

Jets and Jet-Related Correlation Measurements in PHENIX

Anthony Hodges for the PHENIX Collaboration
RHIC/AGS Annual Users' Meeting

Online

October 22nd, 2020

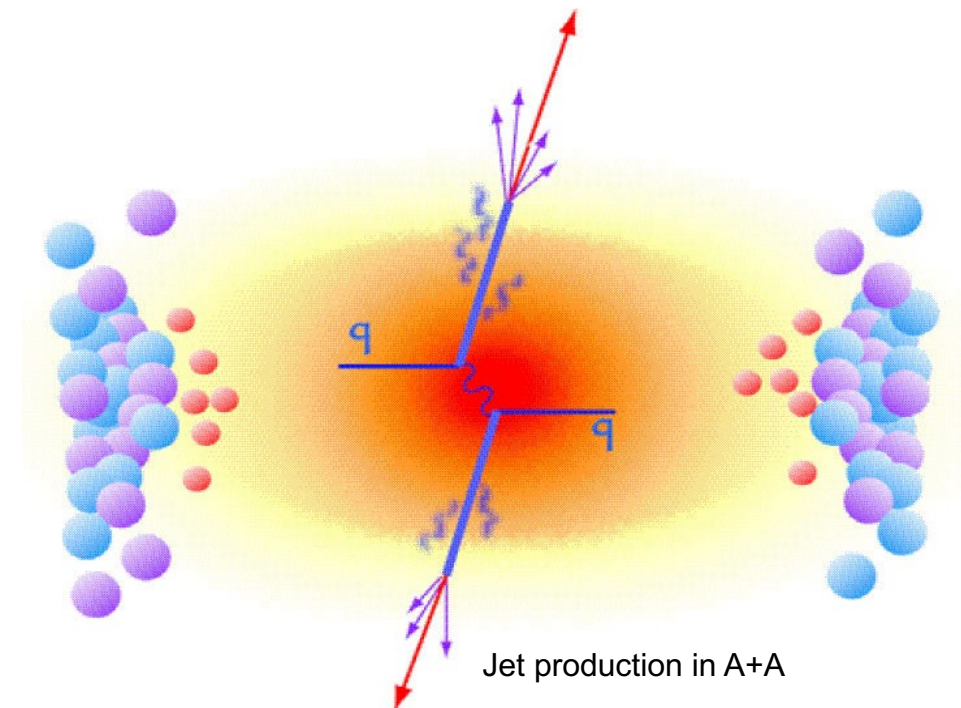
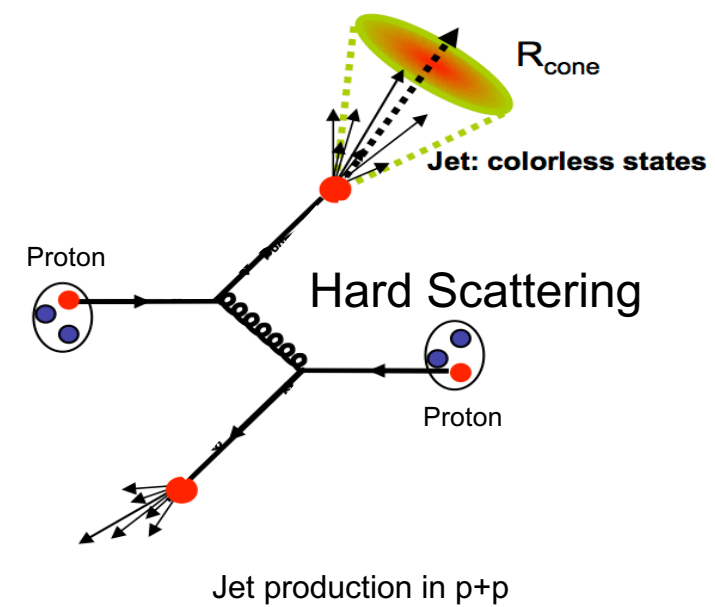


Georgia State
University®



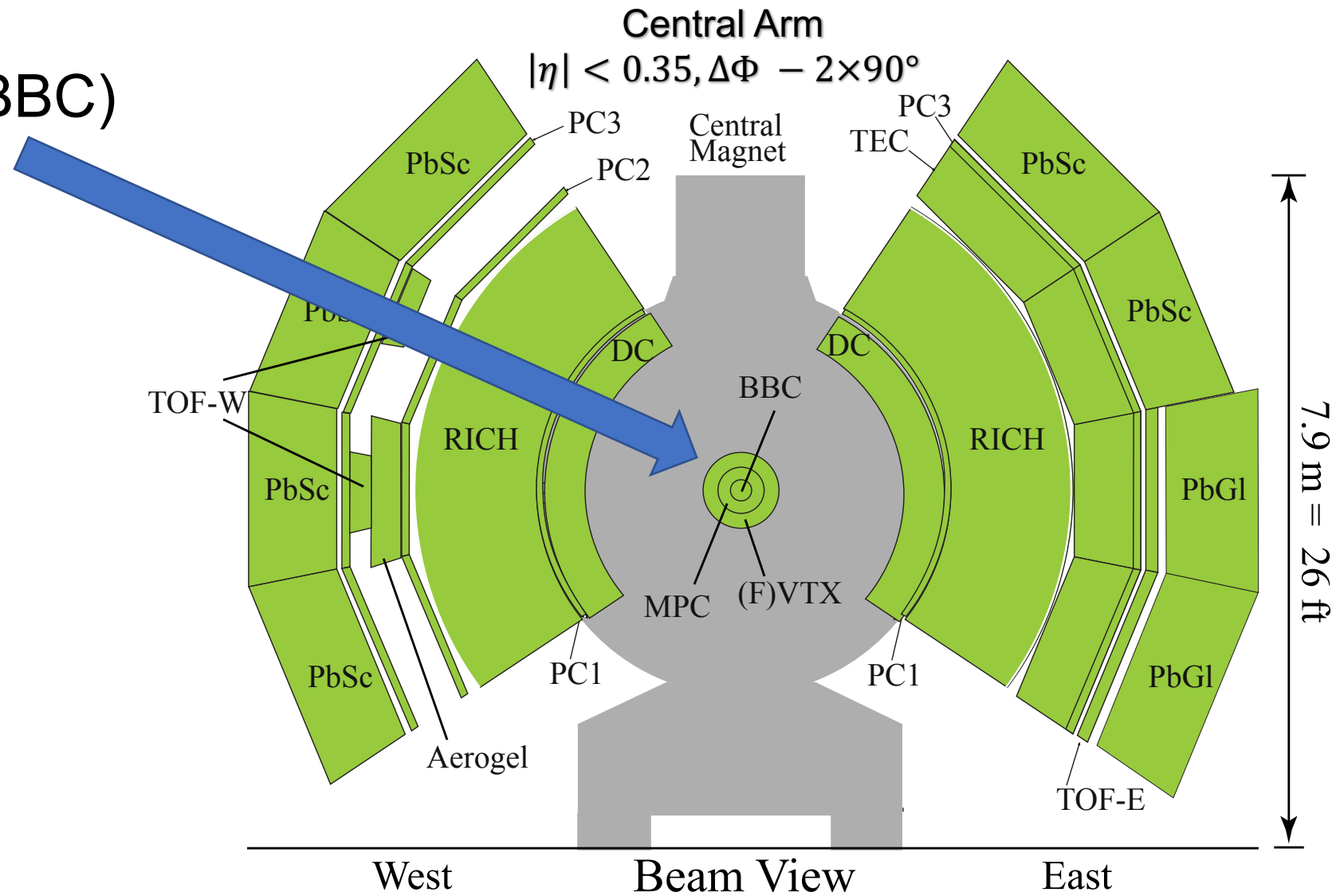
Jets and Jet Modification

- In p+p:
 - Cold QCD, spin
 - New unfolded cross section, Jet A_{LL}
 - Unmodified, baseline for A+A studies.
- In A+A:
 - Jets are modified by medium interactions.
 - Jet modification can tell us about QGP properties.
 - Jet R_{AB} , σ_{Away} , I_{AA}



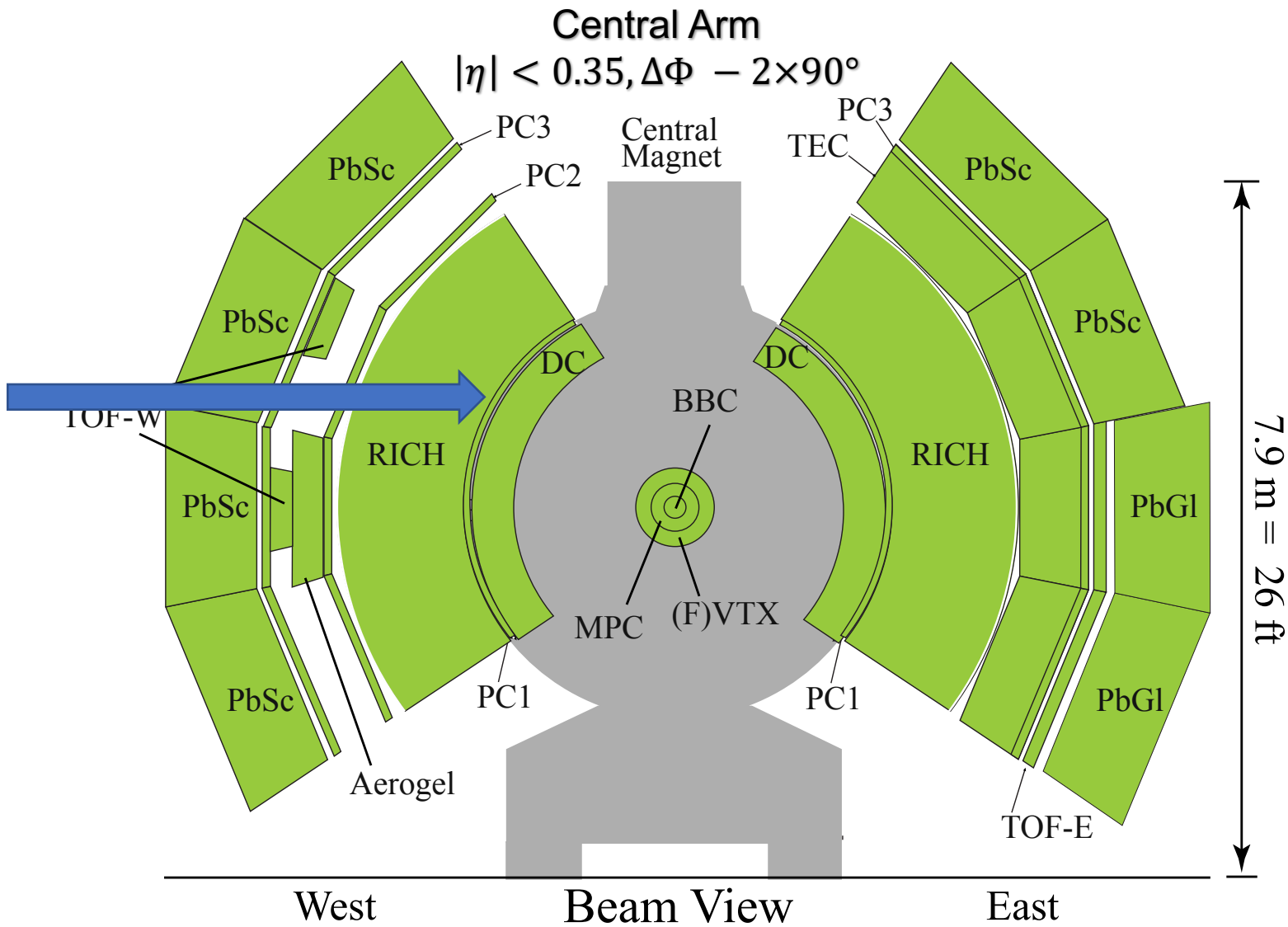
The PHENIX Detector

- Beam-Beam Counter (BBC)
 - Event Characterization
 - Centrality, z-vertex



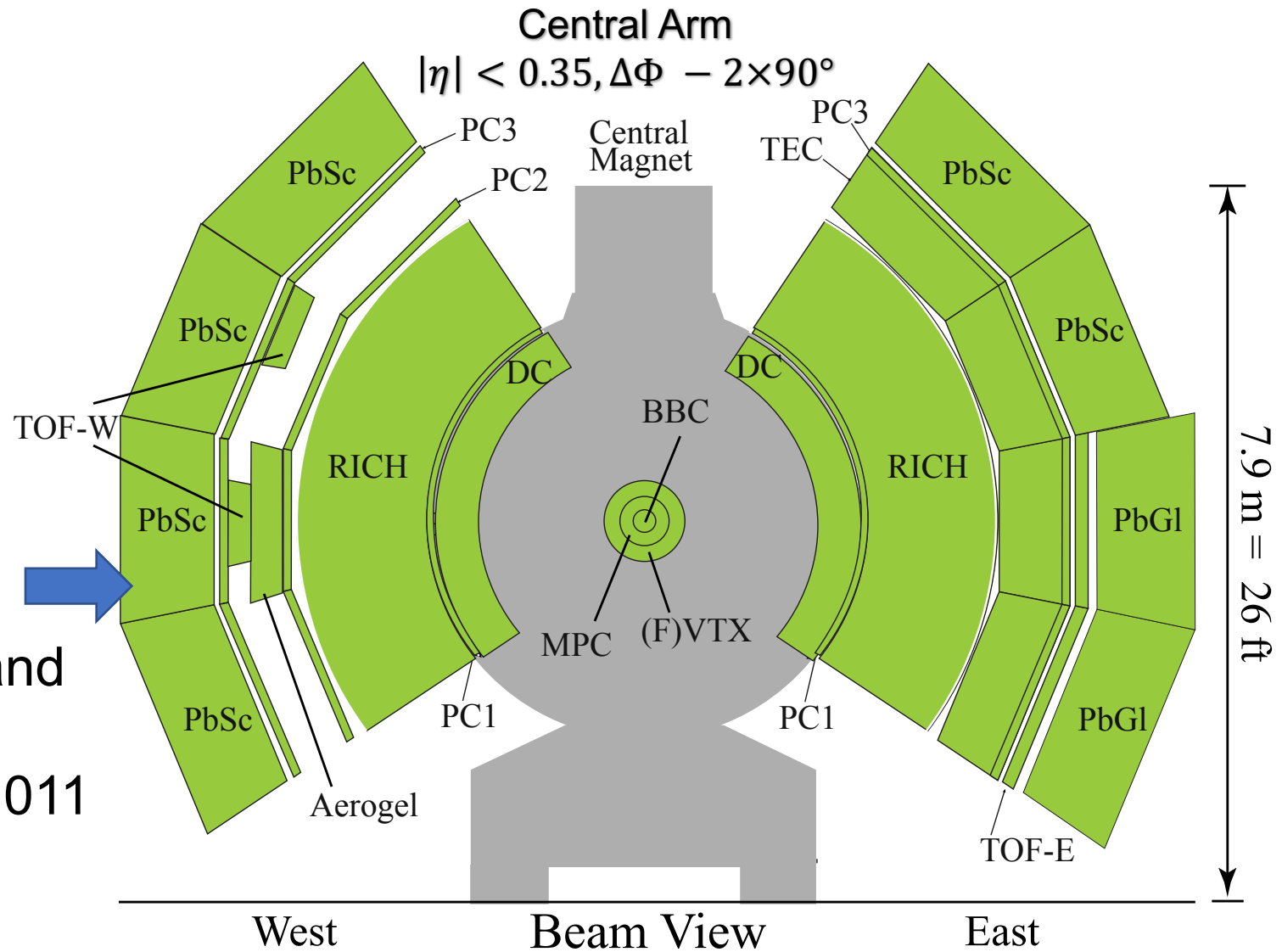
The PHENIX Detector

- Drift and Pad Chambers
 - Charge track reconstruction
 - Momentum measurement



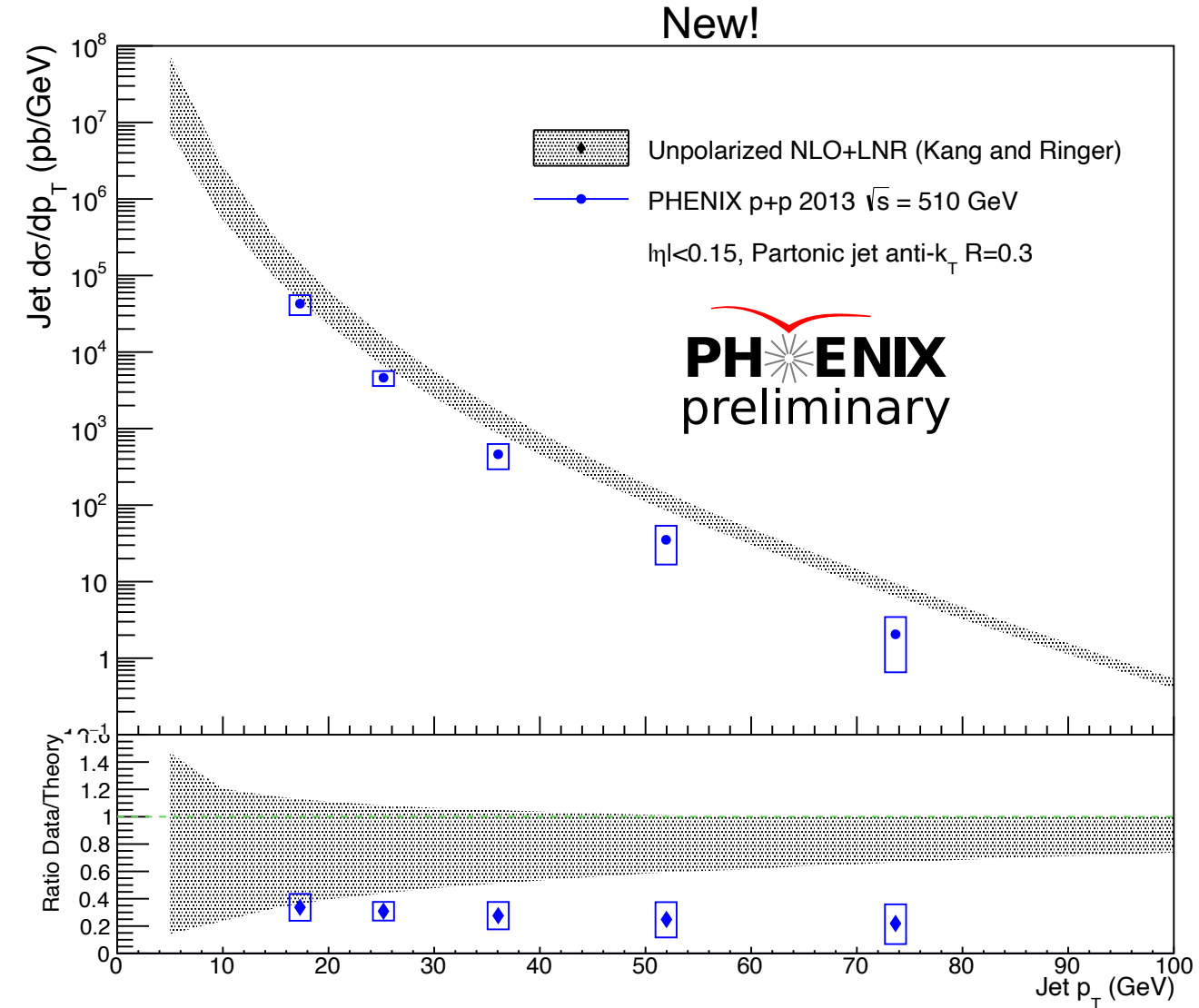
The PHENIX Detector

- Electromagnetic Calorimeter
 - Measures energy of photons and electrons
 - Granularity, $\delta\eta \times \delta\phi \leq 0.011 \times 0.011$



Full Jet Reconstruction in PHENIX

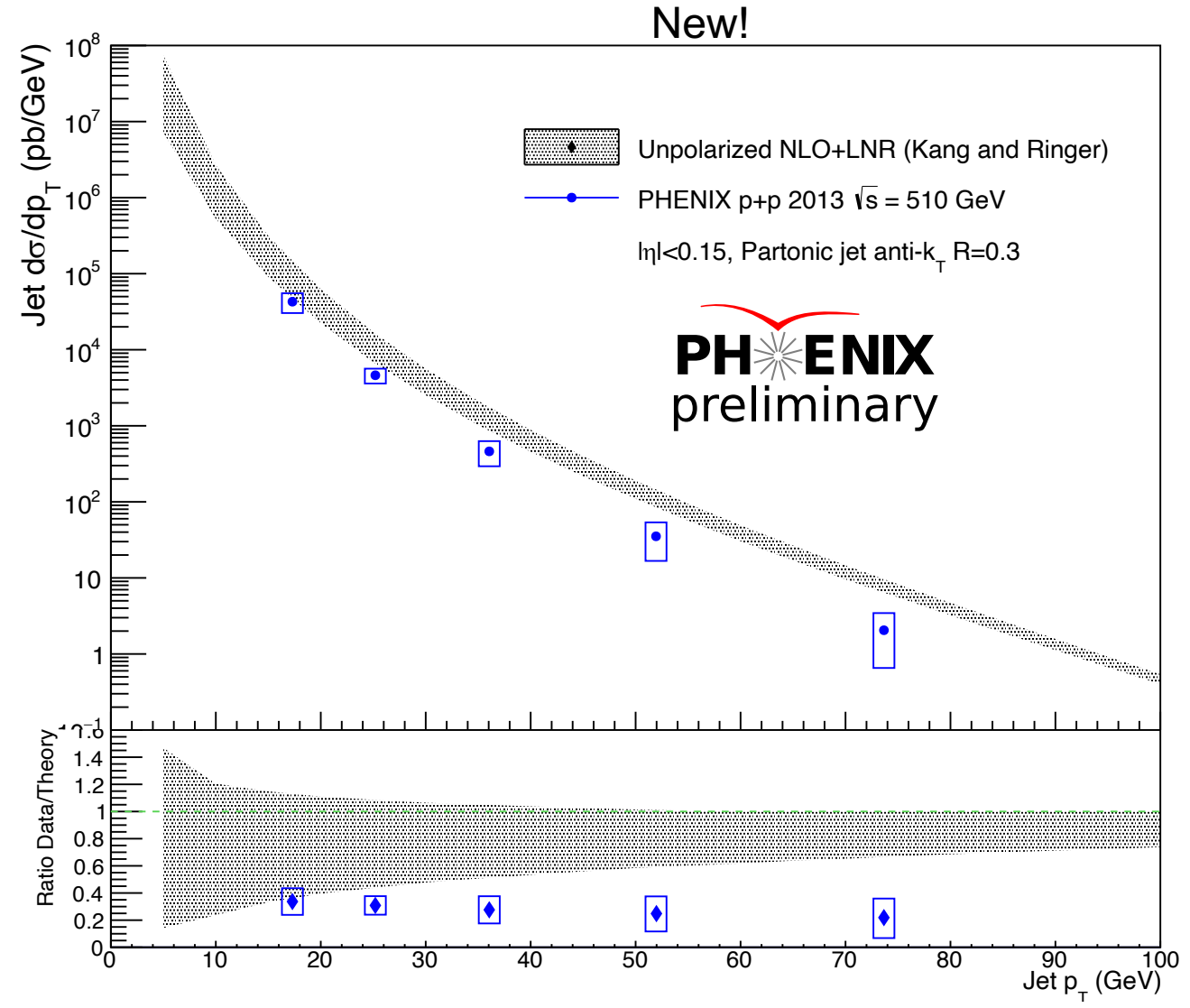
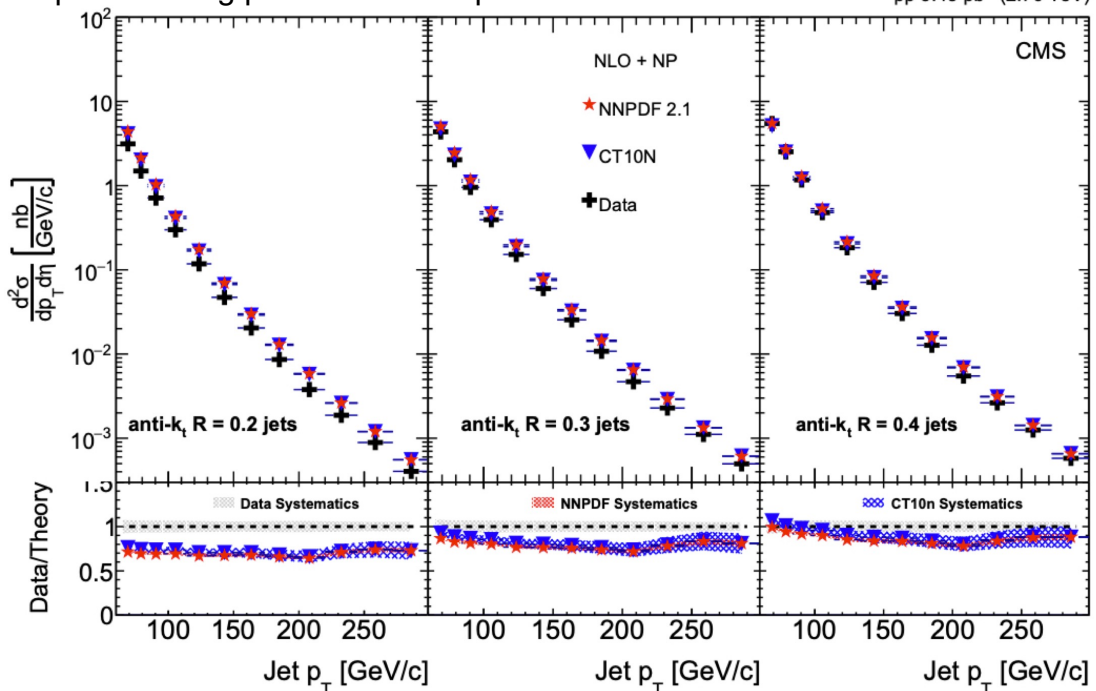
- New unfolded cross section in polarized p+p collisions at $\sqrt{s_{NN}} = 510\text{GeV}$
- Jet reconstructed with anti- k_T with $R=0.3$



Full Jet Reconstruction in PHENIX

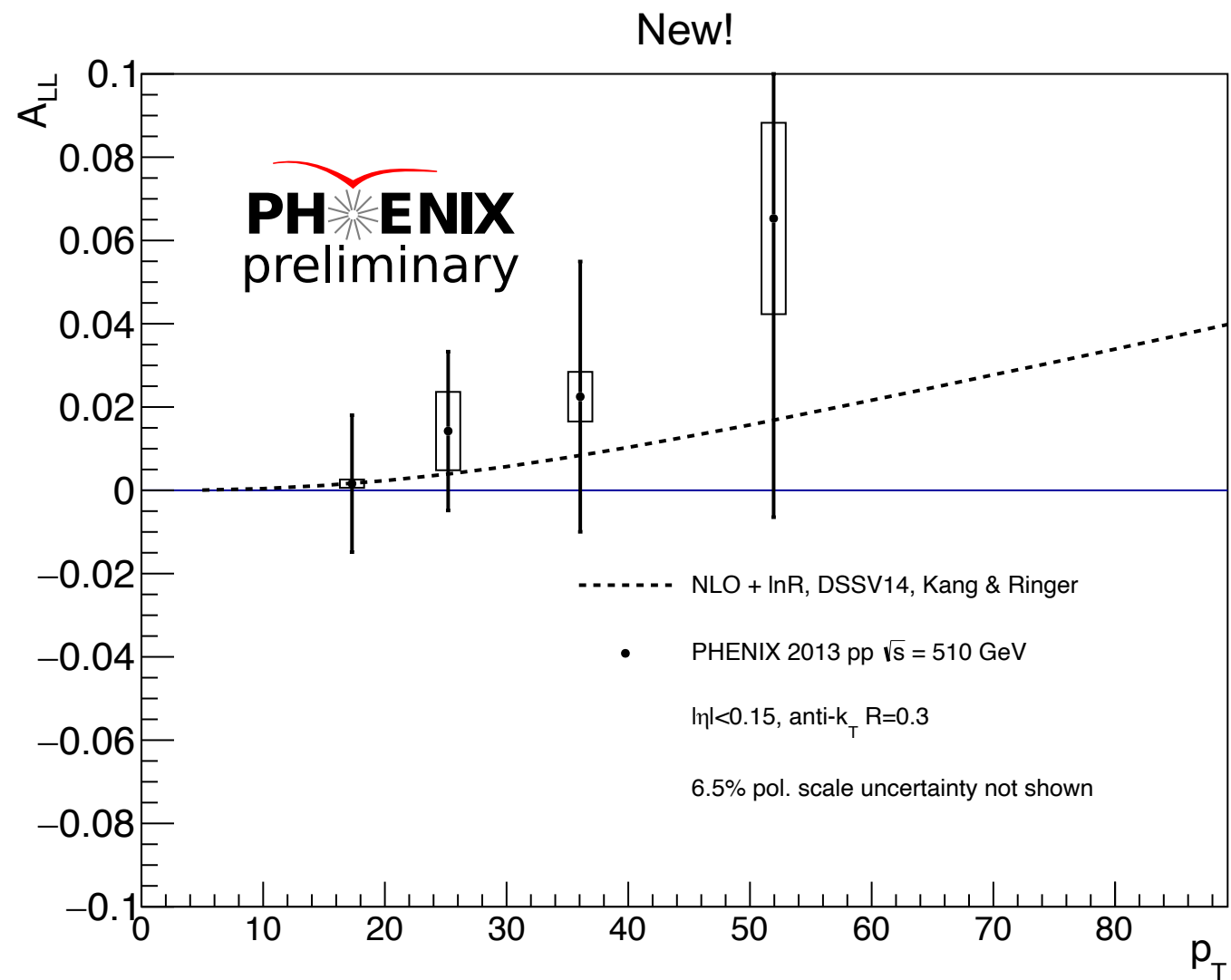
- New unfolded cross section in polarized p+p collisions at $\sqrt{s_{NN}} = 510\text{GeV}$
- Cross section systematically lower than theory predictions
 - Consistent with LHC observed dependence on resolution parameter

<https://arxiv.org/pdf/1609.05383.pdf> pp 5.43 pb⁻¹ (2.76 TeV)



Full Jet Reconstruction in PHENIX

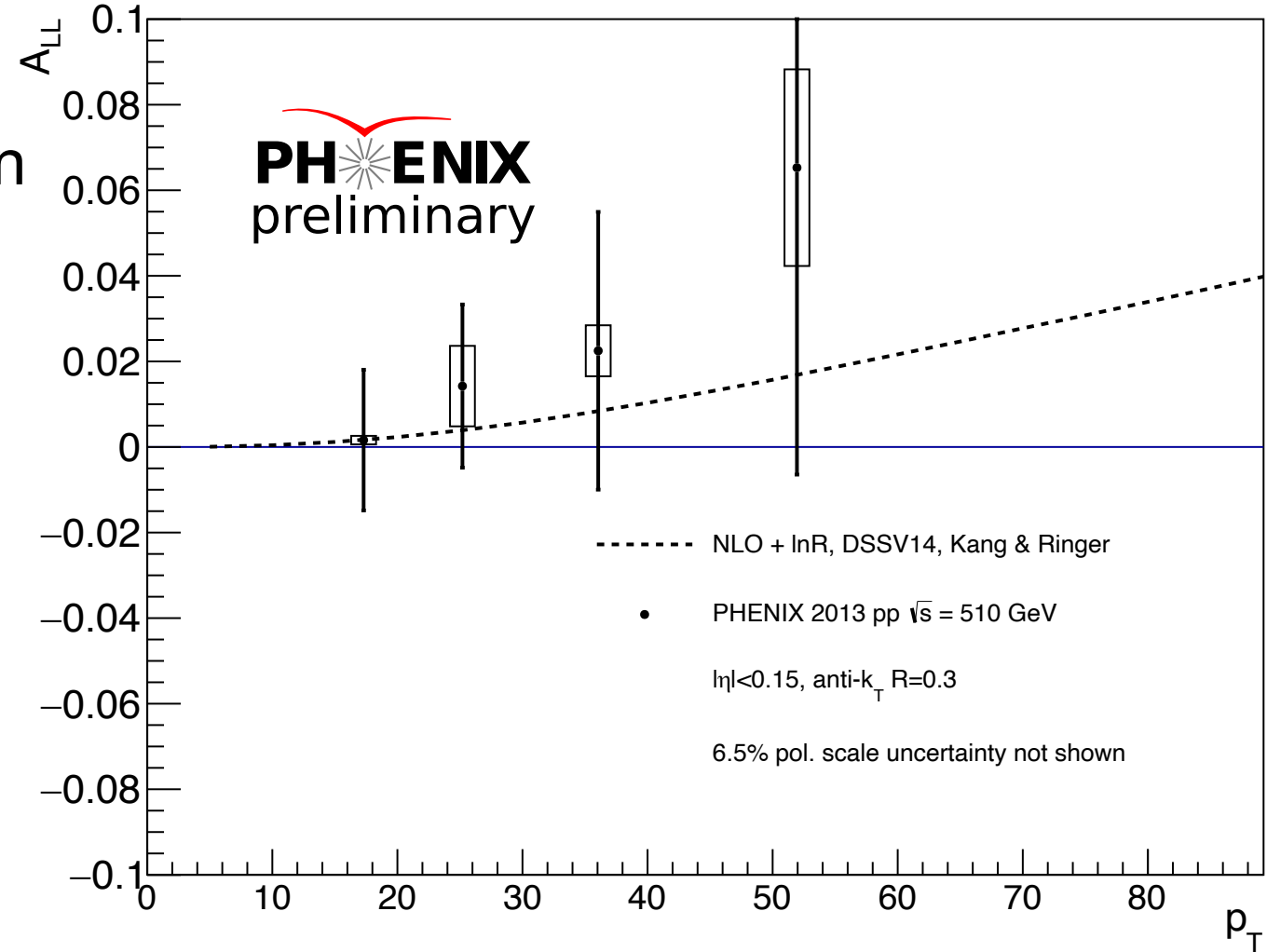
- New measurement of jet longitudinal double spin asymmetry A_{LL}



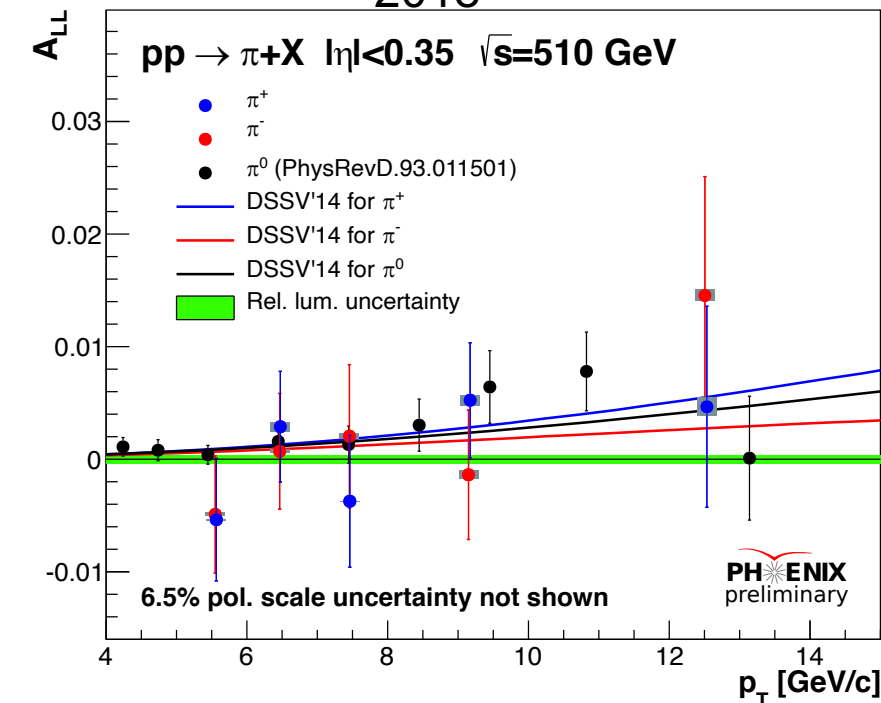
Full Jet Reconstruction in PHENIX

- New measurement of jet longitudinal double spin asymmetry A_{LL}
- Jet A_{LL} consistent with non-zero gluon polarization based on previous PHENIX π^0 A_{LL} results (below)

New!

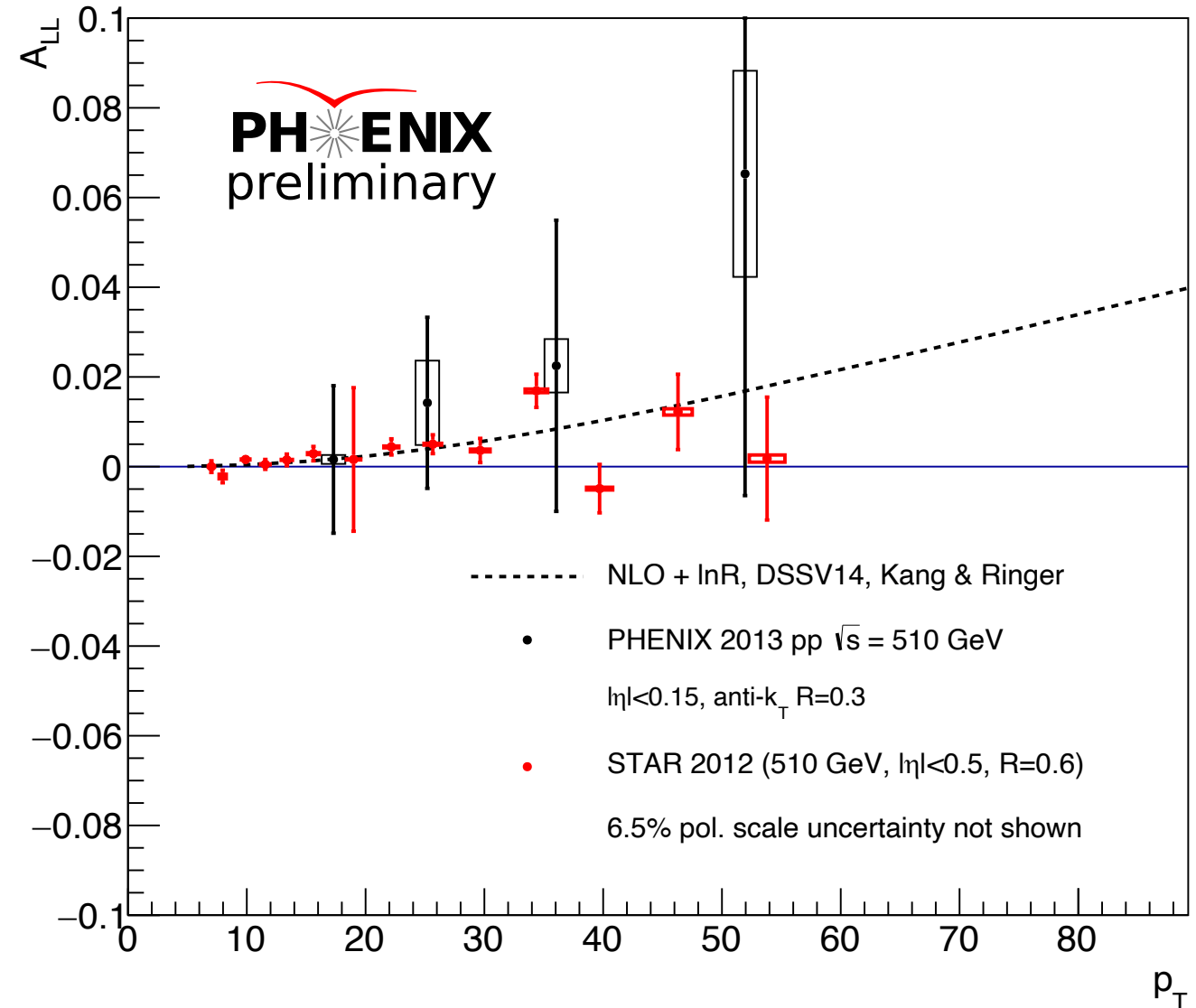


2018



Full Jet Reconstruction in PHENIX

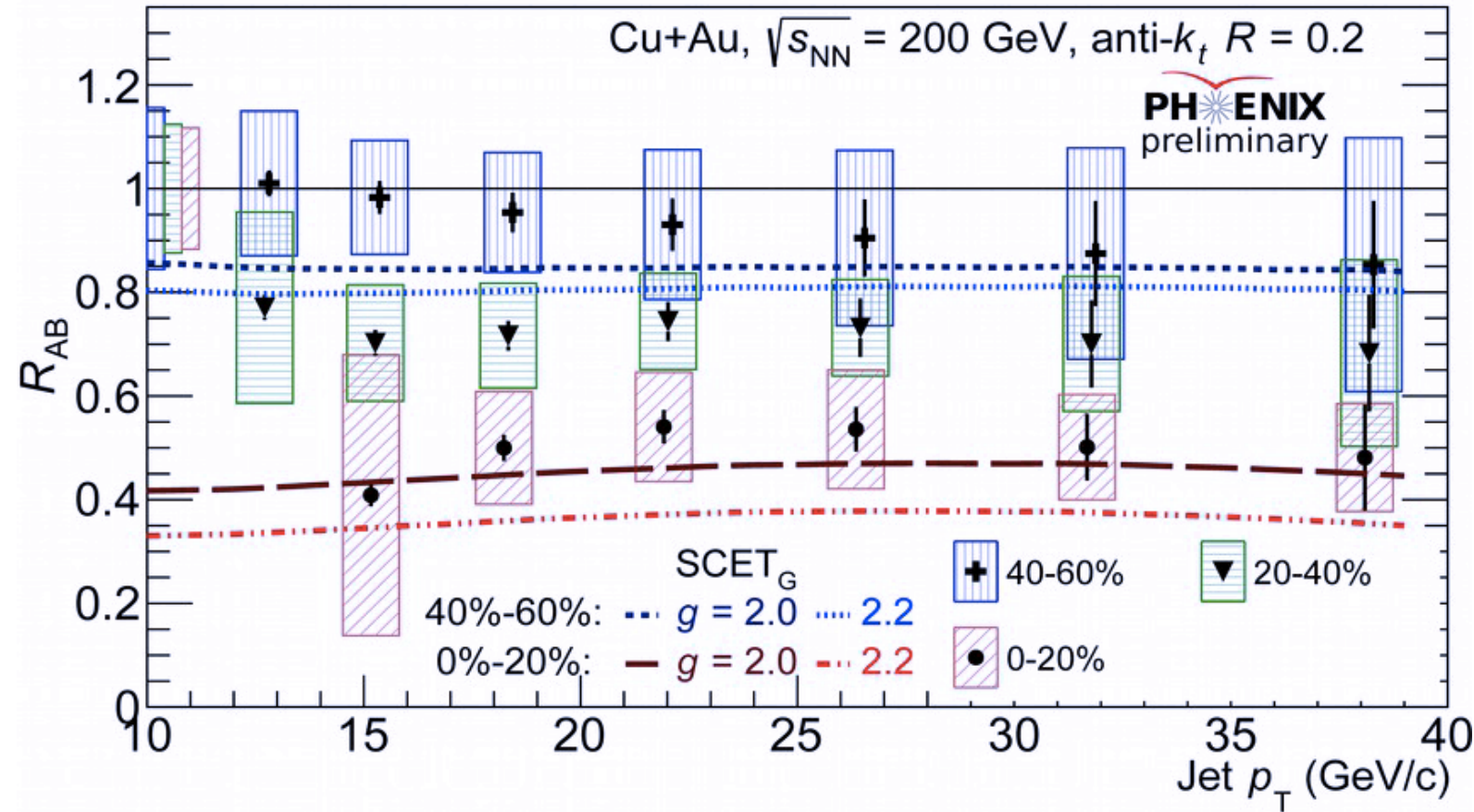
- A_{LL} measured by PHENIX found to be consistent with STAR results



More Information:
 Milap Patel: [PHENIX Cold QCD Highlights](#)
 Thursday, October 22nd, 12:15PM

Full Jet Reconstruction in PHENIX

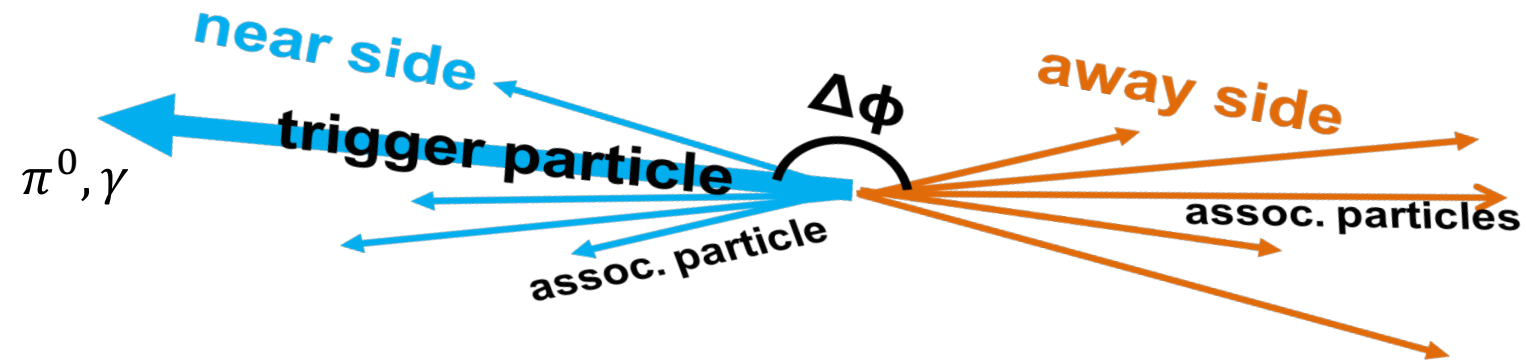
- Anti- k_T algorithm with $R = 0.2$
- Unfolding via SVD
- Measured suppression shows clear dependence on centrality
- SCET_g calculation with jet-medium coupling $g = 2.0$ shows good agreement to data to within uncertainty



SCET_g: Phys. Rev. D93, 074030 (2016)

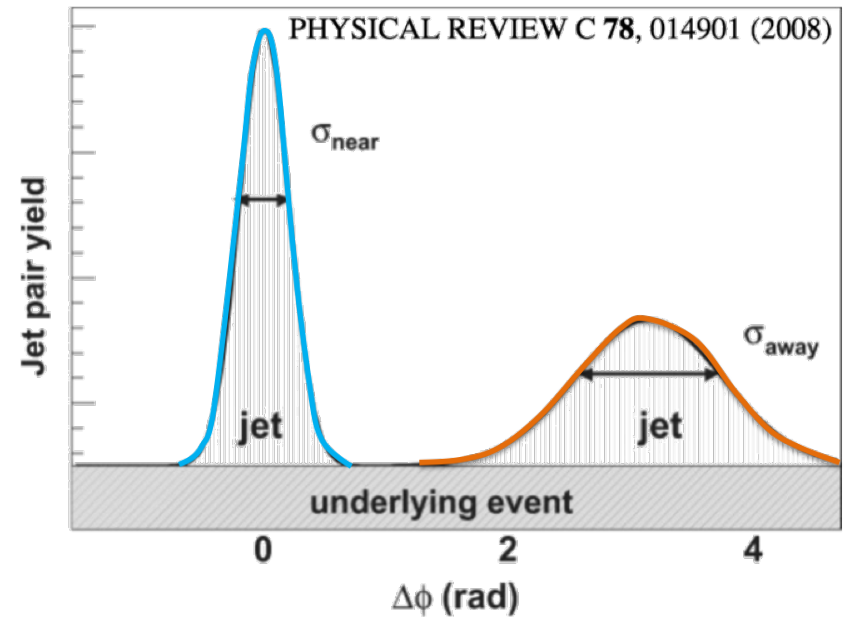
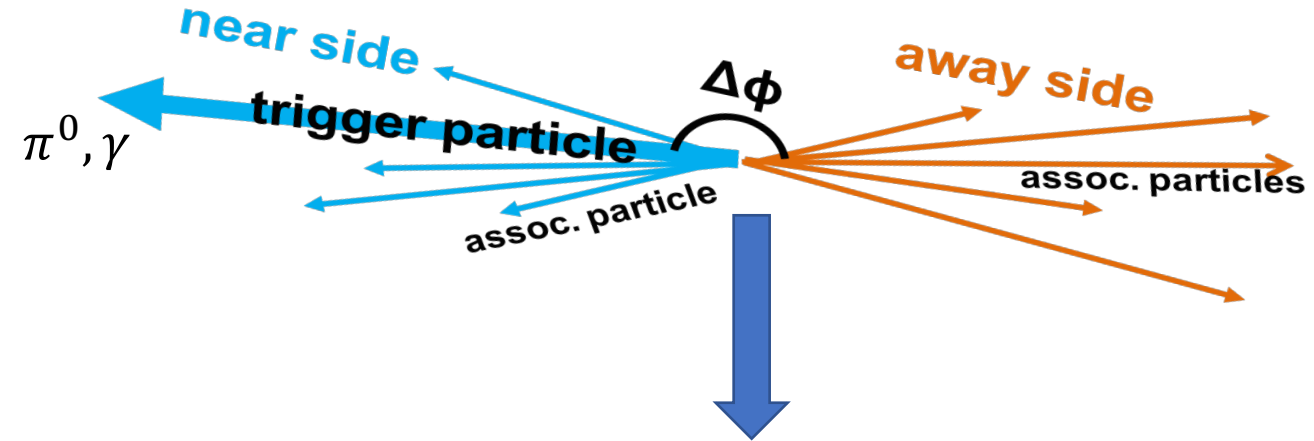
Jets in PHENIX – Two-Particle Correlations

- Two-particle Correlations
 - π^0 -hadron correlations
 - Direct γ -hadron correlations



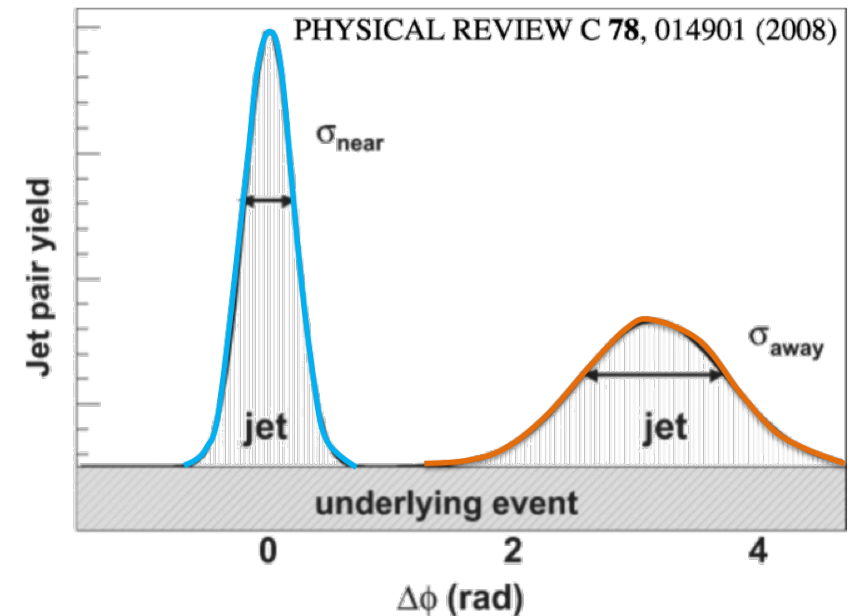
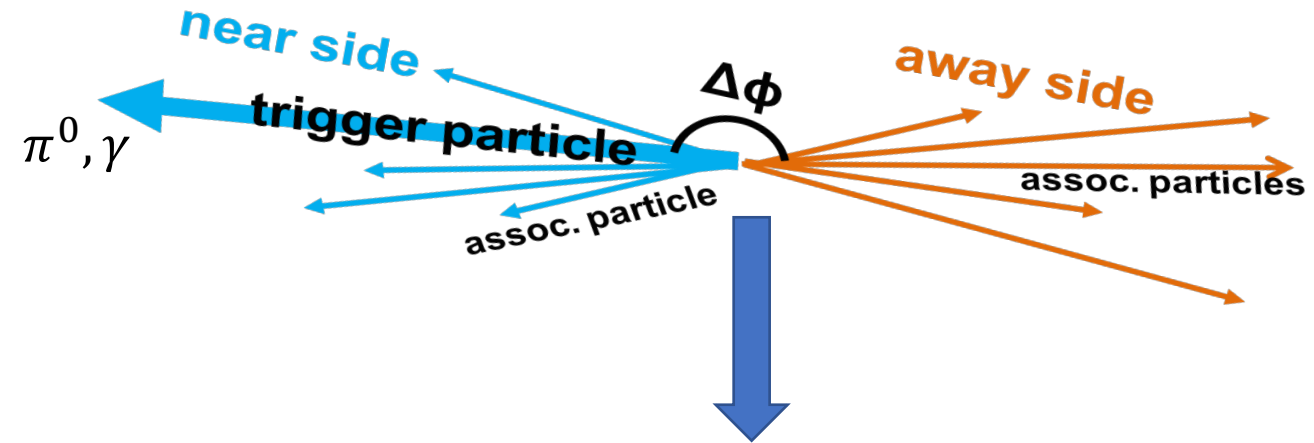
Jets in PHENIX – Two-Particle Correlations

- Two-particle Correlations
 - π^0 -hadron correlations
 - Direct γ -hadron correlations
- Measuring Jet Modification
 - Shape modification: σ_{Away}
 - Yield modification: $I_{AA} = \frac{\gamma^{AA}}{\gamma^{pp}}$



Jets in PHENIX – Two-Particle Correlations

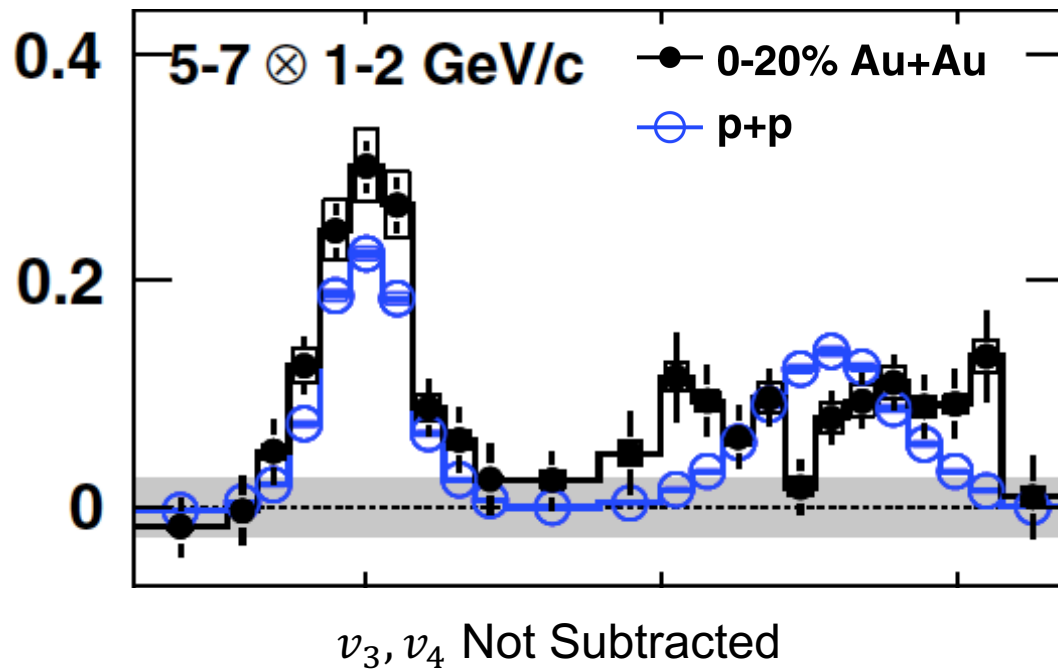
- Two-particle Correlations
 - π^0 -hadron correlations
 - Direct γ -hadron correlations
- Measuring Jet Modification
 - Shape modification: σ_{Away}
 - Yield modification: $I_{AA} = \frac{Y^{AA}}{Y^{pp}}$
- New! Substructure modification: $I_{AA}(\Delta\phi)$



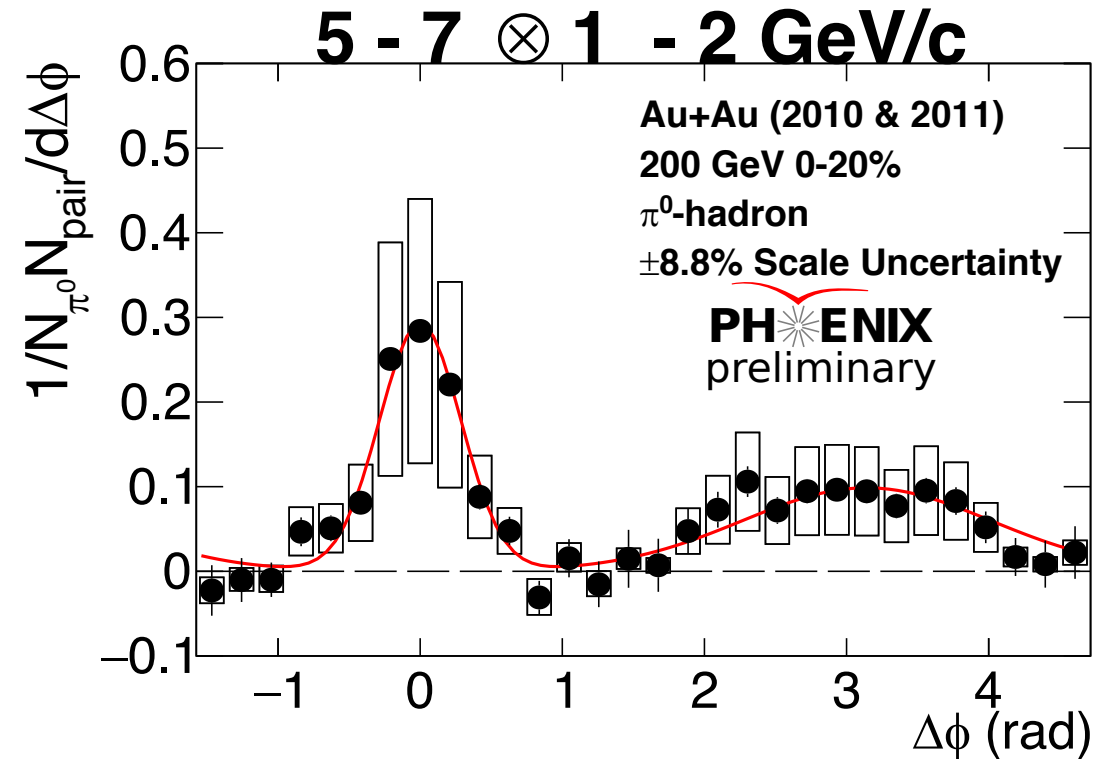
Underlying Event Subtraction

2007

PRL 104 252301 (2010)

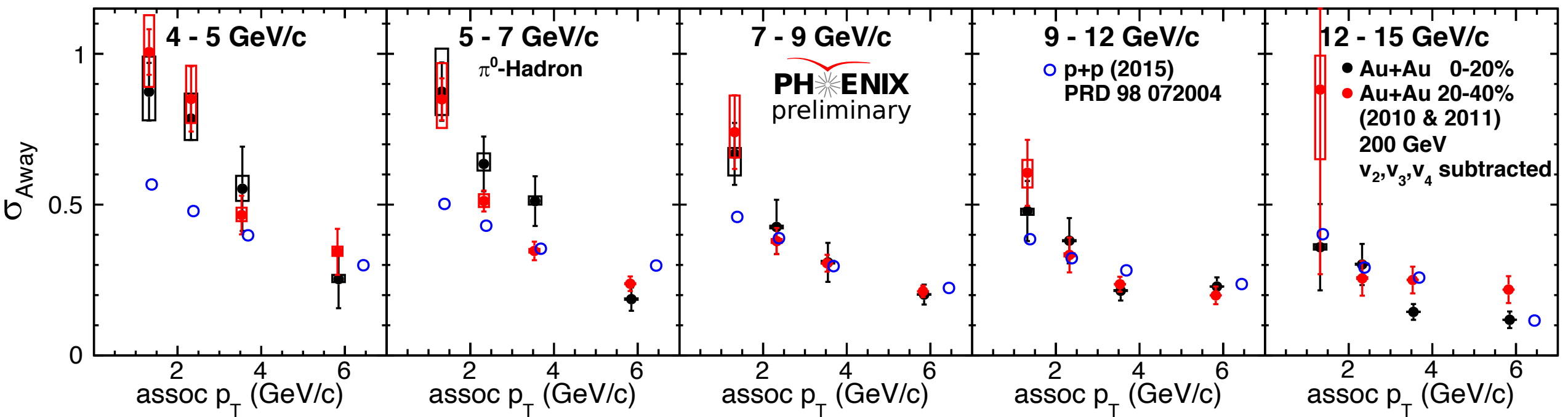


2010+2011



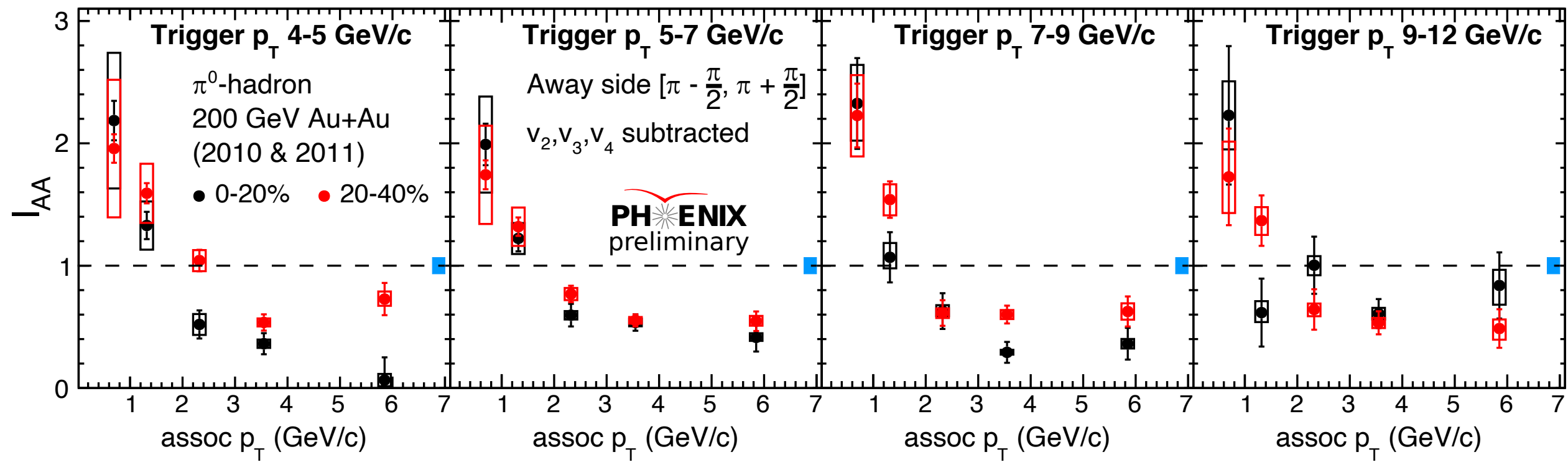
- $v_2, v_3,$ and v_4 subtracted in new results \rightarrow more flow contamination removed

π^0 - Hadron Correlations - $\sigma_{Away}(p_T)$



- Away side jet peaks are broader at low $p_T^{h^\pm}$
- Consistent with p+p widths at high $p_T^{h^\pm}$

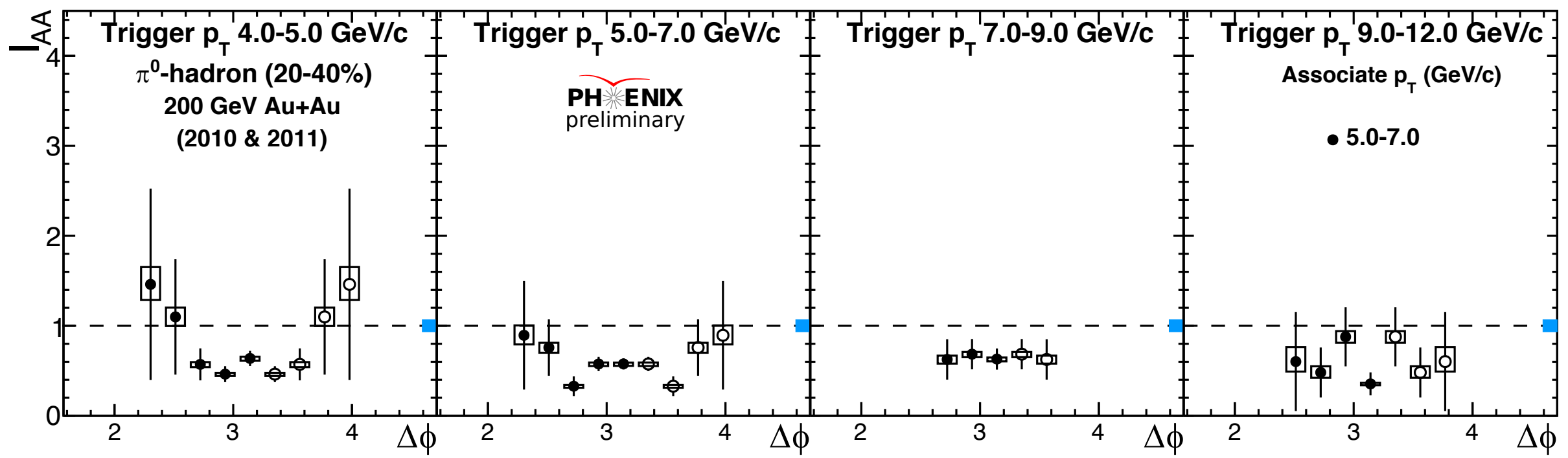
π^0 -Hadron Correlations - $I_{AA}(p_T)$



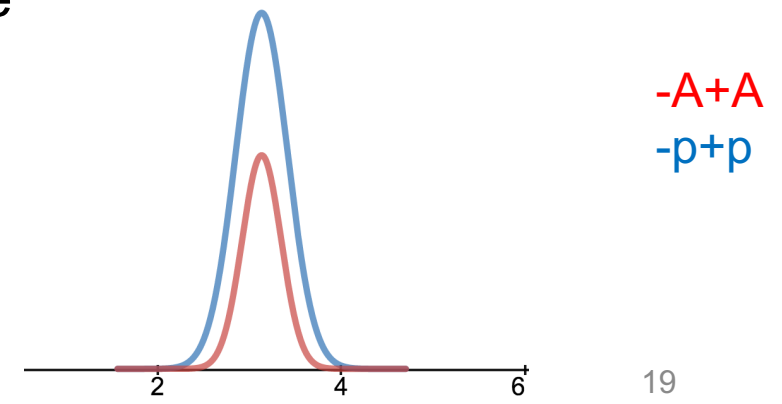
$$I_{AA} = \frac{Y_{Away}^{AA}}{Y_{Away}^{pp}}$$

- Enhancement of yield ($I_{AA} > 1$) at low associate particle momentum
- Depletion ($I_{AA} < 1$) at high associate particle momentum

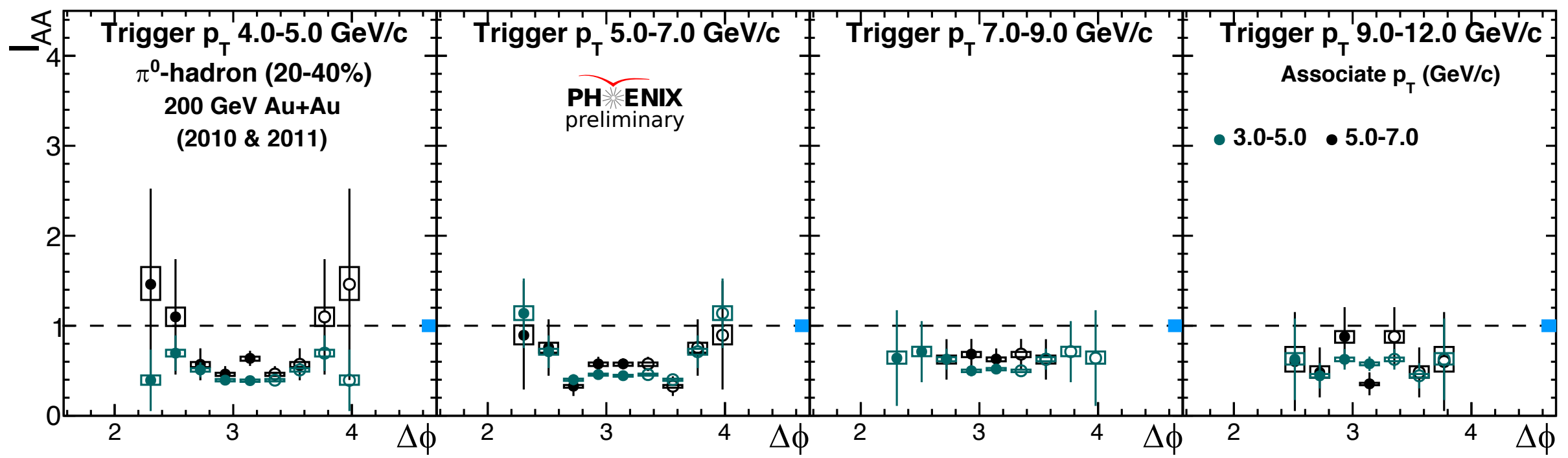
π^0 -Hadron Correlations – $I_{AA}(\Delta\phi)$



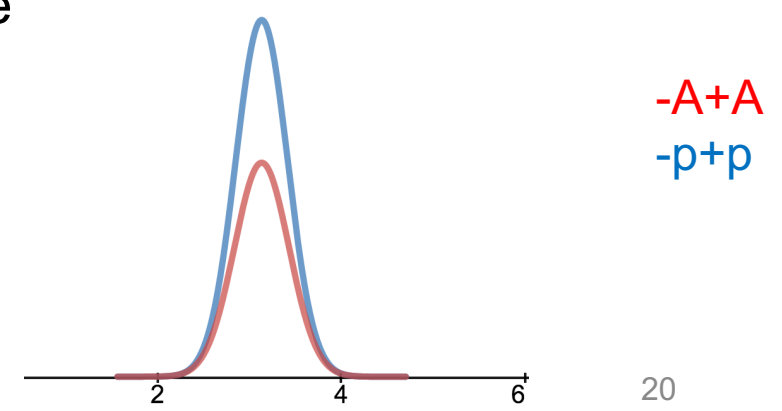
- Calculate ratio in yields between Au+Au jet function and p+p baseline
- Shows modification to away-side jet peak at substructure level



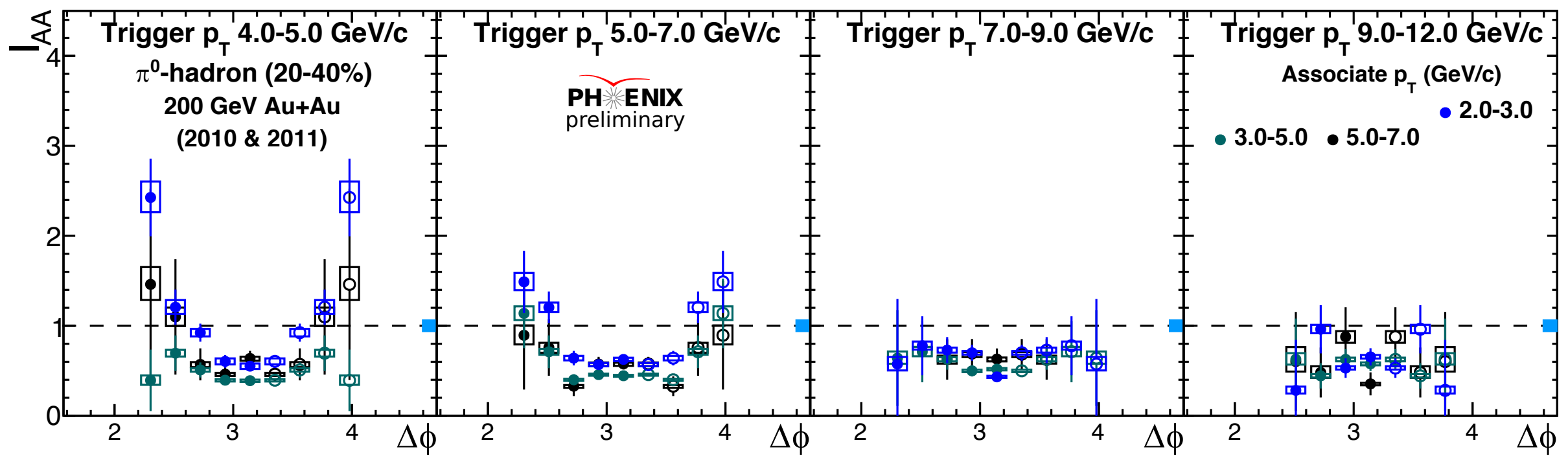
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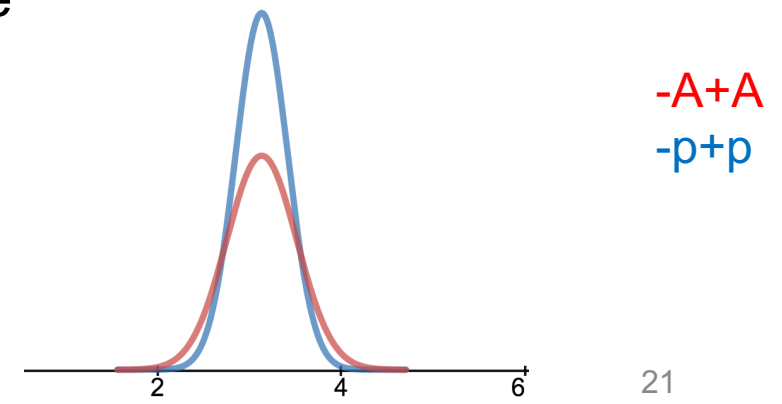
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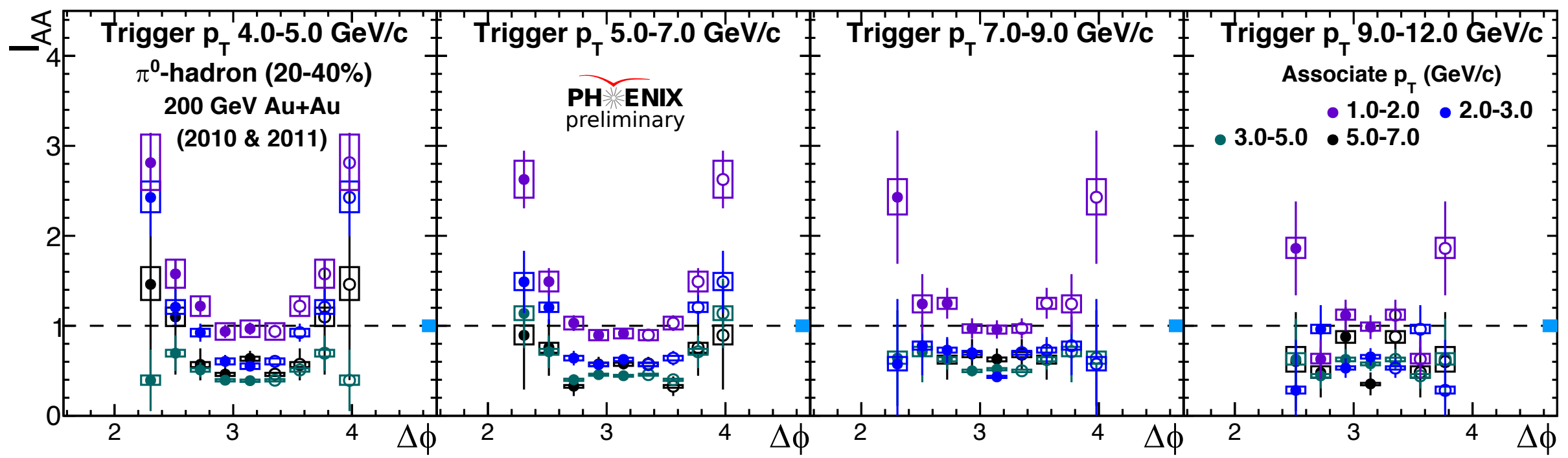
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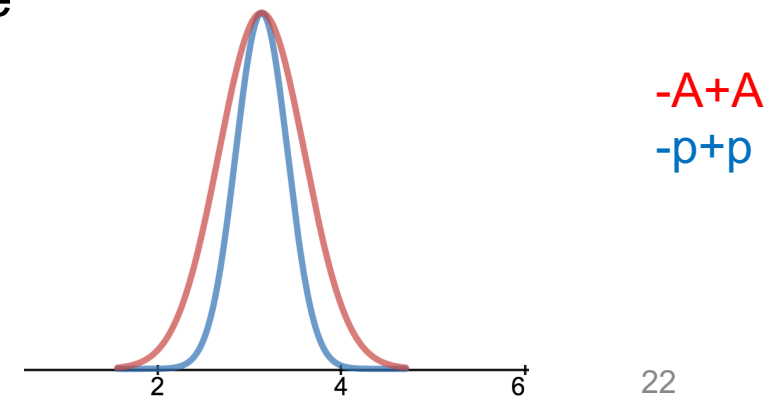
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- Shows modification to away-side jet peak at substructure level
- Skirt of jet is the first to see significant enhancement



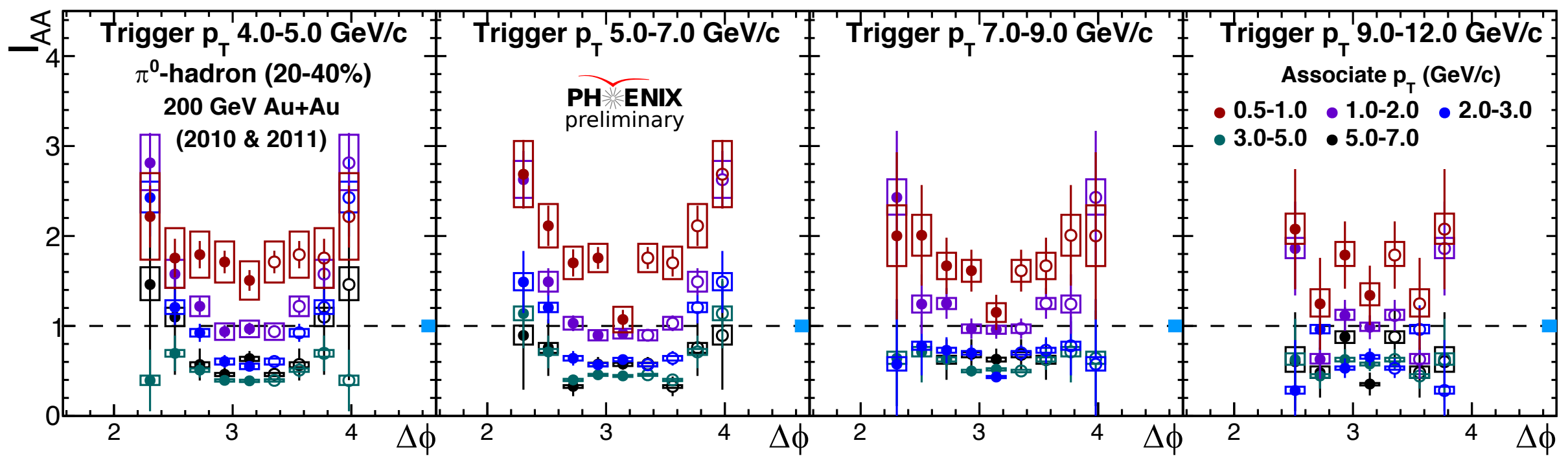
π^0 -Hadron Correlations – $I_{AA}(\Delta\phi)$



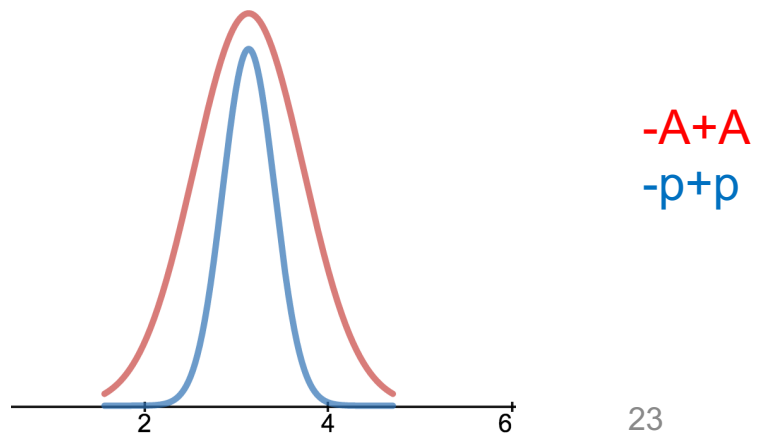
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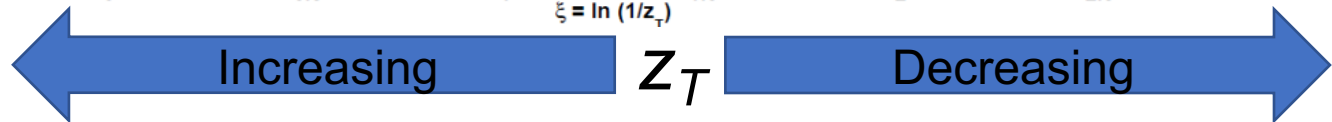
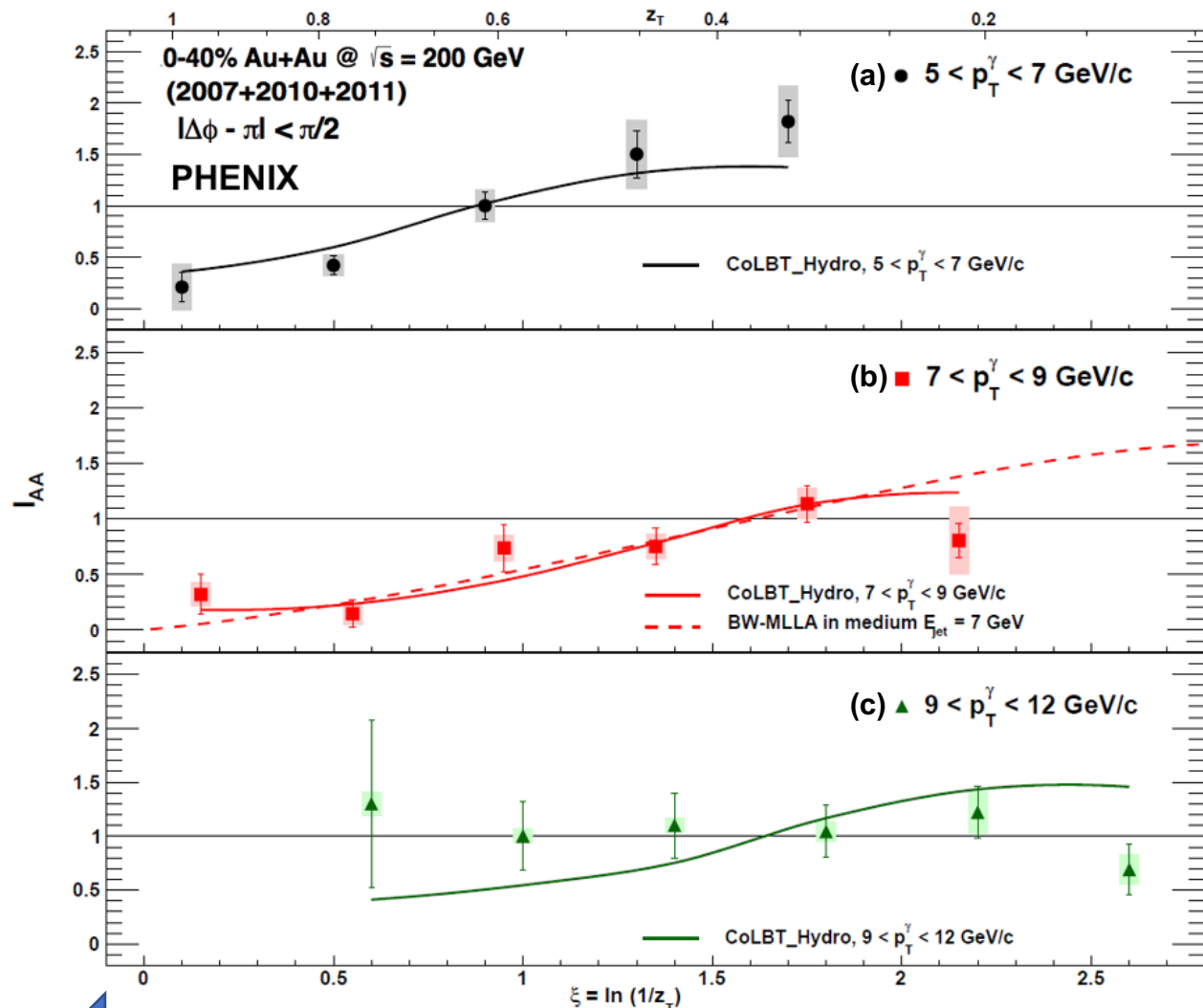


- Calculate ratio in yields between Au+Au jet function and p+p baseline
- Shows modification to away-side jet peak at substructure level
- Skirt of jet is the first to see significant enhancement
- Most intense enhancement at wide angles



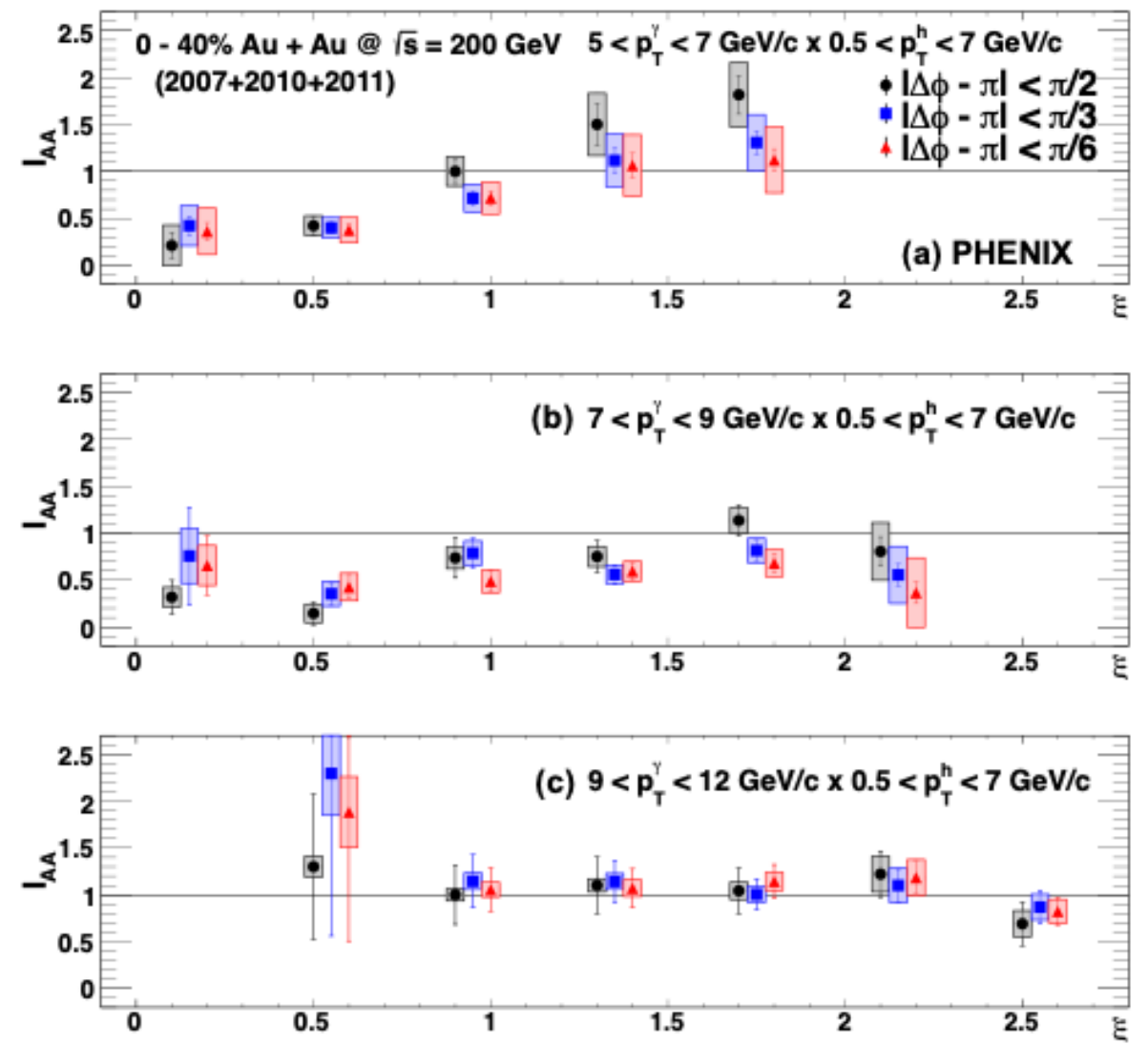
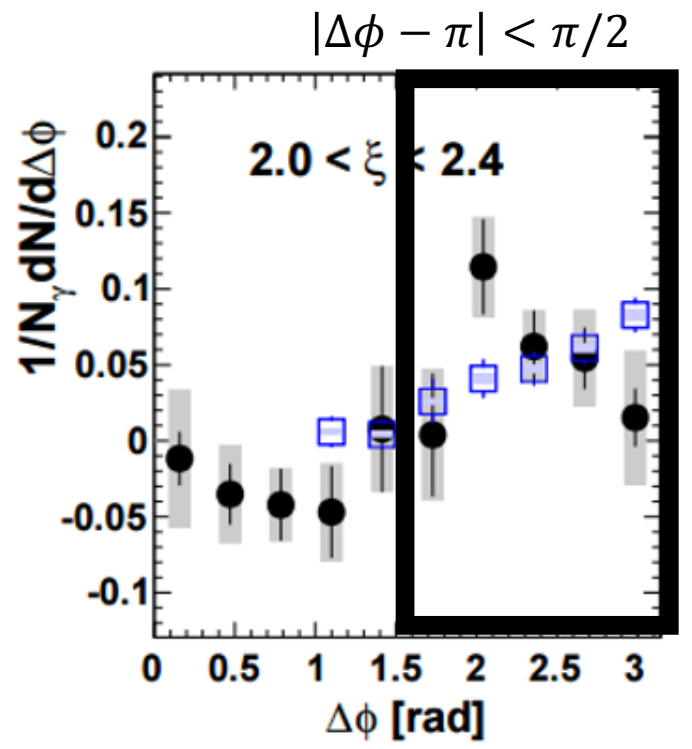
Direct Photon-Hadron Correlations – $I_{AA}(p_T)$

- Access to initial parton energy
- $E_\gamma \approx E_{Jet}$, well calibrated probe
- $\xi = \ln(1/z_T)$; $z_T = p_T^h / p_T^{Trig}$
- $I_{AA}(p_T)$ from photon-hadron correlations show similar trends to those in π^0 -hadron correlations



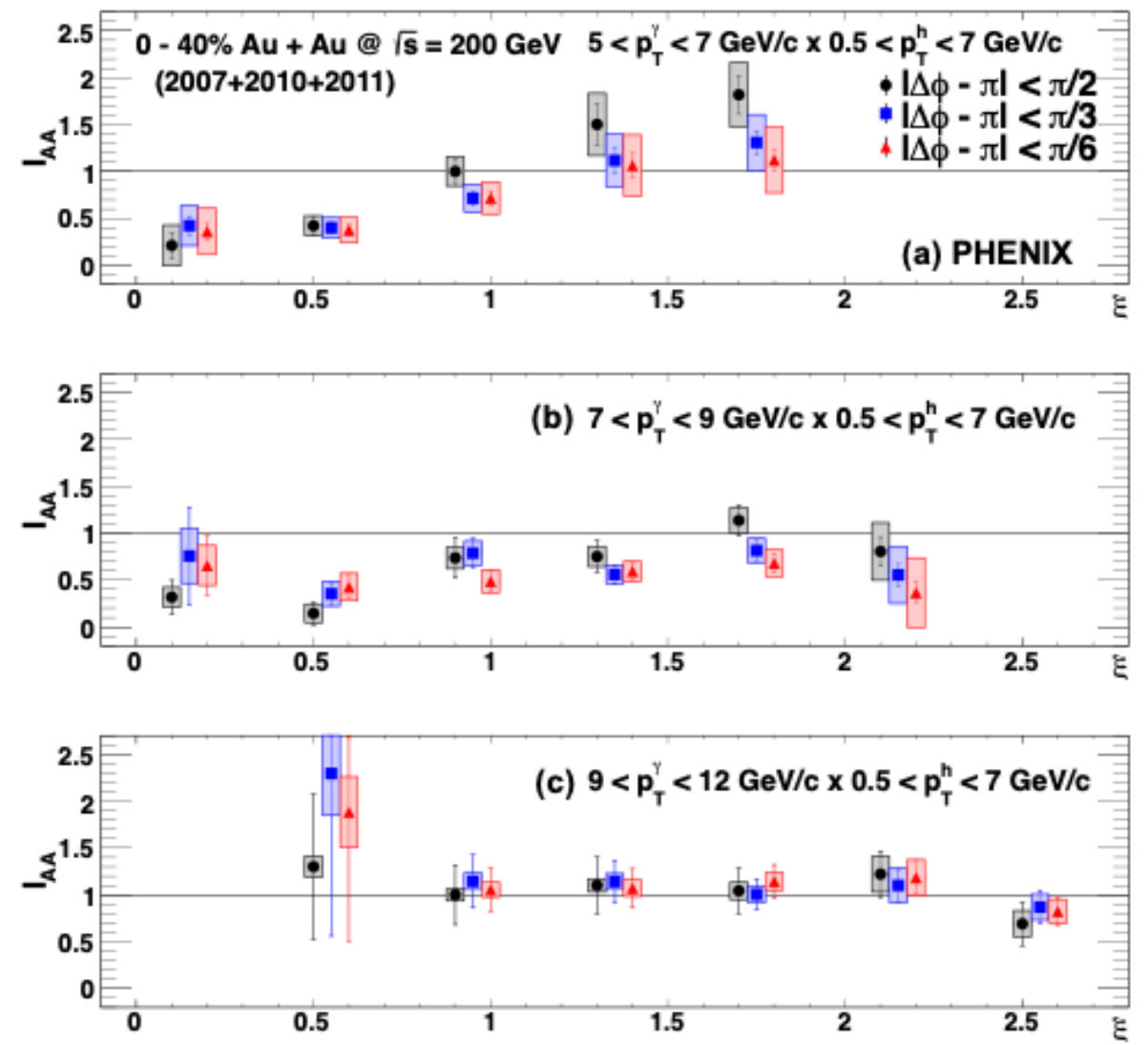
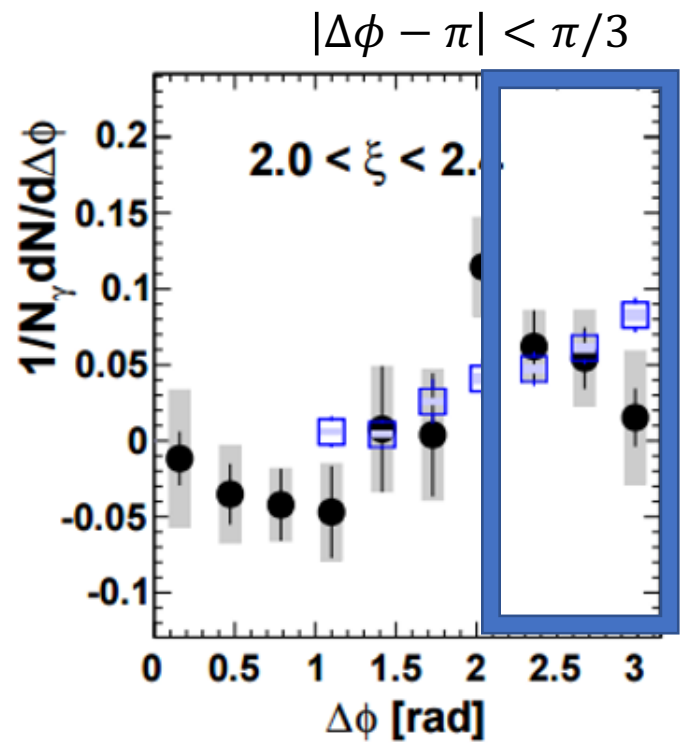
Direct Photon-Hadron Correlations – $I_{AA}(p_T)$

- I_{AA} measured with different integration windows
- Largest integration window sees largest enhancement



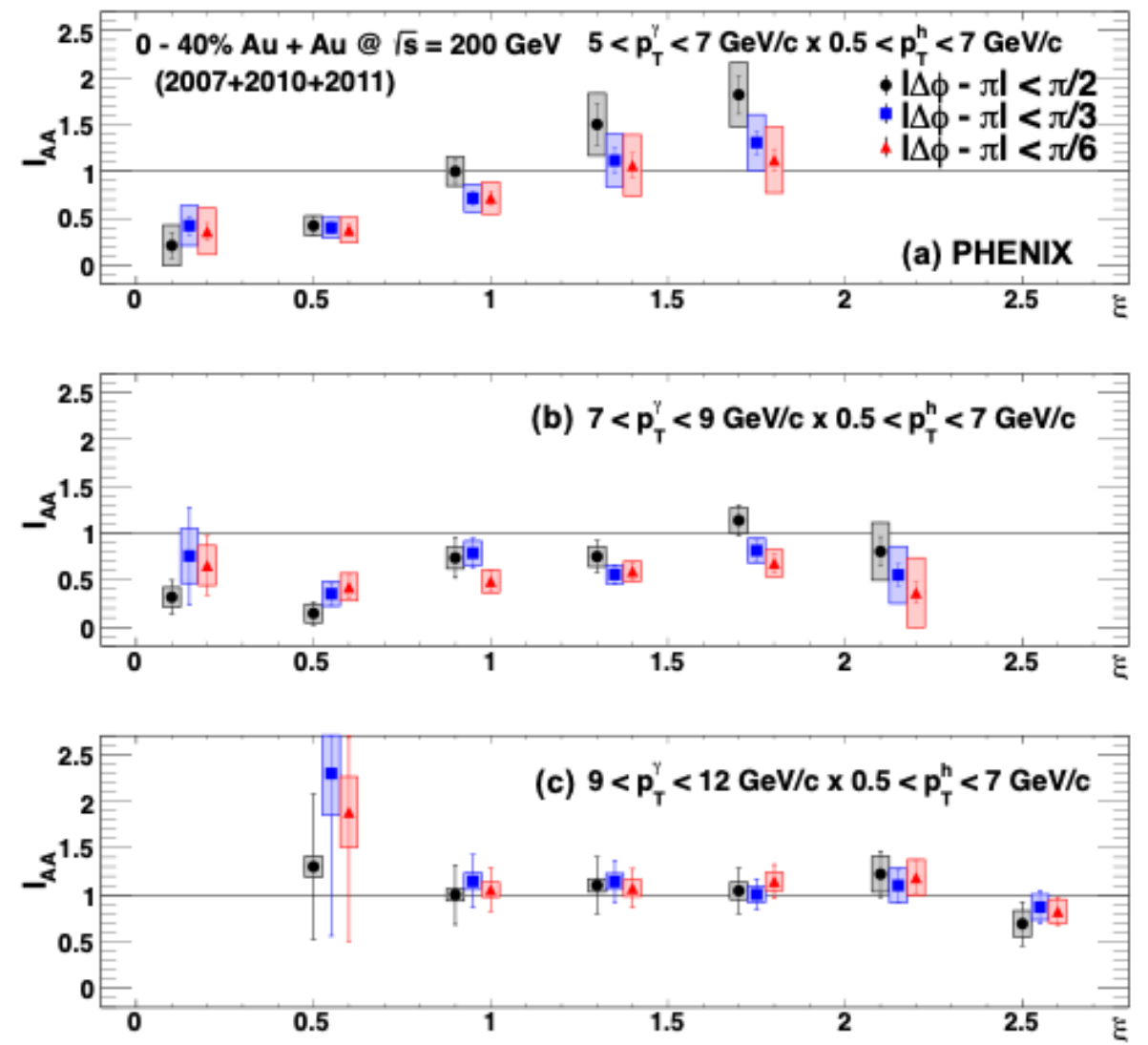
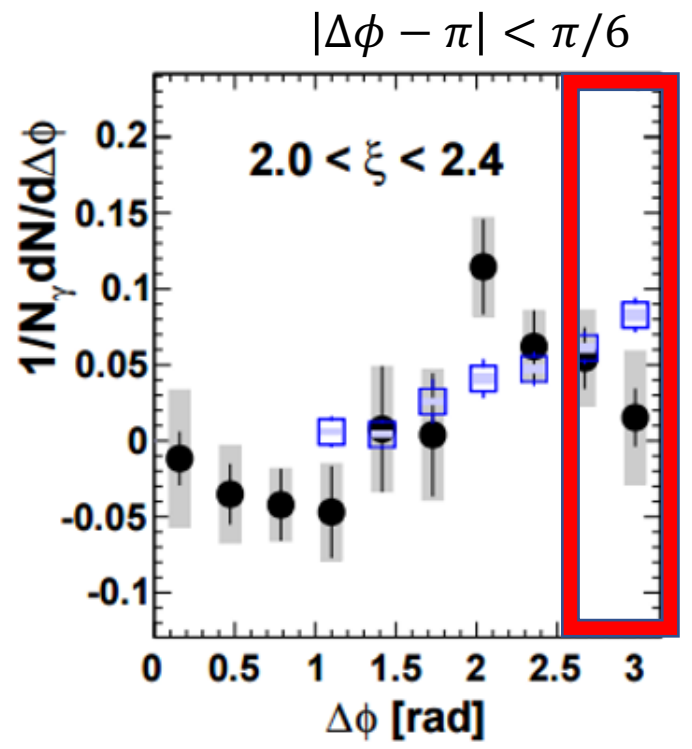
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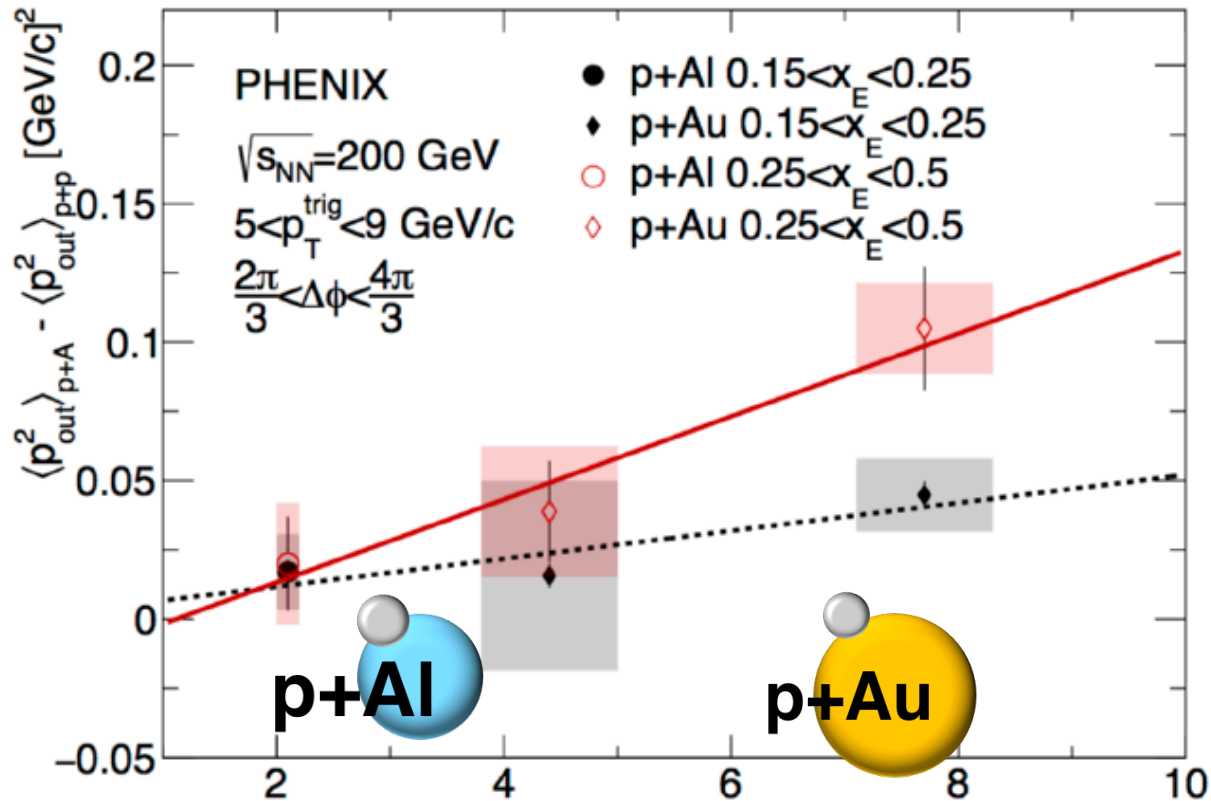
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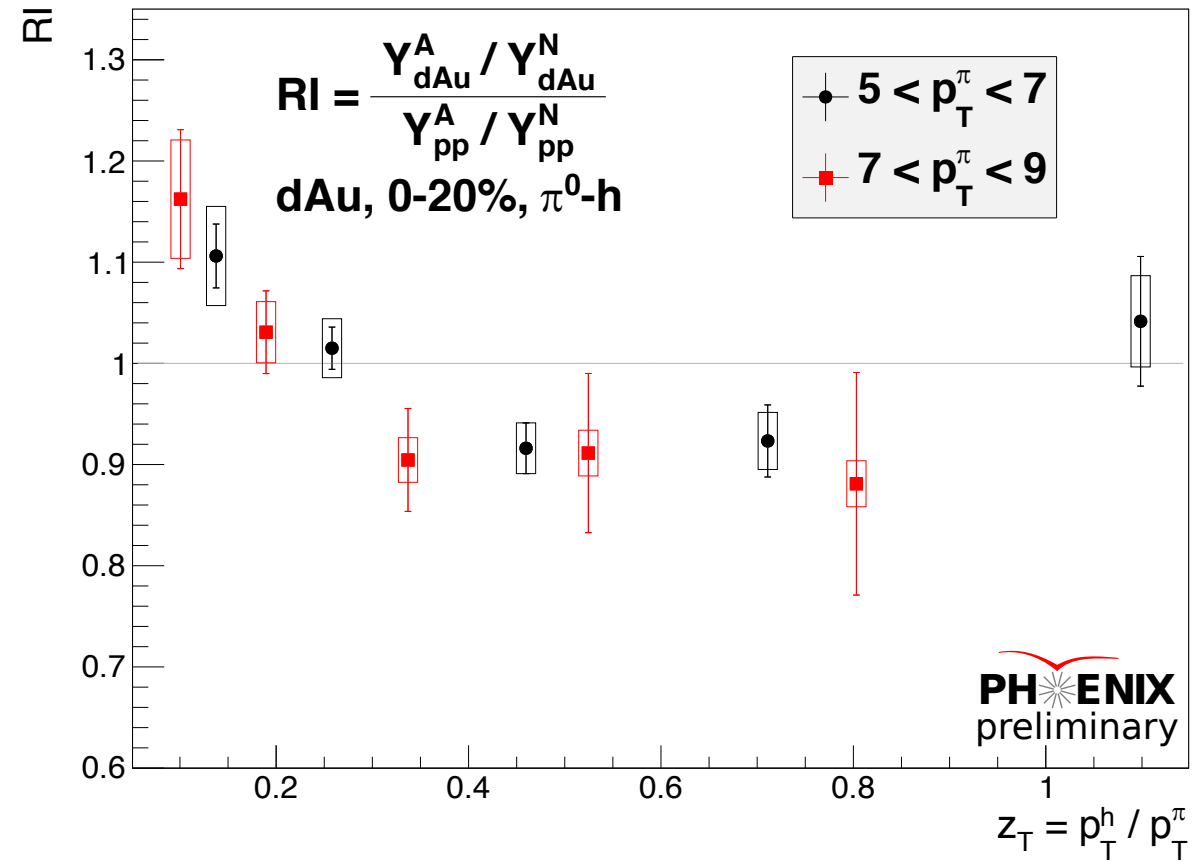


Jet Modification in Small Systems

- PHENIX also results studying jet modification in small systems using two-particle correlations
 - d+Au, 3He+Au, p+Al, p+Au



$$p_{out} = |p_T^{assoc}| \sin\Delta\phi$$



Conclusions and Outlook

- Studies of jets and jet modification at PHENIX using full jet reconstruction
 - New cross section and jet A_{LL} in p+p at $\sqrt{s_{NN}} = 510\text{GeV}$
 - Jet R_{AB} in Cu+Au at $\sqrt{s_{NN}} = 200\text{GeV}$
- Jets measured via π^0 and direct photon correlations show away-side broadening, enhancement of soft particle yield, and suppression of hard particle yield.
- New observable, $I_{AA}(\Delta\phi)$ shows jet modification at substructure level

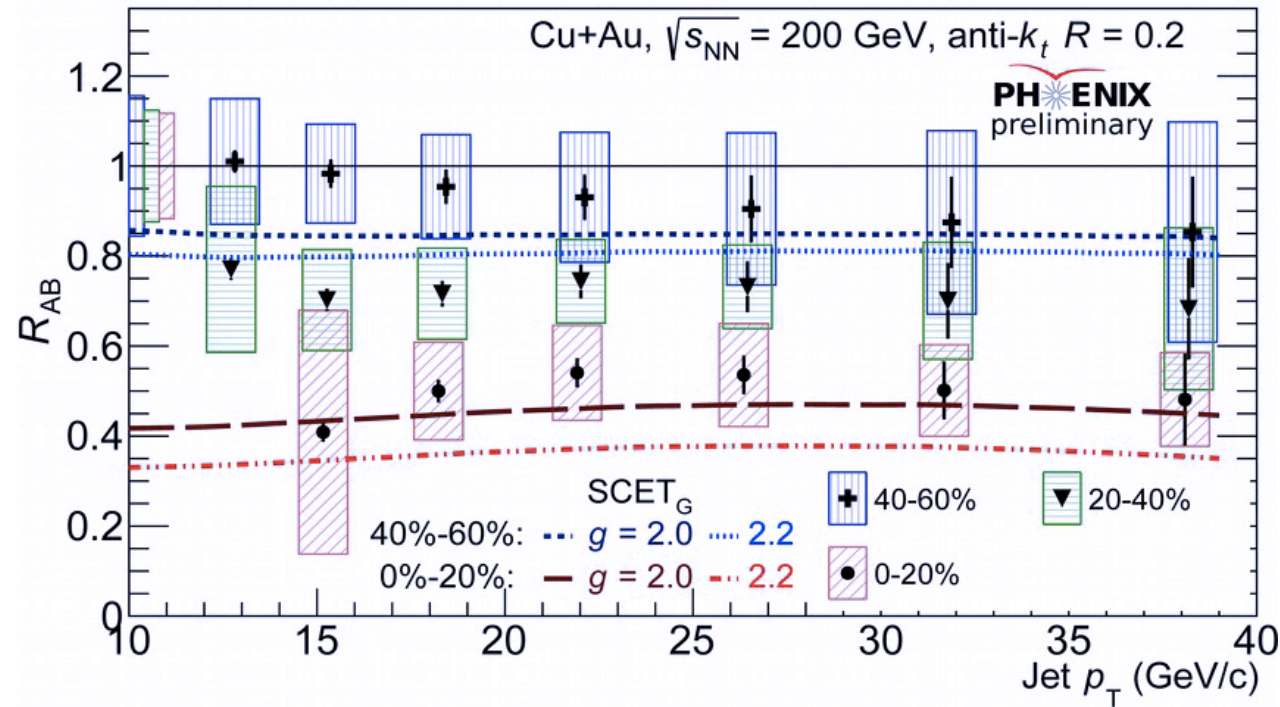
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- Jets measured via π^0 and direct photon correlations show away-side broadening, enhancement of soft particle yield, and suppression of hard particle yield.
- New observable, $I_{AA}(\Delta\phi)$ shows jet modification at substructure level
- Largest PHENIX Au+Au at $\sqrt{s_{NN}} = 200\text{GeV}$ datasets, Runs 14 and 16, currently being analyzed.
 - Run 14 alone has more min bias events than Run 7, 10, and 11 combined
 - Will measure π^0 and direct photon triggered correlations
- New unfolded reconstructed jet cross-section in $p + p$ collisions at 200 GeV coming!

Back-Up

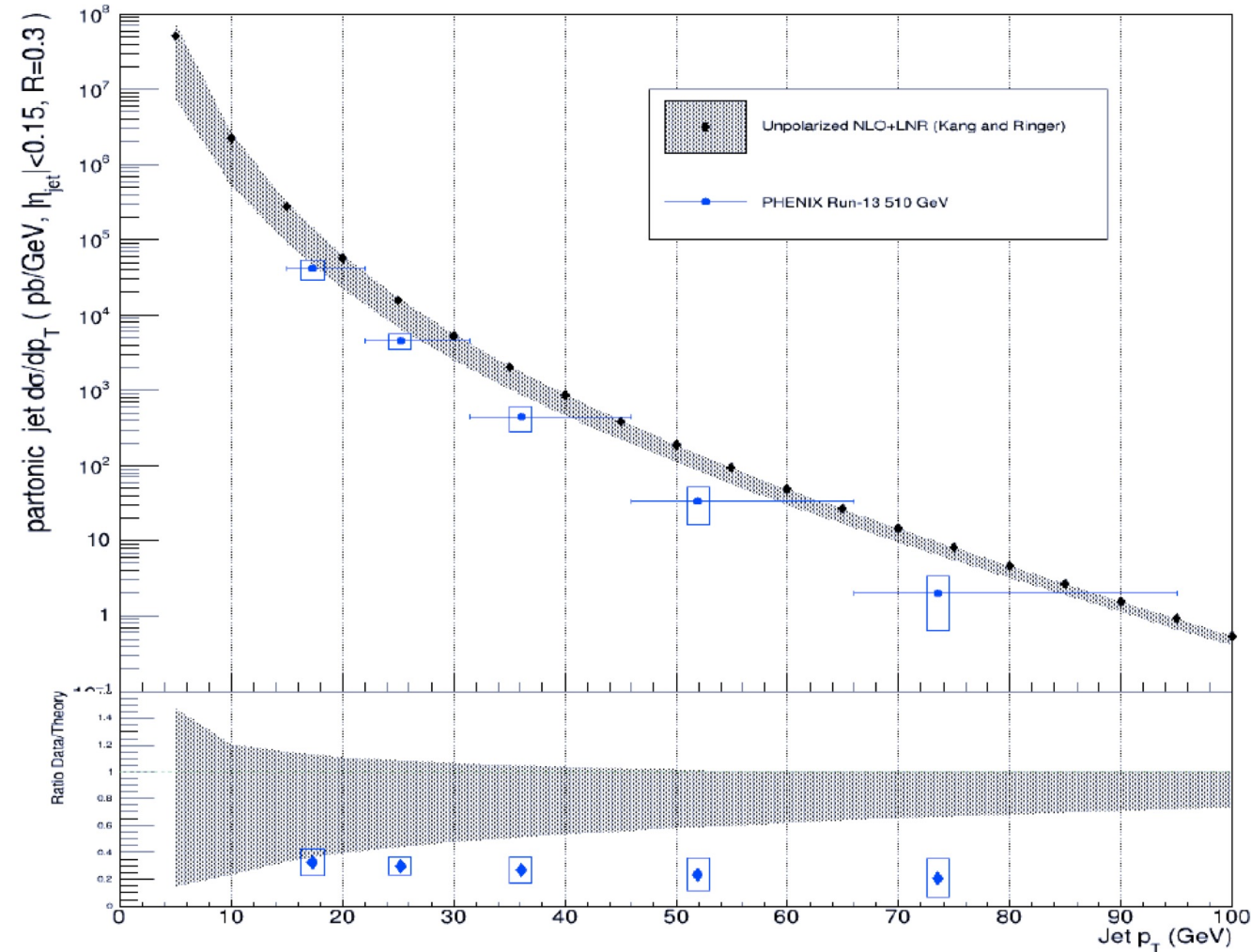
Cu+Au Jet Reconstruction Parameters

- Anti- k_T algorithm with $R = 0.2$
- Unfolding via SVD
- Track $p_T > 0.5$ GeV
- $E_{cluster} > 0.5$ GeV
- Jet particle multiplicity ≥ 3
- Jet axis to edge: $\Delta\eta > 0.05$, $\Delta\phi > 0.12$
- $-0.2 < \text{Charged fraction} < 0.7$



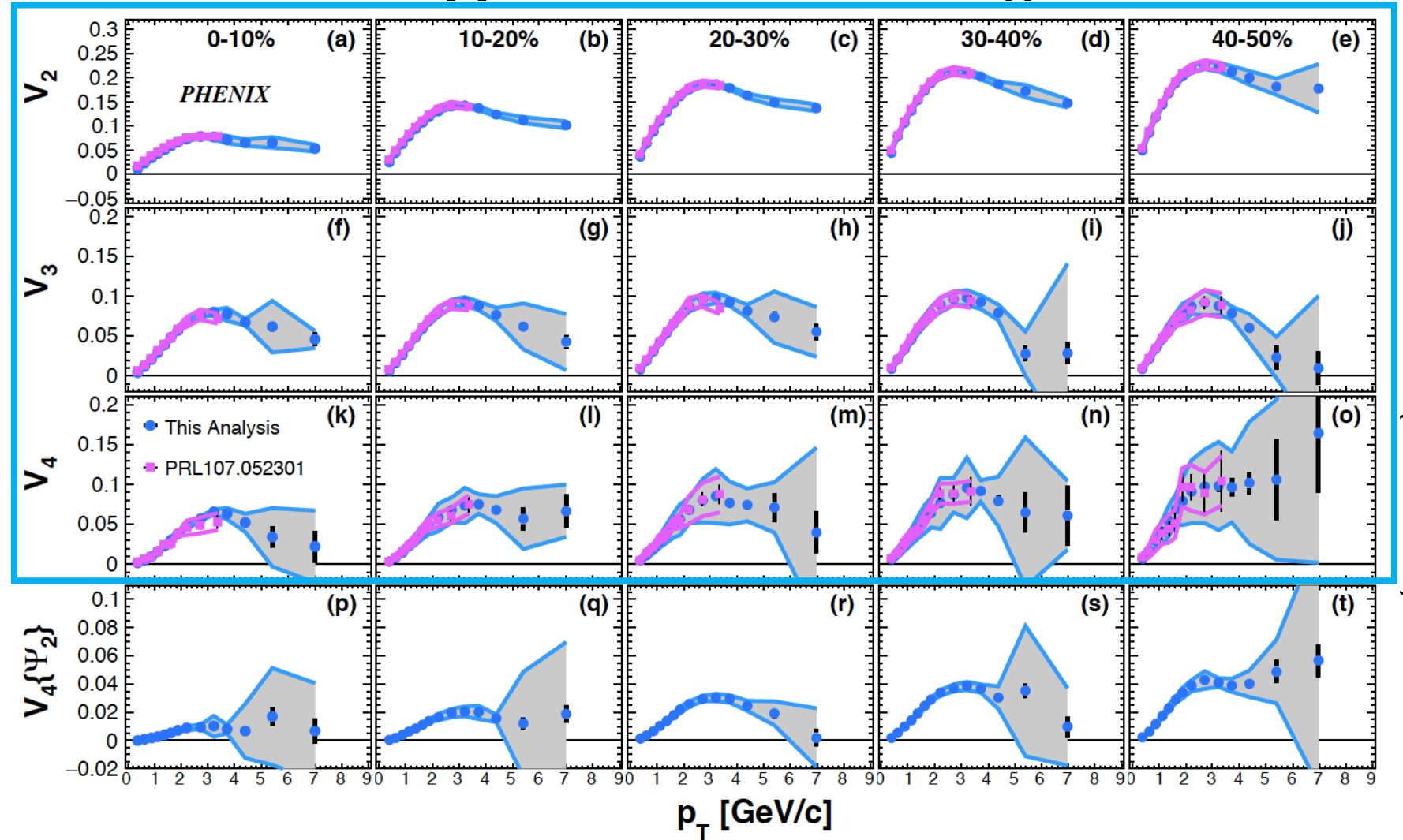
p+p Jet Reconstruction Parameters

- Anti k_T $R=0.3$ jets
- Unfolding via Bayesian iterative method with 2 iterations
- Tracks required to be sufficiency distance from detector edges



Flow Subtraction – Charged Hadron v_n

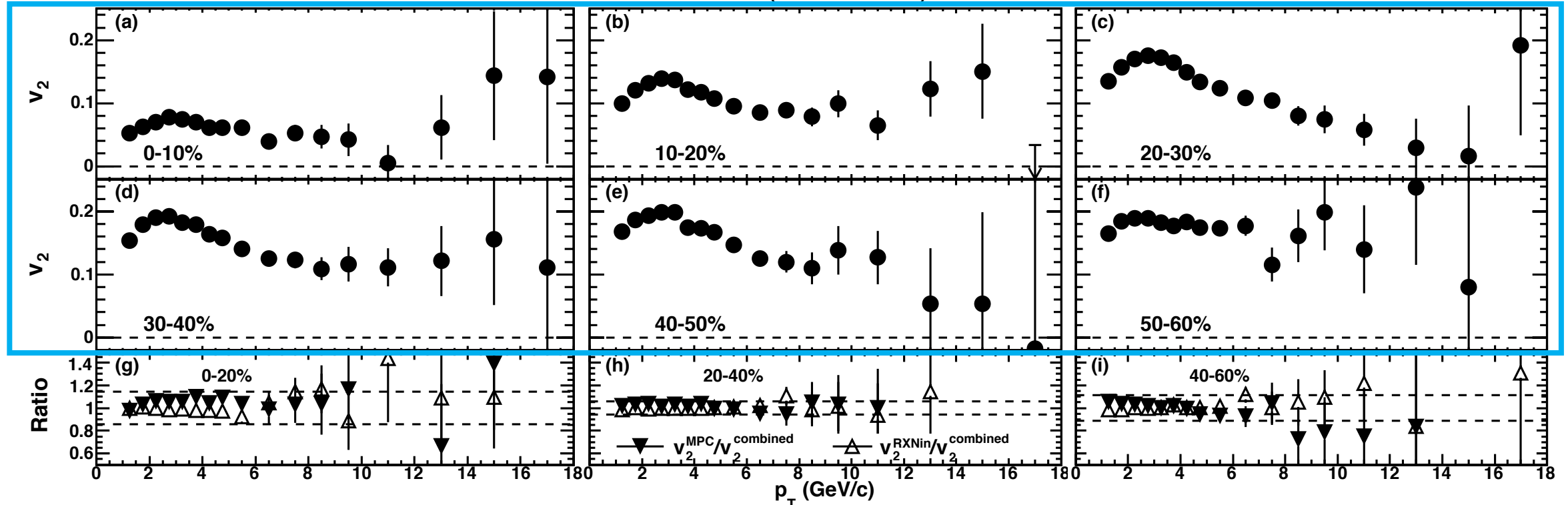
- Charged hadron v_n from PHENIX data
- Measured via event plane method



arXiv:1803.01749v1 (2007 data)

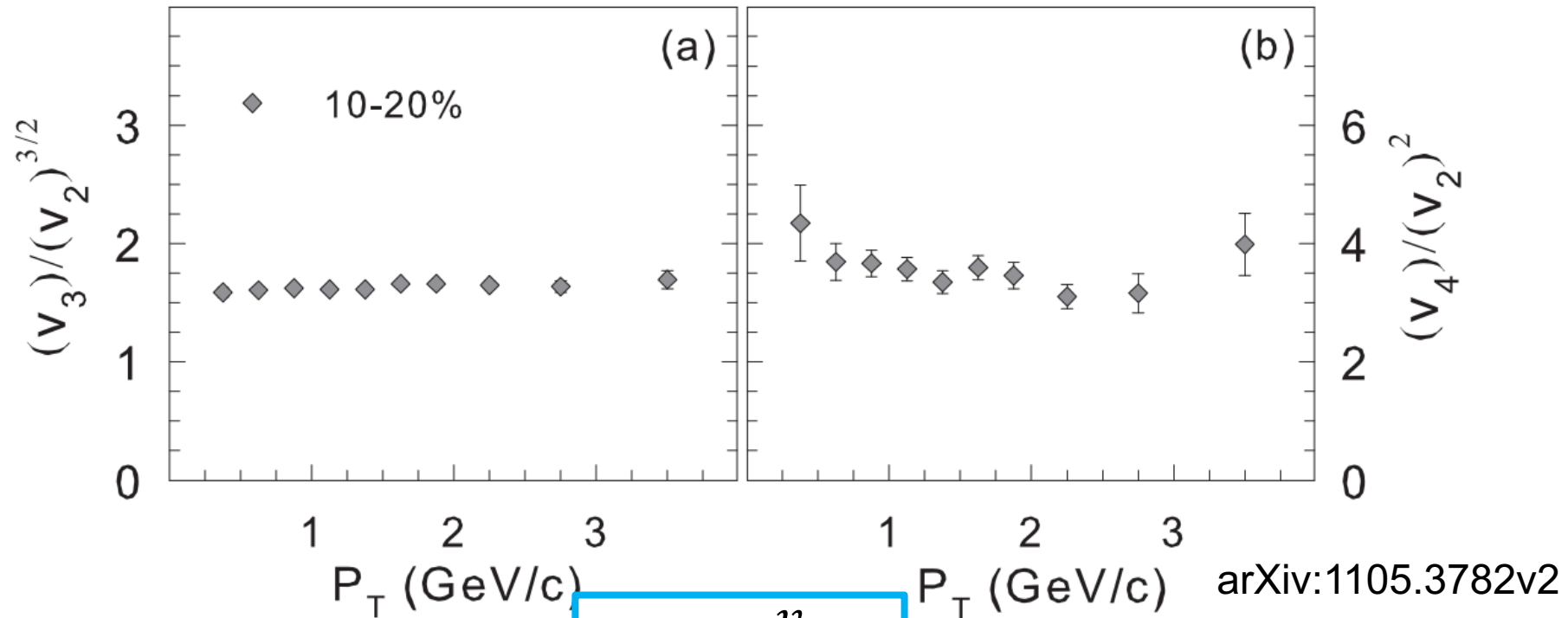
Flow Subtraction - $\pi^0 v_n$

PRL 105, 142301 2010 (2007 data)



- Taken from PHENIX data
- Measured via reaction plane method
- Higher order harmonics not available

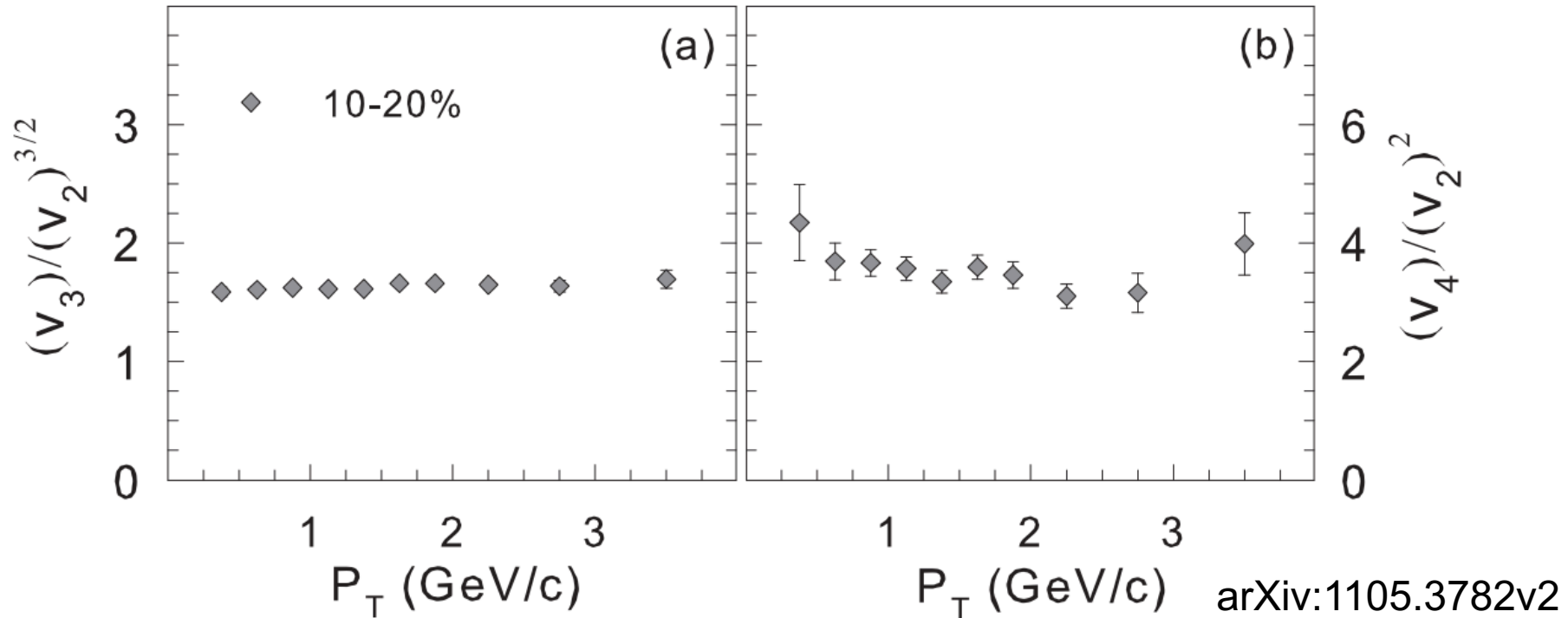
Flow Subtraction – Acoustic Scaling



$$g_n = \frac{v_n}{(v_2)^{n/2}}$$

- Have charged hadron v_n for $(n = 2,3,4)$ from PHENIX results
- No π^0 v_3 or v_4 measured at RHIC energies
- v_n harmonics can be scaled to one another via value g_n

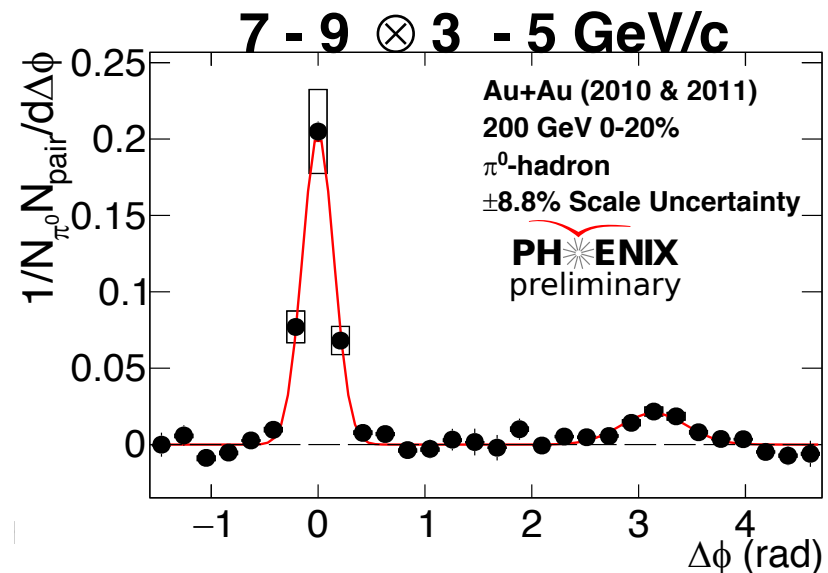
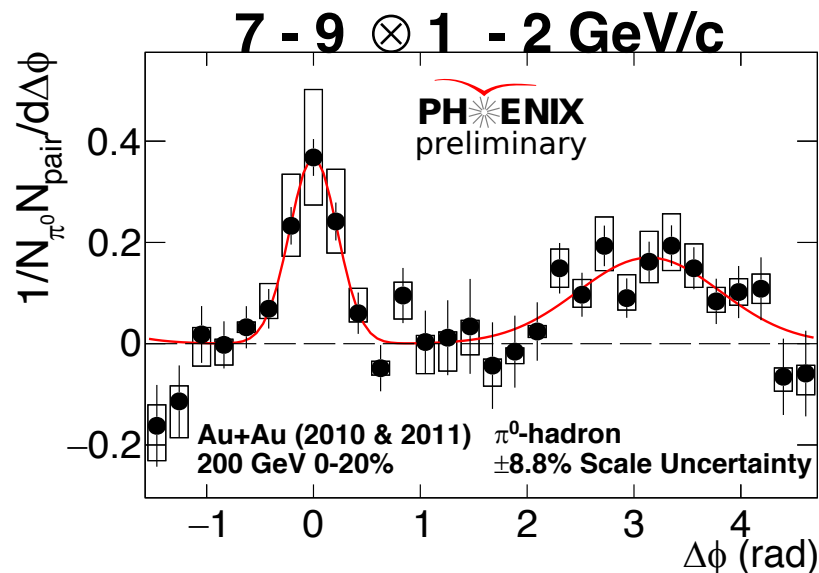
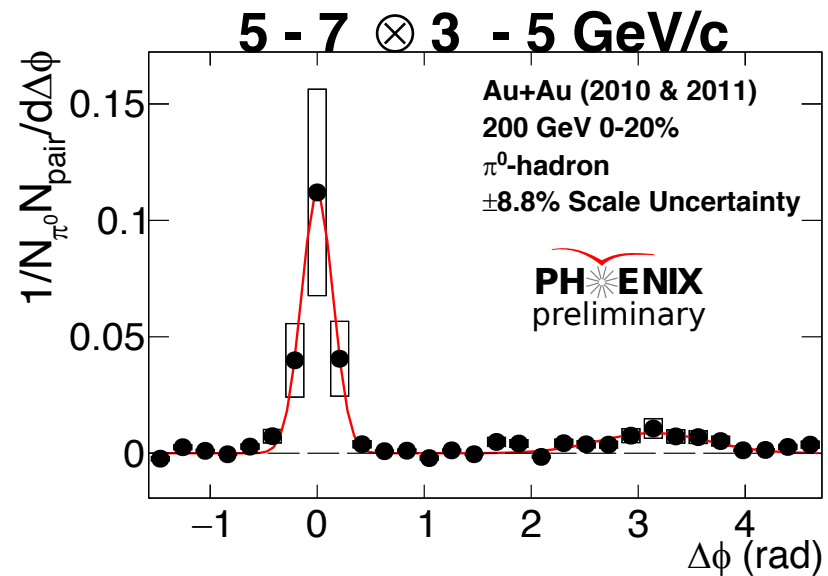
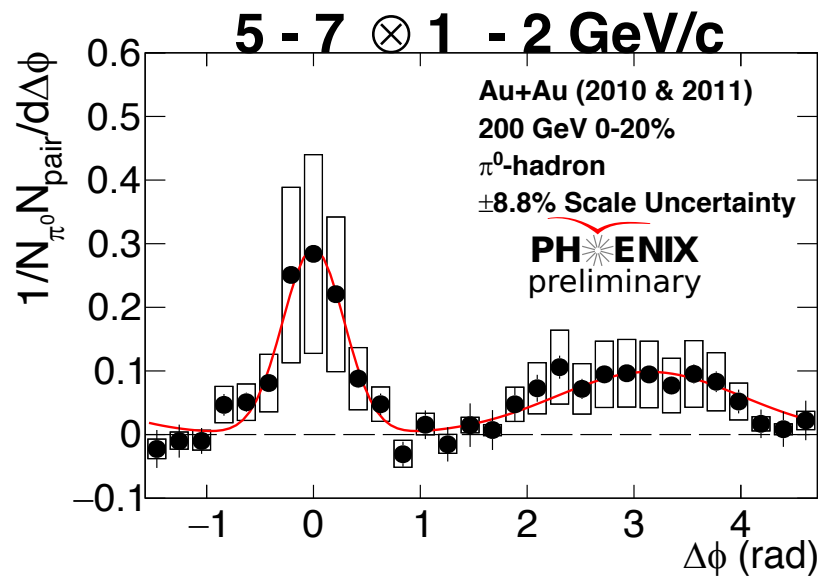
Flow Subtraction – Acoustic Scaling



$$v_n^{\pi^0} = g_n^h (v_2^{\pi^0})^{n/2}$$

- Can calculate $\pi^0 v_3, v_4$ by scaling $\pi^0 v_2$ with charged hadron g_n

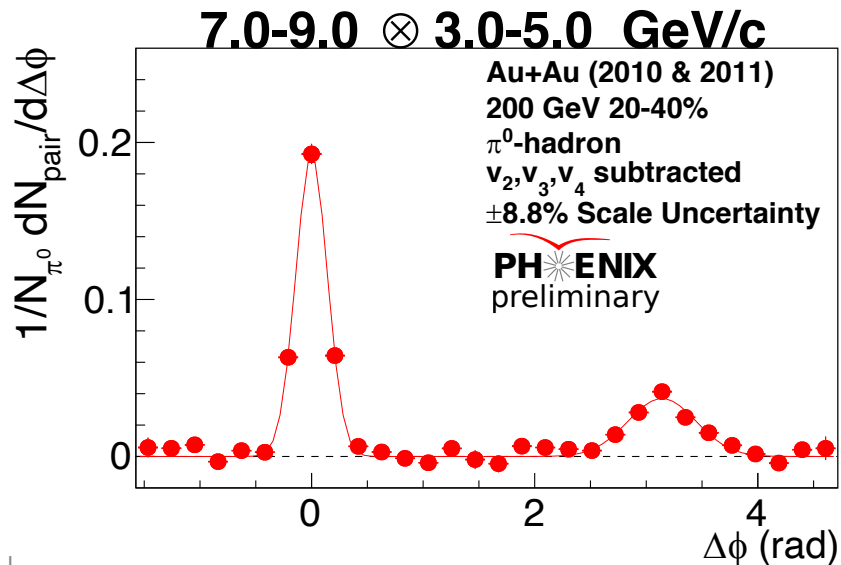
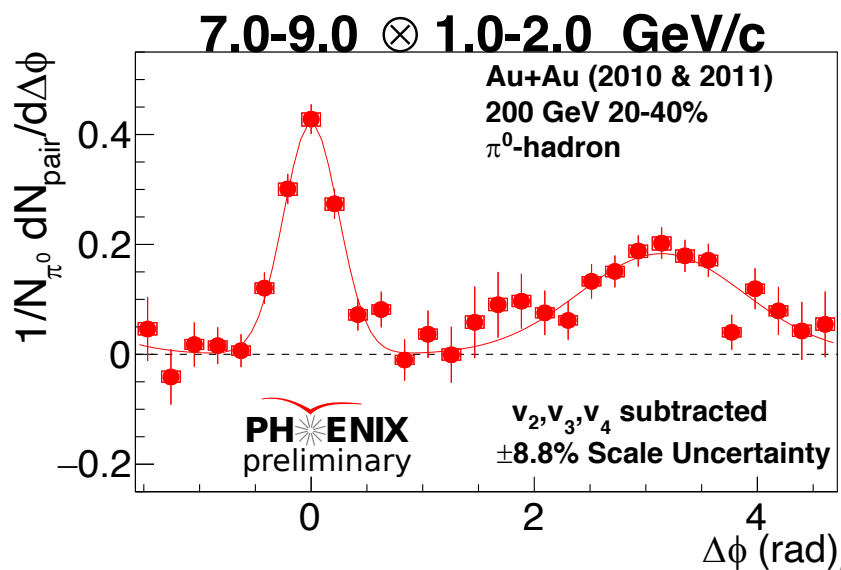
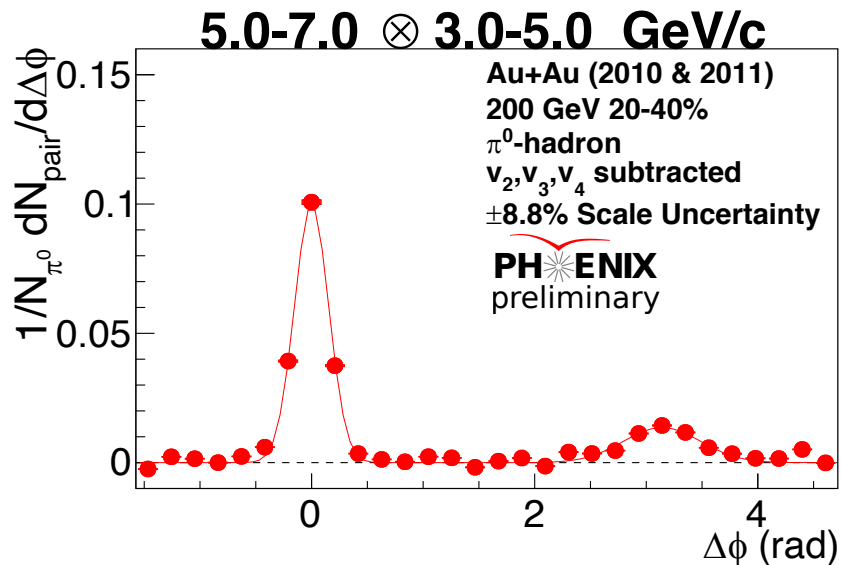
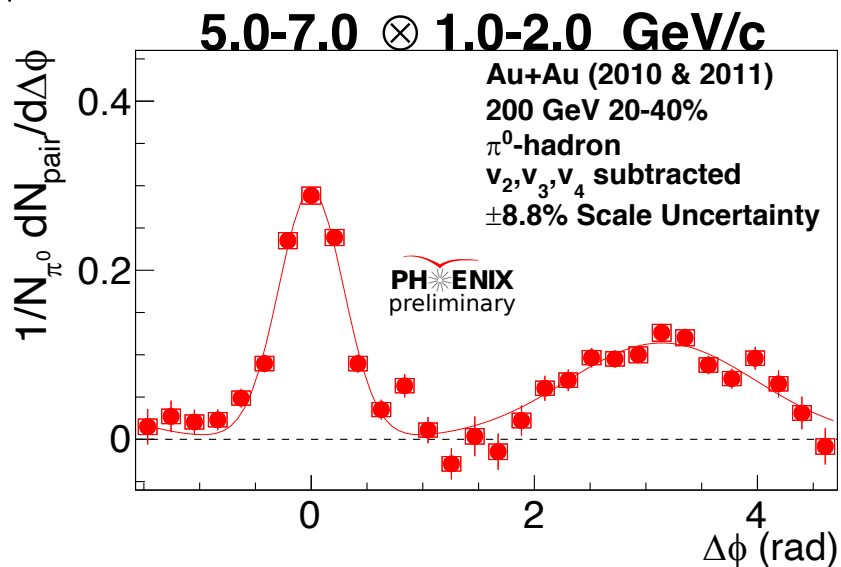
Sample Jet Functions:



0—20%

v_2, v_3, v_4 subtracted

Sample Jet Functions:



20—40%

v_2, v_3, v_4 subtracted