Probing Modification of the Initial State in Small Systems via Jets Detected in PHENIX

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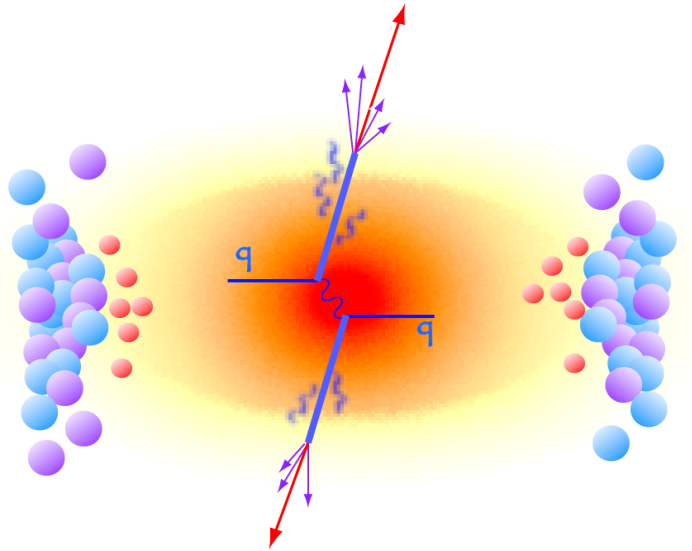
Quark Matter 2019

Wuhan, China

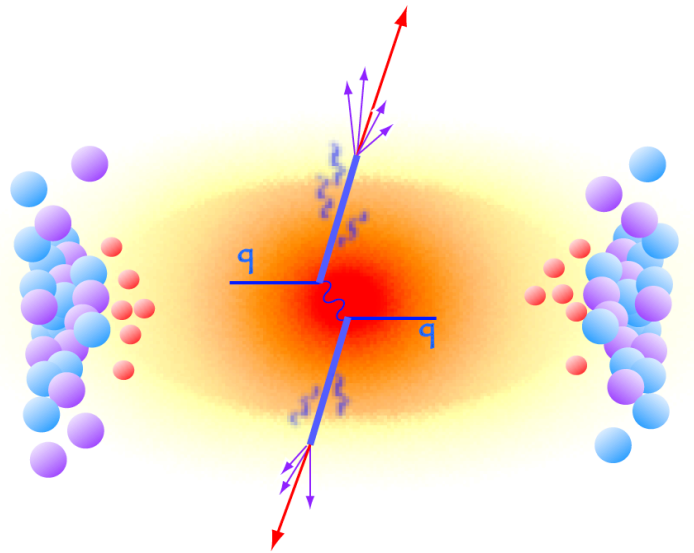
Motivation

- What is a jet?
  - A collimated spray of hadrons originating from a hard scattered parton

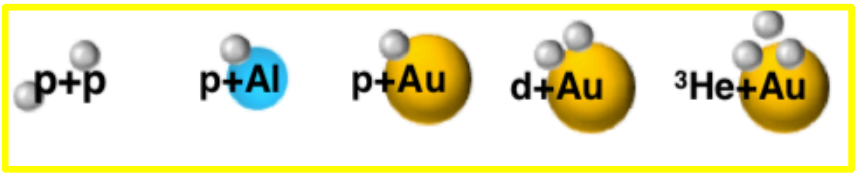


Motivation

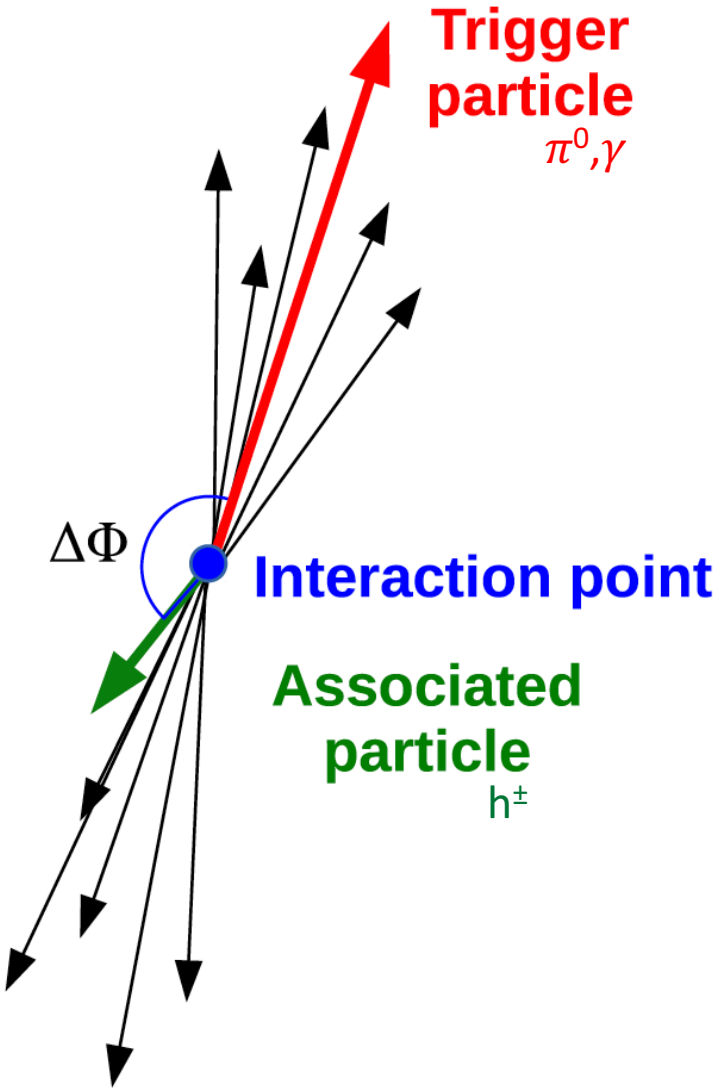
- What is a jet?
  - A collimated spray of hadrons originating from a hard scattered parton
- Understanding how partons interact with the QGP provides essential insight into QCD
- Studies of jet production in small systems are necessary to decouple which effects observed in A+A data come from:
  - Interactions with the medium
  - Initial state effects and modifications of the PDFs
  - Final state interactions



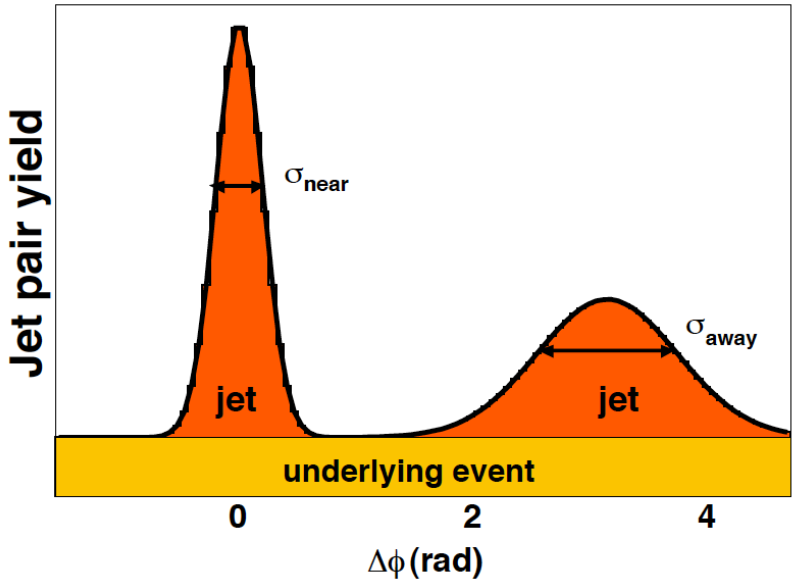
Two particle correlations



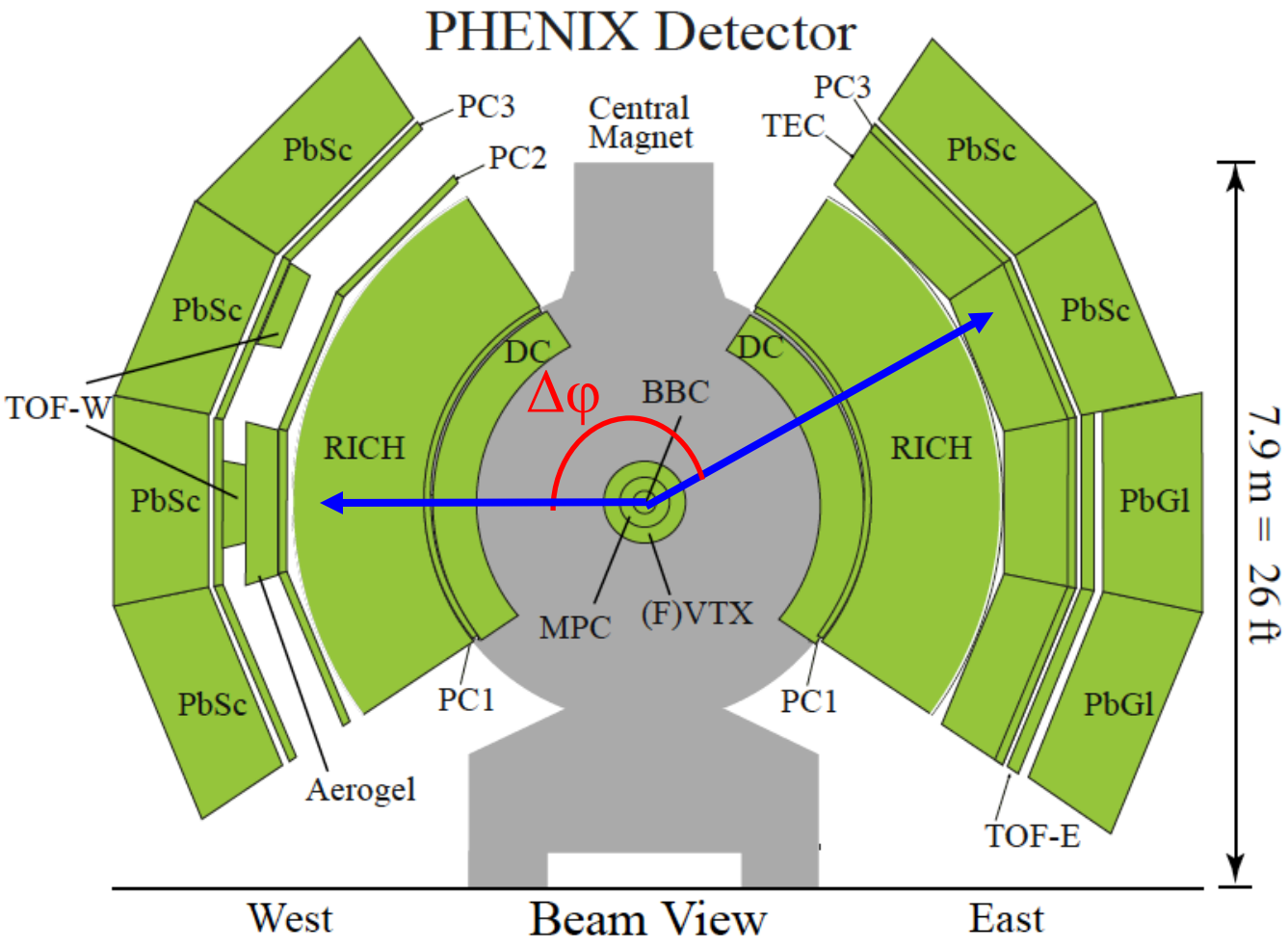
Systems in this talk



- At LO di-jets are produced with $\Delta\phi = \pi$ in the transverse plane
  - Initial and final state radiation broadens that distribution
- We measure the correlation of the "trigger" particle (high p_T) with "associated" particles in the same jet or opposite jet



PHENIX detector overview

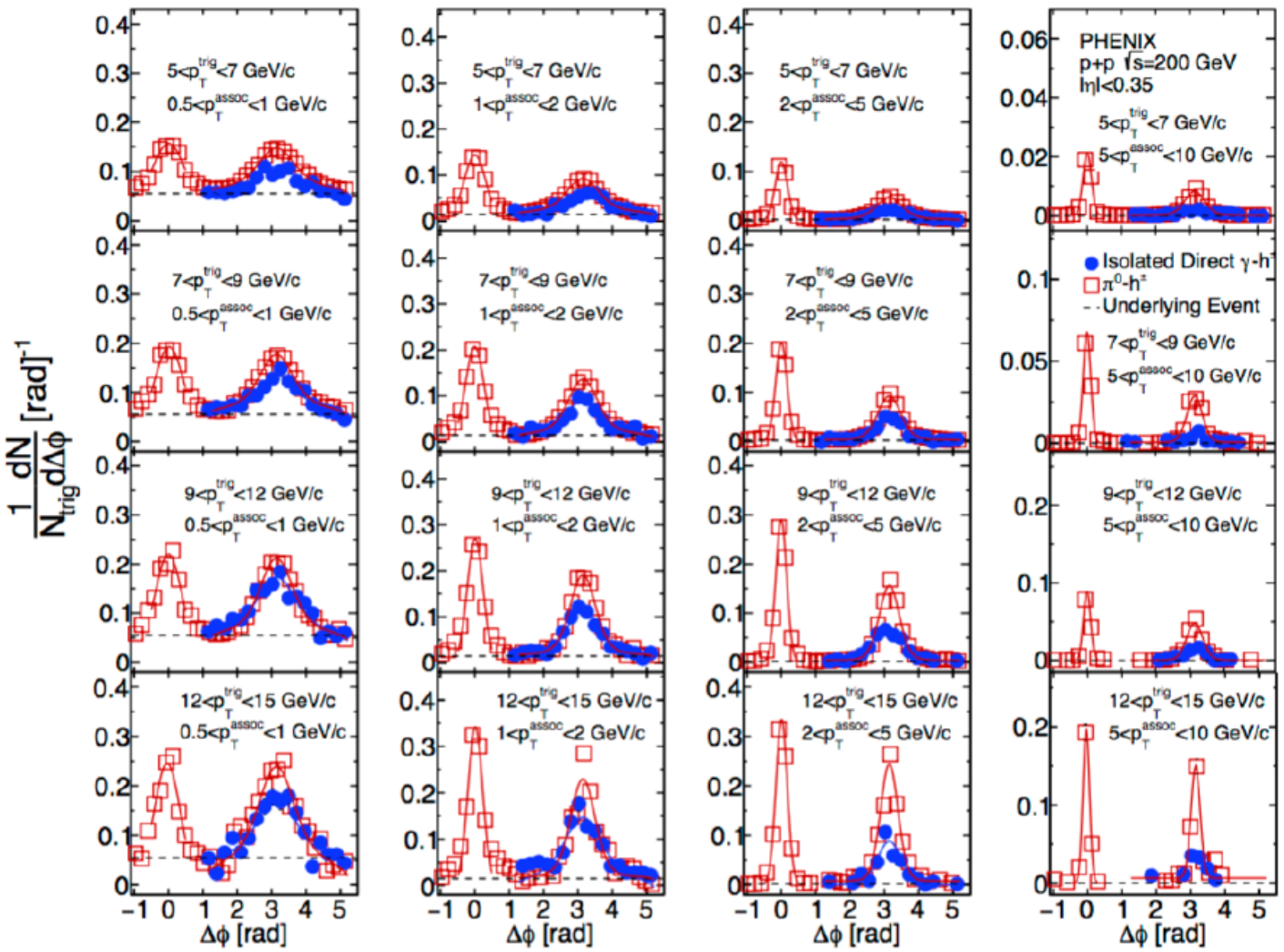


- Two central arms: cover $\phi \sim \pi$ and $|\eta| < 0.35$
- Finely segmented EM calorimeter: able to measure π^0 up to 20 GeV
- Drift chamber and pad chambers measure charged hadrons

Correlation in p+p collisions

p+p

PHENIX



π^0-hadron correlations

γ-hadron correlations

- γ-h shows away-side yields that are consistently smaller than the corresponding π^0-h yields because π^0 probes larger Q^2

PhysRevD.98.072004

Correlation in p+p collisions (II)

p+p

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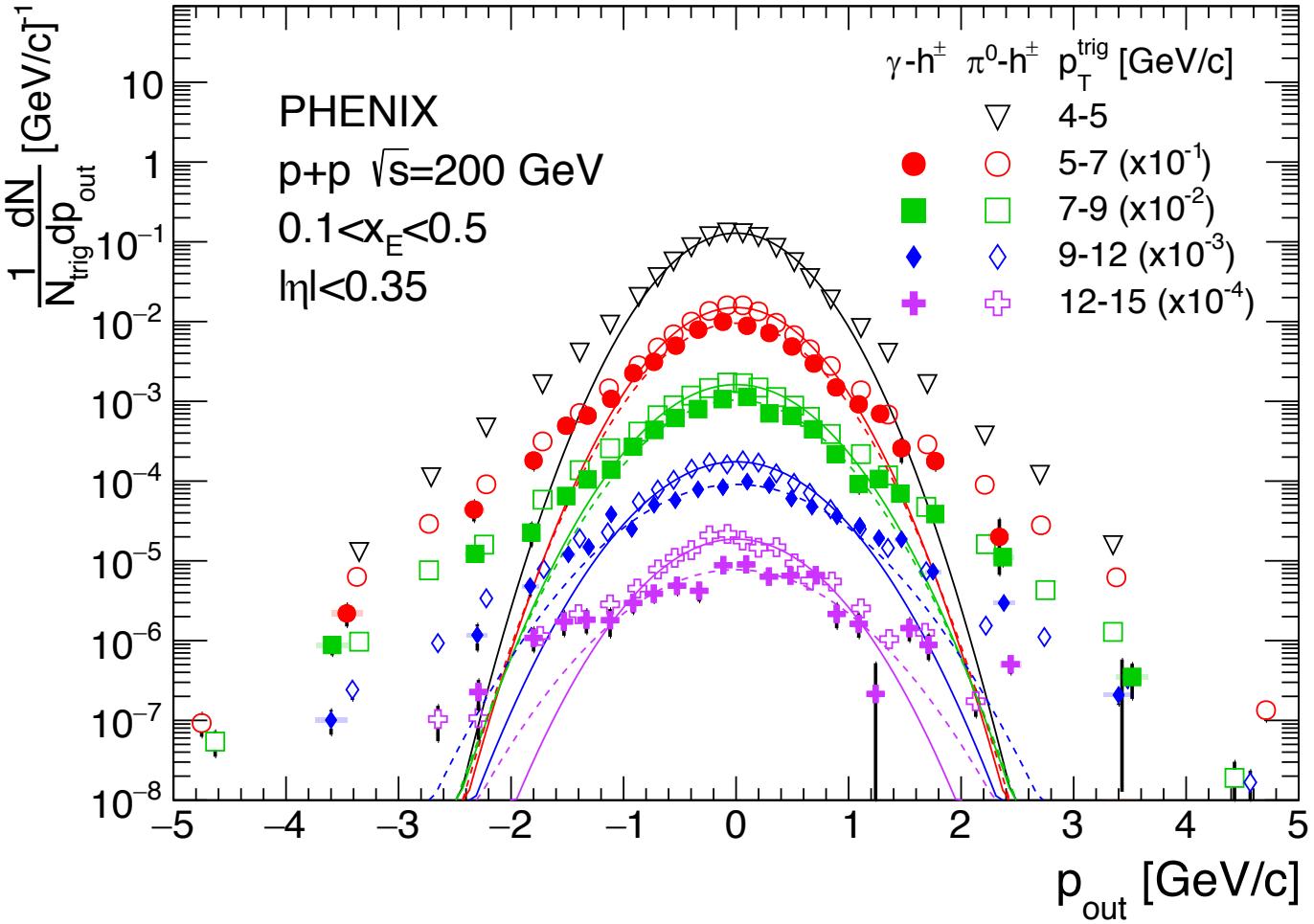

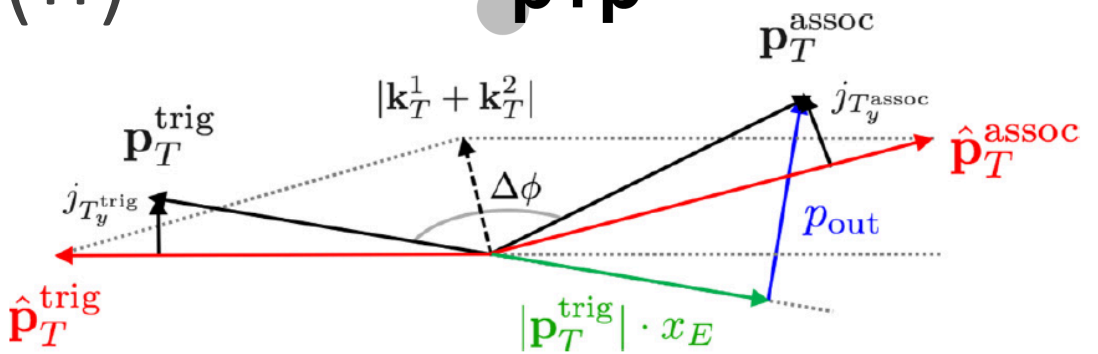

$$p_{out} = |p_T^{assoc}| sin\Delta\phi \qquad x_E = -\frac{|p_T^{assoc}|}{|p_T^{trig}|} cos\Delta\phi$$

- p_{out} allows us to separate effects:
  - non-perturbative (Gaussian)
  - perturbative (non-Gaussian tail)
    - Hard gluon radiation in initial or final state

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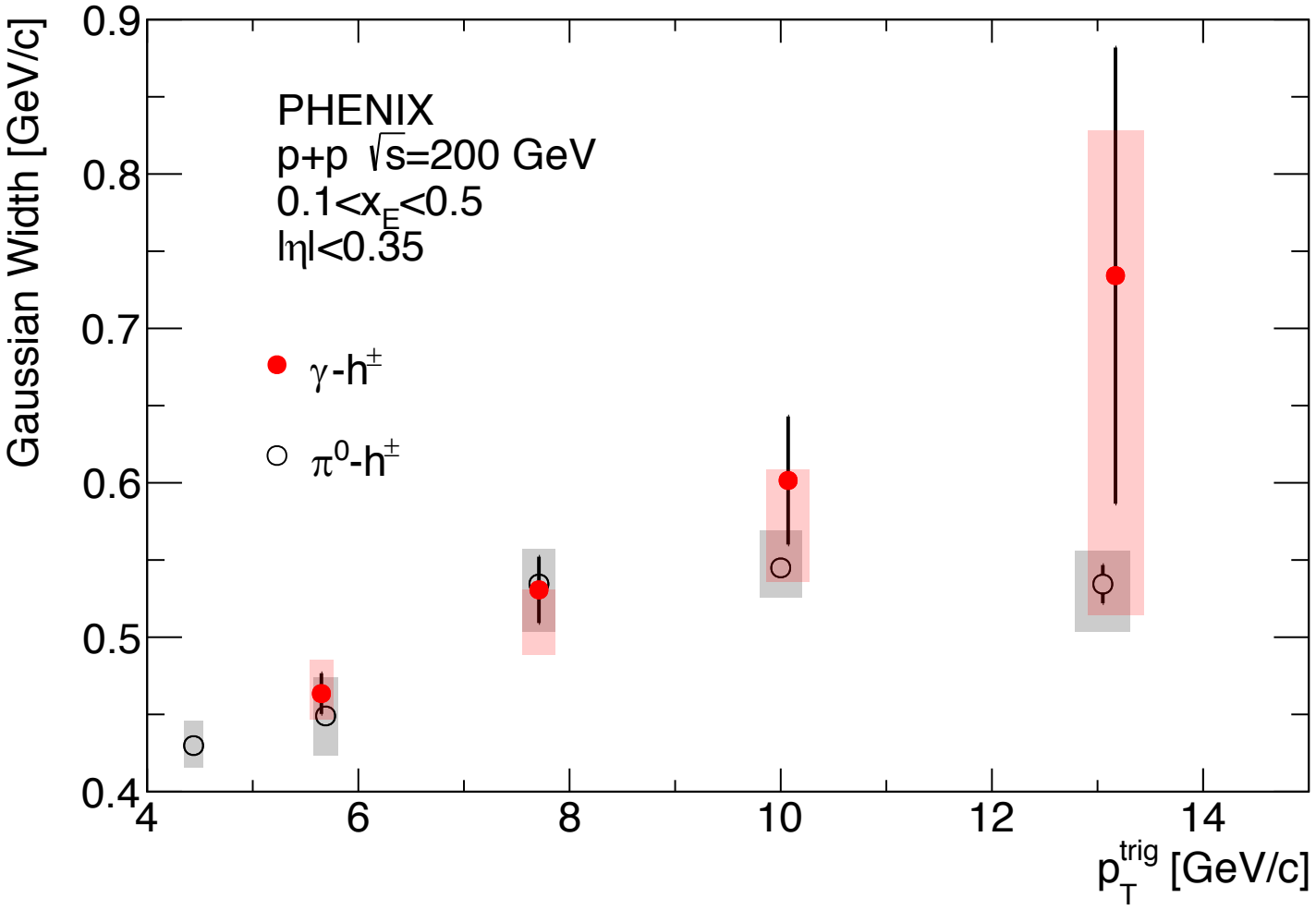
Correlation in p+p collisions (III)

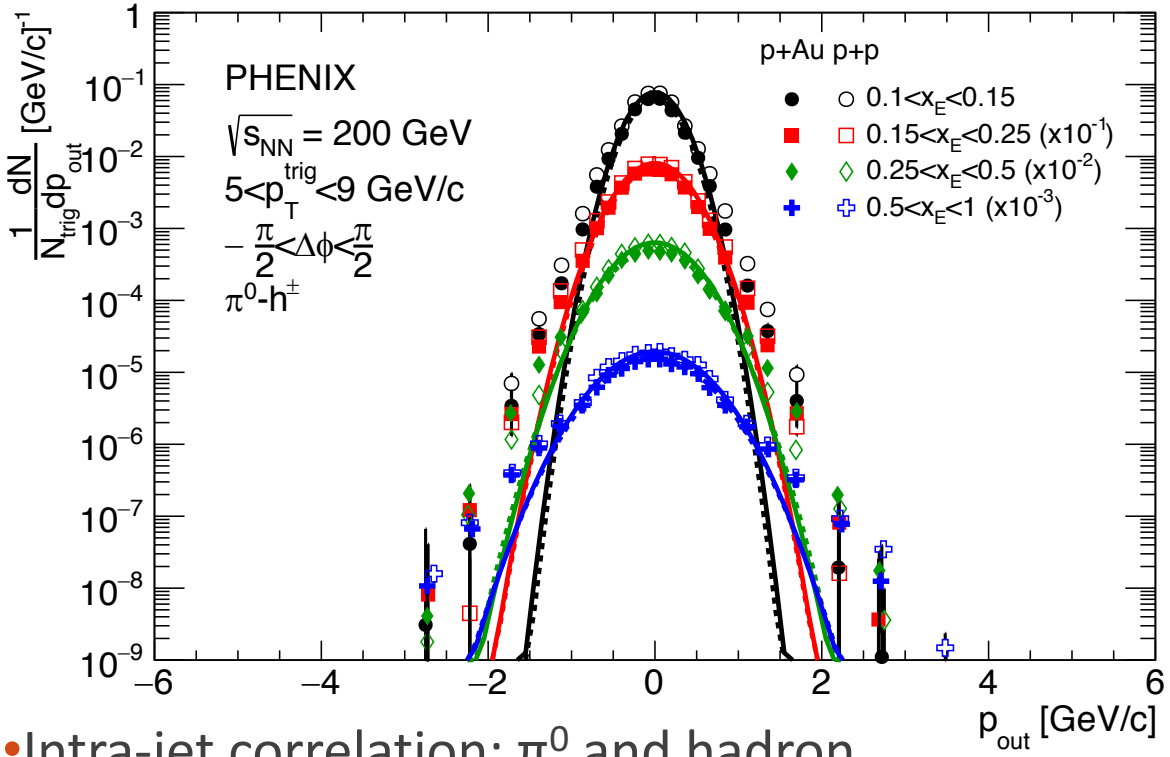


- Fitted Gaussian width as a function of p_T^{trig}
- With increasing p_T^{trig} we see:
  - Larger Gaussian widths
  - Stronger non-perturbative effects

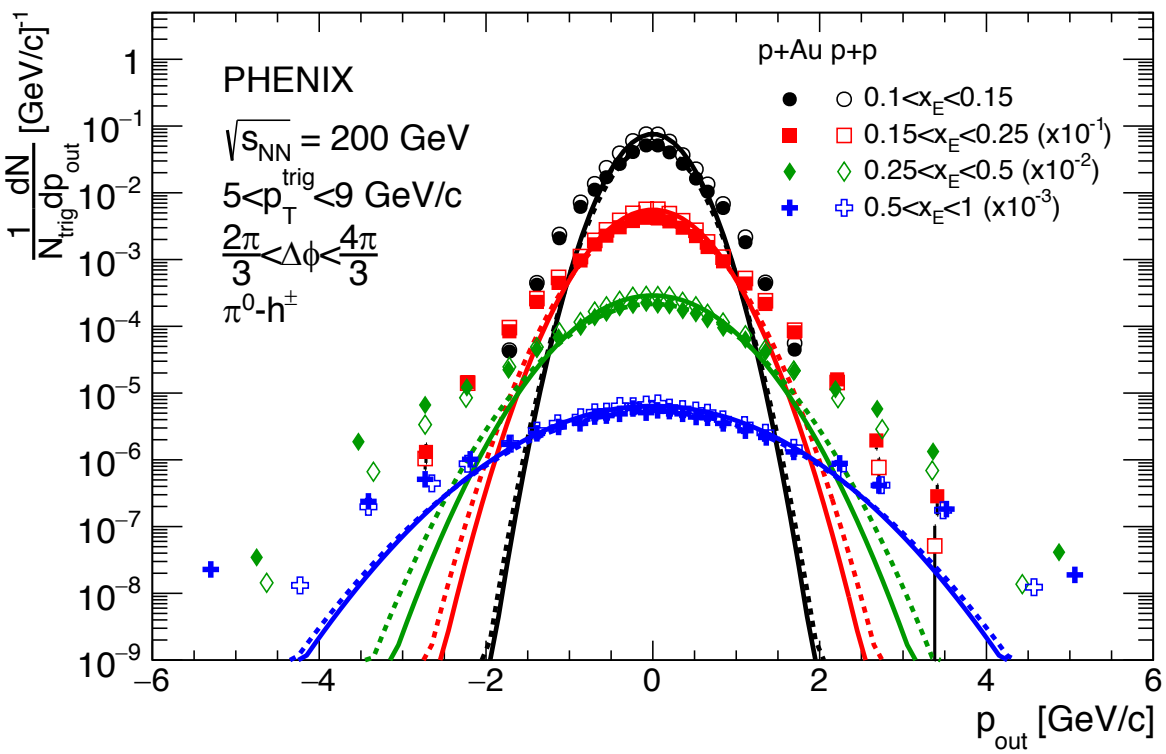
PhysRevD.98.072004

π^0-h correlation in p+Au collisions

Near Side

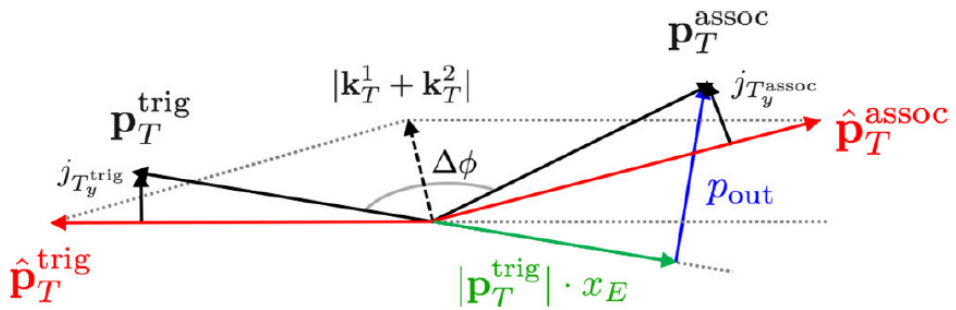


Away Side



- Intra-jet correlation: π^0 and hadron fragment from the same hard parton
  - Narrower than the away side
  - Sensitive only to fragmentation p_T

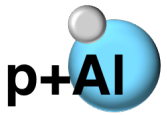
PhysRevC.99.044912

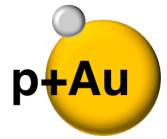


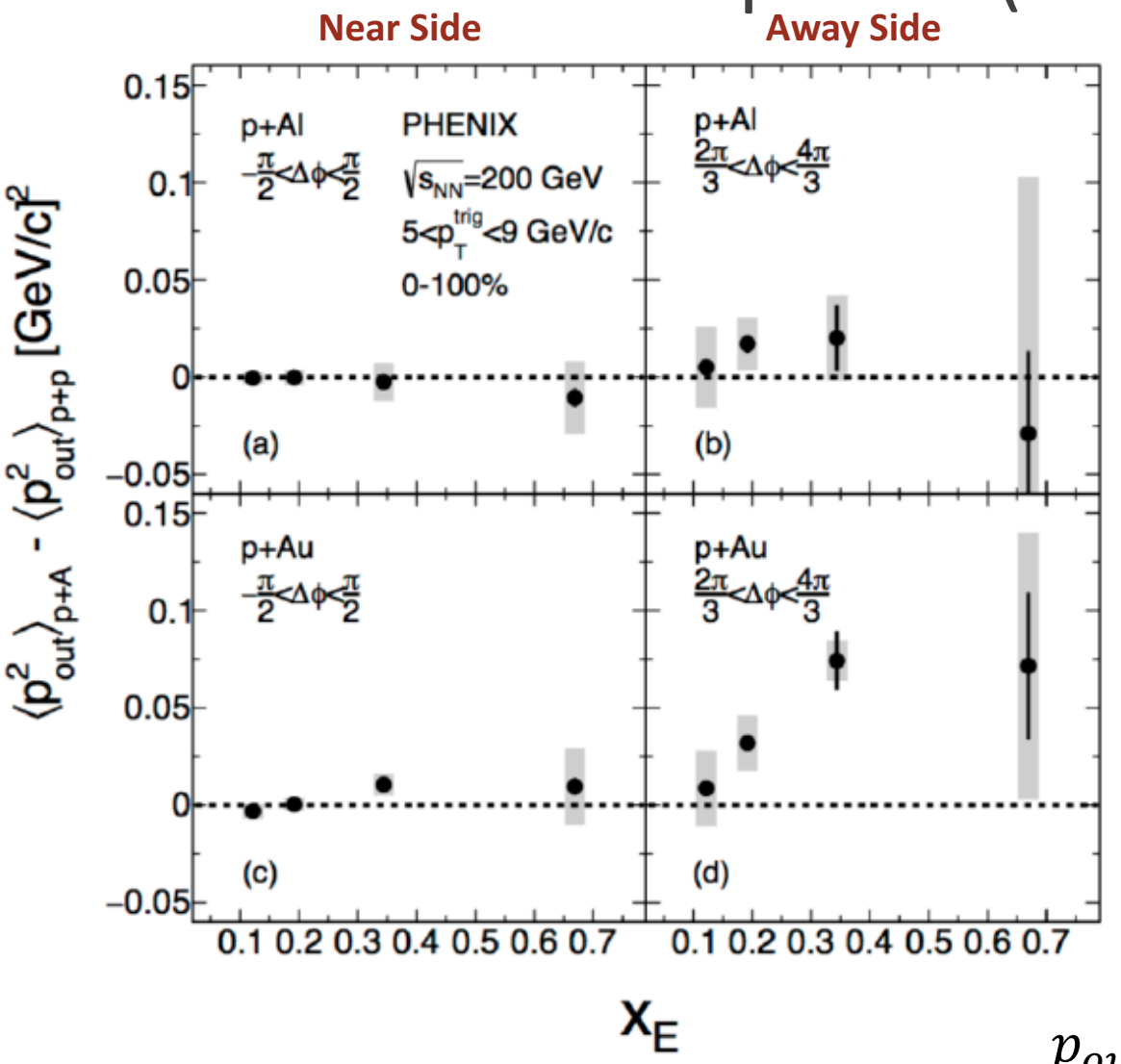
$$p_{out} = |p_T^{assoc}| sin\Delta\phi$$

$$x_E = -\frac{|p_T^{assoc}|}{|p_T^{trig}|} cos\Delta\phi$$

π^0-h correlation in p+Au(Al) collisions





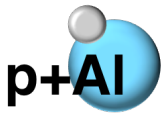


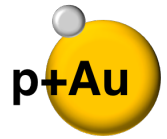
- Near side shows no p_{out} broadening compared to p+p
  - Intra-jet radiation effects are small
- Away side p+Au shows clear p_{out} broadening
- With this in mind let's focus on the away side…

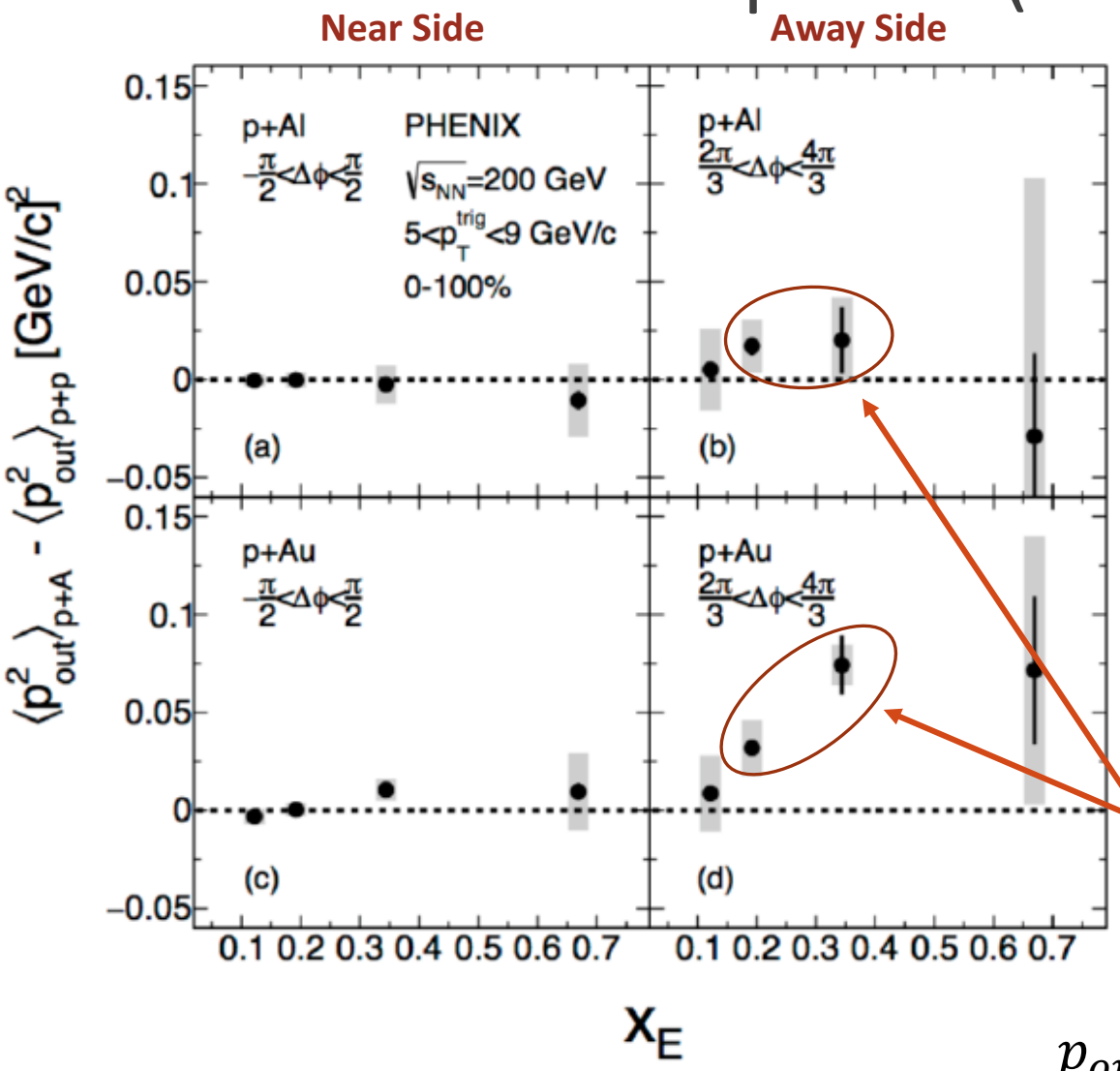
$$p_{out} = |p_T^{assoc}| sin\Delta\phi \qquad x_E = -\frac{|p_T^{assoc}|}{|p_T^{trig}|} cos\Delta\phi$$

PhysRevC.99.044912

π^0-h correlation in p+Au(Al) collisions







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- These bins in particular

$$p_{out} = |p_T^{assoc}| sin\Delta\phi \qquad x_E = -\frac{|p_T^{assoc}|}{|p_T^{trig}|} cos\Delta\phi$$

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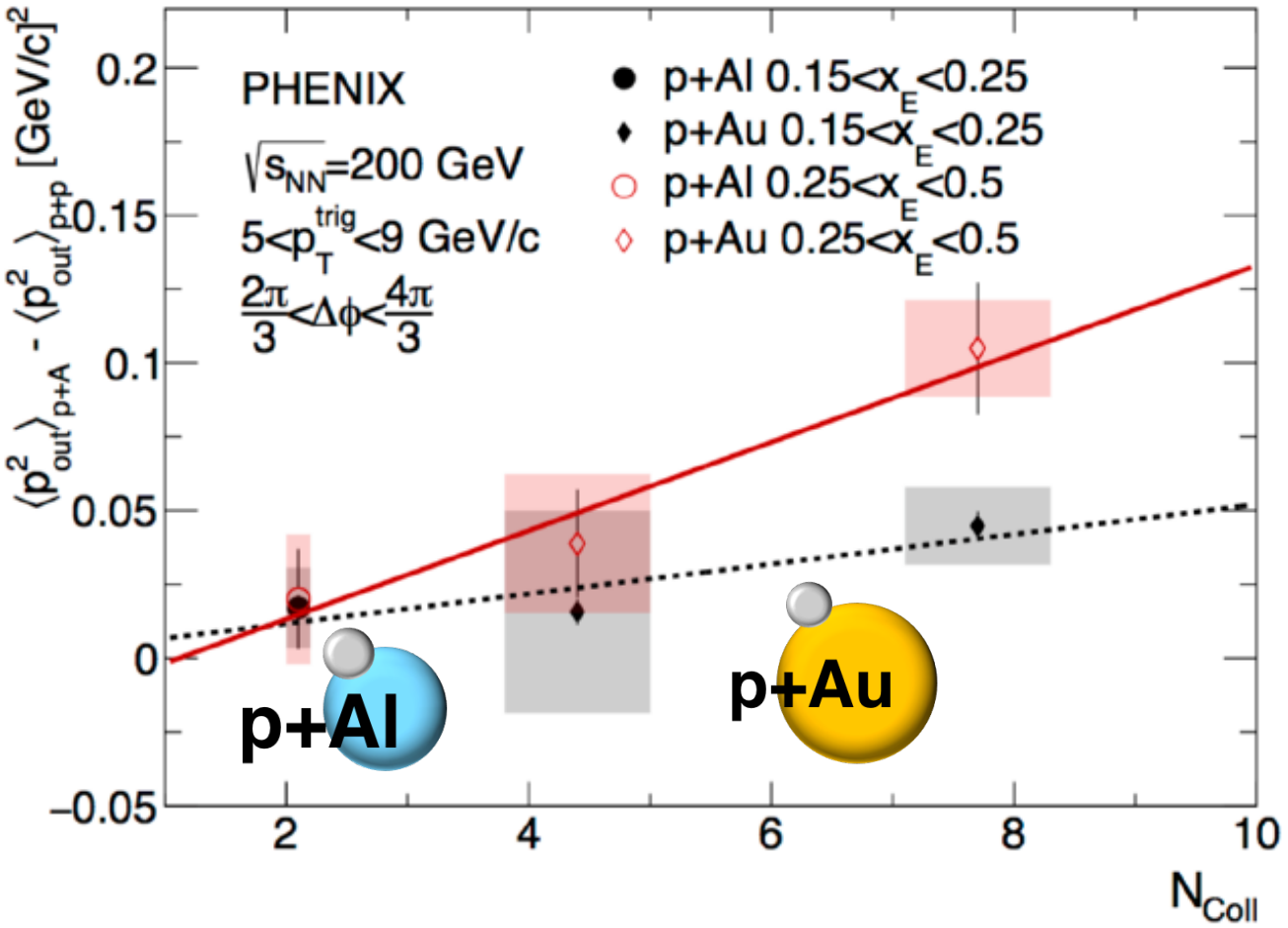
N_{coll} dependance p+Au(Al) (away side)



- **p_{out} broadening shows clear N_{coll} dependence**
- Effects that may possibly contribute:
  - Multiple scattering of partons inside the nuclear medium ("Cronin effect region")
  - Additional k_T (initial transverse momentum) for a parton in the nucleus with respect to p+p
  - Path length dependence->hard scattered partonic energy loss
  - v_2 and v_3 systematically ruled out as contributors

$$p_{out} = |p_T^{assoc}| sin\Delta\phi \qquad x_E = -\frac{|p_T^{assoc}|}{|p_T^{trig}|} cos\Delta\phi$$

PhysRevC.99.044912

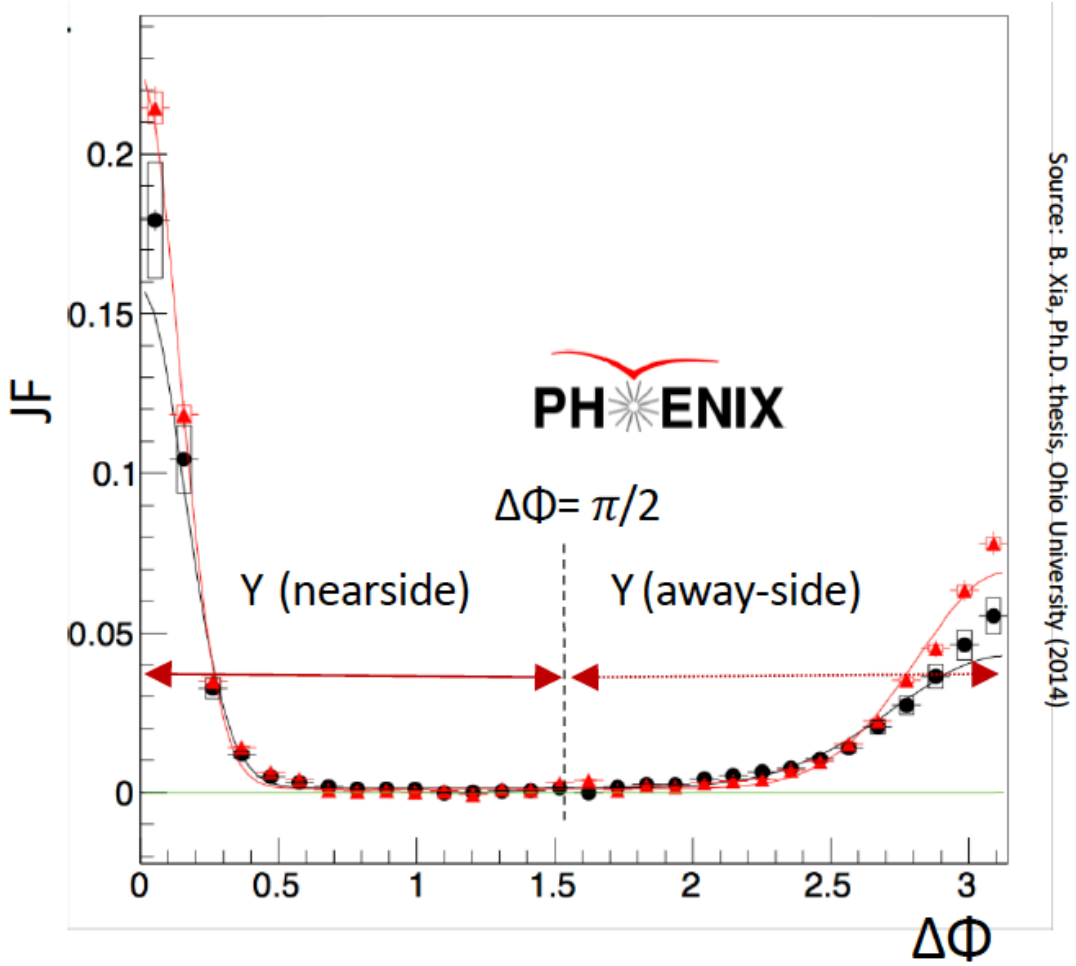
Correlation yields in d+Au

- Look for modification of away side in d+Au by studying ratio with p+p

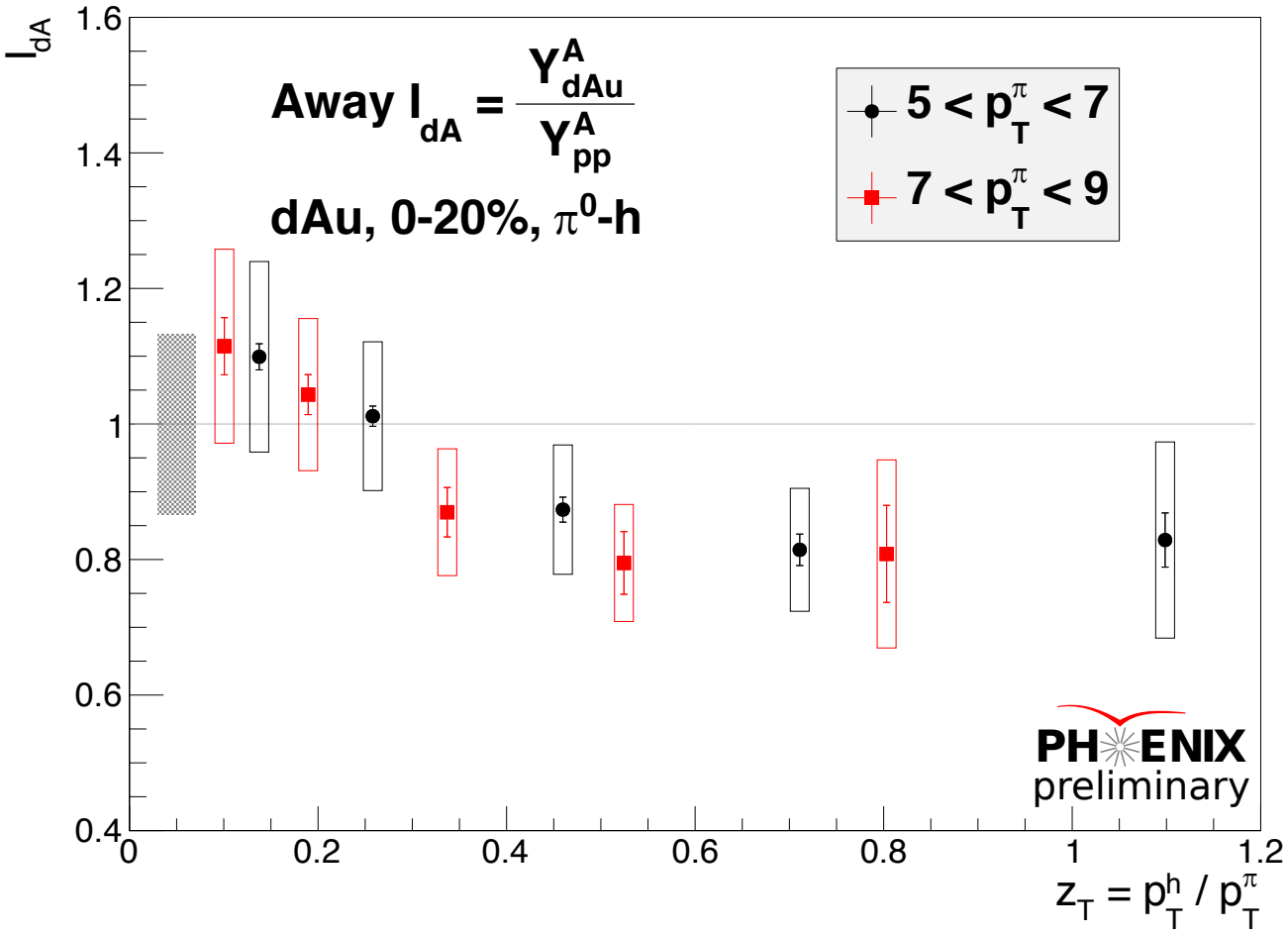
$$I_{dA} = \frac{Y^A_{dAu}}{Y^A_{pp}}$$

- This quantity can be studied as a function of z_T

$$z_T = \frac{p_T^{assoc}}{p_T^{trig}}$$



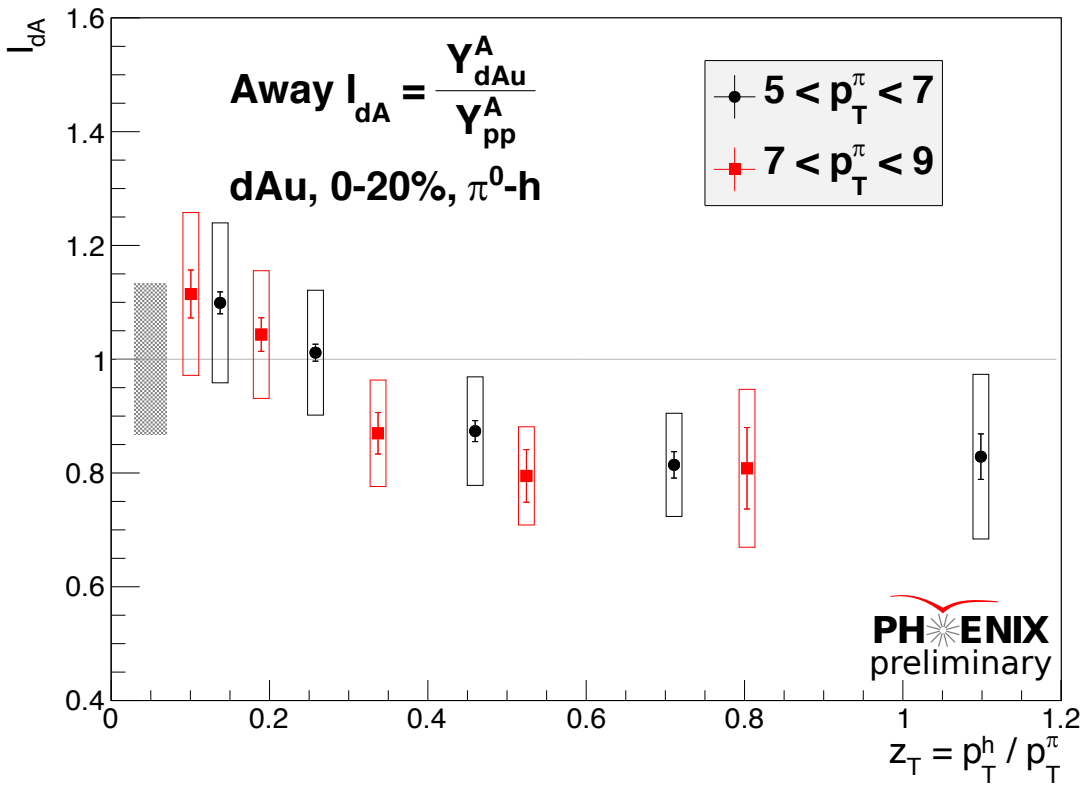
d+Au away yield ratio

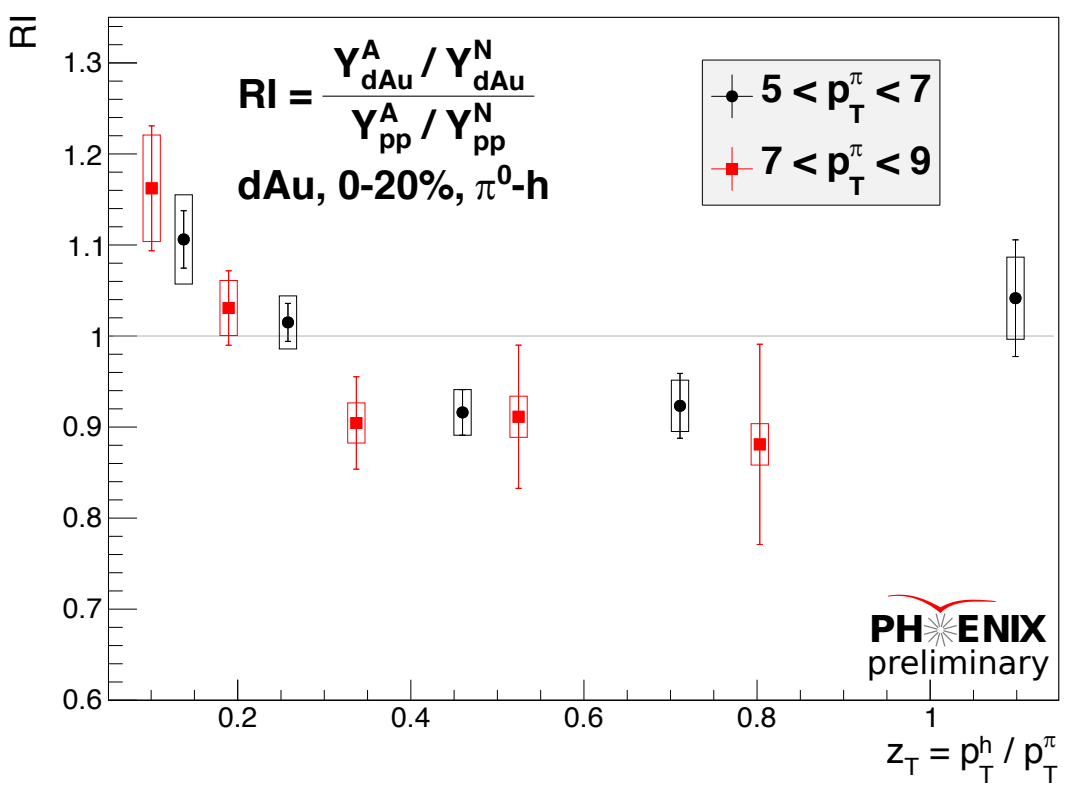


- Suppression at high z_T
- There is a hint of enhancement at low z_T
- Can we improve error bars? Yes!
- Let's look at the double ratio

$$RI = \frac{Y^A_{dAu}/Y^N_{dAu}}{Y^A_{pp}/Y^N_{pp}}$$

d+Au comparison of away yield vs. double ratio

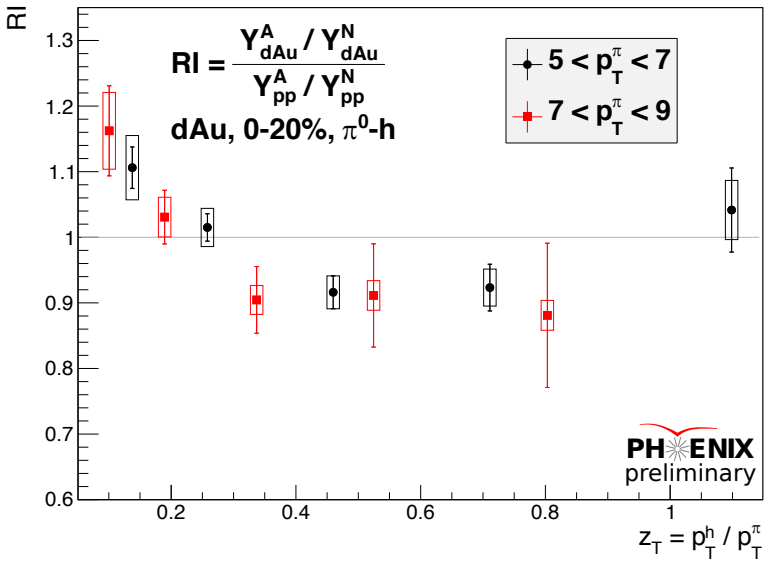




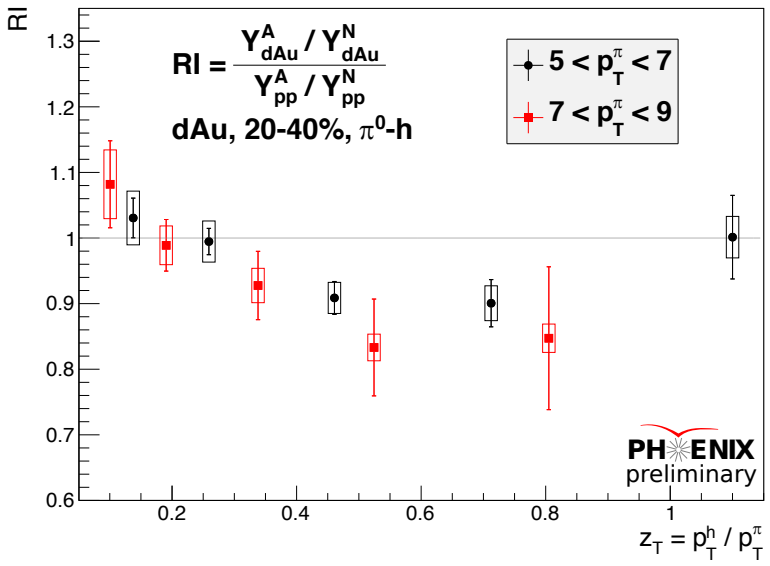
- Clear improvement of uncertainties in RI compared to I_{dAu}
- RI shows small high-z suppression and low-z enhancement in d+Au
- Let's explore this as a function of centrality…

RI Centrality Dependence

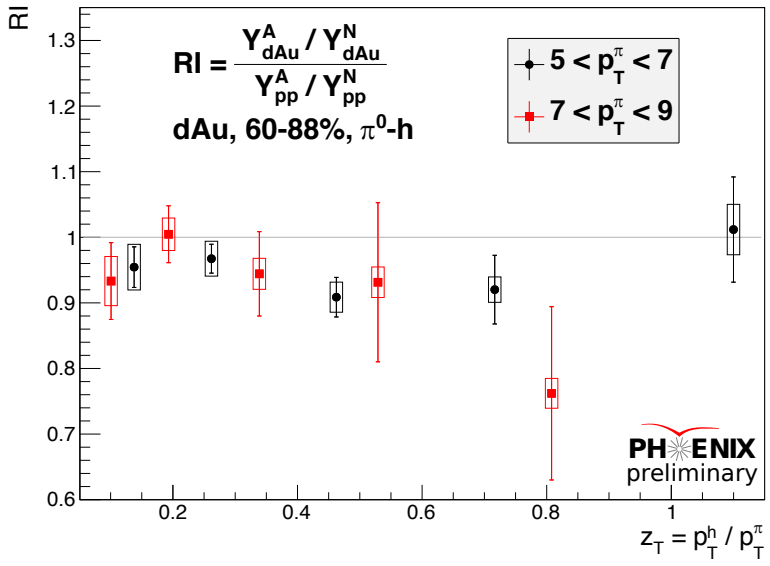
Central



Mid-Central



Peripheral



- Low-z_T enhancement, increasing as a function of centrality
- Indication of high-z_T suppression
- Theory input will be valuable to interpret these results
- Can we study this effect in another system? Yes, ^{3}He+Au!

π^0-h in ^{3}He+Au: Correlation Functions

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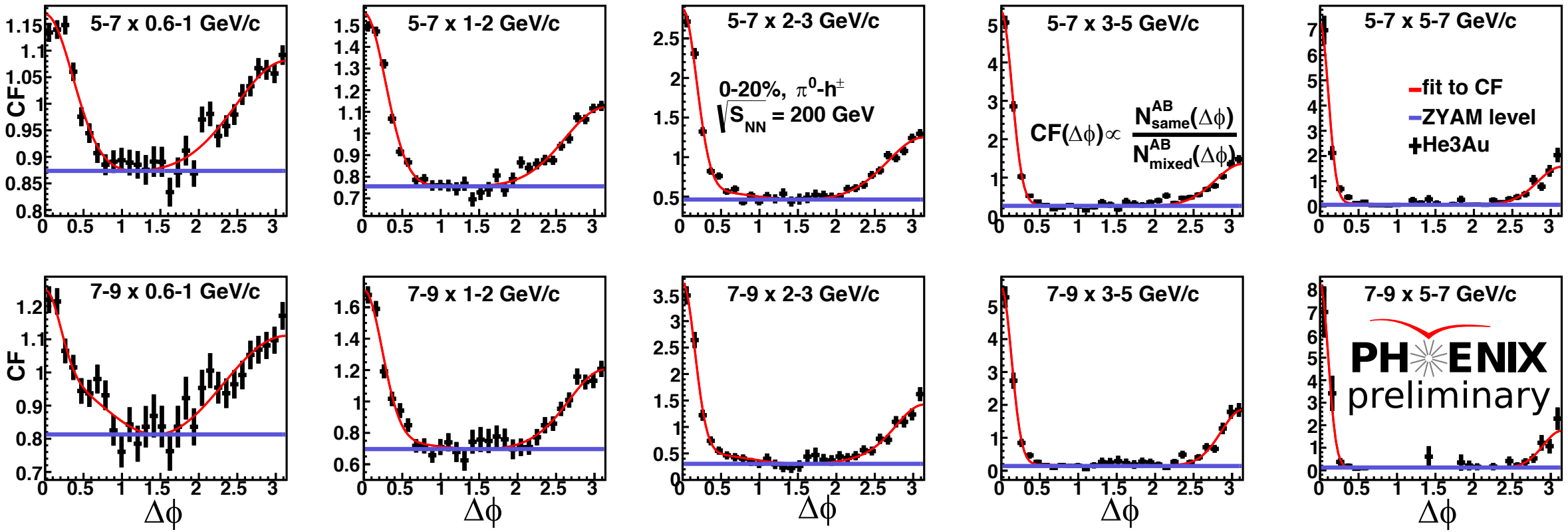
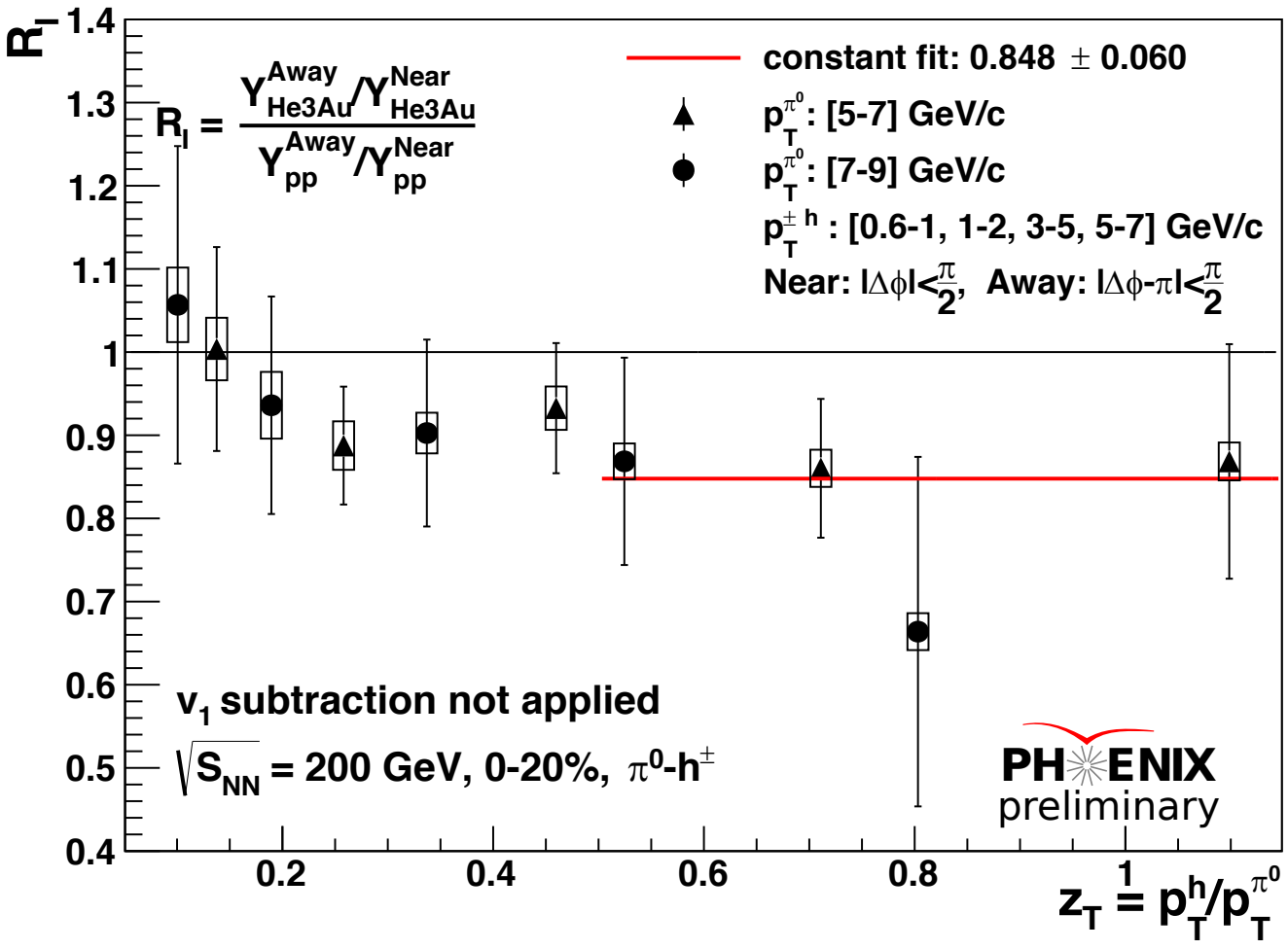
p_T^{assoc}

p_T^{trig}

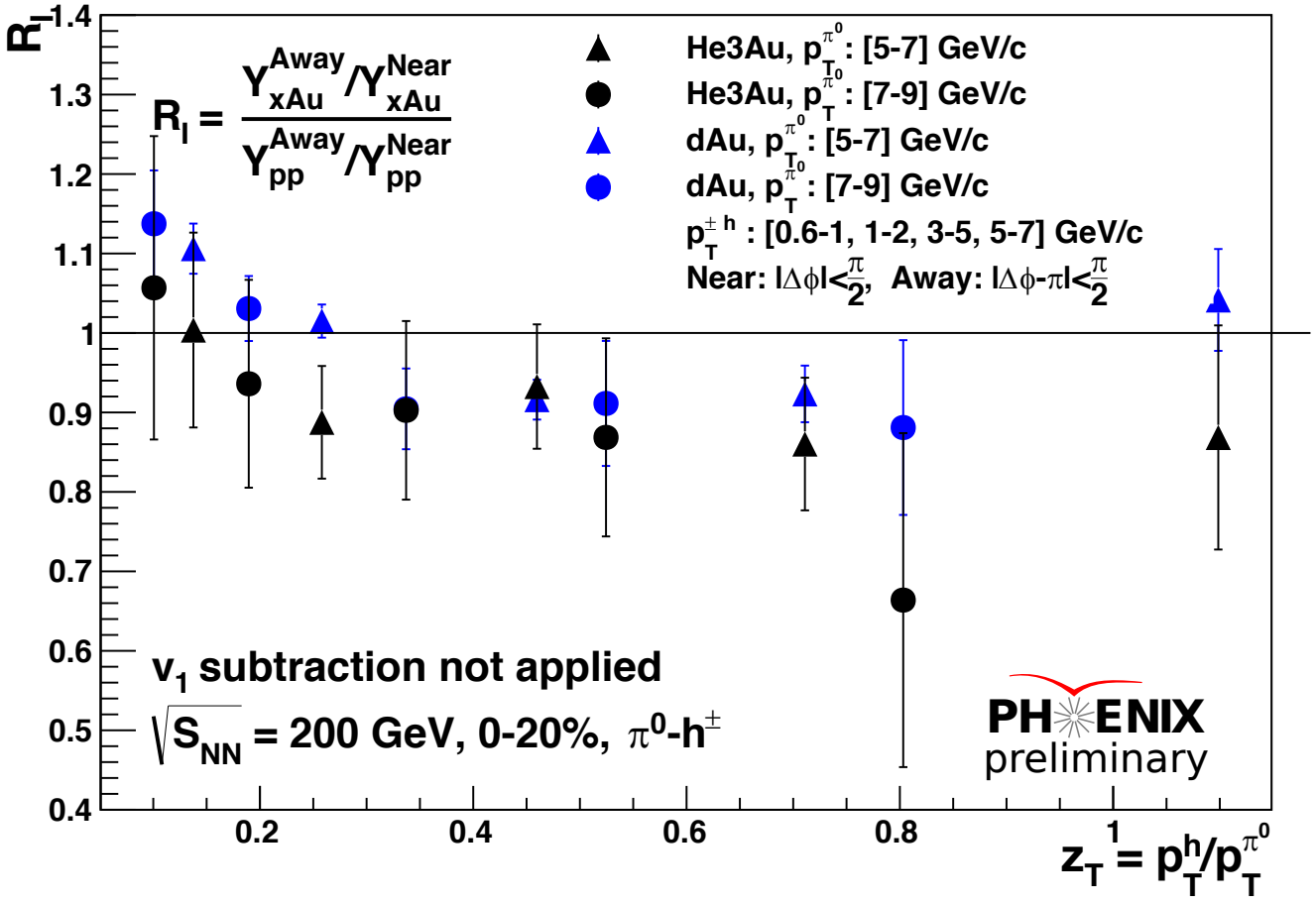


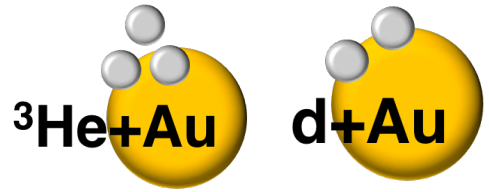
Double ratio in ^{3}He+Au



- High-z_T suppression illustrated by fit
- Similar trend as in d+Au

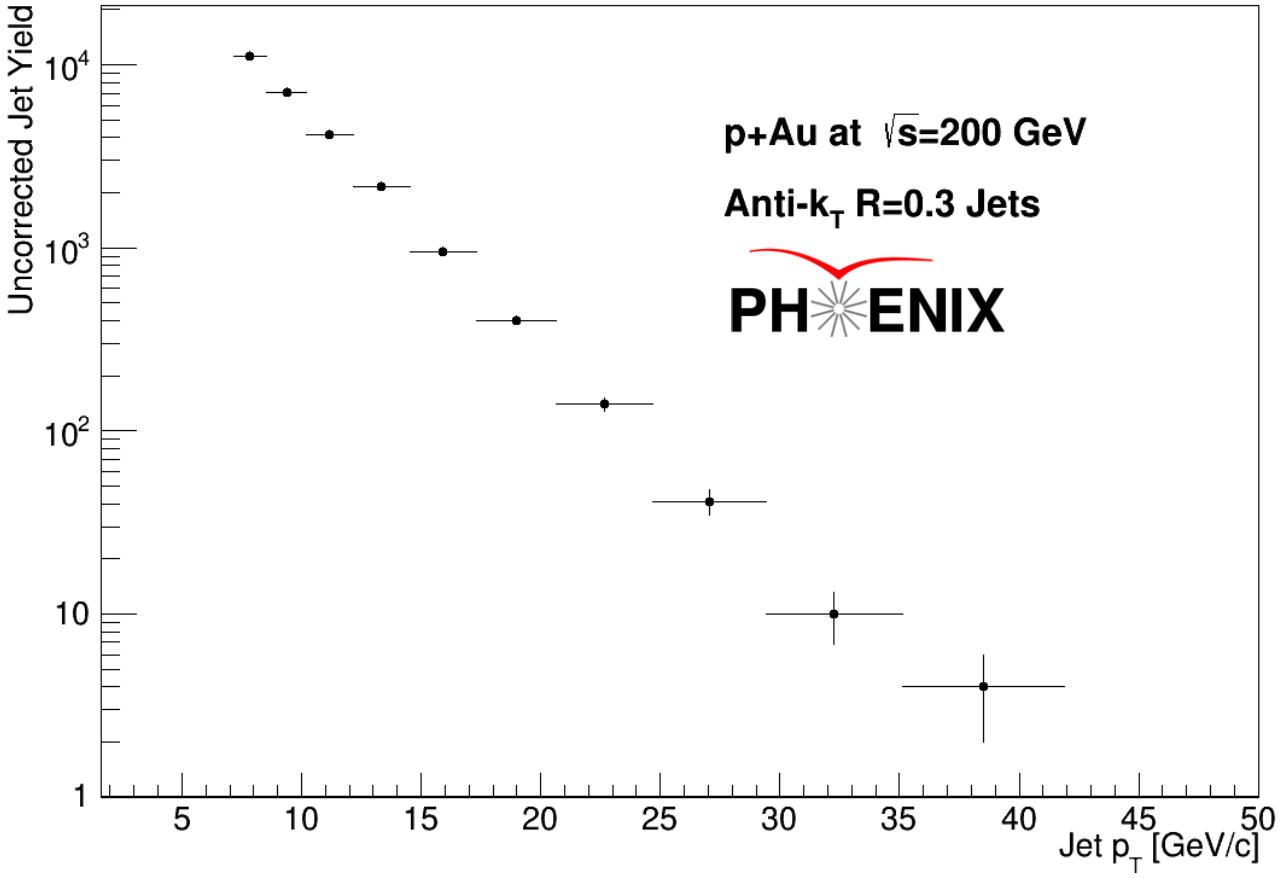
Comparing ^{3}He+Au to d+Au





- Very interesting!
- How do we explain this?
  - CNM energy loss?
- Again, theorist input needed!

Fully reconstructed jets (preview)



- Coming soon! Fully reconstructed jets from 2015 high statistics small systems data sets
- p+p has similar statistics to p+Au (shown)
- We expect results in the coming months

Conclusions

- PHENIX has taken a rich collection of small system measurements
- We have interesting results from two particle correlations:
  - N_{coll} dependence of momentum broadening in p+A
  - Evidence of jet modification in d+Au and ^{3}He+Au
- We are looking forward to input from theorists!
- Stay tuned for new results from fully reconstructed jets in p+p and p+Au

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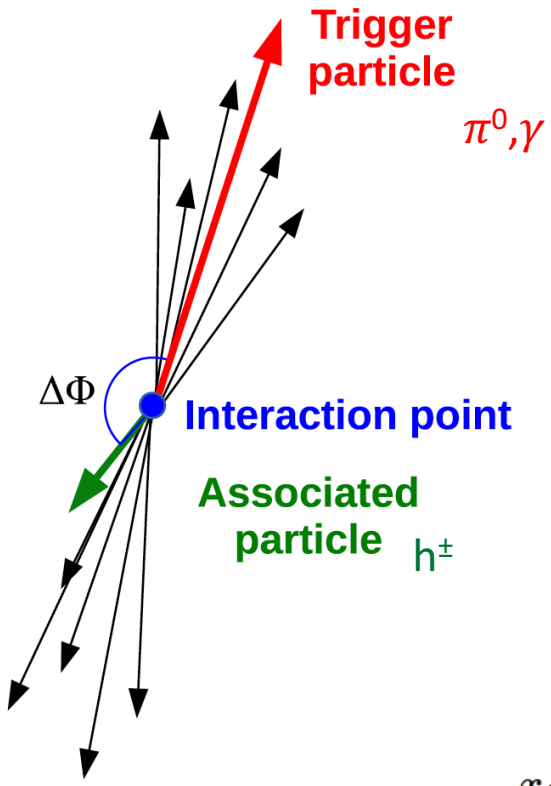
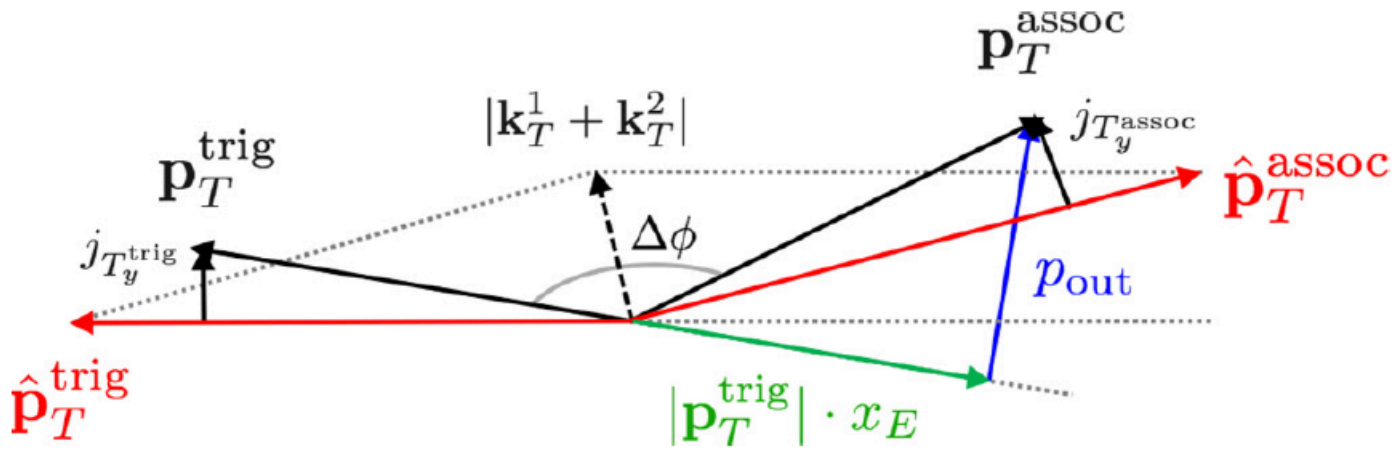
Thank you!

Backup

Hard scattering kinematics





$$p_{\text{out}} = |\mathbf{p}_T^{\text{assoc}}| \sin \Delta\phi$$

Momentum component of the associated hadron perpendicular to the trigger particle

$$x_E = -\frac{\mathbf{p}_T^{\text{trig}} \cdot \mathbf{p}_T^{\text{assoc}}}{|\mathbf{p}_T^{\text{trig}}|^2} = -\frac{|\mathbf{p}_T^{\text{assoc}}|}{|\mathbf{p}_T^{\text{trig}}|} \cos \Delta\phi.$$

Longitudinal momentum fraction of the associated hadron with respect to the trigger particle (proxy for the momentum fraction z)

π^0-h in p+p: Correlation Functions

p+p

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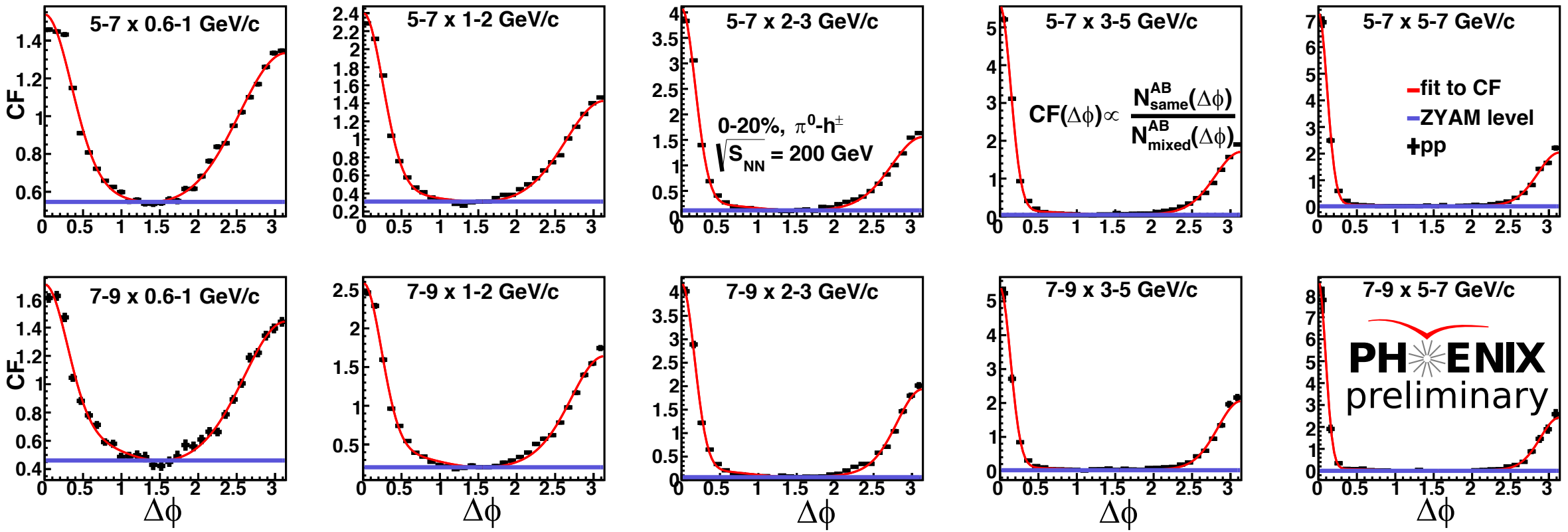
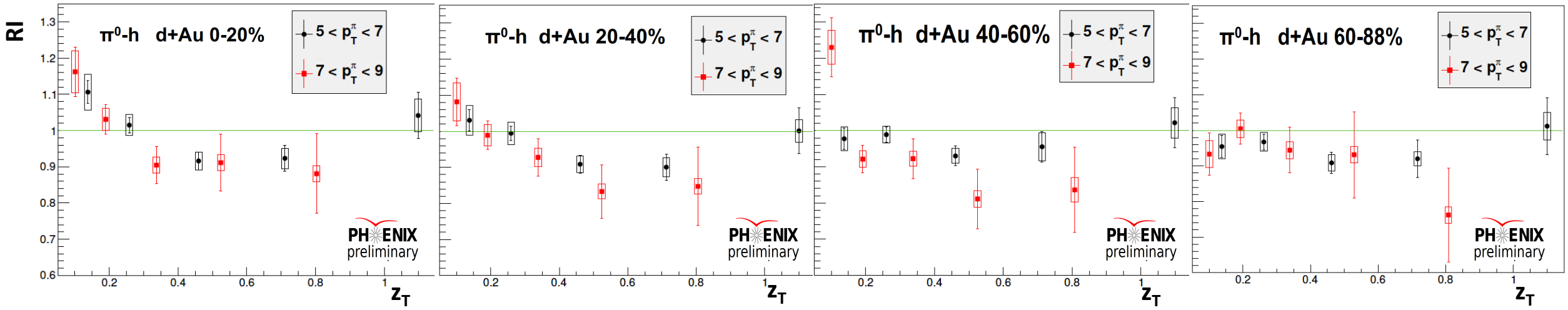
p_T^{assoc}

p_T^{trig}



RI Centrality Dependence

Central **Peripheral**



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- Indication of high-z_T suppression

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Comparing ^{3}He+Au to d+Au