High p_T Pair Correlations with Respect to the Reaction Plane

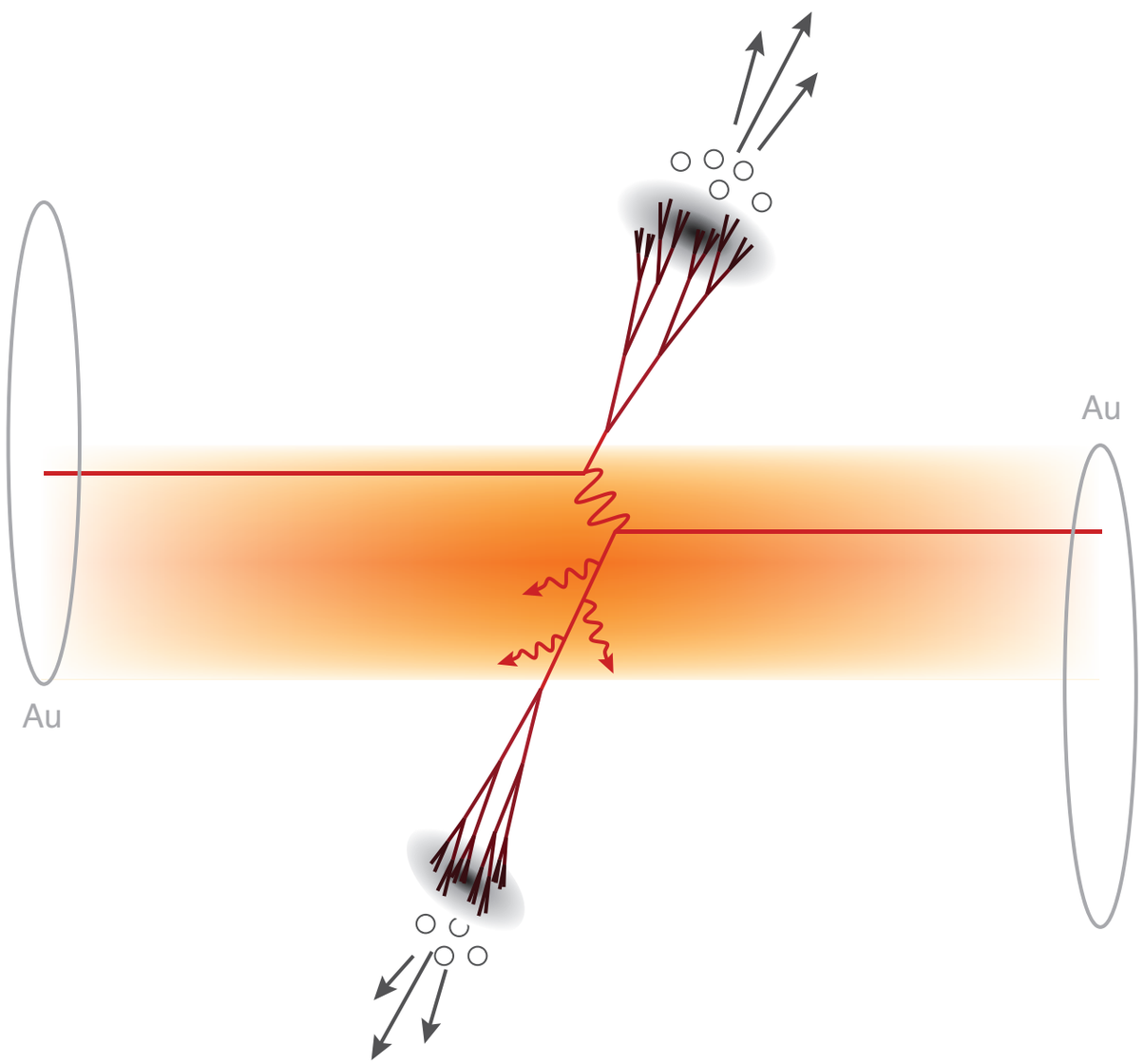
Michael P. McCumber
(University of Colorado)
for the PHENIX Collaboration

RHIC/Users Meeting
10 June 2010

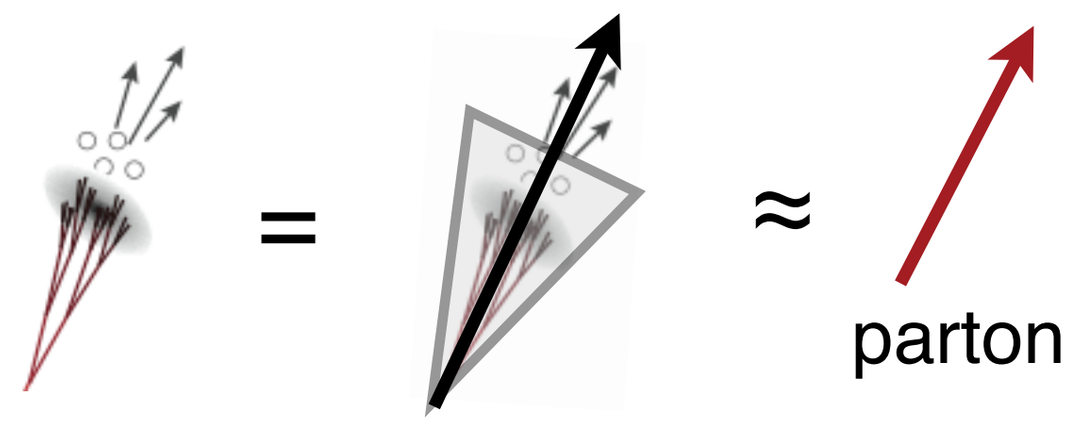
Hard Scattering and Jets

Physics Motivation:

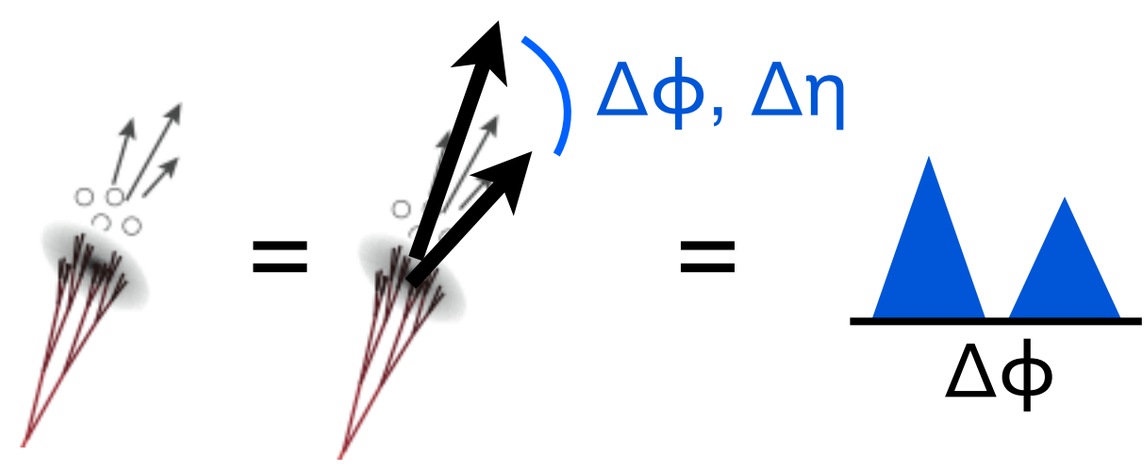
- Energy loss
- Production geometry
- Medium excitations



Jet Reconstruction



Two Particle Correlation



High p_T Energy Loss

Four basic ways to study energy loss...

R_{AA}	$R_{AA}(\Phi_s)$, v_2
I_{AA}	**$I_{AA}(\Phi_s)$, v_2**

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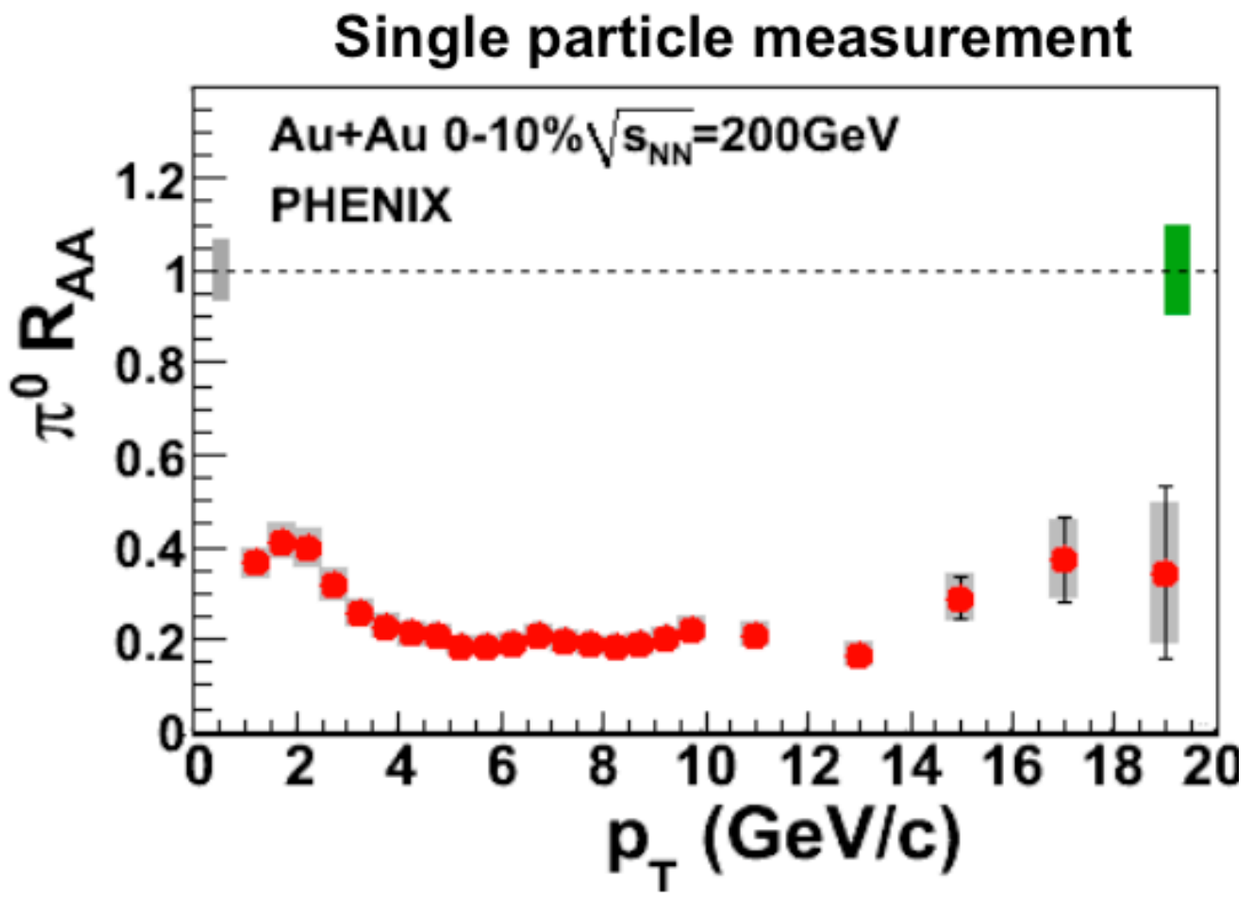

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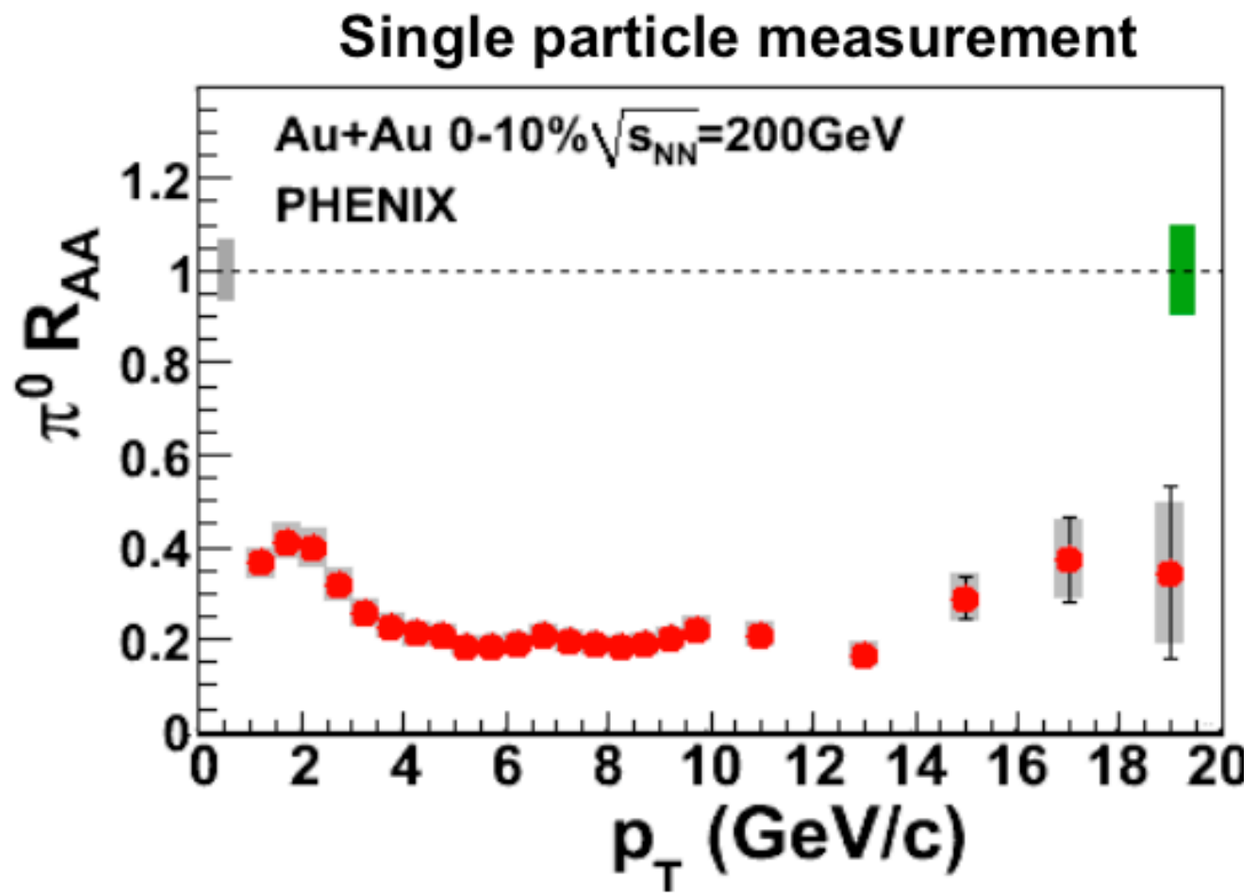
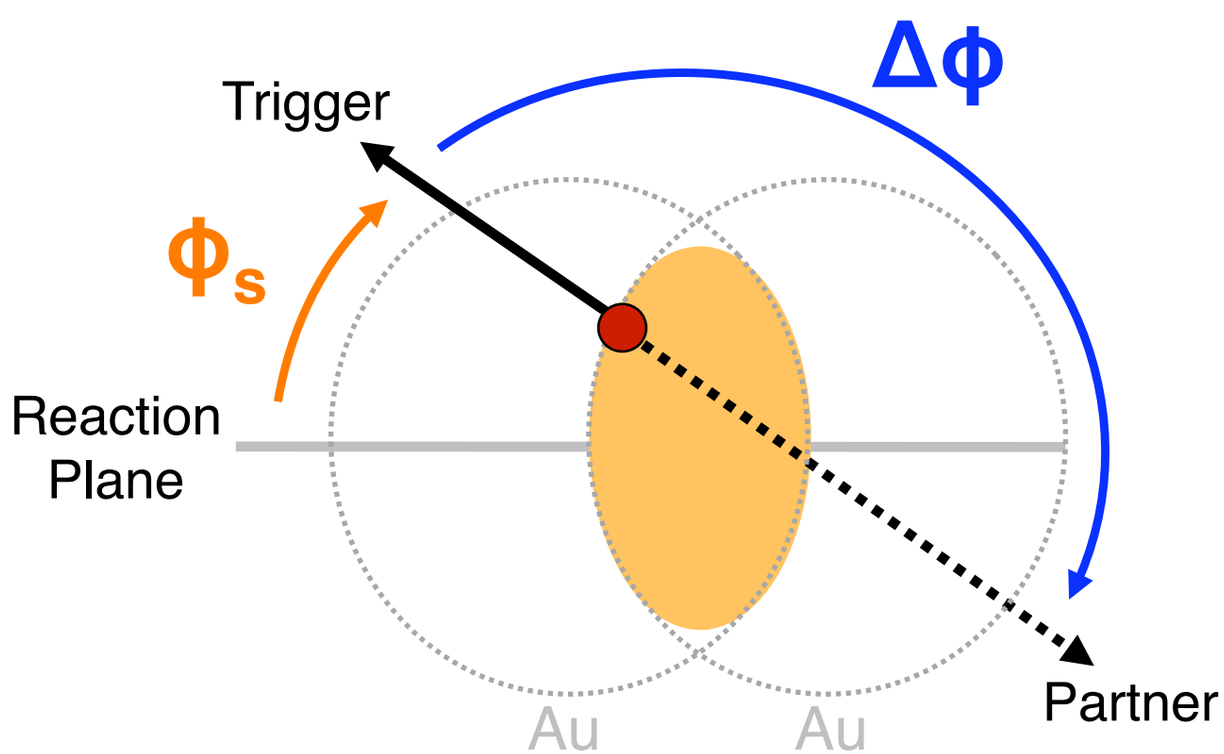
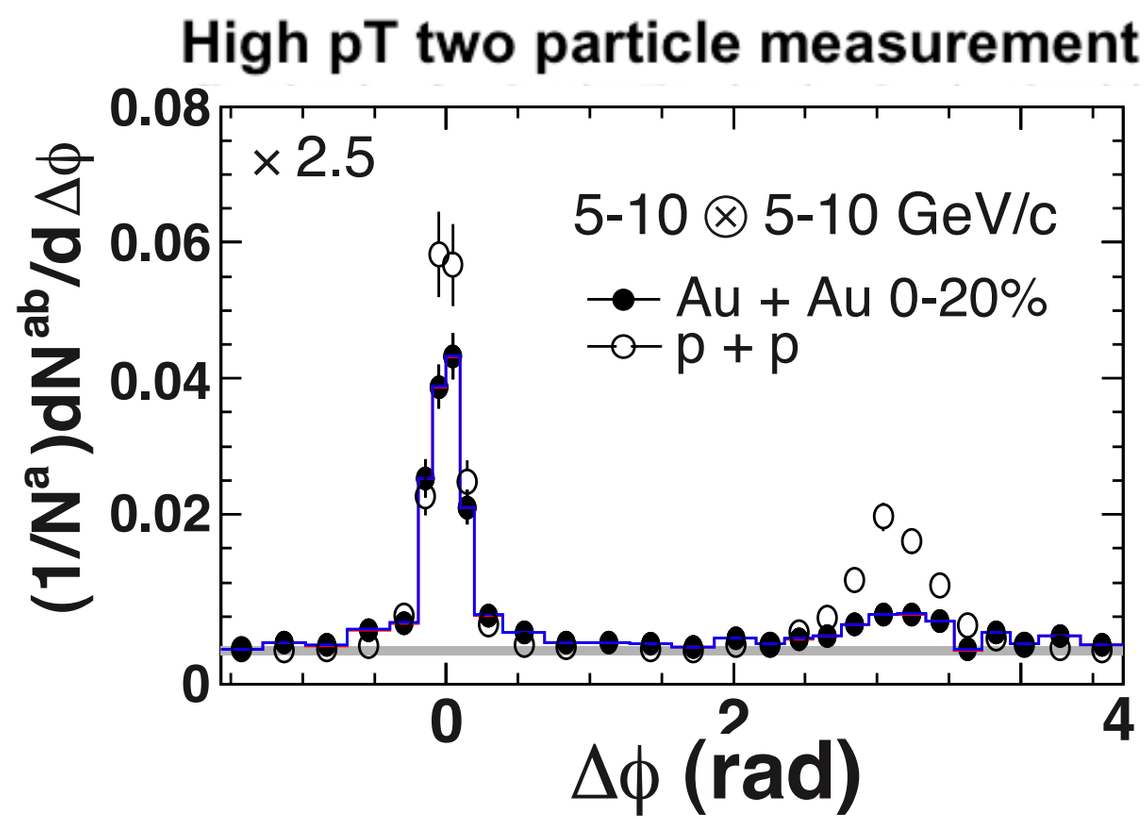
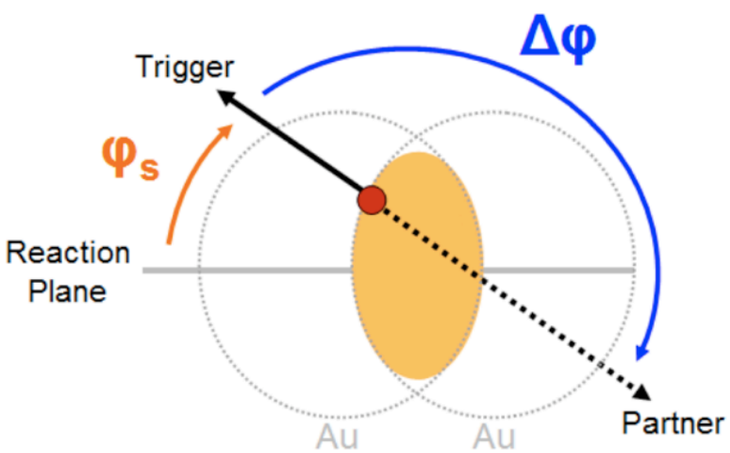


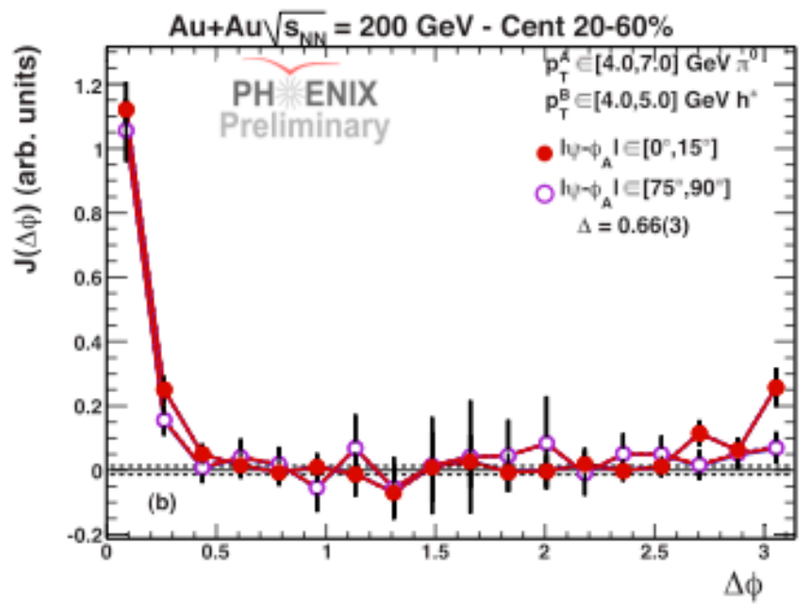




Two Momentum Regimes

Higher pair momentum: $p_T^{\{A,B\}} \gtrsim 4\ \mathrm{GeV}/c$





Explore:
fast parton survival

Learn:
initial deposit geometry
energy loss characteristics

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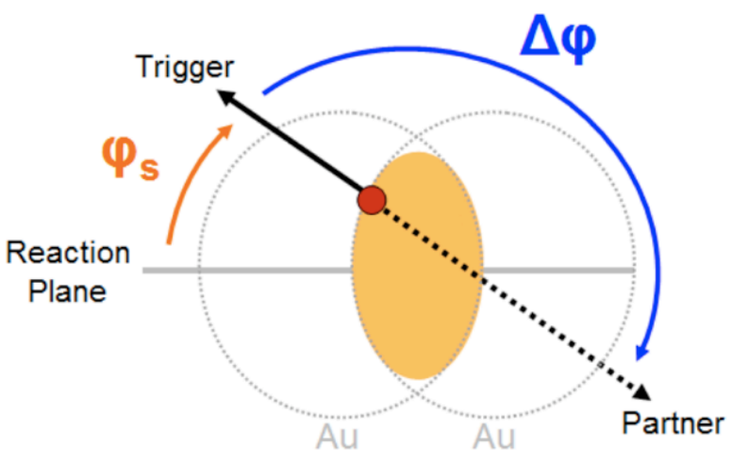

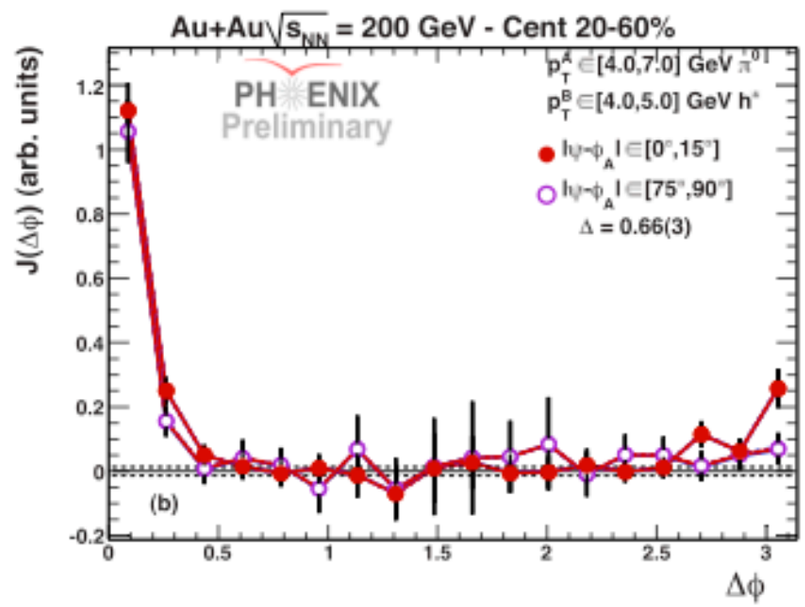

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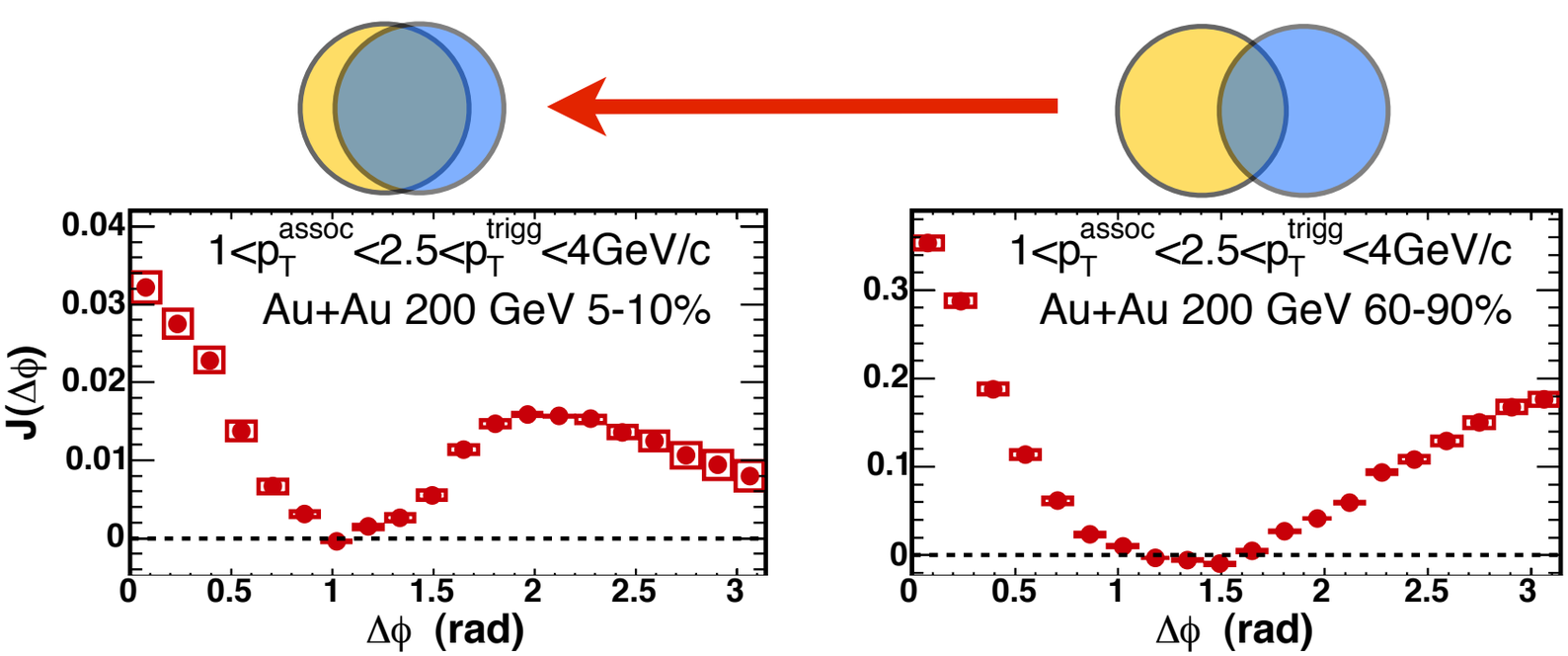
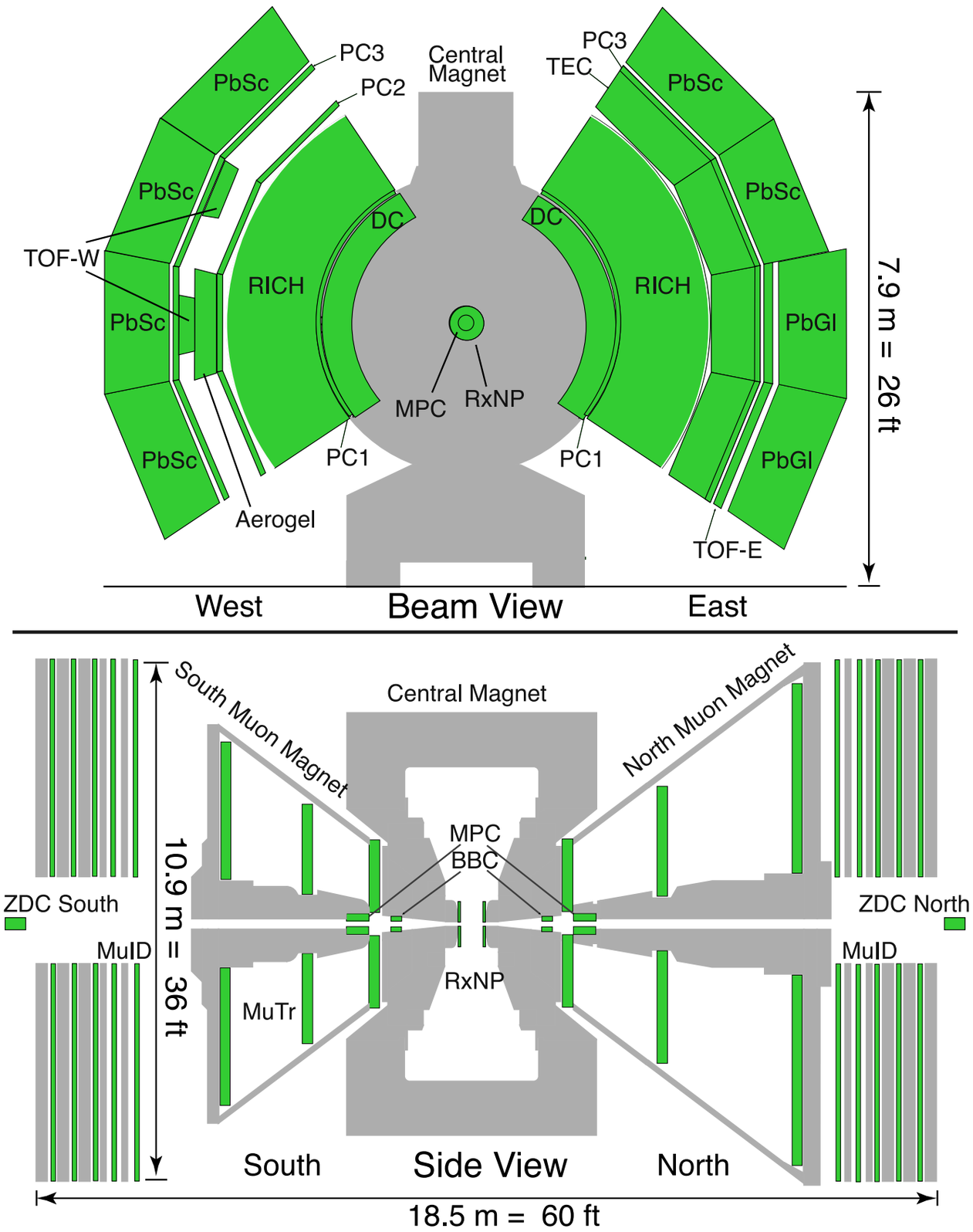
Lower pair momentum: $p_T^{\{A,B\}} \lesssim 4\ \mathrm{GeV}/c$



Explore:
medium response
or triangular flow

Learn:
production mechanisms
medium properties

PHENIX Detector



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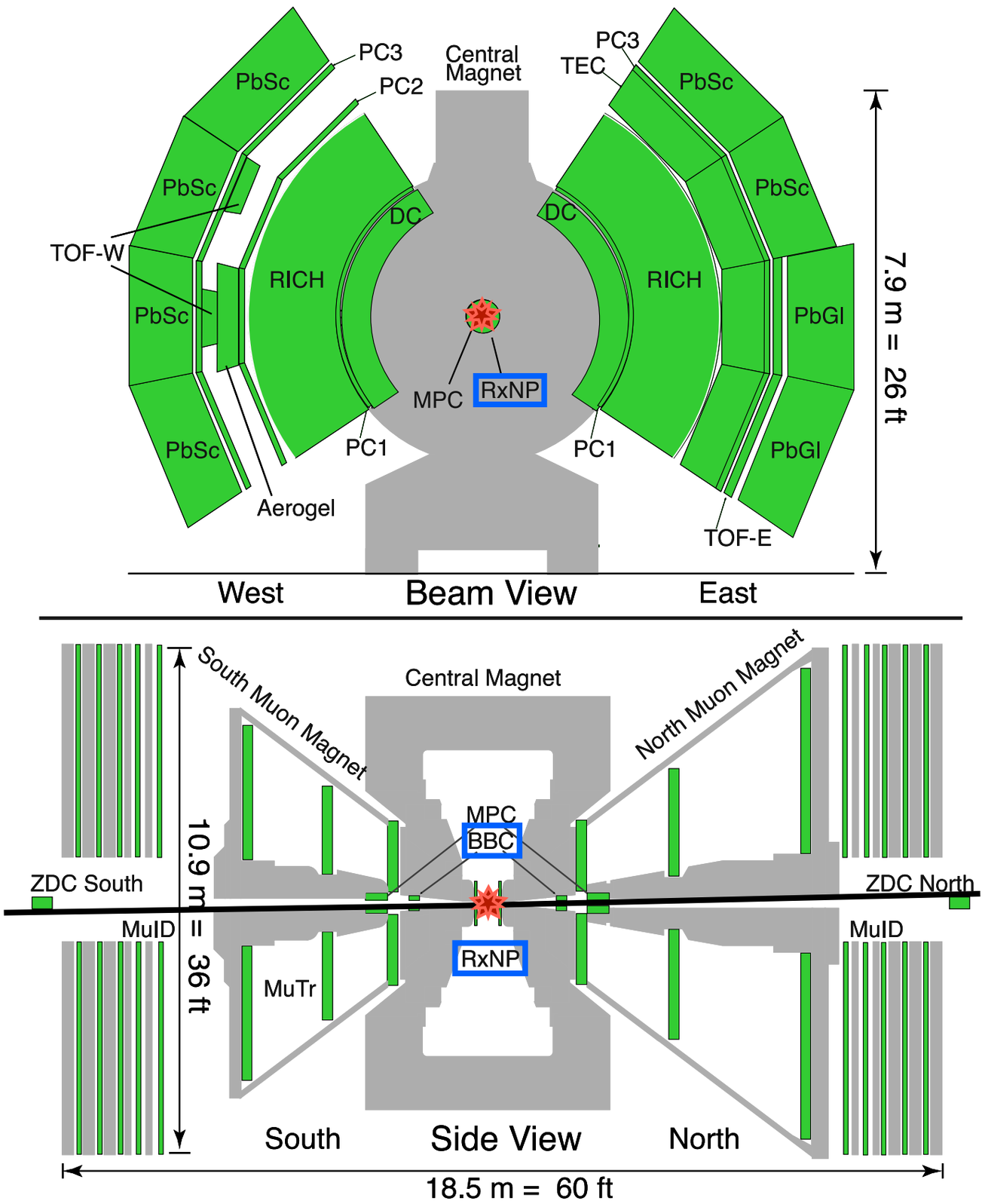

Event Characterization

- Vertex, Centrality, Reaction Plane (BBC, RXPN)

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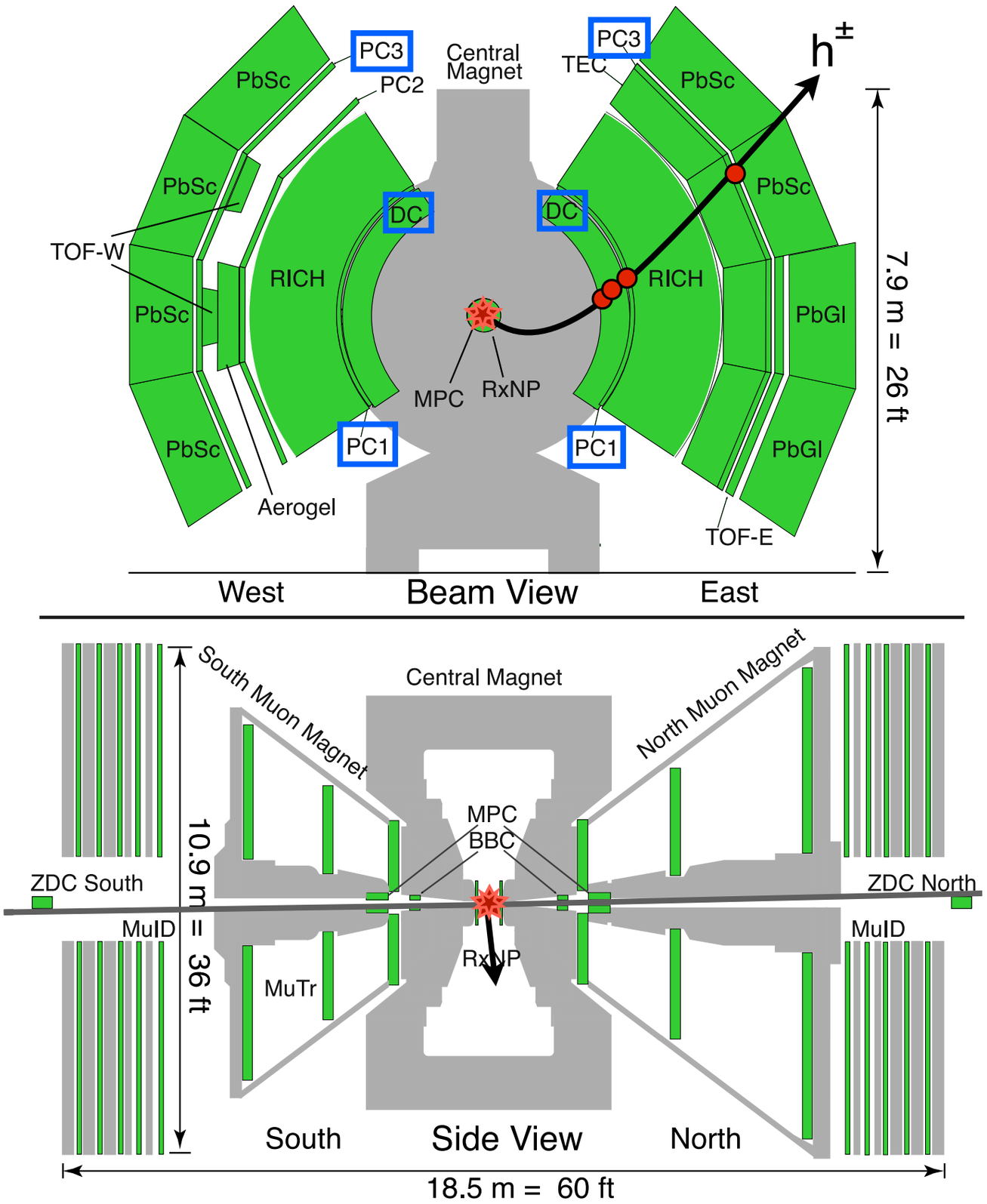

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- Charged Particle Tracking (DC, PC1, PC3, *RICH*)

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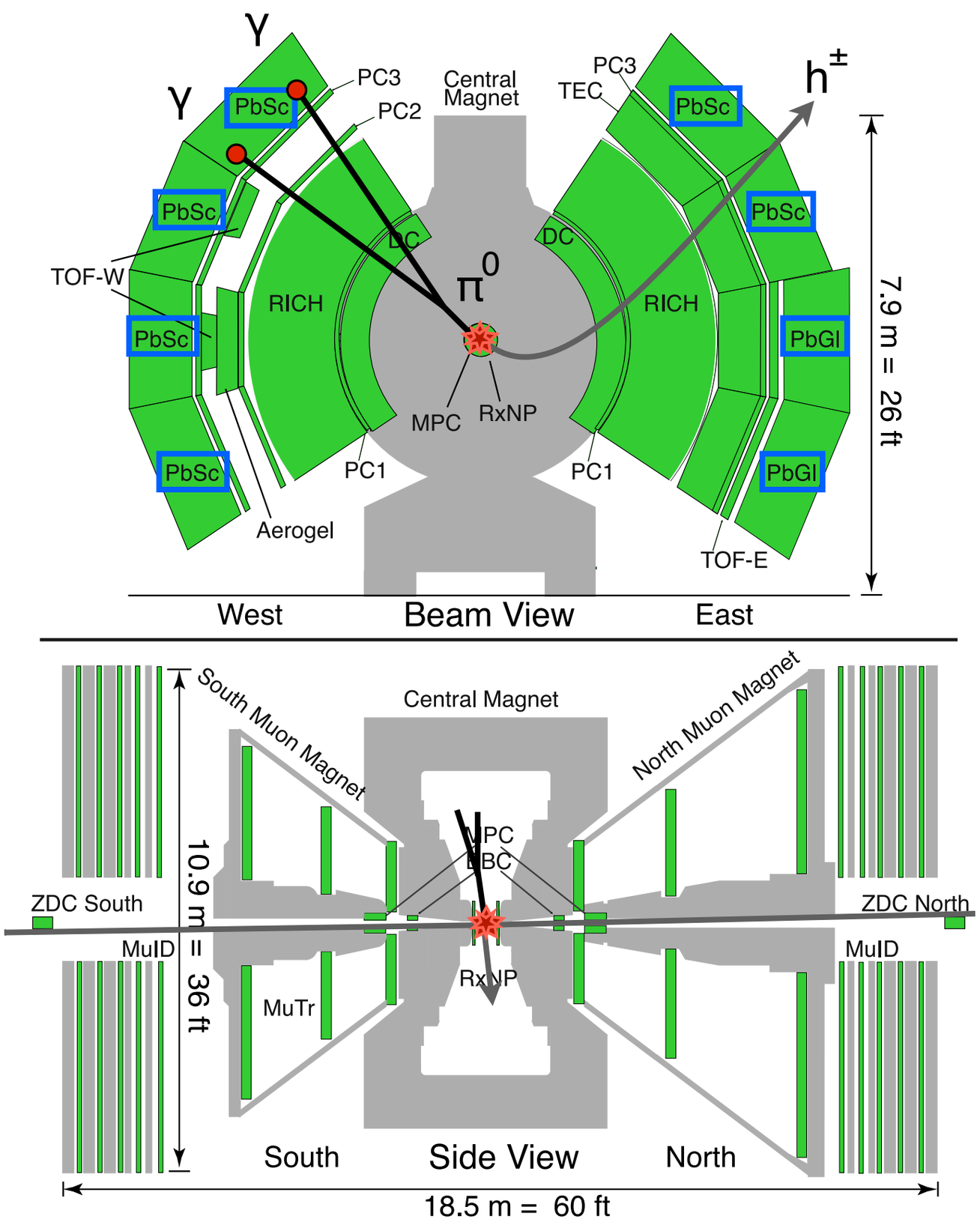


Event Characterization

- Vertex, Centrality, Reaction Plane (BBC RXPN)

Single Particle Reconstruction

- Charged Particle Tracking (DC, PC1, PC3, *RICH*)
- Photon and π^0 Reconstruction (PbSc, PbGl, *PC3*)

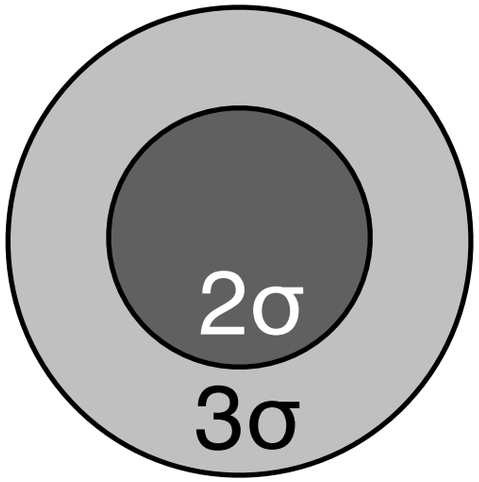
Charge Particle Tracking

High momentum background

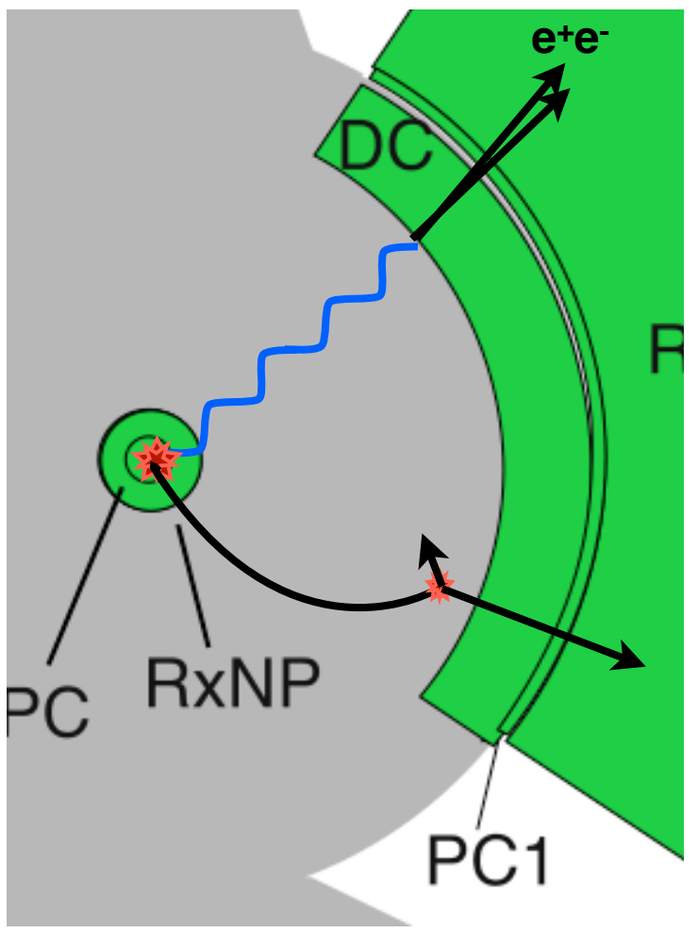
$p_T > 5$ GeV/c

- photon conversion
- post-field decay
- albedo

PC3 Matching



Extend matching requirement in PC3



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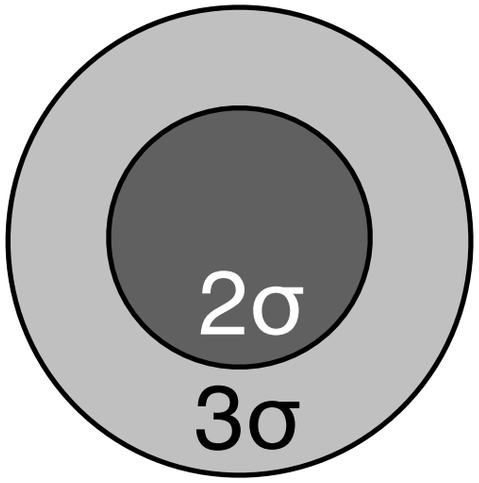

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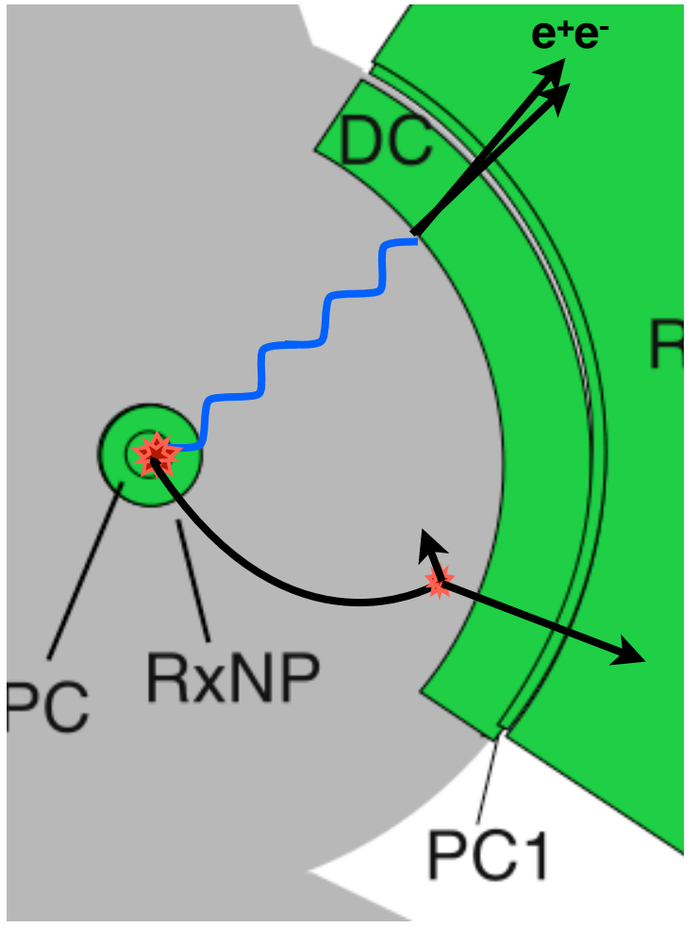
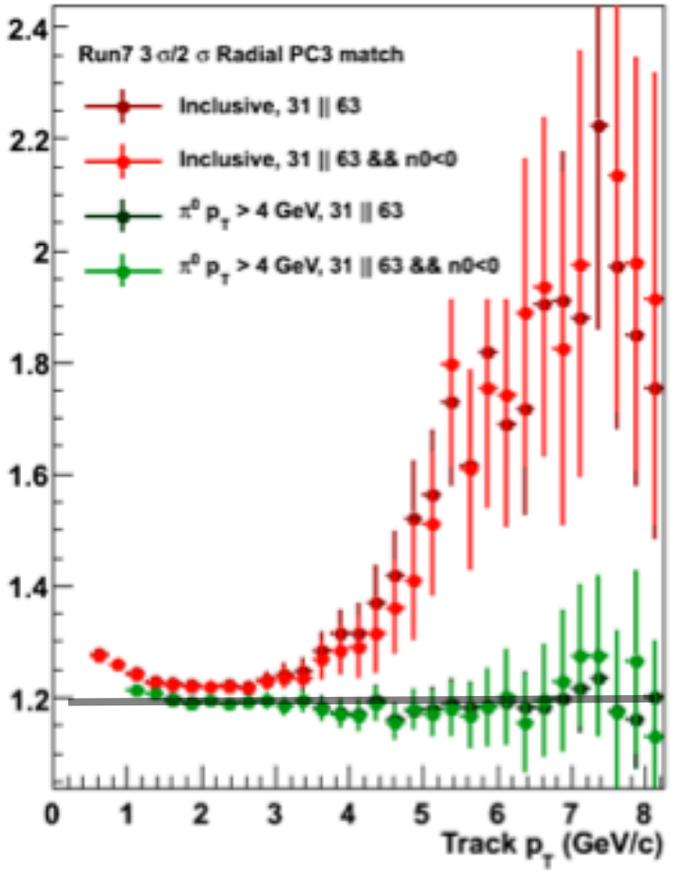


Single Tracks



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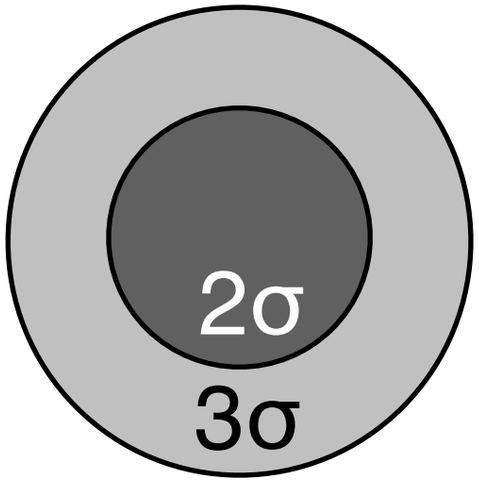

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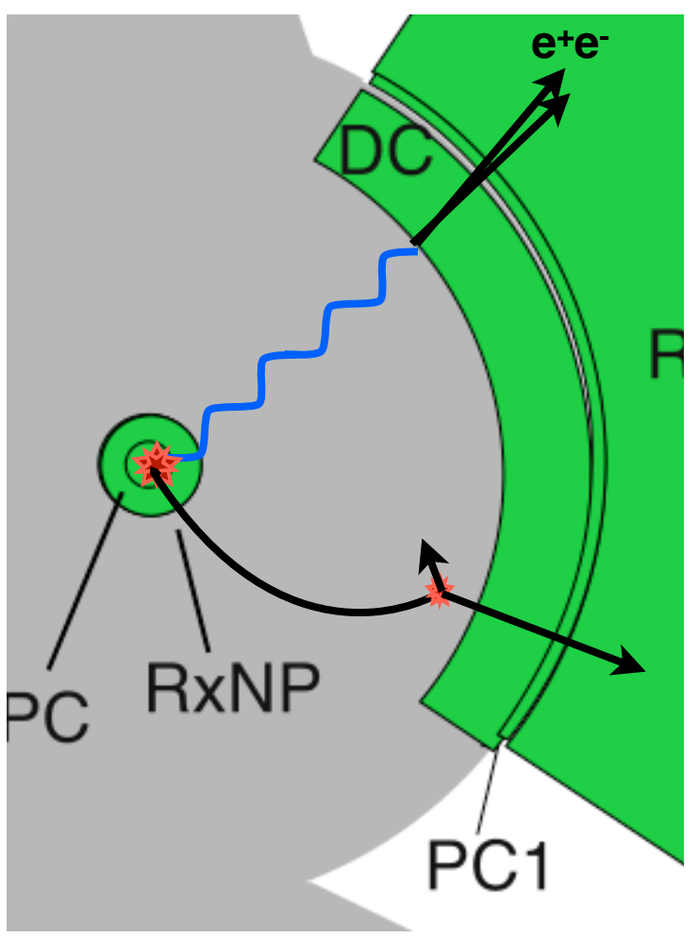

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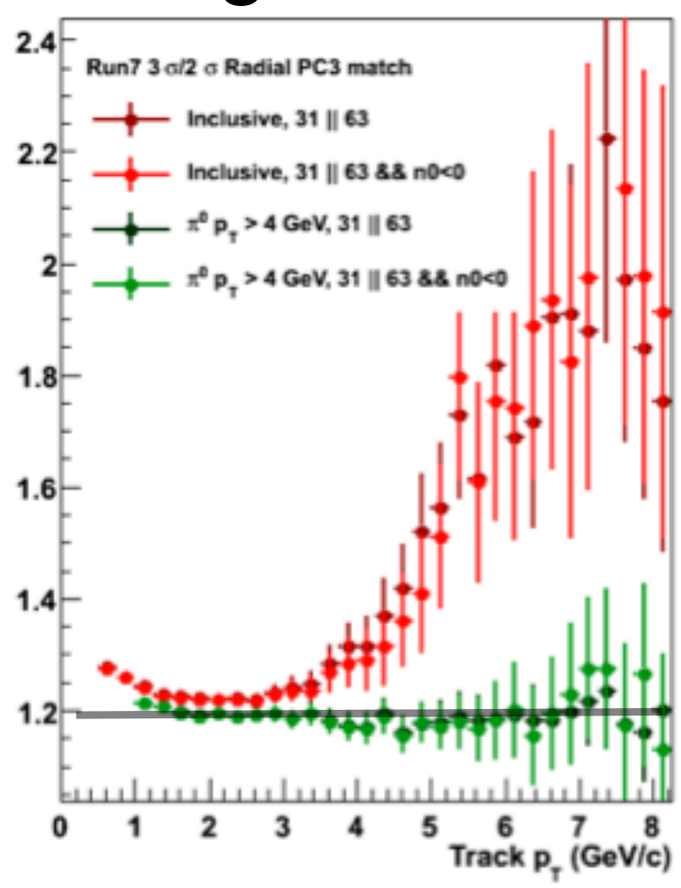
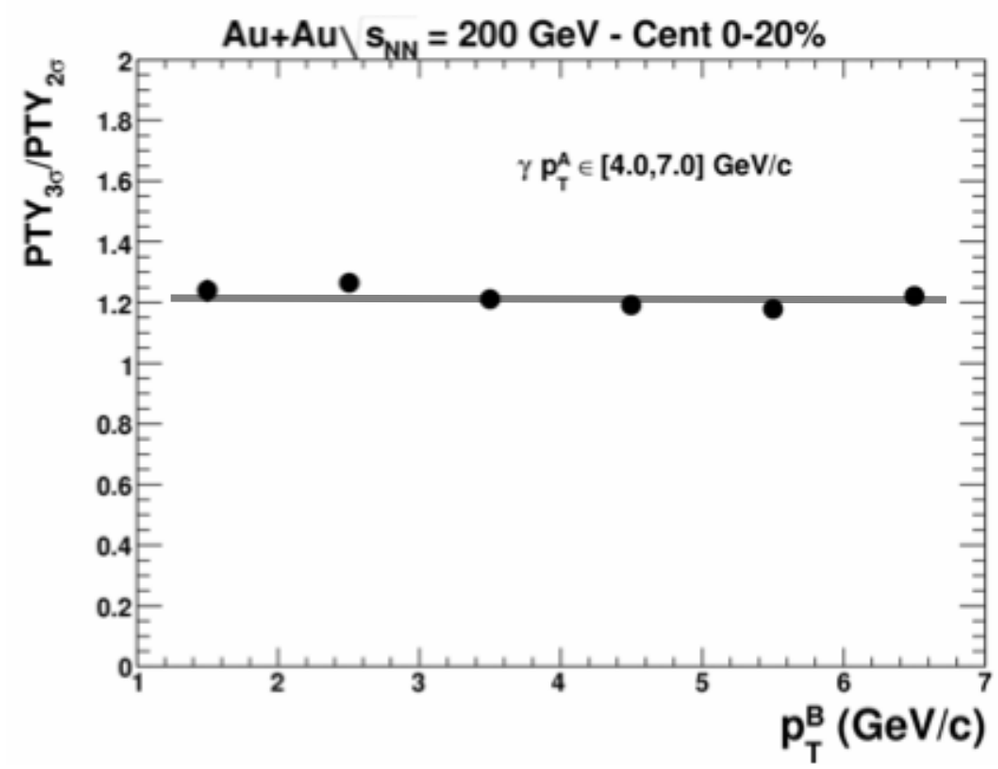


Pair Correlations



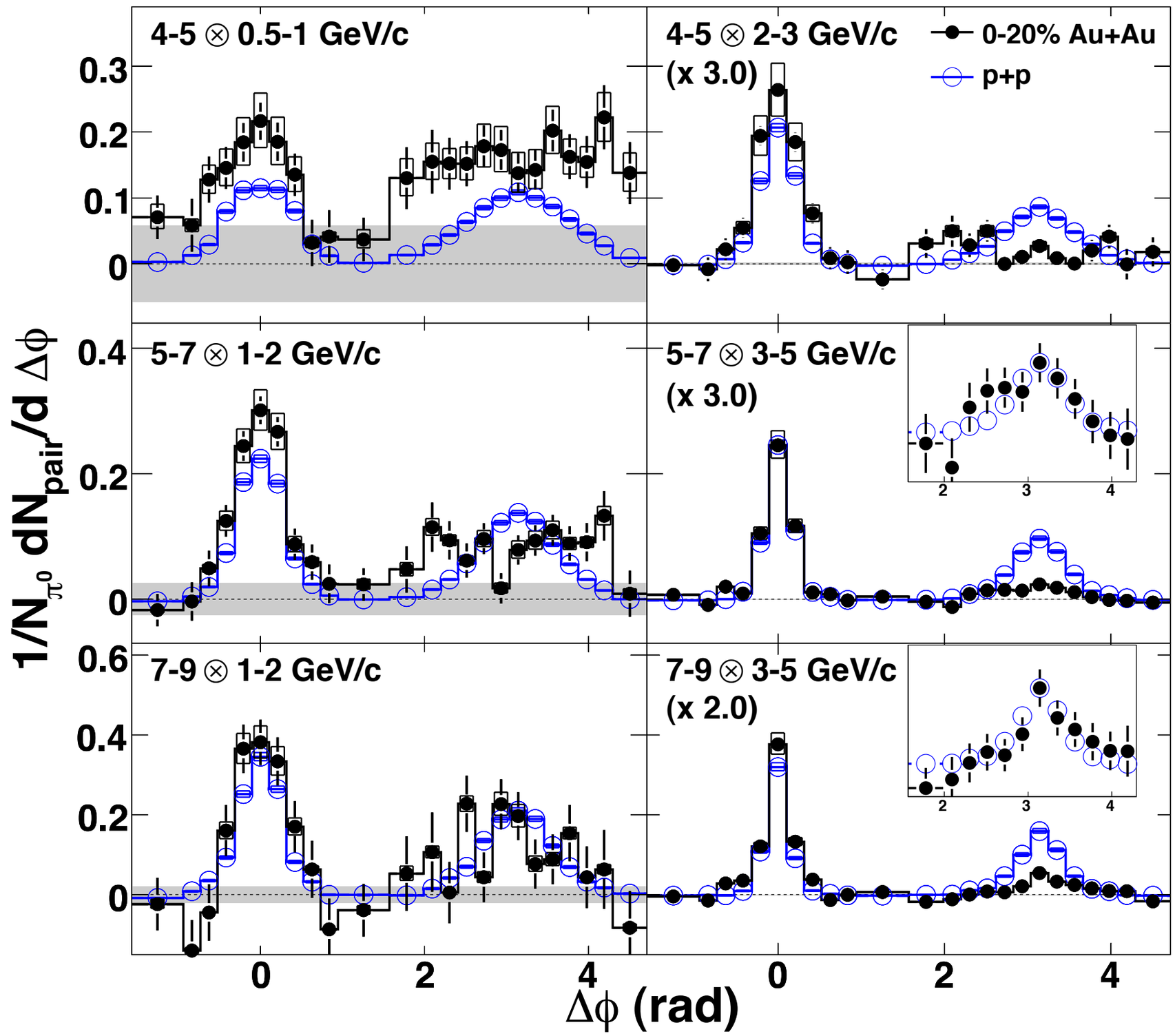
Jet pairs free of background < 7 GeV/c

Two-Particle Correlations

π^0: 4-12 GeV/c
$h^{\pm}$: 0.5-7 GeV/c

Broad range of trigger p^t_T

arXiv:1002.1077v2, Accepted by PRL



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Back-to-back peaks for all measured associated p_T

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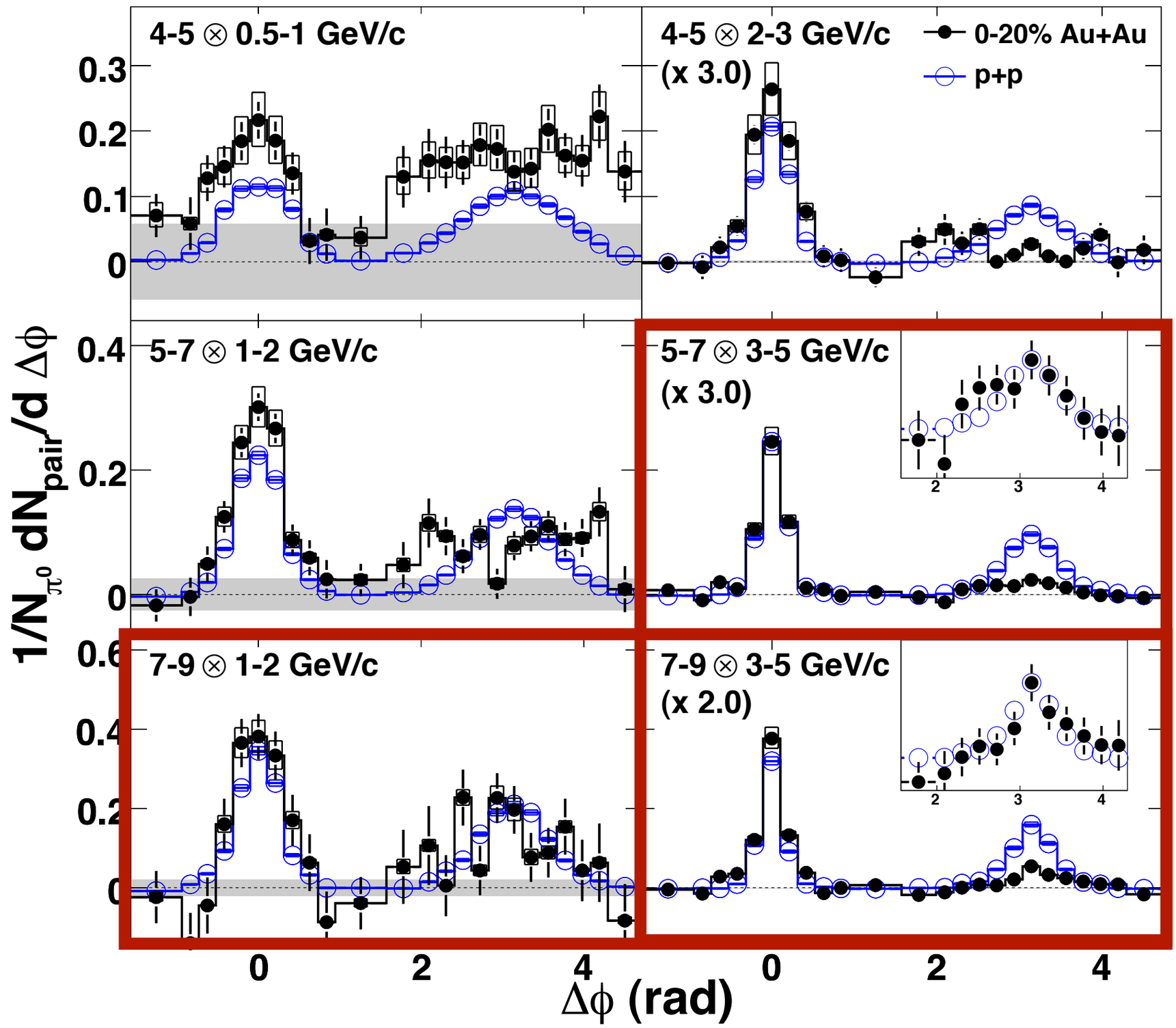

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Still no evidence for jet broadening

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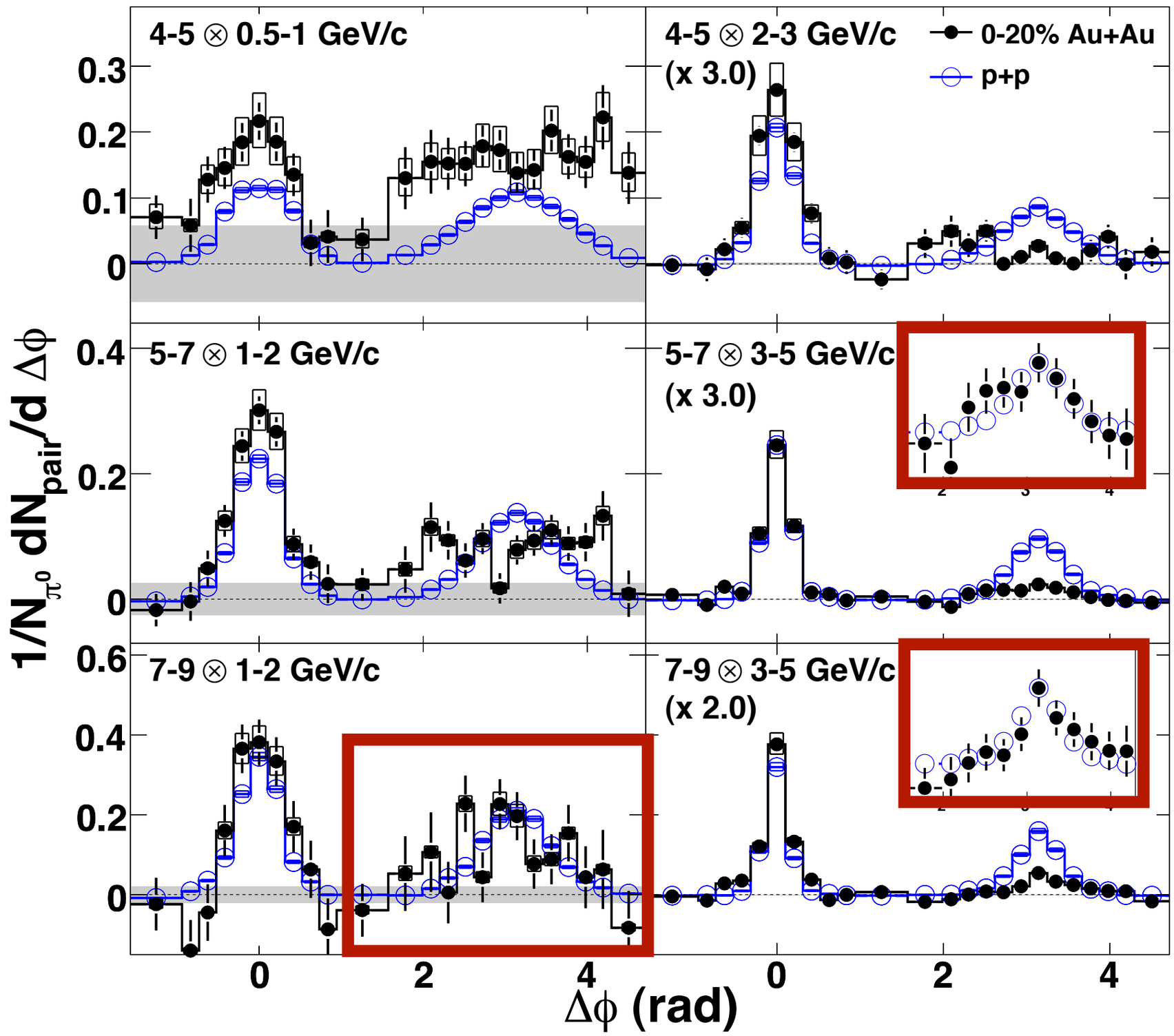
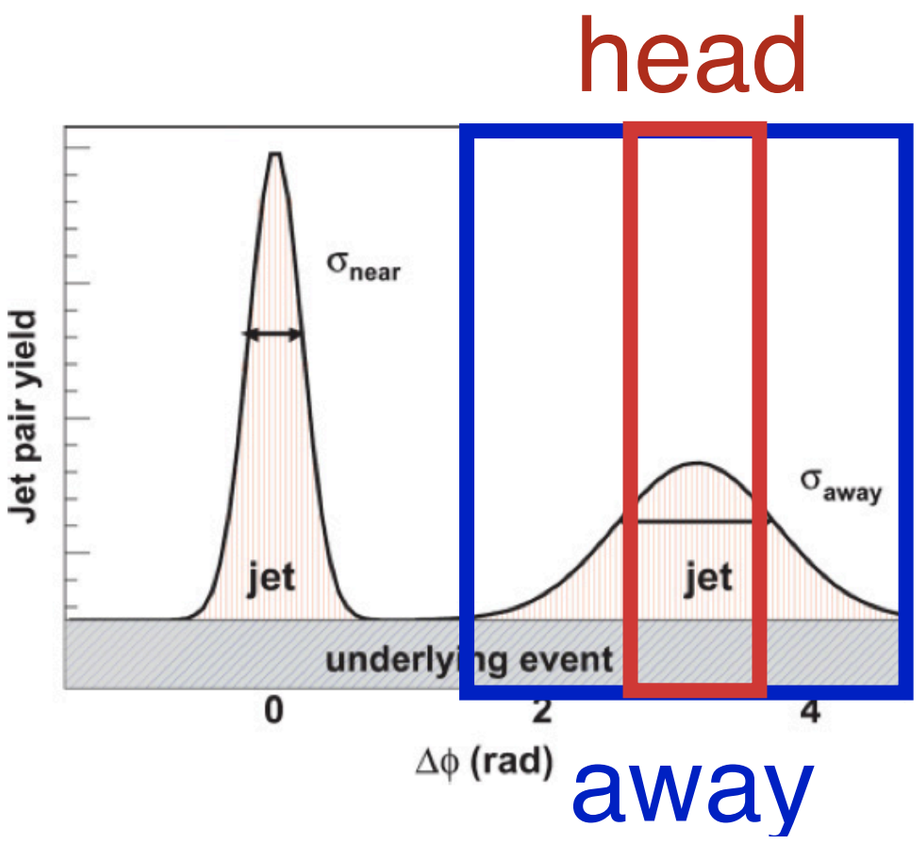


Away-side suppression at large associated p_T

Away-side I_{AA}

$$I_{AA} = \frac{(N^{ta}/N^{t})_{Au+Au}}{(N^{ta}/N^{t})_{p+p}}$$



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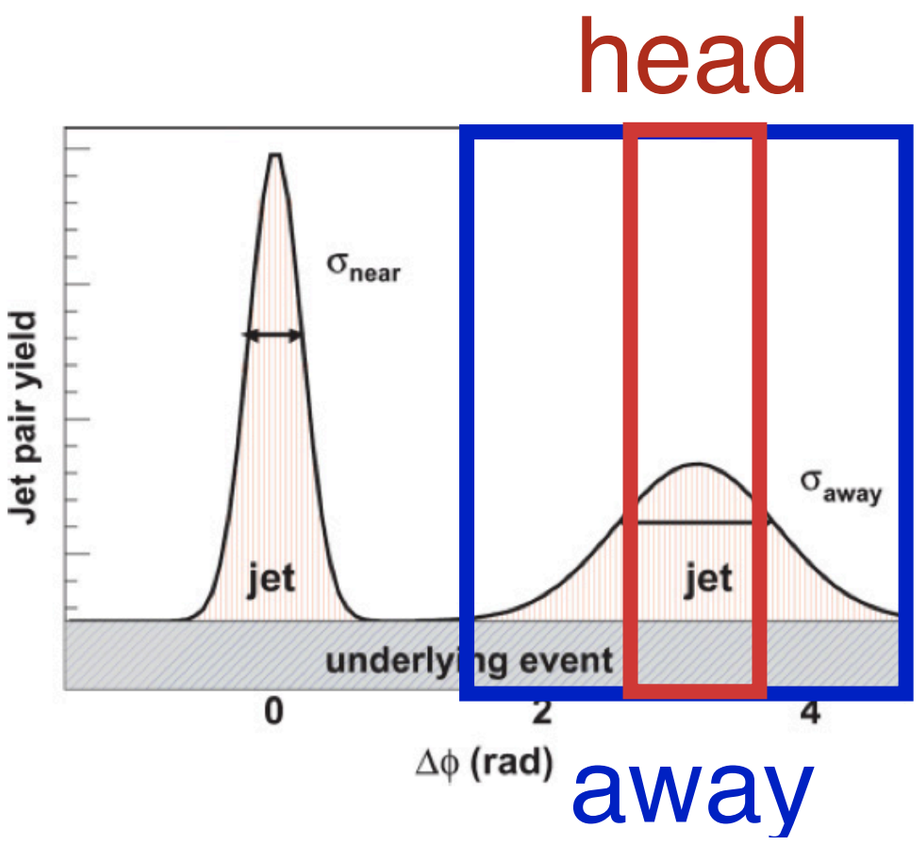

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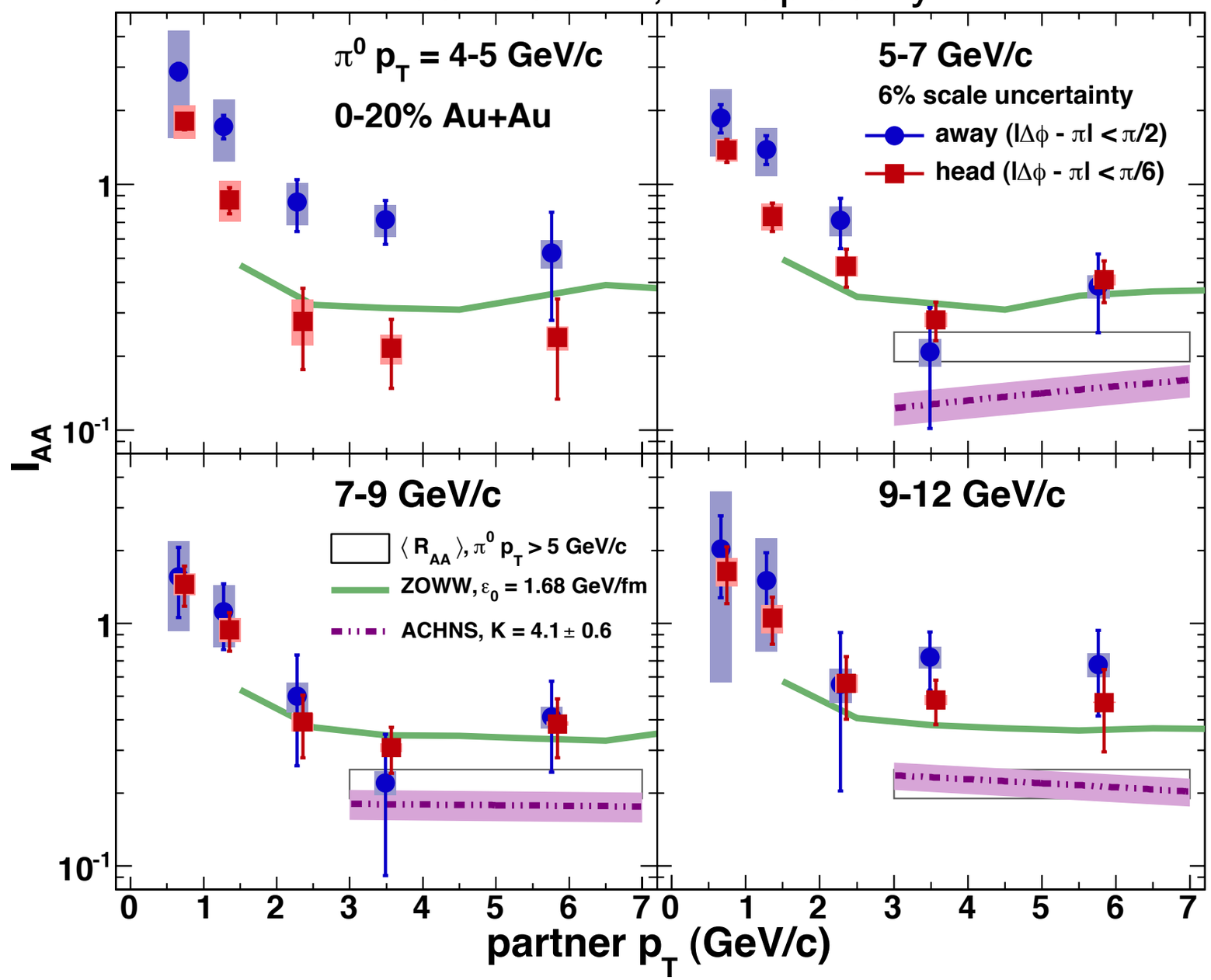

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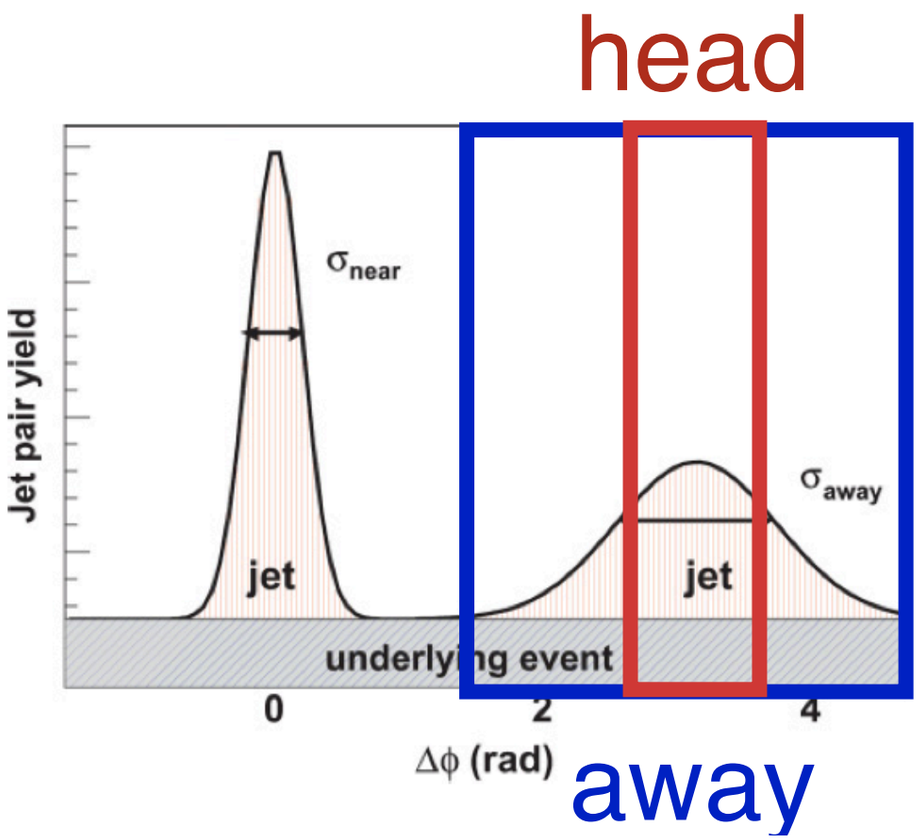

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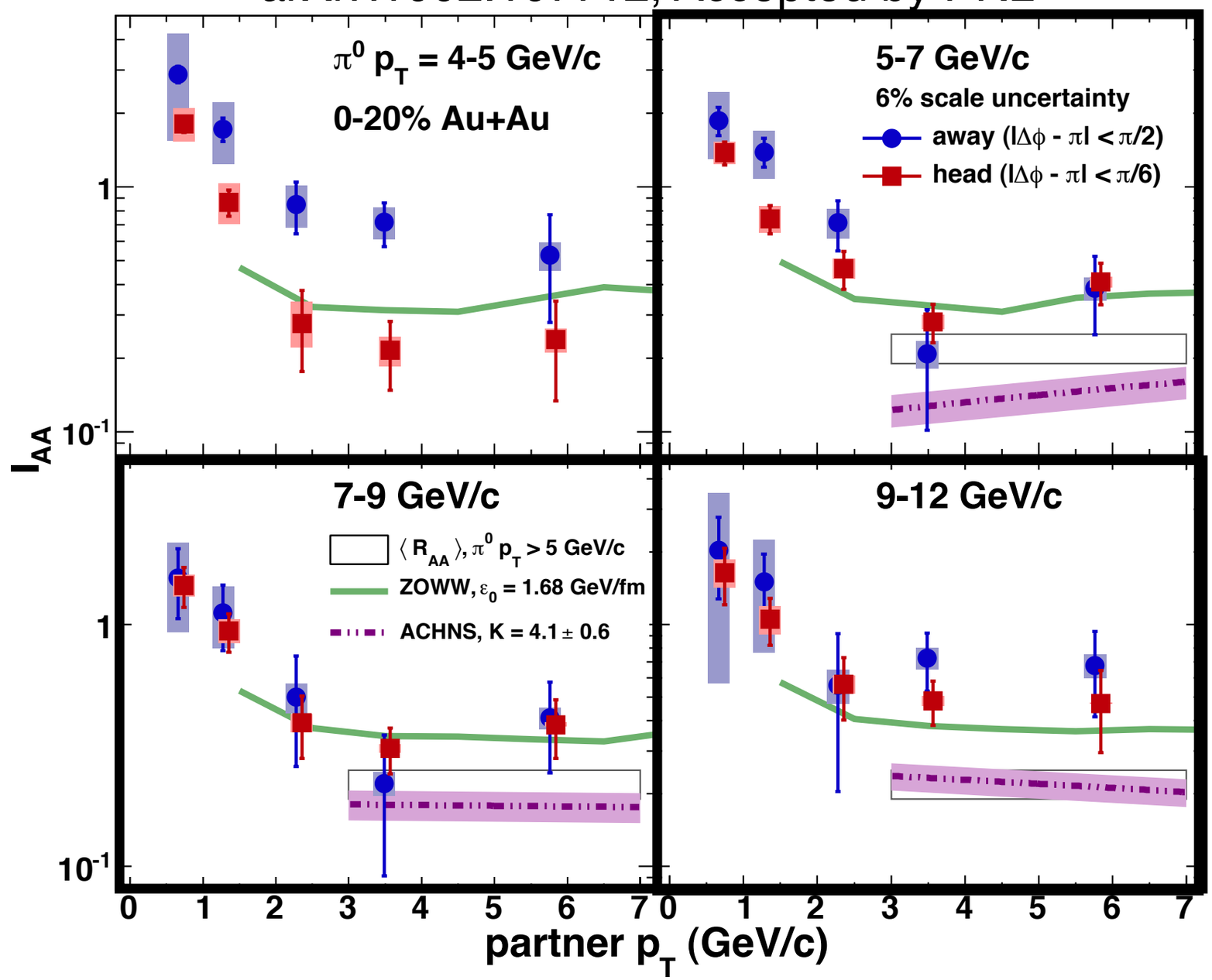

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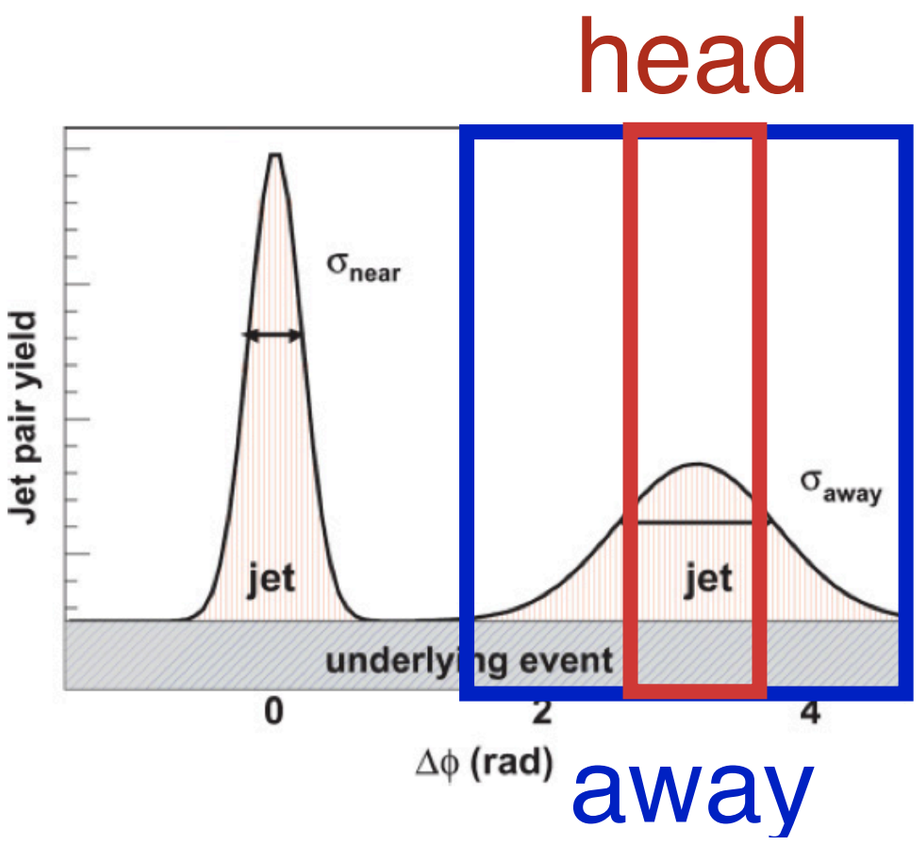

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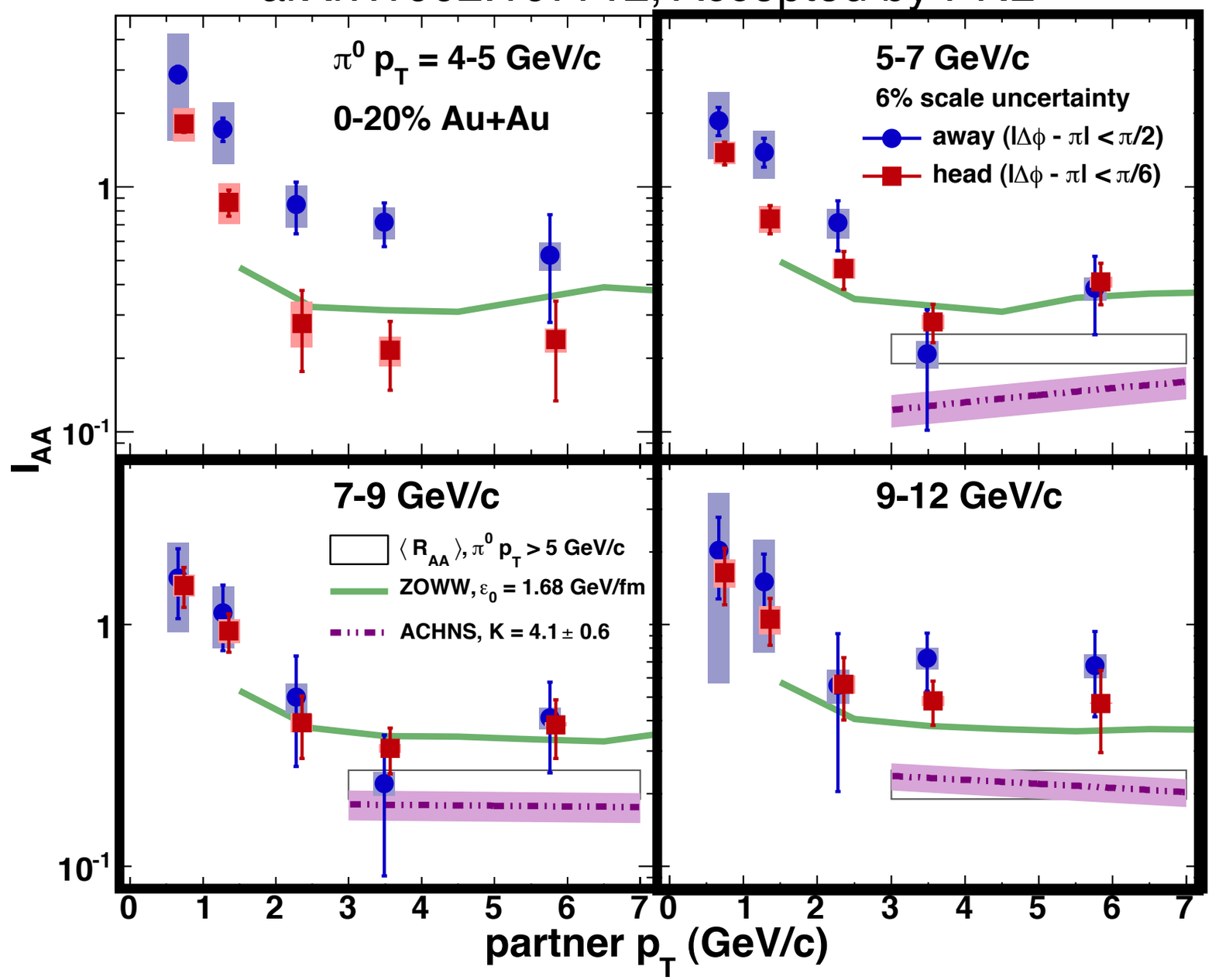

No shape change implies: $I_{AA}^{away} = I_{AA}^{head}$

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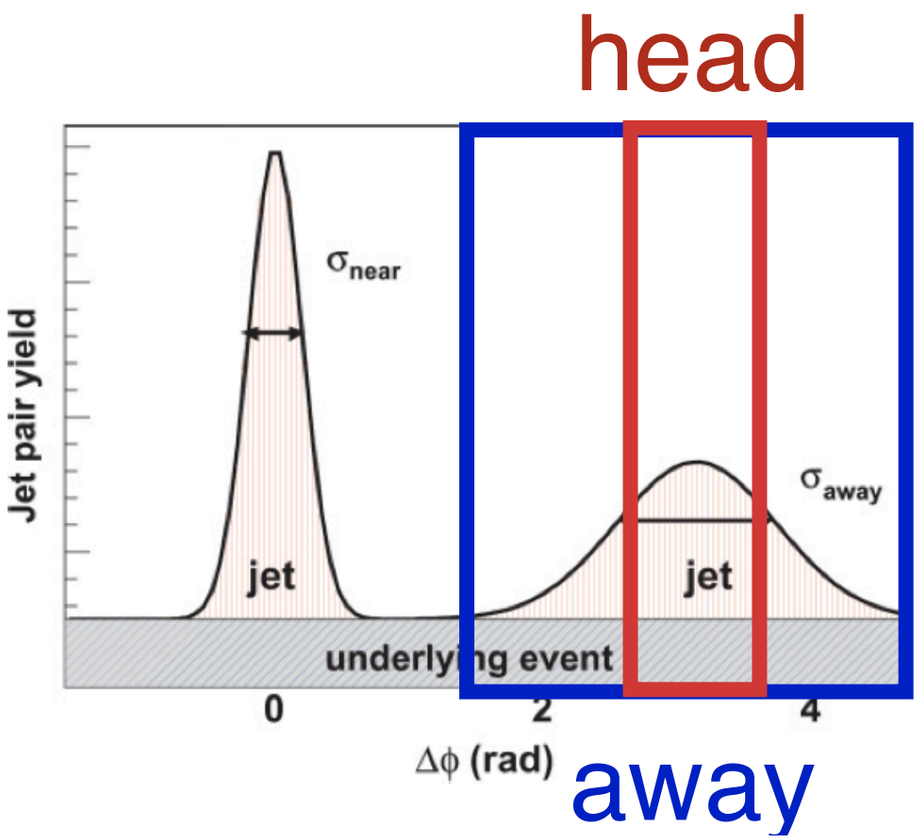

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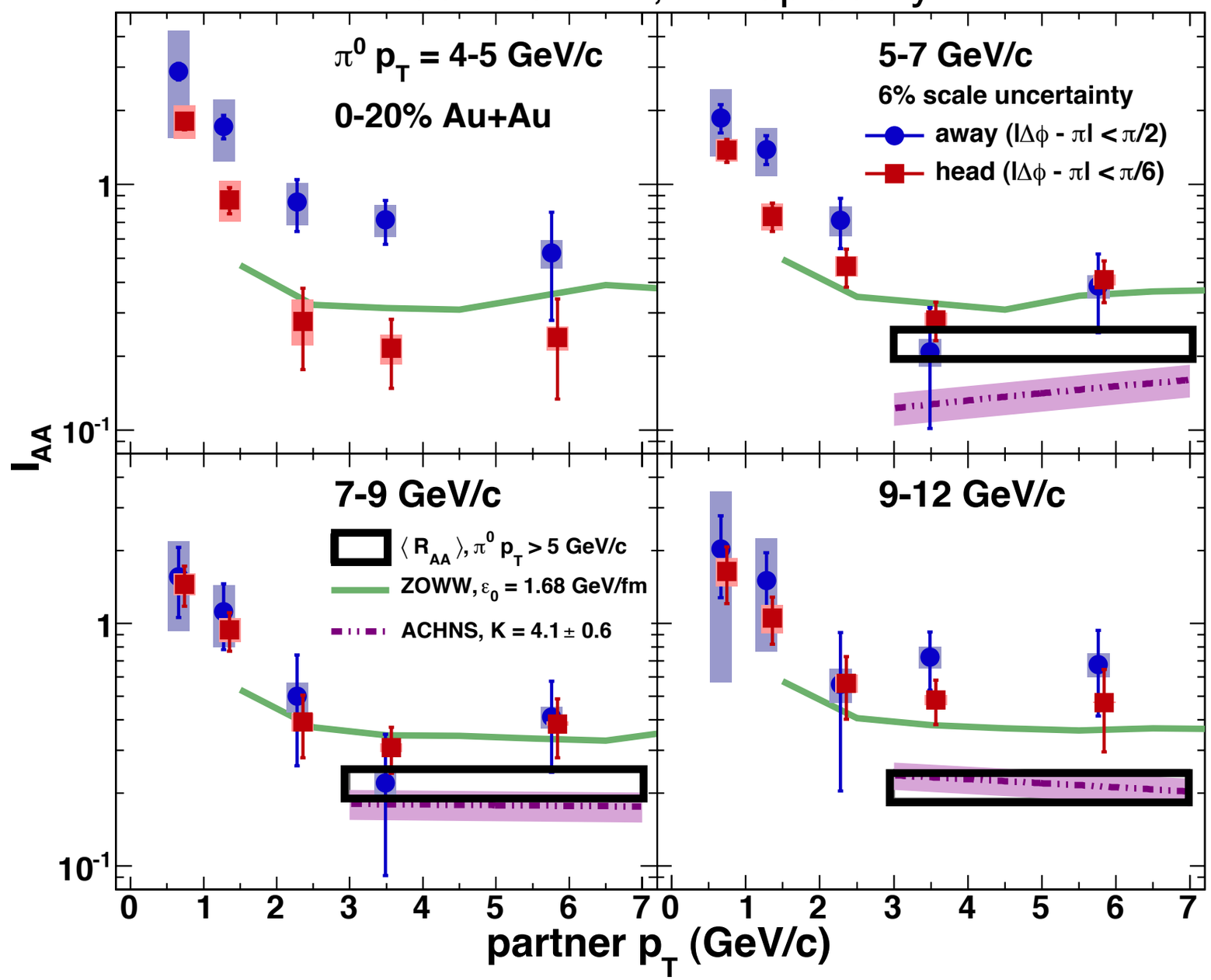
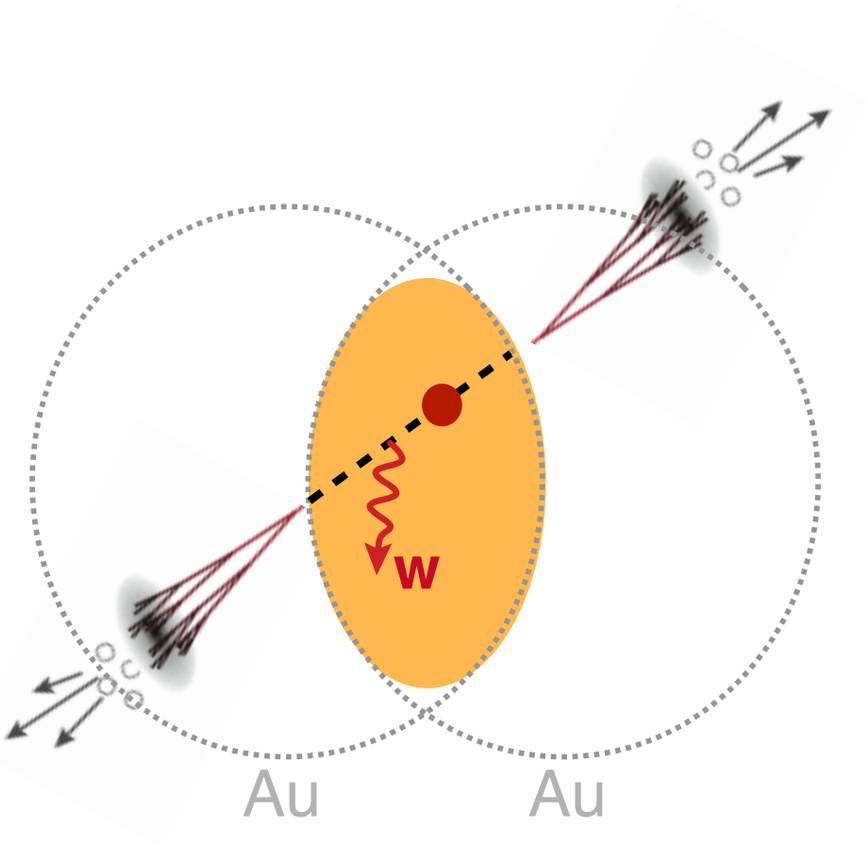


Observation: Surprisingly at high p_T, $I_{AA} > R_{AA}$

How can $I_{AA} > R_{AA}$?

Pythia + simple energy loss + Glauber geometry toy model



Assume:

$$d\hat{E}/\hat{E}_0 = dE/E_0$$

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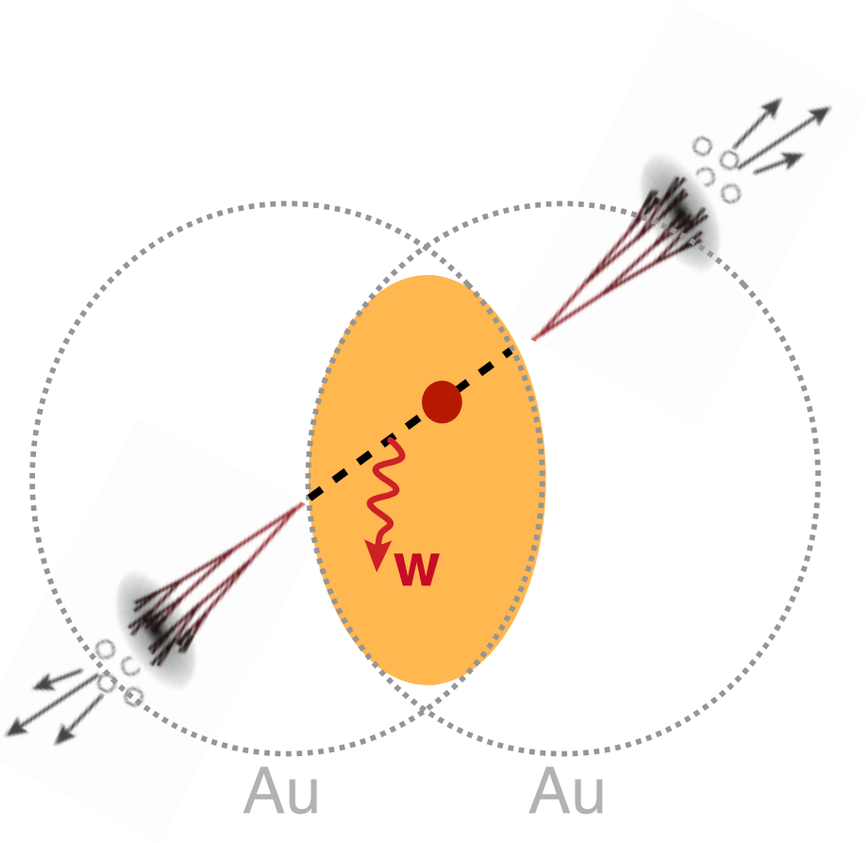

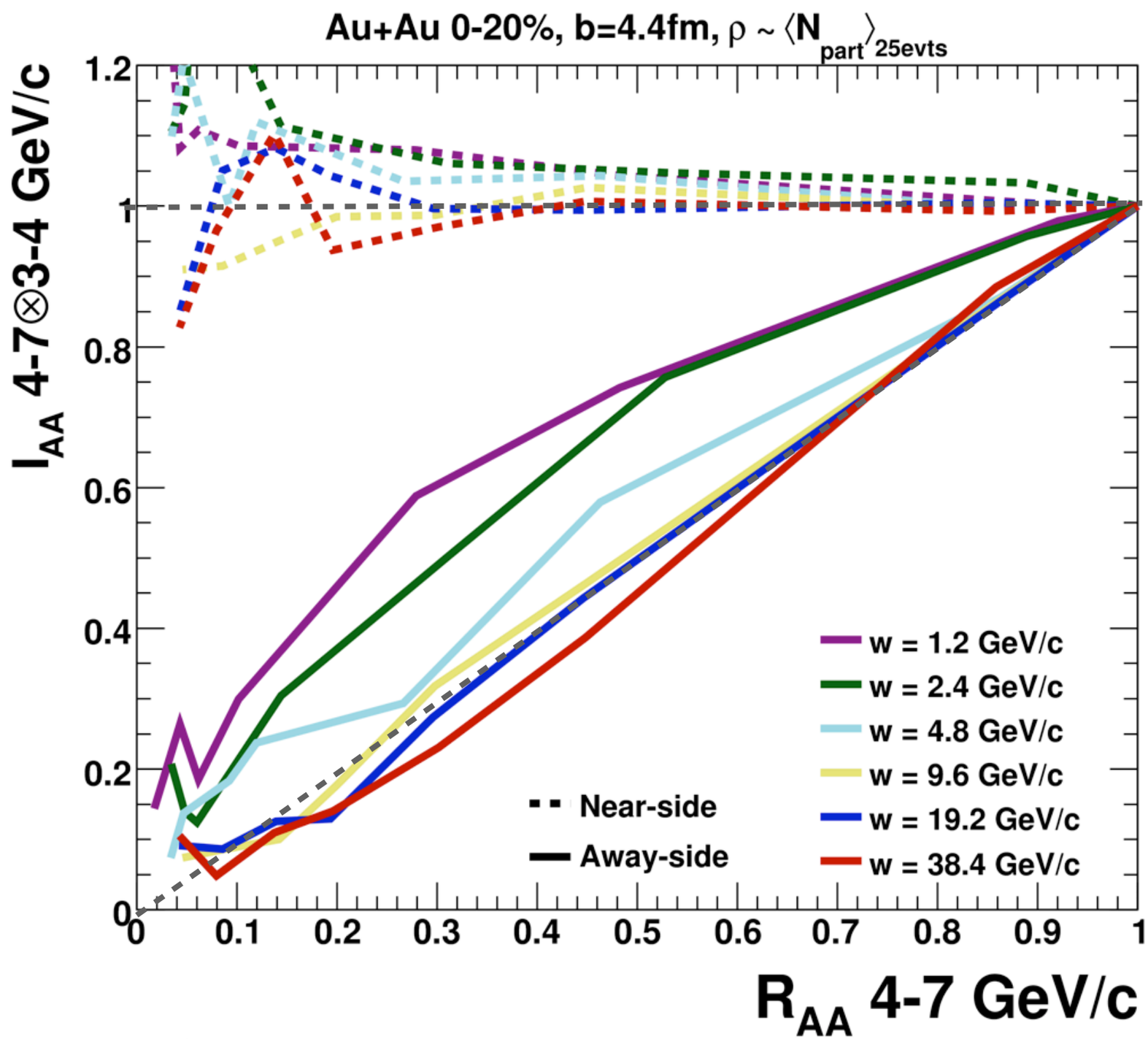

Assume:

$$d\hat{E}/\hat{E}_0 = dE/E_0$$

Can get:

$$I_{AA} > R_{AA}$$

Momentum shifts against the harder conditional spectra

increasing interaction probability

Away-side I_{AA}

Increasing trigger p_T:

- further hardens the away-side spectrum

- results in larger I_{AA} values

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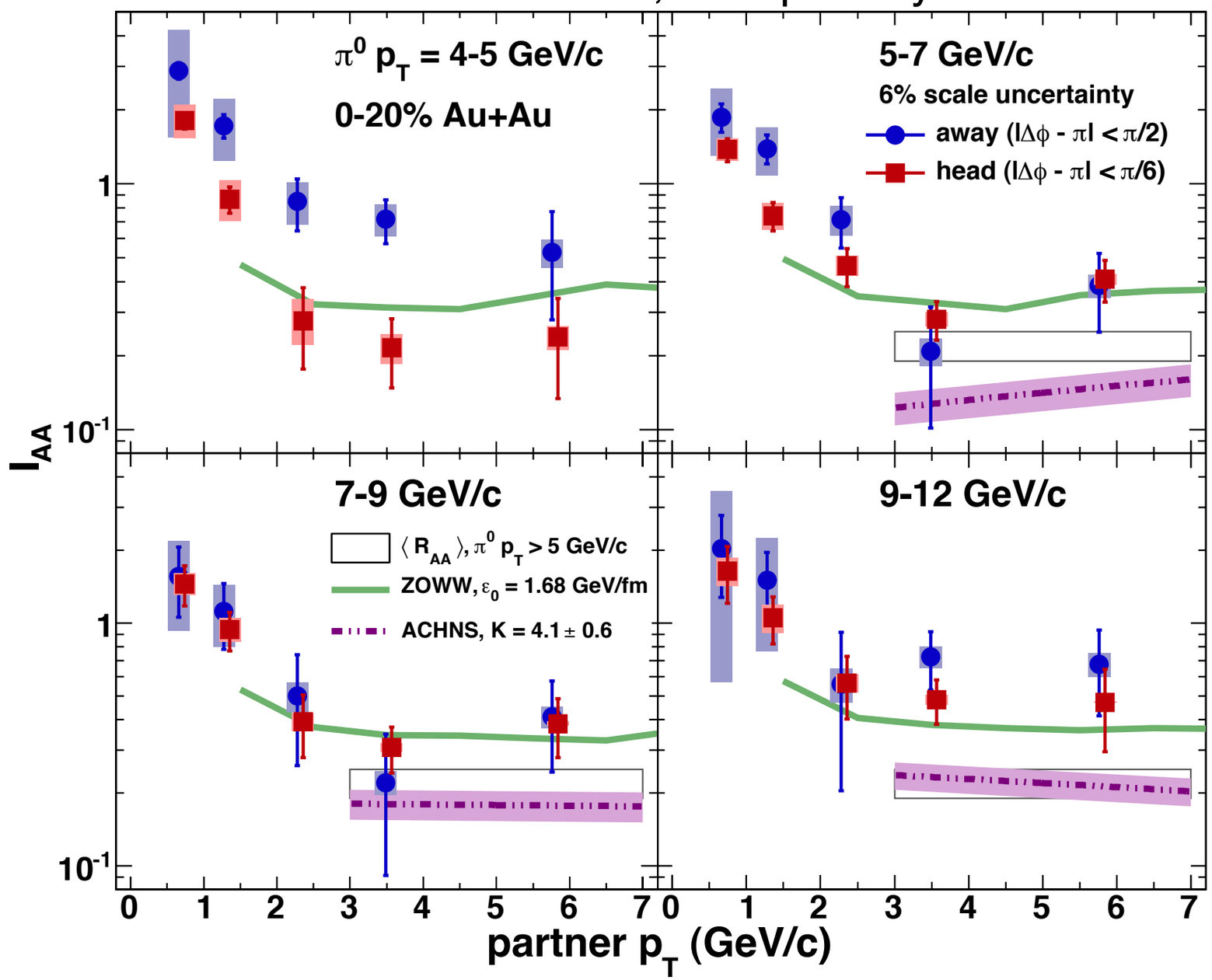

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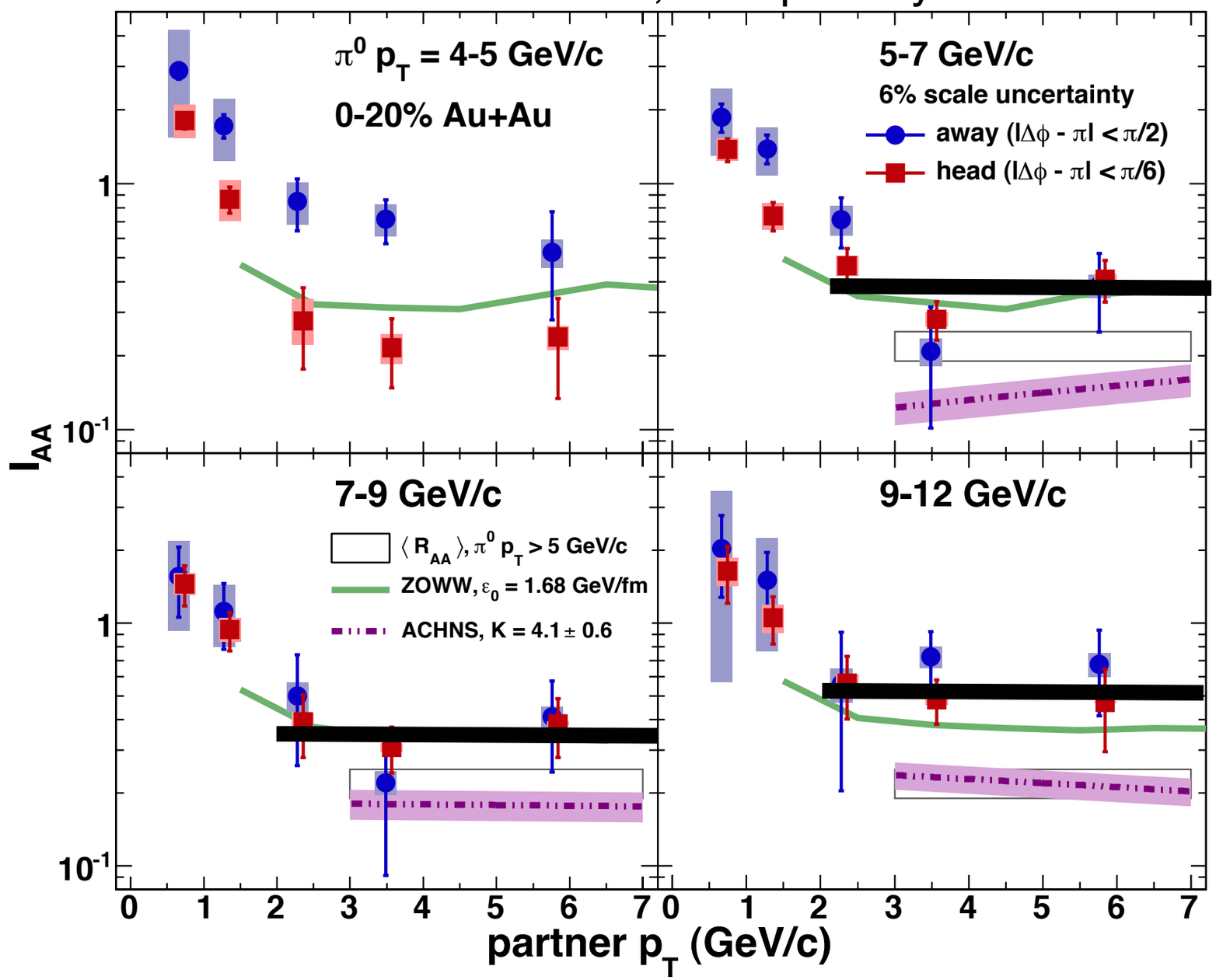

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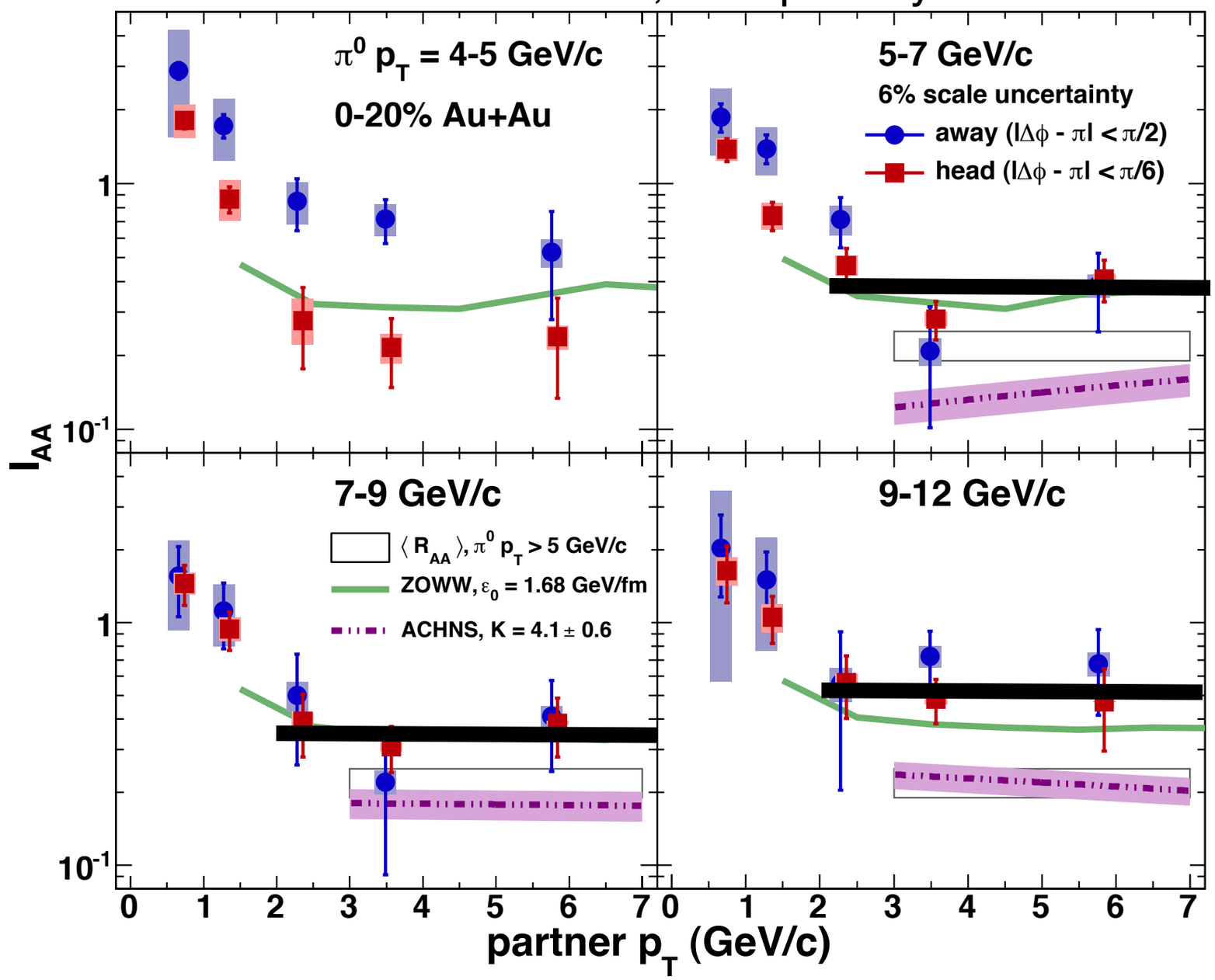

increasing p_T^t

	Cent 0–20%			Cent 20–60%		
p_T^t	I_{AA}^{head}	$\pm\sigma_{stat}$	$\pm\sigma_{syst}$	I_{AA}^{head}	$\pm\sigma_{stat}$	$\pm\sigma_{syst}$
5–7	0.35	0.04	0.03	0.55	0.02	0.04
7–9	0.34	0.05	0.03	0.64	0.04	0.02
9–12	0.50	0.08	0.02	0.73	0.06	0.02

Theoretical Away-side I_{AA}

ACHNS

Consistently falls below data

ASW energy loss + full hydro evolution (gives correct R_{AA})

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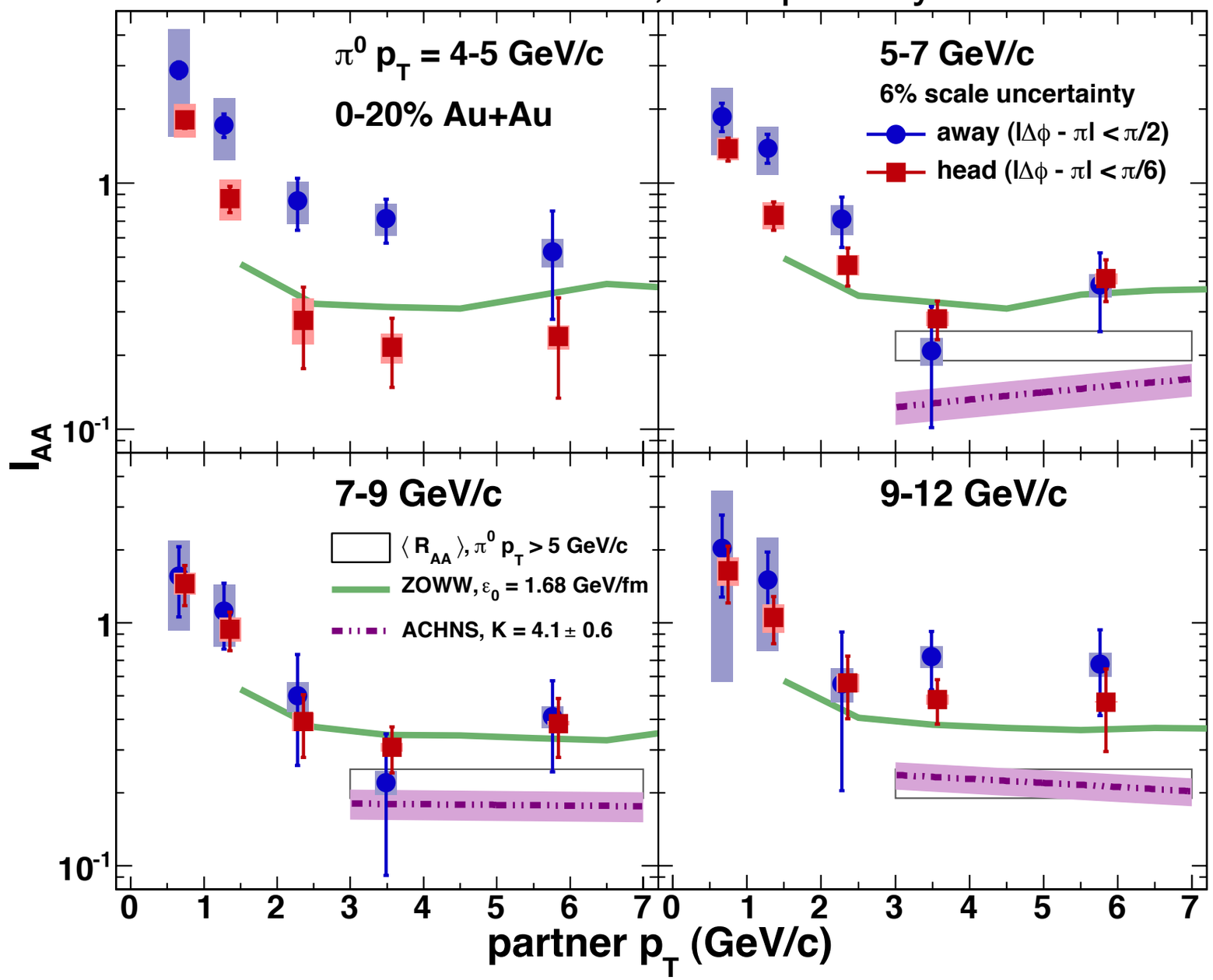

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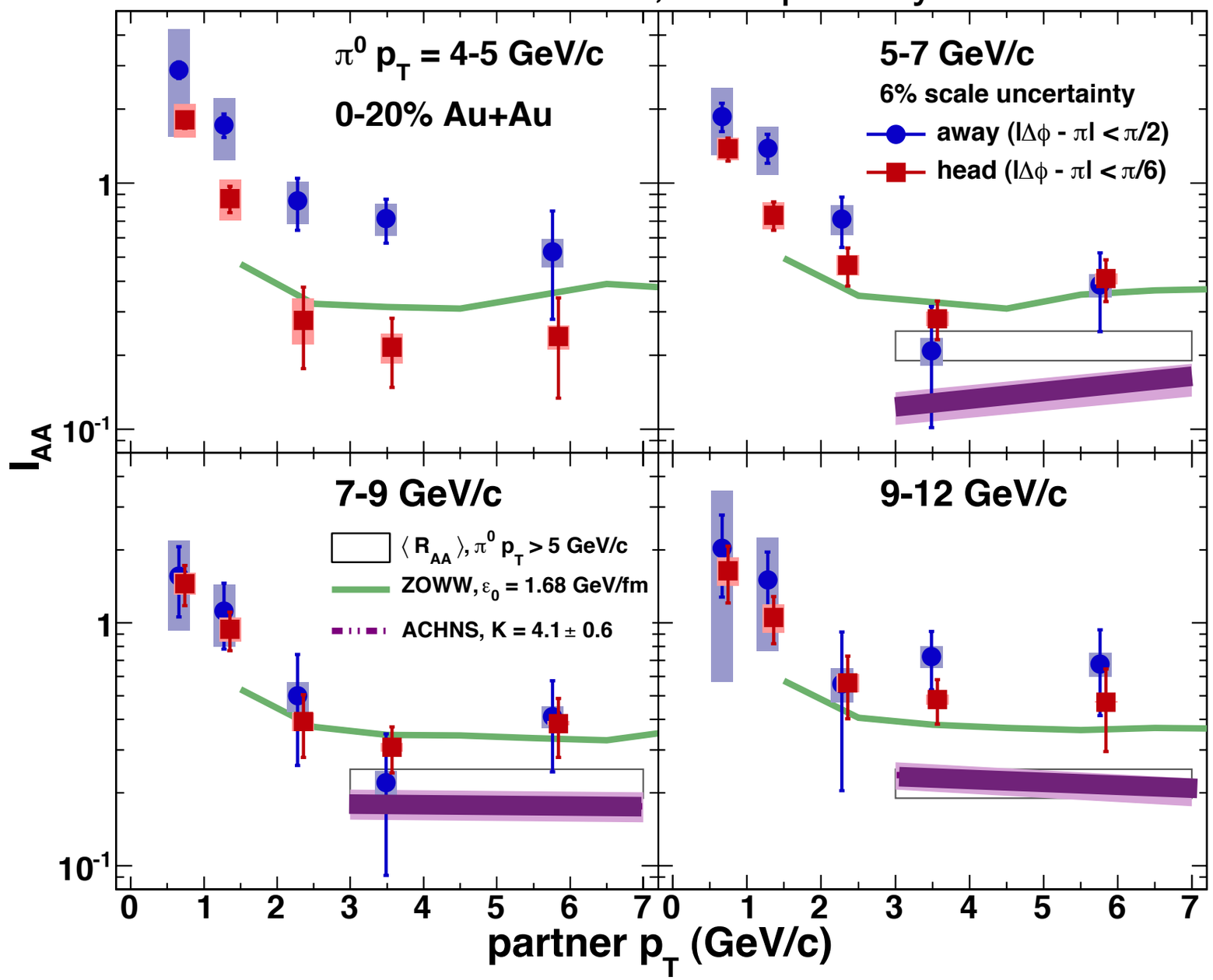

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ZOWW

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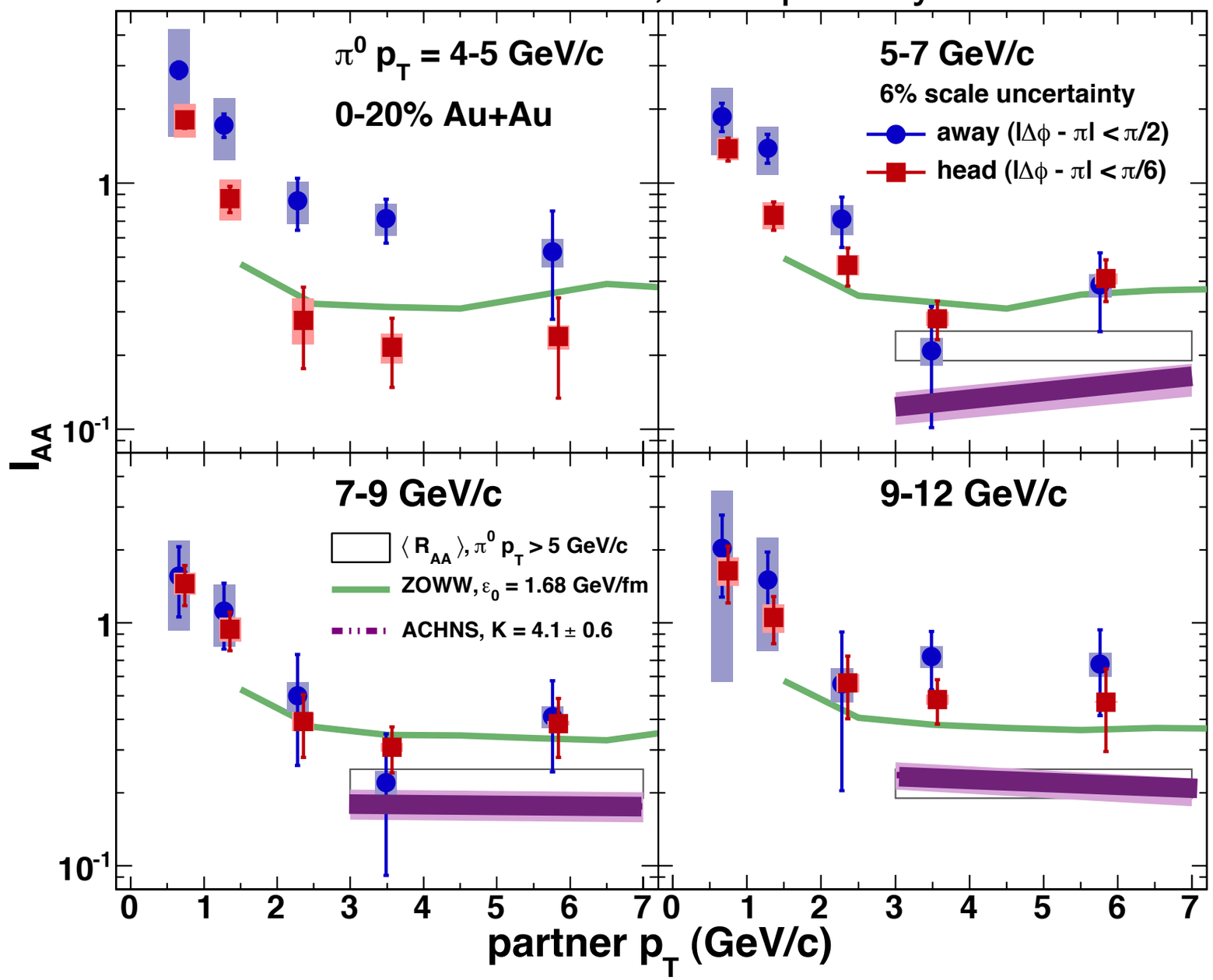
Uses a simple hard sphere geometry



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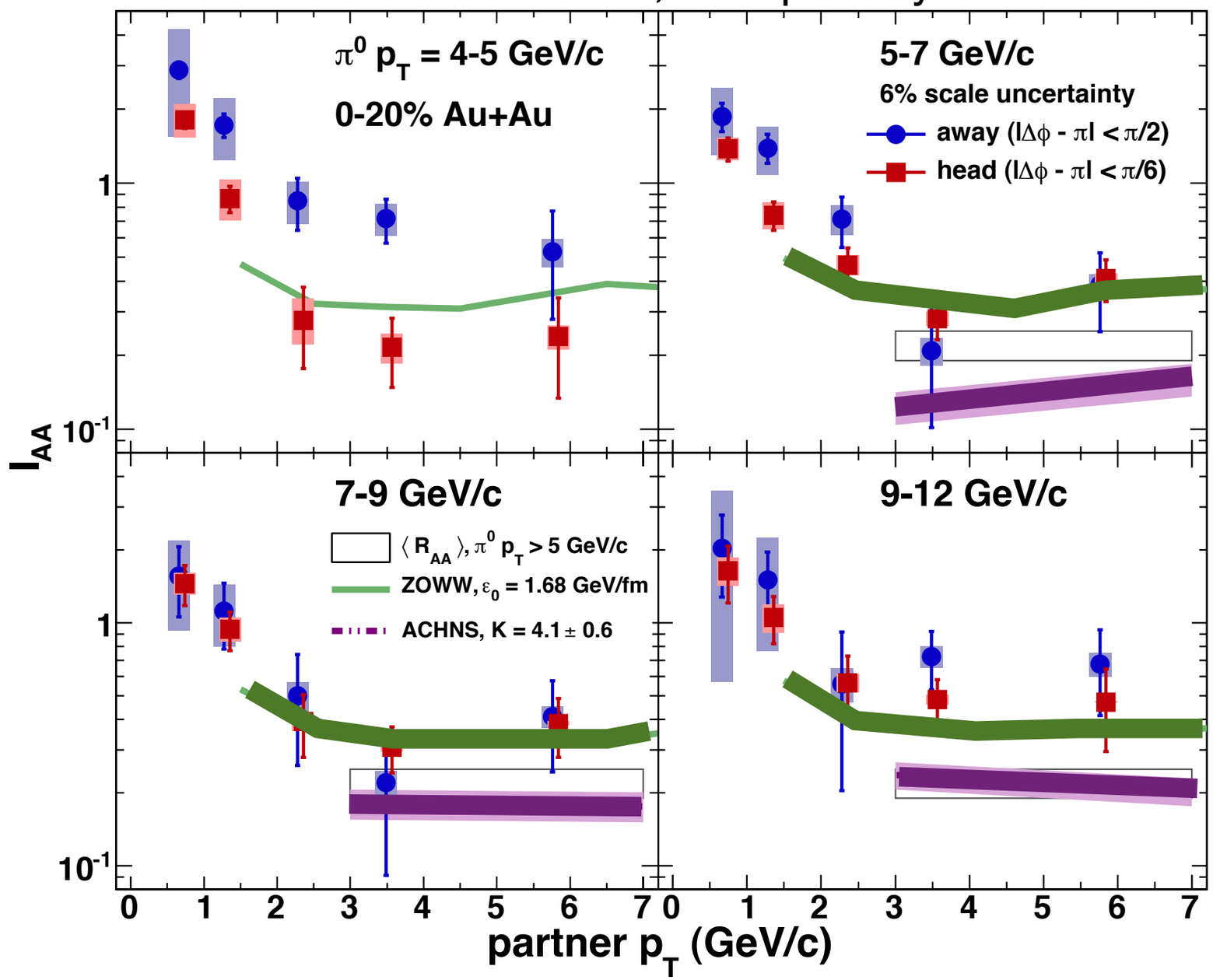

Theoretical Away-side I_{AA}

arXiv:1002.1077v2, Accepted by PRL

ACHNS

Consistently falls below data

ASW energy loss + full hydro evolution (gives correct R_{AA})

ZOWW

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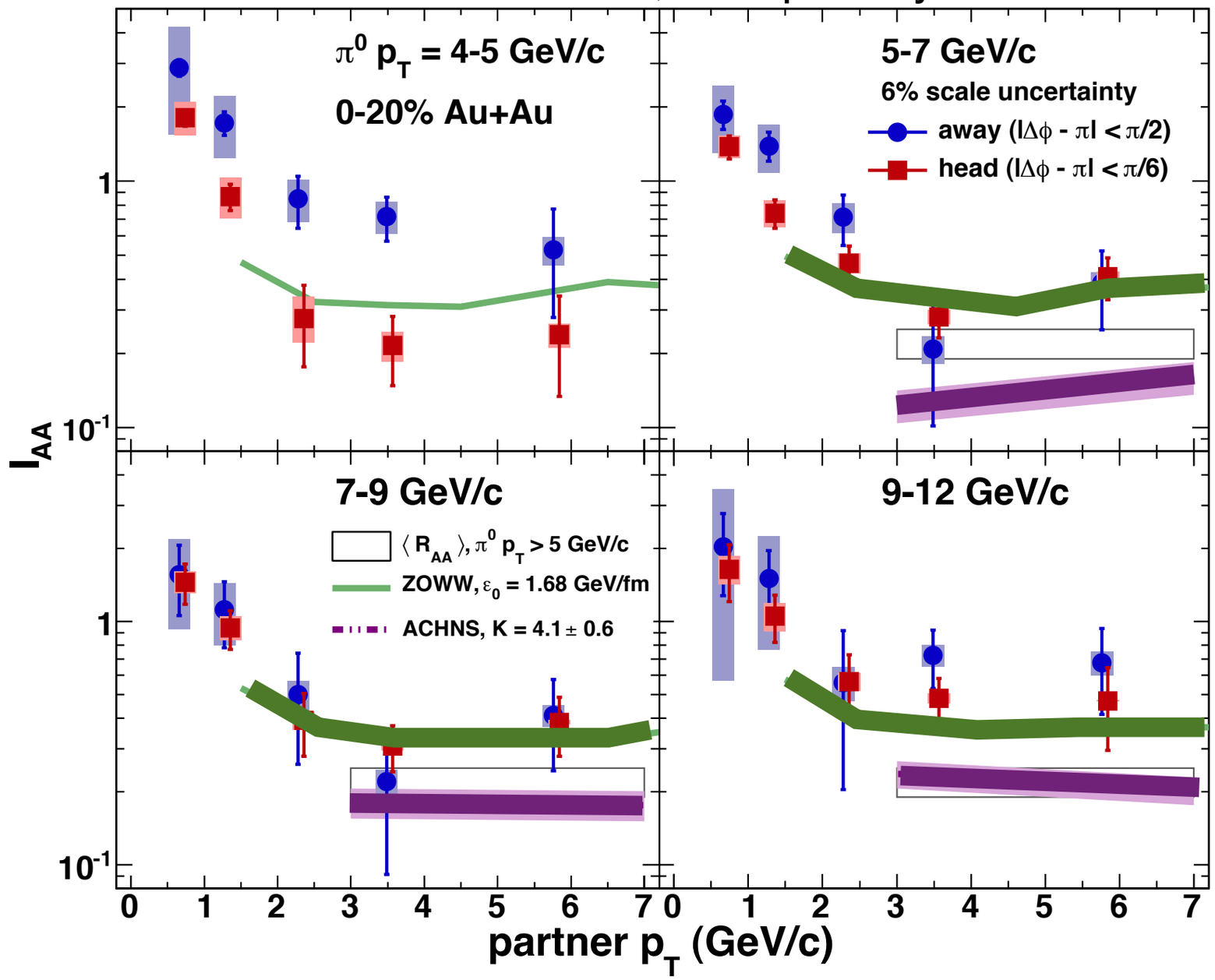

Is energy loss or medium geometry the crucial difference?

Theoretical Away-side I_{AA}

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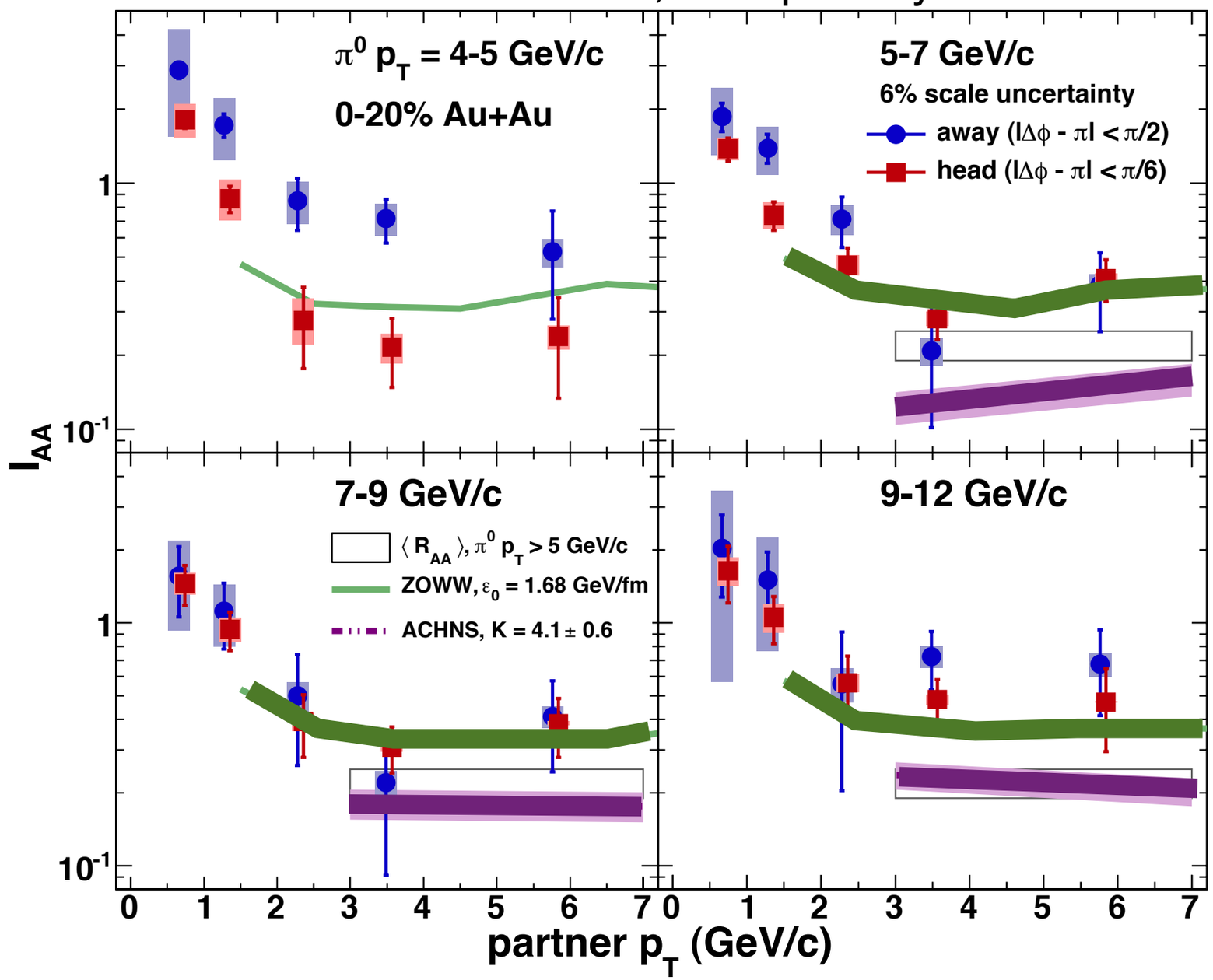
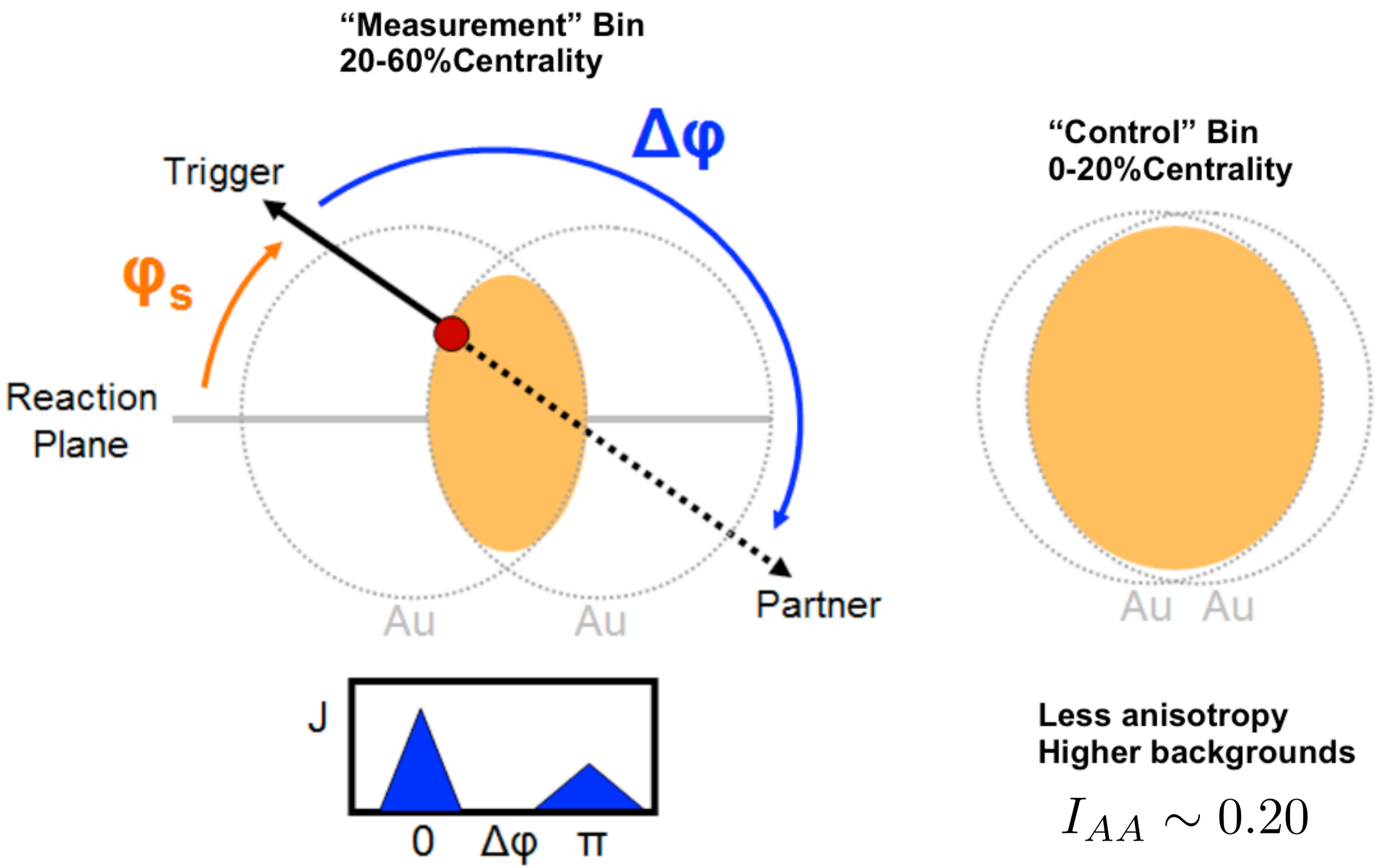


Is energy loss or medium geometry the crucial difference?

Any full description requires realistic: spectra, energy loss, *geometry*

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



$I_{AA} \sim 0.45 \quad t_{RMS} \in [3.2, 4.8]$ fm

$I_{AA} \sim 0.20$

$t_{RMS} \in [5.0, 5.8]$ fm

Method

Two source model:

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

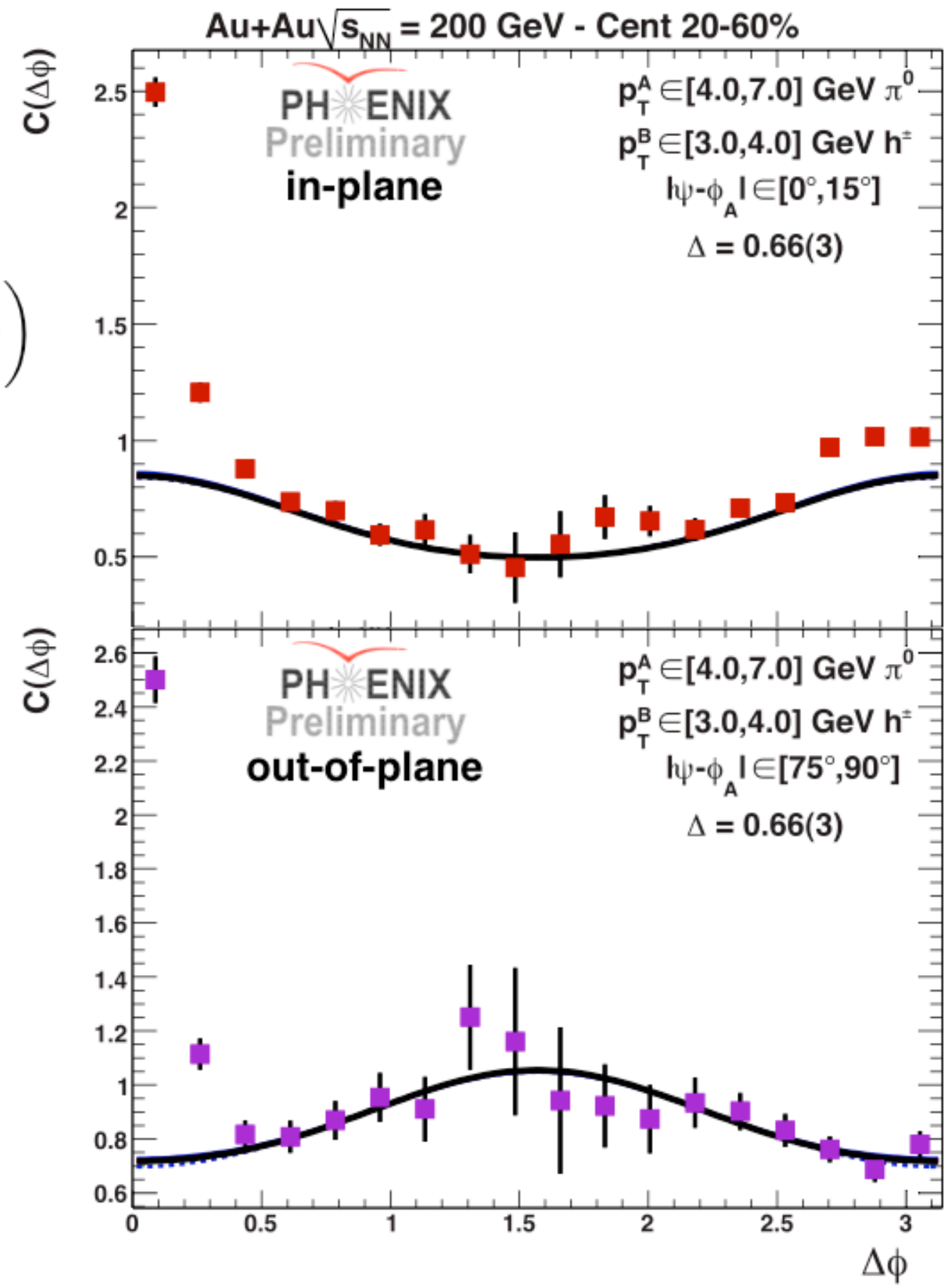
and rxpn-binning requires:

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

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

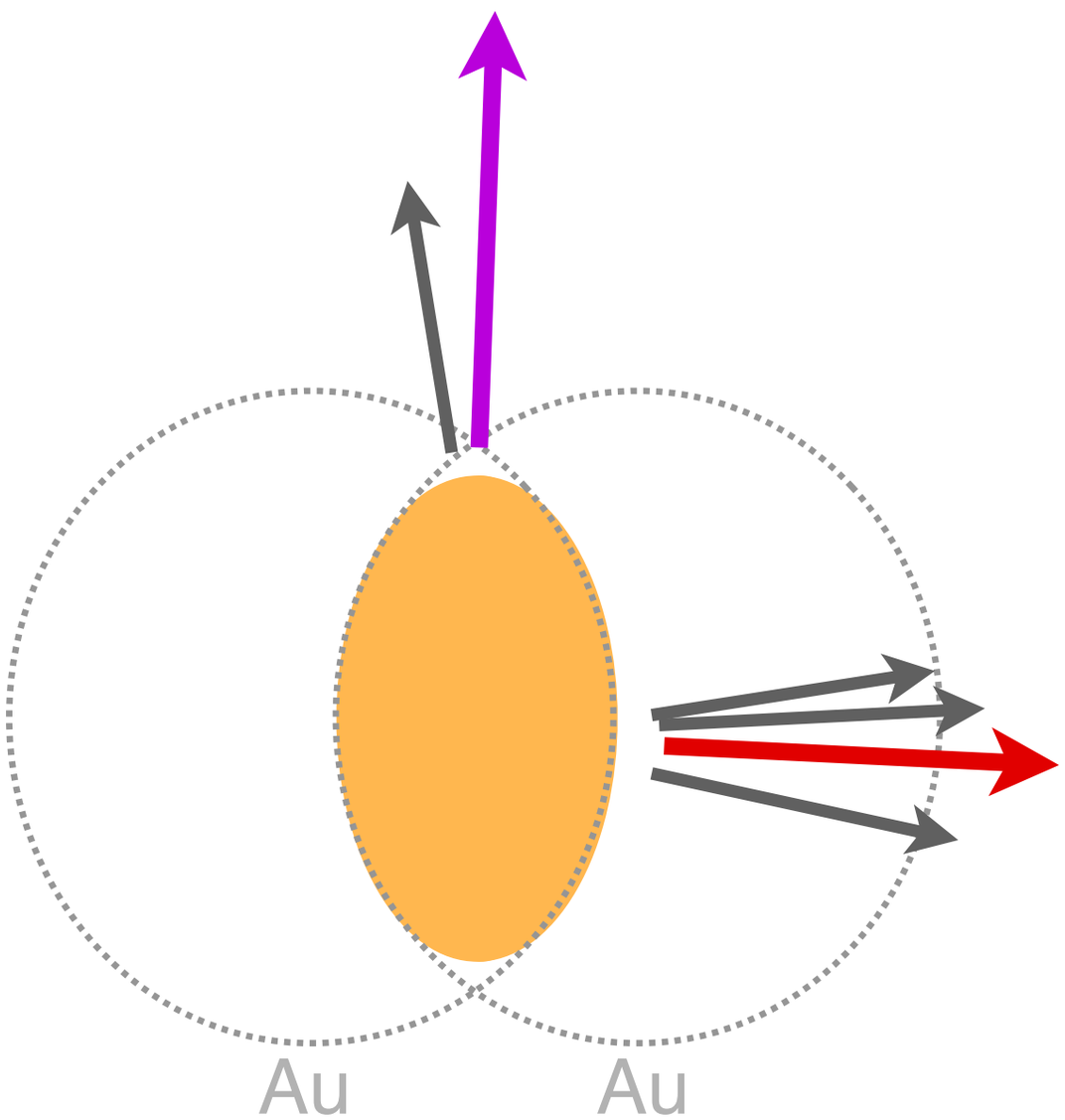
$$\gamma = 2v_4^A v_4^B + 2v_4^B\left(1 + v_2^A\right)cos(4\phi_s)\frac{sin(4c)}{4c}\Delta_4 + 2v_2^A v_4^B\left(cos(2\phi_s)\frac{sin(2c)}{2c}\Delta + cos(6\phi_s)\frac{sin(6c)}{6c}\Delta_6\right) + 2v_4^A v_4^B cos(8\phi_s)\frac{sin(8c)}{8c}\Delta_8$$

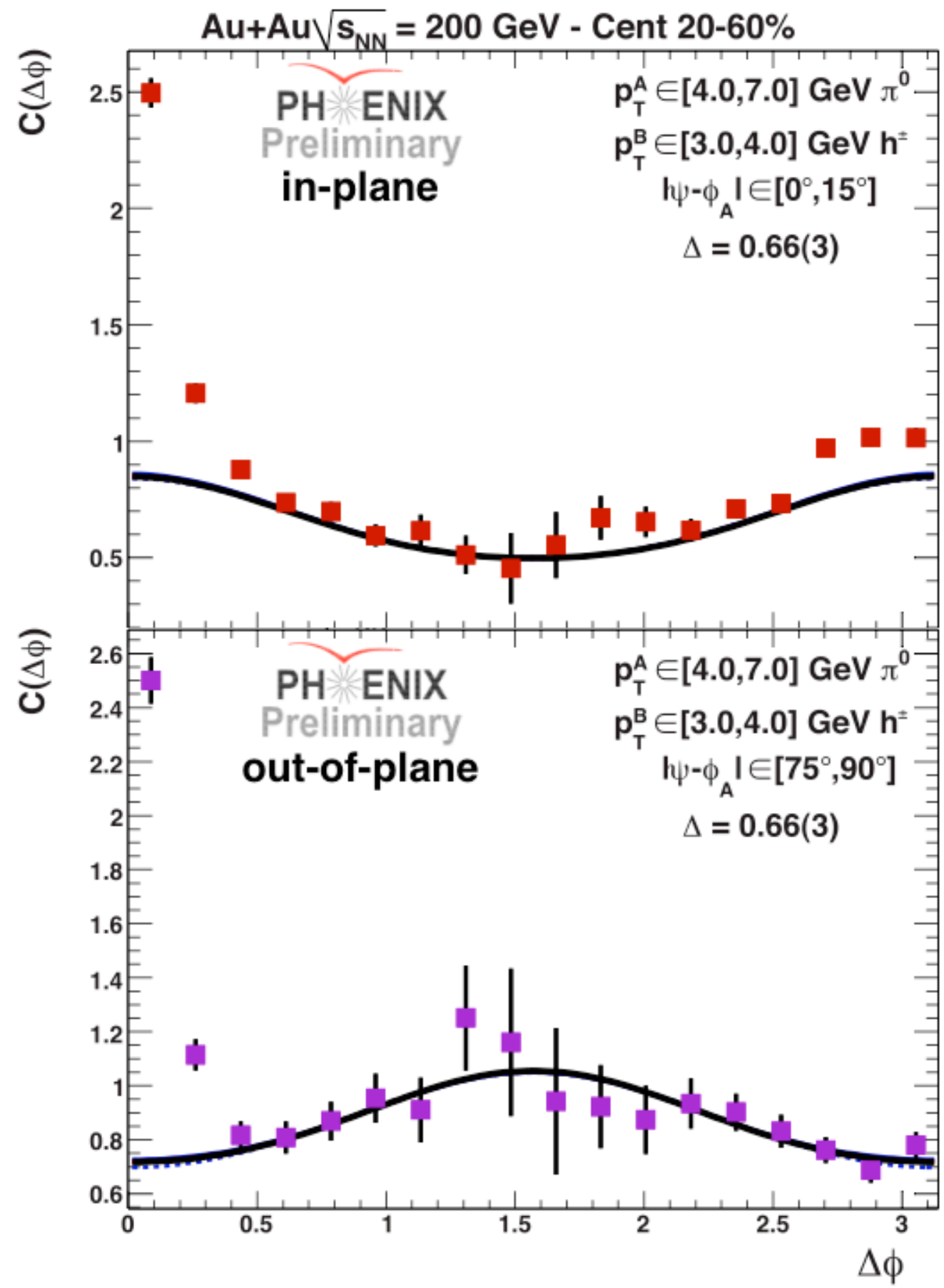
high order



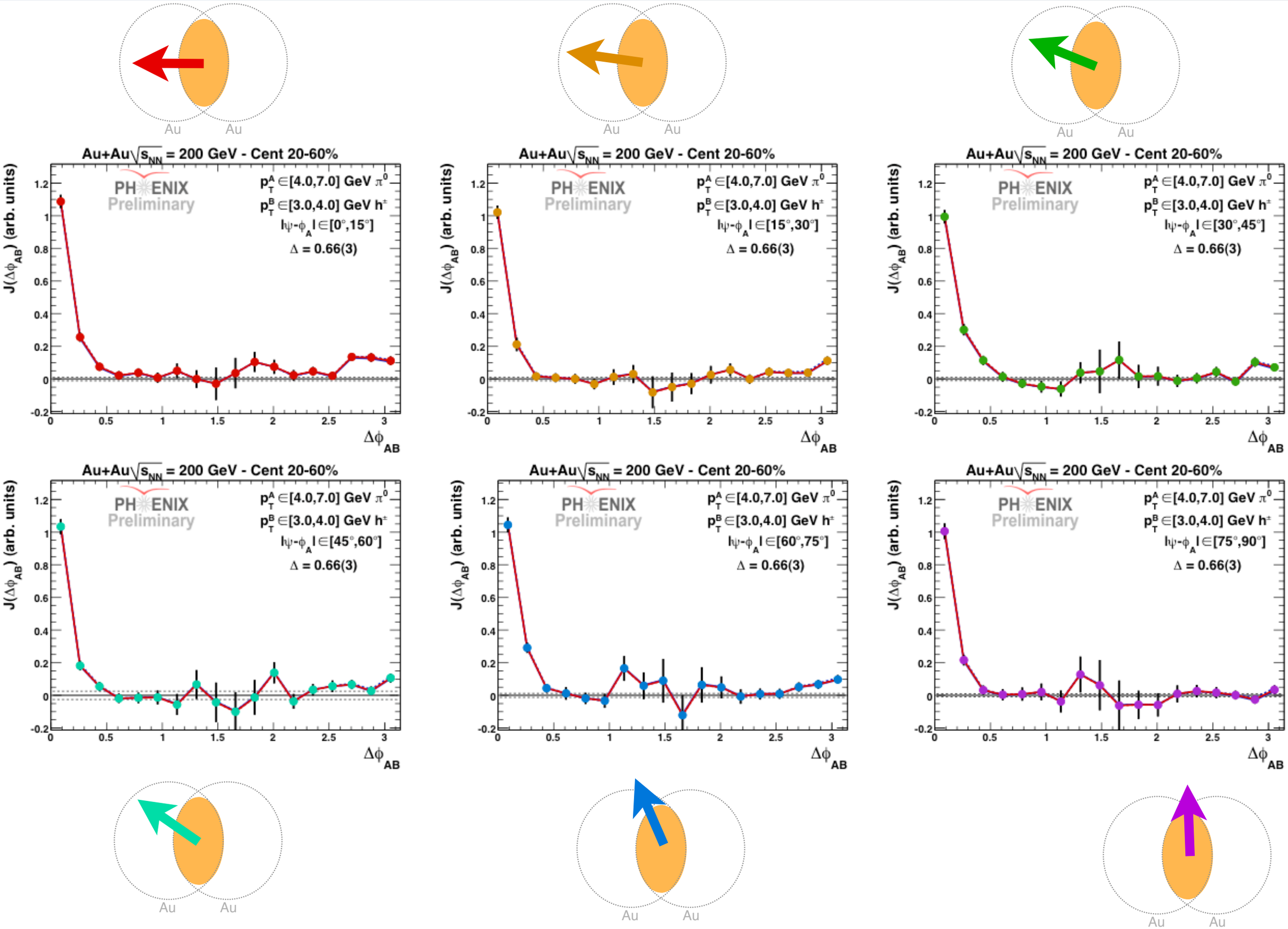
Method

But more simply:





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



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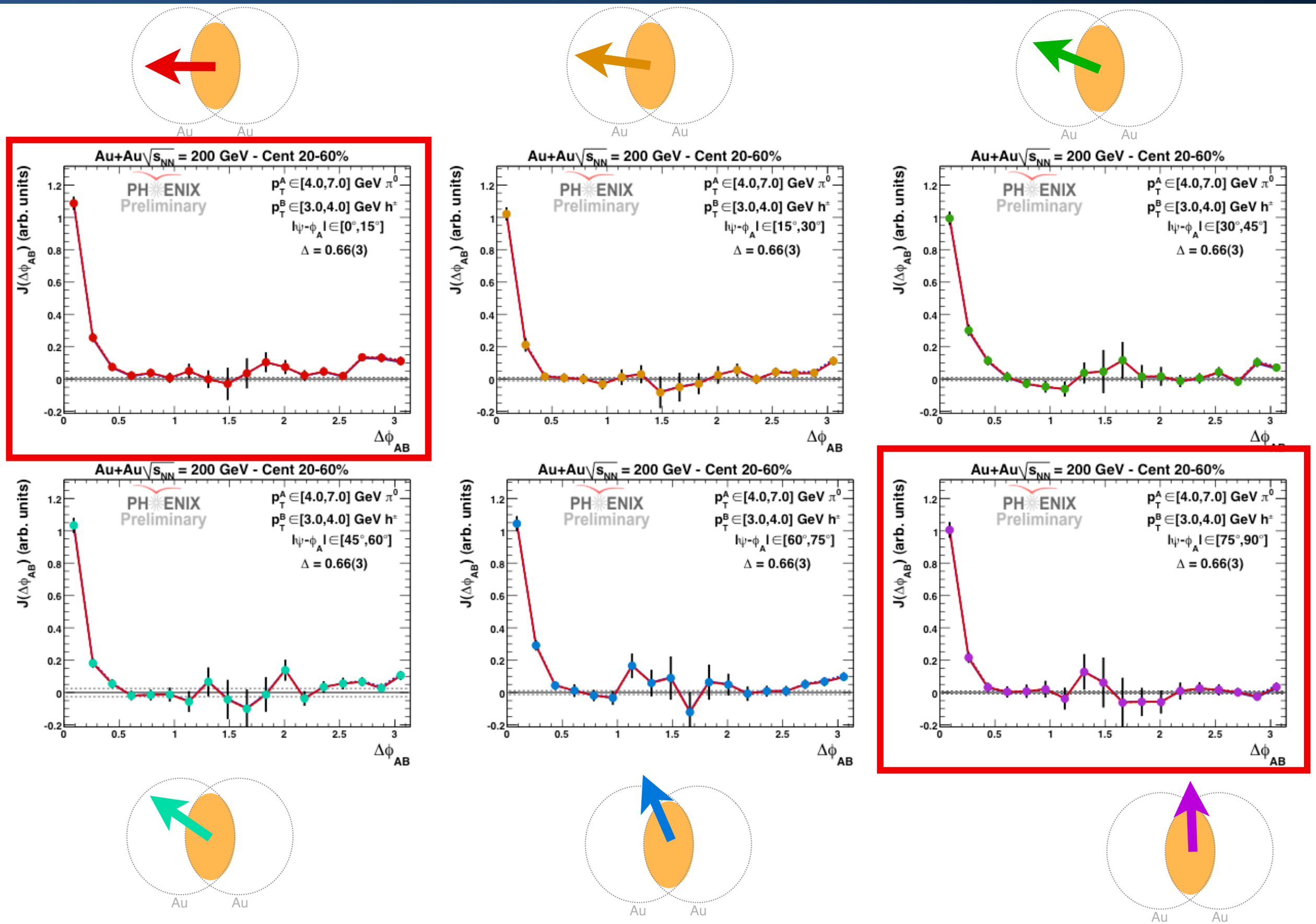
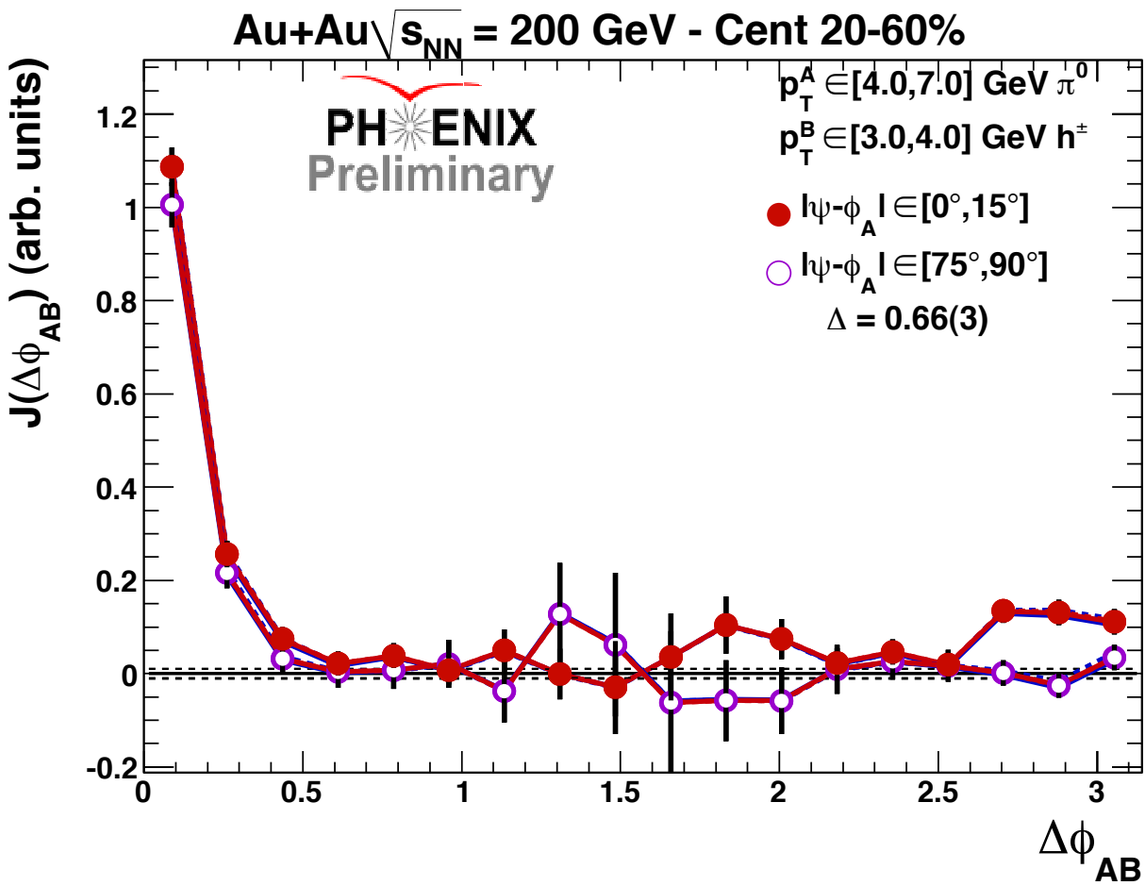


Away-side ϕ_S Dependence



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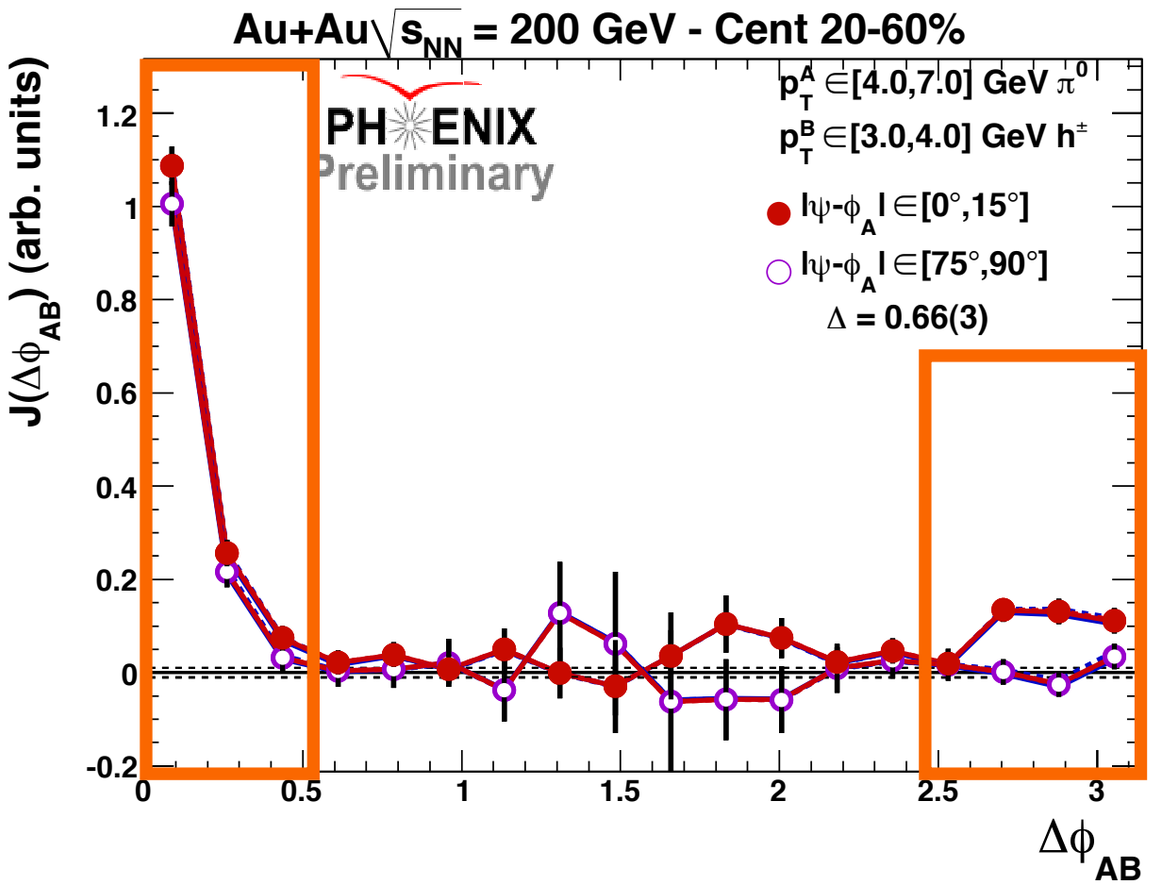
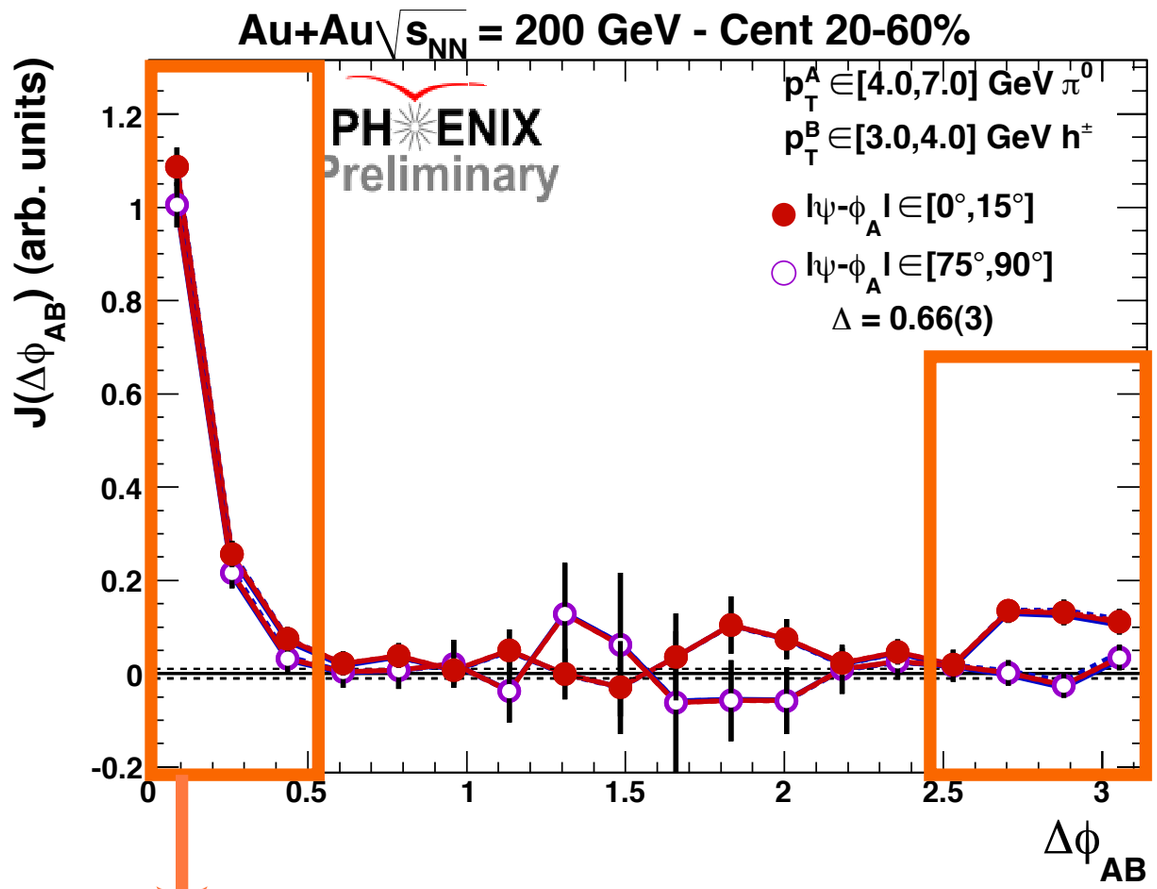
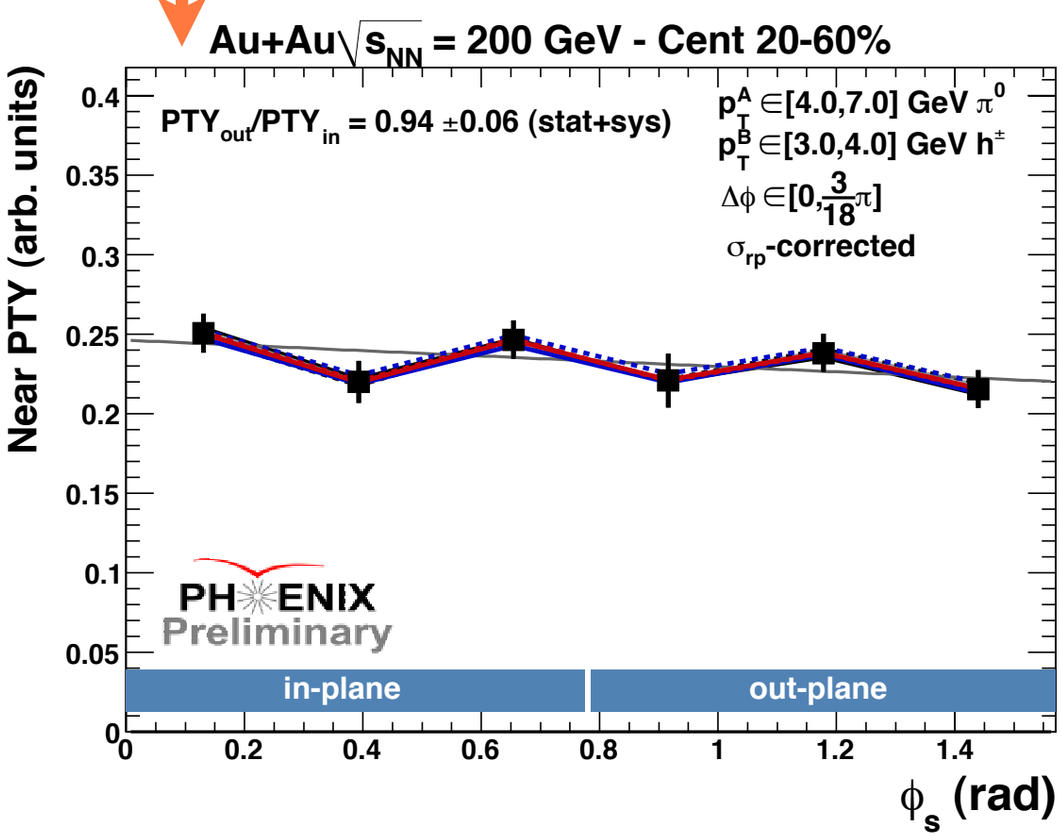


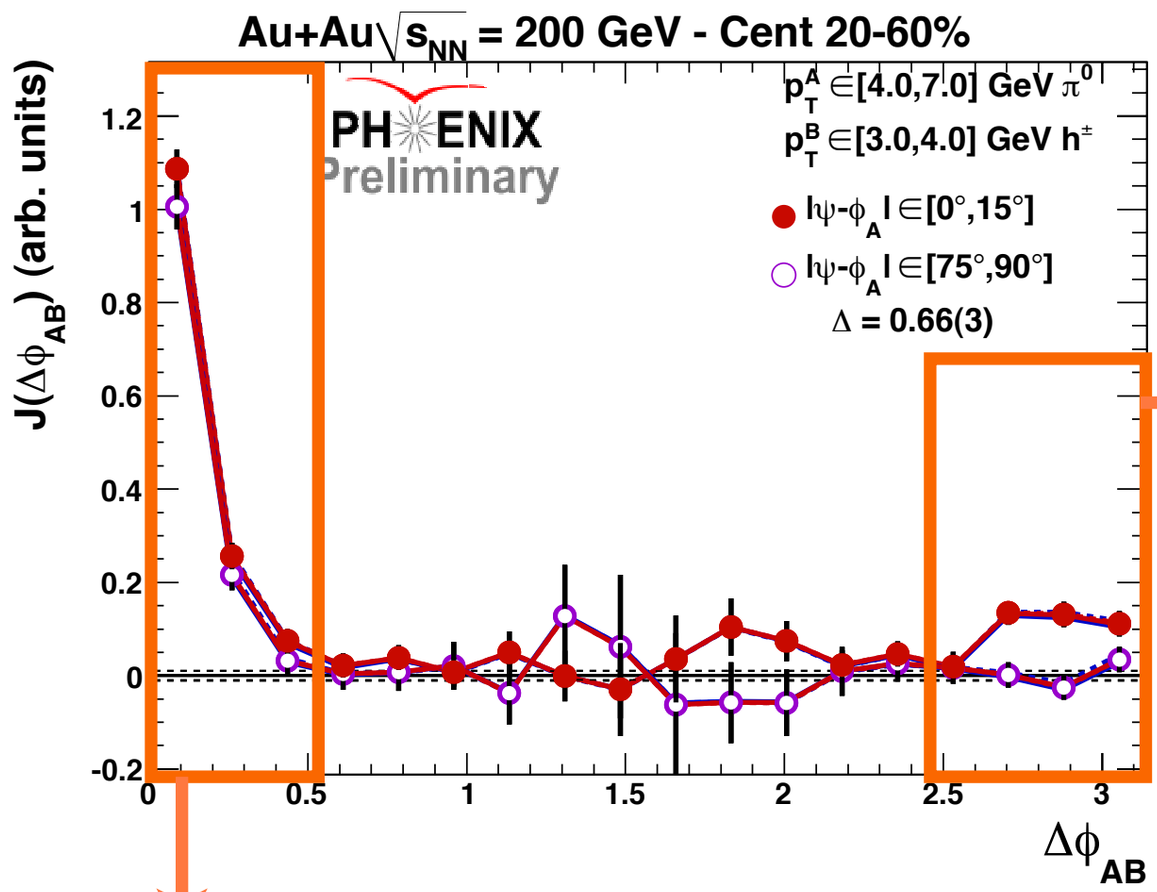
Away-side ϕ_s Dependence

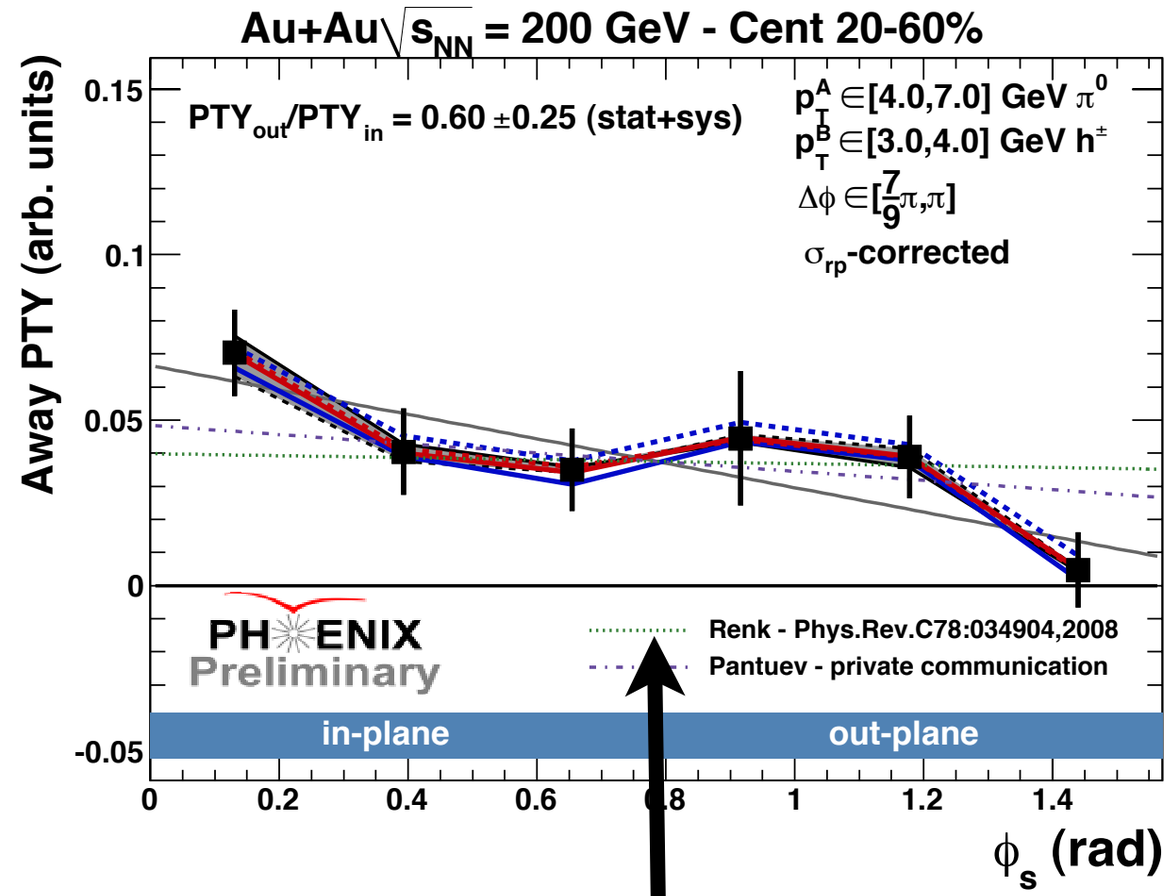




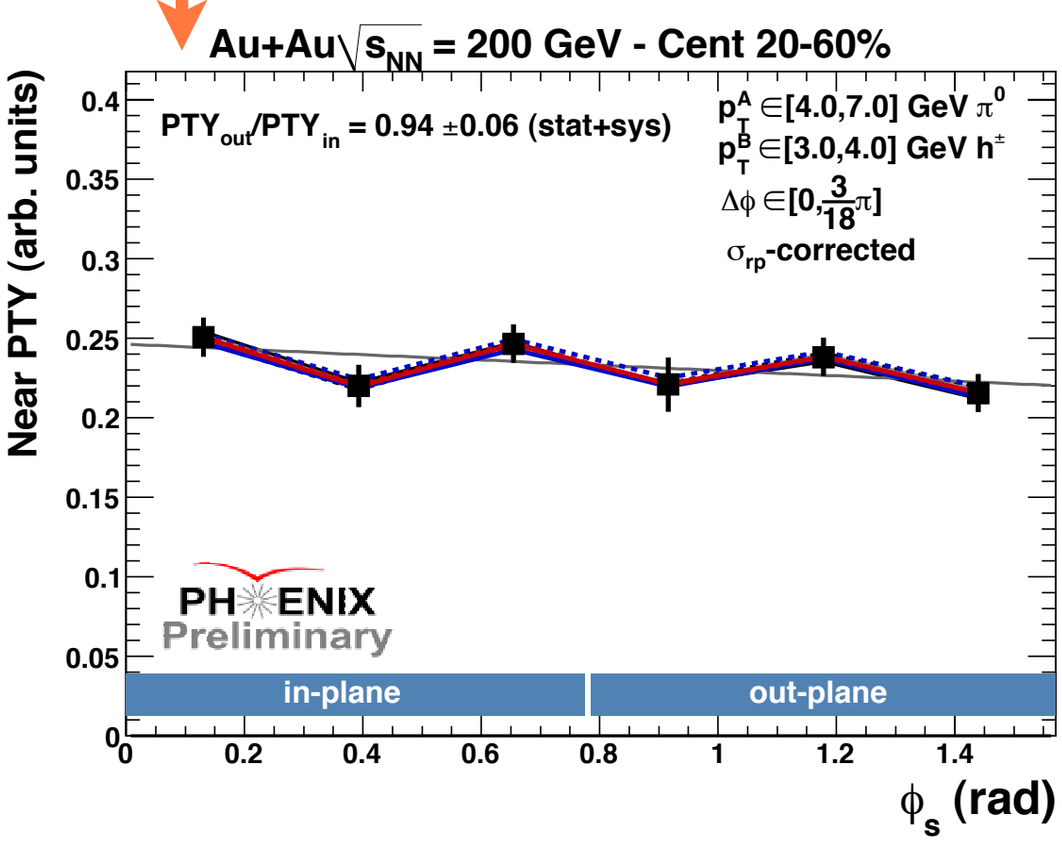
insignificant near-side trend

Away-side ϕ_s Dependence



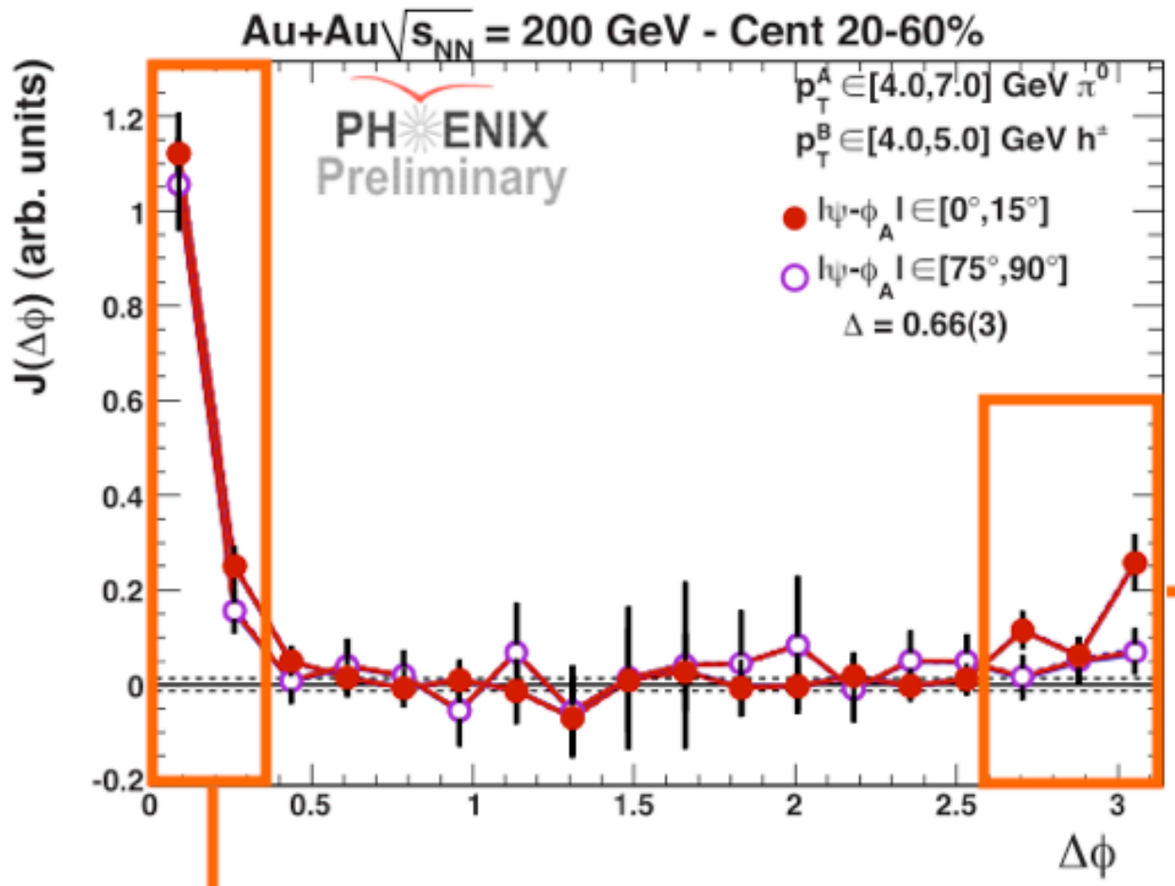


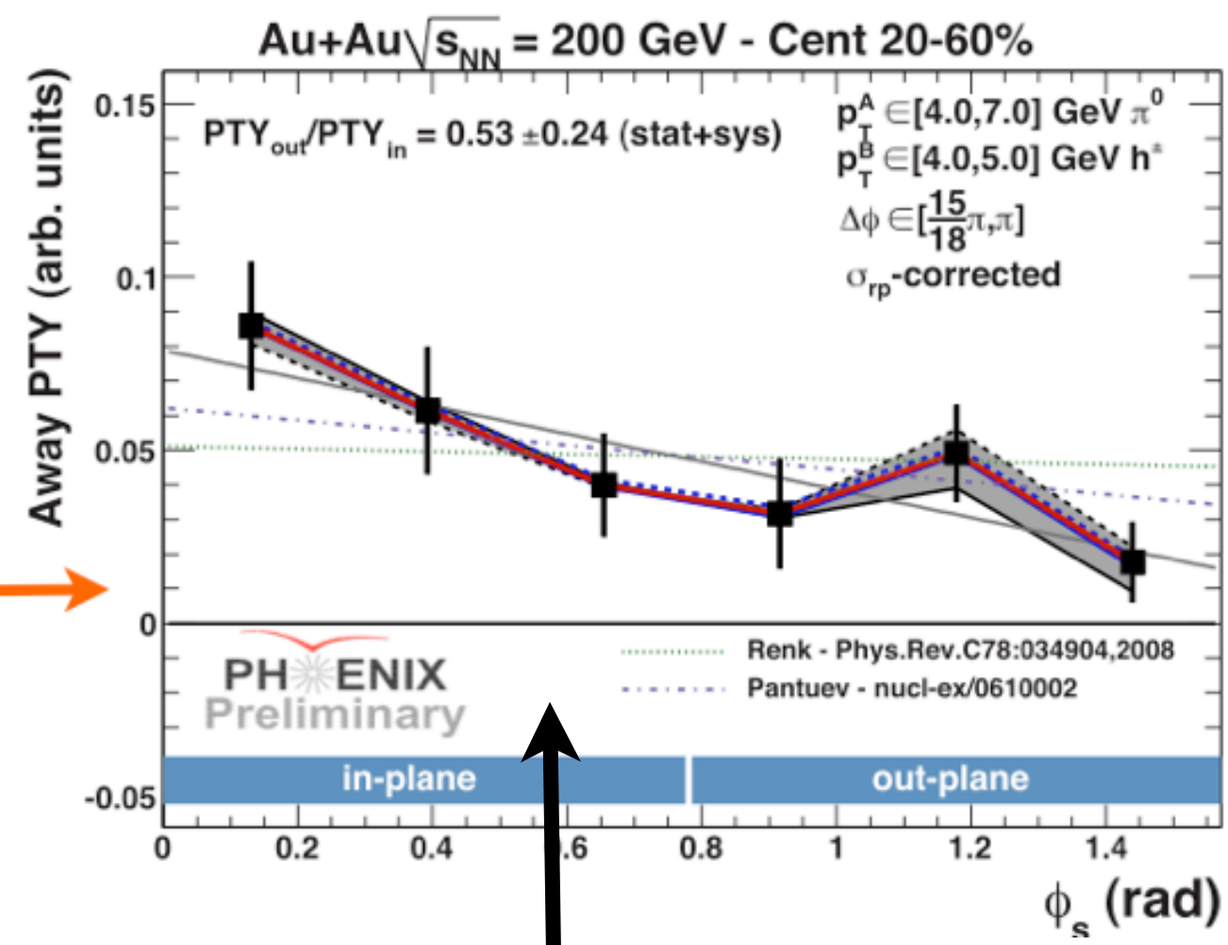
falling away-side trend

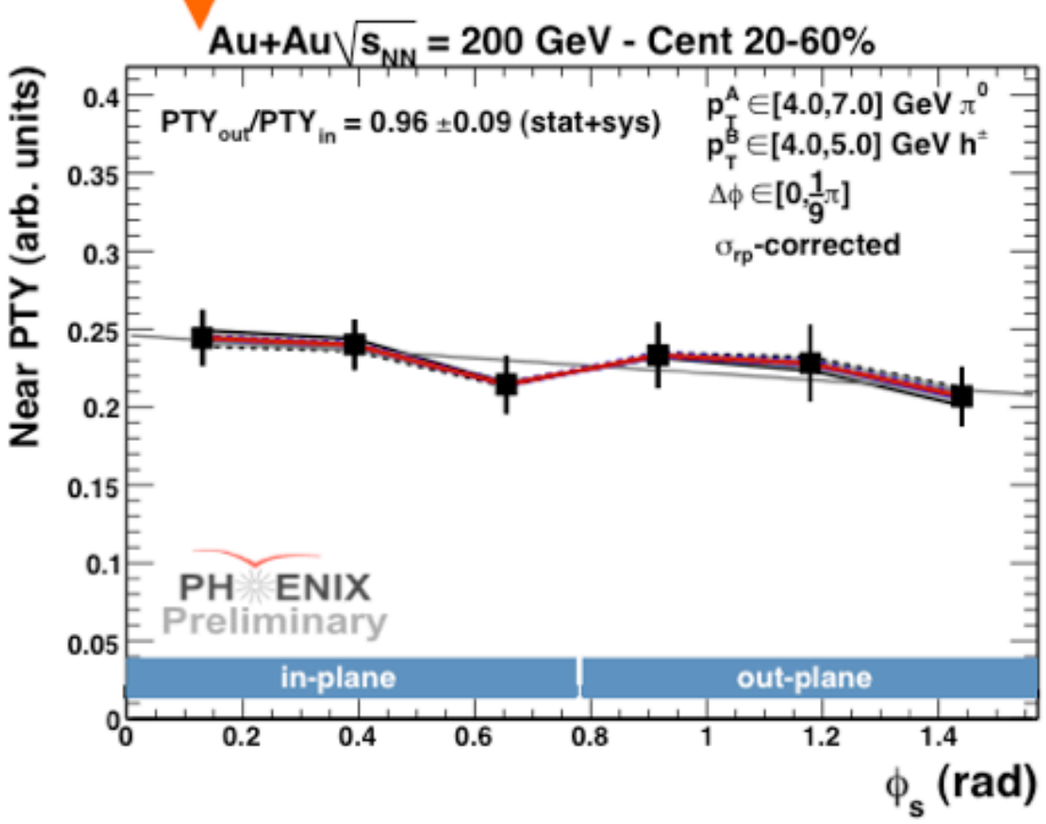


insignificant near-side trend

Away-side ϕ_S Dependence





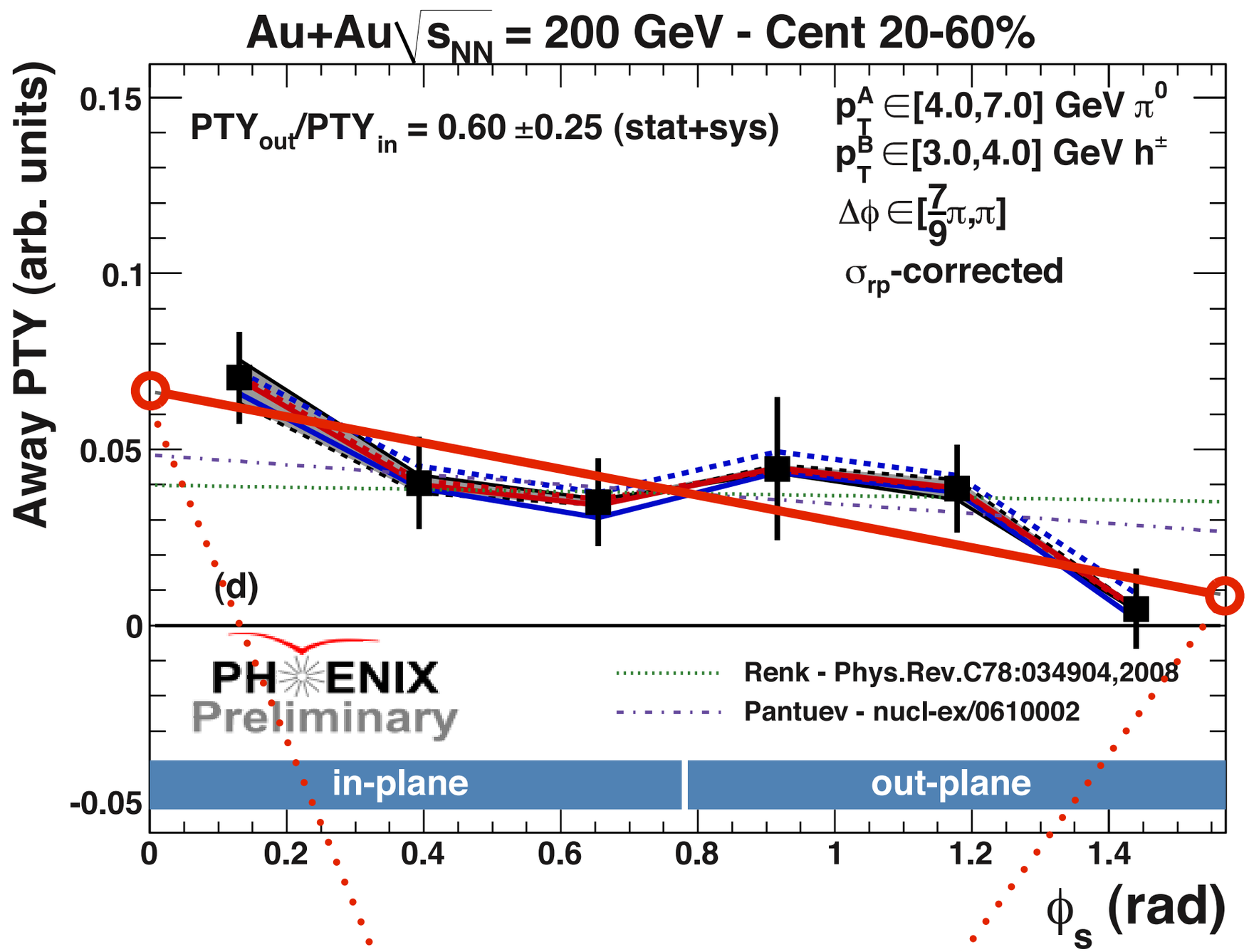


Same story at 4-5 GeV/c

Characterization

Both partner bins:

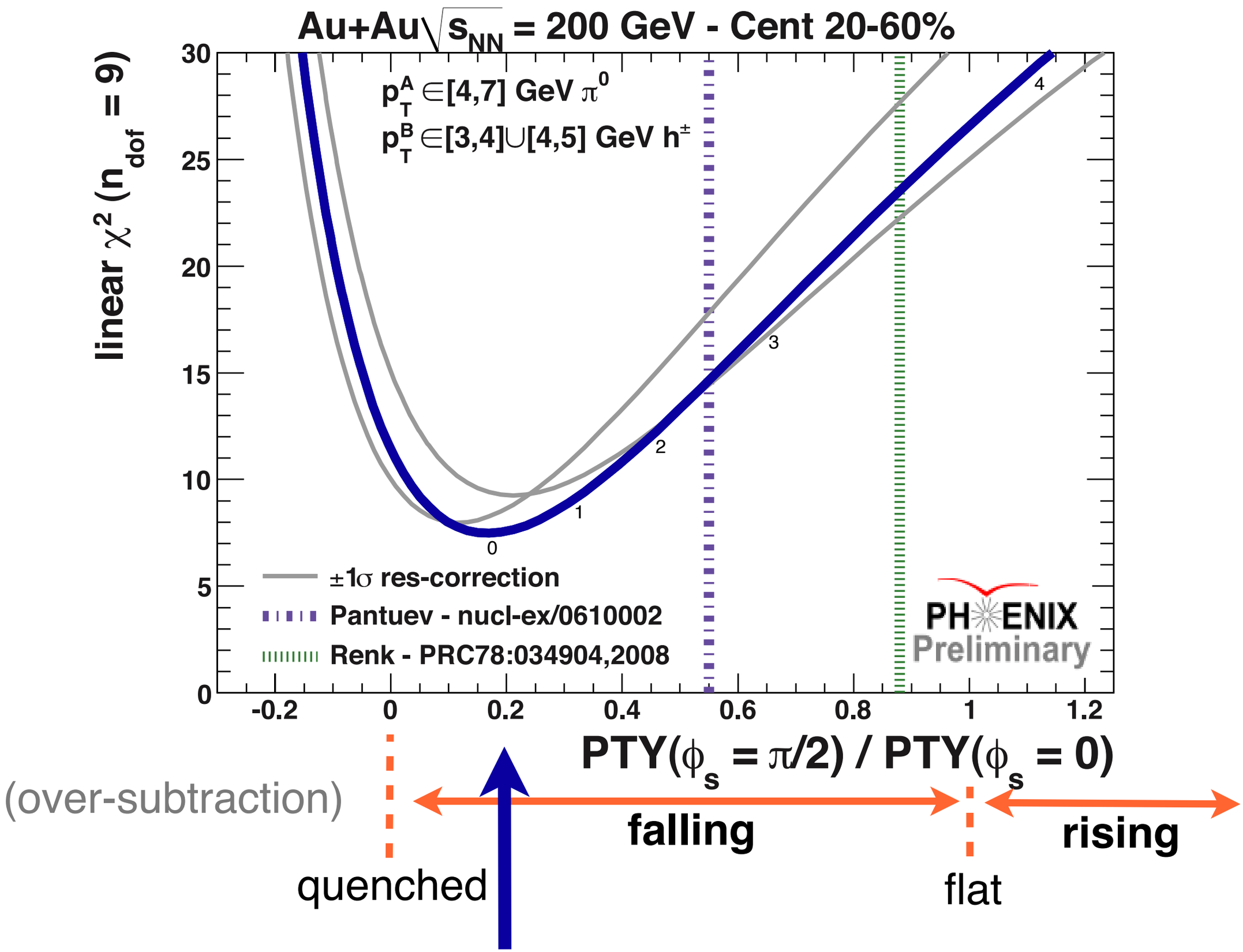
- Consistent with a linear falling function
- Steeply falling



Trend Characterization:
ratio of extrema yields

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

Variations by Reaction Plane

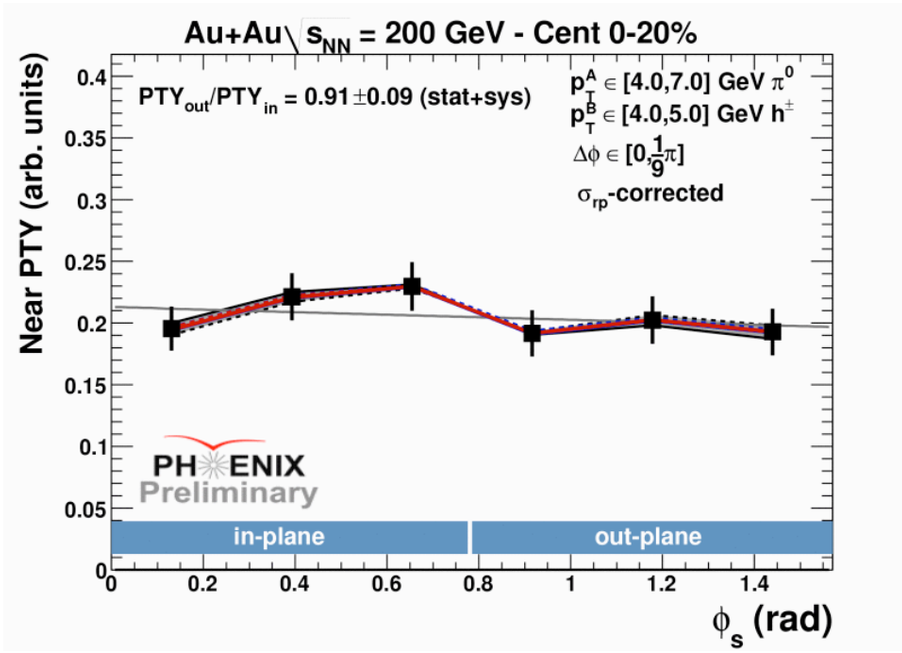


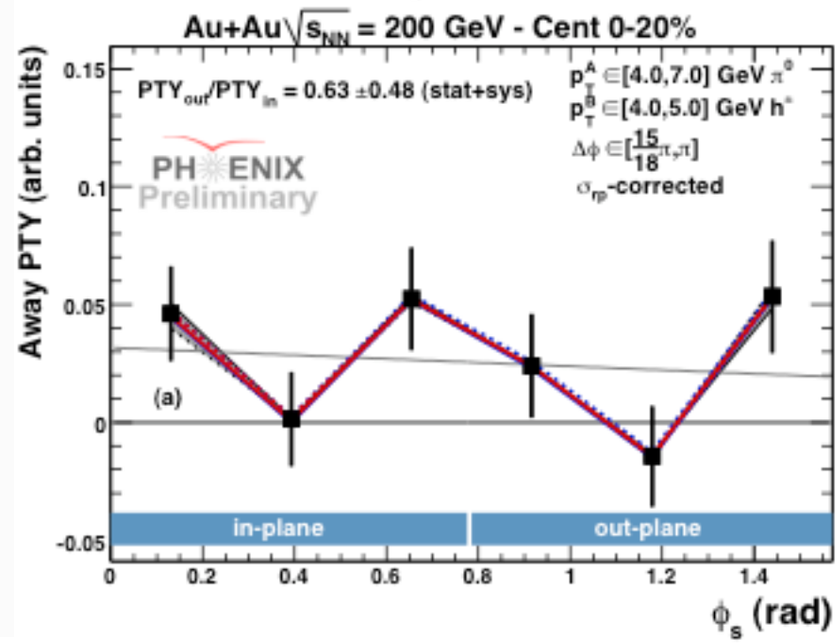
“Control” Centrality 0-20%

Near-side **Away-side**

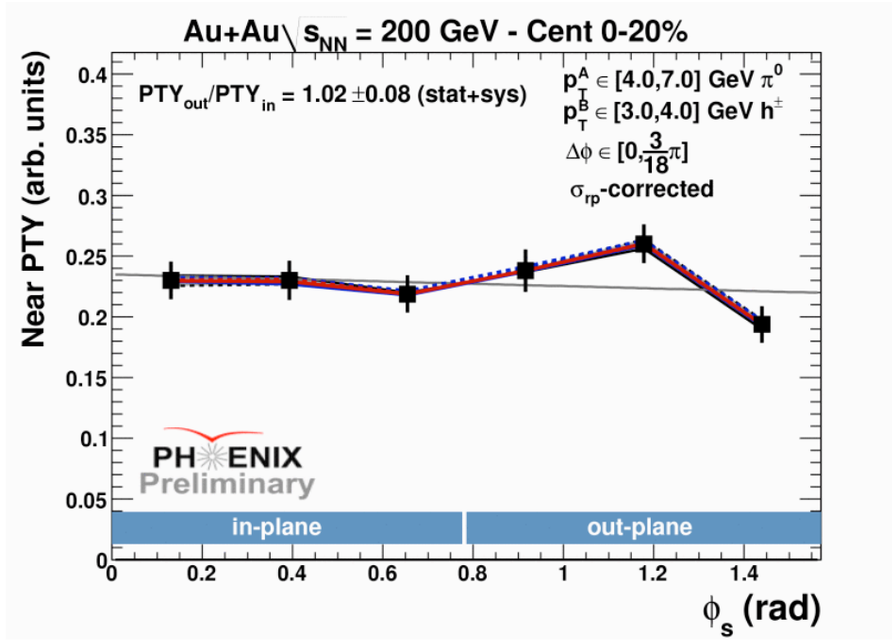
Partners:

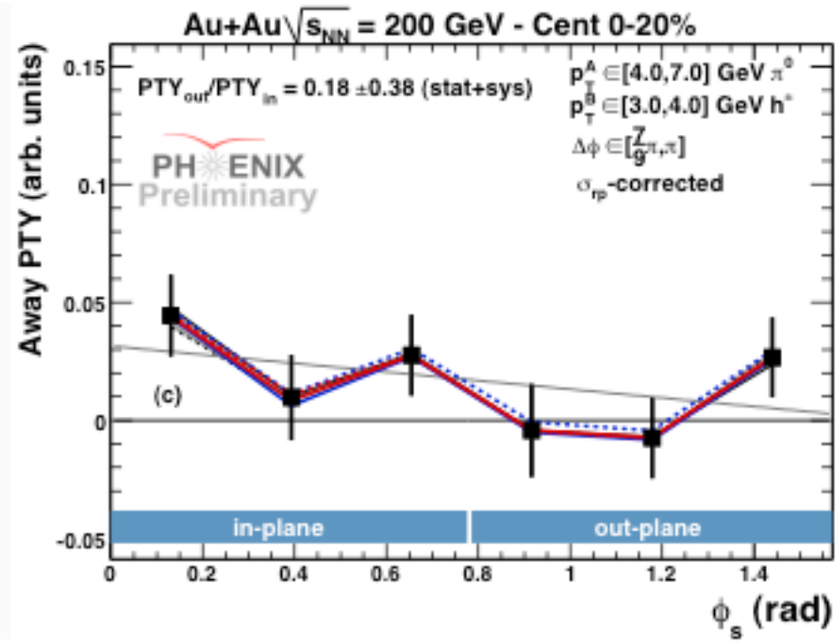
4-5 GeV/c





3-4 GeV/c





No significant trends, large away-side suppression

Another attempt...

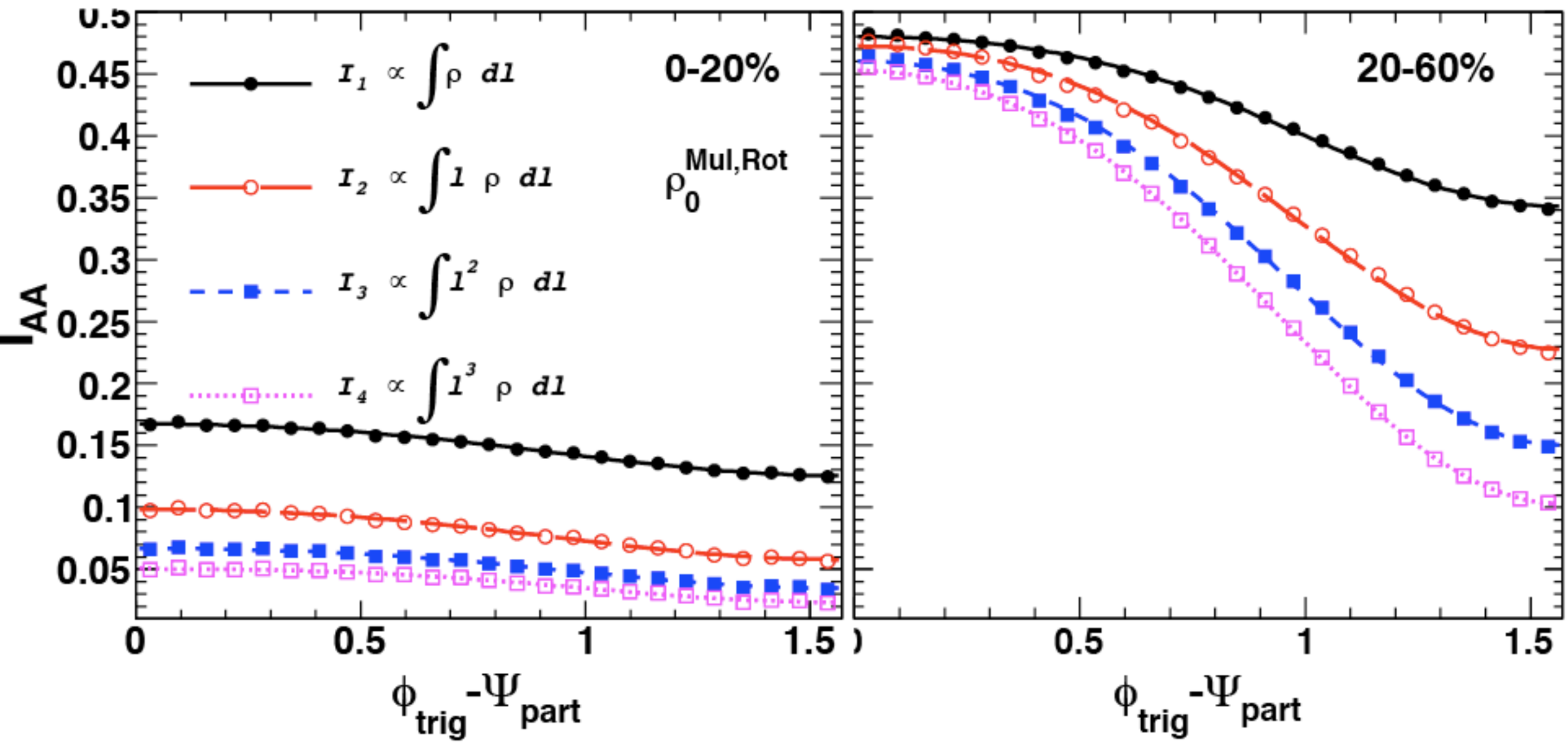
Dissecting the role of initial collision geometry for jet quenching observables in relativistic heavy ion collisions

Jiangyong Jia[1,2] and Rui Wei[1]

Simple energy loss (L-dependence) + realistic geometry

but no energy loss fluctuations

arXiv:1005.0645



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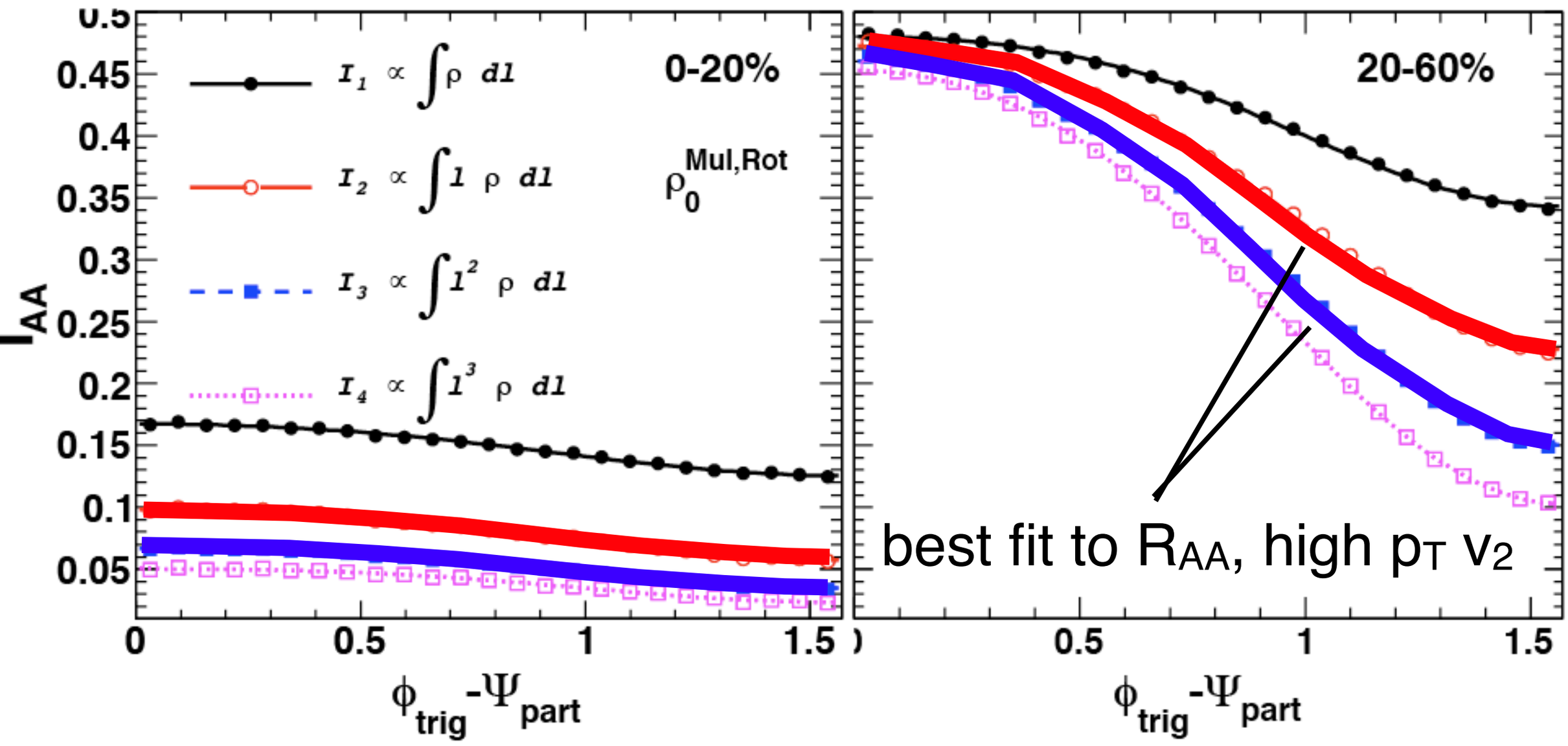

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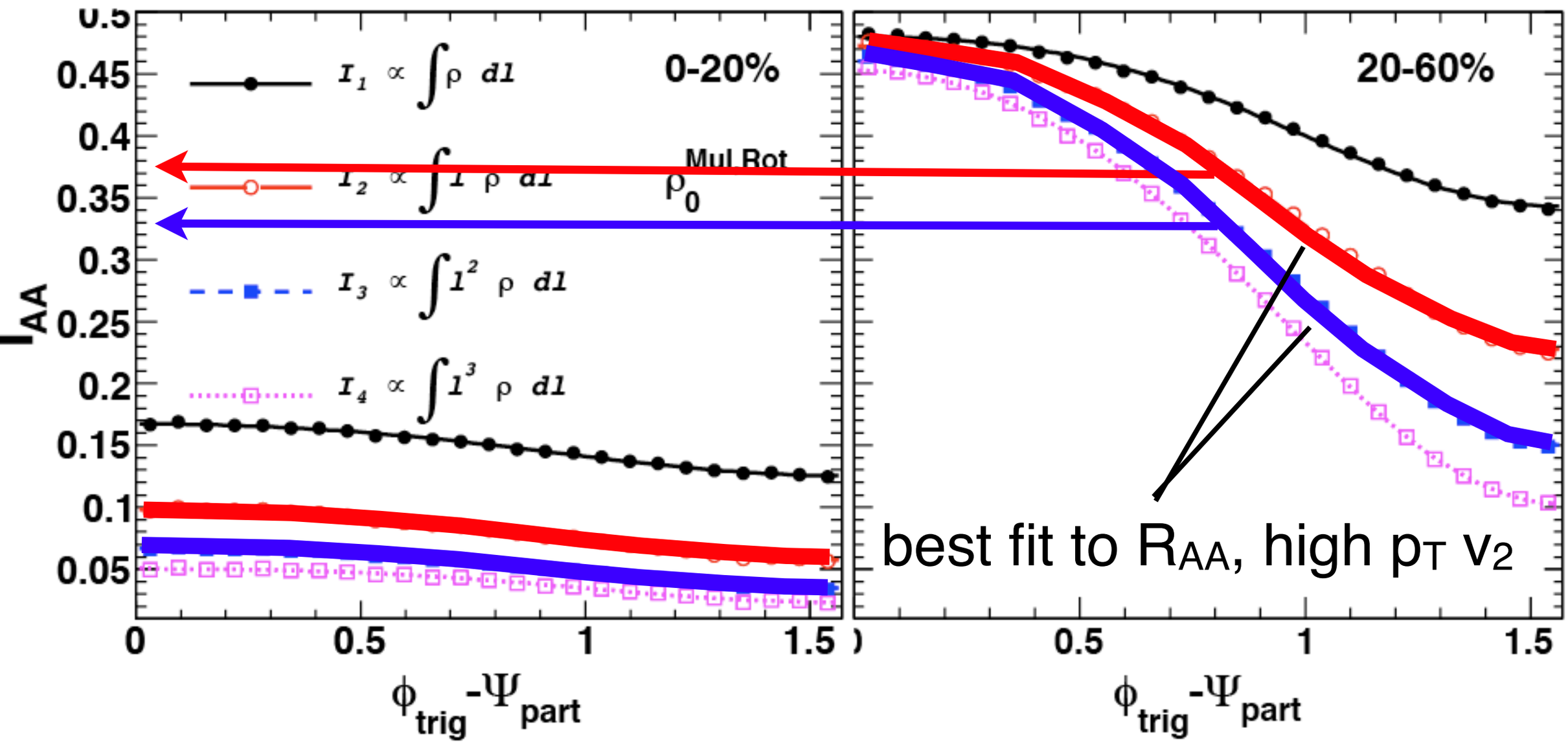


Summary

High p_T - Energy Loss

I_{AA} is not consistent with simple increased suppression:

- a feature missed in some theories (could be related to spectral slope)

Steep away-side suppression by trigger orientation:

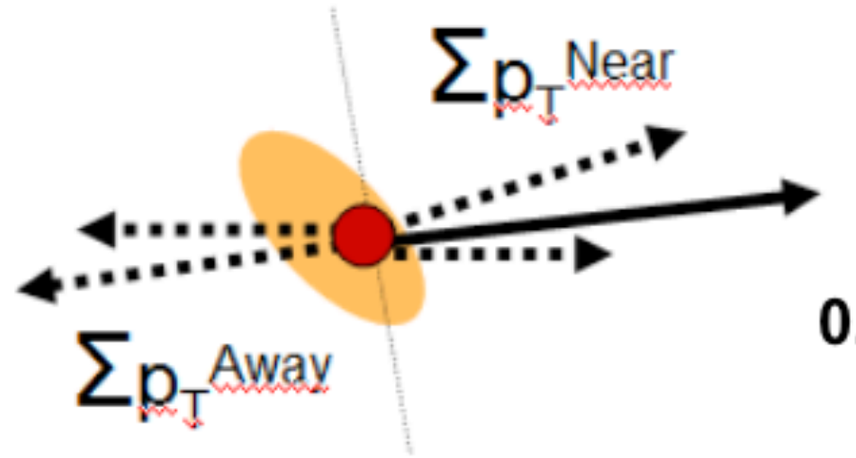
- a large initial anisotropy

or

- a large path-length dependence

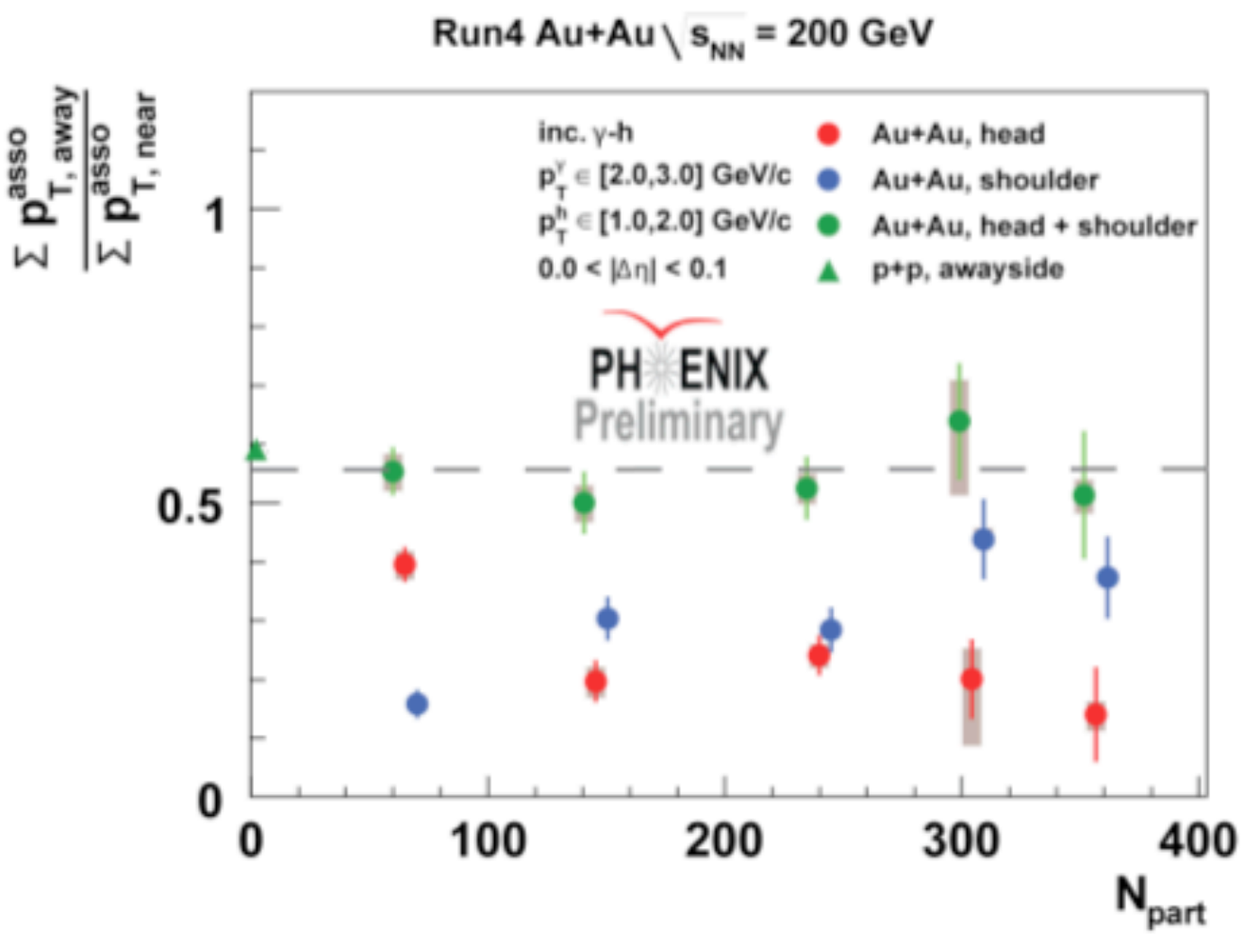
Extra Slides

Ridge & Shoulder Balance

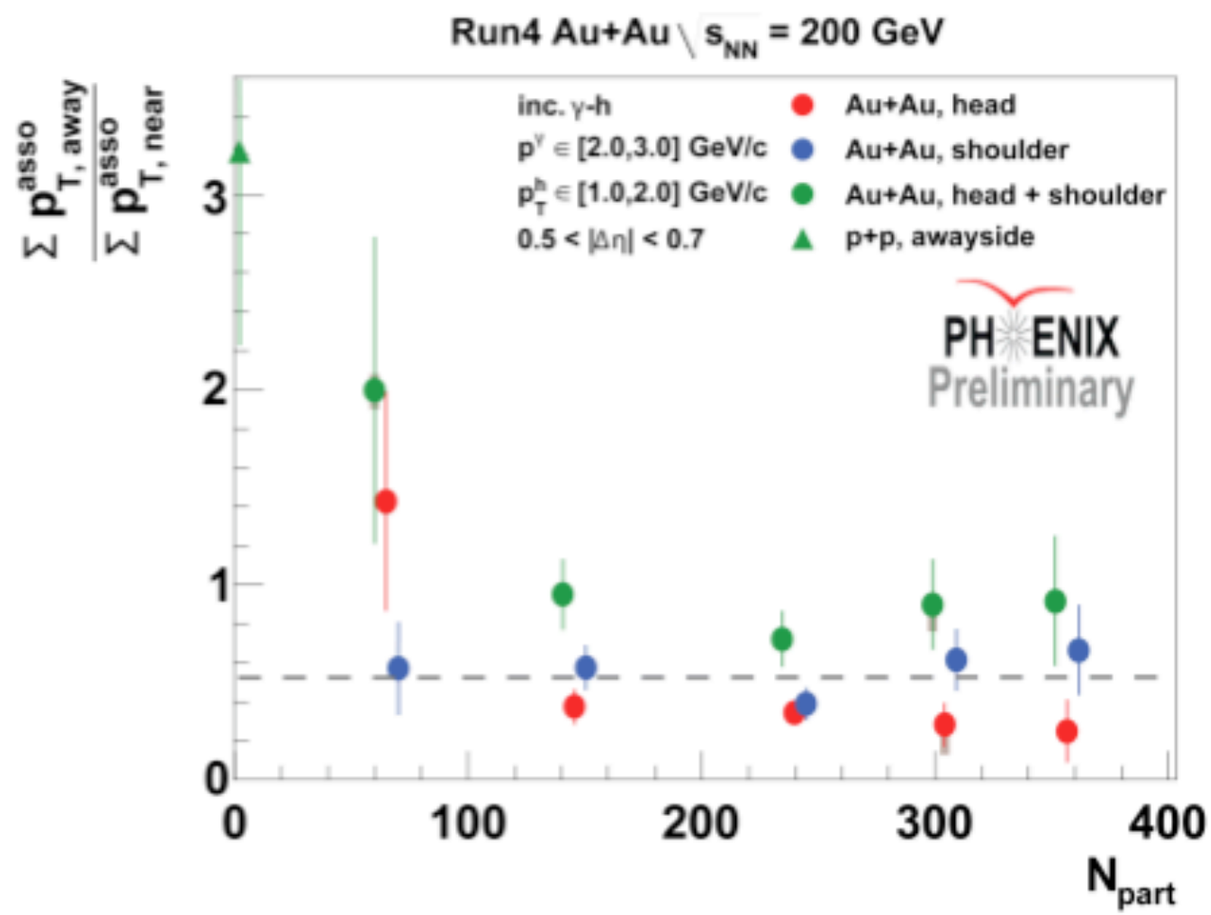


$0.0 < |\Delta\eta| < 0.1$

$0.5 < |\Delta\eta| < 0.7$



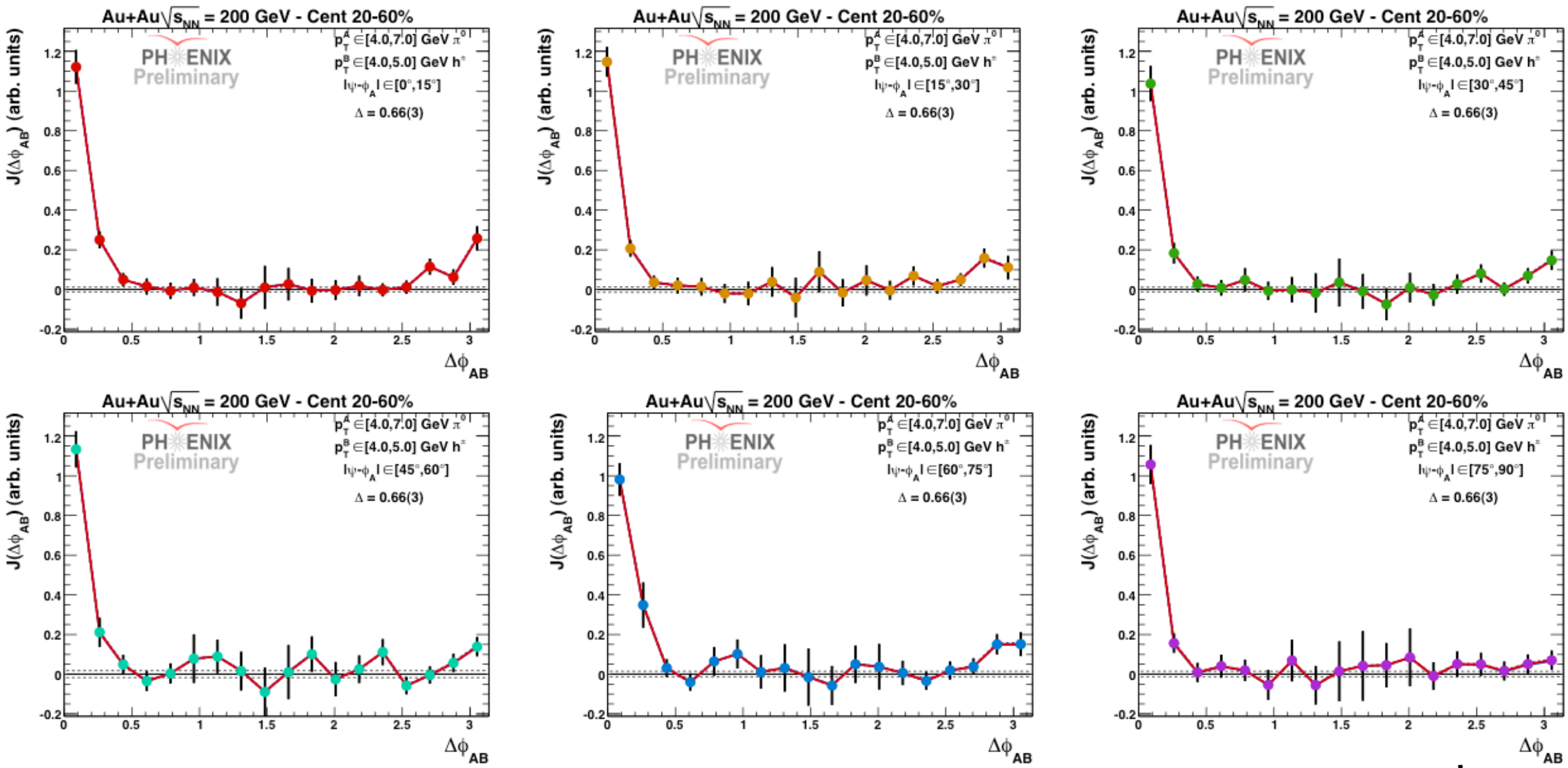
Jet + Ridge balances Shoulder + Head



Ridge balances Shoulder!

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

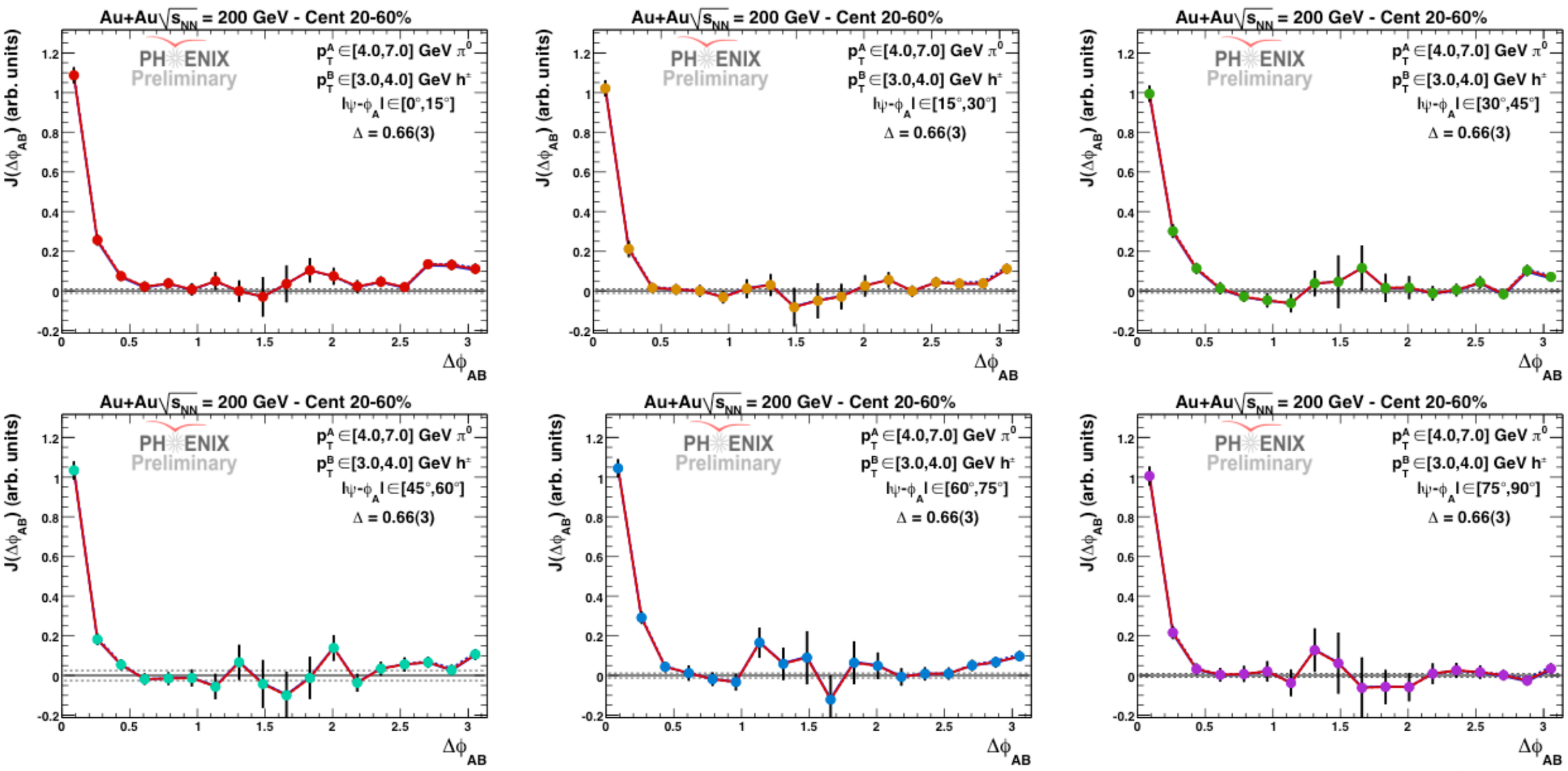
most in-plane



most out-of-plane

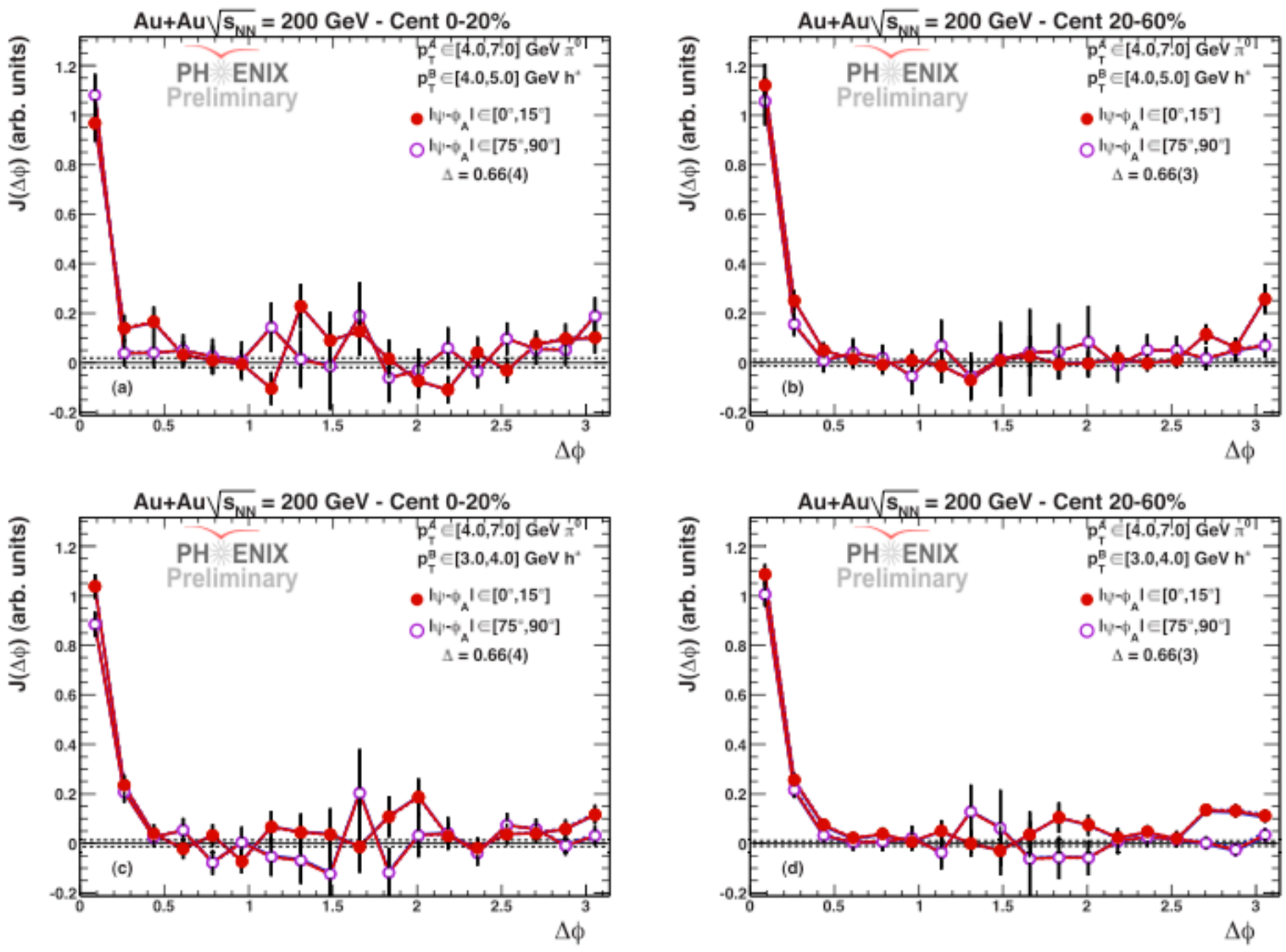
Jet Functions - Full Set @ 3-4 GeV/c

most in-plane

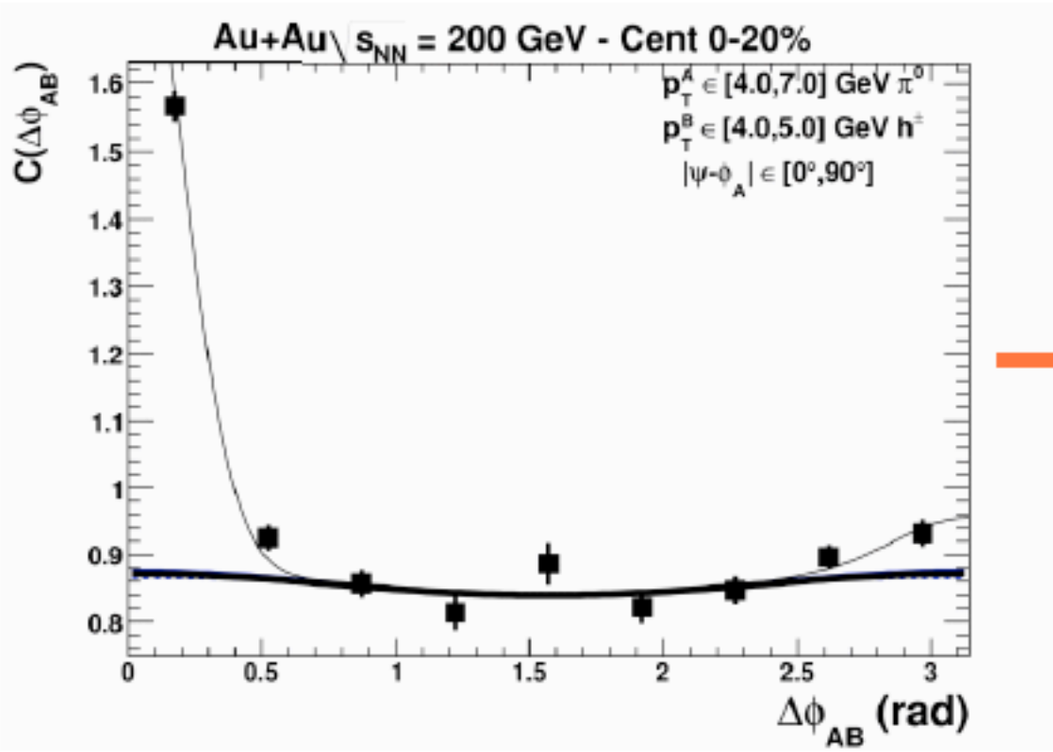


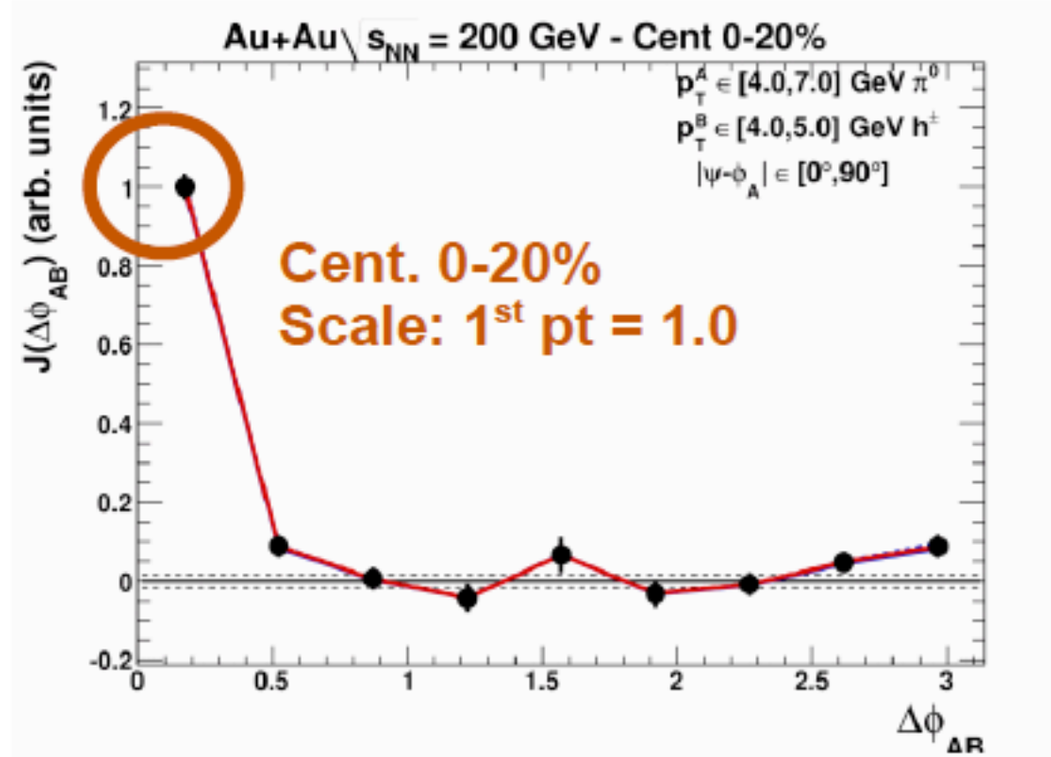
most out-of-plane

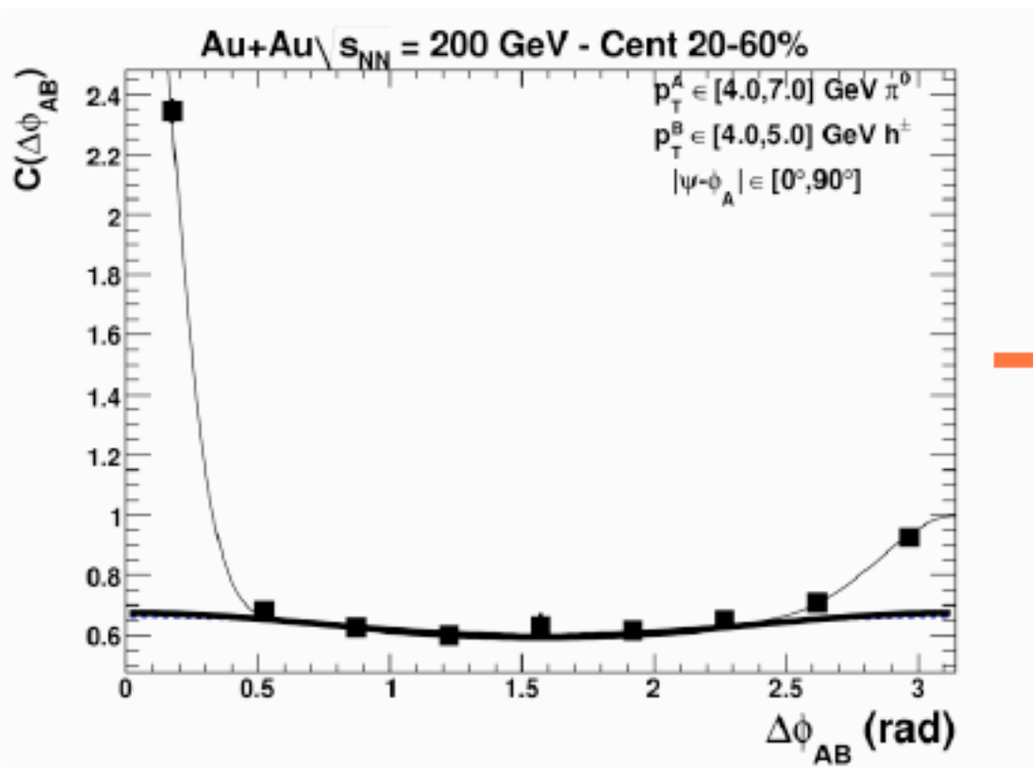
Overlays

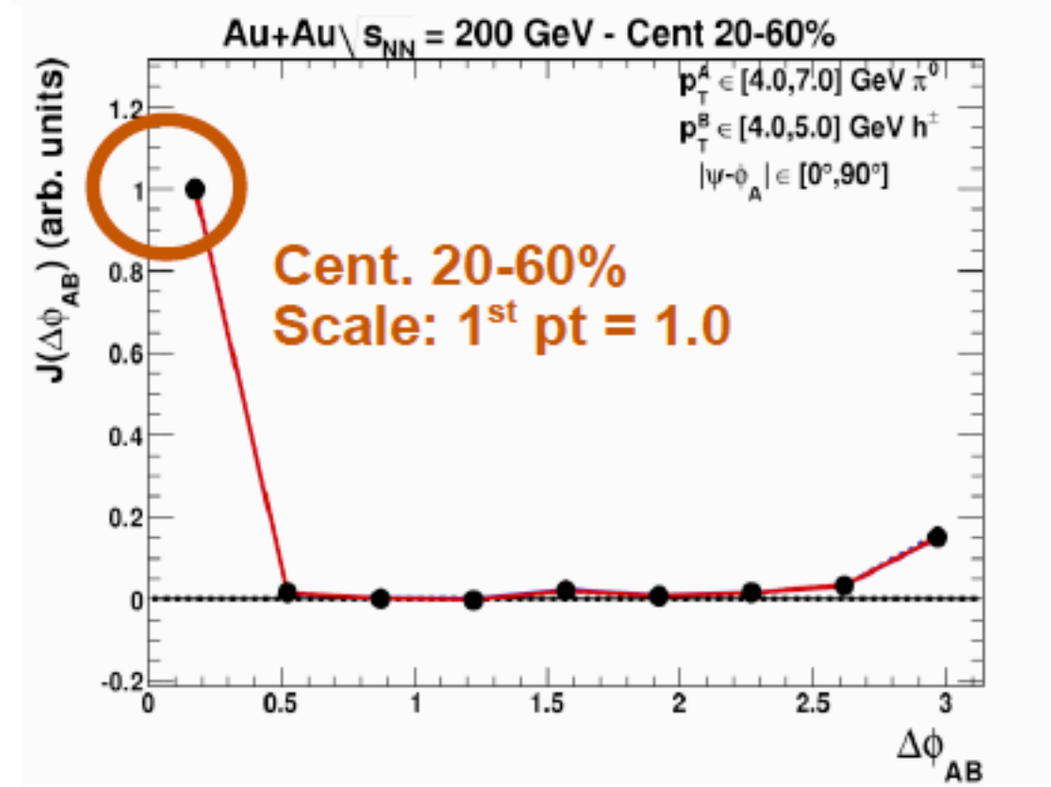

Au+Au $\sqrt{s_{NN}}$ = 200 GeV - Cent 0-20%
Au+Au $\sqrt{s_{NN}}$ = 200 GeV - Cent 20-60%
PHENIX Preliminary
$p_T^A \in$ [4.0,7.0] GeV π^0
$p_T^B \in$ [4.0,5.0] GeV h$^\pm$
$p_T^B \in$ [3.0,4.0] GeV h$^\pm$
$|\psi-\phi_A| \in$ [0°,15°]
$|\psi-\phi_A| \in$ [75°,90°]
Δ = 0.66(4)
Δ = 0.66(3)
(a)
(b)
(c)
(d)
J(Δφ) (arb. units)
Δφ

Arb. Scale Definition



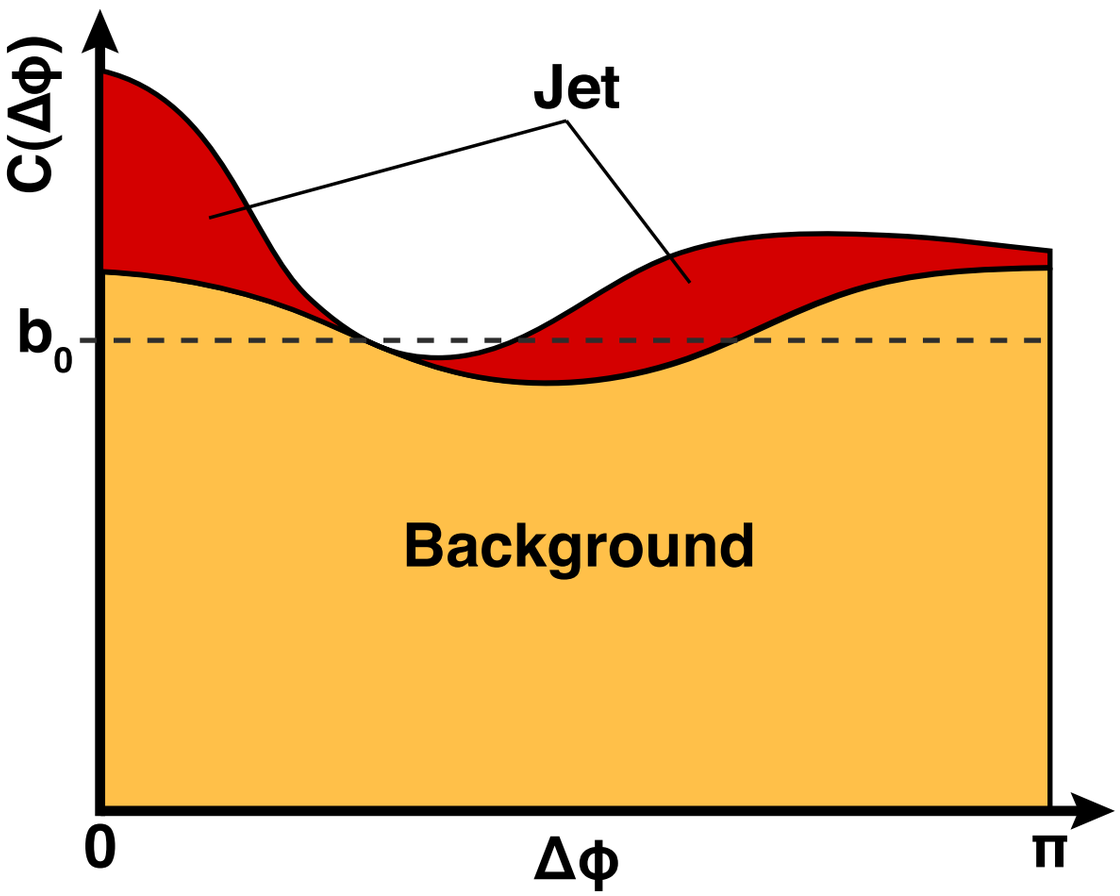




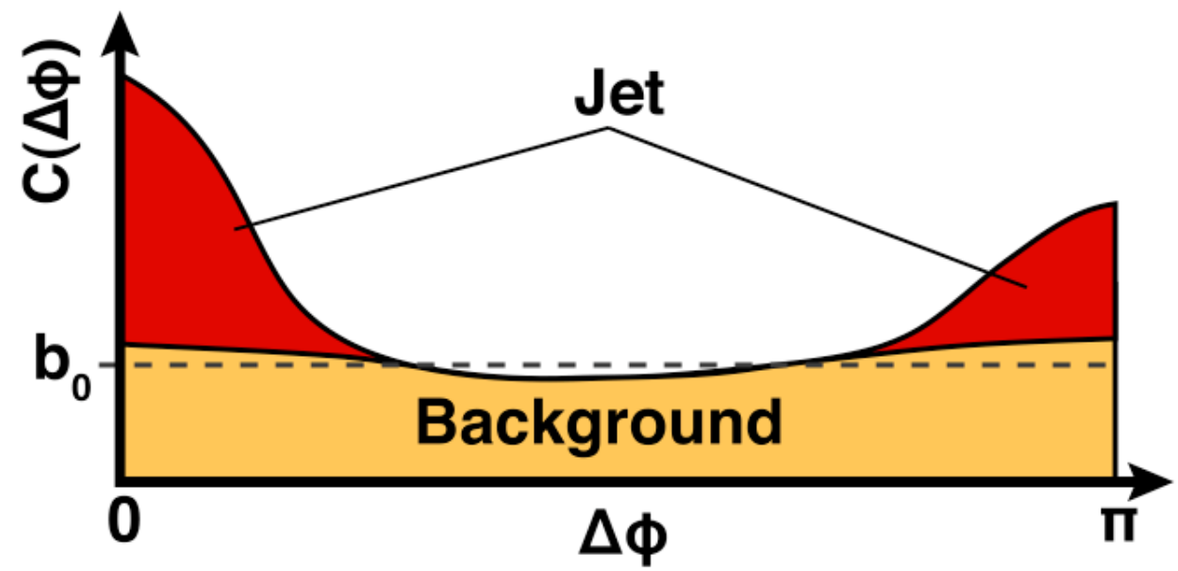


Pair Correlation Regimes

Modification



Suppression



$p_T^{A,B}$

"intermediate"

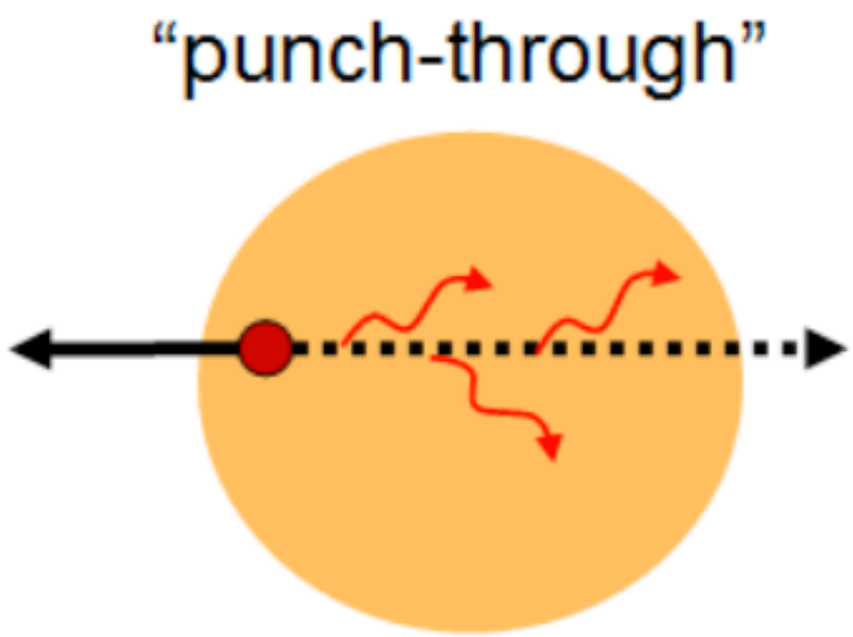
~1 - 4 GeV/c

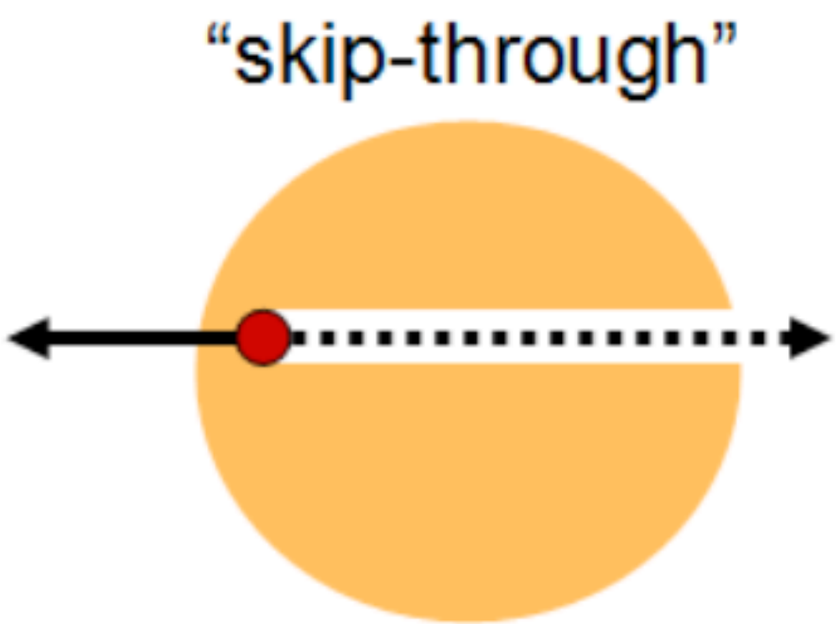
"high"

≳ 4 GeV/c

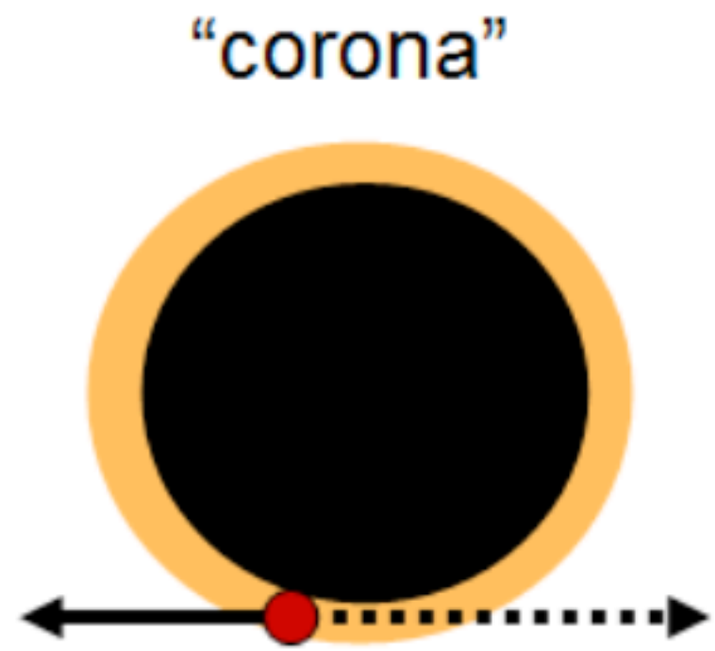
Energy Loss Categories

Nuclear Overlap Crossing



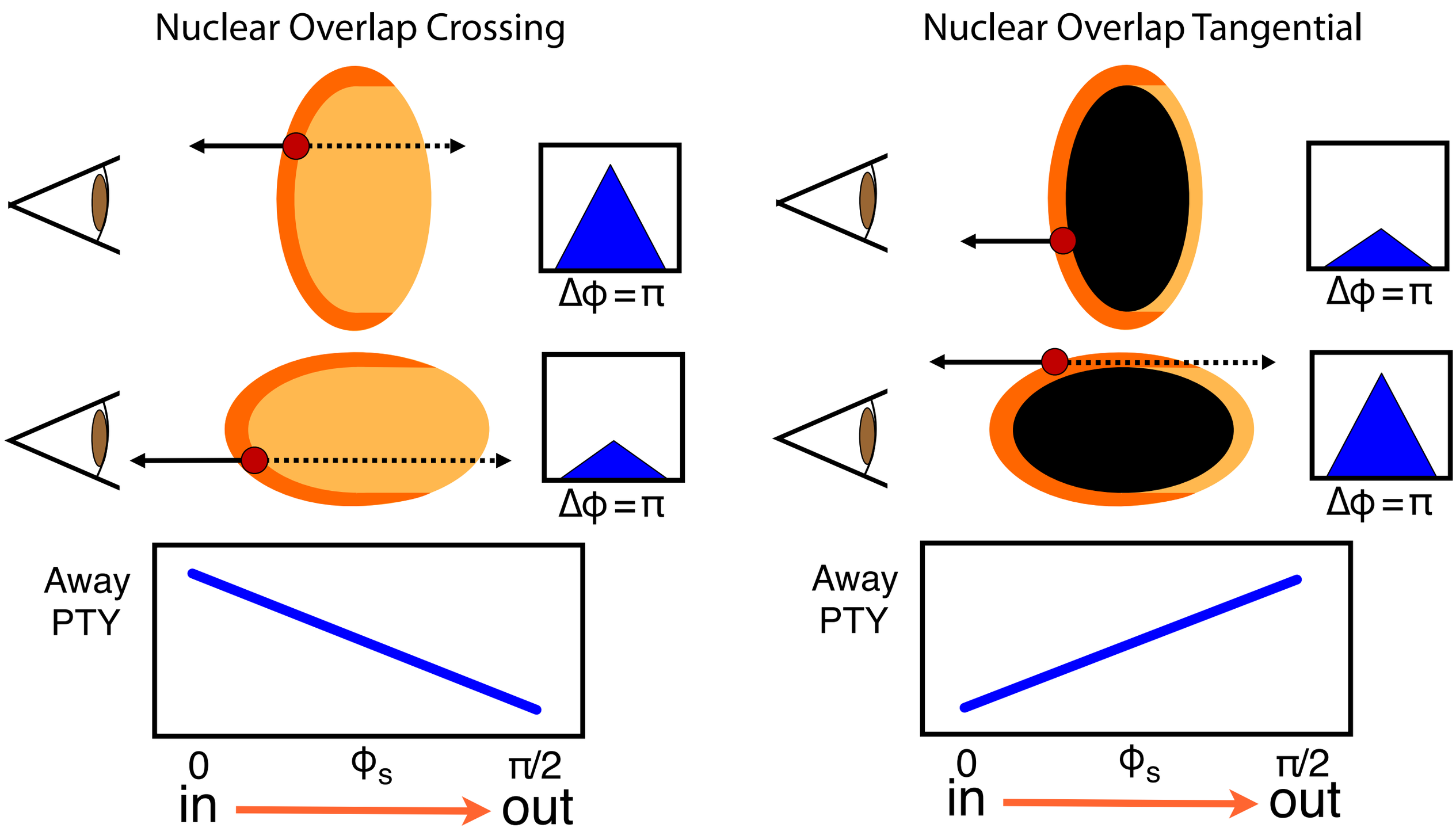


Nuclear Overlap Tangential



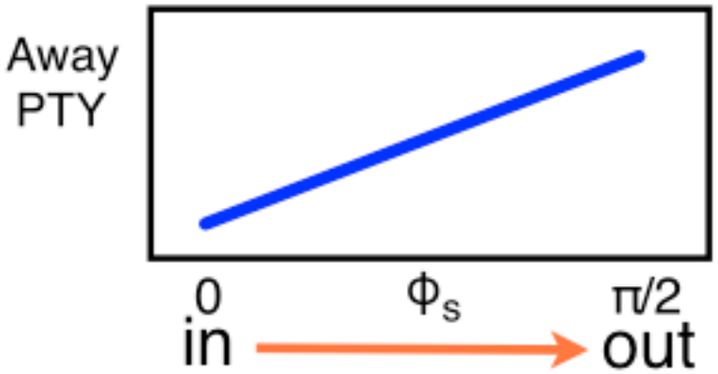
Q: Can a fast parton enter the nuclear overlap and survive?

Variation with Reaction Plane



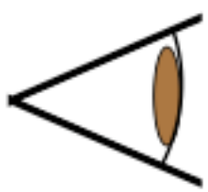
The dependence of away-side PTY can discriminate between models.

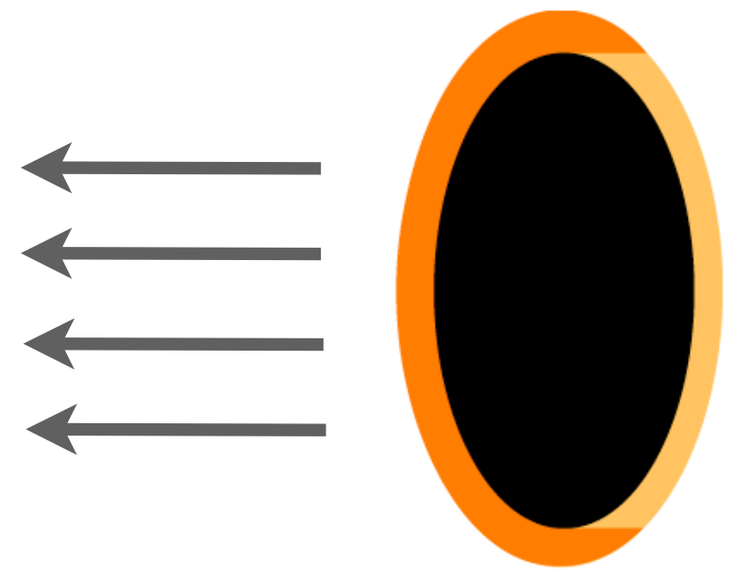
Tangential Rising PTYs



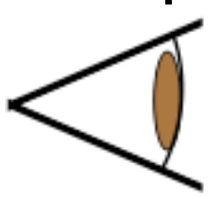
Integrated Column Density / Trigger Multiplicity

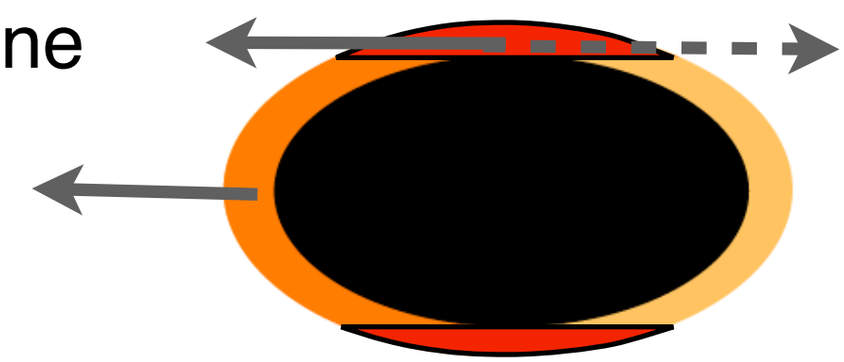
in-plane

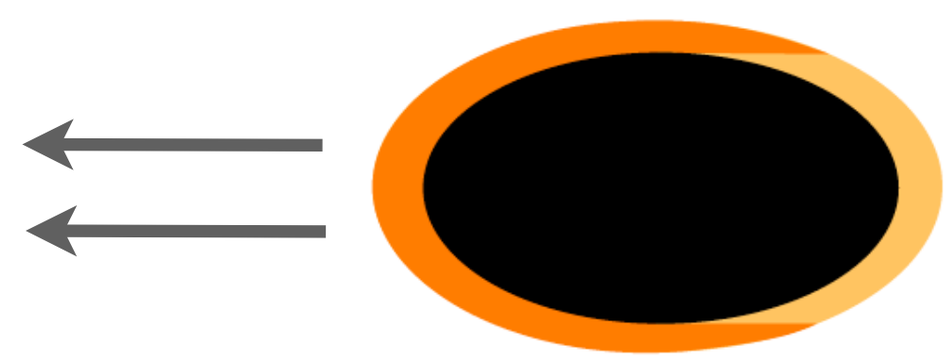




out-of-plane





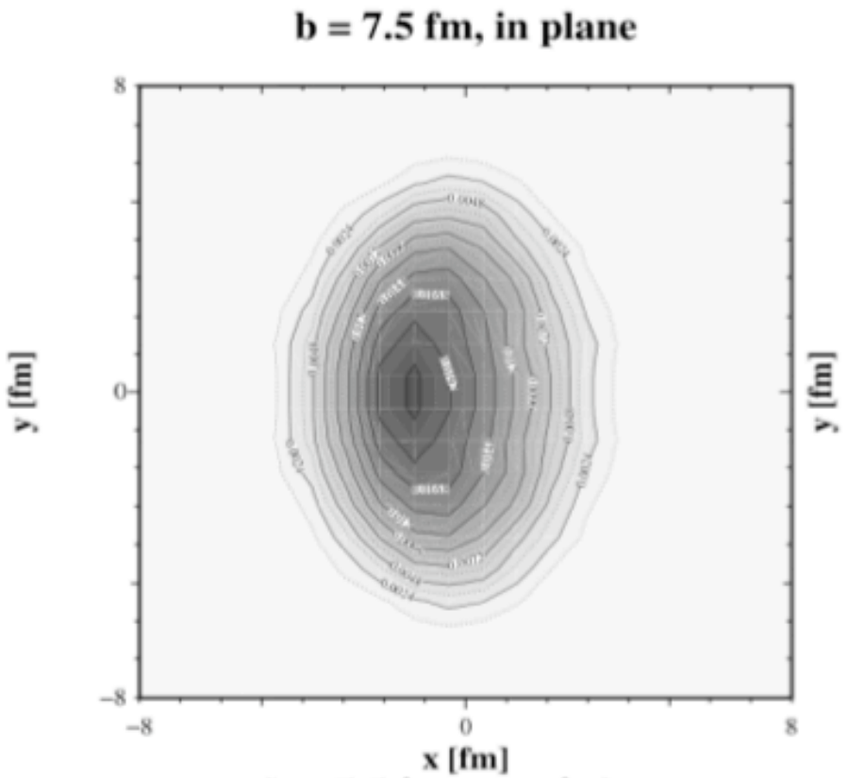


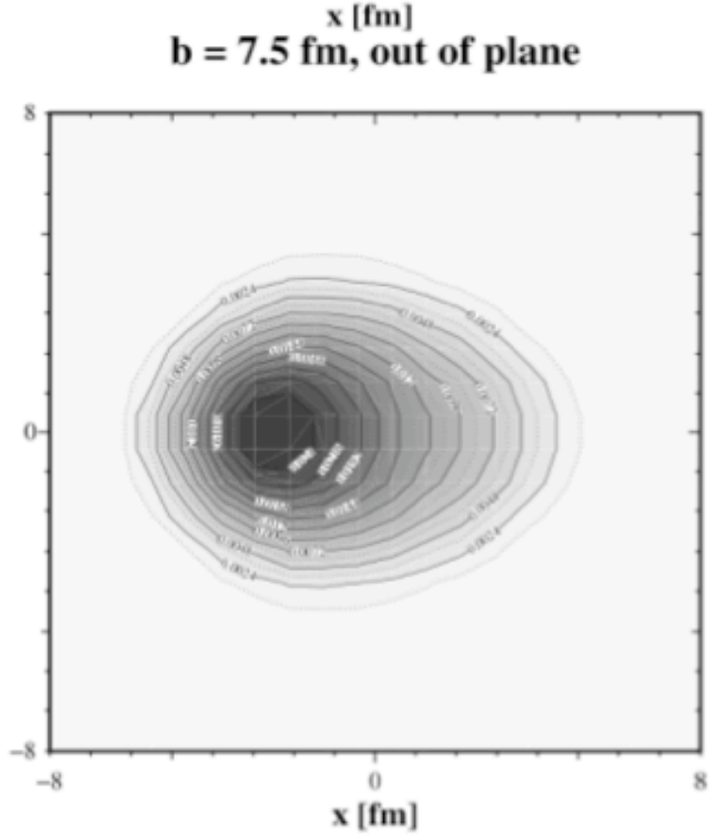
Predicitons: Renk

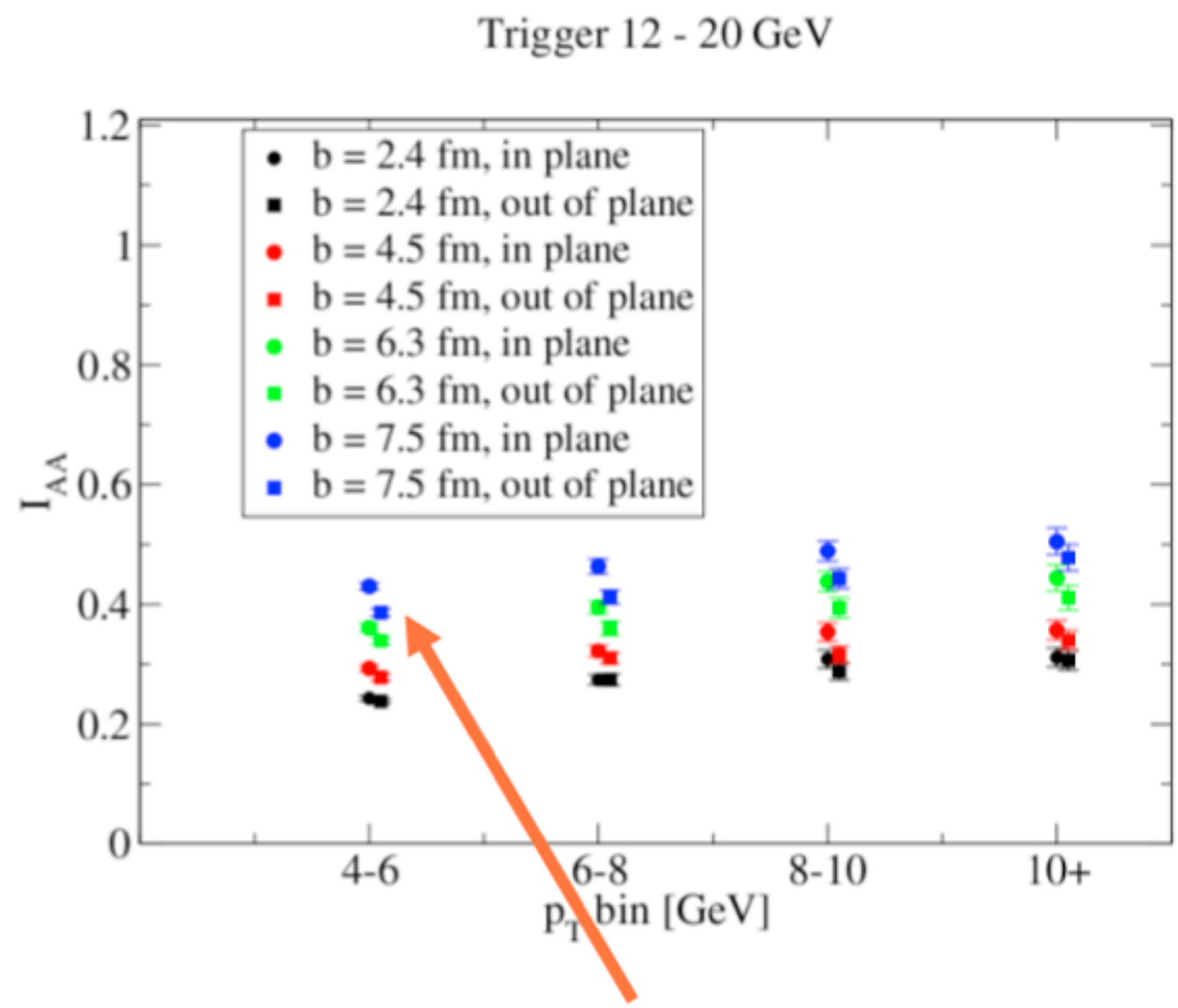
Angular variation of hard back-to-back hadron suppression in heavy-ion collisions

arXiv:0803.0218v2

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







falling with increasing rp-angle
max ~12% variation in mid-central

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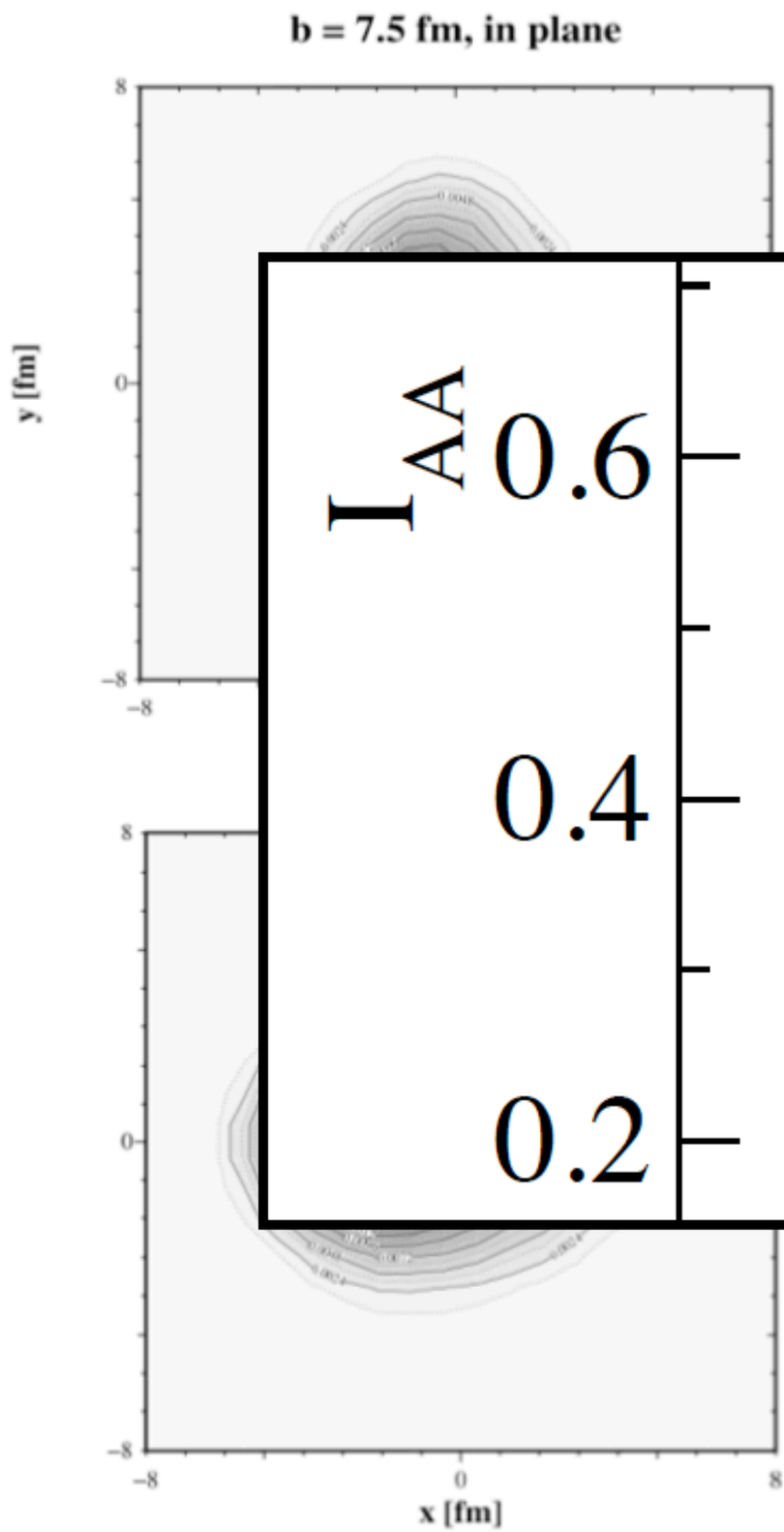
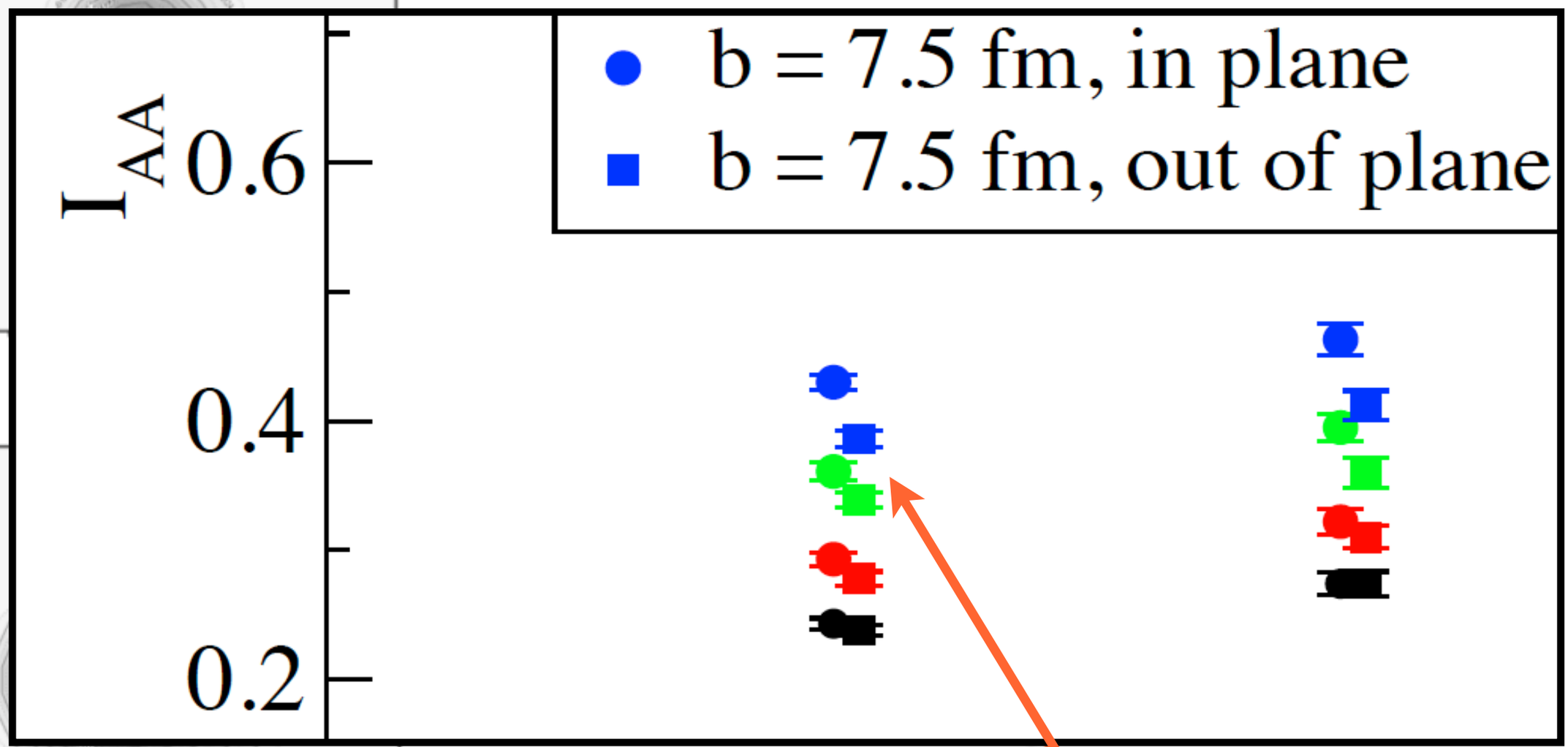
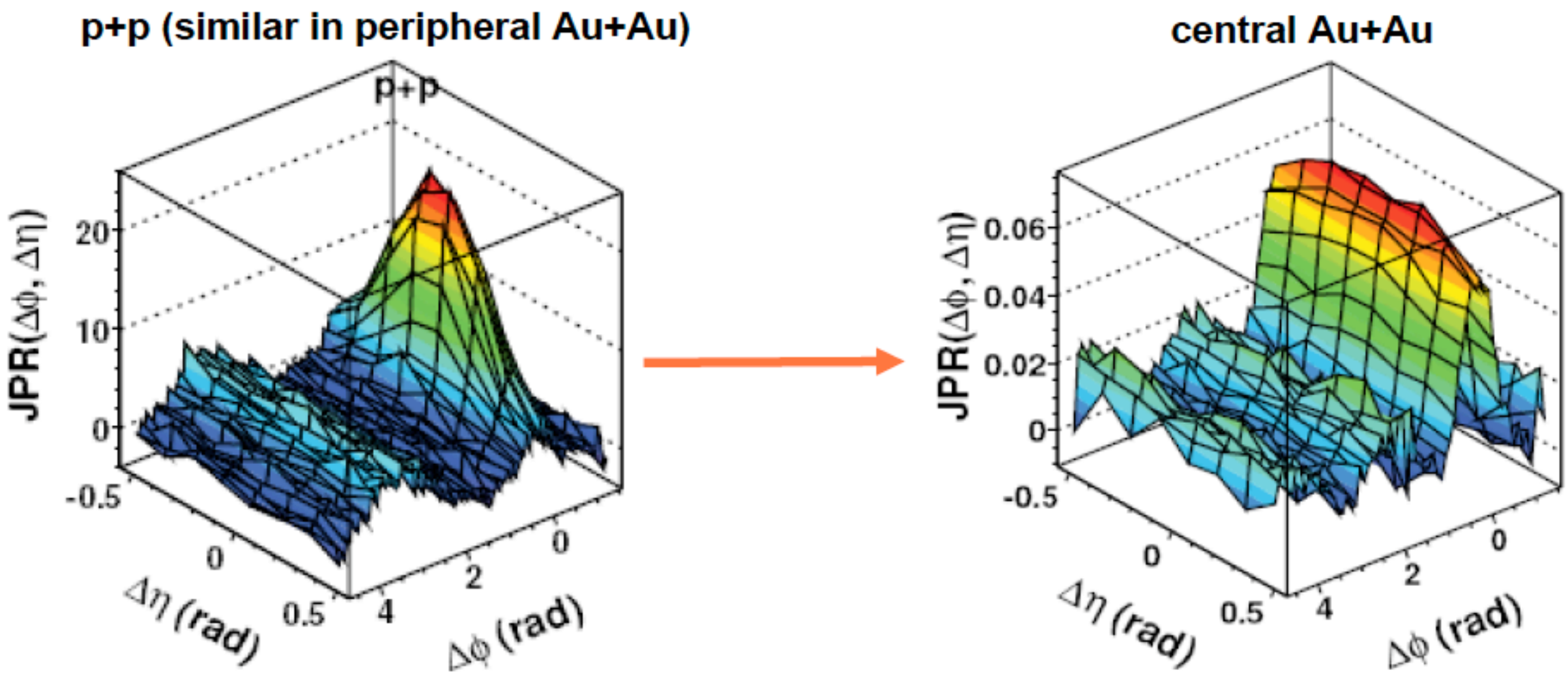




falling with increasing rp-angle
max ~12% variation in mid-central

Intermediate p_T Medium Response



Typical:
- Near-side Jet
- Away-side Jet - "Head"

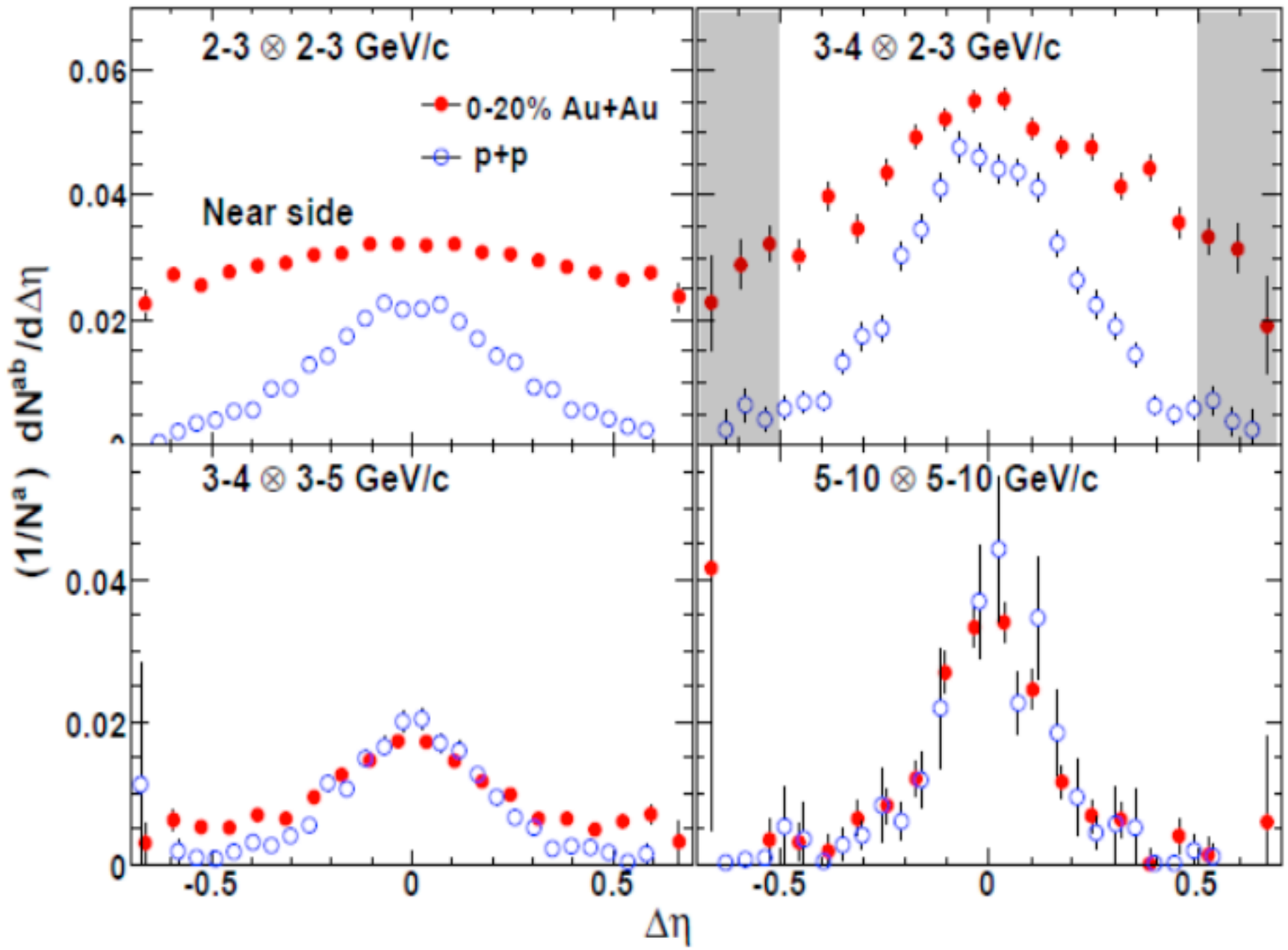
New:
- Near-side Modification- "Ridge"
- Away-side Modification - "Shoulder"

Near-side Ridge

- Broad Δη near-side enhancement measured in Au+Au collisions at intermediate p_T

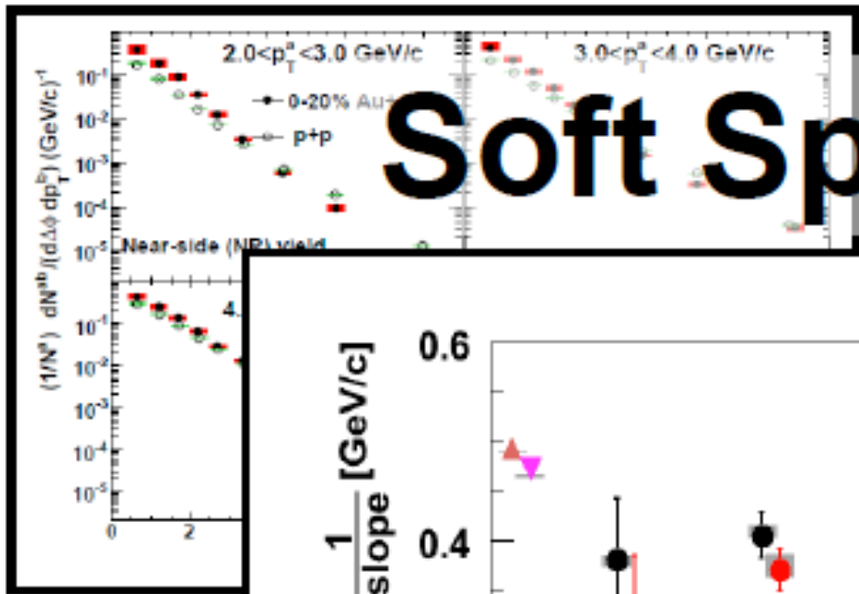
- High p_T near-sides are similar

- Intermediate p_T p+p near-side is narrower in Δη than central collisions

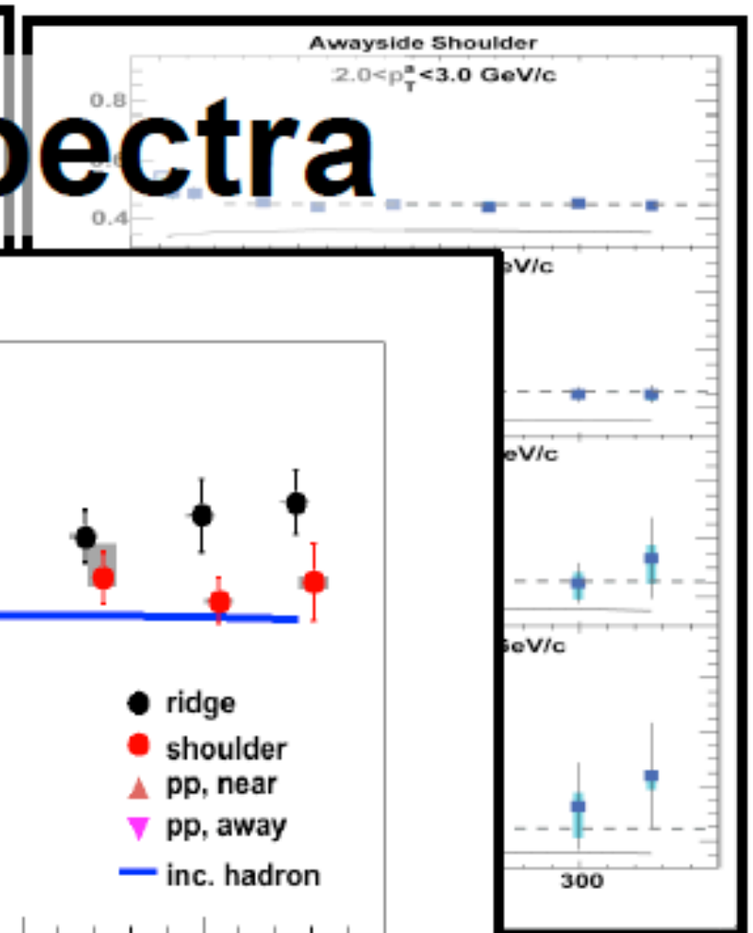


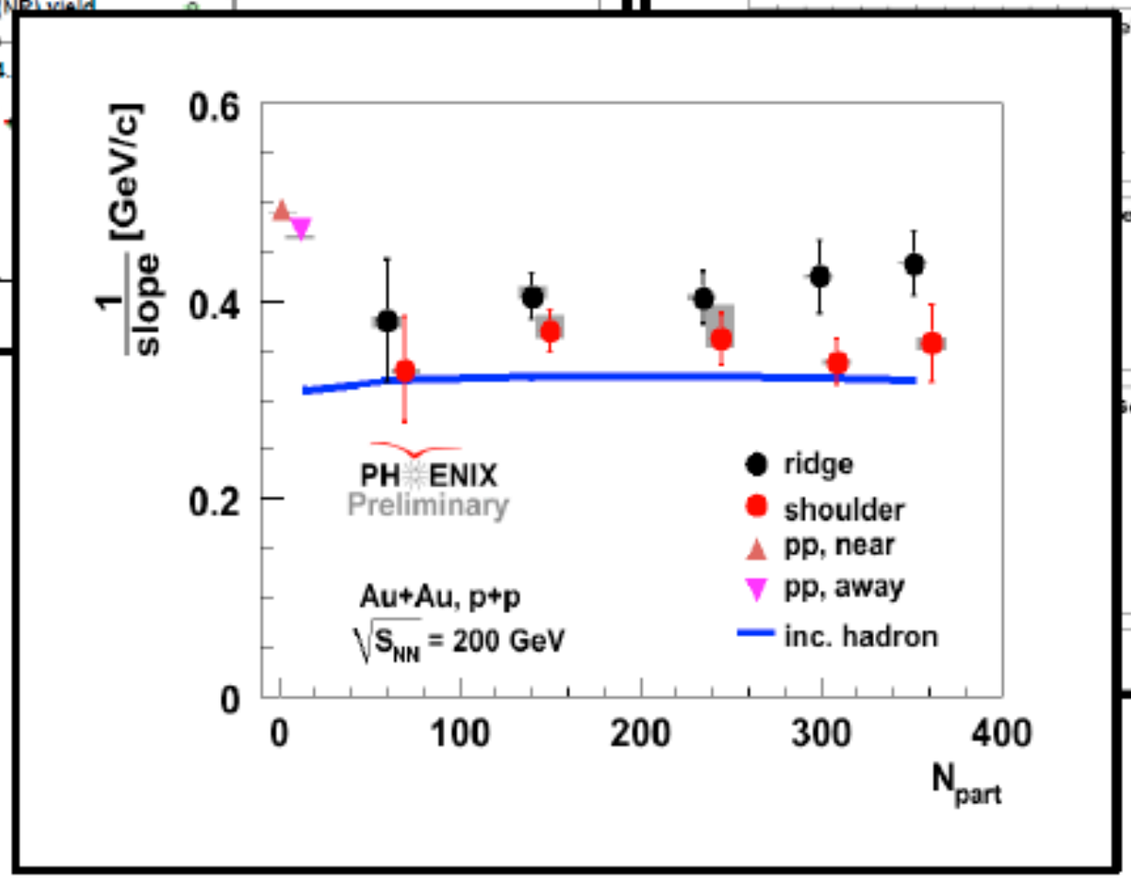
- At intermediate p_T, little p-p jet beyond Δη > 0.5

Many Similarities

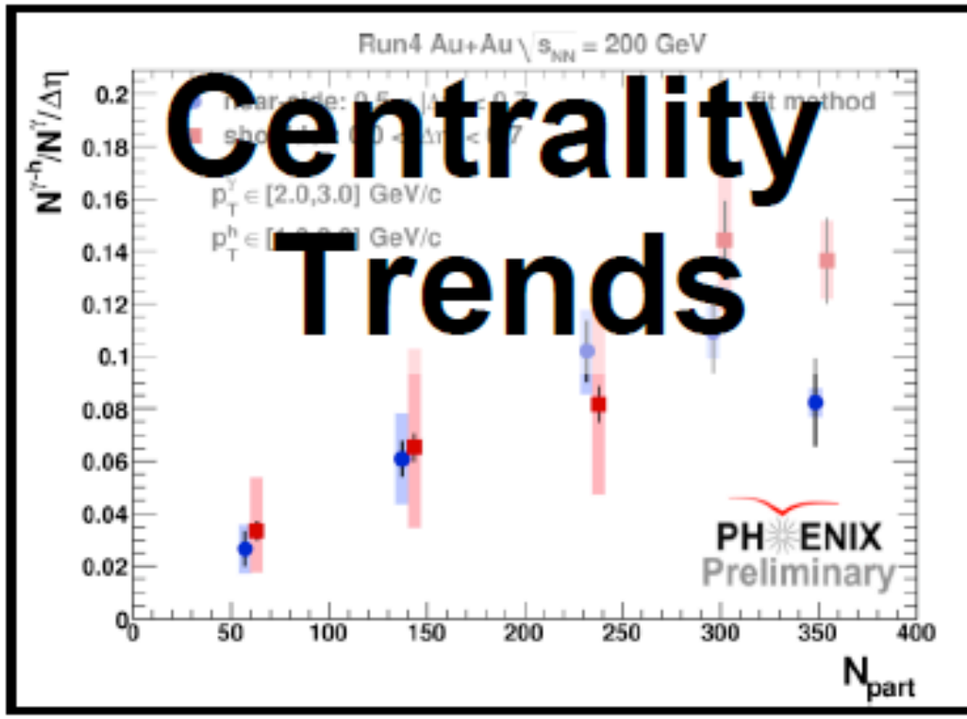


Soft Spectra

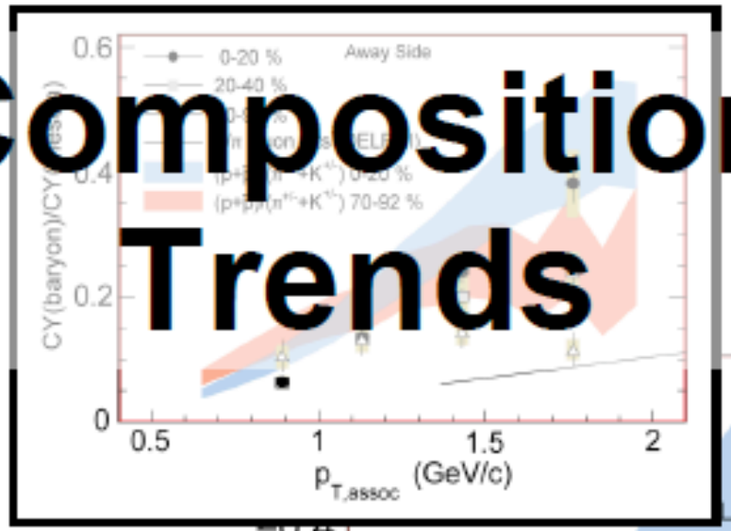




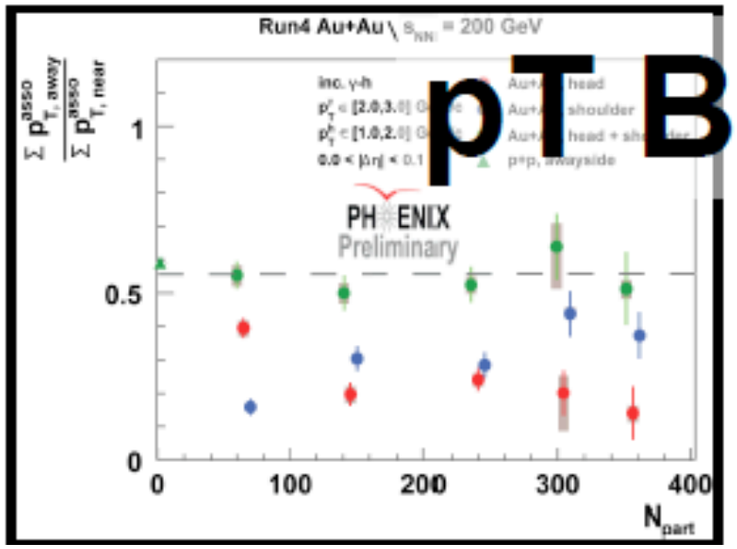
Centrality Trends

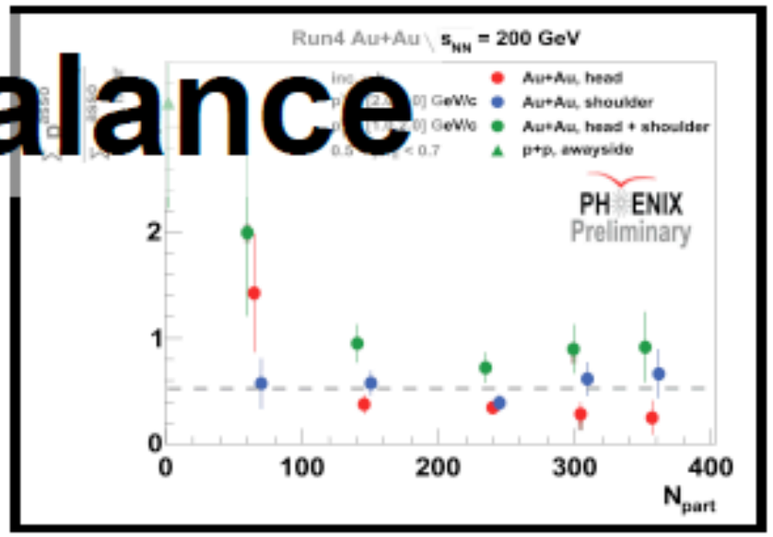


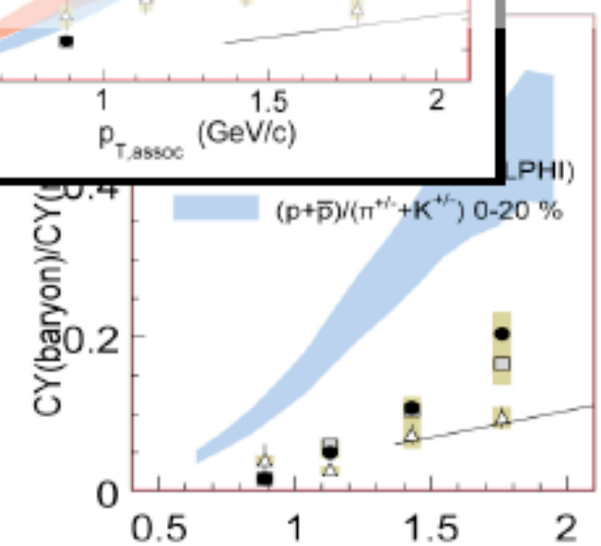
Composition Trends



pT Balance





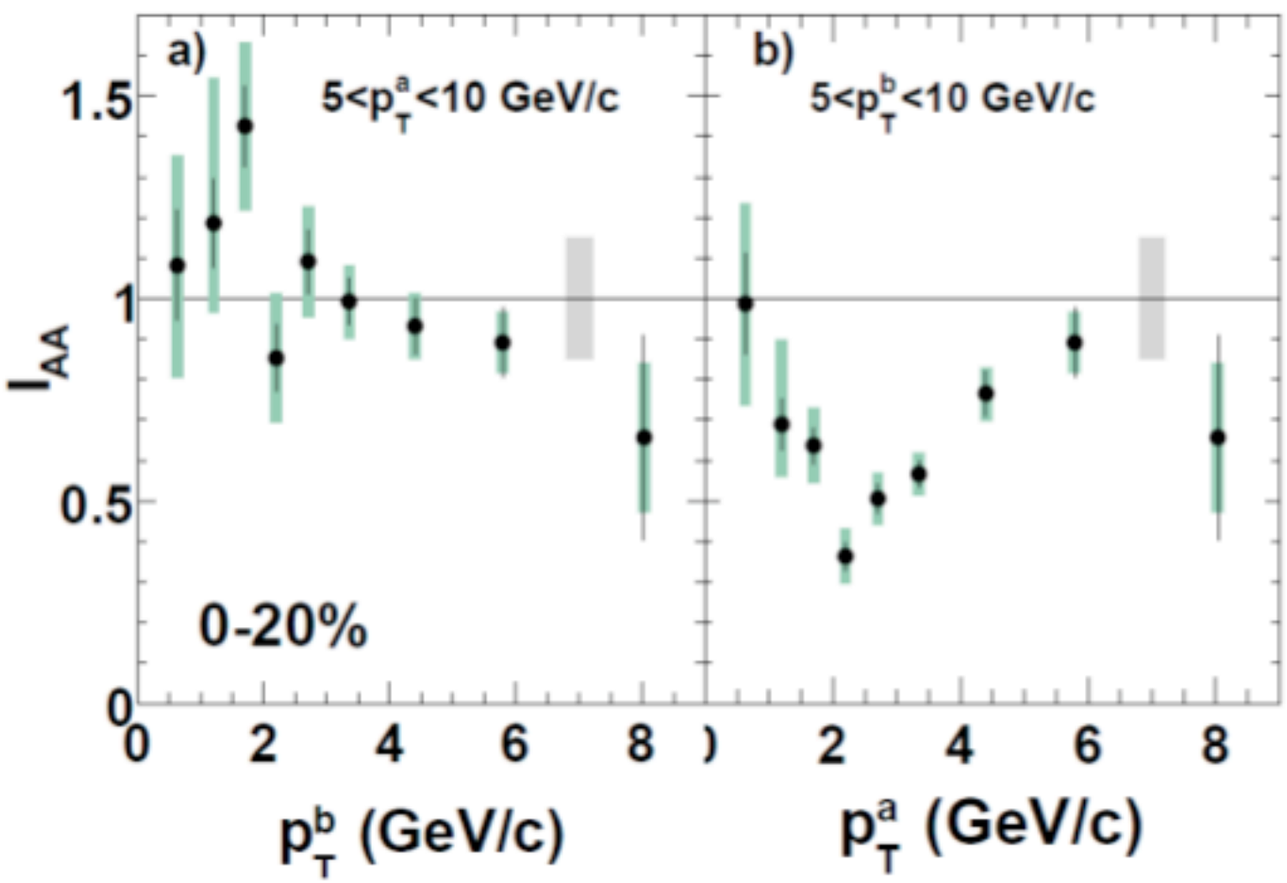


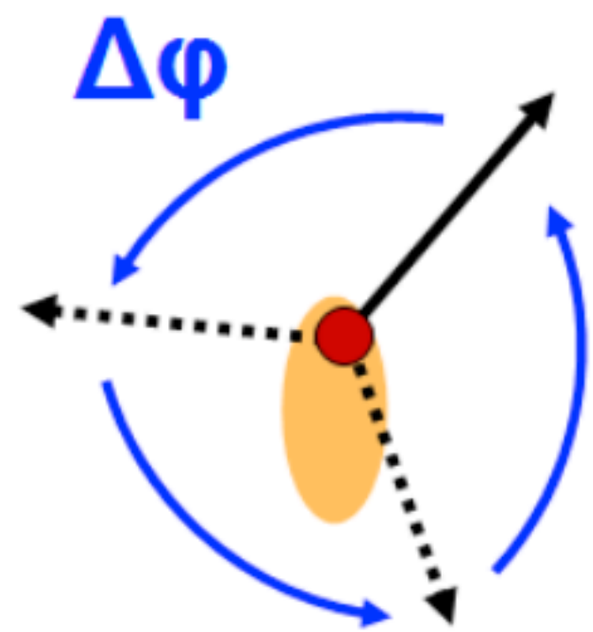
McCumber, QM08 Chen, HP08

Intermediate p_T Triggers

- I_{AA} trigger-partner anti- symmetry indicates not all triggers at intermediate pT 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 $\Delta\varphi = 0$ and $\Delta\varphi = \pi \pm 1.1$

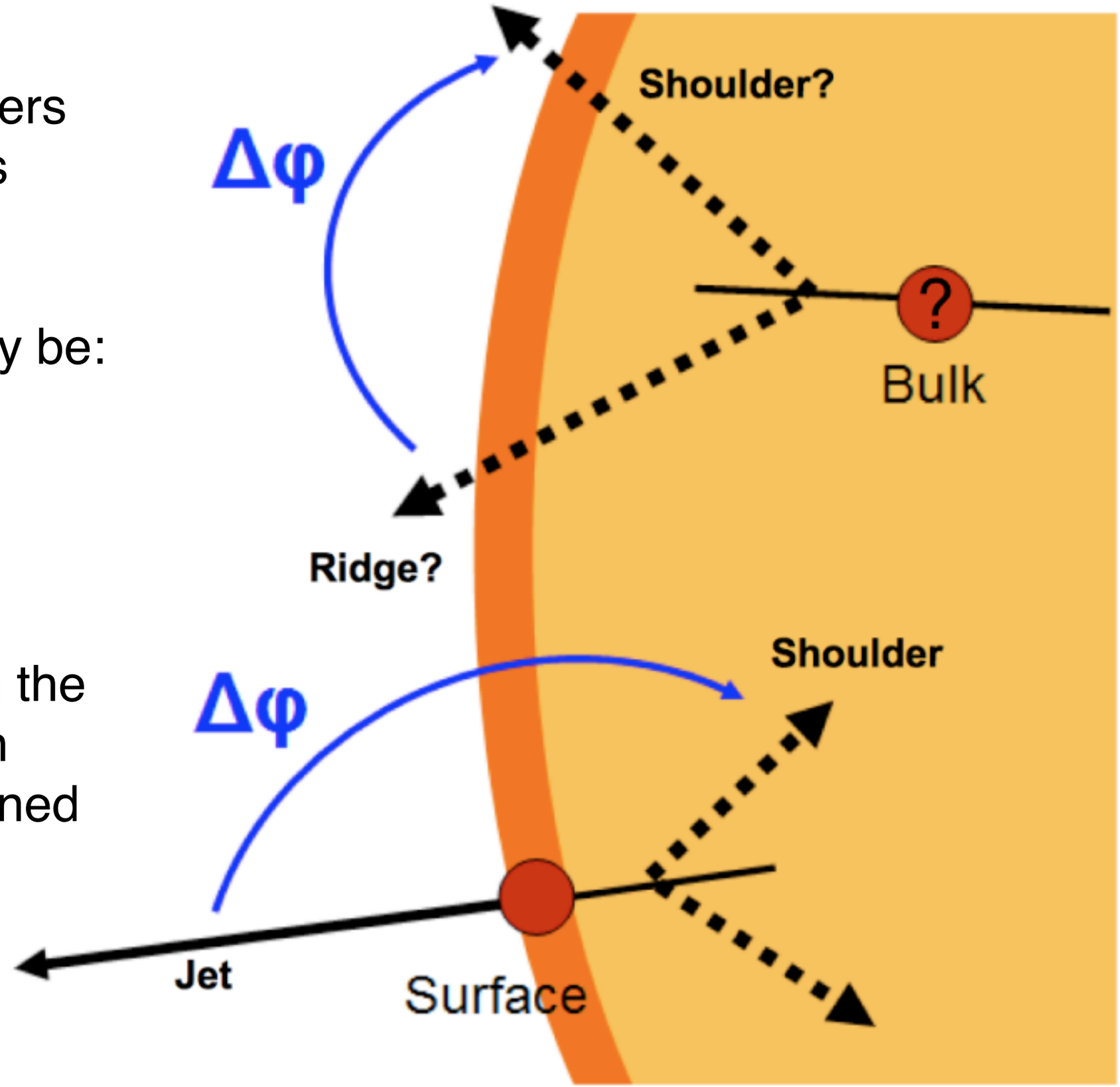
Medium Response Triggers

Non-fragmentation triggers significantly complicates interpretation

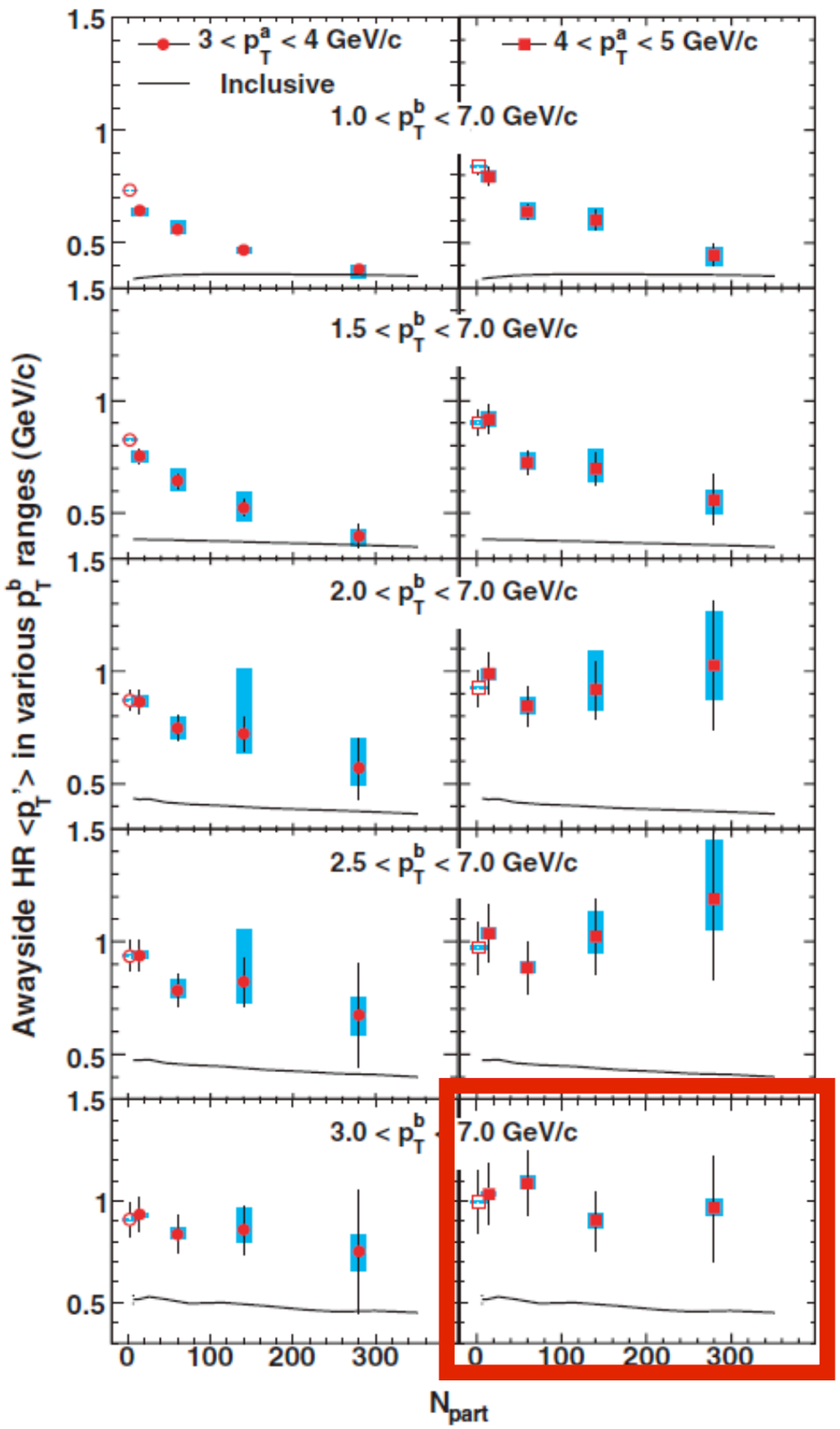
Ridge and Shoulder may be:

- jet-correlated
- self-correlated

Medium Response from the bulk and Recombination effects should be examined



Away-side p_T Spectra



A. Adare, et al., Phys.Rev.C **78** : 014901(2008)

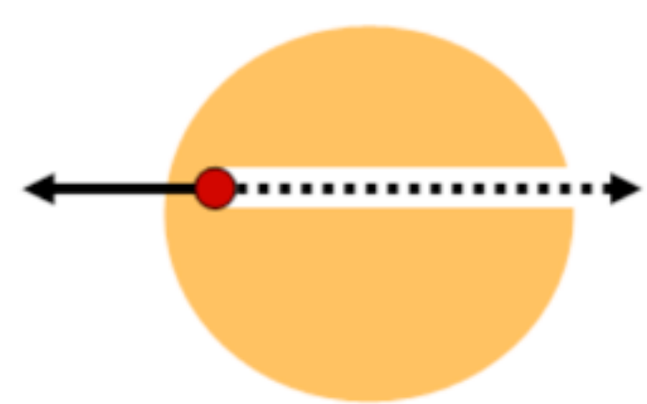
Reaction-plane dependence prefers crossing production

Spectral centrality dependence shows consistent slopes at high p_T

Surviving Partons:

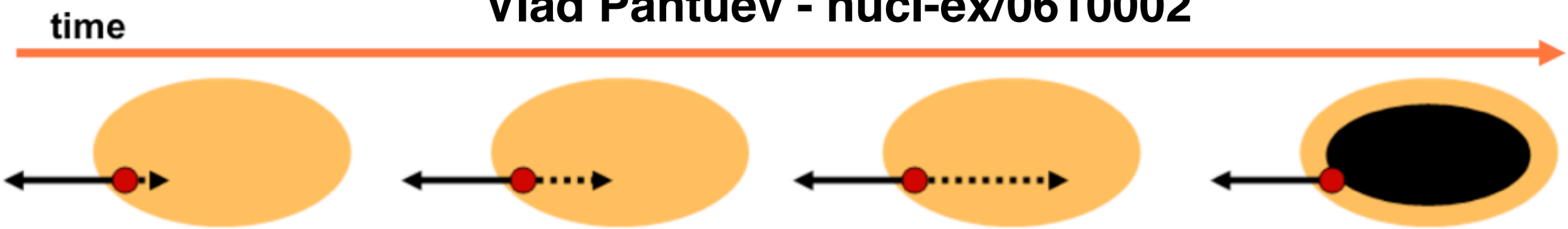
- cross the nuclear overlap
- lose little energy

"skip-through" production indicated for mid-central collisions



Predictions: Pantuev

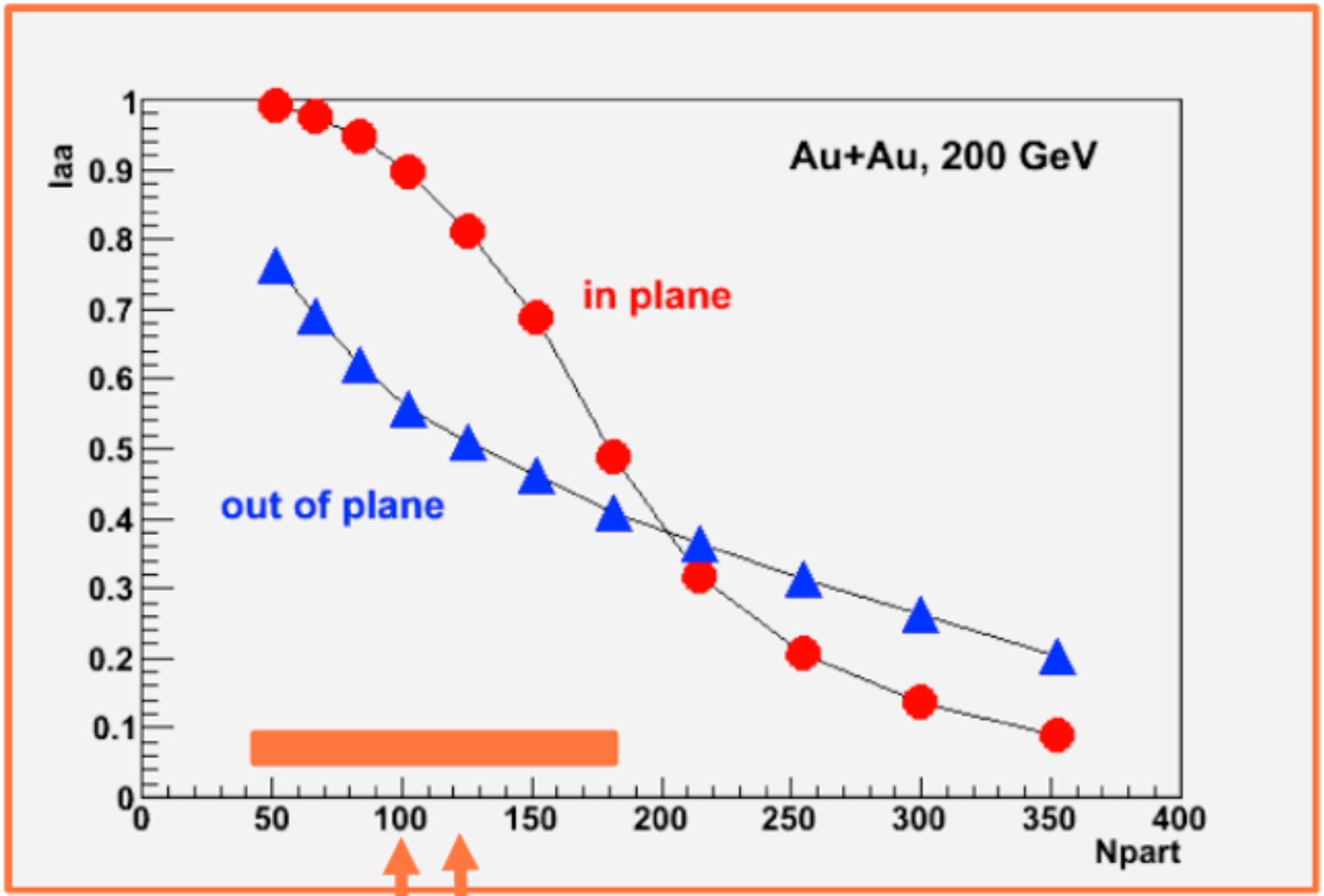
Vlad Pantuev - nucl-ex/0610002



Tangential-dominance only in more central collisions

Transition driven by formation time of black core

Large falling variation in mid-central bin ~45%



Trigger Weighted Npart 20-60% ~ 125

Npart 20-60% = 100

Two Source Assumption

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

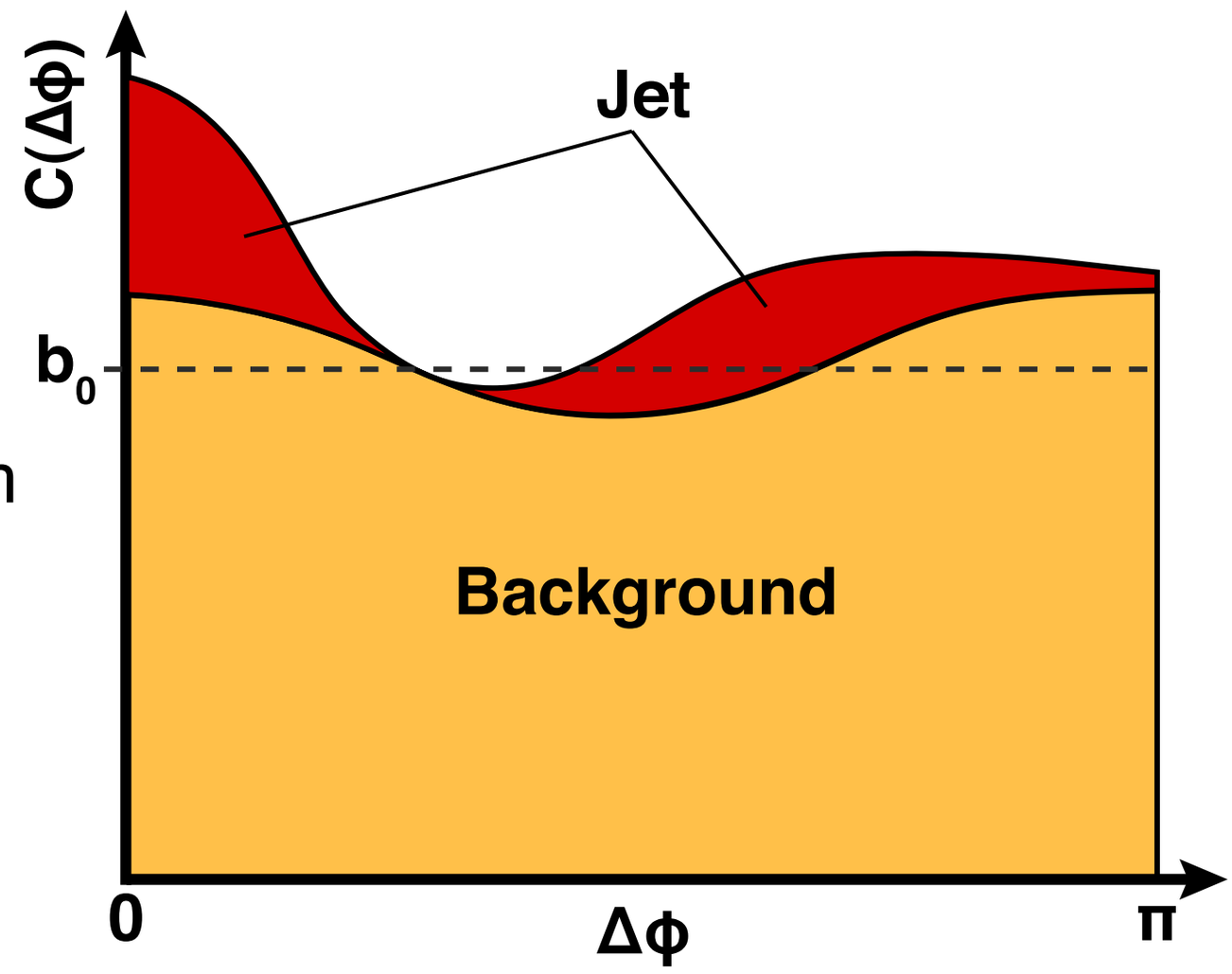
Some correlation sources (HBT, decay) are small

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



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?