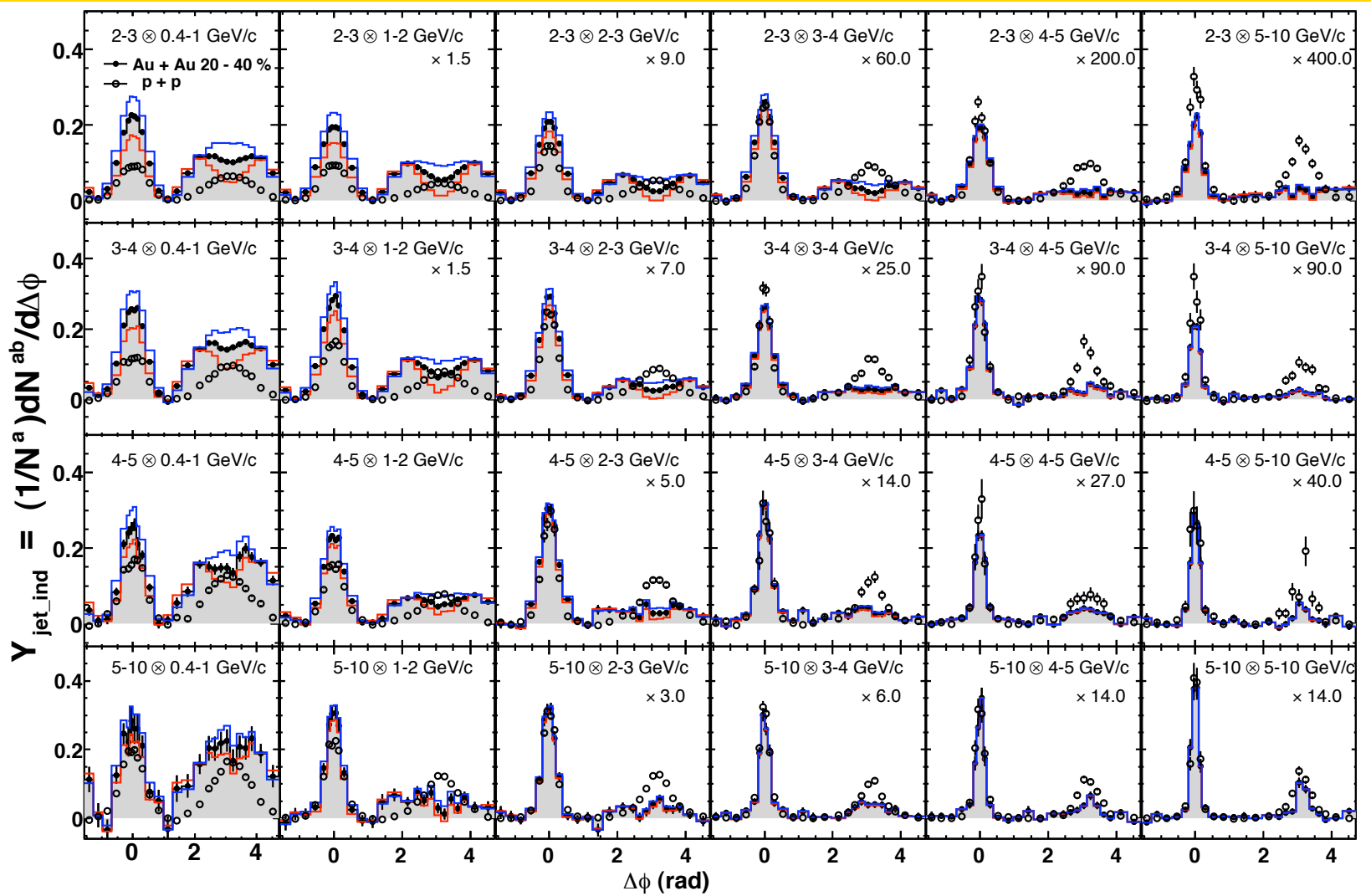

Summary of Unidentified Charged Hadron Correlations

60-92% Au+Au (closed) and p+p (open)

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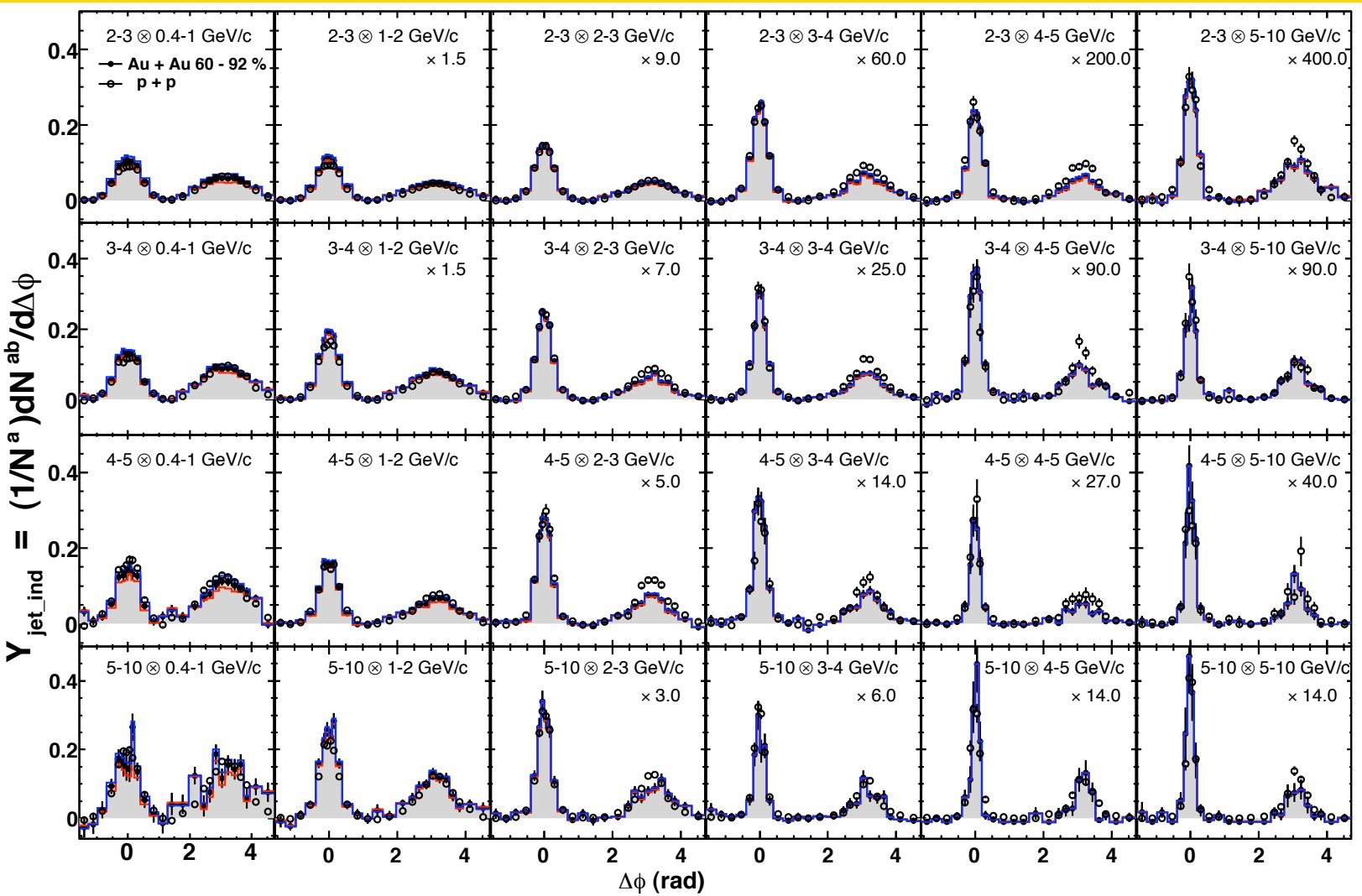
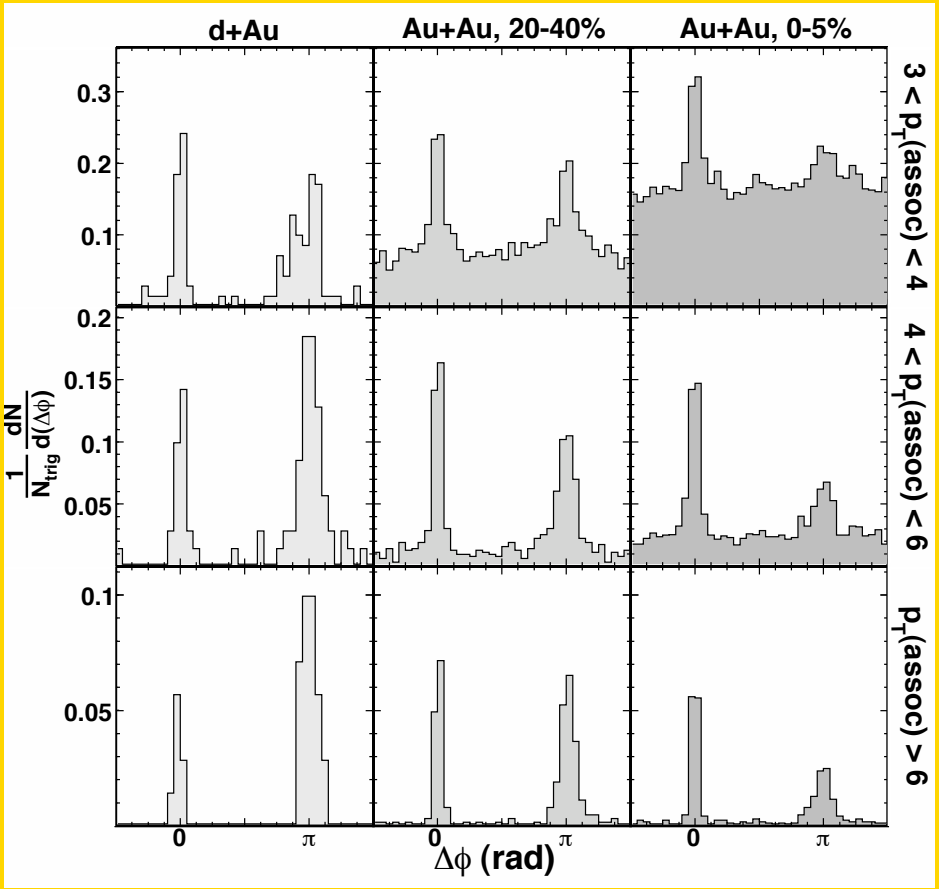


Focus on High-p_T: $h - h$ Widths

- Look first to high-p_T where jets dominate the pairs.
- Trigger h $8 < p_T < 16$ GeV
- Associated: h $p_T > 3$ GeV

STAR *Phys. Rev. Lett.* **97**, 162301 (2006)



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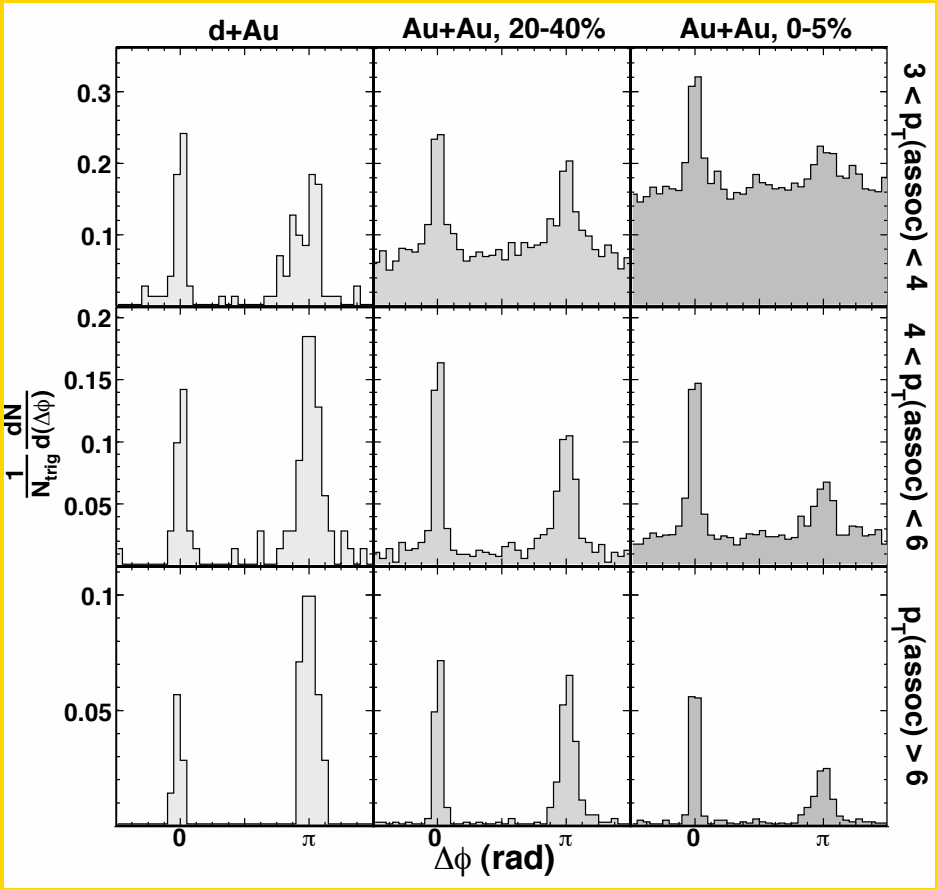
- Widths are show no modification

system	width (rad)
d+Au	0.24± 0.07
20-40% Au+Au	0.20±0.02
0-20% Au+Au	0.22±0.02

STAR *Phys. Rev. Lett.* **97**, 162301 (2006)



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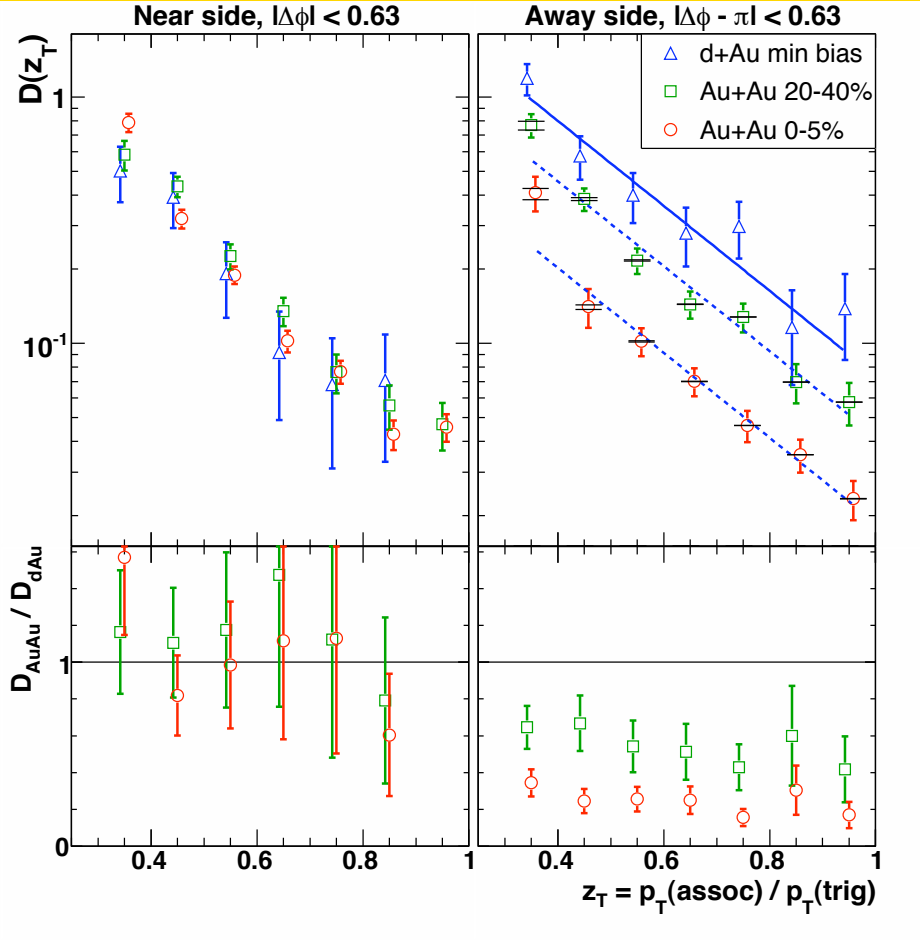

- Comparison of yields in d+Au and Au+Au as a function of $z_T = p_{T,assoc}/p_{T,trigg}$

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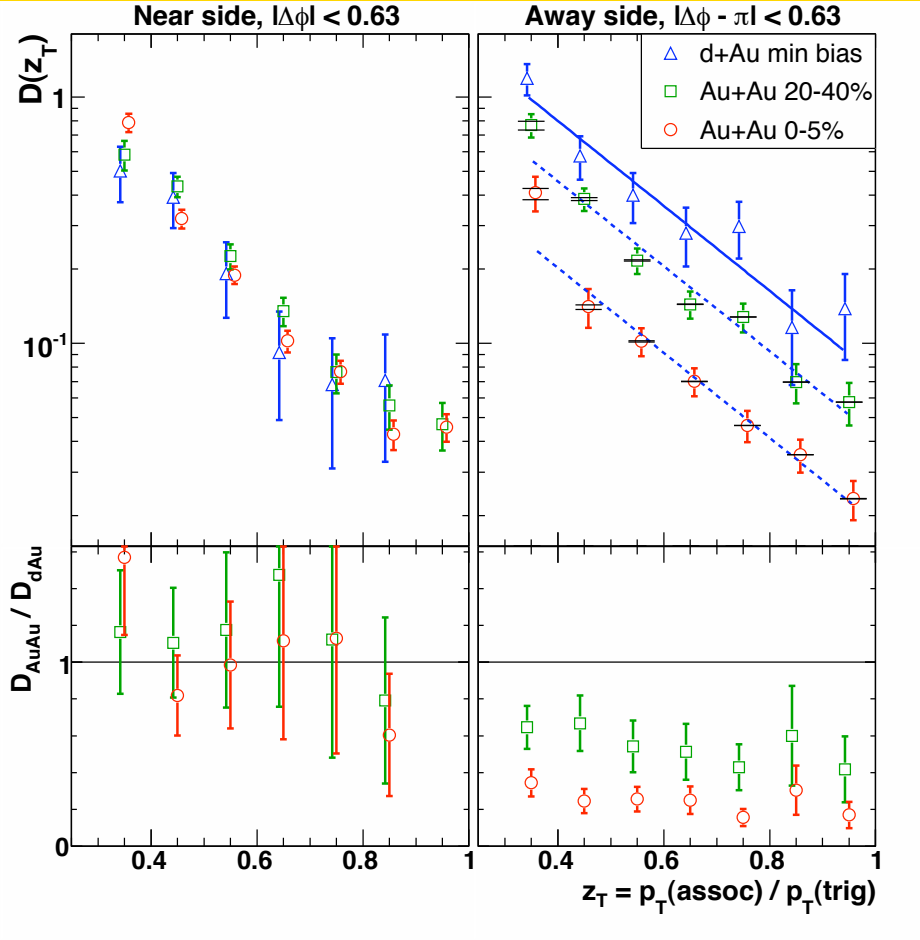

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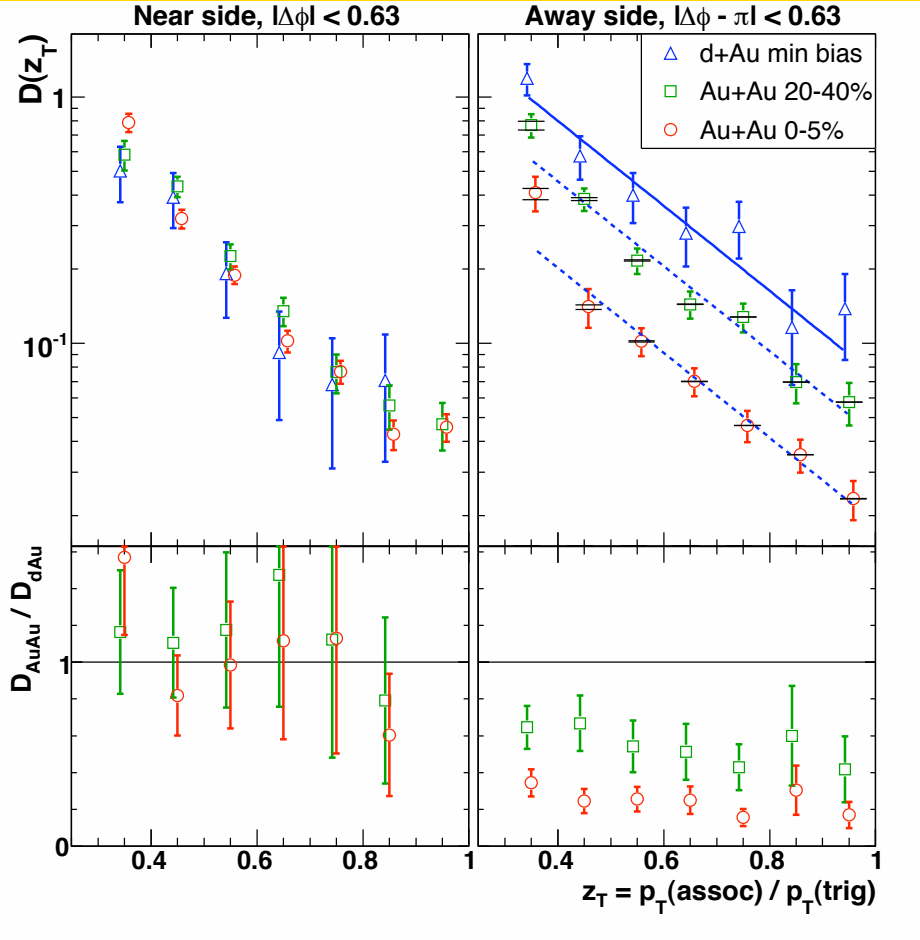

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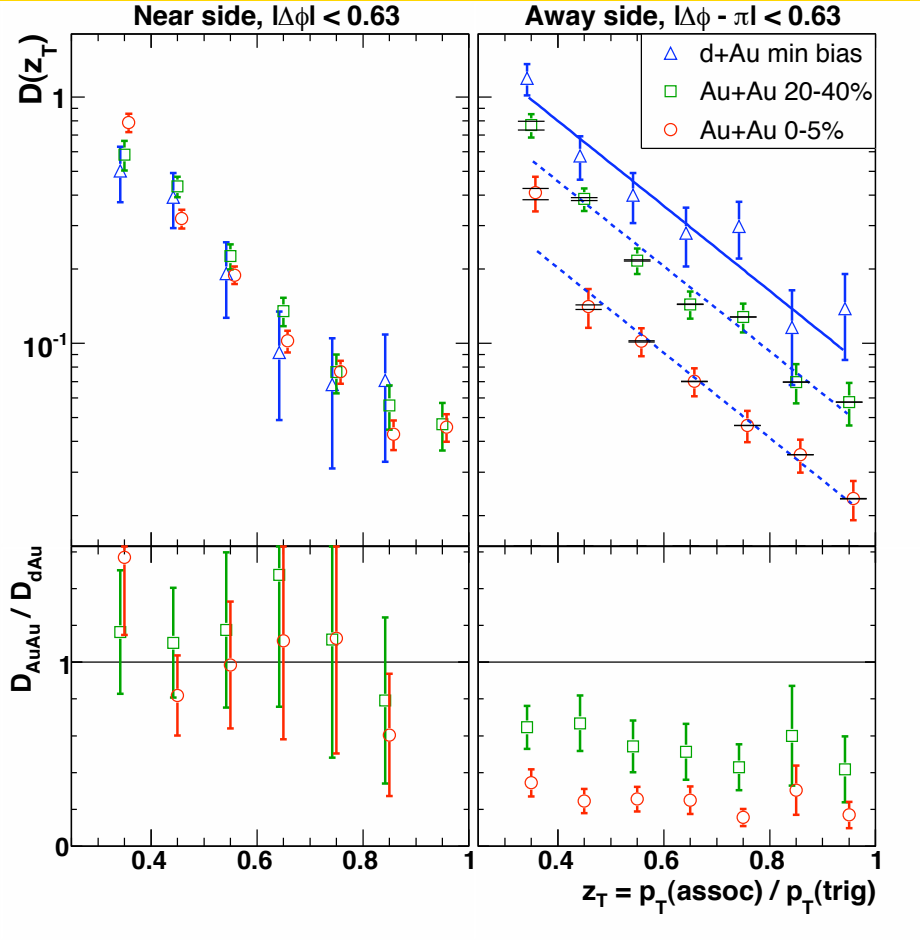

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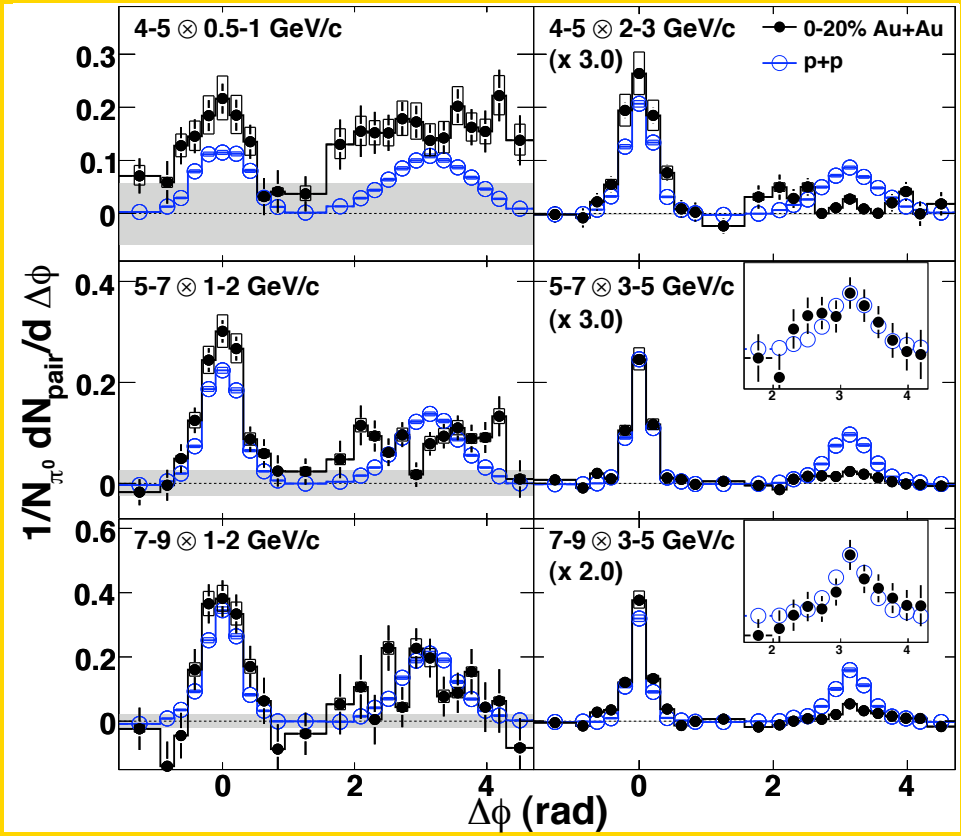
- Away-side yields are suppressed with $I_{AA} \sim R_{AA}$

Focus on High-p_T: $\pi^0 - h$ Correlations

- Study high-p_T in more detail
- Trigger: π^0 $4 < p_T < 12$ GeV
- Associated: h $0.4 < p_T < 10$ GeV

PHENIX arXiv:1002.1077



scaled Au+Au away-side to match p+p at $\Delta\phi = \pi$

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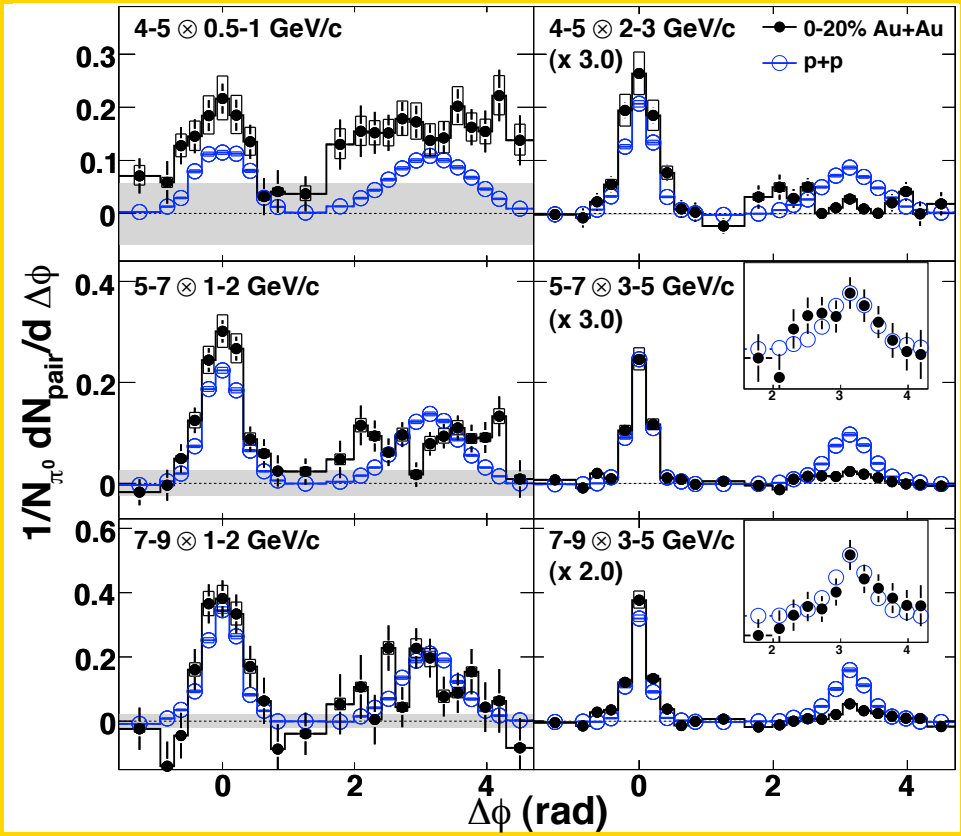

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- Au+Au away-side shape qualitatively similar to $p + p$

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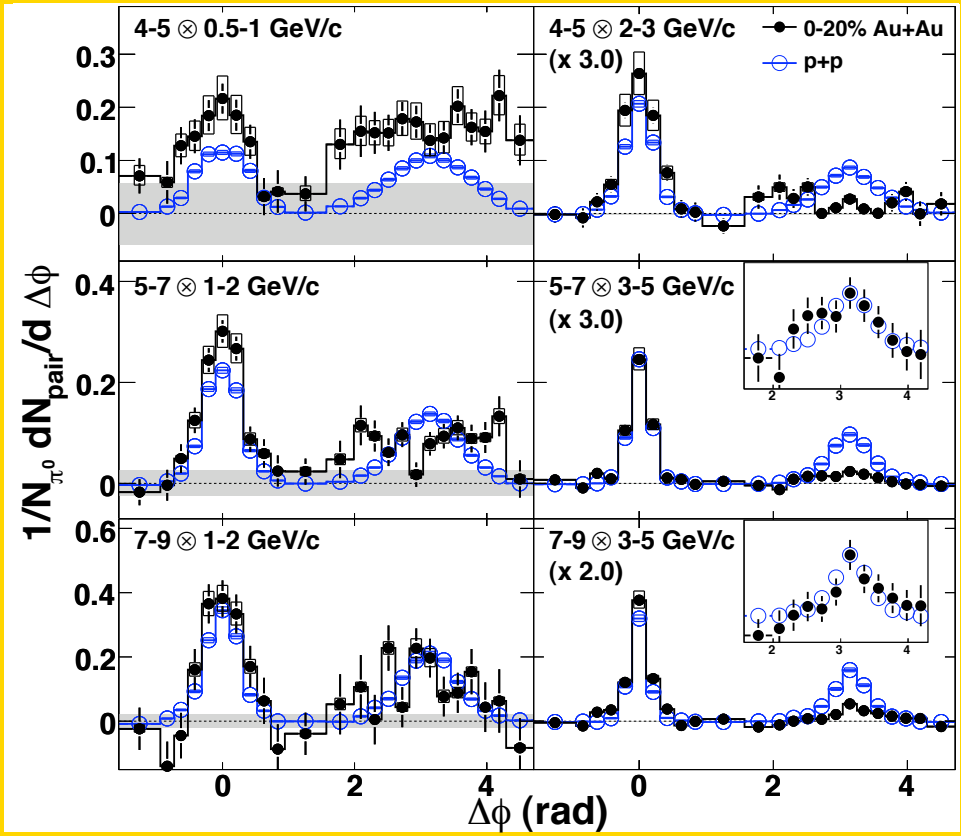

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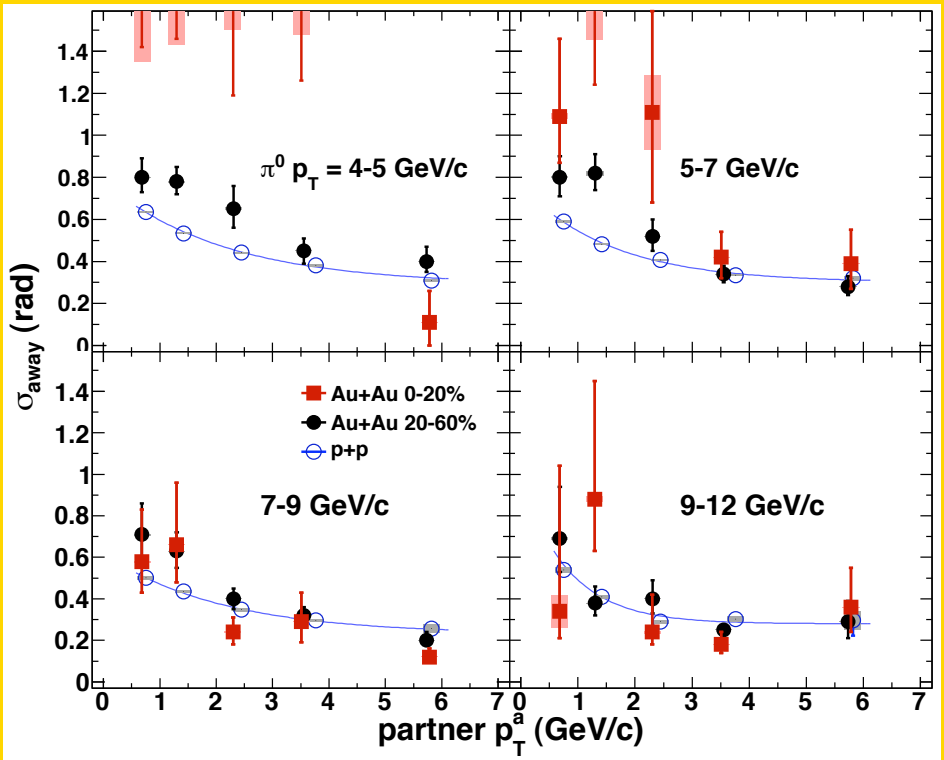

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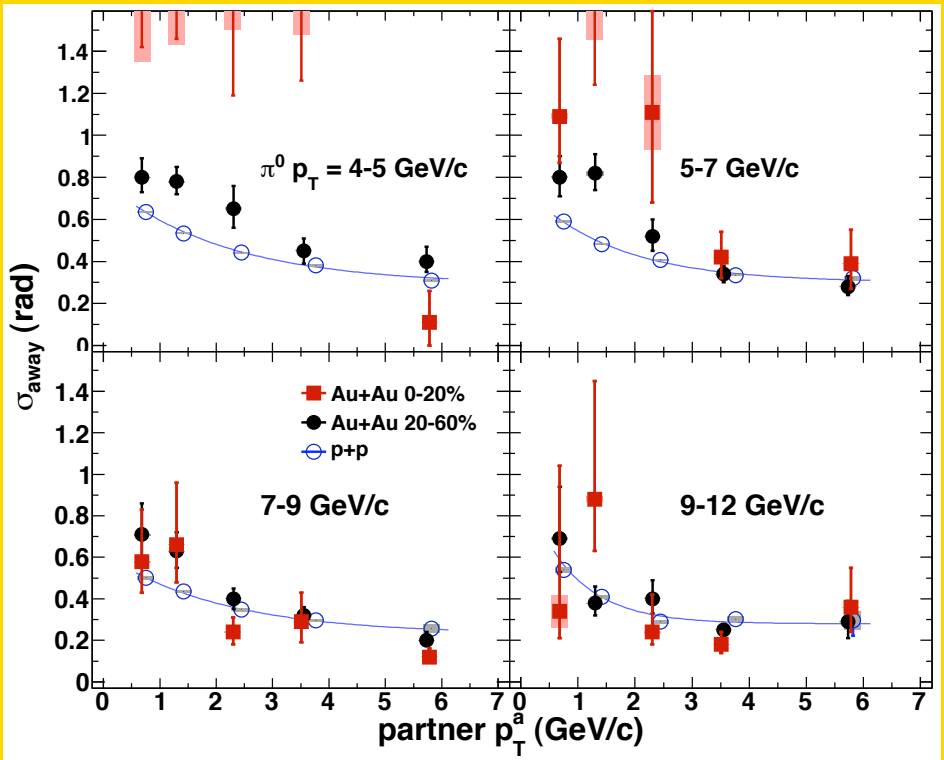

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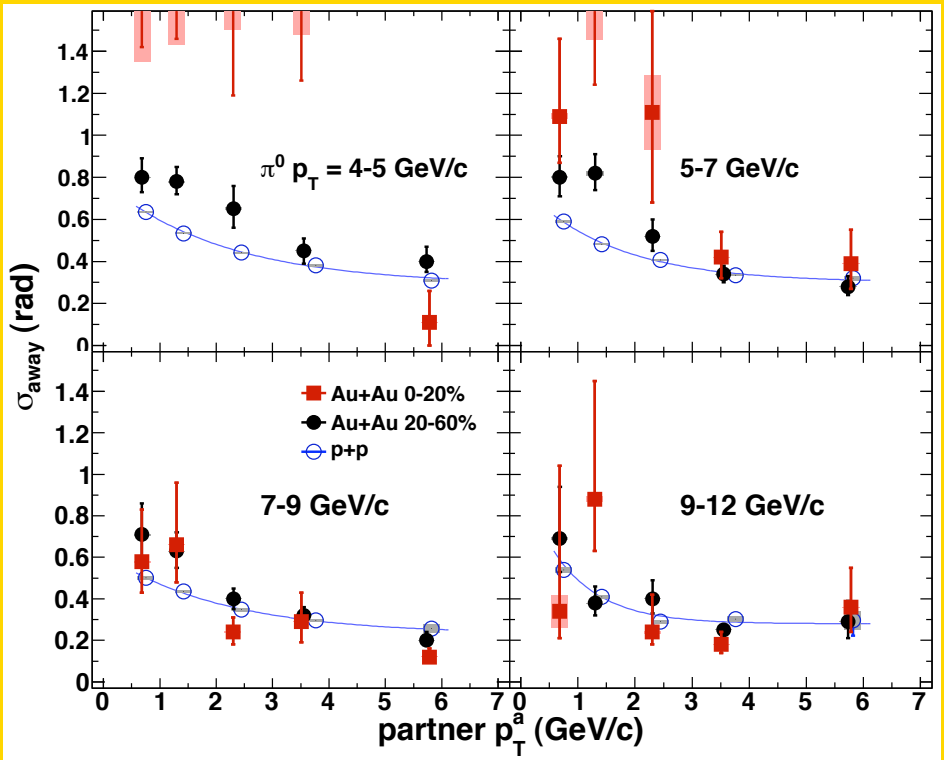

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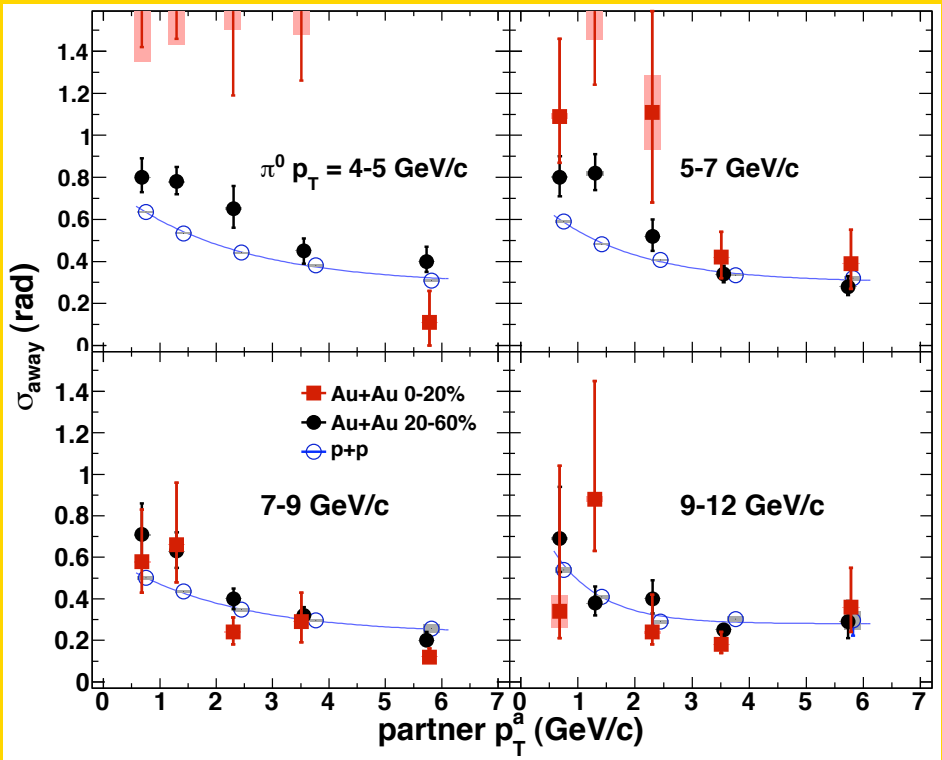

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- For the highest trigger and associated p_T, Au+Au widths are similar to $p + p$
- Transition between medium response-dominated lobes to jet-like central peak in 5-7 GeV trigger.

Focus on High-p_T: $\pi^0 - h$ Yields

- Comparison of the away-side yields in $p + p$ and Au+Au

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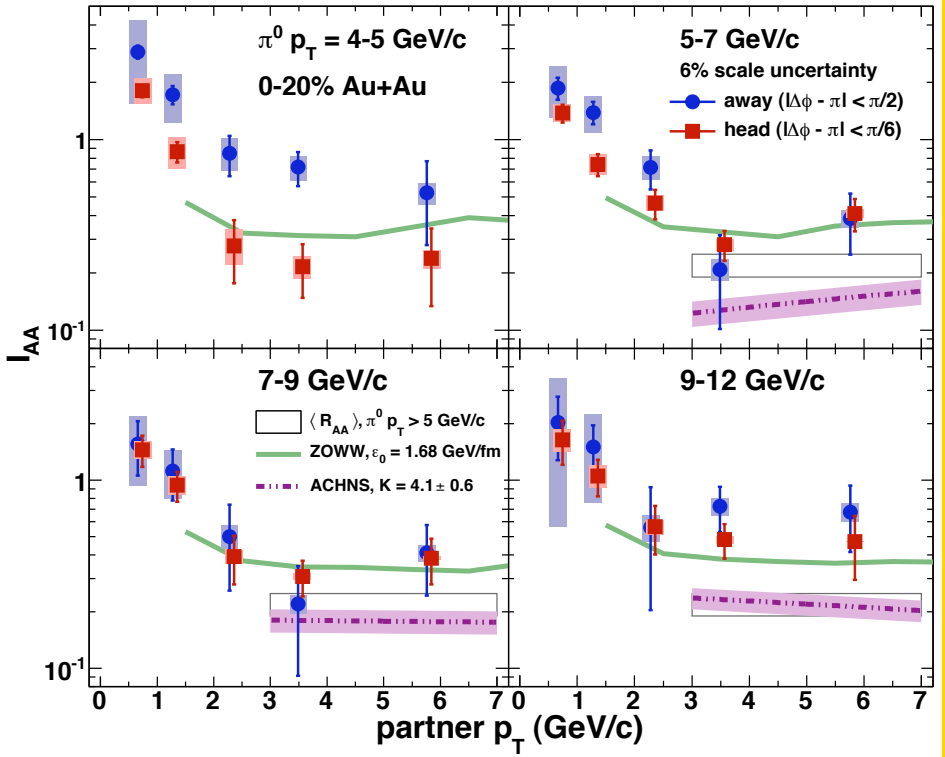

away-side yield in $|\Delta\phi - \pi| < \pi/2$ (blue circles)
"Head" yield in $|\Delta\phi - \pi| < \pi/6$ (red squares)

Focus on High-p_T: $\pi^0 - h$ Yields

- Comparison of the away-side yields in $p + p$ and Au+Au
- Similar transition between double peak to jet-like peaks seen in yields.

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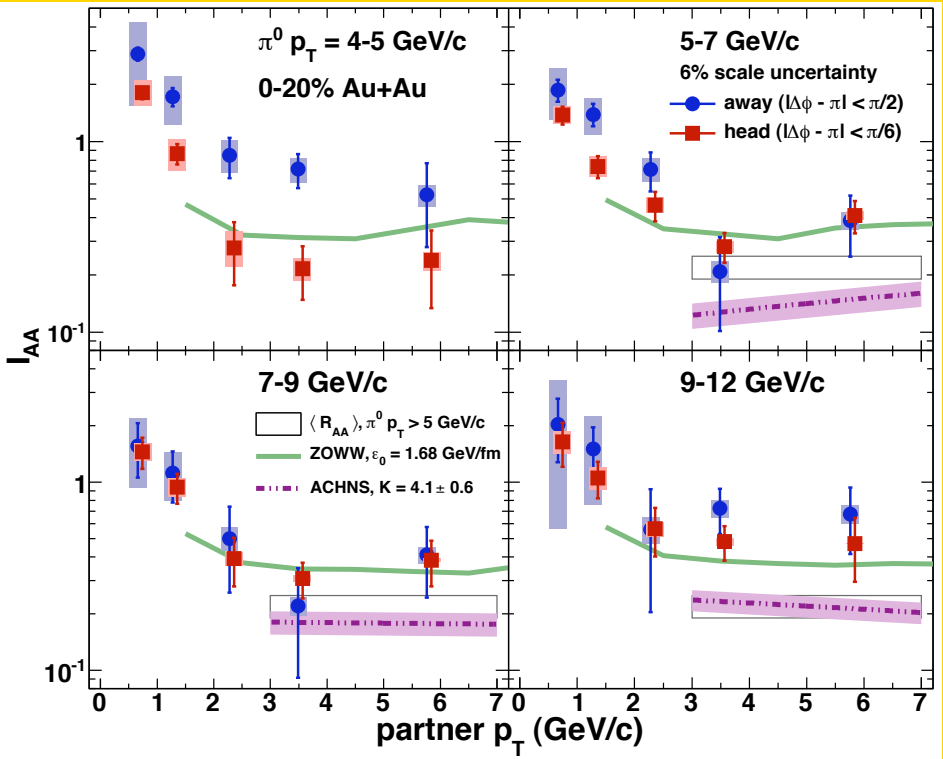

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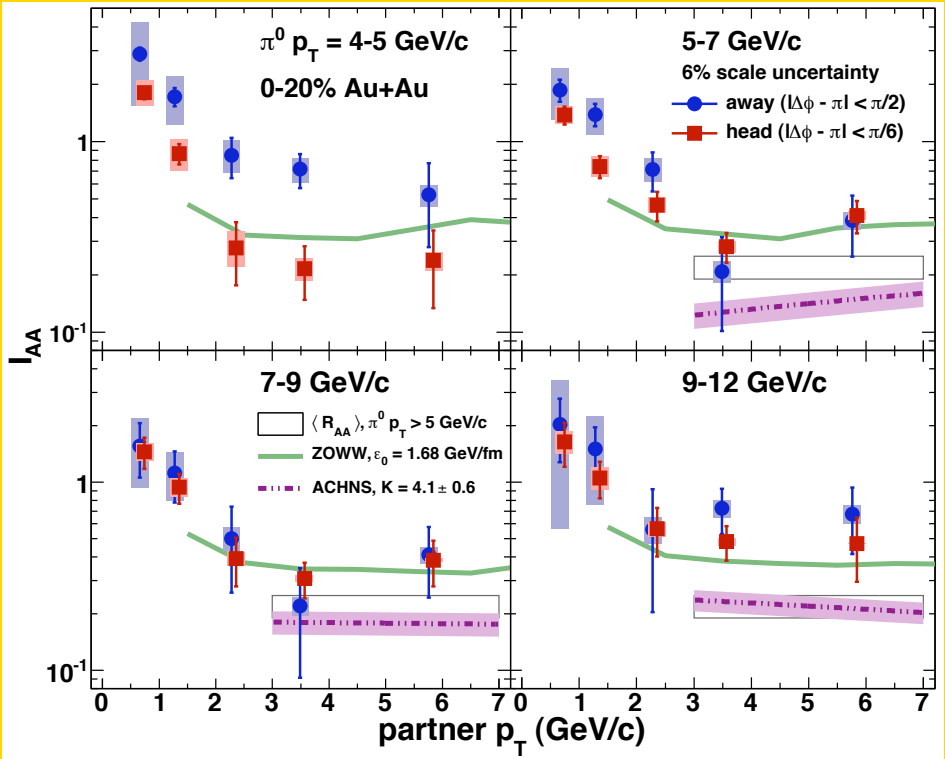

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- $I_{AA} > R_{AA}$
  - Harder associated spectrum means less shift from ΔE

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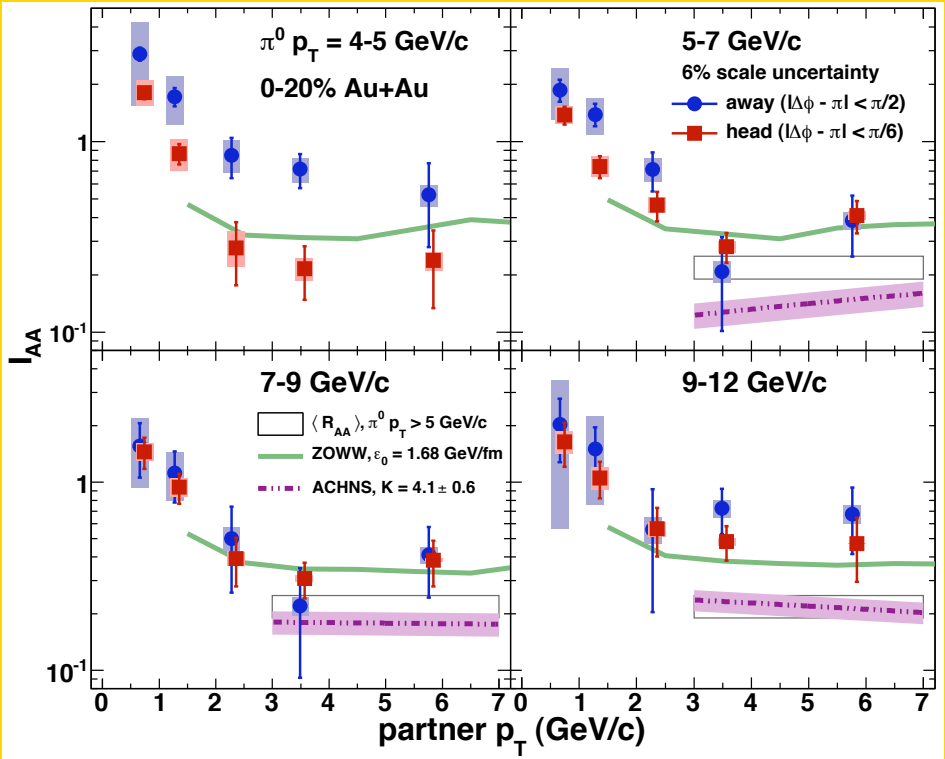

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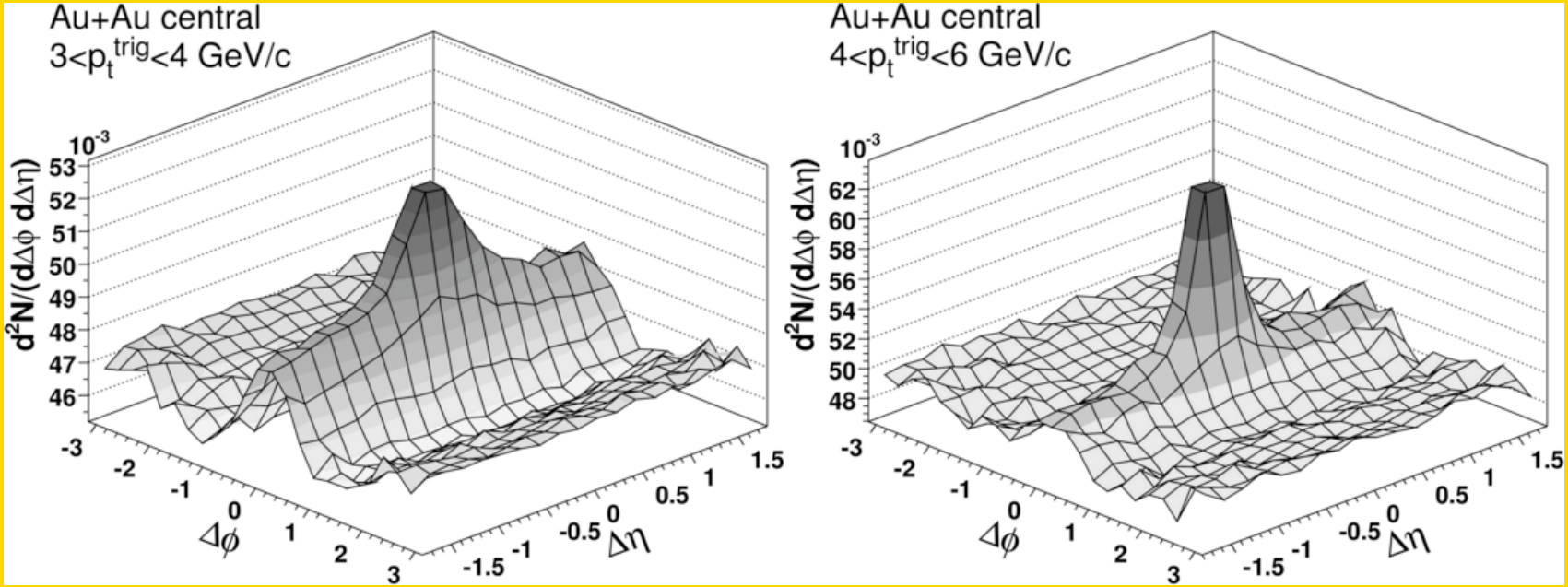
- High-p_T pairs dominantly from jets
  - Widths are consistent between $p+p$/d+Au and central Au+Au.
  - Yields are suppressed with $I_{AA} > R_{AA}$
- Plenty of data at high-p_T in singles and pairs to start incorporating when testing models of energy loss.

Moderate p_T: The Ridge

- Extended longitudinal correlations observed in association with a jet
- Exists up to trigger $p_T > 6$ GeV



STAR *Phys. Rev.* **C80** 064912 (2009)

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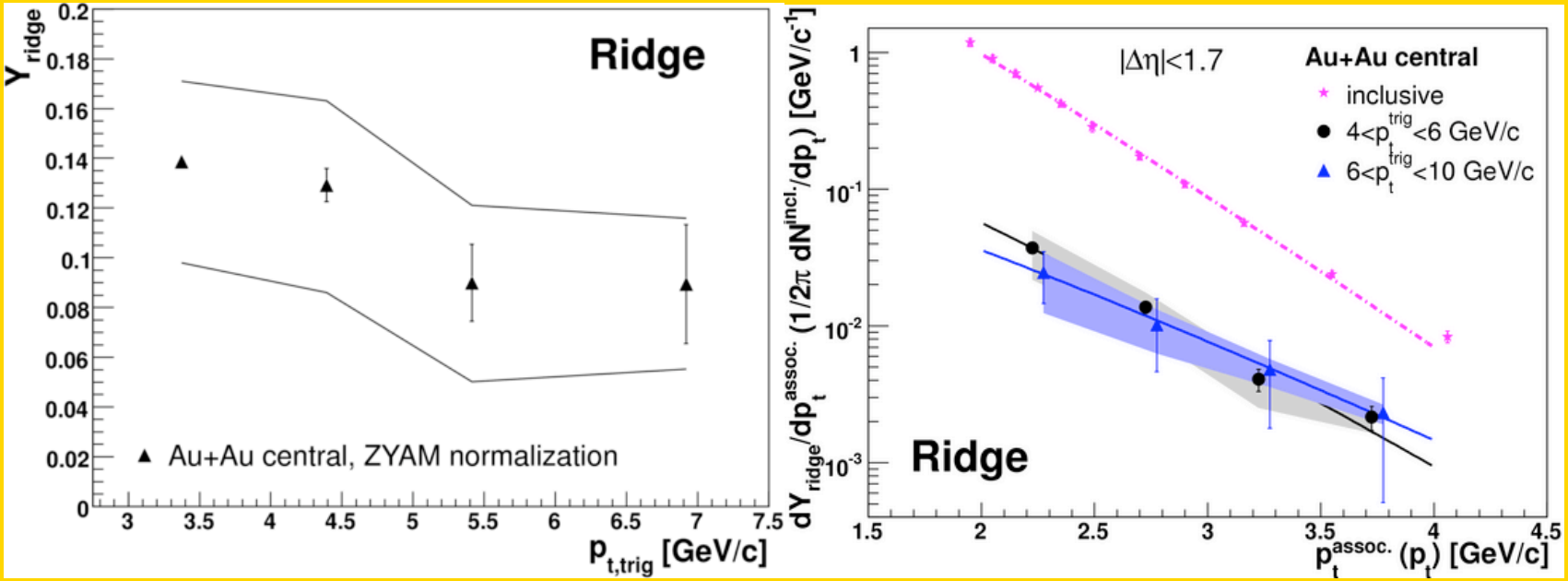
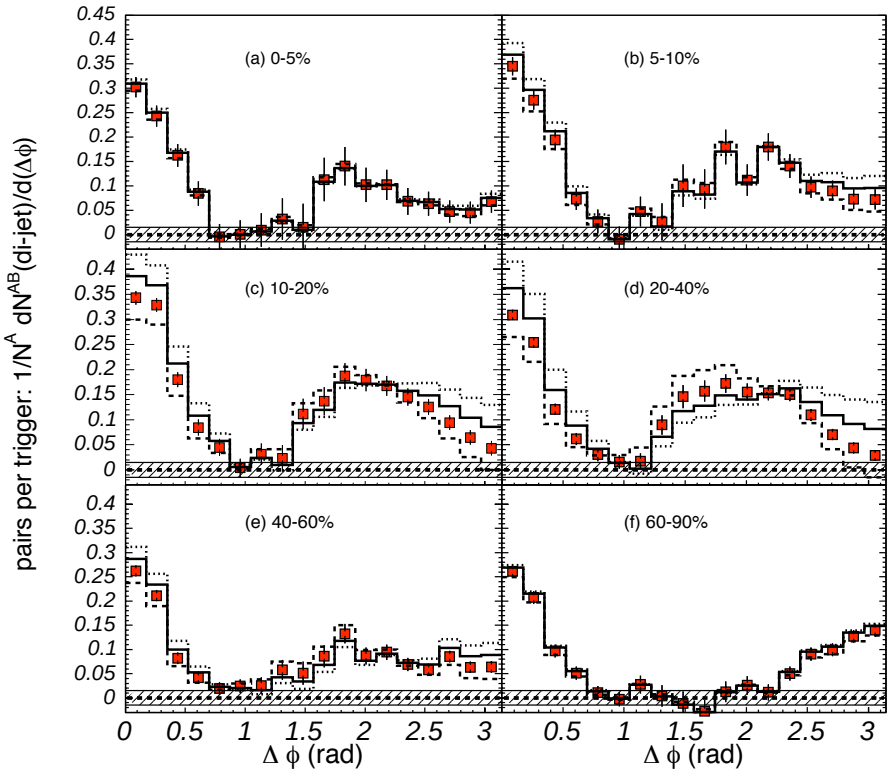


- The integrated yield show a slight dependence on trigger p_T.
- The spectrum of particles in the ridge is similar to inclusive particles.
  - The medium response to the passage of a jet?

Moderate p_T: The Double Peak

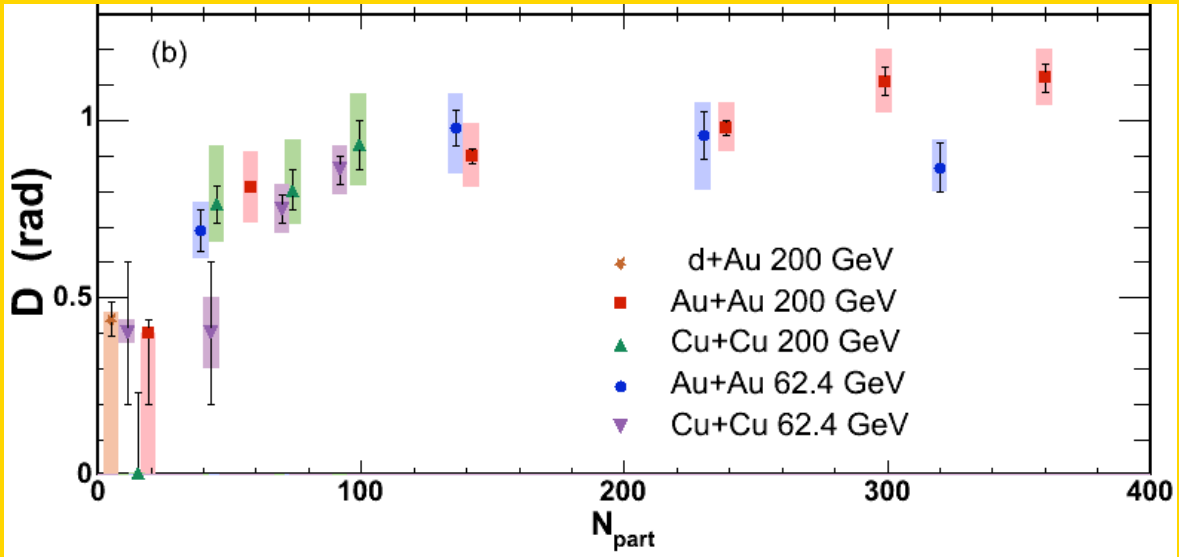
- Trigger: h $2.5 < p_T < 4.0$ GeV
- Trigger: h $1.0 < p_T < 2.5$ GeV
- After subtracting the flowing background peak appears away from π.

PHENIX *Phys. Rev. Lett.* **97** 052301 (2006)



Moderate p_T: The Peak Offset

PHENIX *Phys. Rev. Lett.* **98** 232302 (2007)



Au+Au 0-20% 3-5 GeV trigger

$p_{T,assoc}$	D [rad]
1-1.5	1.04±0.03±0.03
1.5-2	1.07±0.04±0.04
2-2.5	1.05±0.03±0.06
2.5-3	1.07±0.06±0.06
3-5	0.88±0.13±0.16

- The offset from π is a smooth function of N_{part} across systems and $\sqrt{s_{NN}}$.
- Independent of $p_{T,assoc}$

Moderate p_T: Summary

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- Novel structures seen in RHIC 2-particle correlation data

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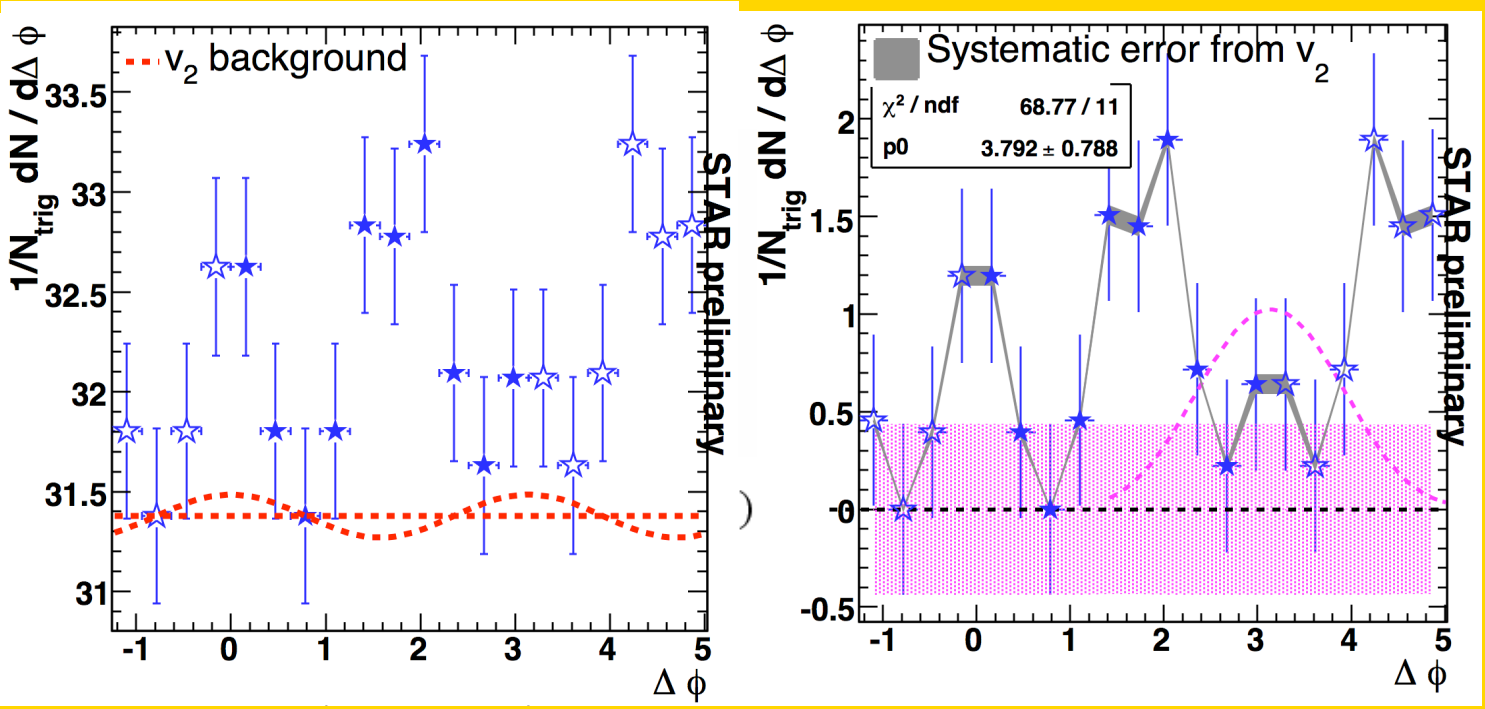
- What does this tell us about energy loss and the medium response?
  - Really, what does this tell us about energy loss and the medium response?

Heavy Flavor Energy Loss: $e - h$ Correlations

B. Biritz QM 2009 [open points are reflections]



- 0-20% Cu+Cu
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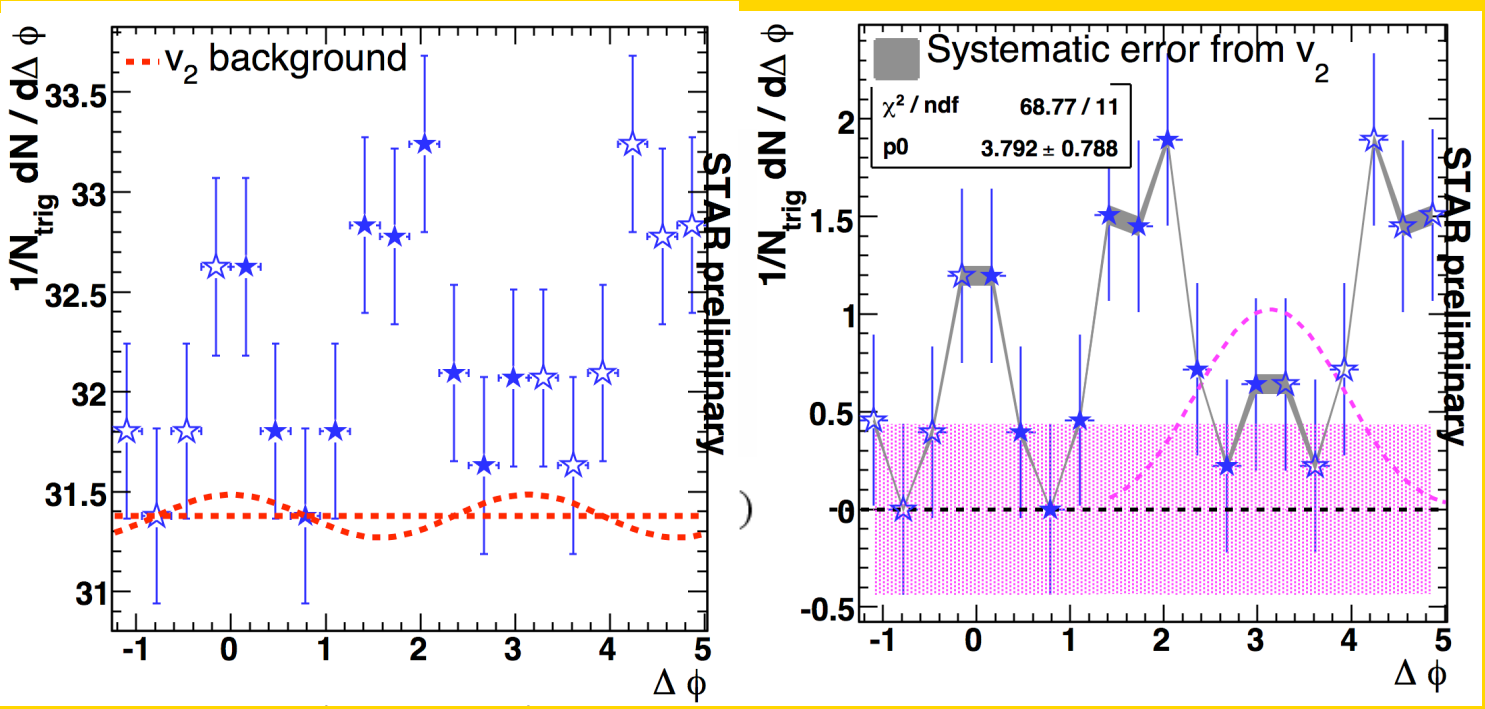

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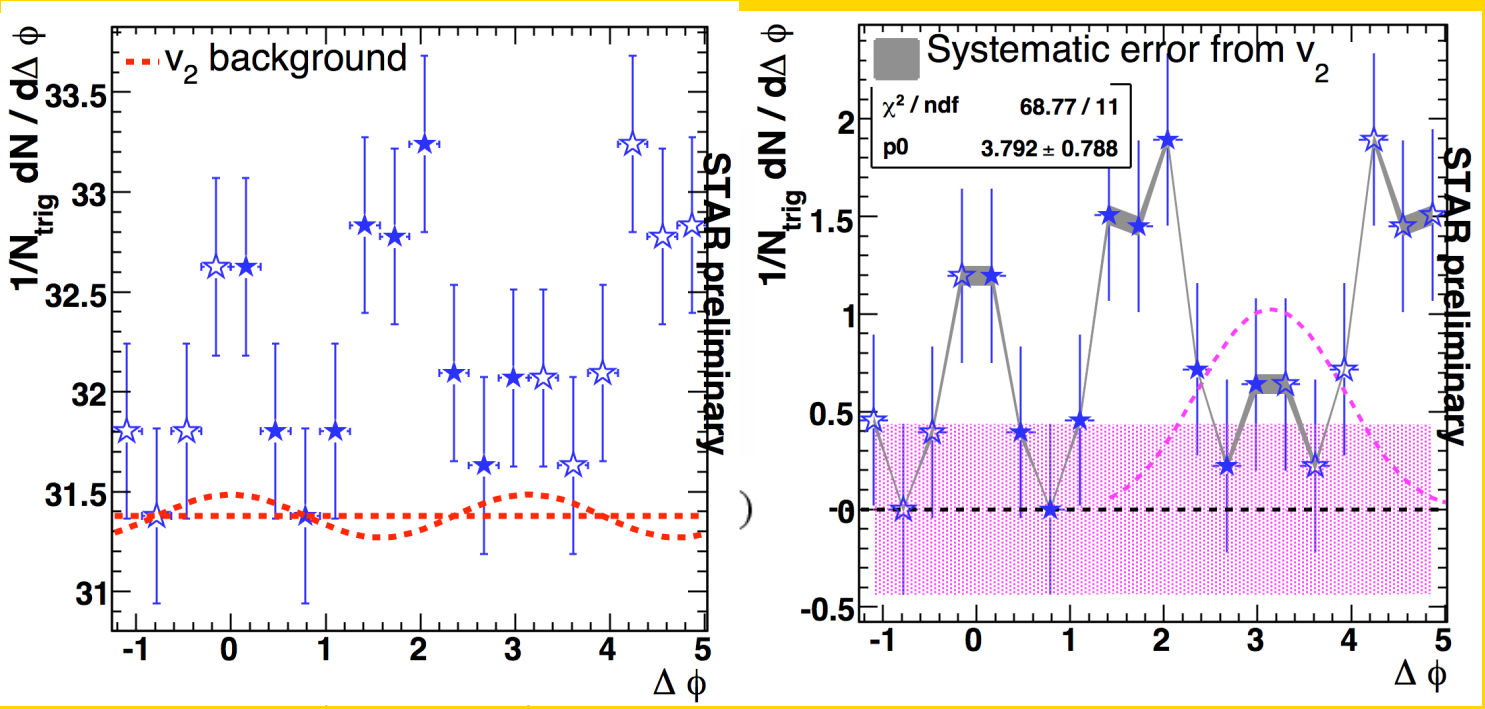

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- Little to no hint of the jet-like peak in away-side

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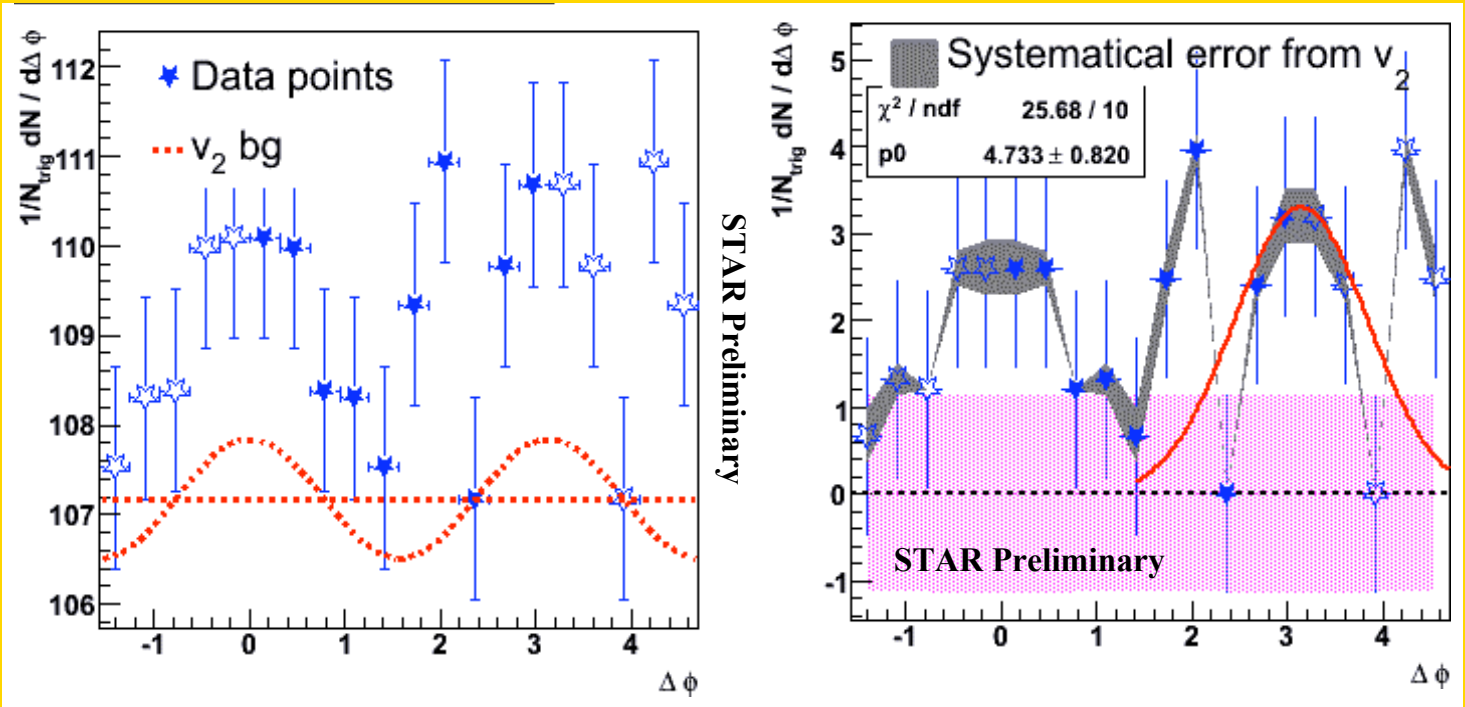

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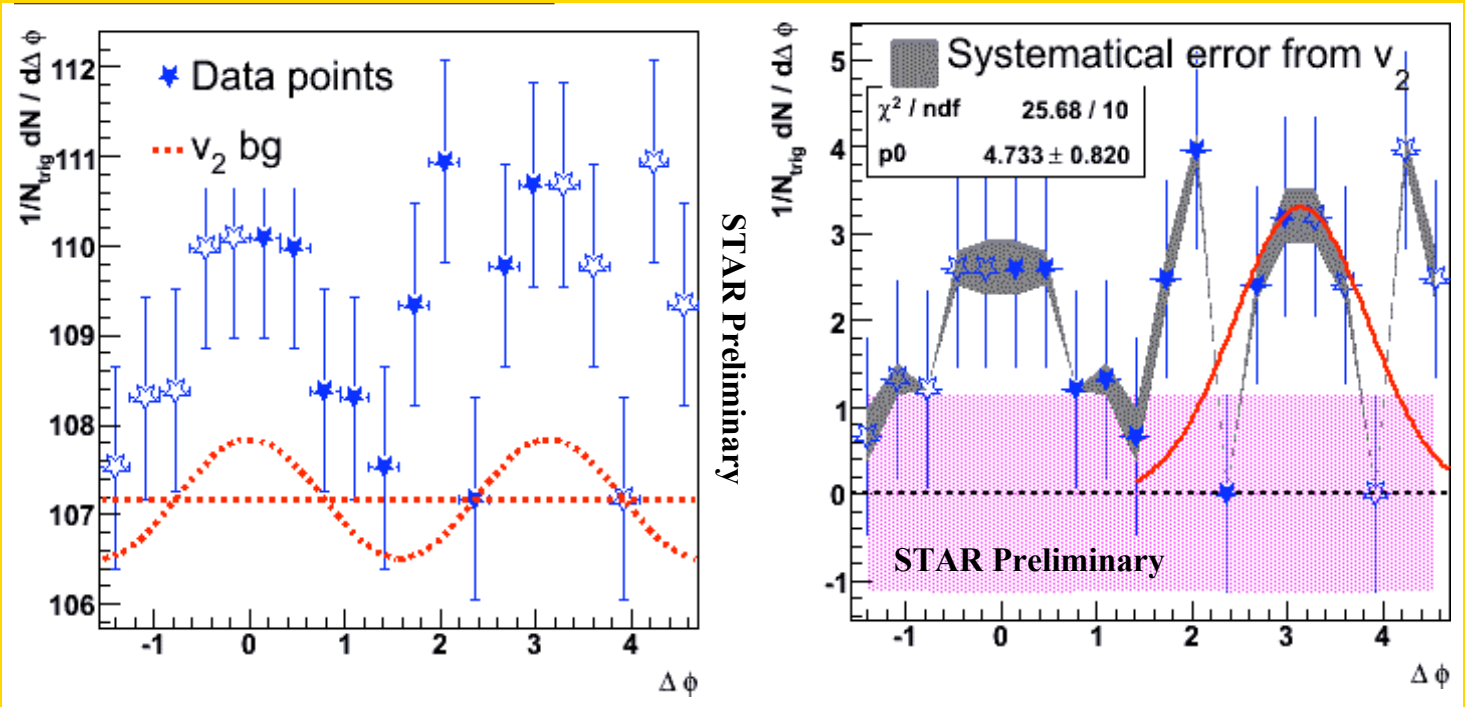

- 0-20% Au+Au
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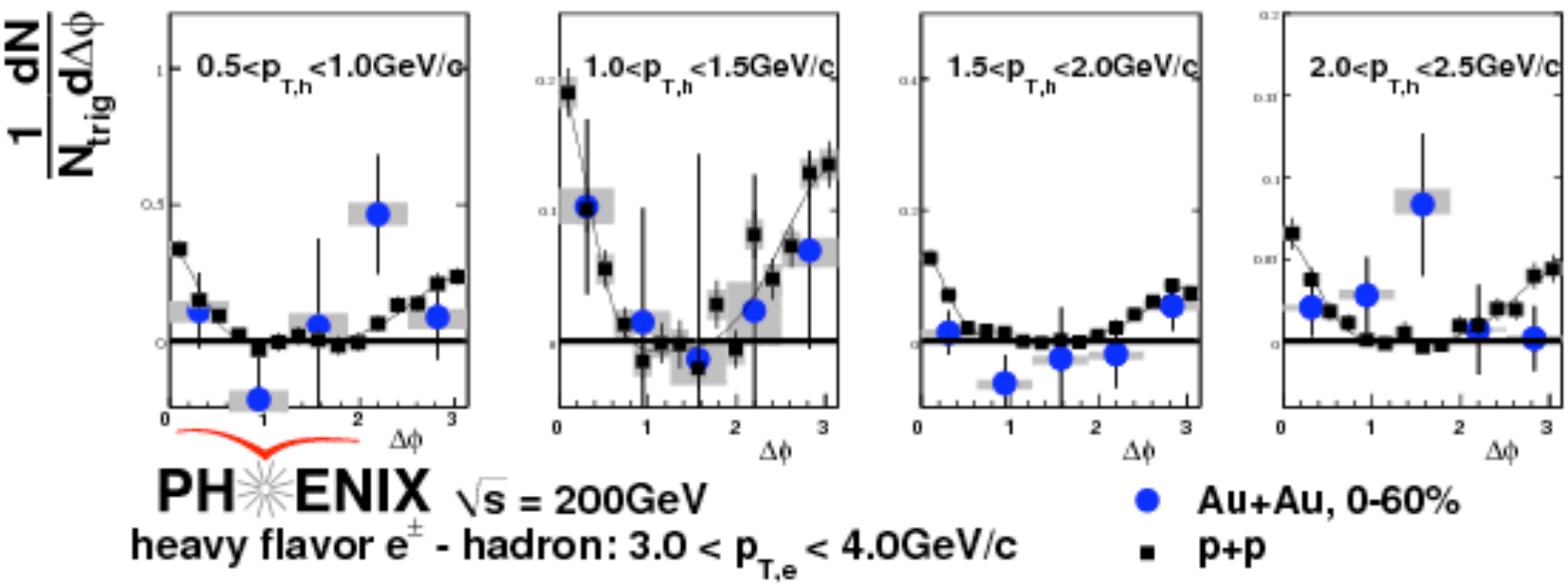
- Broad away-side (and near-side!) structure is present

Heavy Flavor Energy Loss: $e - h$ Correlations

A. Sickles QM 2009



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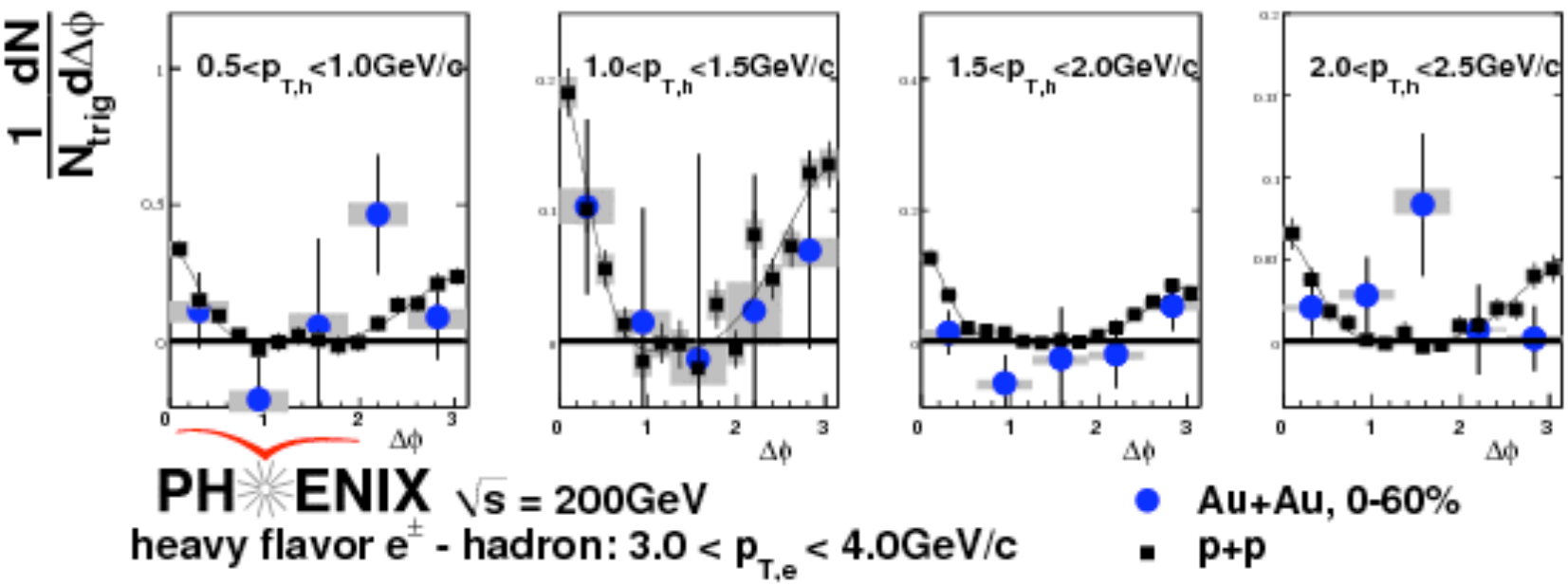

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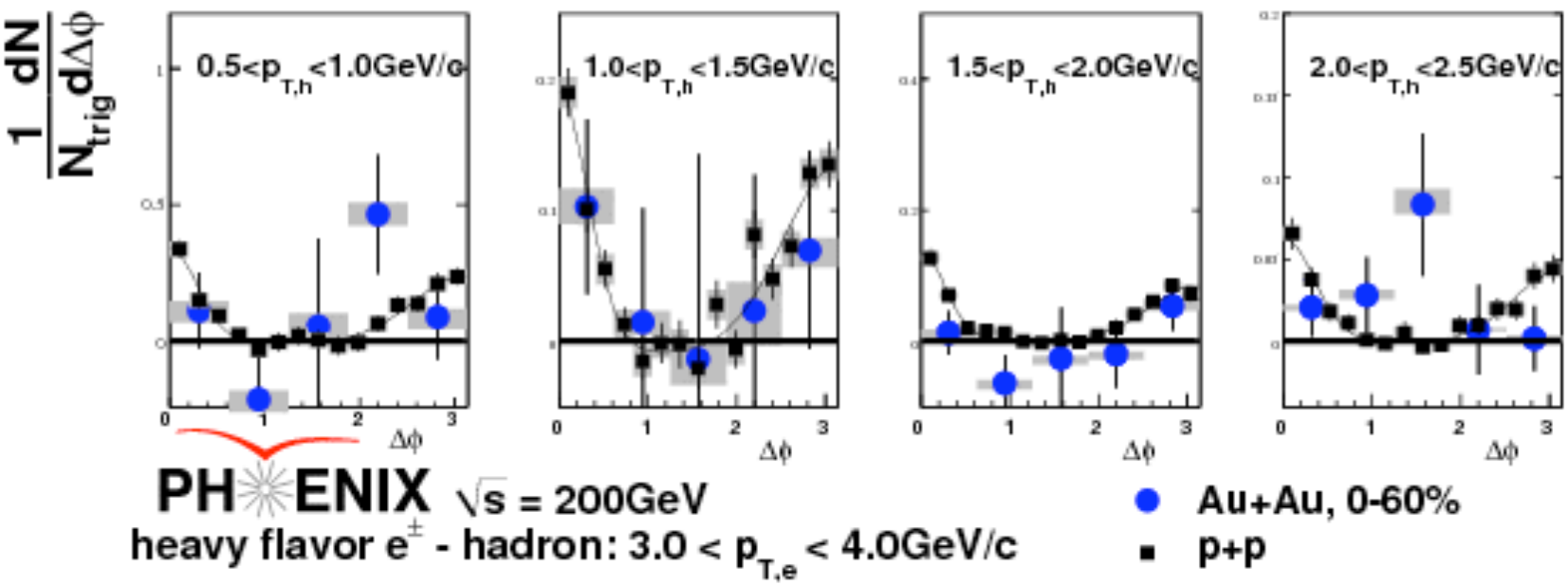

- Heavy-flavor correlations are seen in p+p
- Statistics are poor in Au+Au to make any strong conclusions

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  - Statistics are lacking not only from the charm cross section but from the BR to electrons.
- Silicon tracking is required to push this further in both PHENIX and STAR.

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  - From γ-jet correlations (A. Hamed, J. Chen)
  - From full jets (E. Bruna, Y.-S. Lai)

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- What are the medium properties?
  - Still an open question for me
  - Depends on weak vs. strong-coupling, cerenkov vs mach cone, what the ridge mechanism is, etc.