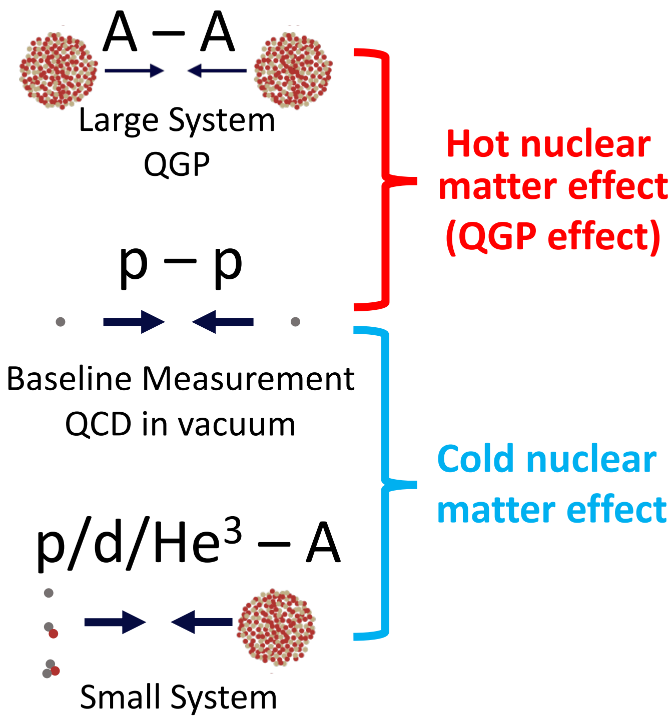
Exploring jet modification via gamma-hadron and π^0-hadron correlations in AuAu collisions at PHENIX

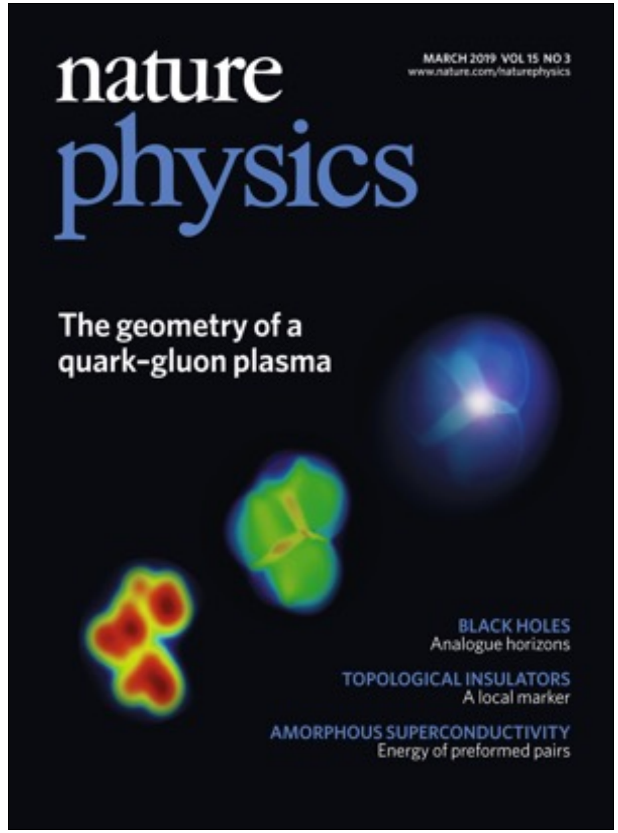
Cheuk-Ping Wong
on behalf of PHENIX collaboration

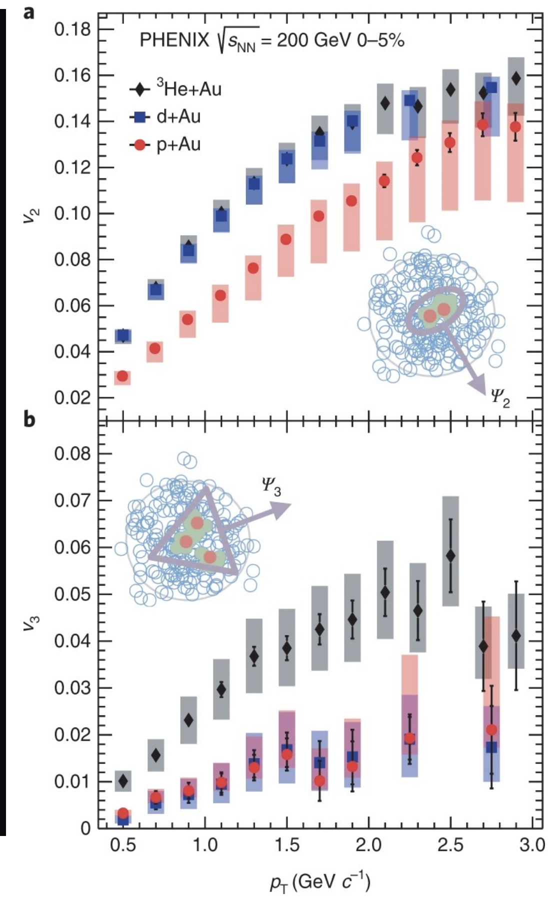
03-01-2022

LA-UR-22-21621

RHIC Program







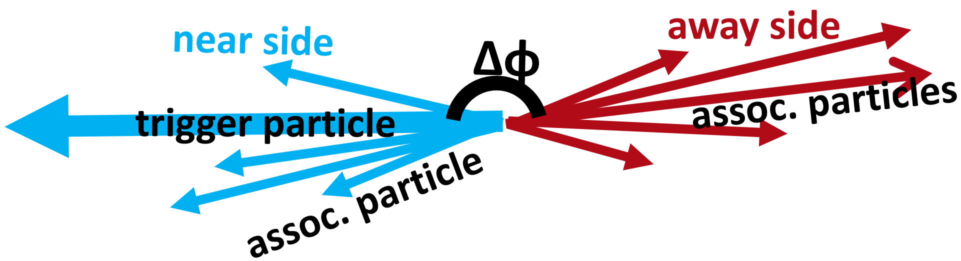
Nature Physics **15**, p. 214–220 (2019)

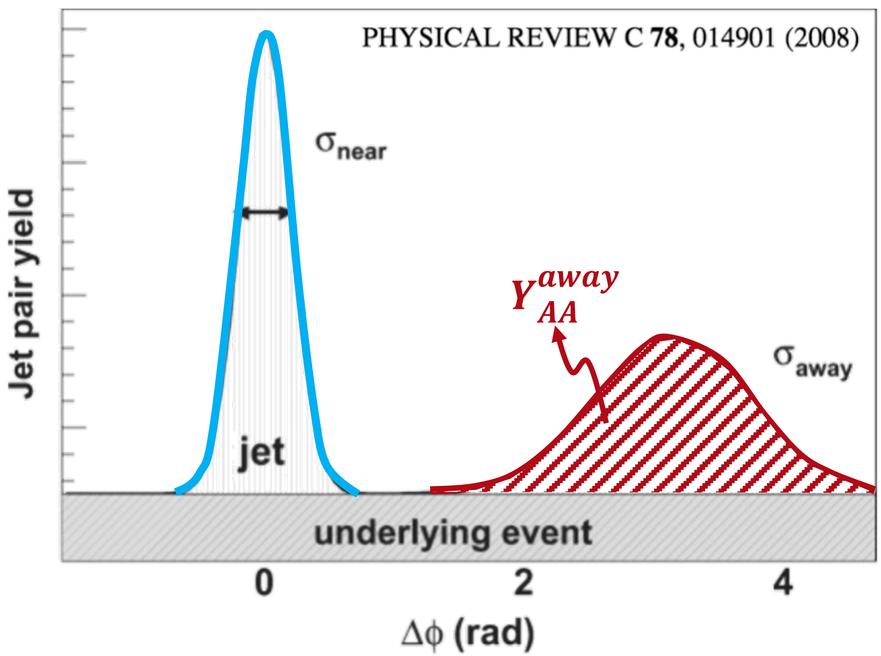
- Non-zero charged hadron v_n measured in small systems
- v_n depends on initial geometry

Cold nuclear matter and QGP droplet

More **small system** measurements are needed to understand QGP effect in large system

Probing Jet Modification via Two-particle Correlations





Schematics of jet function from p+p collision

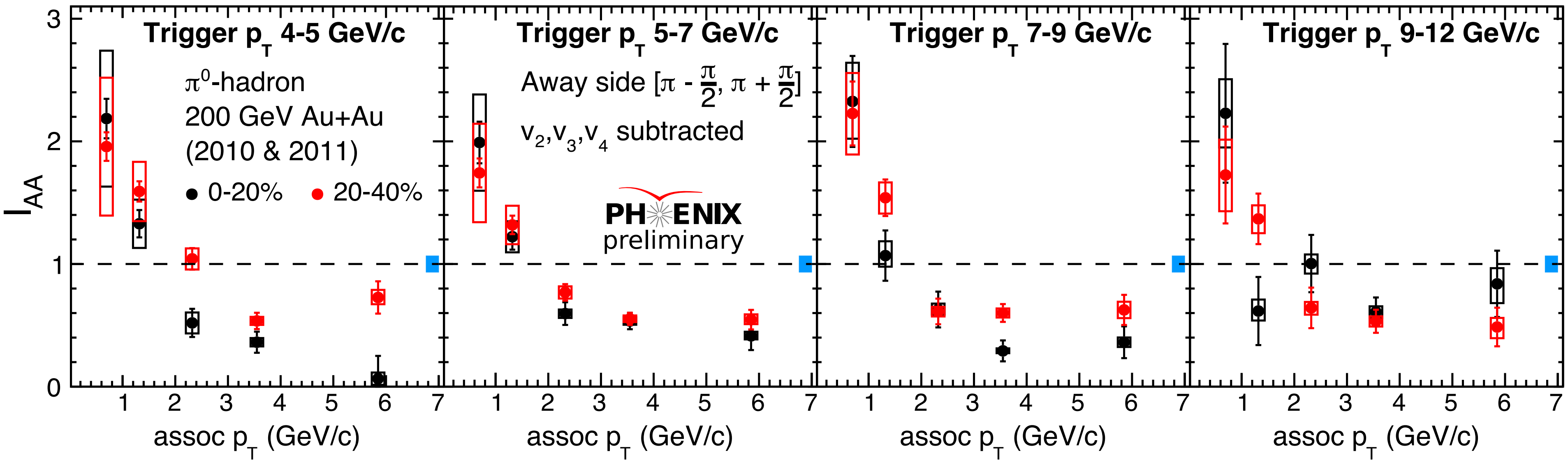
Compare Au+Au (with QGP) to p+p (no QGP)

- angular width (σ) → jet broadening
- yield (Y) → energy loss

$$I_{AA}(p_T^{assoc}) = \underbrace{\frac{Y_{AA}}{Y_{pp}}}_{\text{Yield}} = \underbrace{\frac{D_{AA}}{D_{pp}}}_{\text{Fragmentation function}}$$

Modification of fragmentation function

Away-side Yield Modifications in Au+Au Collisions

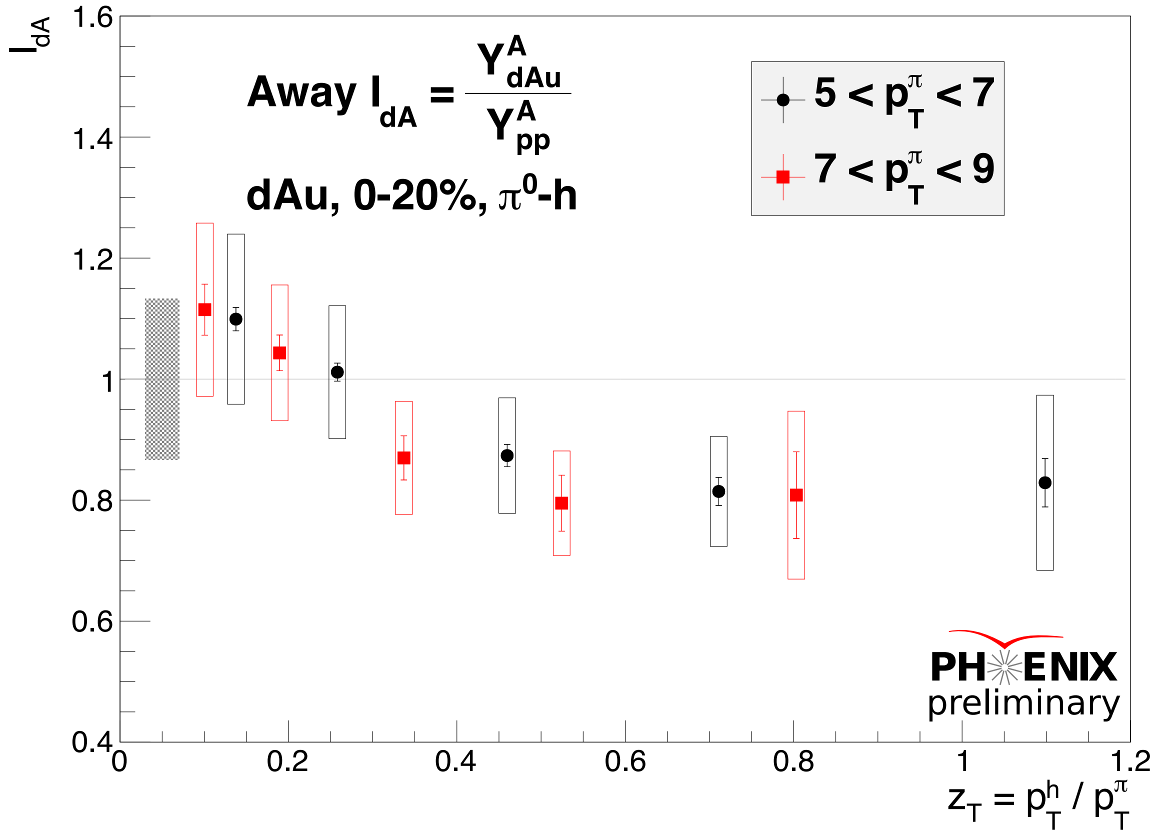


$$I_{AA}(p_T^{assoc}) = \frac{Y_{AA}}{Y_{pp}}$$

- Clear modification shown:
  $I_{AA} > 1$ at low p_T^{assoc} and $I_{AA} > 1$ at high p_T^{assoc}
- Suggesting hard partons loses energy when traversing the QGP leads to jet quenching: suppression of hard jet particle, but enhancement of soft particles
- No significant centrality dependence within uncertainty

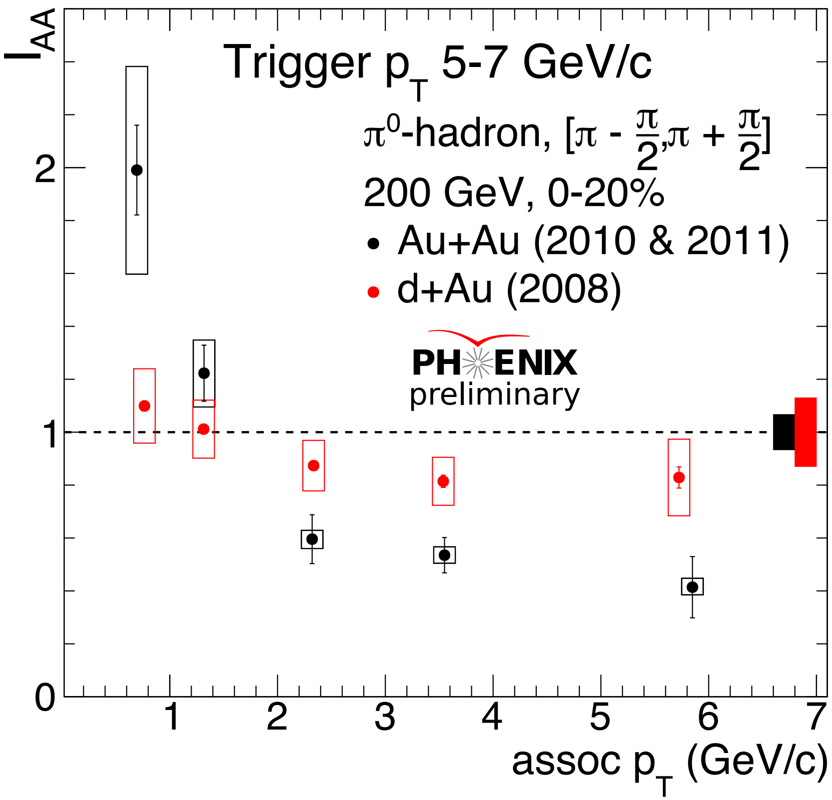
d+Au

Away-side Yield Modifications in d+Au Collisions



- I_{dA}<1 at high z_T , I_{dA}>1 at low z_T → Hints to yield modification
- However, the I_{dA} is consistent with 1 because of the sizable systematic uncertainties

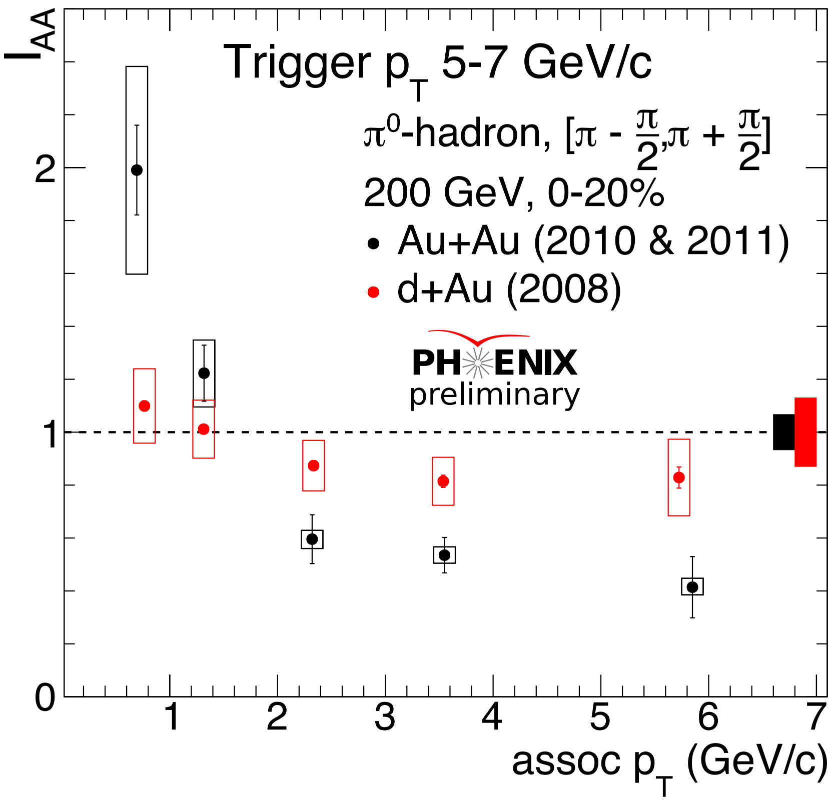
Away-side I_{AA} Comparison

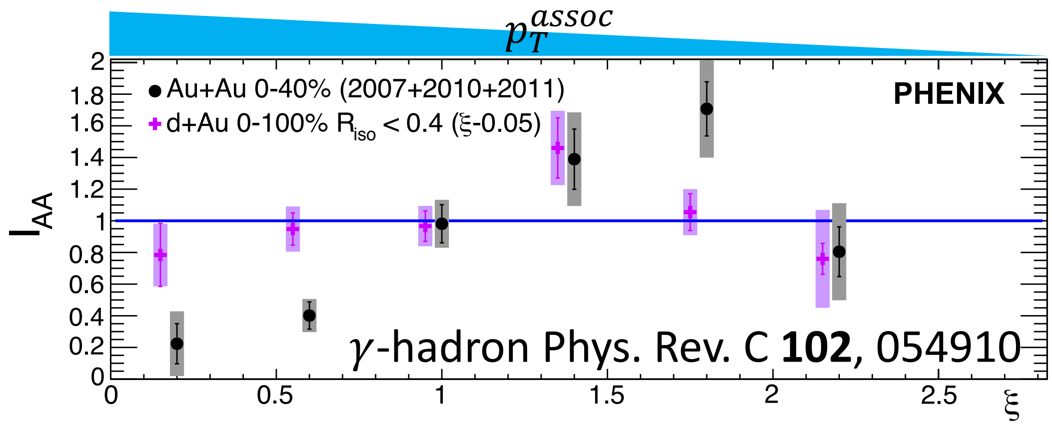


- $I_{AA} > I_{dA}$ in low p_T , $I_{AA} < I_{dA}$ in high p_T
- Larger away-side yield modification in Au+Au collisions than in d+Au collisions

d+Au

Away-side I_{AA} Comparison



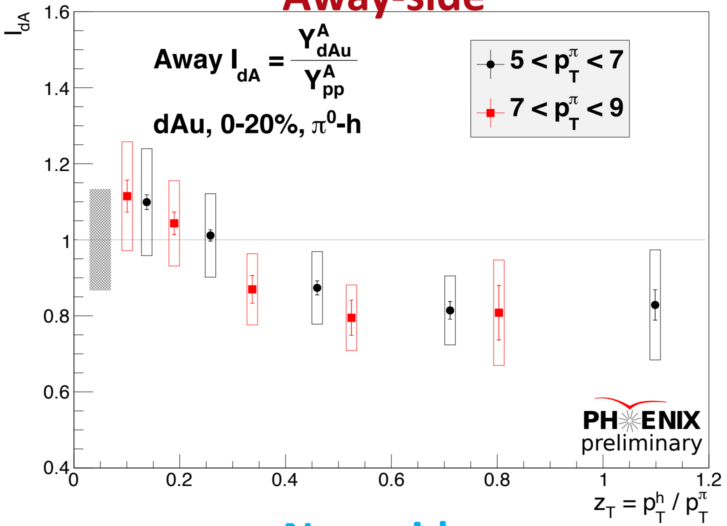


- $\xi = \ln\left(\frac{1}{z_T}\right) = \ln(p_T^{\gamma}/p_T^{h})$
- Same observation found in the comparison of away-side yield modification from γ-hadron correlations

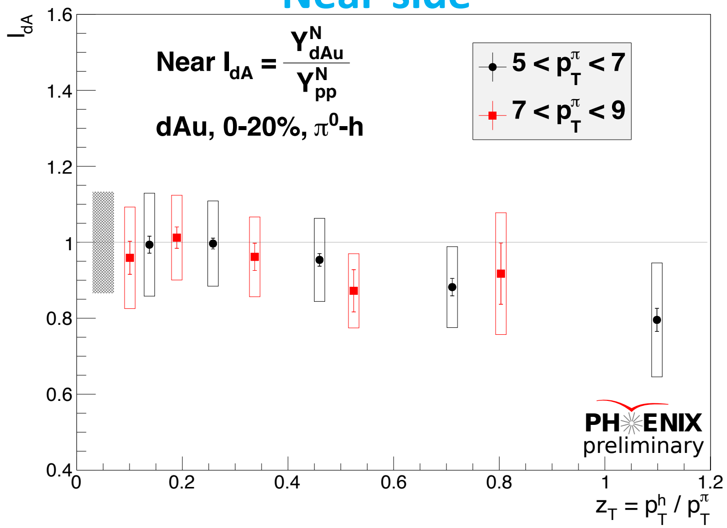
- $I_{AA} > I_{dA}$ in low p_T , $I_{AA} < I_{dA}$ in high p_T
- Larger away-side yield modification in Au+Au collisions than in d+Au collisions

Away-Side Yield Modification in d+Au Collisions

Away-side



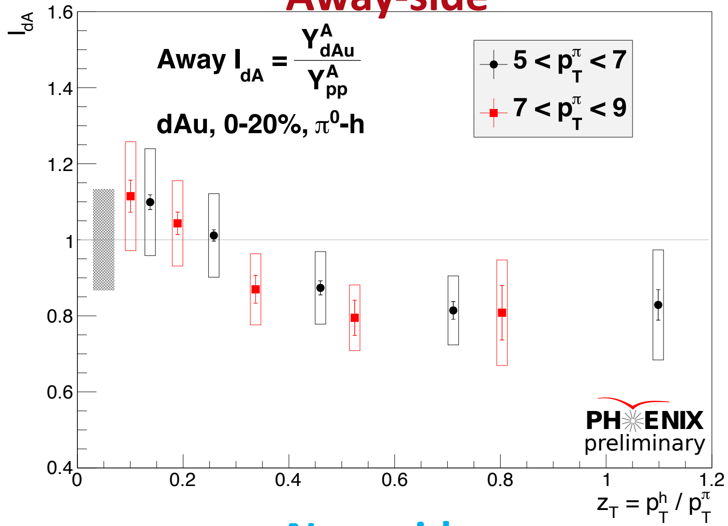
Near-side



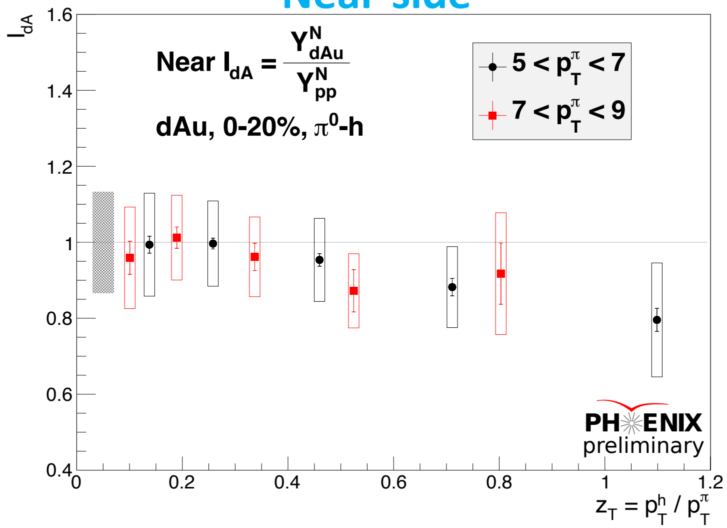
- Hints of suppression at high p_T^{assoc}, and enhancement at low p_T^{assoc}
- Near-side is consistent with unity

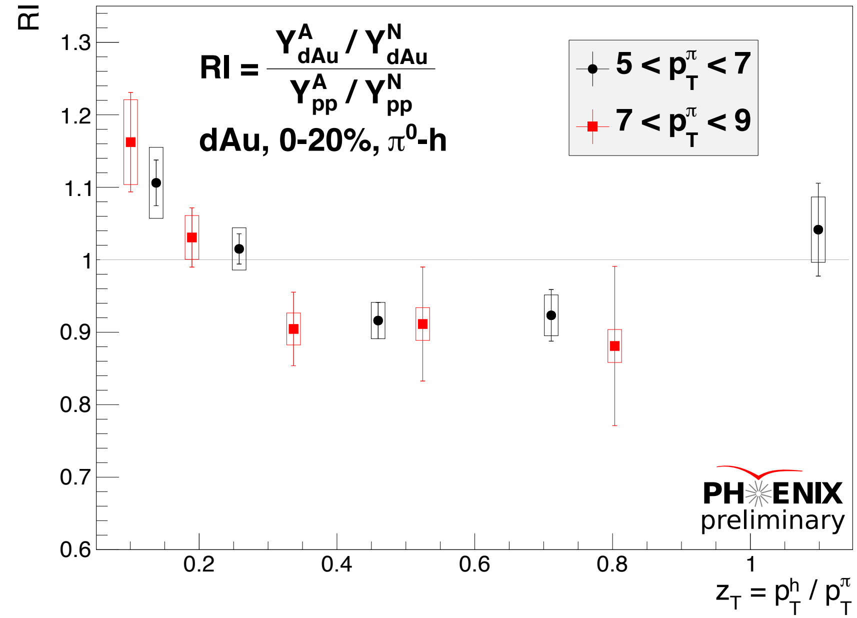
Away-Side Yield Modification in d+Au Collisions

Away-side



Near-side

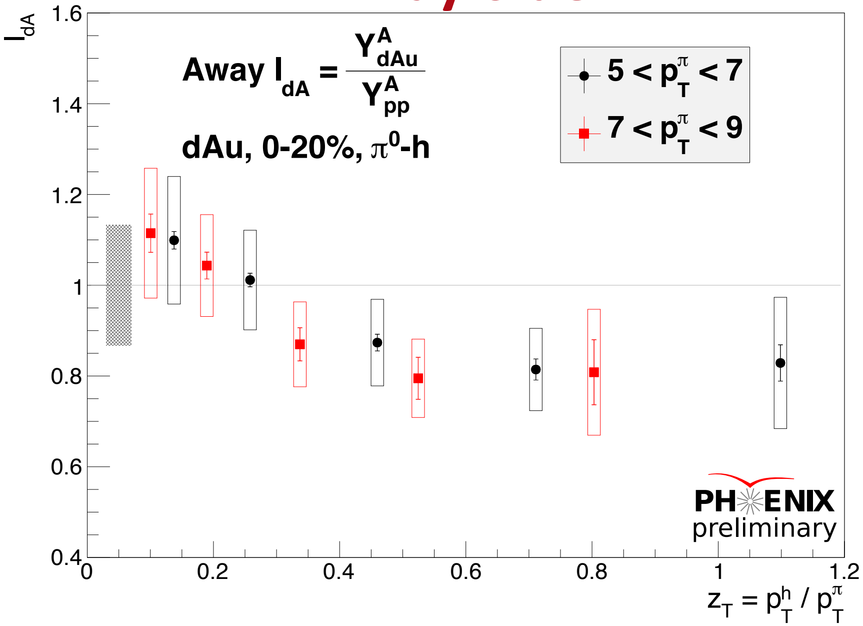


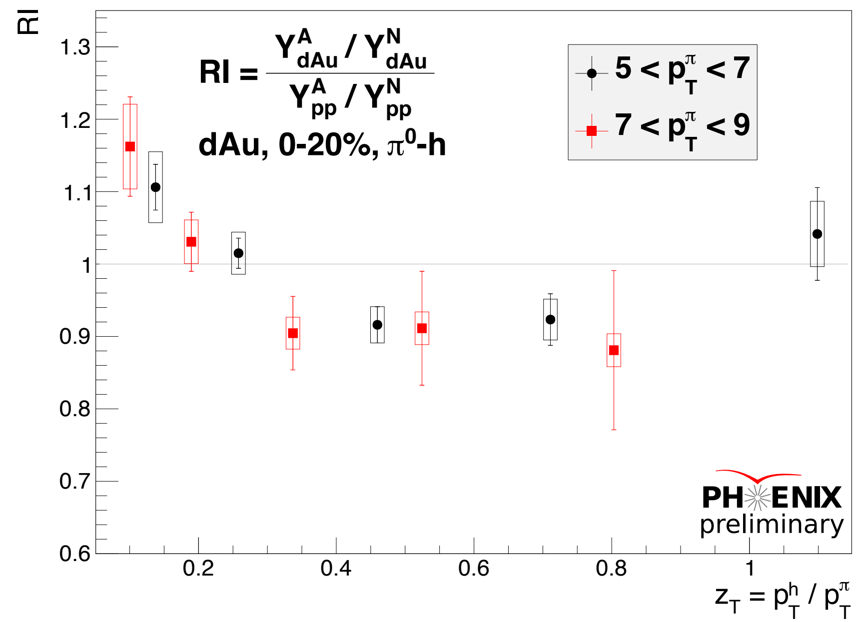


- Hints of suppression at high p_T^{assoc}, and enhancement at low p_T^{assoc}
- Near-side is consistent with unity
- Double Ratio $R_I = \frac{I_{dA}^{away}}{I_{dA}^{near}}$ is introduced: some systematic uncertainties are canceled out

Away-Side Yield Modification in d+Au Collisions

Away-side





- R_I shows away-side suppression at high z_T
- Clear enhancement of low p_T jet particles is shown in R_I results as systematic uncertainty reduced compared to I_{dA}

Away-Side Yield Modification in d+Au Collisions

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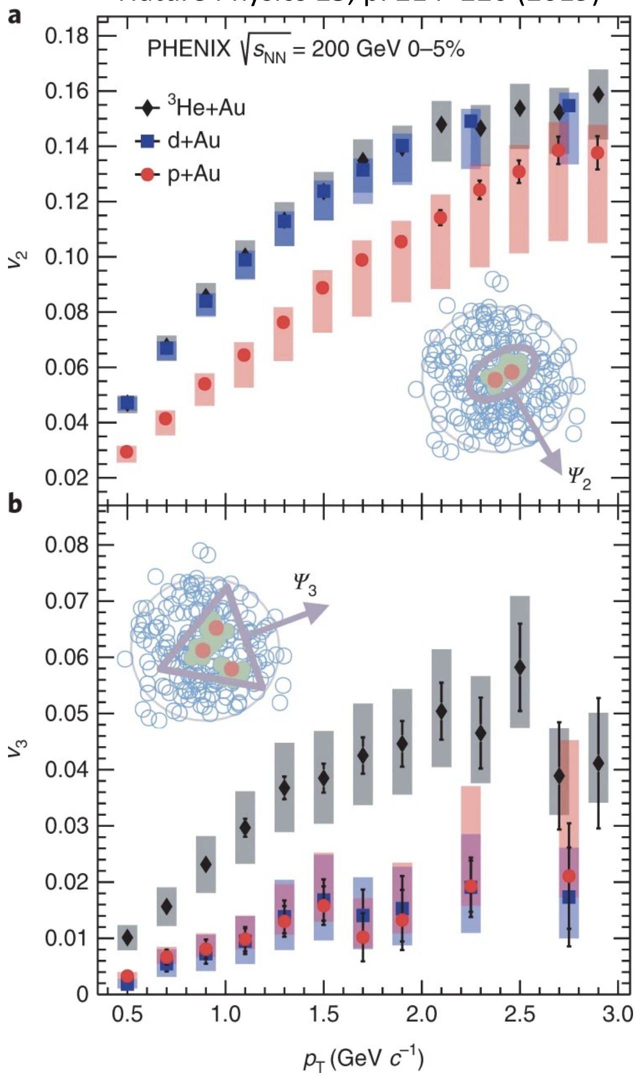
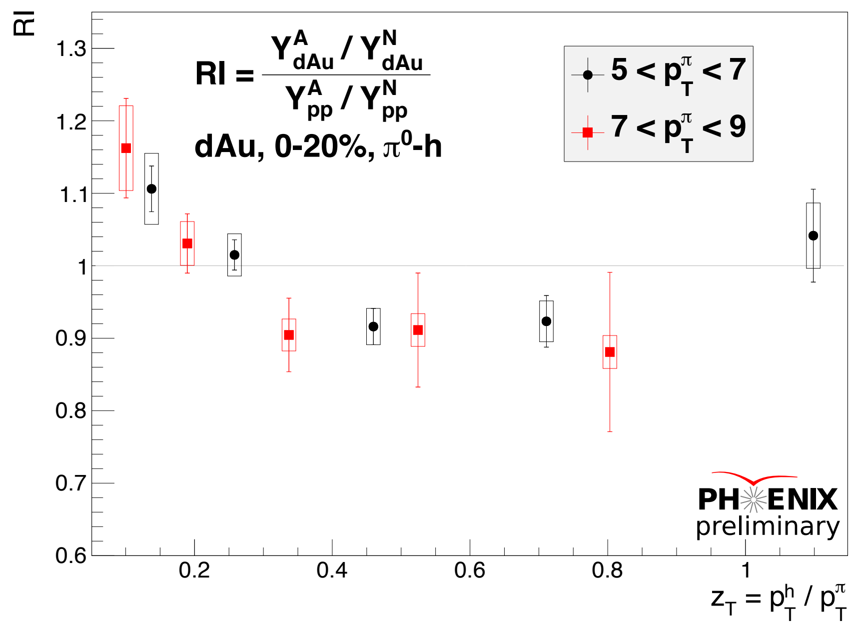
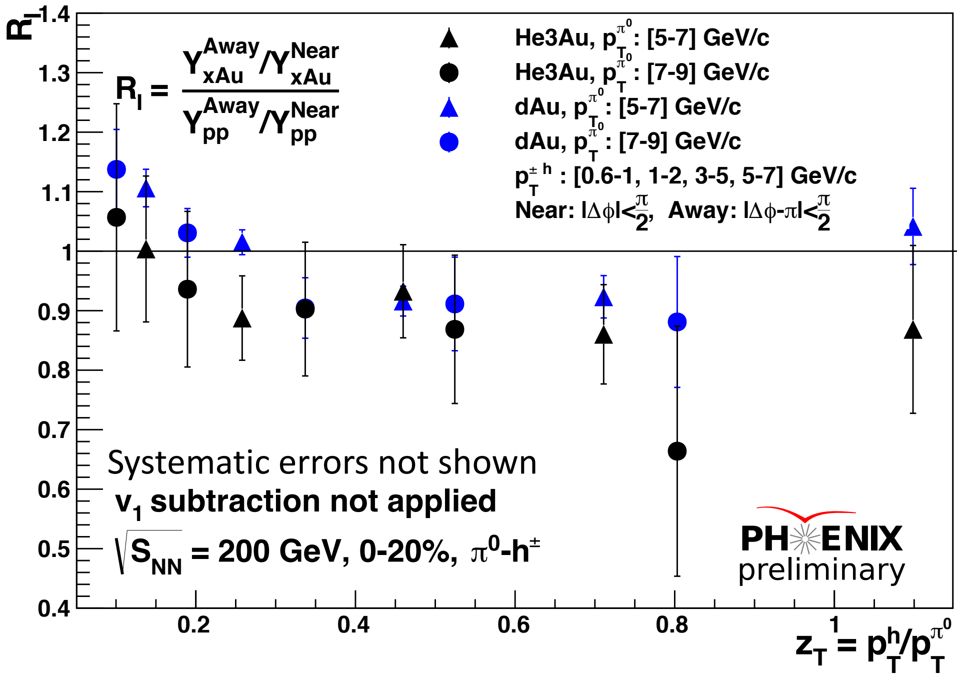


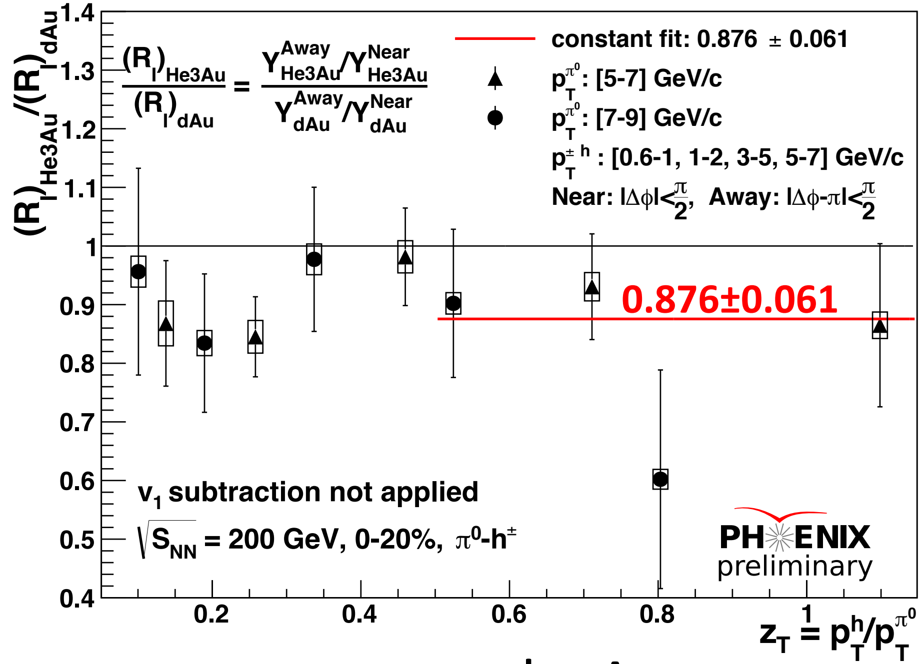


Variety of collision systems:

- Initial geometry dependence study in flow harmonic coefficients
- System size dependence study in Jet modification

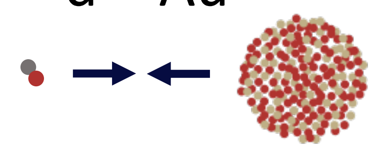
Away-Side Yield Modification in Small Systems



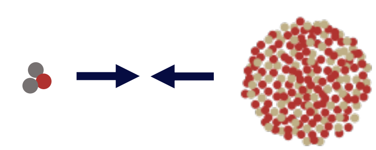


- ^{3}He+Au and d+Au results are within uncertainty
- R_I of He^3+Au results are systematically lower than d+Au
  →more suppressed at high p_T compared to d+Au
  →hints to **system size dependence**

d – Au



^{3}He – Au



- Locate the enhancement and suppression of jet particles inside a jet
- Study yield modification at jet substructure level using a new observable, $\boldsymbol{I_{AA}(\Delta\phi)}$

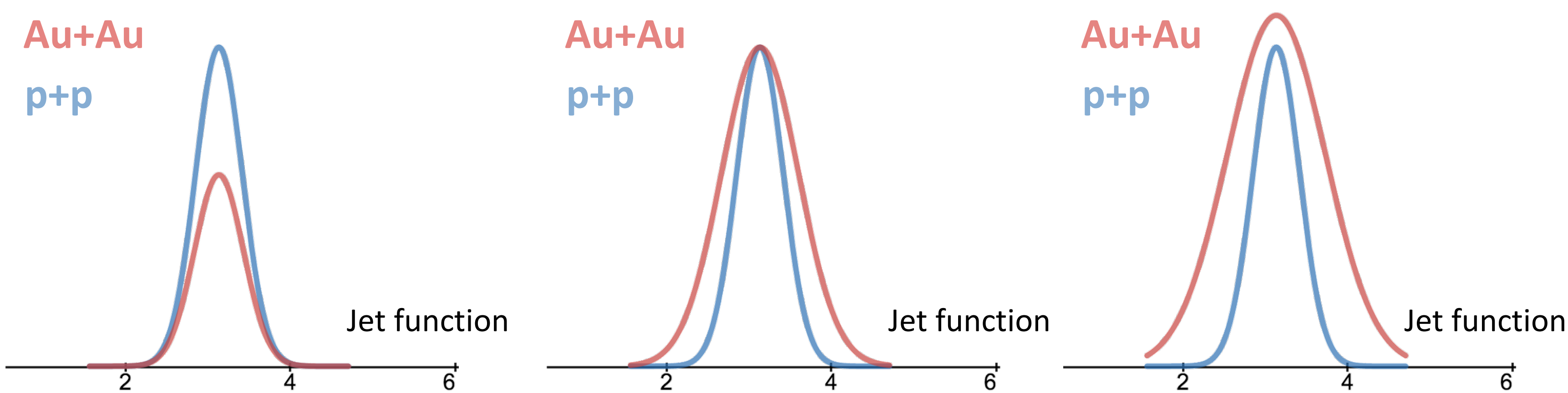
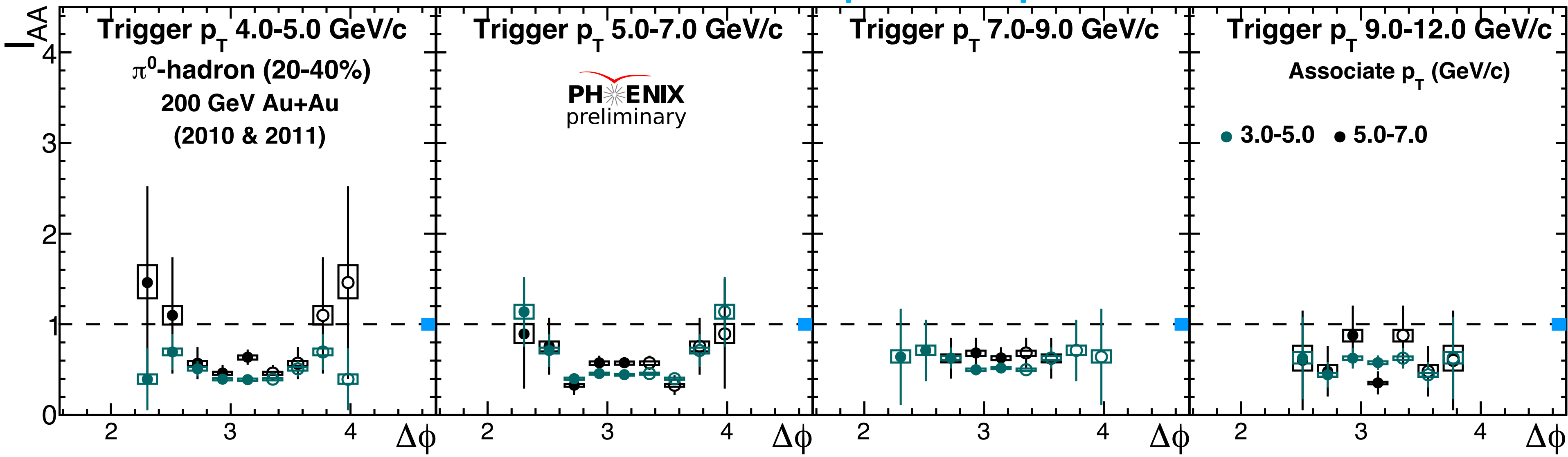


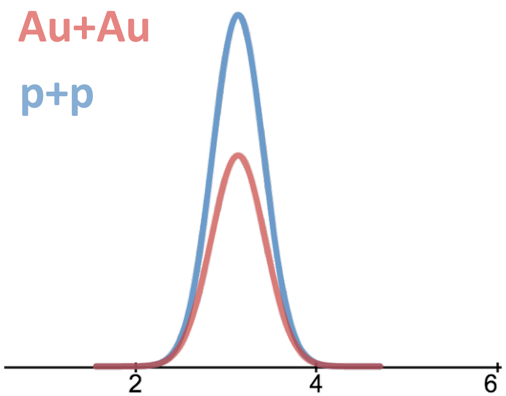
Illustration of jet function at different associate p_T

$I_{AA}(\Delta\phi)$ in Au+Au Collisions

Yield modification in position space

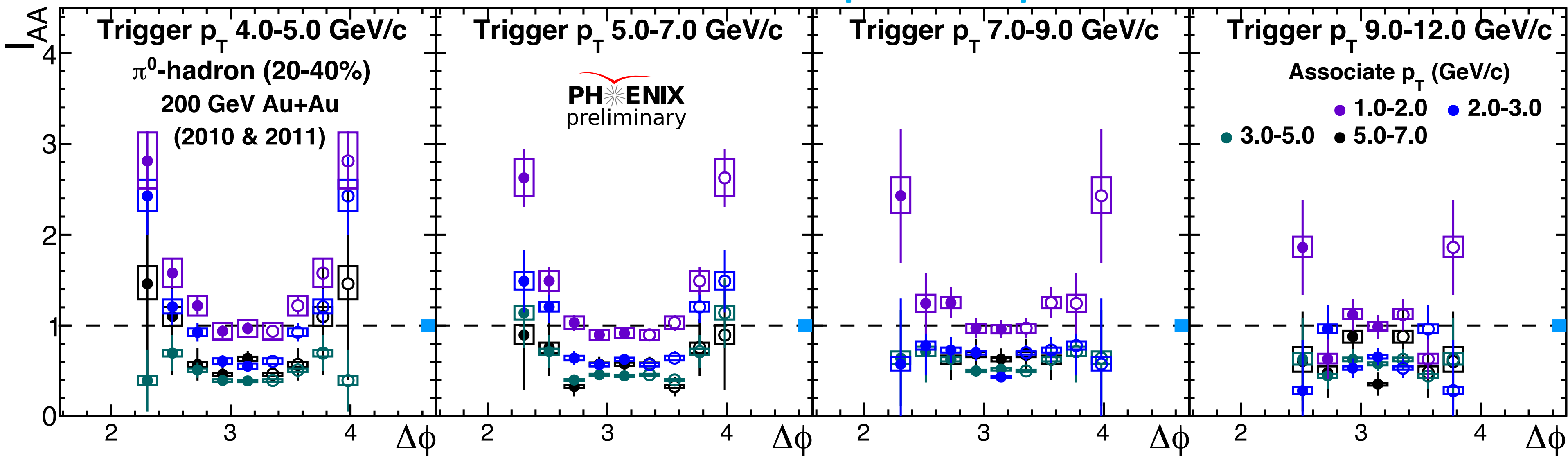


- Show modification of jet substructure level
- High associate p_T: suppressed overall in $\Delta\phi$. The modification is relatively even

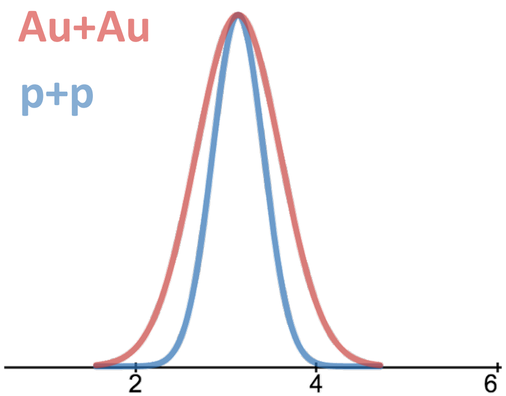


$I_{AA}(\Delta\phi)$ in Au+Au Collisions

Yield modification in position space



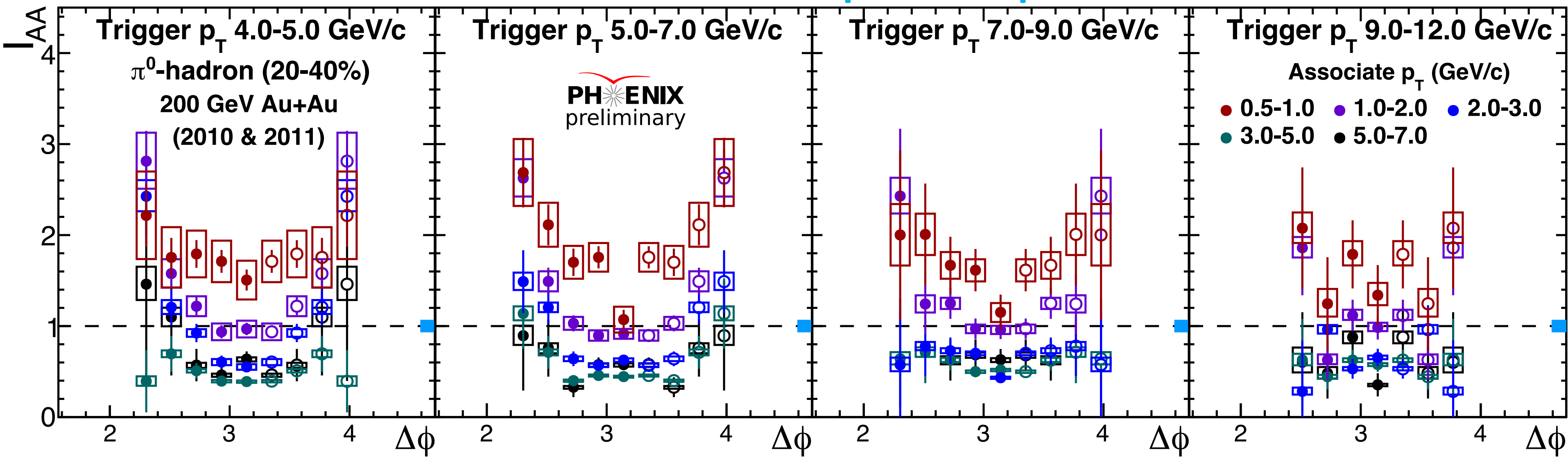
- Show modification of jet substructure level
- High associate p_T: suppressed overall in $\Delta\phi$. The modification is relatively even
- Mid associate p_T : suppression at the core of the jet, but enhancement shows at the skirt of the jet



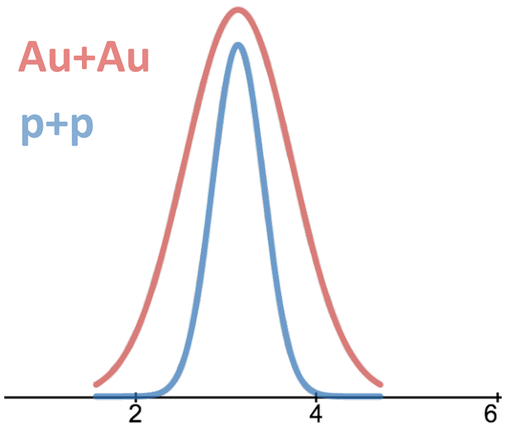
Au+Au

$I_{AA}(\Delta\phi)$ in Au+Au Collisions

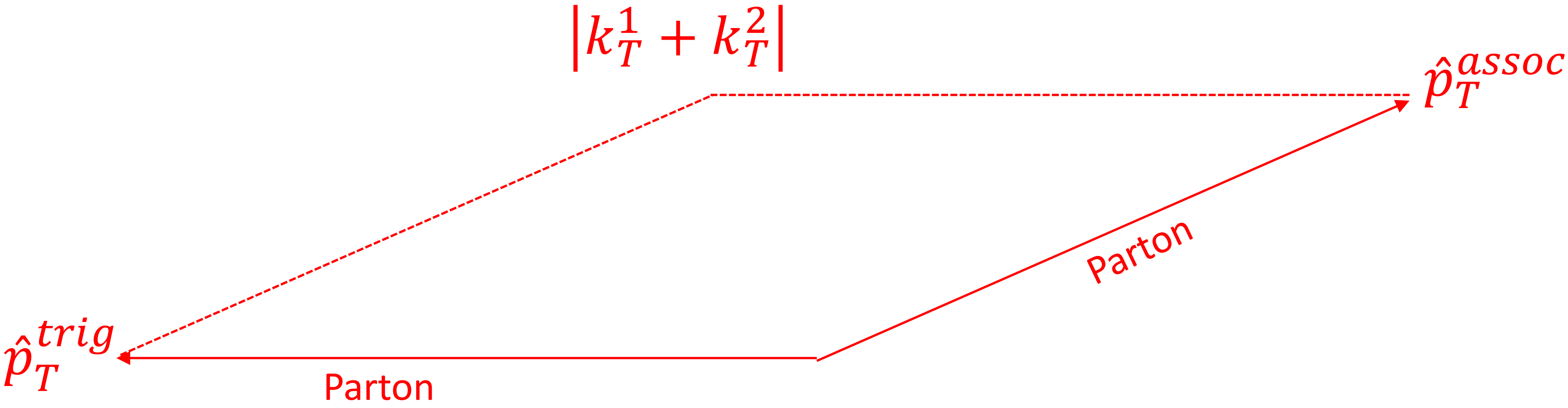
Yield modification in position space



- Show modification of jet substructure level
- High associate p_T: suppressed overall in $\Delta\phi$. The modification is relatively even
- Mid associate p_T : suppression at the core of the jet, but enhancement shows at the skirt of the jet
- Low associate p_T: enhancement within the away-side jet especially at the skirt of the jet

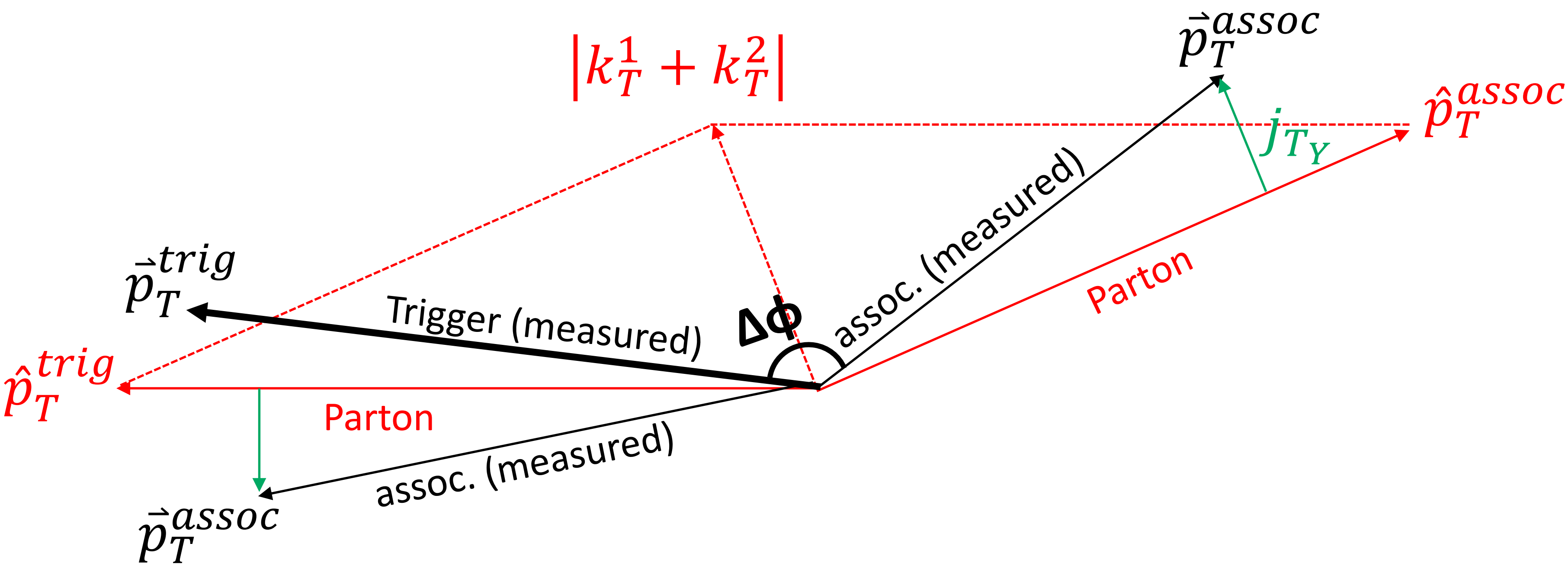


Transverse Momentum $\vec{p}_{out}$



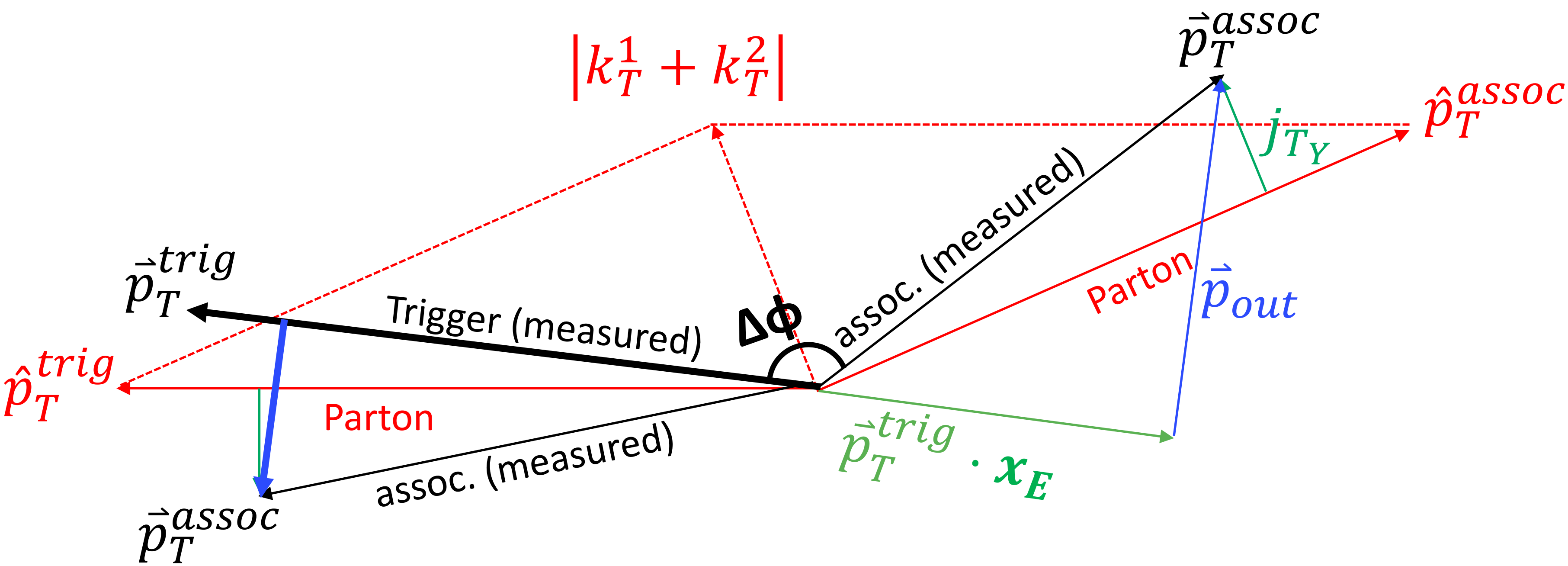
Hard scattering

Transverse Momentum $\vec{p}_{out}$



Hard scattering → fragmentation

Transverse Momentum $\vec{p}_{out}$



Study the associate particle transverse momentum ($\vec{p}_{out}$) w.r.t. the trigger particle:

longitudinal — transverse

$$\vec{p}_T^{assoc} = \vec{p}_T^{trig} \cdot x_E + \vec{p}_{out}$$

Longitudinal fraction w.r.t. the trigger particle

$$x_E = -\frac{|\vec{p}_T^{assoc}|}{|\vec{p}_T^{trig}|} \cdot \cos(\Delta\phi)$$

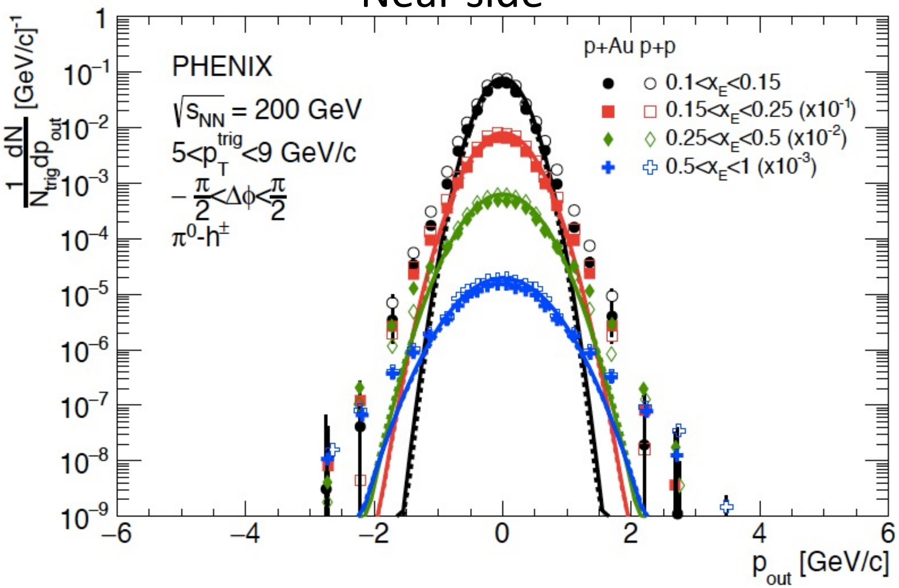
Associate particle transverse momentum w.r.t. the trigger particle

$$\vec{p}_{out} = \vec{p}_T^{assoc} \cdot \sin(\Delta\phi)$$

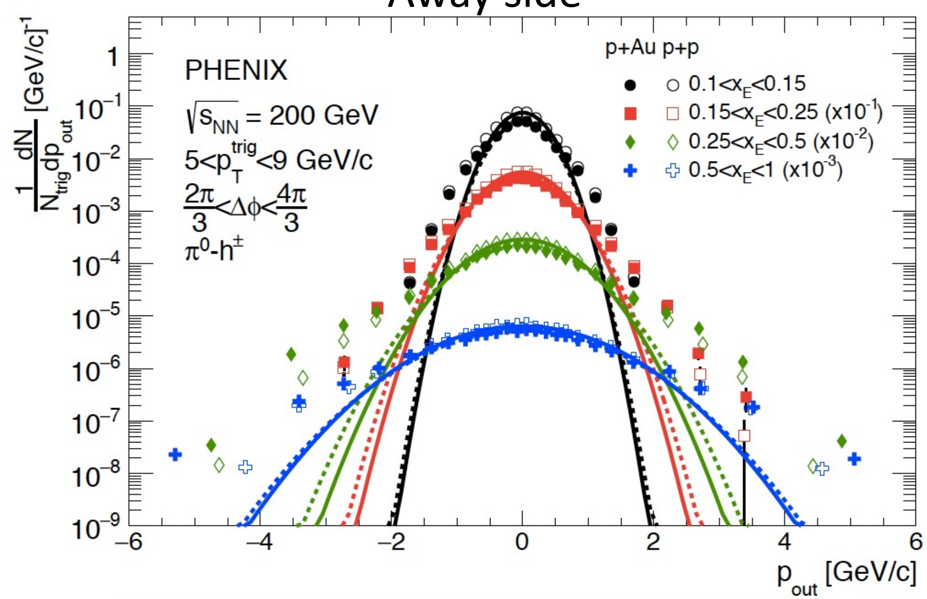
$\vec{p}_{out}$ Distribution in p+A

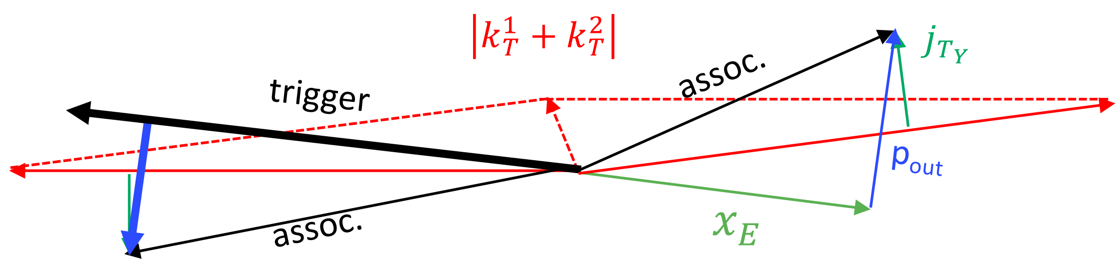
Phys. Rev. C **99**, 044912

Near side



Away side



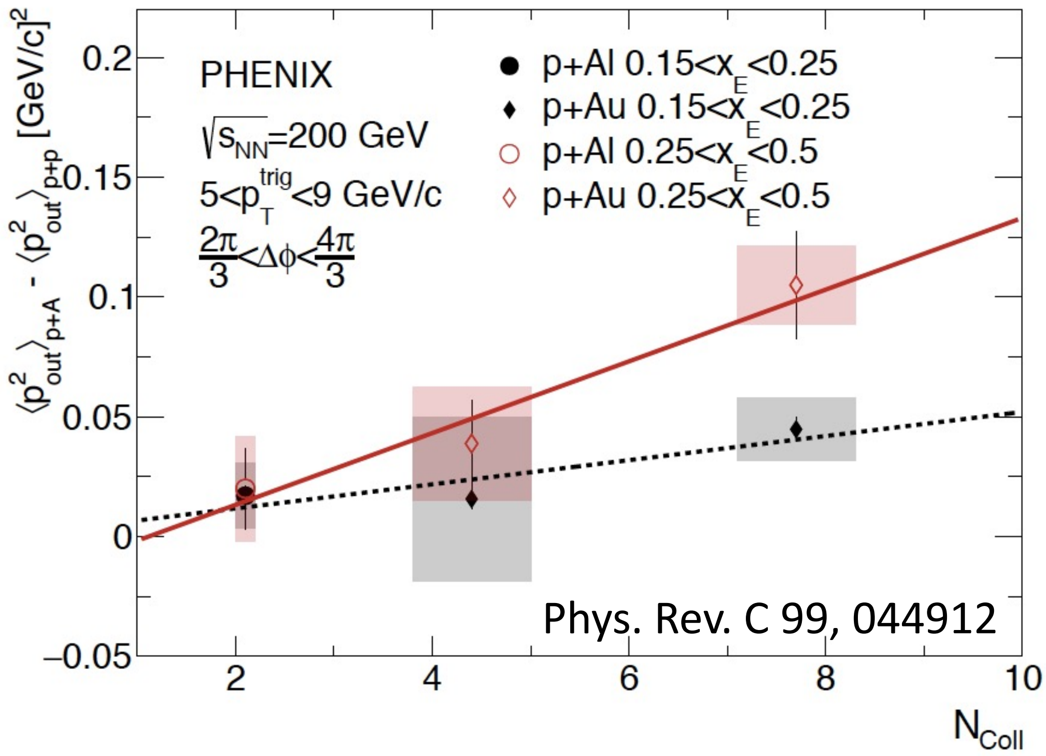


$$x_E = -\frac{|\vec{p}_T^{\,assoc}|}{|\vec{p}_T^{\,trig}|}\cdot\cos(\Delta\phi)$$

$$\vec{p}_{out} = \vec{p}_T^{\,assoc}\cdot\sin(\Delta\phi)$$

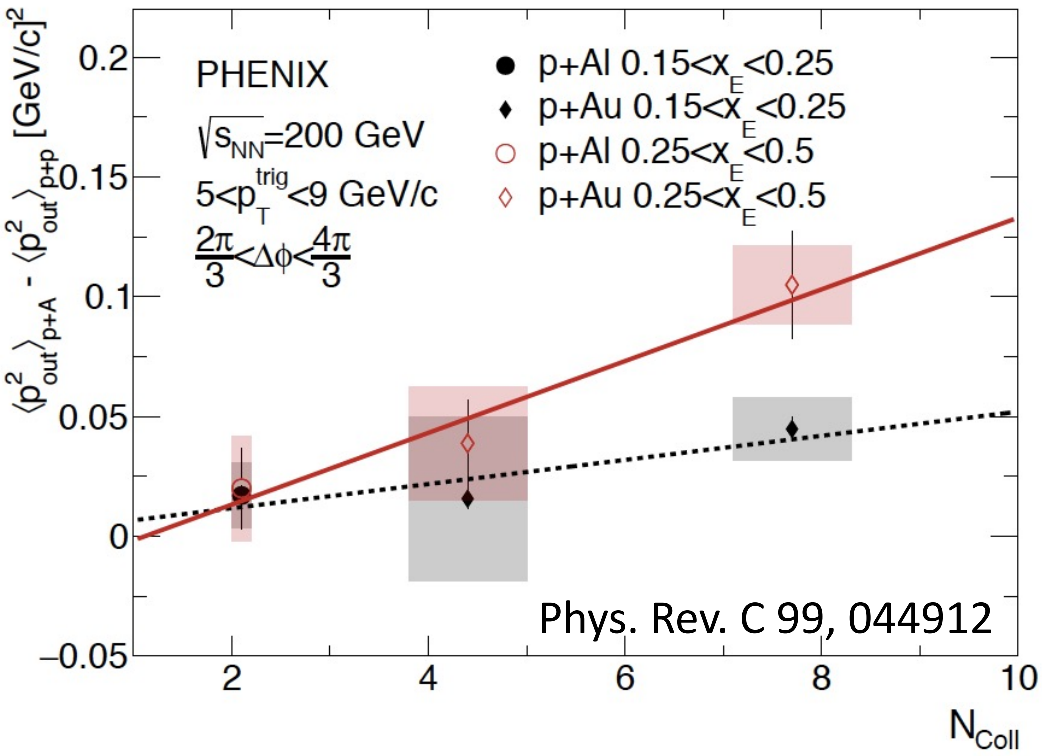
$p + Al\,, p + Au$

$\vec{p}_{out}$ Broadening in p+A



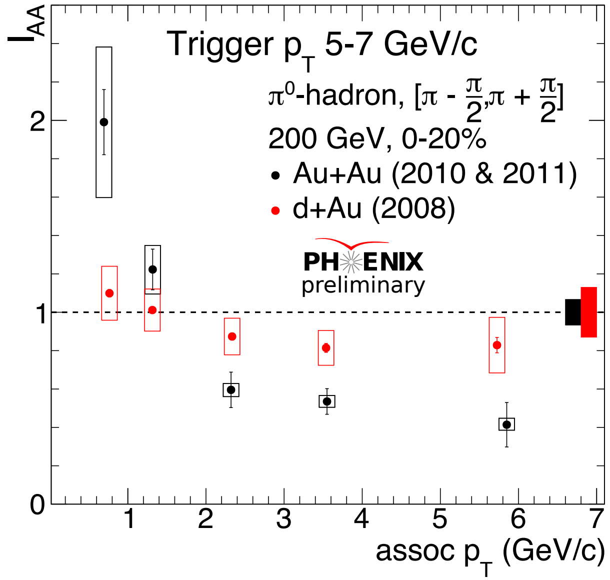
$p + Al\,, p + Au$

$\vec{p}_{out}$ Broadening in p+A

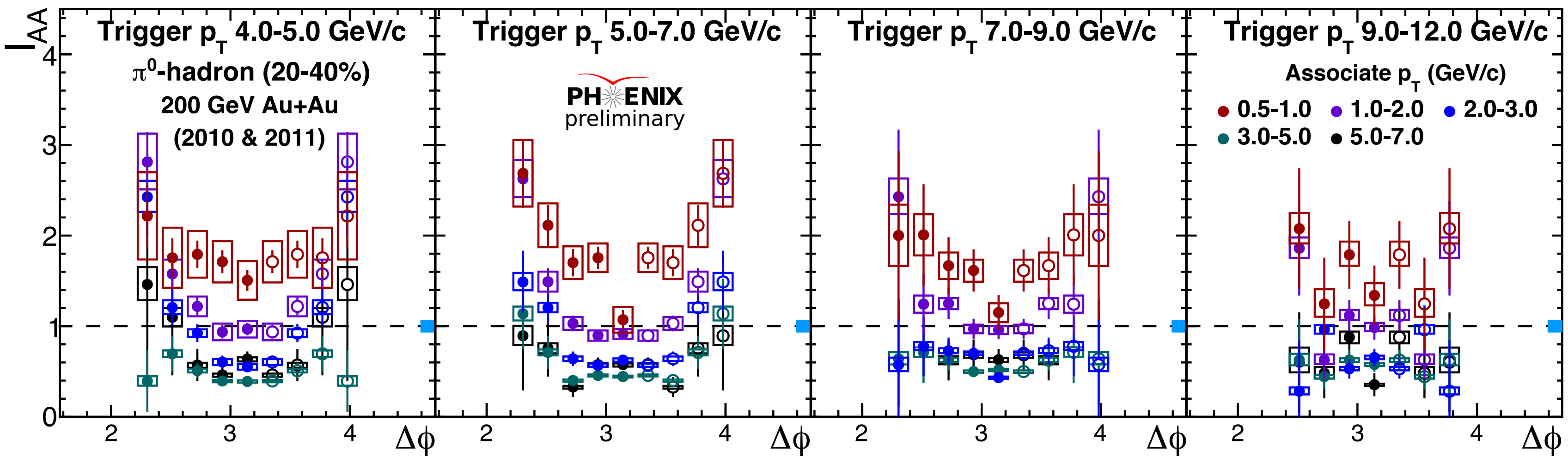


- Underlying flow? v_2 and v_3 are ruled out
- Higher k_T for parton in nucleus?
- Energy loss?

Summary from Au+Au Collisions



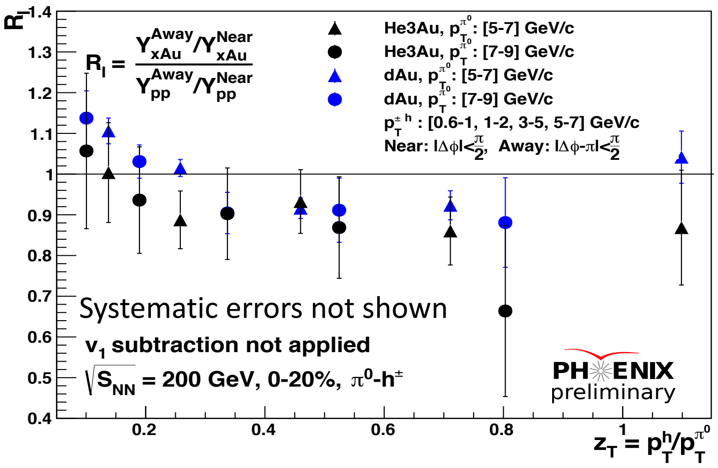
- Thorough study of yield modification in Au+Au collisions: momentum dependence and angular dependence
- Clear modification is shown in Au+Au than in d+Au collisions
- The new observable, $I_{AA}(\Delta\phi)$, shows yield modification at jet substructure level



Summary from Small Collision Systems

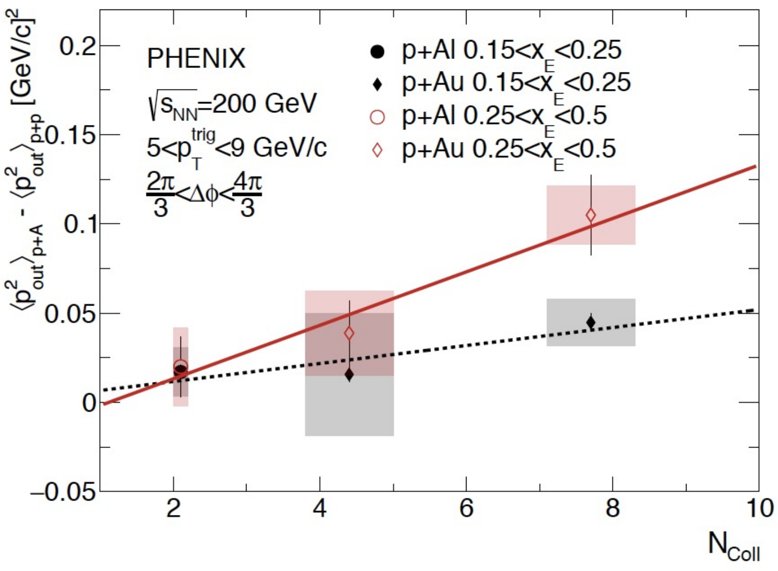
<u>$d/^3He+Au$ collisions:</u>
<u>yield modification</u>

- Away-side I_{dA} shows **suppression of hard jet particles**. However, the yield suppression is **smaller than in Au+Au results**
- R_I measurements
  - Reduction of systematic uncertainty
  - Show **enhancement of soft jet particles** in the away-side, but suppression of hard jet particles

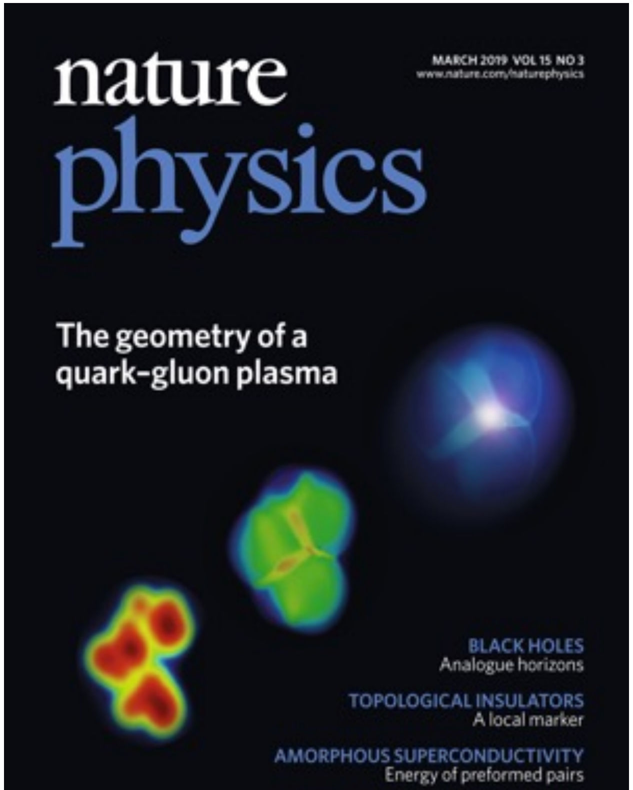


<u>p+A collisions:</u>
<u>momentum modification</u>

- Away side **broadening in p_{out}** measurement
- Away side p_{out} broadening shows N_{Coll} dependence



Summary from Small Collision Systems



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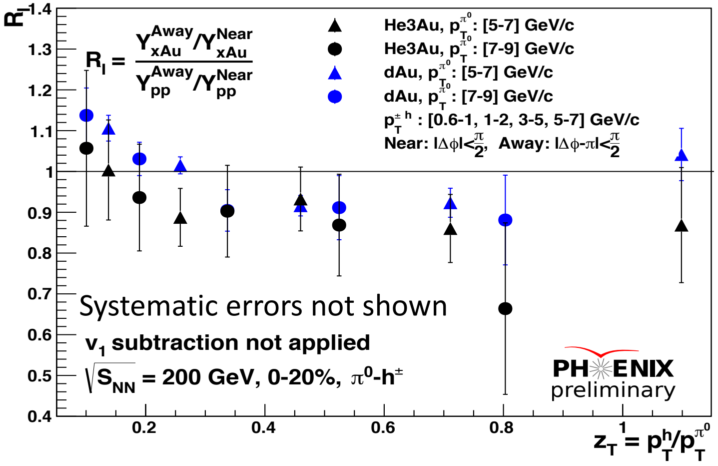
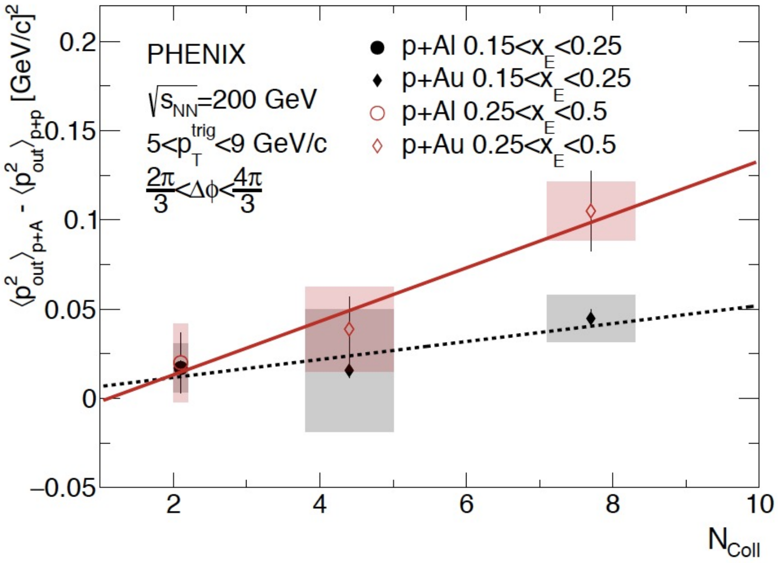
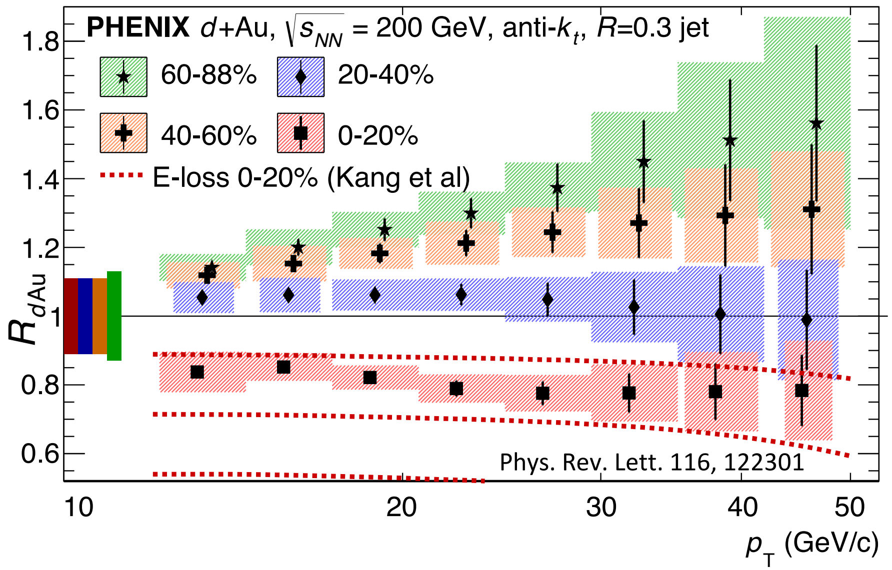
Both two-particle correlations results show system size dependence

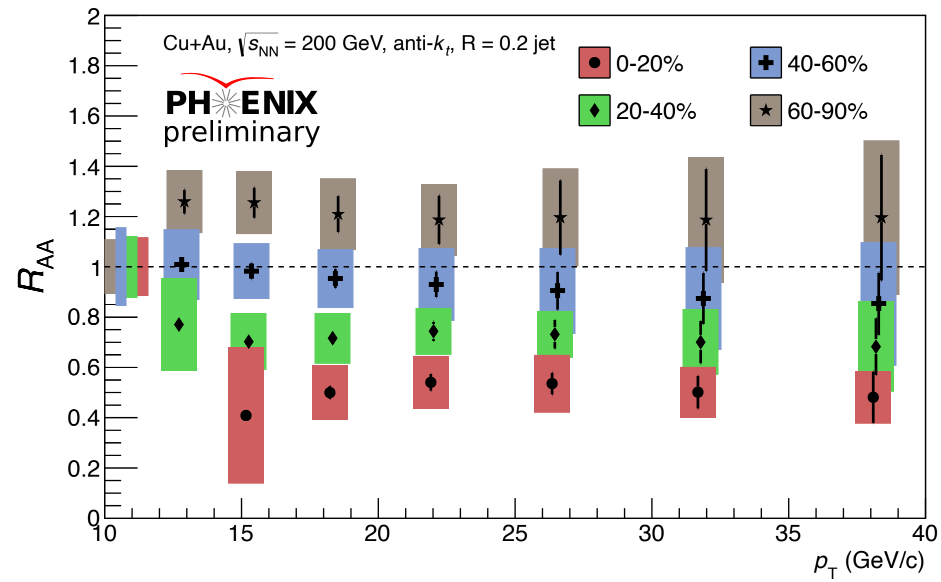




Back Up

Jet Measurements in d+Au Collisions

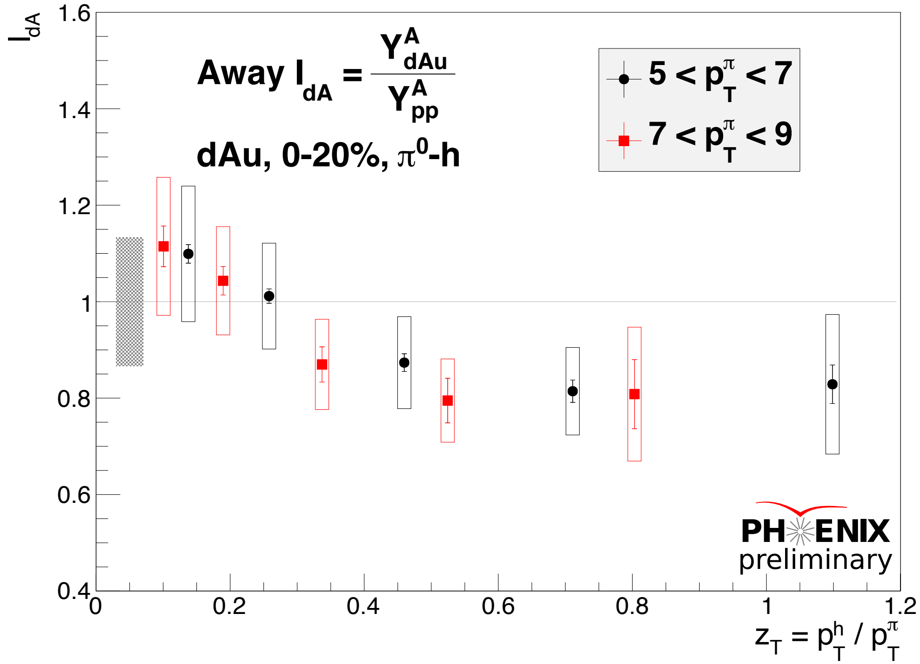


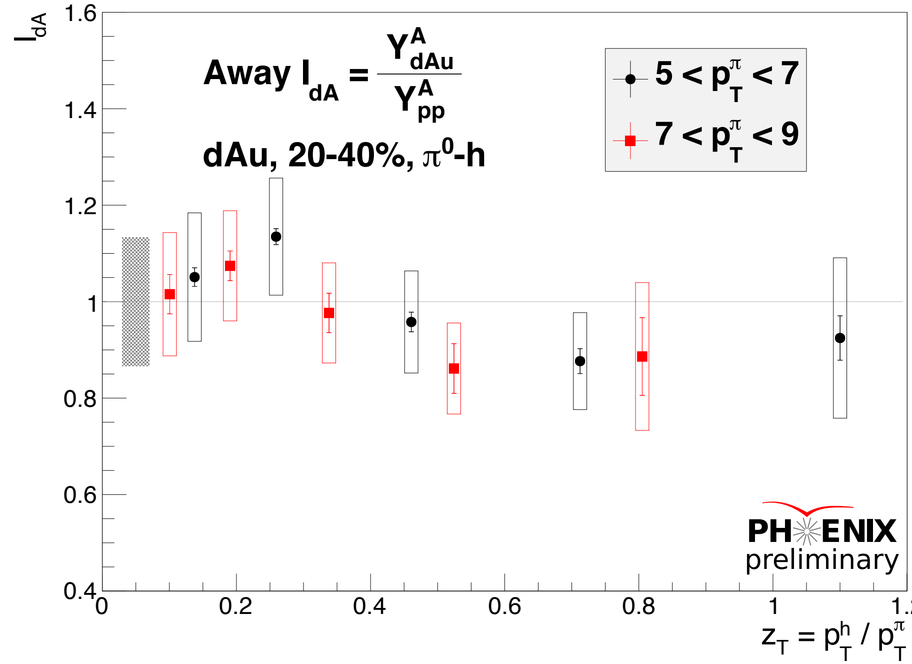


- R_{dA} shows centrality dependence
  - R_{dA} < 1 in the most central events indicating suppression of jets
  - R_{dA} > 1 in the less central events indicating enhancement of jets
- R_{dA}<R_{AA} indicating larger suppression of jets in Cu+Au collisions

d+Au

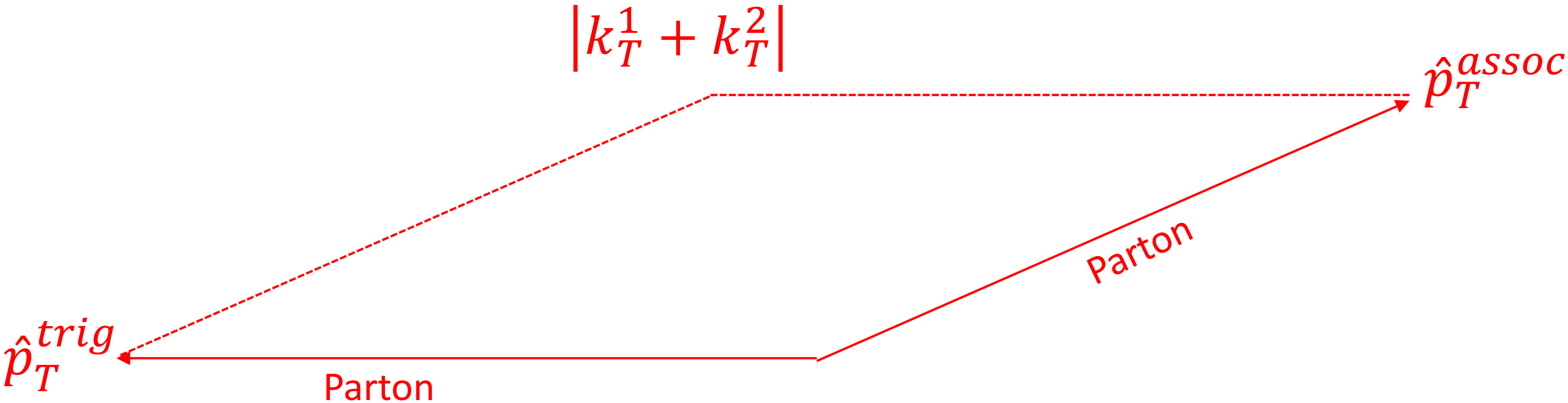
Away-side Yield Modifications in d+Au Collisions





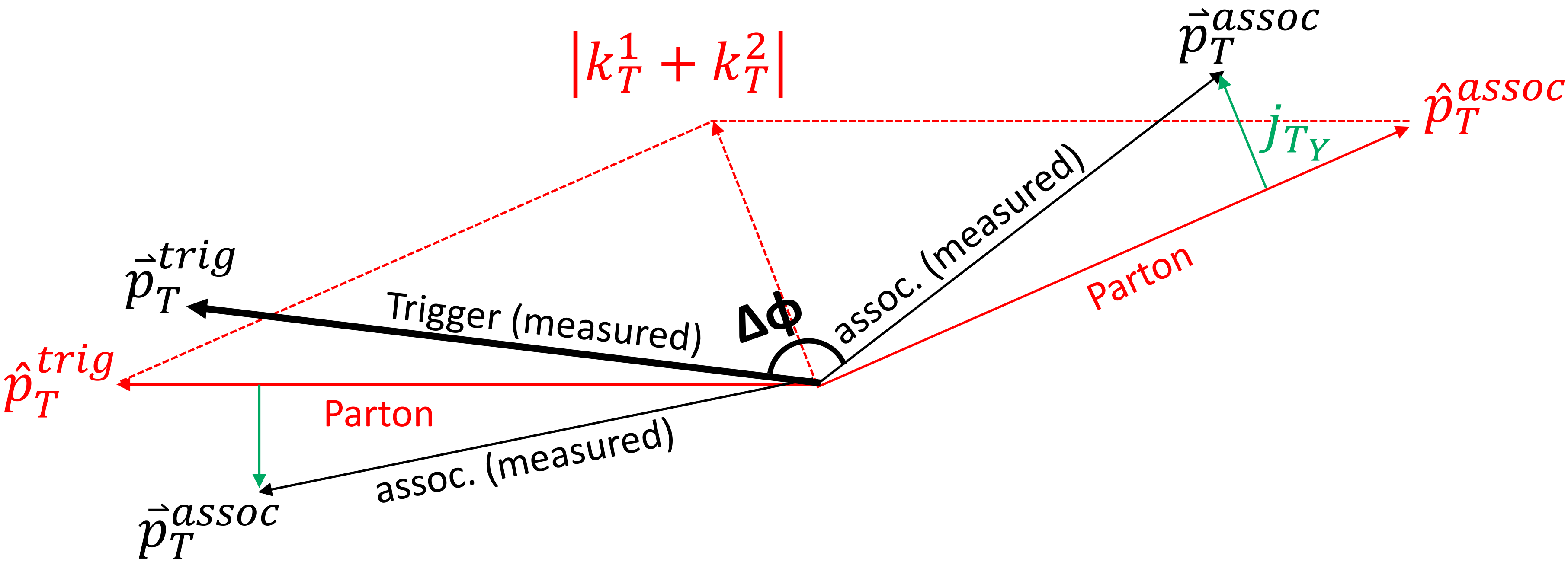
- $I_{dA}<1$ at high z_T and $I_{dA}>1$ at low z_T

Transverse Momentum $\vec{p}_{out}$



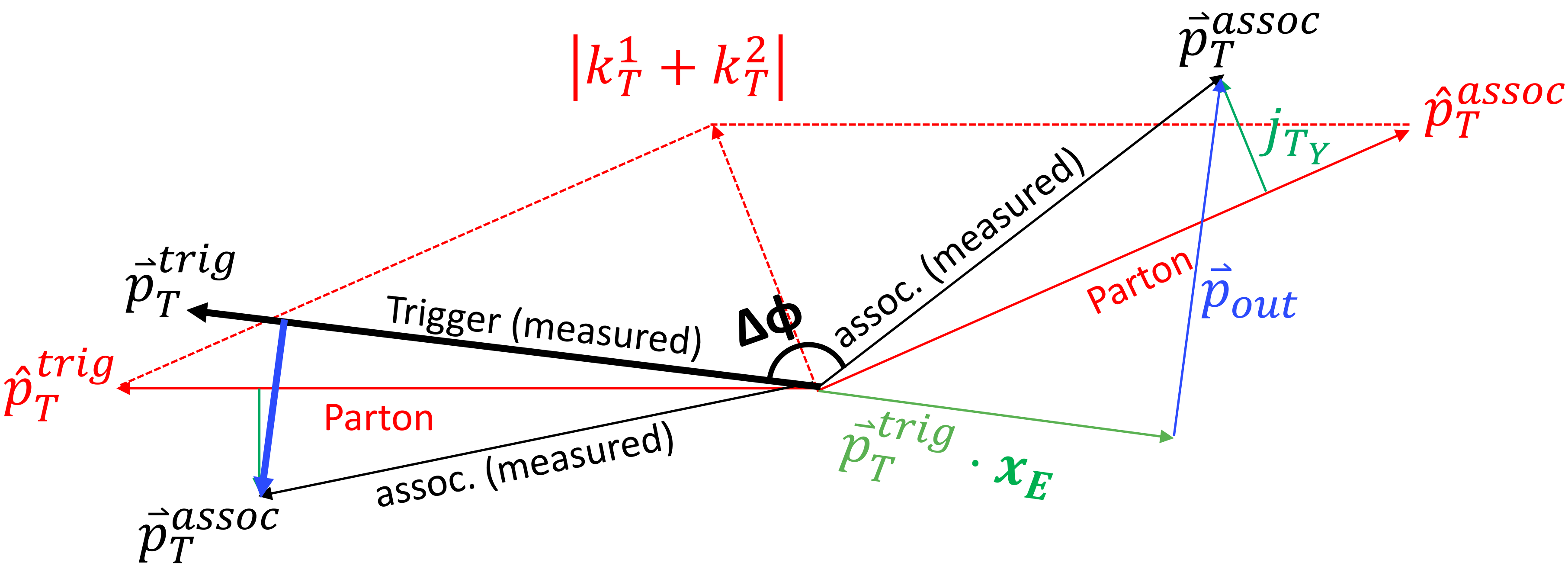
Hard scattering

Transverse Momentum $\vec{p}_{out}$



Hard scattering → fragmentation

Transverse Momentum $\vec{p}_{out}$



Study the associate particle transverse momentum ($\vec{p}_{out}$) w.r.t. the trigger particle:

longitudinal transverse

$$\vec{p}_T^{assoc} = \vec{p}_T^{trig} \cdot x_E + \vec{p}_{out}$$

Longitudinal fraction
w.r.t. the trigger particle

$$x_E = -\frac{|\vec{p}_T^{assoc}|}{|\vec{p}_T^{trig}|} \cdot \cos(\Delta\phi)$$

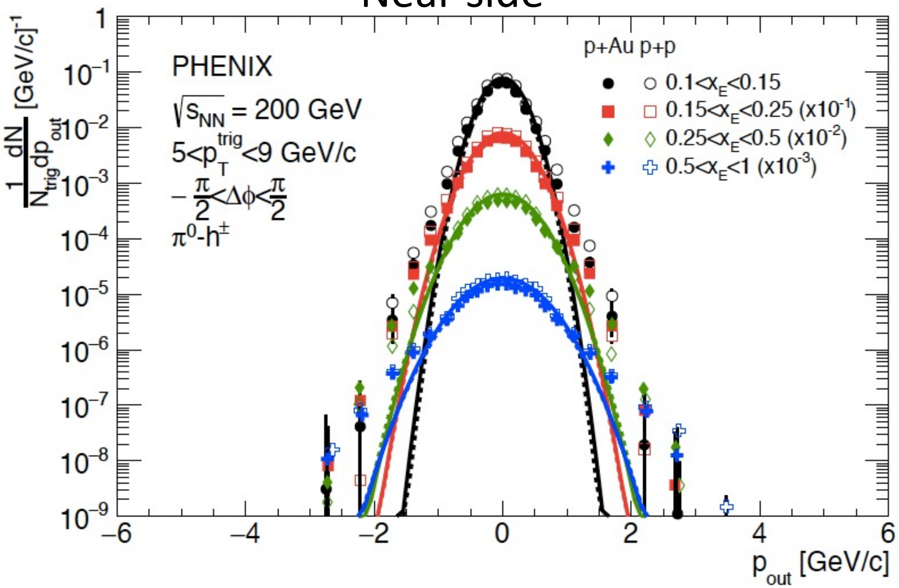
Associate particle
transverse momentum
w.r.t. the trigger particle

$$\vec{p}_{out} = \vec{p}_T^{assoc} \cdot \sin(\Delta\phi)$$

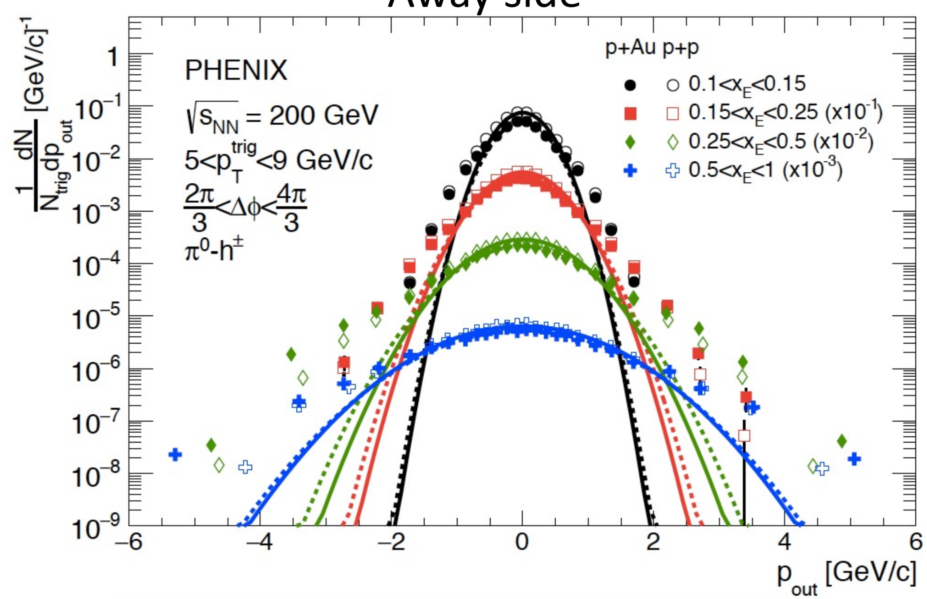
$\vec{p}_{out}$ Distribution in p+A

arXiv:1809.09045v1

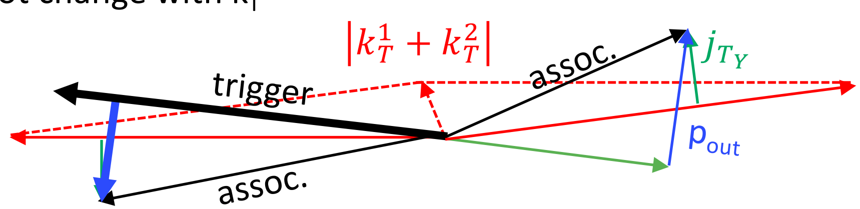
Near side



Away side



Near side p_{out} does not change with k_T



- Narrower near side p_{out} distribution than the away side as p_{out}^{near} depends on j_T only
- p_{out}^{away} depends on both k_T and j_T

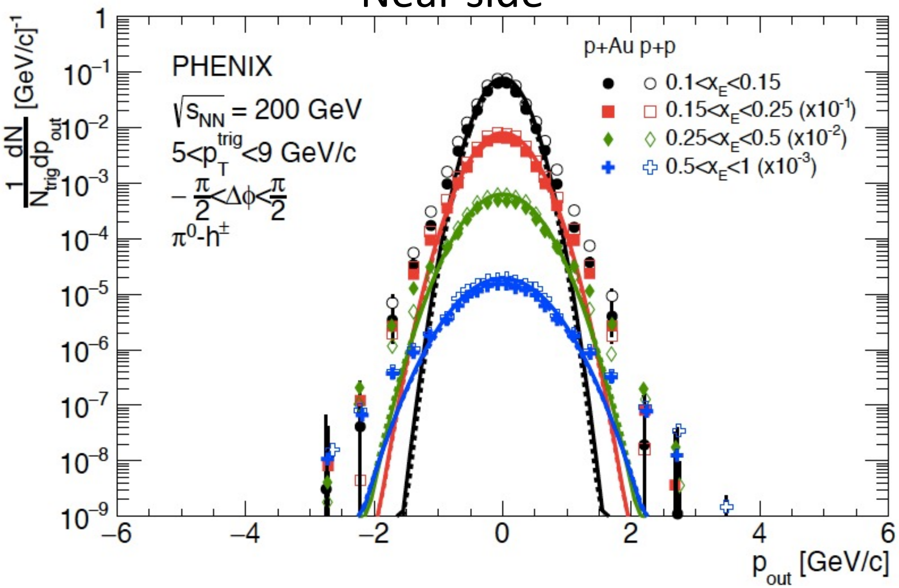
$$x_E = -\frac{|\vec{p}_T^{\,assoc}|}{|\vec{p}_T^{\,trig}|}\cdot\cos(\Delta\phi) \qquad \vec{p}_{out} = \vec{p}_T^{\,assoc}\cdot\sin(\Delta\phi)$$

$p + p$, $p + Au$

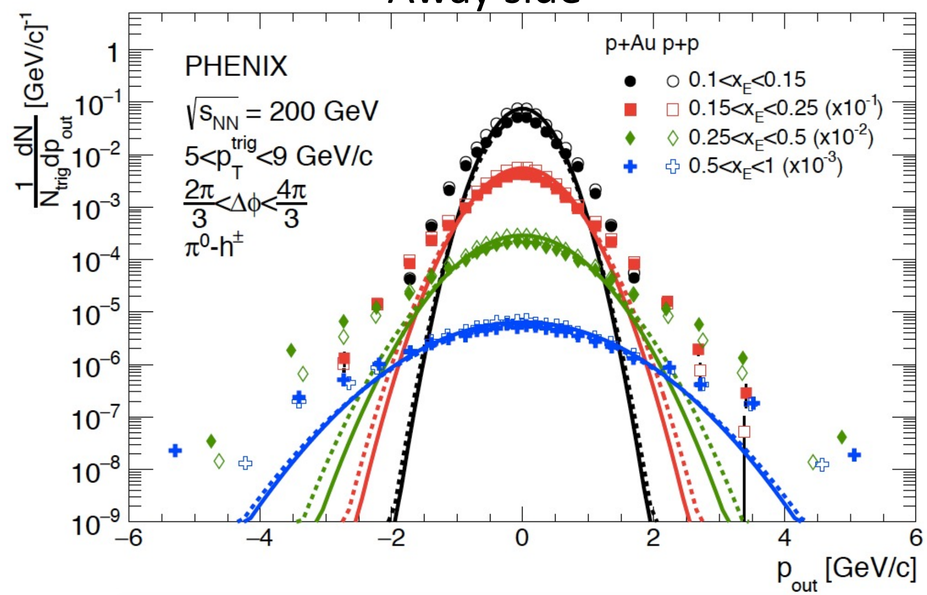
$\vec{p}_{out}$ Distribution in p+A

arXiv:1809.09045v1

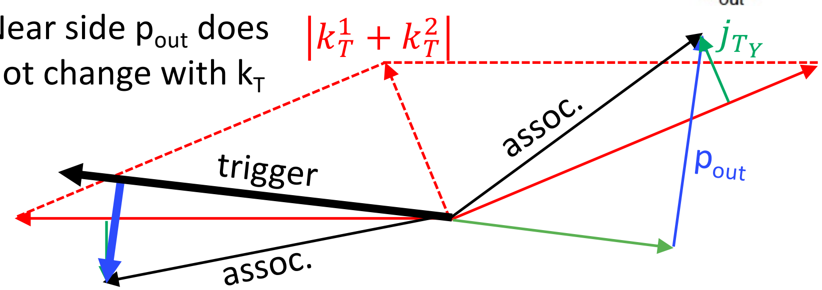
Near side



Away side



Near side p_{out} does not change with k_T



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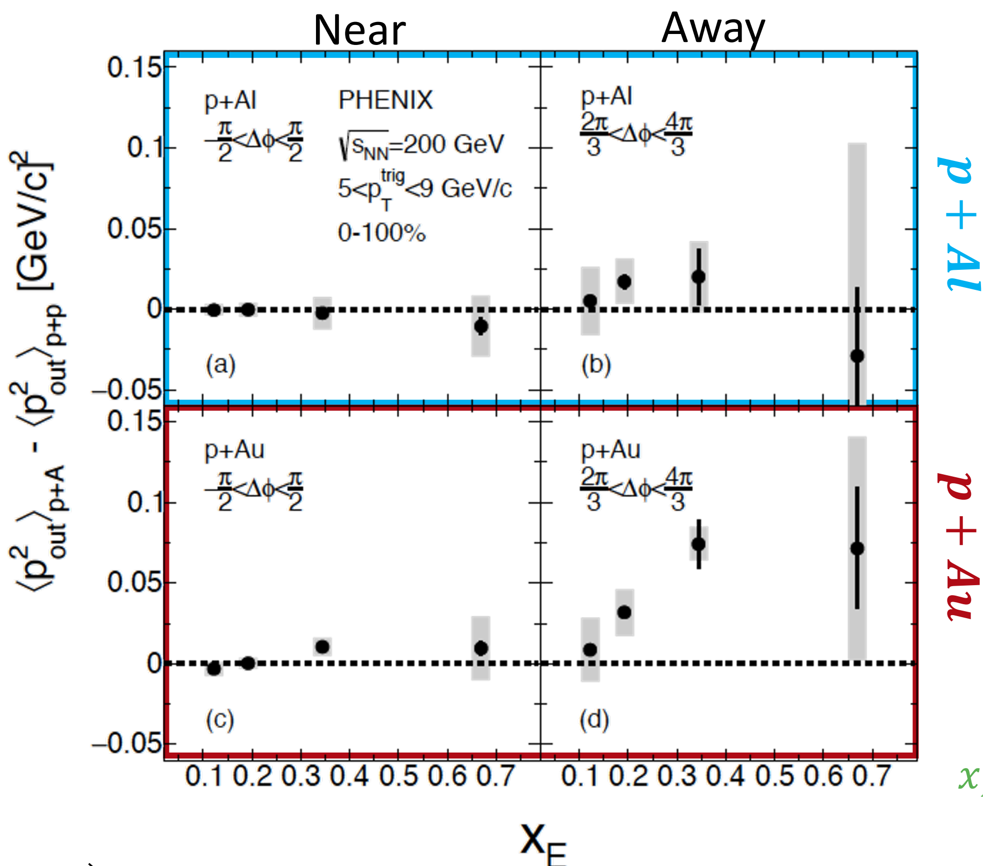
$\vec{p}_{out}$ Broadening in p+A

arXiv:1809.09045v1



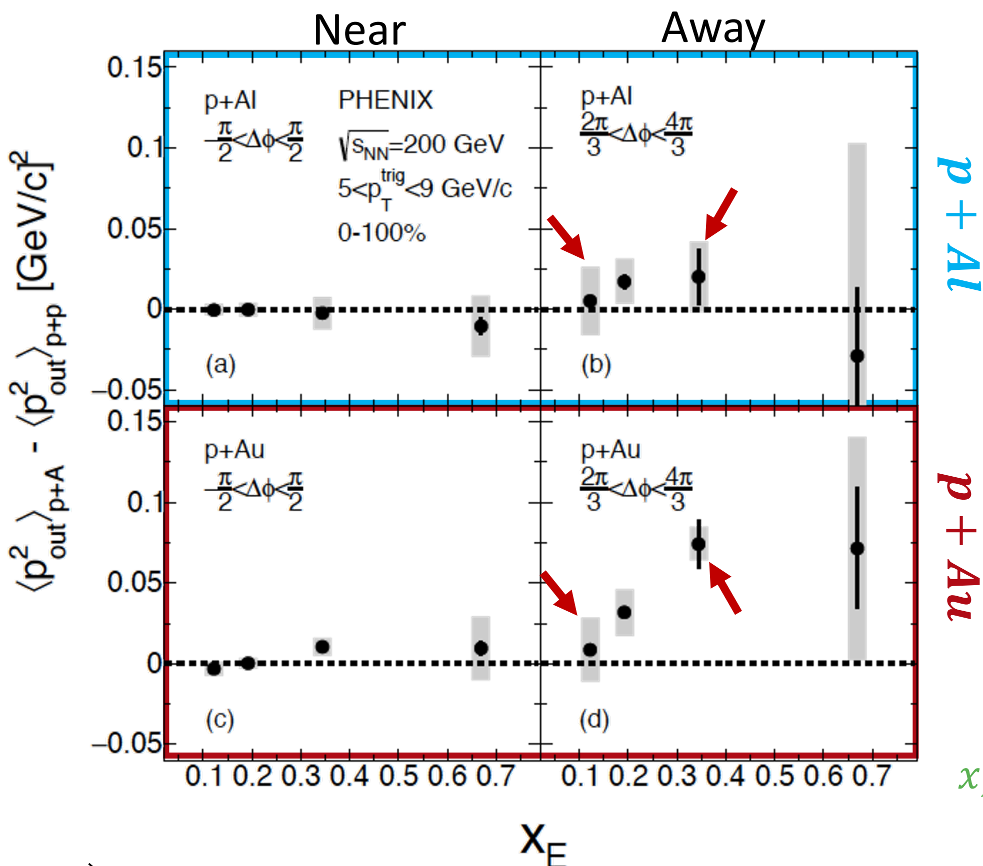
$$x_E = -\frac{|\vec{p}_T^{\,assoc}|}{|\vec{p}_T^{\,trig}|} \cdot \cos(\Delta\phi)$$

$$\vec{p}_{out} = \vec{p}_T^{\,assoc} \cdot \sin(\Delta\phi)$$

- No near side $\overrightarrow{p_{out}}$ broadening
- No significant away side broadening in $p + Al$ data
- Away side $\overrightarrow{p_{out}}$ broadening in the $p + Au$ data ← k_T effect?

$\vec{p}_{out}$ Broadening in p+A

arXiv:1809.09045v1



$$x_E = -\frac{|\vec{p}_T^{\,assoc}|}{|\vec{p}_T^{\,trig}|} \cdot \cos(\Delta\phi)$$

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- No near side $\overrightarrow{p_{out}}$ broadening
- No significant away side broadening in $p + Al$ data
- Away side $\overrightarrow{p_{out}}$ broadening in the $p + Au$ data ← k_T effect?

Au+Au

$I_{AA}(\Delta\phi)$ in Au+Au Collisions

Yield modification in position space