Highlights from PHENIX

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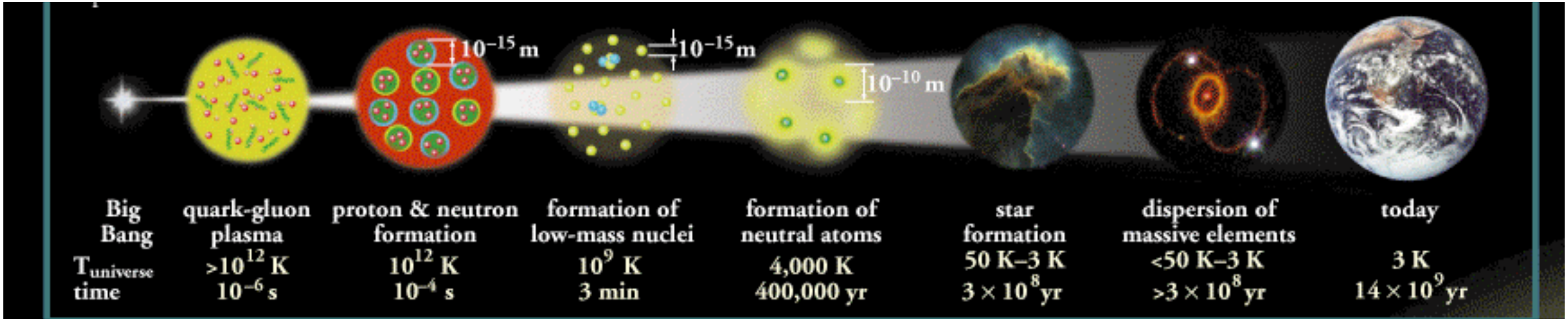
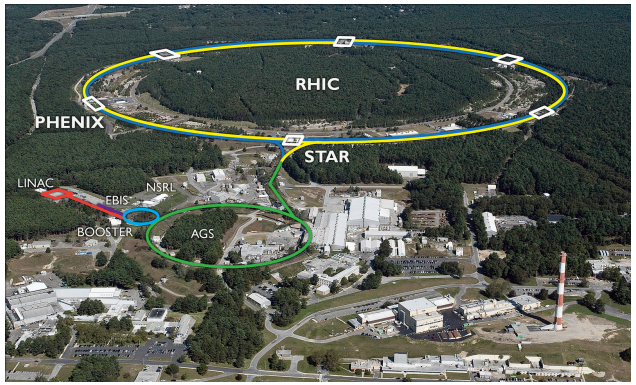
Georgia State University
for the PHENIX Collaboration

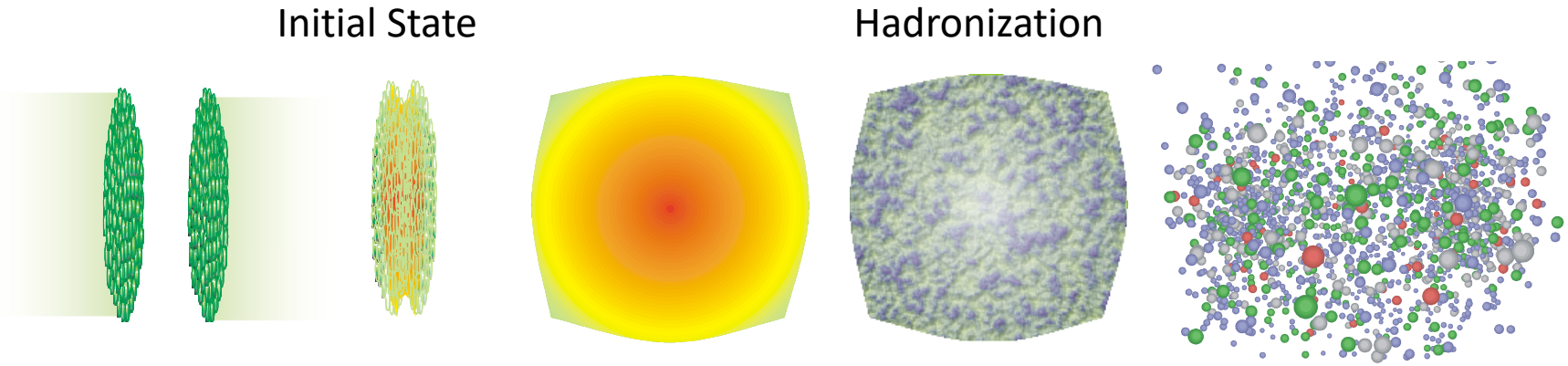
QNP2022 - The 9th International Conference on Quarks and Nuclear Physics

Online
September 2022

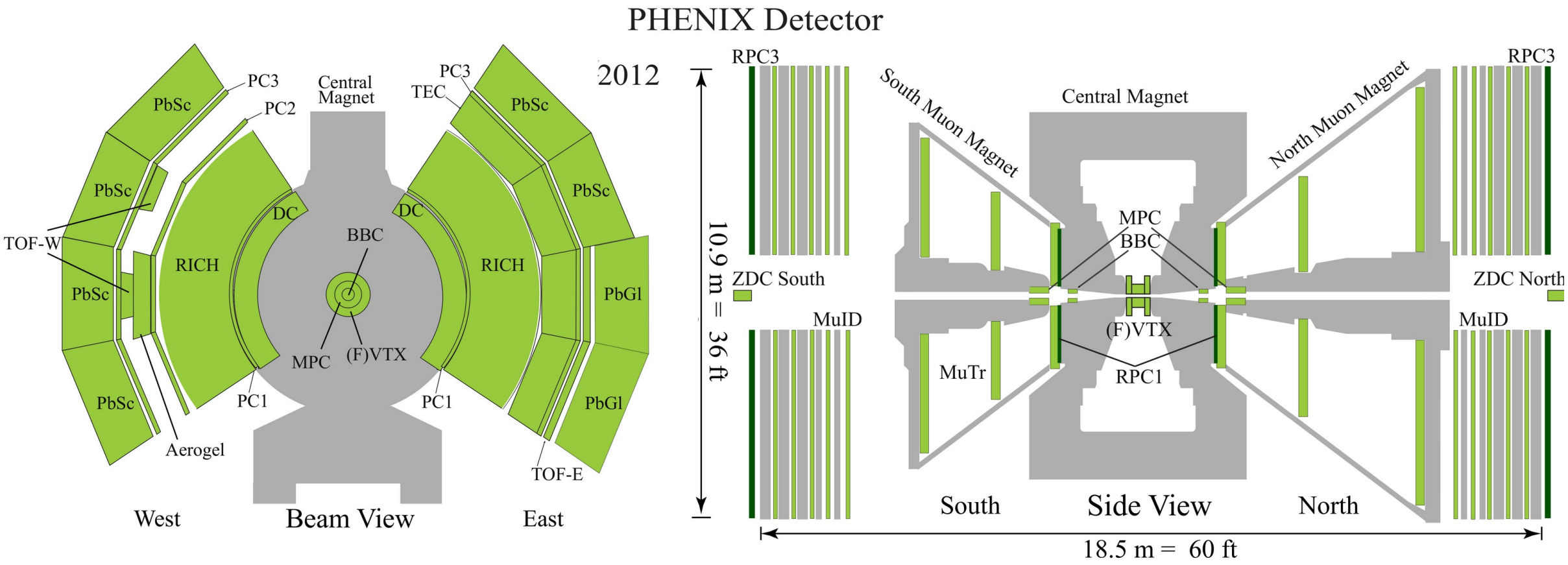
Creating Quark Gluon Plasma







PHENIX Detector



Central detectors |η|<0.35

Forward/backward detectors

Muon Arms

PHENIX Highlights

√s [GeV]	p+p	p+Al	p+Au	d+Au	^{3}He+Au	Cu+Cu	Cu+Au	Au+Au	U+U
510	✓								
200	✓	✓	✓	✓	✓	✓	✓	✓	✓
130								✓	
62.4	✓			✓		✓		✓	
39				✓				✓	
27								✓	
20				✓		✓		✓	
14.5								✓	
7.7								✓	

- Hard Probes
  - Jets
  - Jet like correlations
  - Heavy Flavor
  - High p_T hadrons
- Bulk Measurements
  - Flow
  - Thermal photons

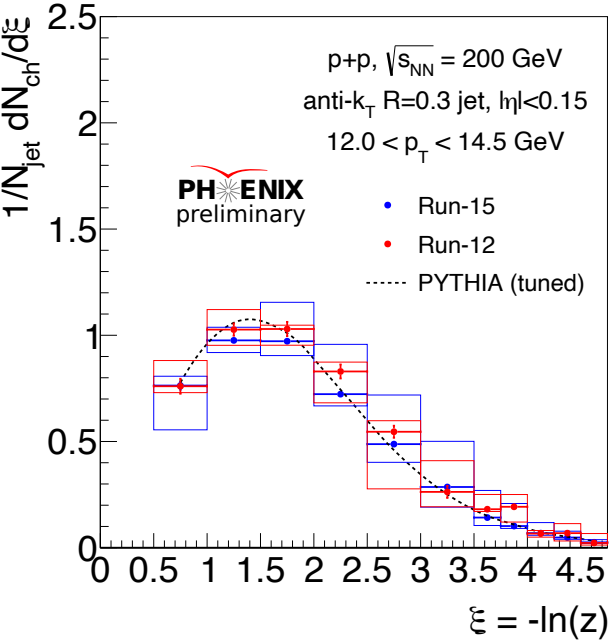
Anthony Frawley
Heavy Flavor & Quarkonia
Sept 9, 8:25 am

Recent Papers:

arXiv:2207.10745 ϕ meson production in Cu+Au and U+U collisions
arXiv:2203.17058 Charm and bottom quark production in 200 GeV Au+Au collisions
arXiv:2203.17187 Non-prompt direct photon production in Au+Au collisions
arXiv:2203.12354 Low-p_T direct-photon production in Au+Au collisions at 39 and 62.4 GeV
arXiv:2203.09894 Second-harmonic Fourier coefficients from azimuthal anisotropies in p+p, p+Au, d+Au, & ^{3}He+Au collisions
arXiv:2203.06087 Study of ϕ meson production in p+Al, p+Au, d+Au, and ^{3}He+Au collisions
arXiv:2202.03863 ψ(2S) nuclear modification at backward and forward rapidity in p+p, p+Al, and p+Au collisions at 200 GeV

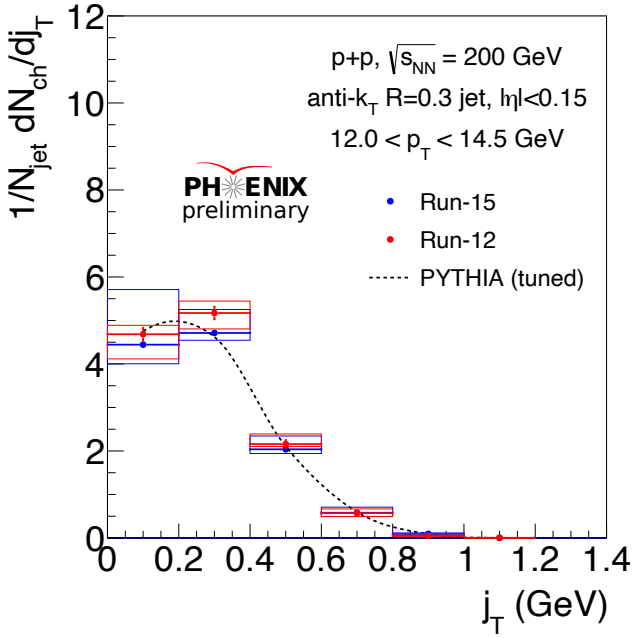
Jets in p+p

Fragmentation Function



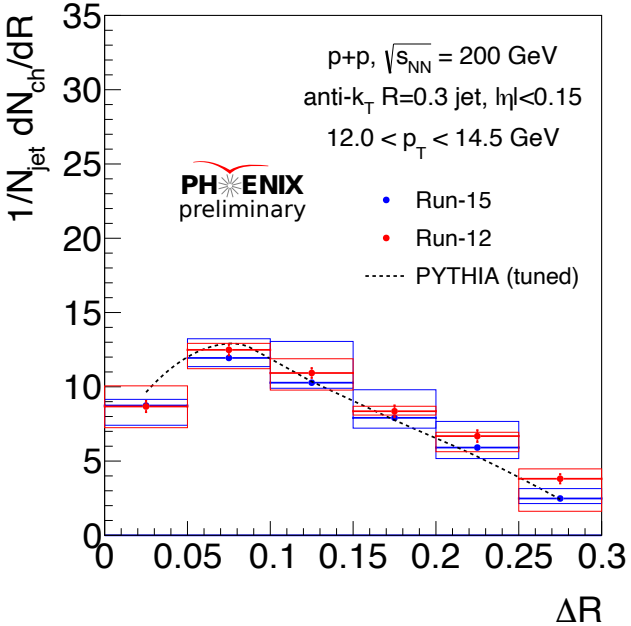
$\xi = -\ln(z) = \ln(p_{T,jet}/p_{Th})$

Transverse fragmentation



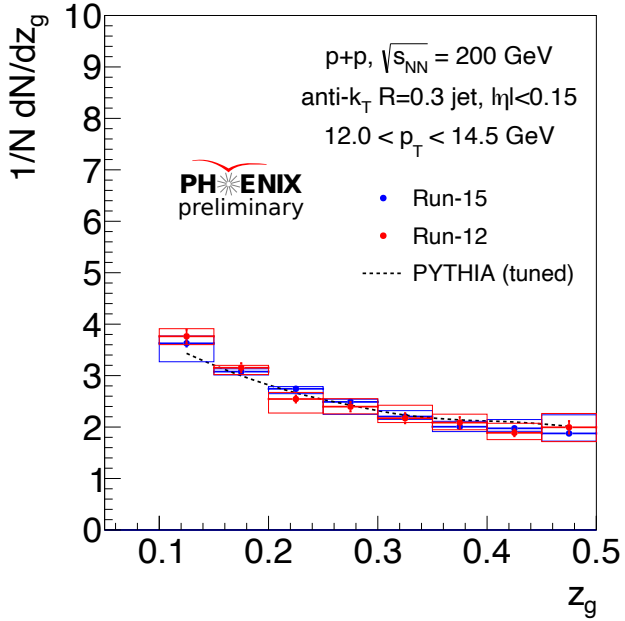
$j_T = |p_{jet} \times p_{track}| / |p_{jet}|$

Radial profile



$\Delta R = \sqrt{(\Delta\phi^2 + \Delta\eta^2)}$

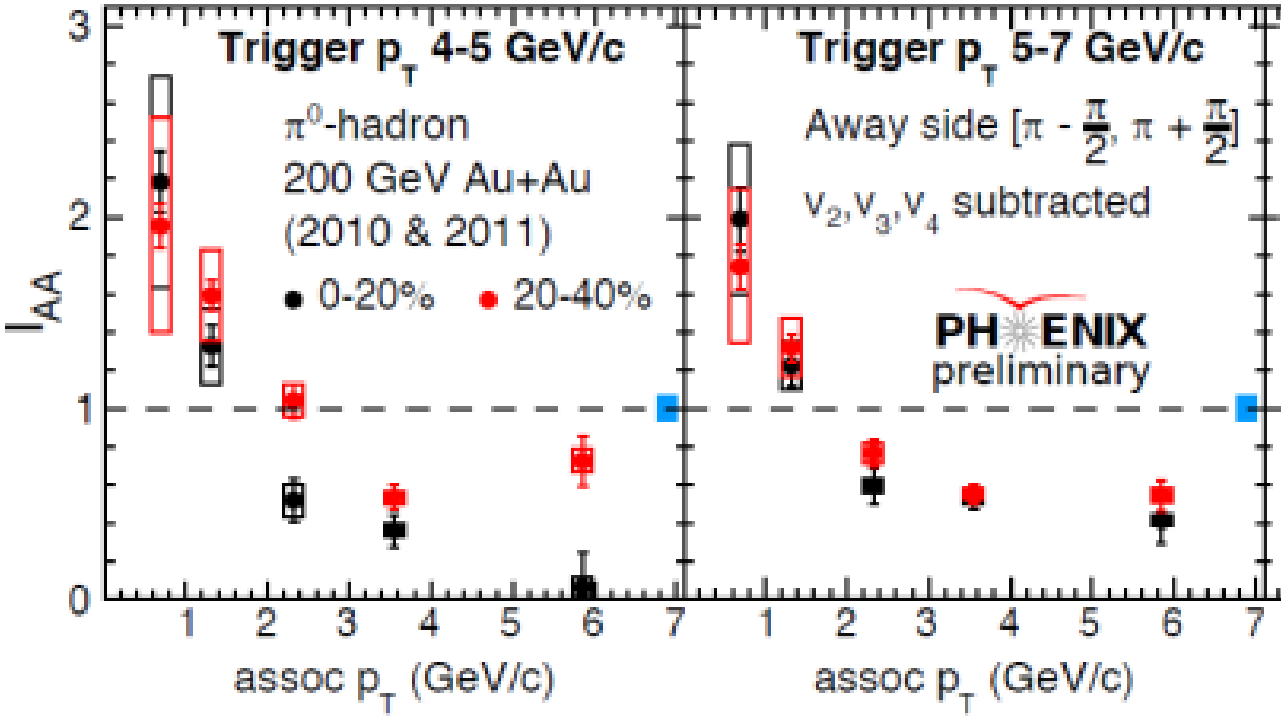
Jet splitting function

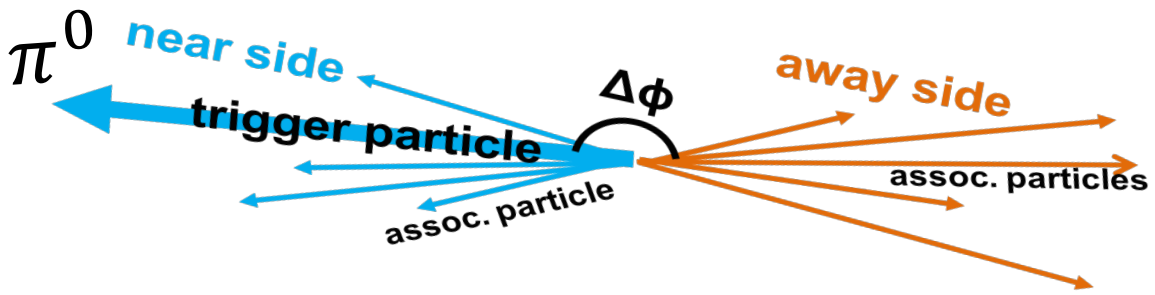


$z_g = \min(p_{T1}, p_{T2})/(p_{T1} + p_{T2})$

- PHENIX measured Jet Substructure with Reconstructed Jets in pp
- Baseline for p+A and A+A

Jet Modification in A+A

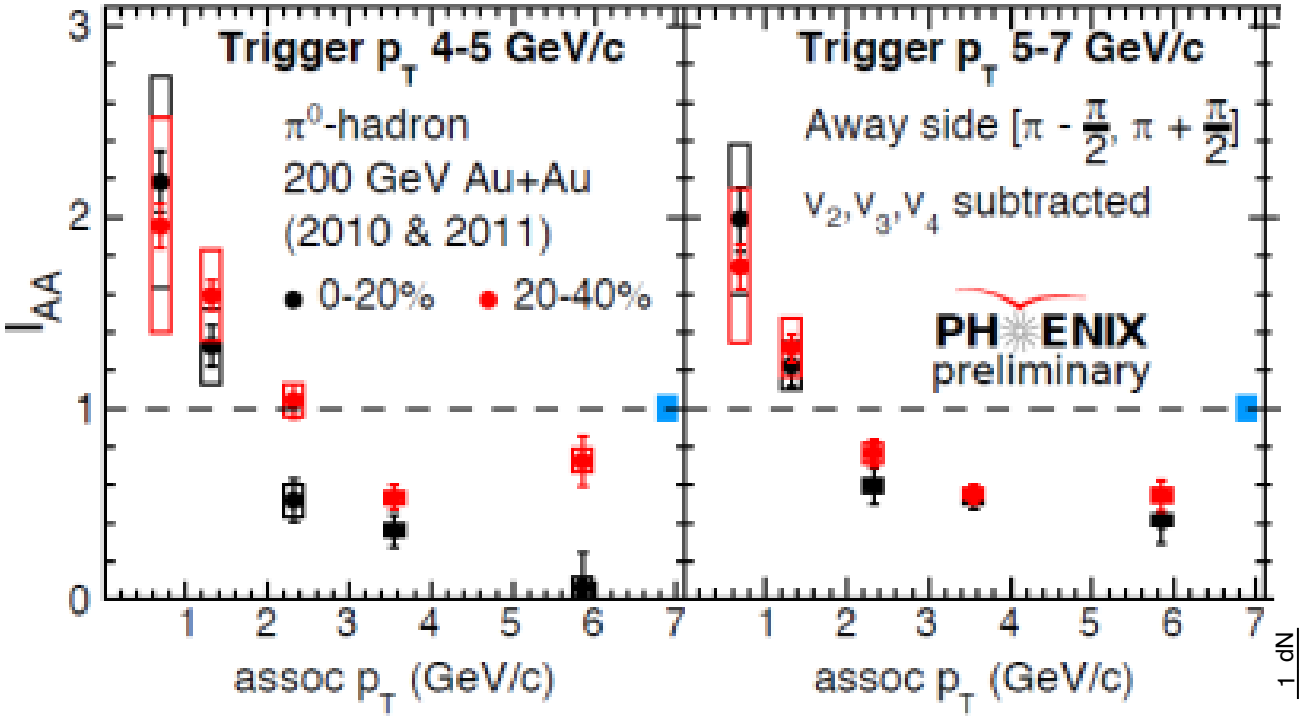


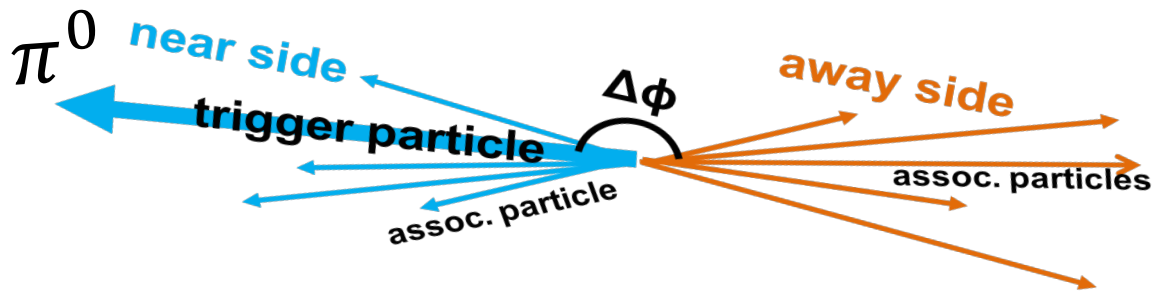


$$I_{AA} = \frac{Y^{AA}_{Away}}{Y^{pp}_{Away}}$$

- Suppression at high p_{Th}
- Enhancement at low p_{Th}
- Transition at similar p_{Th} for all trigger p_T

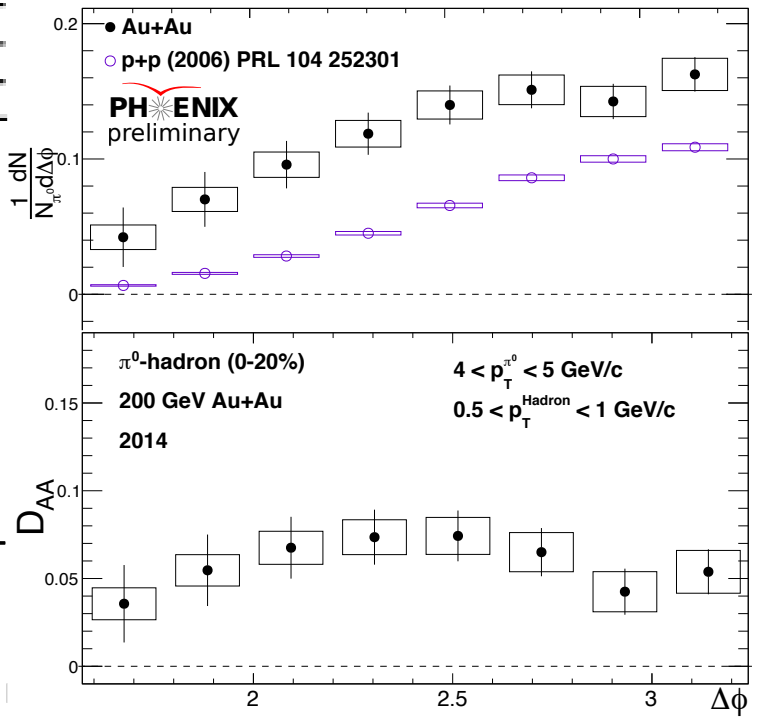
Jet Modification in A+A





$$I_{AA} = \frac{Y^{AA}_{Away}}{Y^{pp}_{Away}}$$

$$D_{AA} = YA_A - Yp_p$$



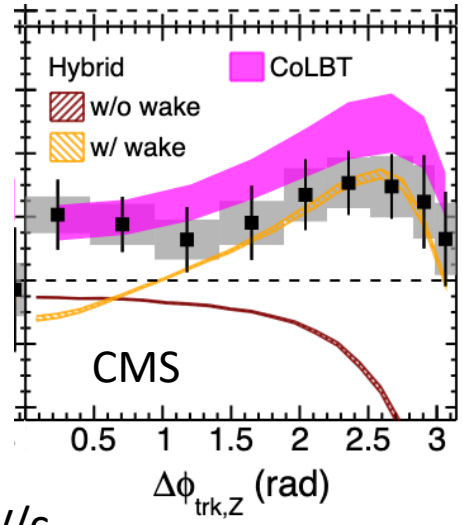
- Suppression at high p_{Th}
- Enhancement at low p_{Th}
- Transition at similar p_{Th} for all trigger p_T

- Less sensitive to yields near zero than ratio

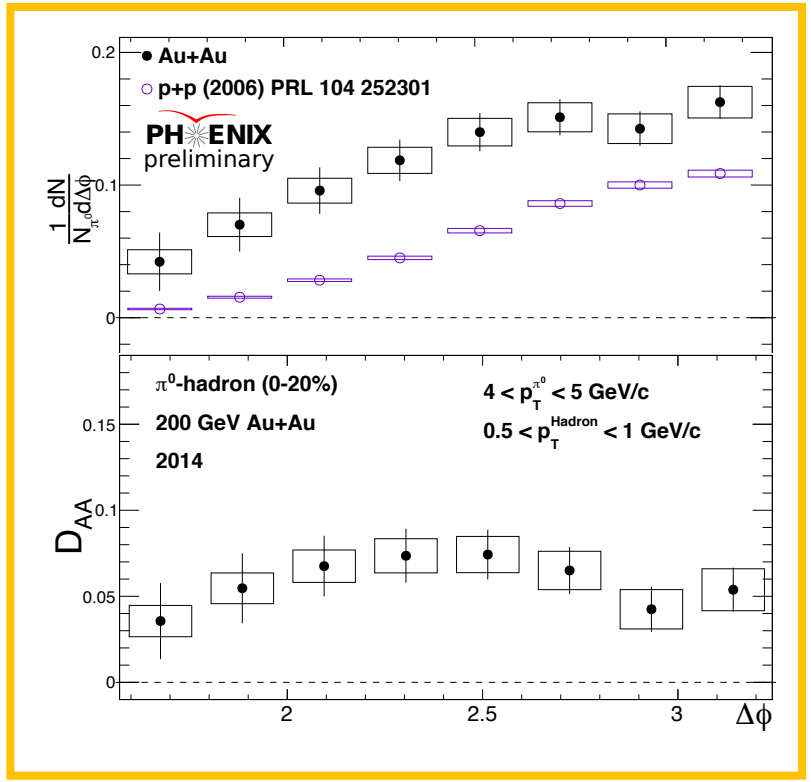
- Enhancement: $D_{AA} > 0$
- Suppression: $D_{AA} < 0$

Medium Response

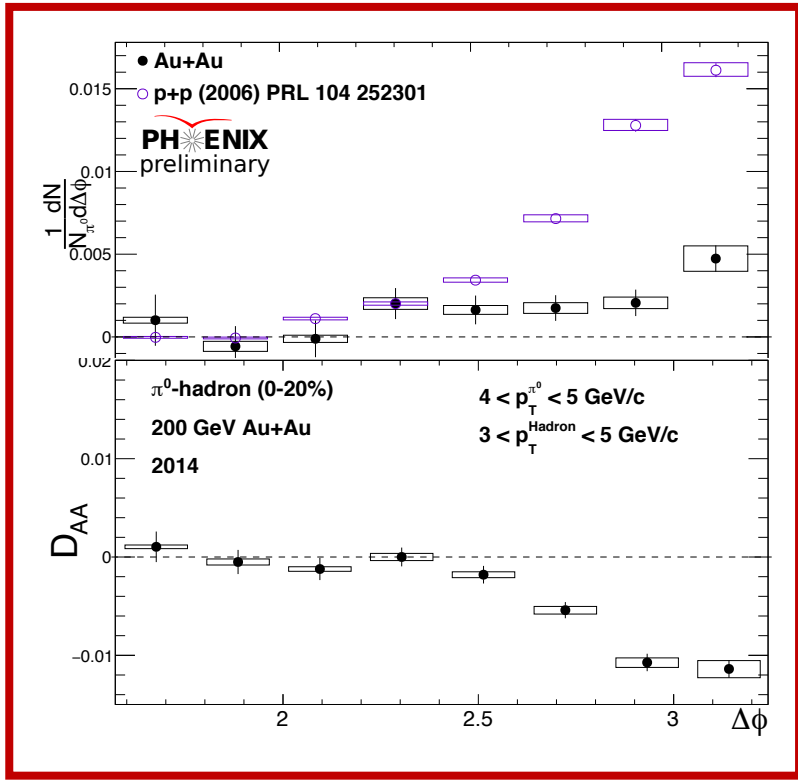
- Hybrid model shows different behavior with and without wake (medium response)
- What is the p_T dependence to this feature?
  - PHENIX π^0–h may imply wake is more relevant for low p_T hadrons



$0.5 < p_{T,h} < 1$ GeV/c



$3 < p_{T,h} < 5$ GeV/c



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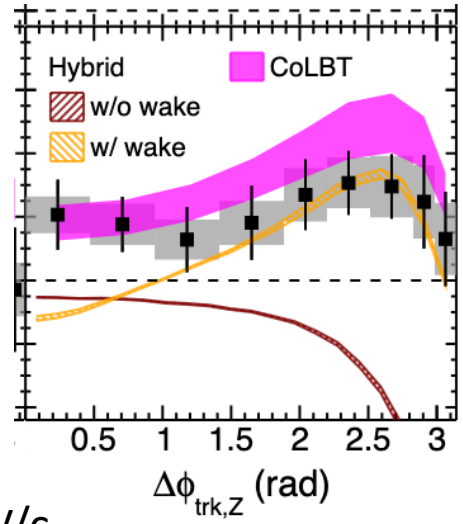

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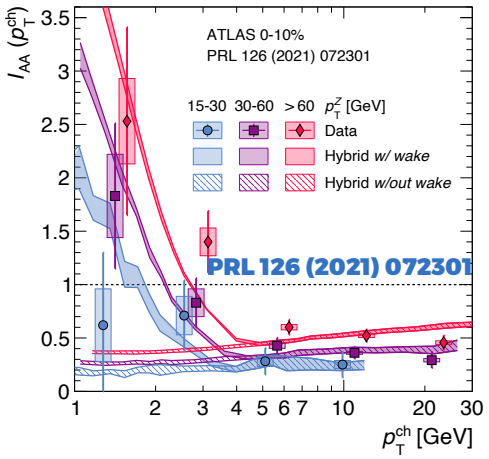

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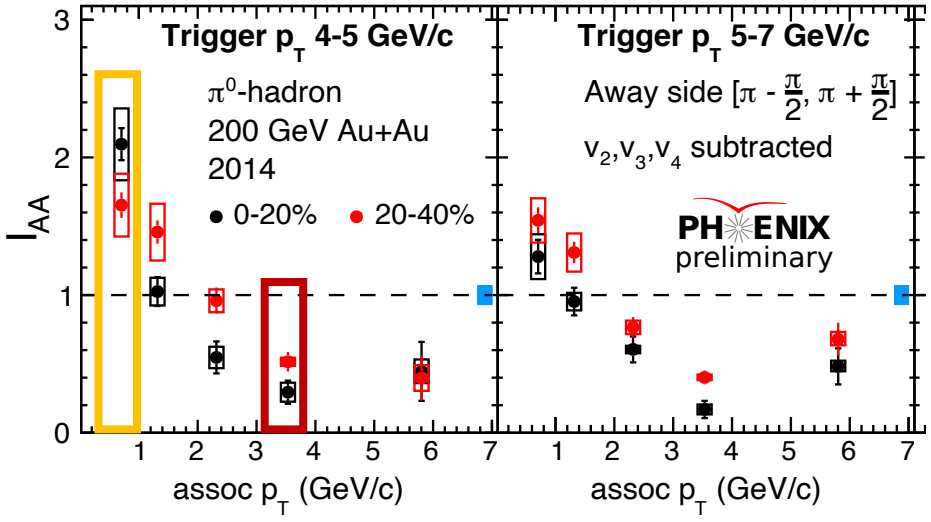
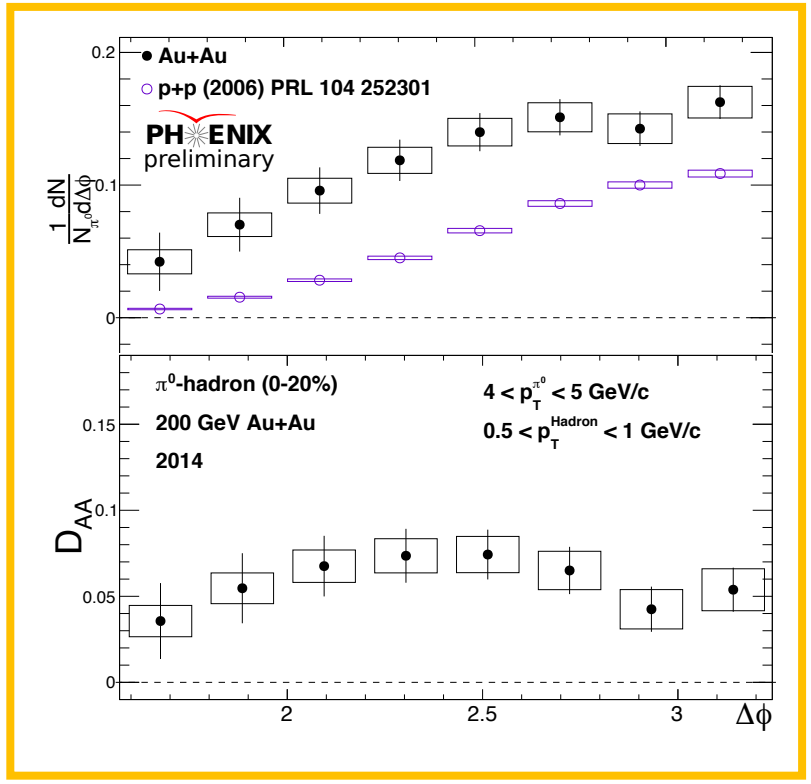
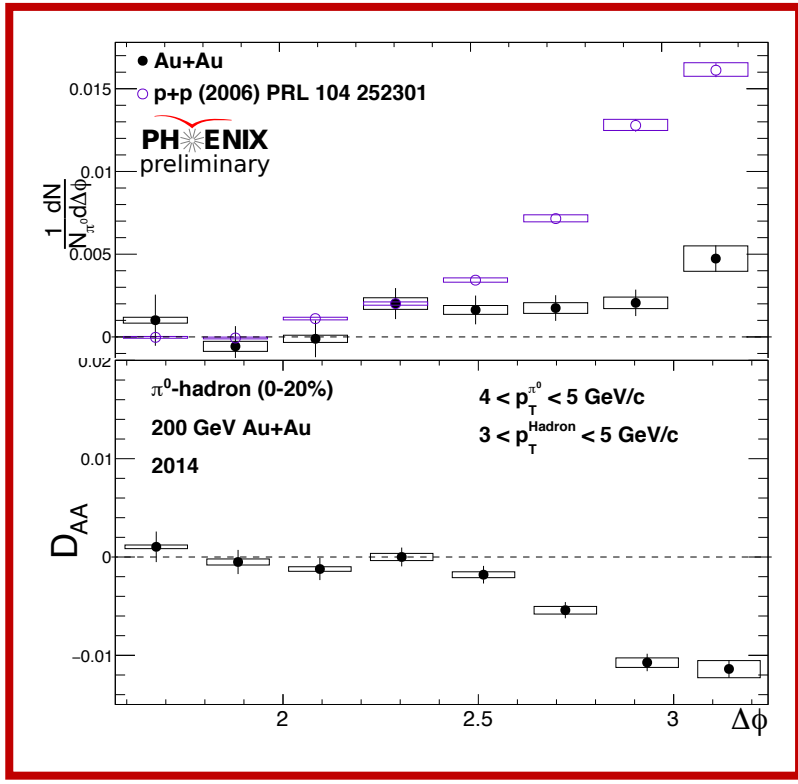
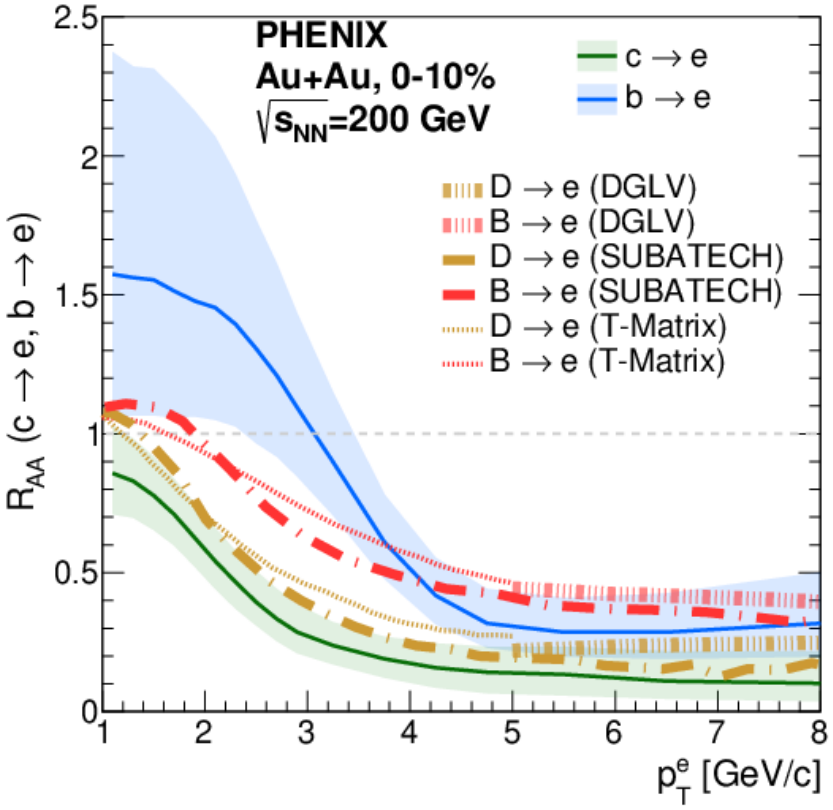


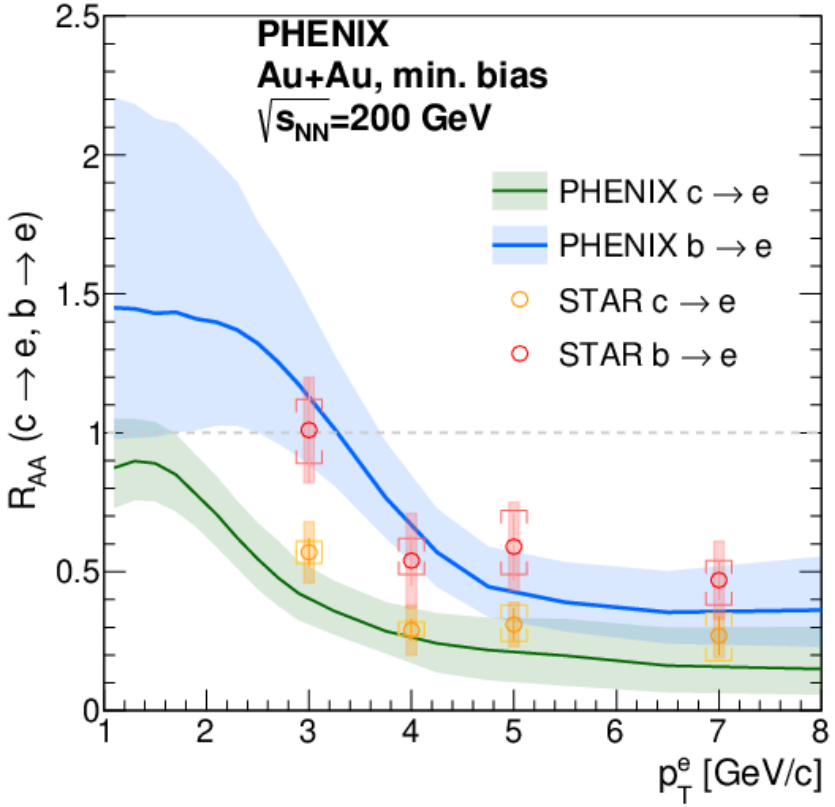




Quark Mass Dependent Energy Loss

arXiv:2203.17058

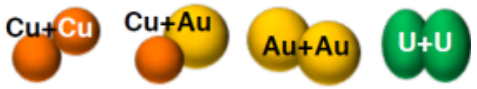




Beauty is less suppressed than charm

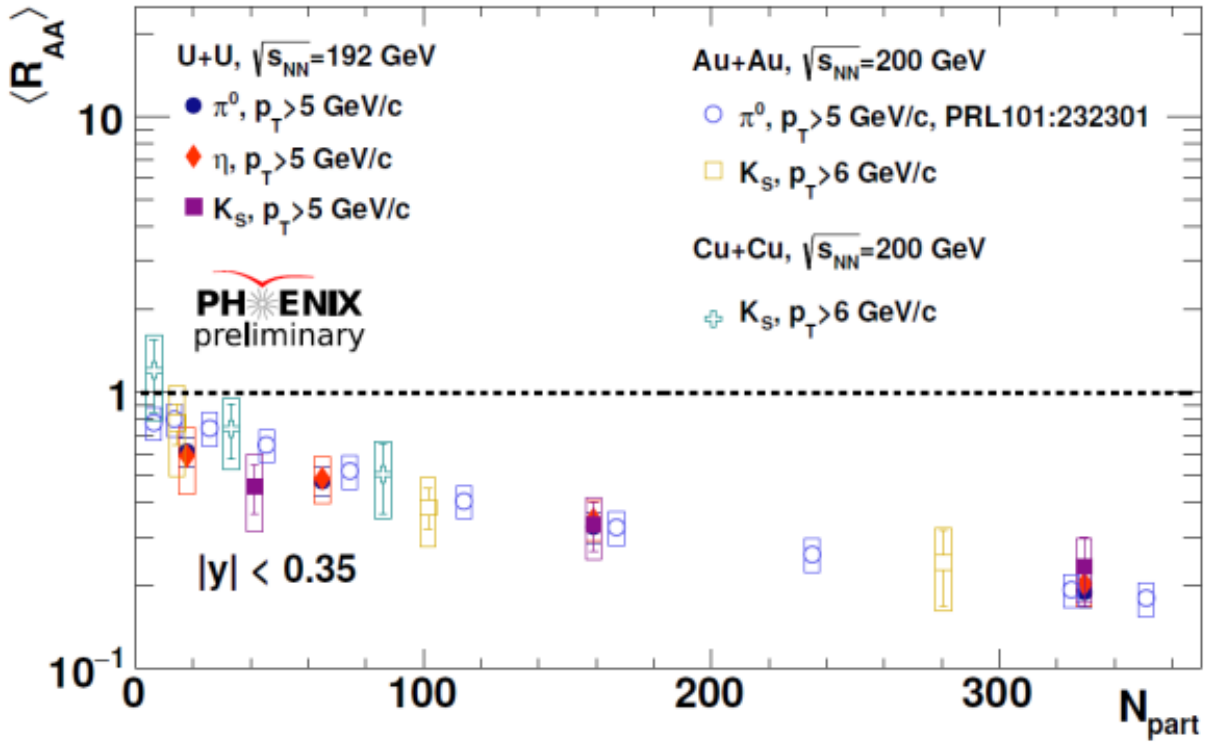
See A. Frawley's talk for more HF and Quarkonia results

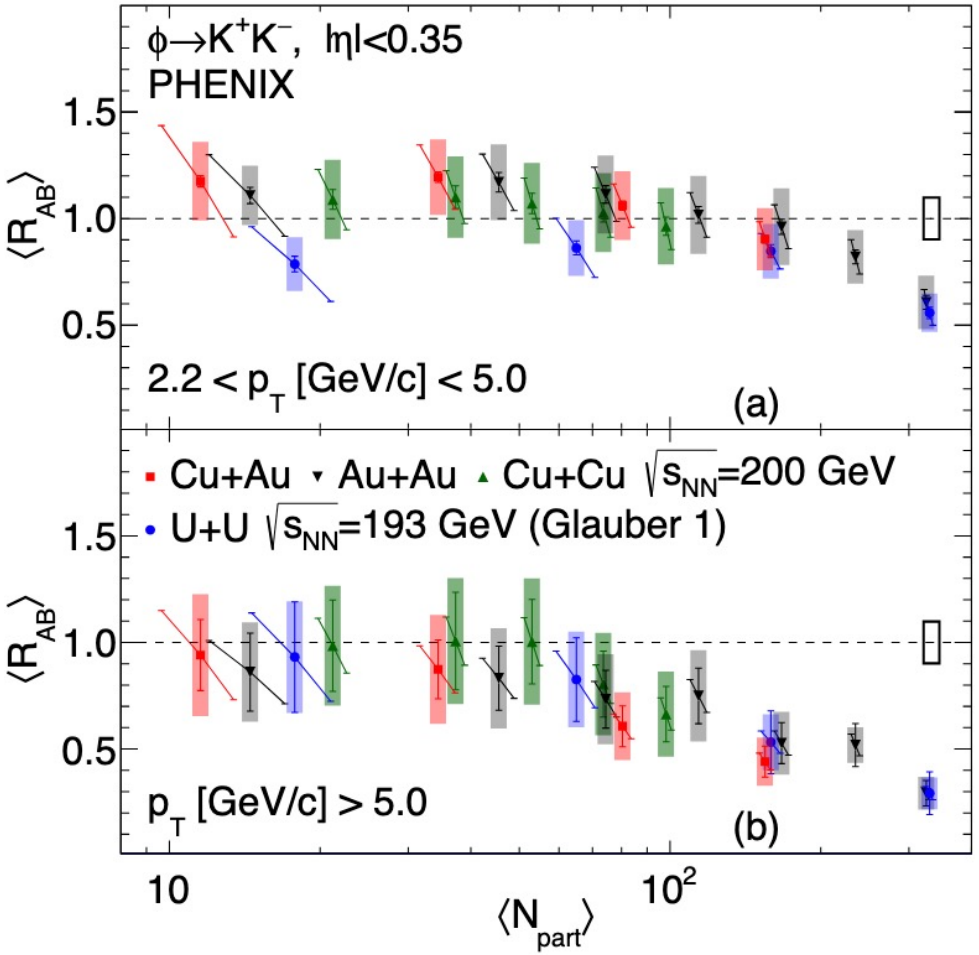
Various Collision Systems: R_{AA} at High p_T



- For p_T> 6 GeV/c same trend for all systems and particles as a function of N_{part}
- $\langle R_{AB} \rangle$ for ϕ mesons consistent across Cu+Cu, Cu+Au, Au+Au and U+U

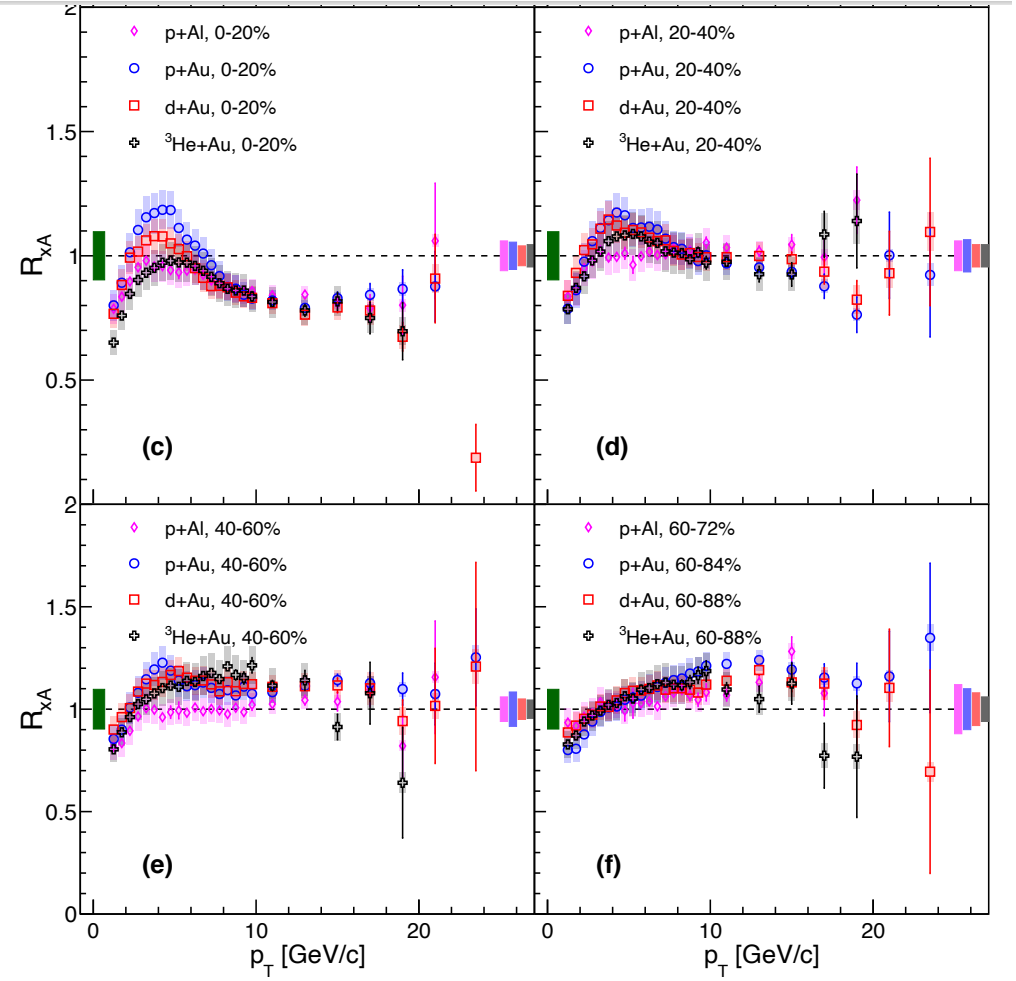
arXiv:2207.10745





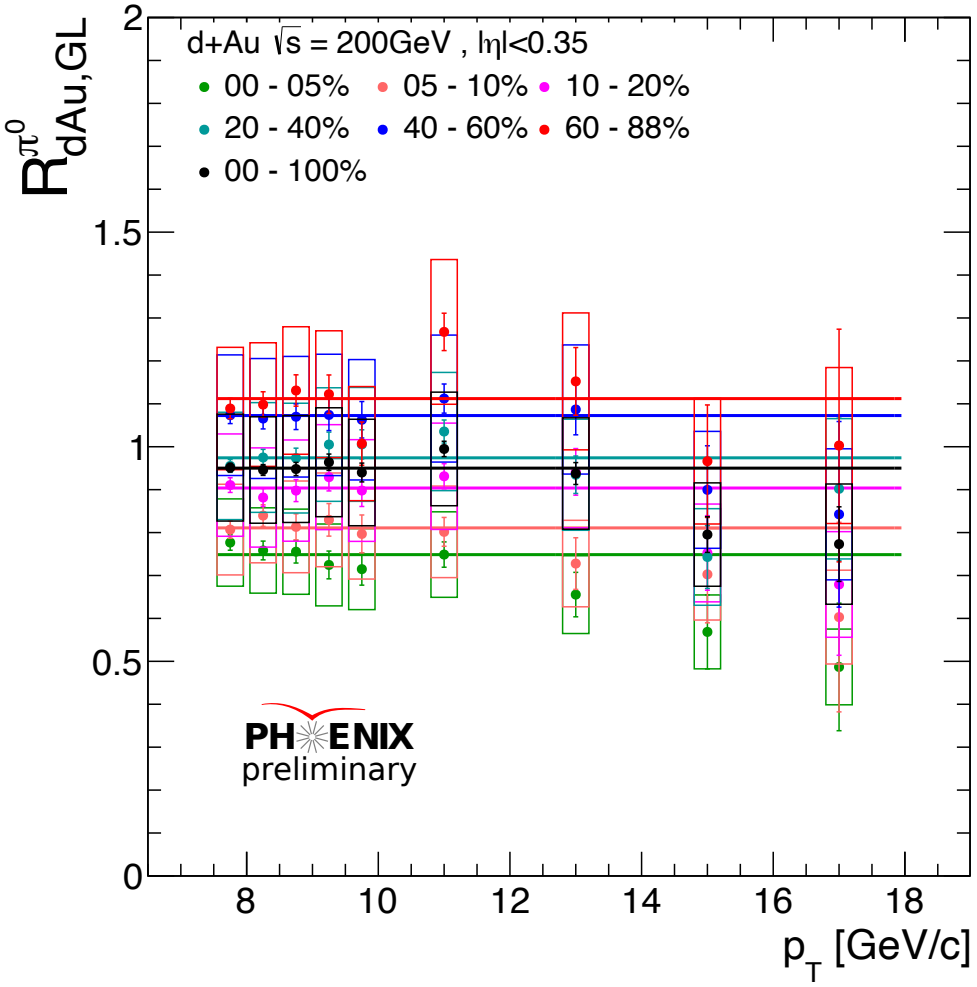
System Size Dependence…Small Systems

PRC 105, 064902 (2022)



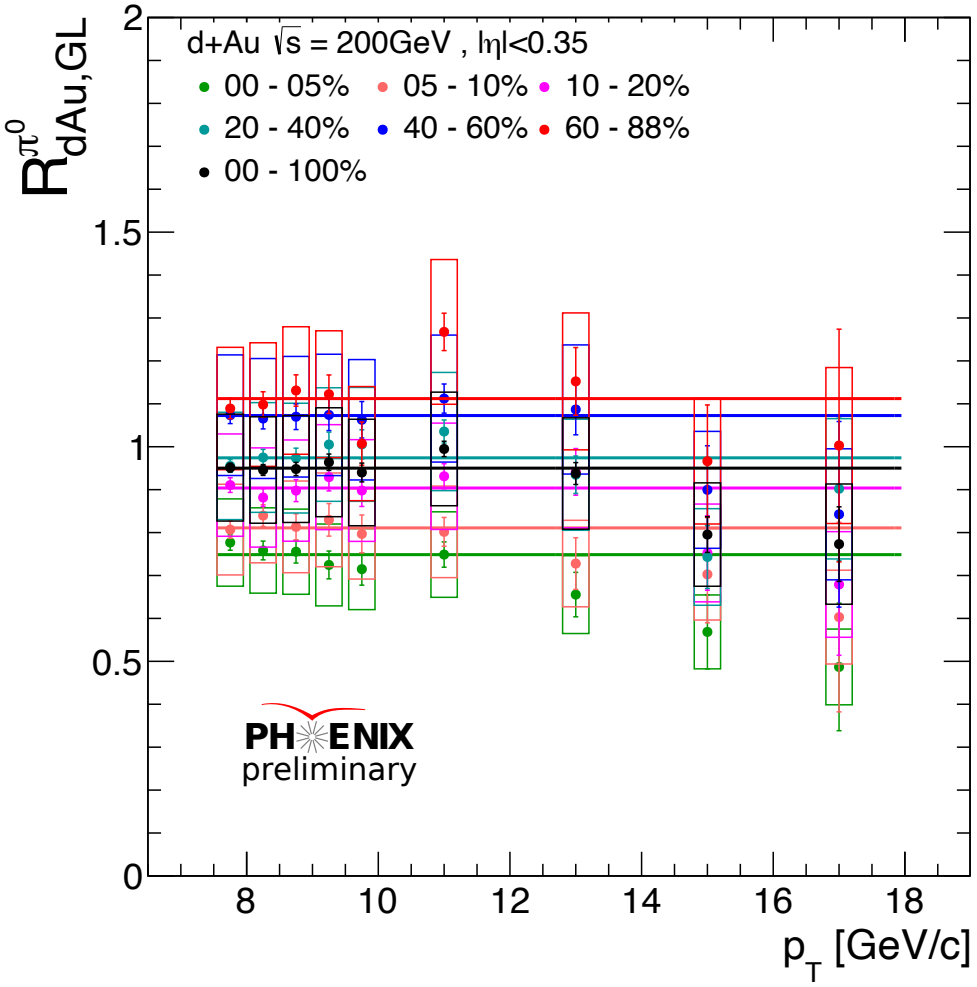
- High p_T R_{xA} similar across all collision systems
- Suppression in central collisions
- Enhancement in peripheral collisions
  - Difficult to explain…

System Size Dependence…Small Systems

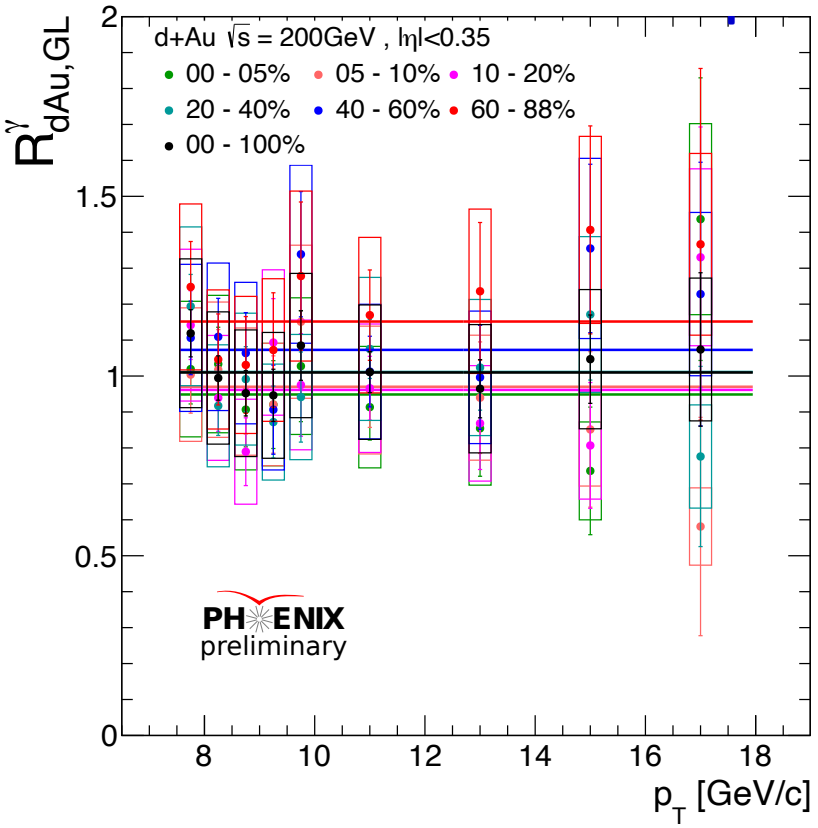


- Previously observed centrality dependence of R_{dA}
  - 0-5% < 1 < 60-88%
- High p_T direct photons should not be modified

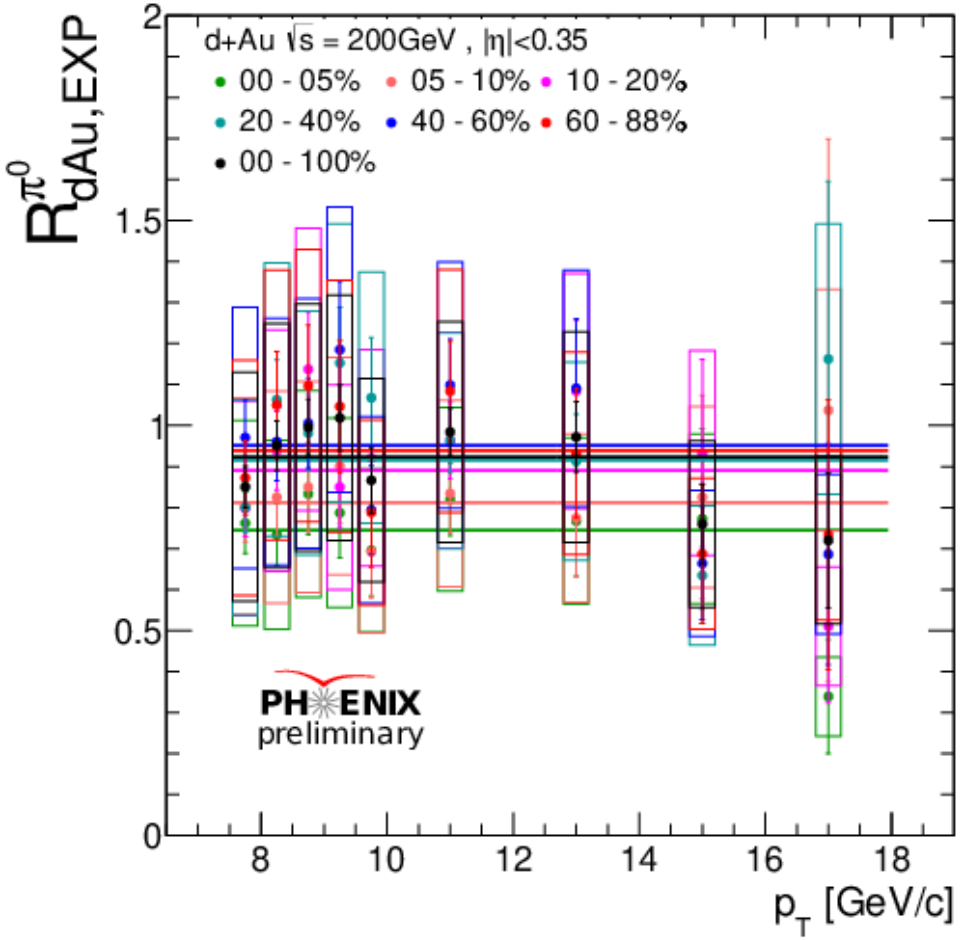
System Size Dependence…Small Systems

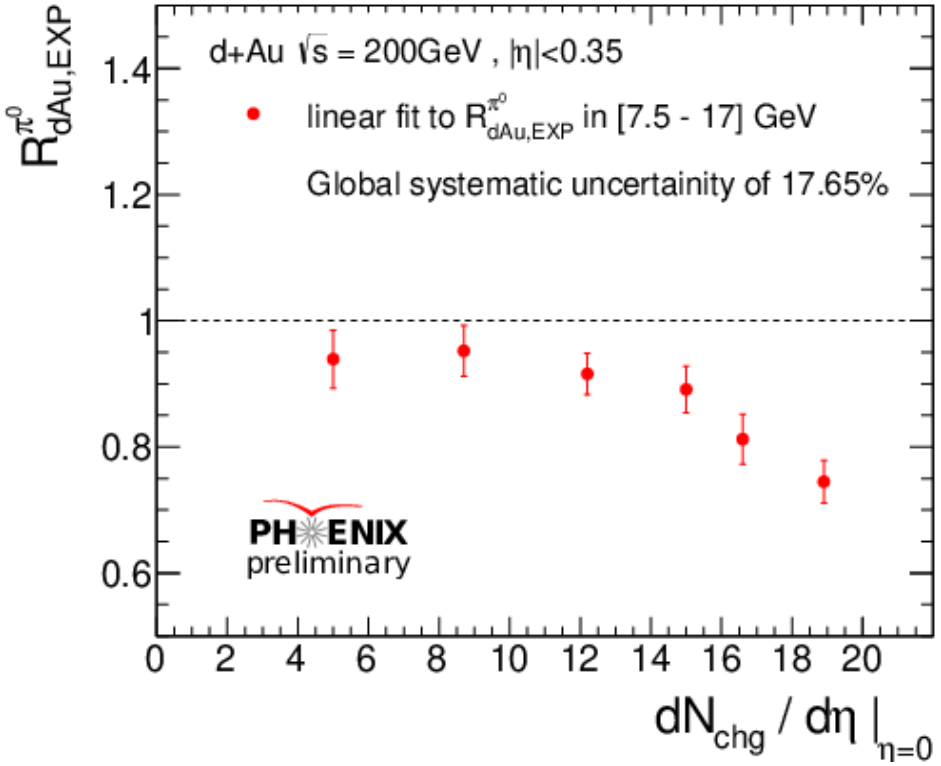


- Previously observed centrality dependence of R_{dA}
  - 0-5% < 1 < 60-88%
- High p_T direct photons should not be modified
- But similar trend is observed!
- Can use photon R_{dAu} to correct for bias in N_{coll} determination



Direct Photons as a calibration tool

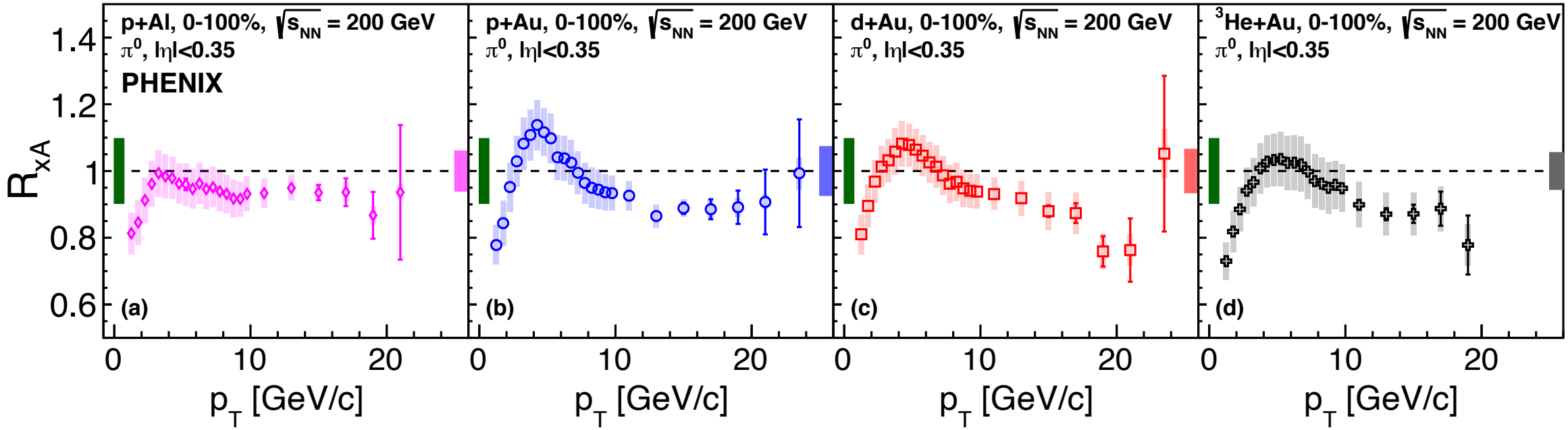




- Removes apparent enhancement in peripheral collisions
- Small suppression in central collisions remains
  - EMC effect? QGP?

System Size Dependence at Lower p_T

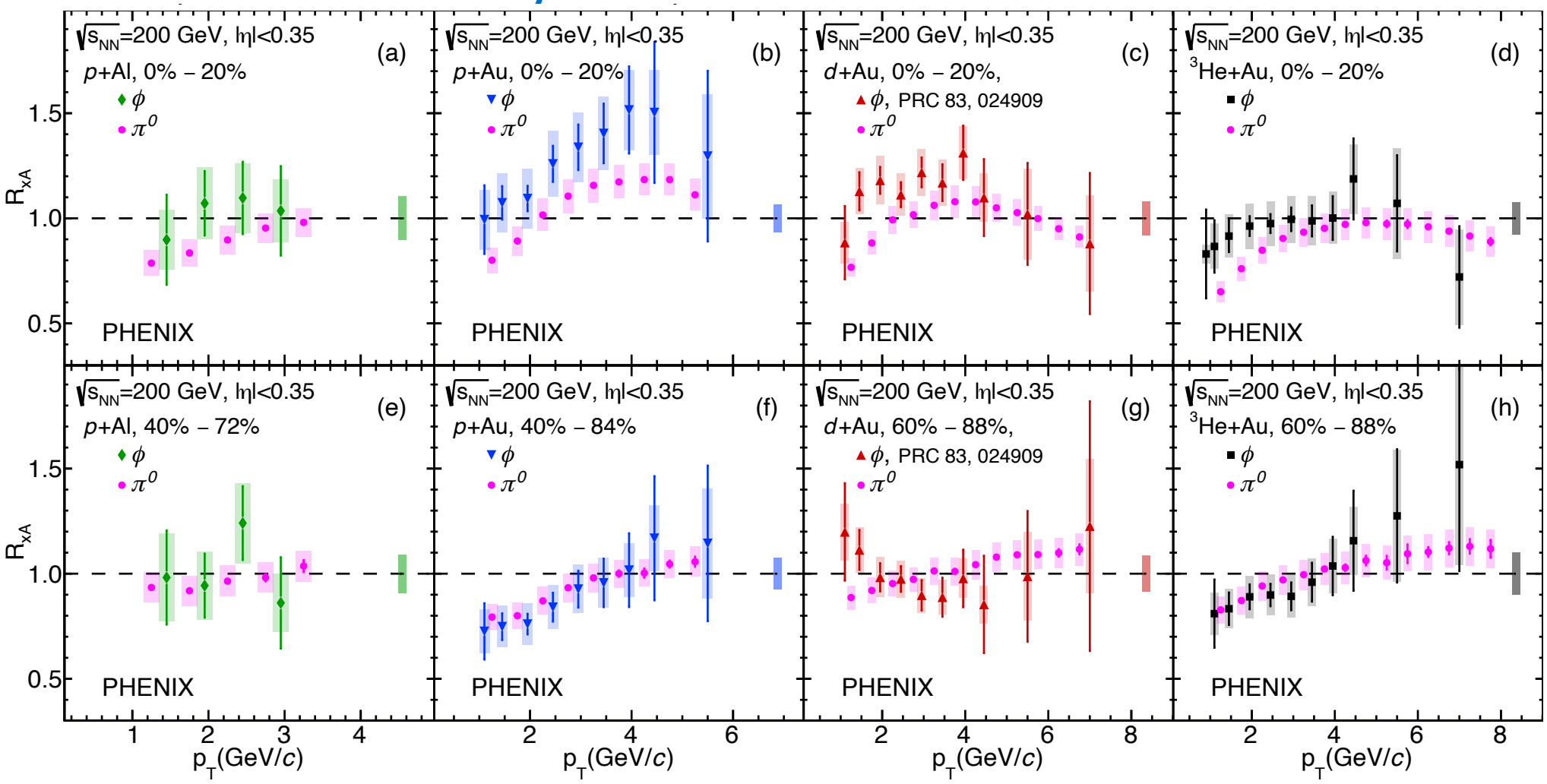
PRC 105, 064902 (2022)



- Varying the collision system (minimum bias shown)
- Cronin enhancement at intermediate p_T
  - Lighter target shows smaller enhancement (p+Al < p+Au)
  - Heavier projectile shows smaller enhacement (He+Au < d+Au < p+Au)

ϕ mesons in small systems

arXiv:2203.06087



- R_{xA} for ϕ similar to π^0
- Hints of slight ϕ enhancement relative to π^0

ϕ mesons in small systems

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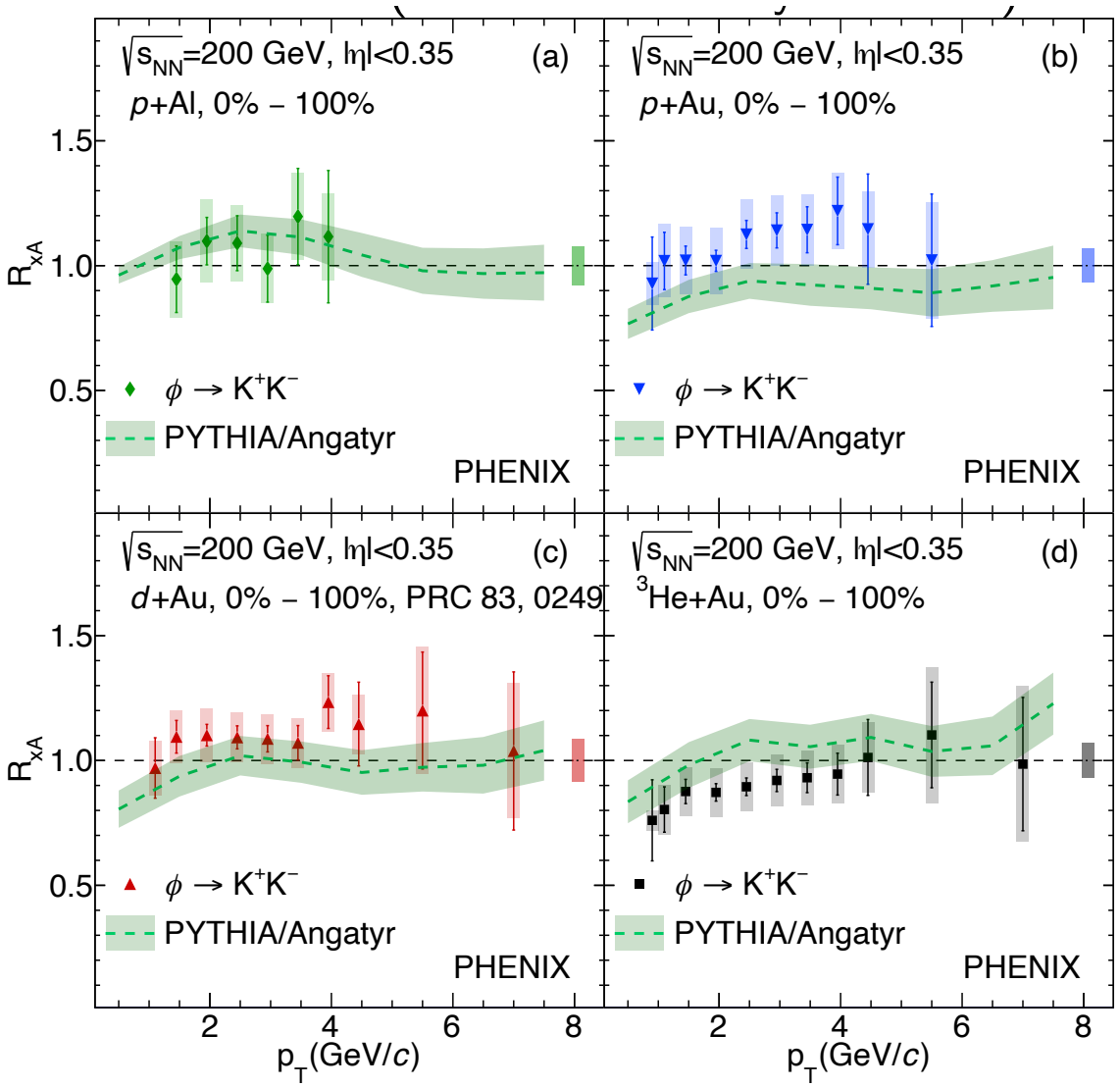

- R_{AA} well-described by PYTHIA/Angantyr
  - Misses verall system size ordering
- R_{AA} also well-described by PYTHIA with nPDFs
  - Misses verall system size ordering

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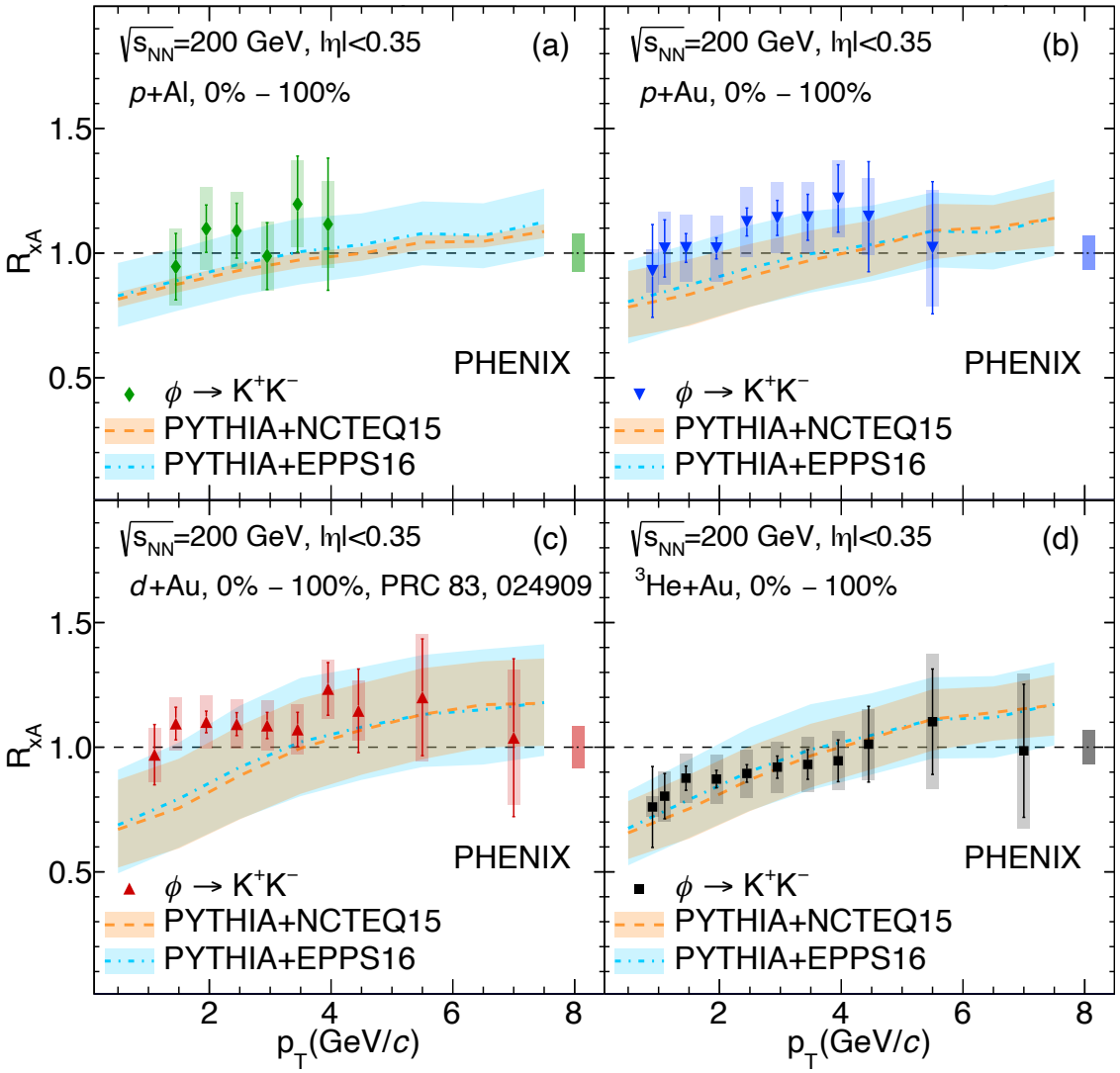

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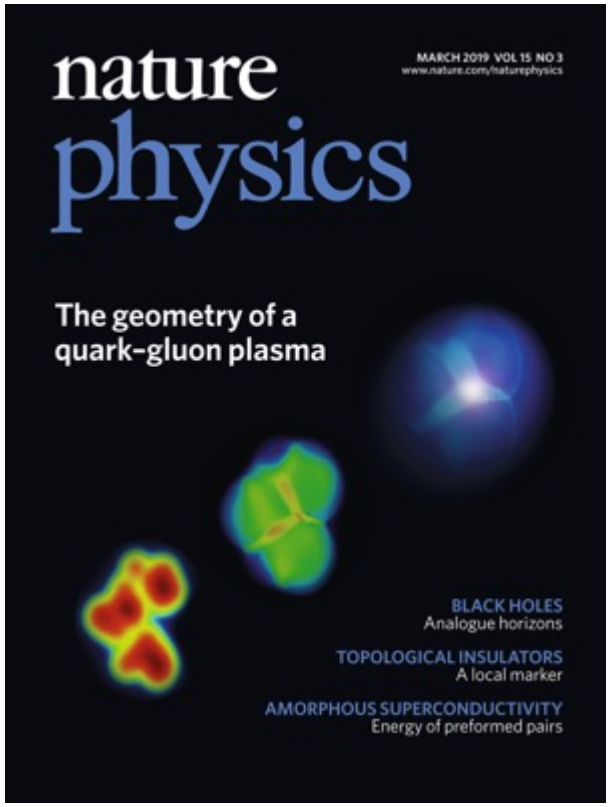
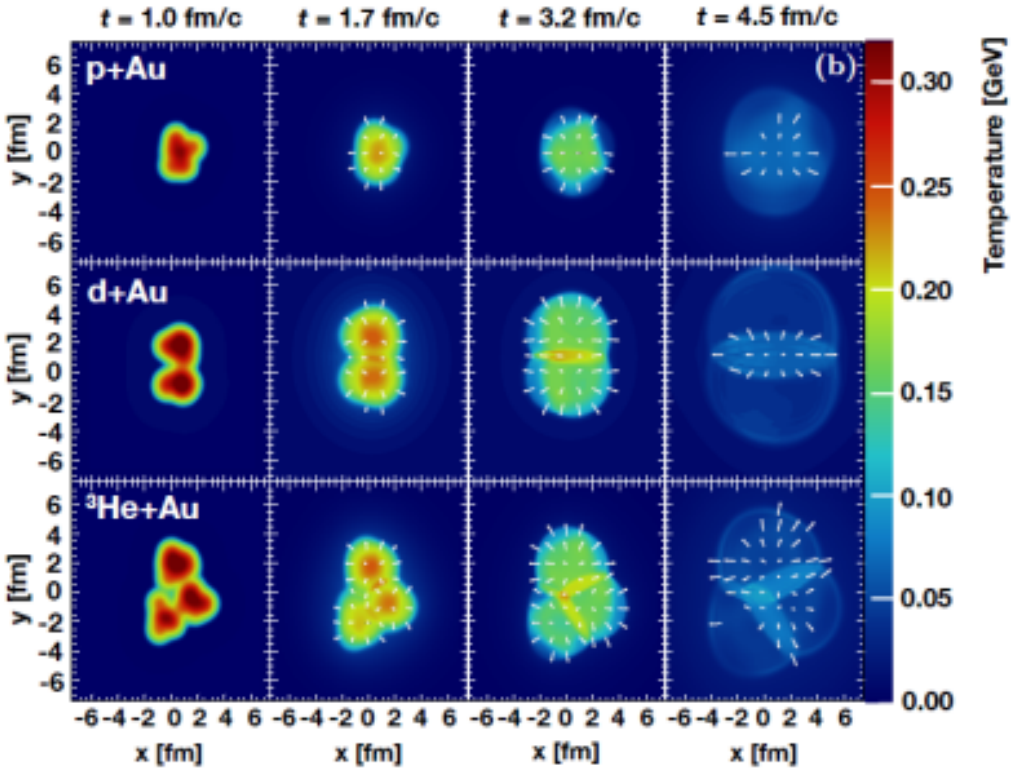
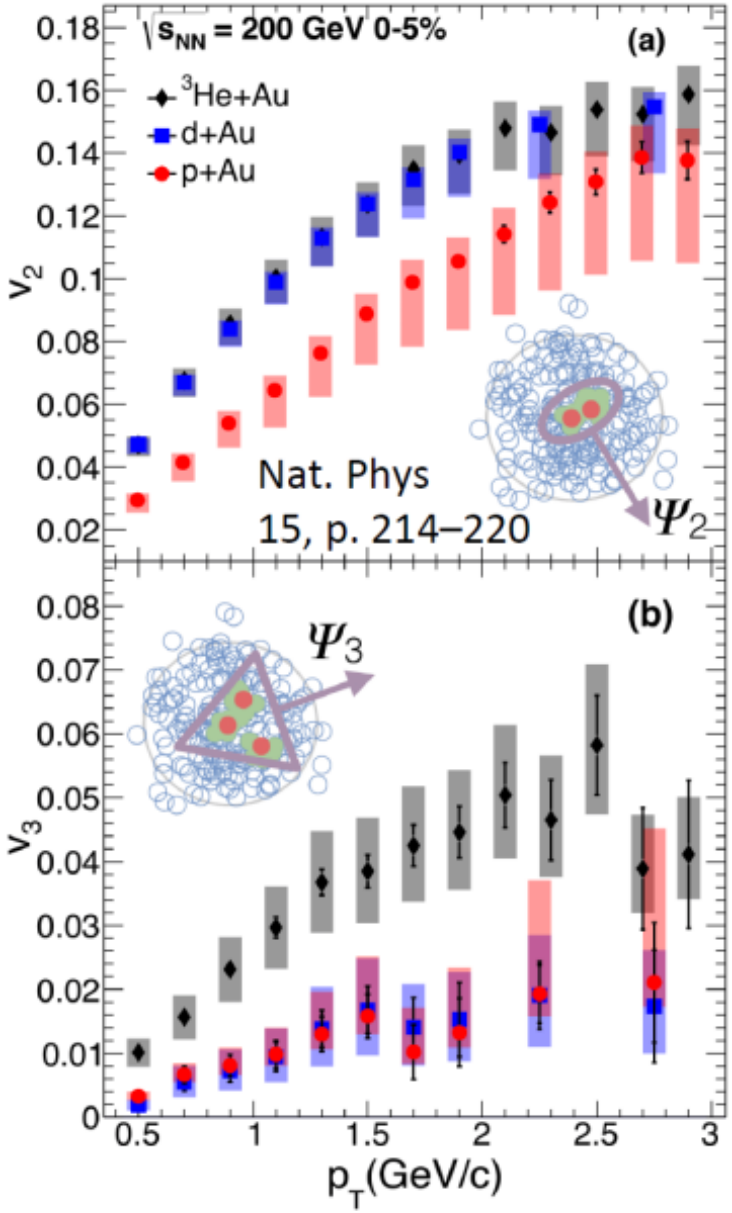
Evidence of QGP Droplets in small systems



Nature Physics **15**, pages214–220 (2019)





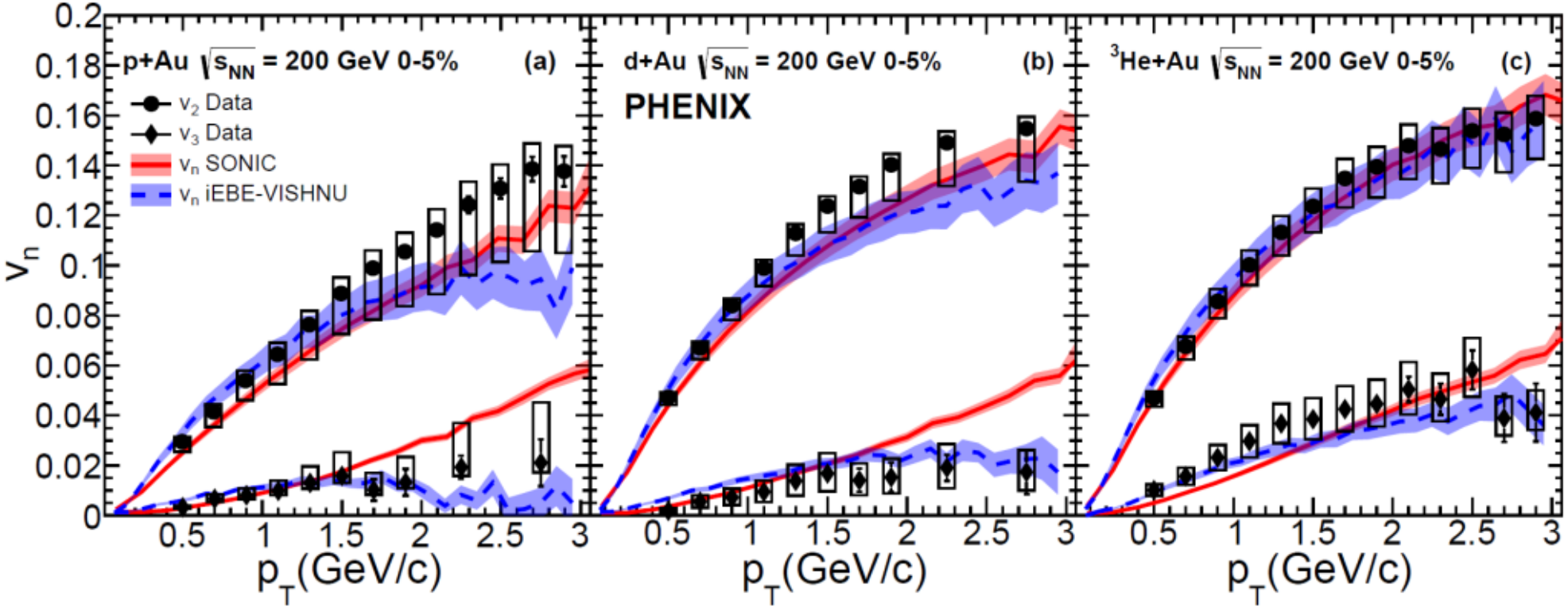
Lower v_2 in p+Au

Higher v_3 in ^{3}He+Au

Importance of initial state geometry

Evidence of QGP Droplets in small systems

Nature Physics **15**, pages214–220 (2019)



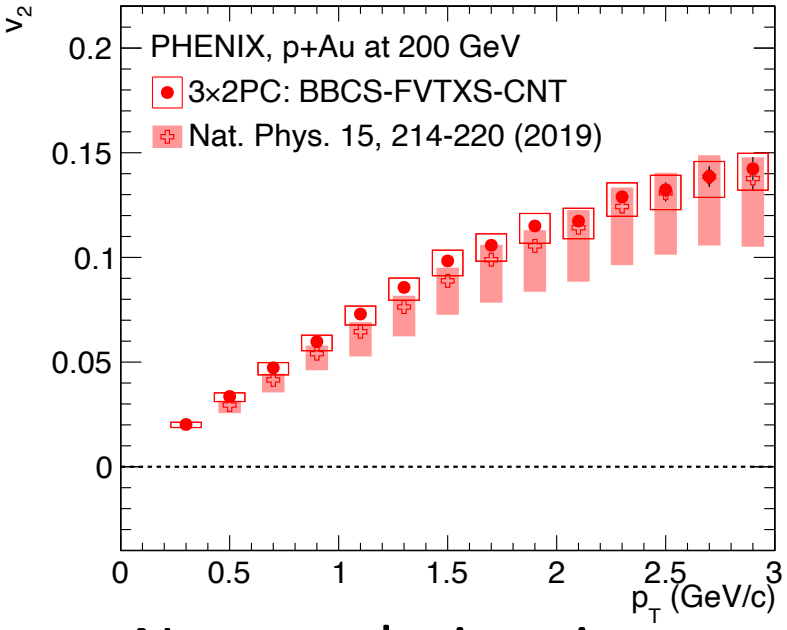
Excellent agreement between data and hydrodynamic predictions

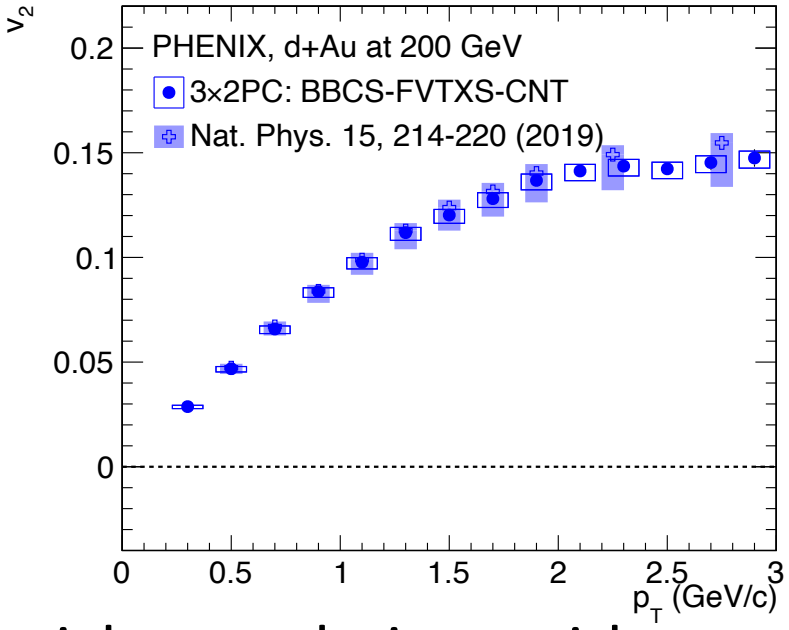
Only hydrodynamic models reproduce the data

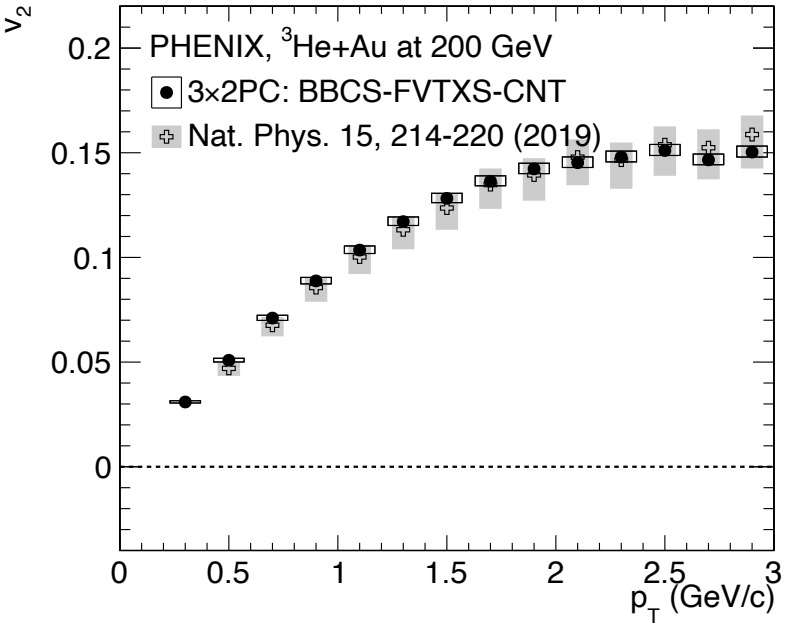
Models indicate the temperatures achieved in small systems sufficient for QGP formation

Confirmed Small System v_2

PRC 105, 024901 (2022)



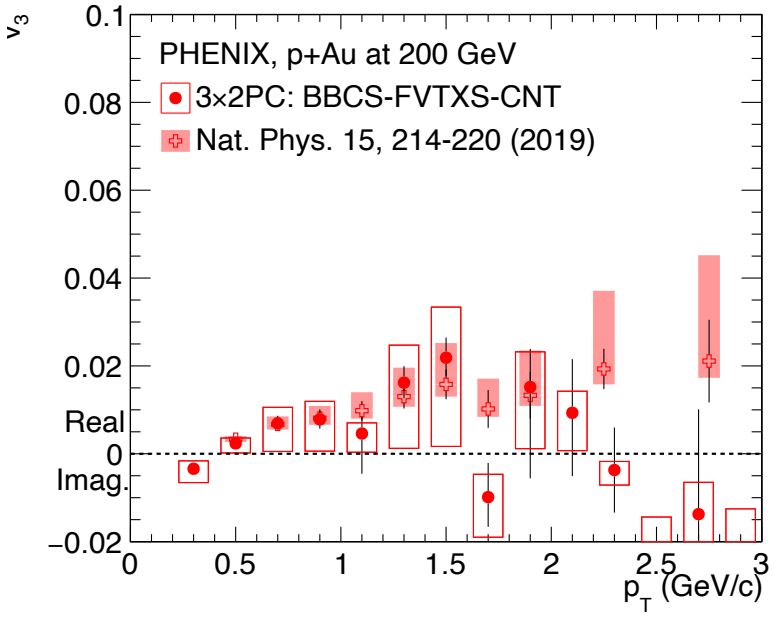


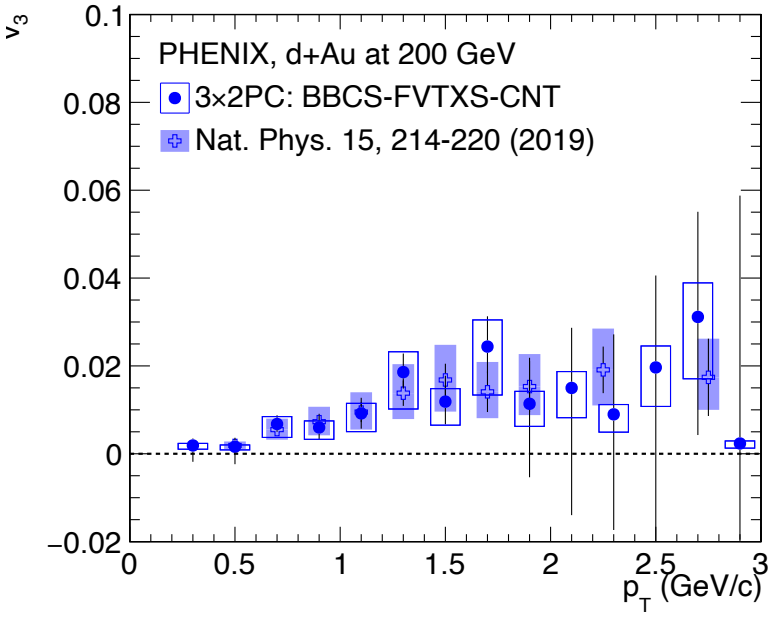


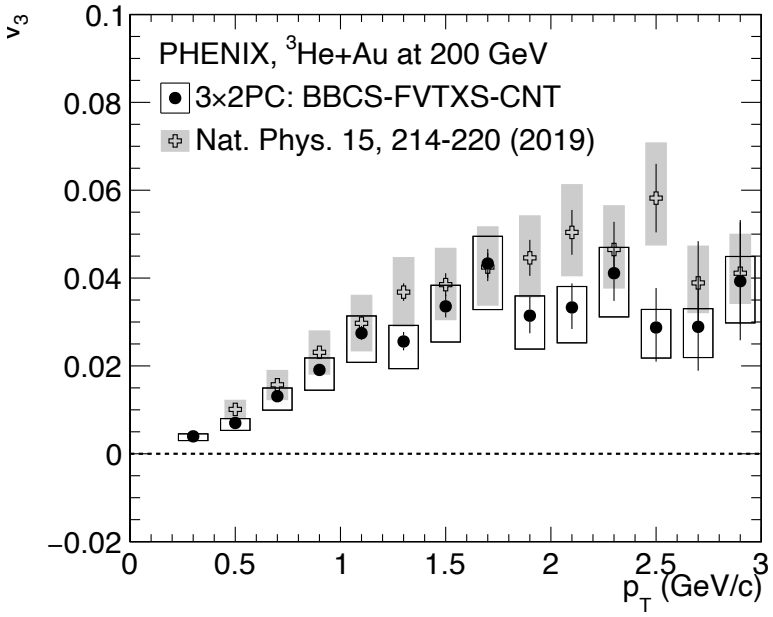
- New analysis using two-particle correlations with event mixing
- Nature Physics publication used event plane method
- Both use same detector combinations but very different sensitivity to key experimental effects (beam position, detector alignment)

Confirmed Small System v_3

PRC 105, 024901 (2022)







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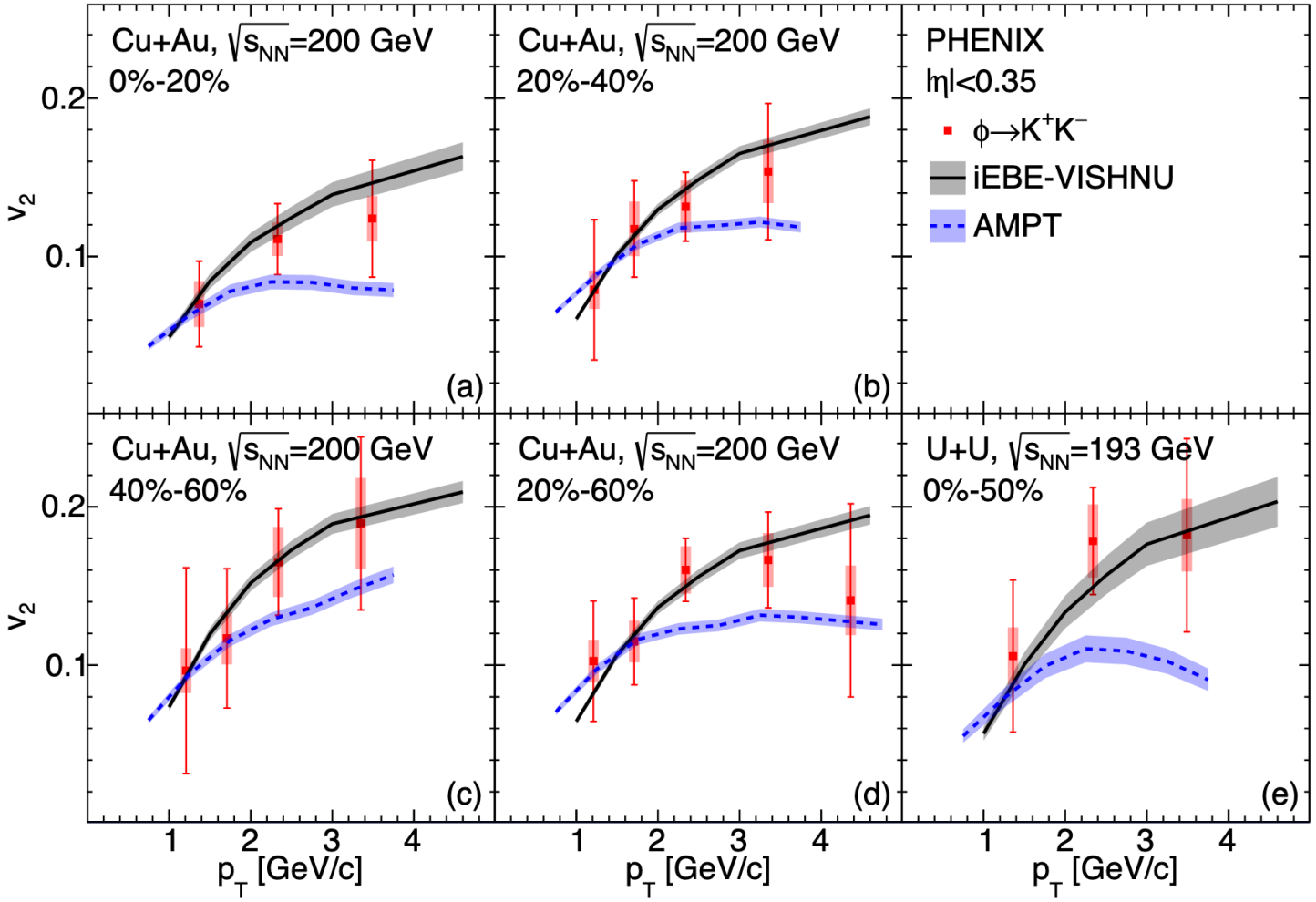
ϕ meson v_2 in Cu+Au and U+U

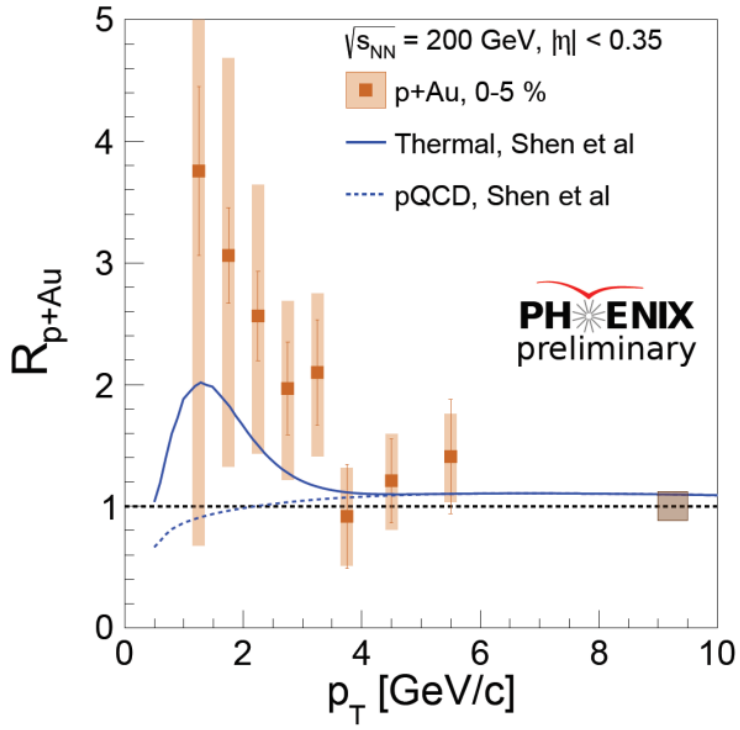
arXiv:2207.10745

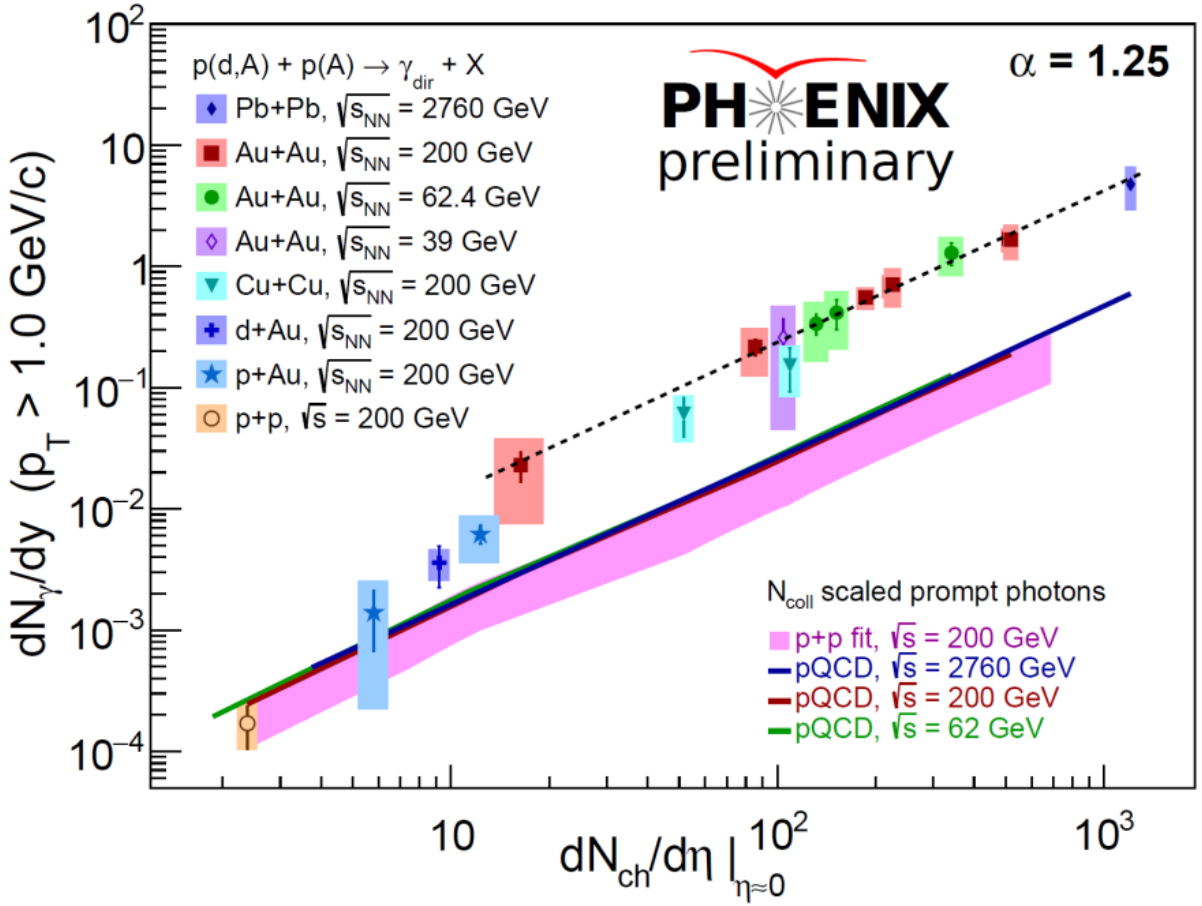
- ϕ v_2 scales with 2nd order eccentricity and characteristic nuclear overlap length
- Agrees with same hydrodynamic model shown for the small systems



Thermal photons in small systems

- Enhancement of low p_T photons in central p+Au
- Consistent with expected thermal photon production (PRC 95 014906 (2017))





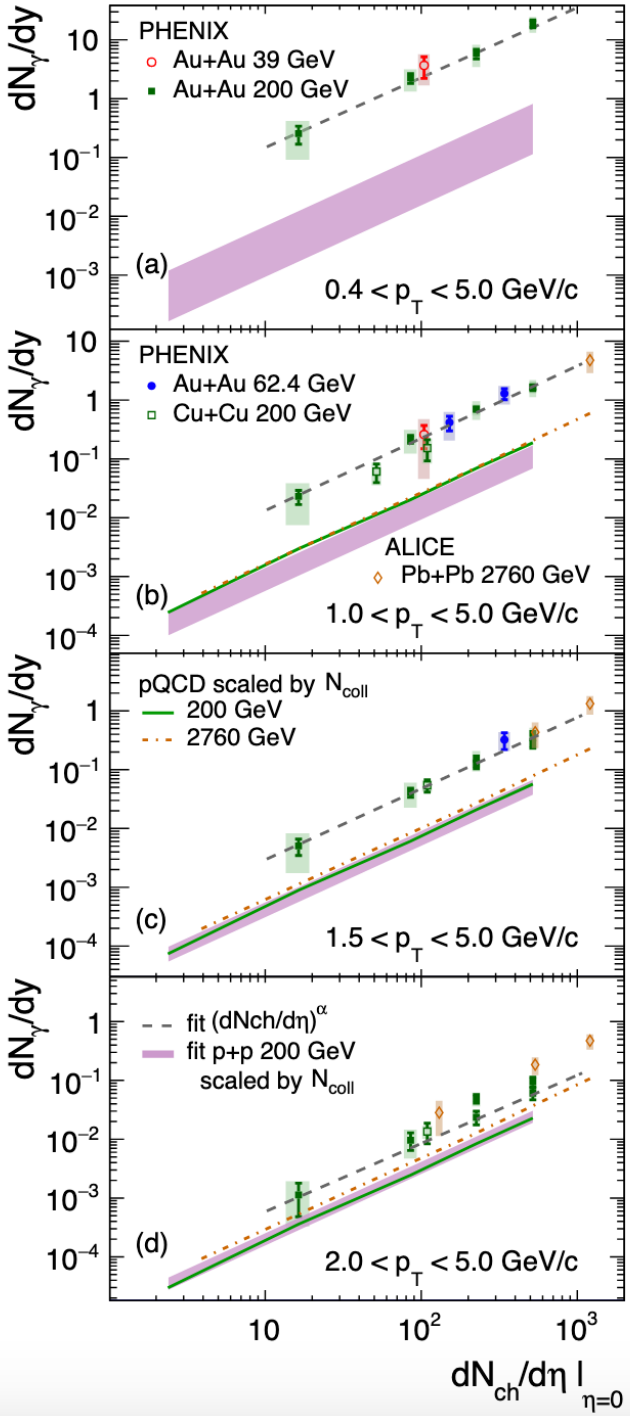
Smooth trend between small and large systems

Thermal Photons in Au+Au

- Submitted paper (arXiv:2203.12354) publishing 39 and 62.4 GeV Au+Au data
- Studies α in more detail

$$\int_{p_{T,\min}}^{5\,\mathrm{GeV}/c} \frac{1}{2\pi p_T}\frac{d^2N}{dp_T dy}\,dp_T = A_{ch}\left(\frac{dN_{\mathrm{ch}}}{d\eta}\right)^{\alpha}$$

- $\alpha = 1.21 \pm 0.04$ (stat) consistent for all p_{Tmin}
- Consistent but slightly less than the previously used $\alpha = 1.25$ from $N_{coll} \propto (dN_{ch}/d\eta)^{\alpha}$
- Also insensitive to collision energy and centrality
- May suggest that direct-photon radiation at low p_T originates from thermal processes while system transitions from the QGP phase to a hadron gas



Data and Analysis Preservation (DAP)

- To ensure reproducibility of published results:
  - Standardized analysis notes
  - All analysis code, macros, relevant files stored in HPSS
  - Upload published data to HEPData
- Ideal Goal: re-analysis possible “forever” by “everyone”
  - Docker/REAna
  - Github and Zenodo
  - CERN OpenData for the general public
  - RIVET
- Find out more at on the Analysis tab on the phenix website: https://www.phenix.bnl.gov/

Conclusions

- The PHENIX collaboration continues to measure many unique and important results…
  - Spanning hard probes and bulk measurements
  - Spanning a variety of collision systems and energies
  - Several new publications and PhD theses
  - DAP will ensure this can continue far into the future

…and many more results to come soon…