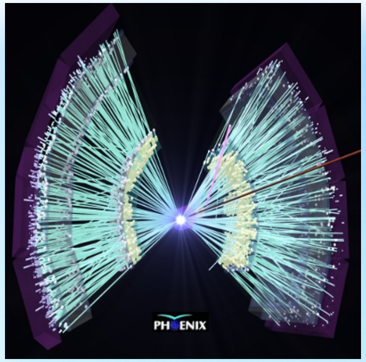


PHENIX
Small System Summary

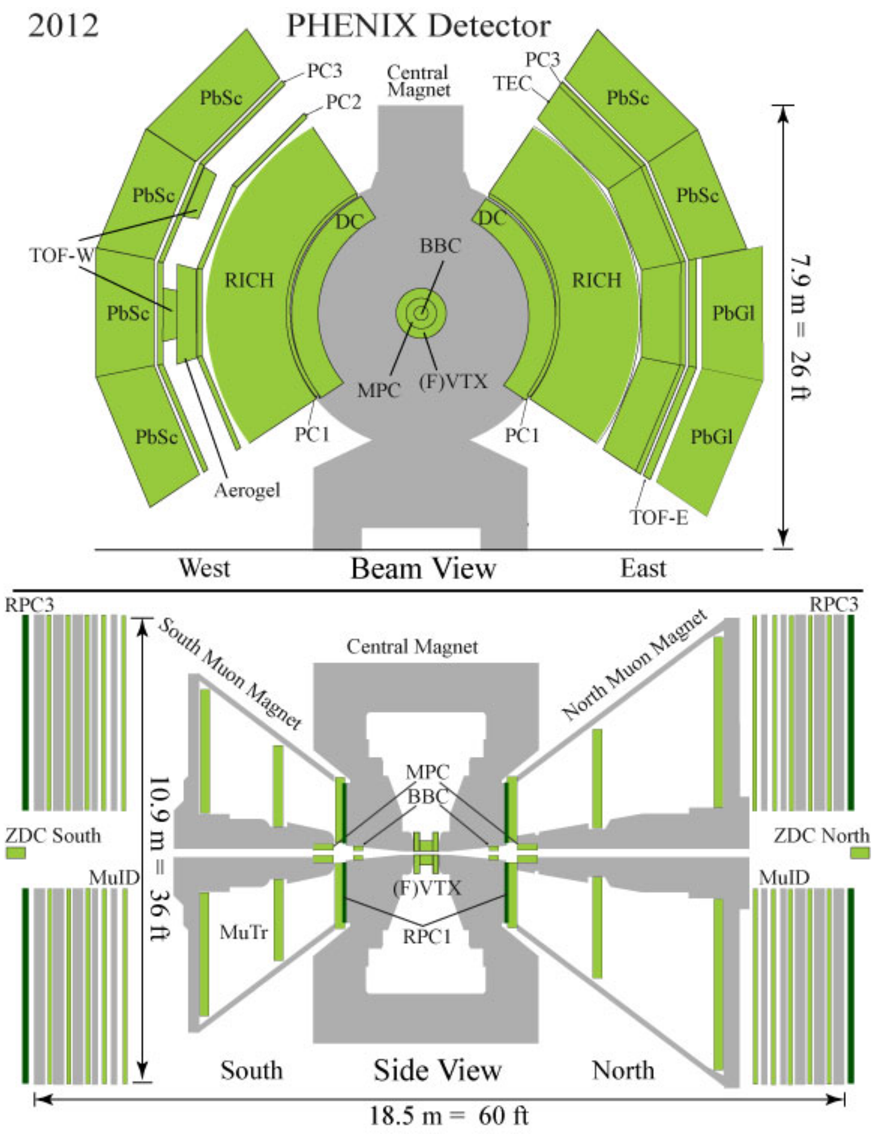
Maya SHIMOMURA for the PHENIX Collaboration
Nara Women's University

2022 RHIC/AGS Annual Users' Meeting
June 7th 2022

THE PHENIX EXPERIMENT

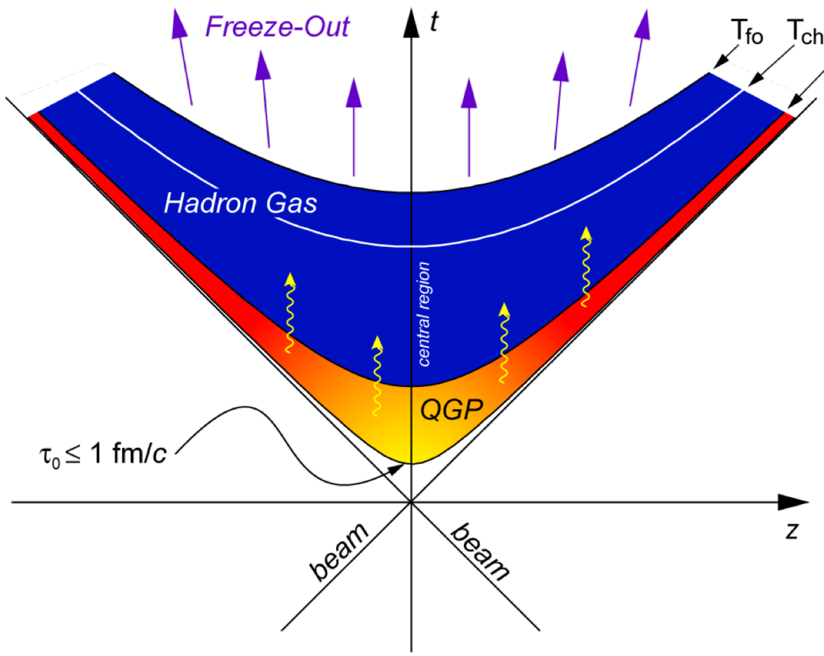
- Data taking is completed in 2016.
- Collaboration is actively working for data analysis
- Data with 9 collision species and 9 collision energies have been obtained.

$\sqrt{s_{NN}}$ [GeV]		Al	Au	Au	Au	Cu Cu	Cu Au	Au Au	U U
510	✓								
200	✓	✓	✓	✓	✓	✓	✓	✓	✓
130								✓	
62.4	✓			✓		✓		✓	
39				✓				✓	
27								✓	
20				✓		✓		✓	
14.5								✓	
7.7								✓	



Time evolution

The matter produced in the high energy heavy ion collision is expected to undergo several stages from the initial hard scattering to the final hadron emission.



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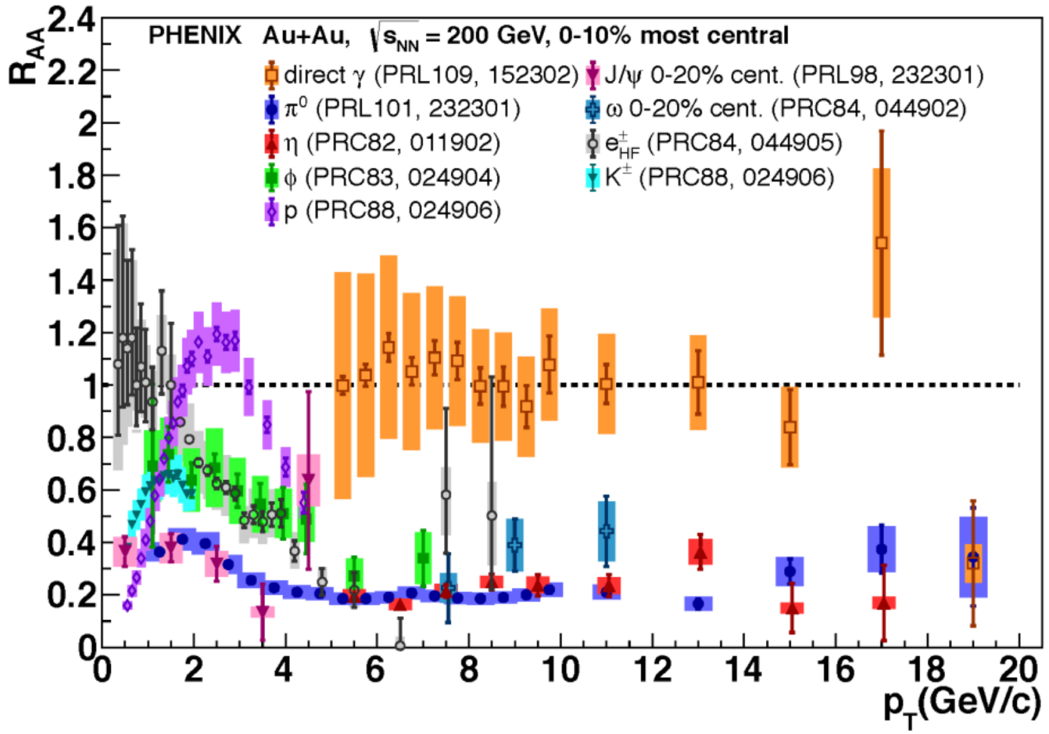
	Kinematical freeze-out
Hadron gas	Chemical freeze-out
Mixed phase	Hadronization Expansion & Cooling
QGP	Thermalization
pre-equilibrium	Hard scatterings
Collision	

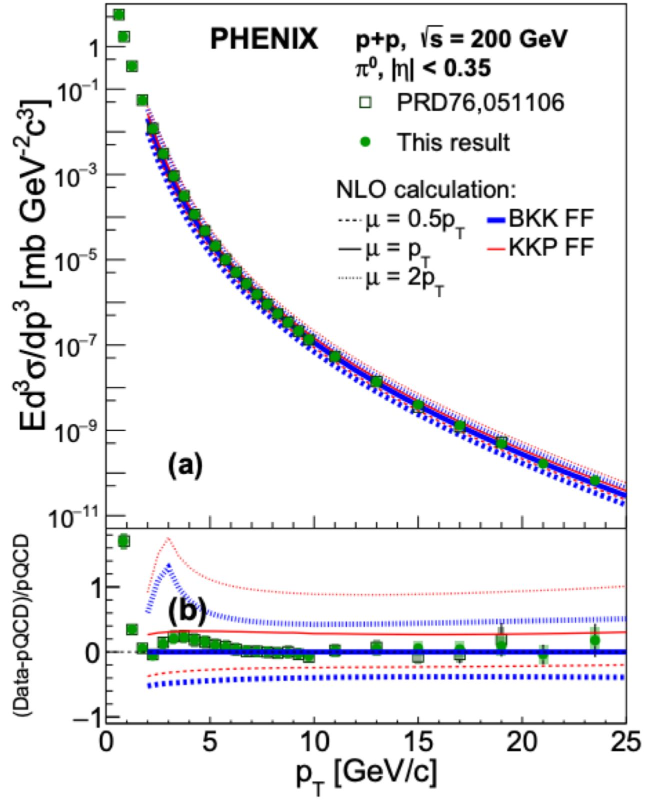
Need a comprehensive understanding from initial hard scattering to final freeze out.

R_{AA} for hadrons & γ in Au + Au

$$R_{AA} = \frac{yield(AuAu)}{N_{coll} \cdot yield(pp)}$$



How is between ?



- Hadrons are strongly suppressed. →strongly interacted with QGP
- γ is not → no interaction with QGP.
- pQCD calculations agree well to data in p+p.

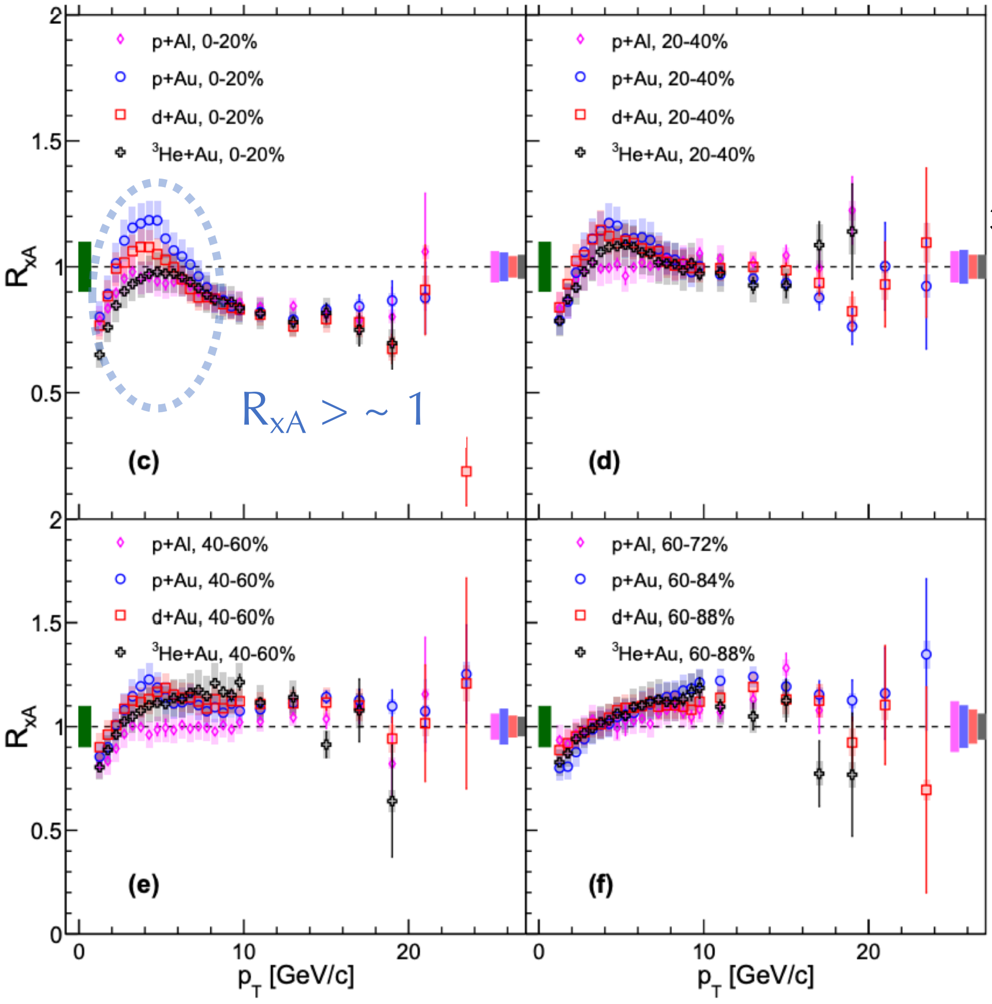
Contents

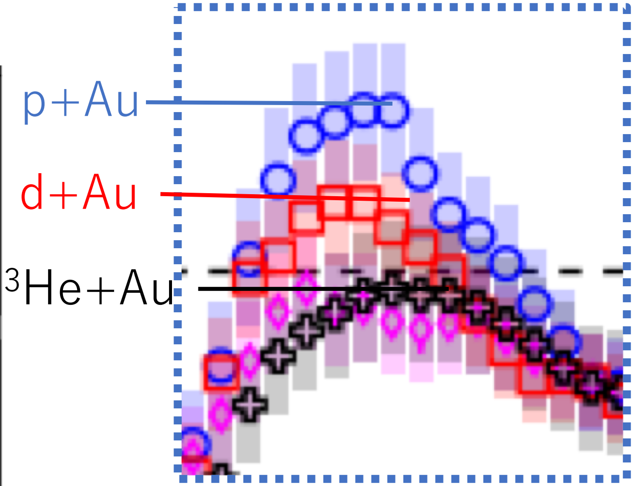
Focus on Small systems

- π^0 R_{xA} in pAl, pAu and ^{3}HeAu
- π^0 and γ R_{dAu} for experimental N_{coll}
- ϕ and π^0 R_{AB}
- J/ψ, ψ(2S)R_{AB}
- v_2 and v_3 with 3x2PC

π^0 R_{xA} in pAl, pAu, dAu and ^{3}HeAu

PRC **105**, 064902



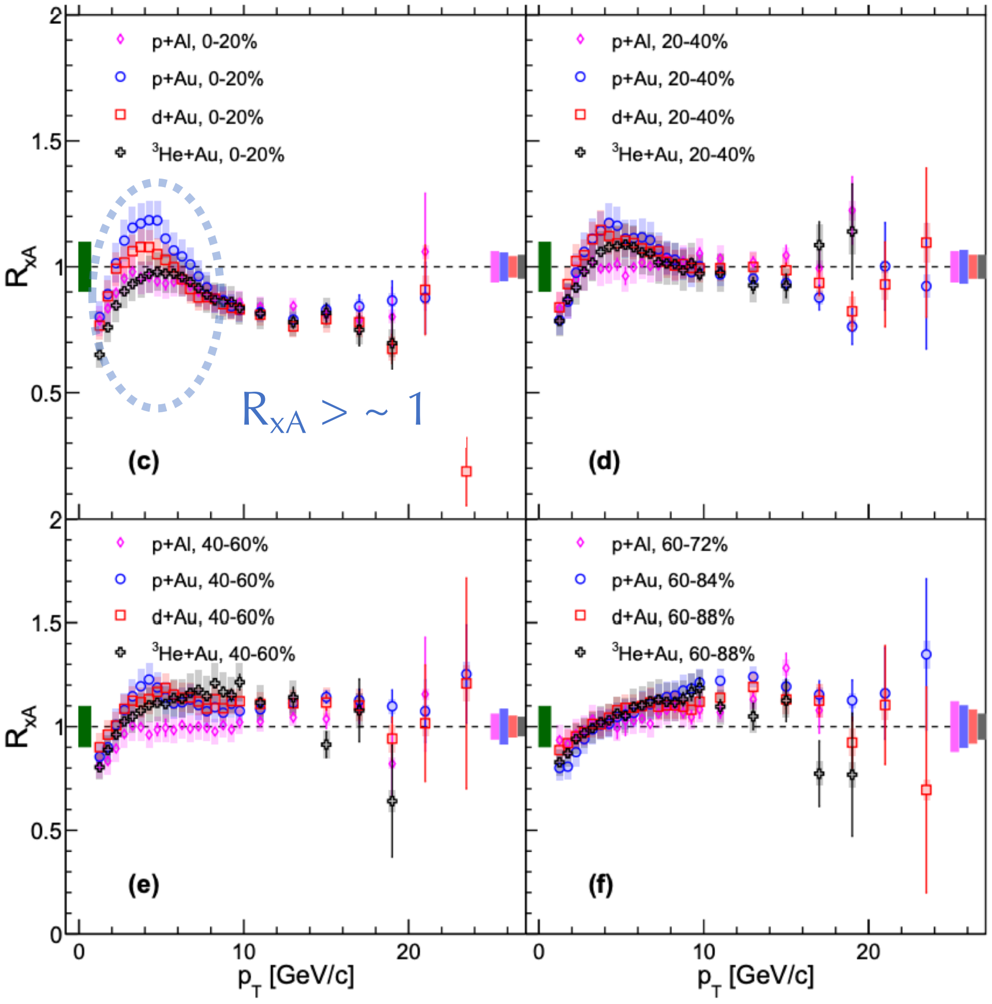


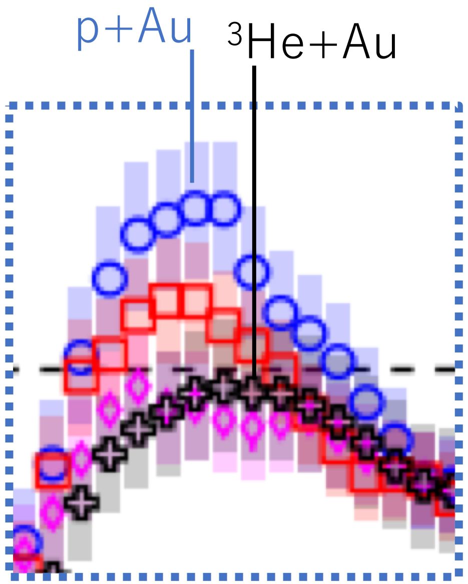
KT broadening ?
Why this order ?
-some bias ?

At low p_T at 0-20 %
- R_{xA} > ~ 1
- Target difference (Al/Au): p+Al < p+Au
- Projectile difference (p/d/^{3}He):
  ^{3}He+Au < d+Au < p+Au
- The peak shifts to more right with the larger system.

π^0 R_{xA} in pAl, pAu, dAu and ^{3}HeAu

PRC **105**, 064902





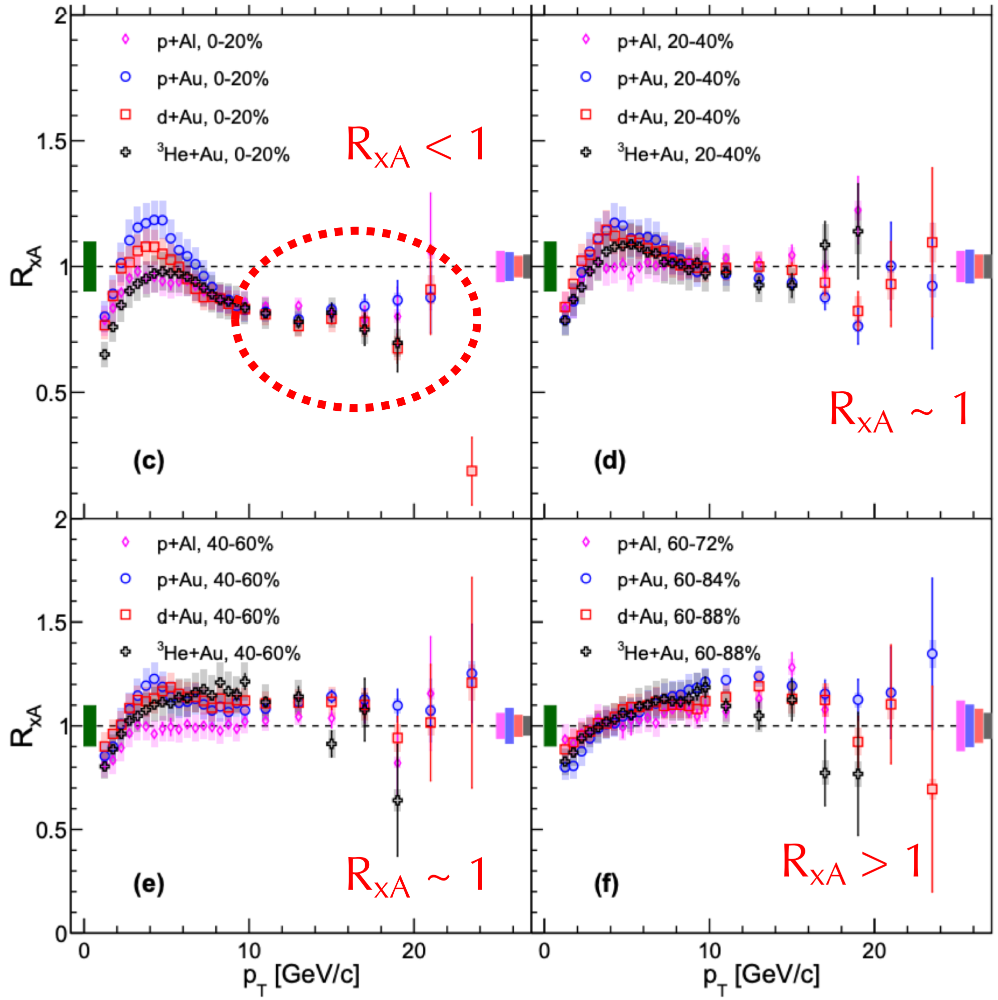
KT broadening ?
Why this order ?
-some bias ?

Radial flow effect ?

At low p_T at 0-20 %
- $R_{xA} > 1$
- Target difference (Al/Au): p+Al < p+Au
- Projectile difference (p/d/^{3}He):
  ^{3}He+Au < d+Au < p+Au
- The peak shifts to more right with the larger system.

π^0 R_{xA} in pAl, pAu, dAu and ^{3}HeAu

PRC **105**, 064902

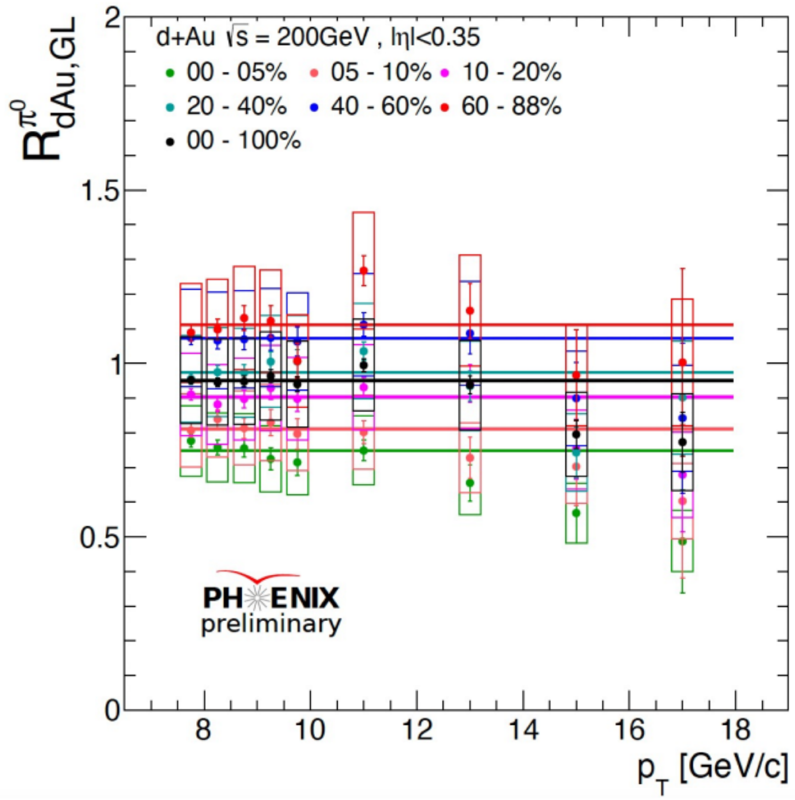


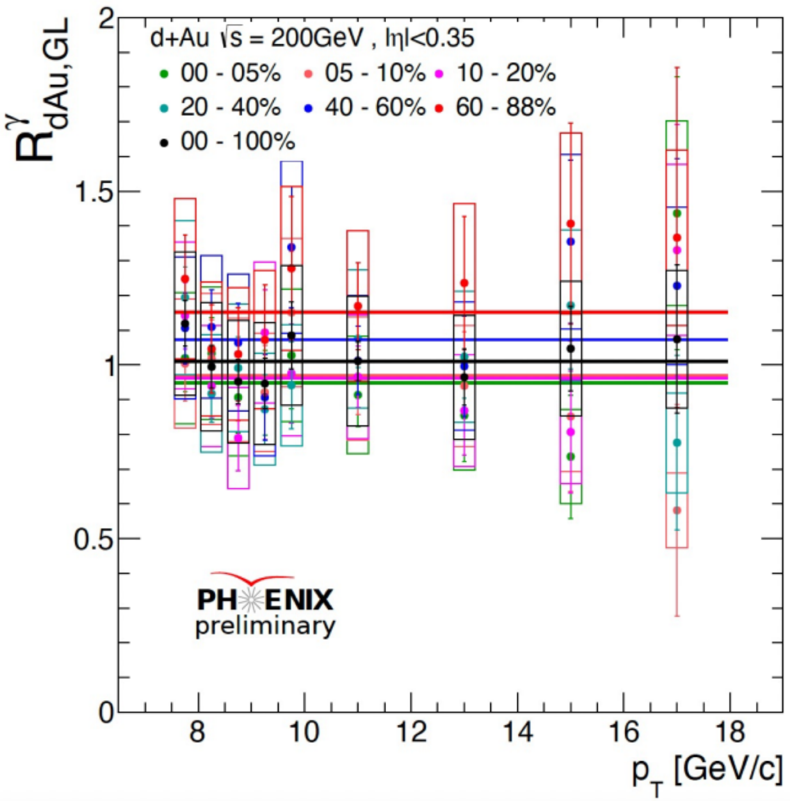
At high p_T ($p_T > 10$ GeV/c)
- $R_{xA} < 1$ at central
- $R_{xA} \sim 1$ at mid central
- $R_{xA} > 1$ at peripheral

Central collision events with high p_T particles may incorrectly categorized as peripheral events due to energy conservation. →Corrected

Suppression is observed at very high p_T at central collisions for small systems.
→ Energy loss ?
→ MC-Glauber Ncoll is really OK for peripheral ??

π^0 and γ R_{dAu} with MC-Glauber N_{coll}





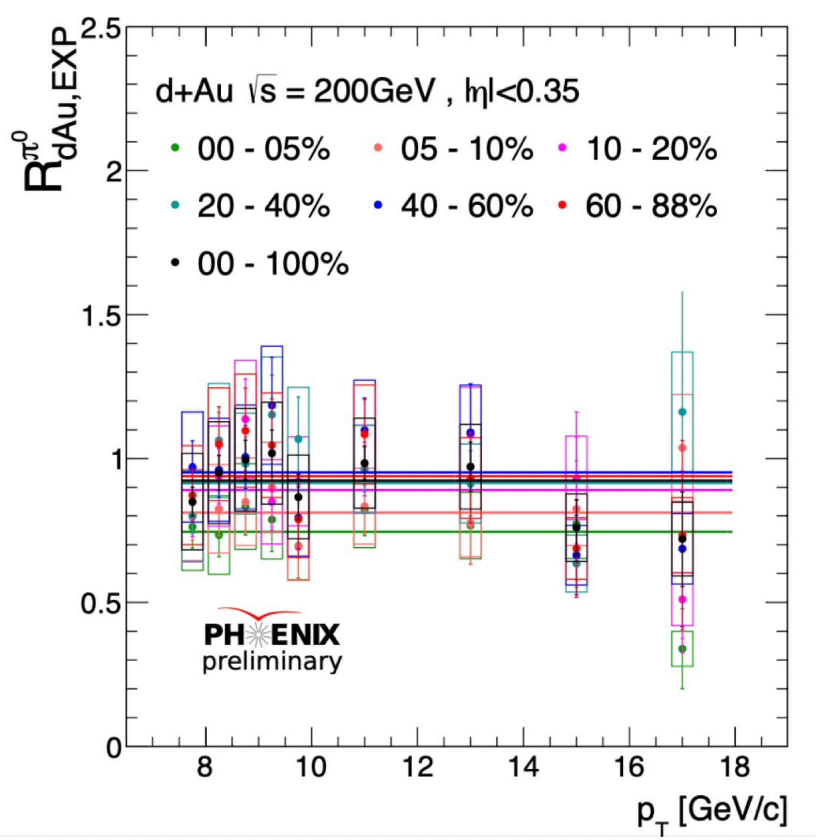
There seems to be some bias on MC-Glauber Ncoll calculation at peripheral.

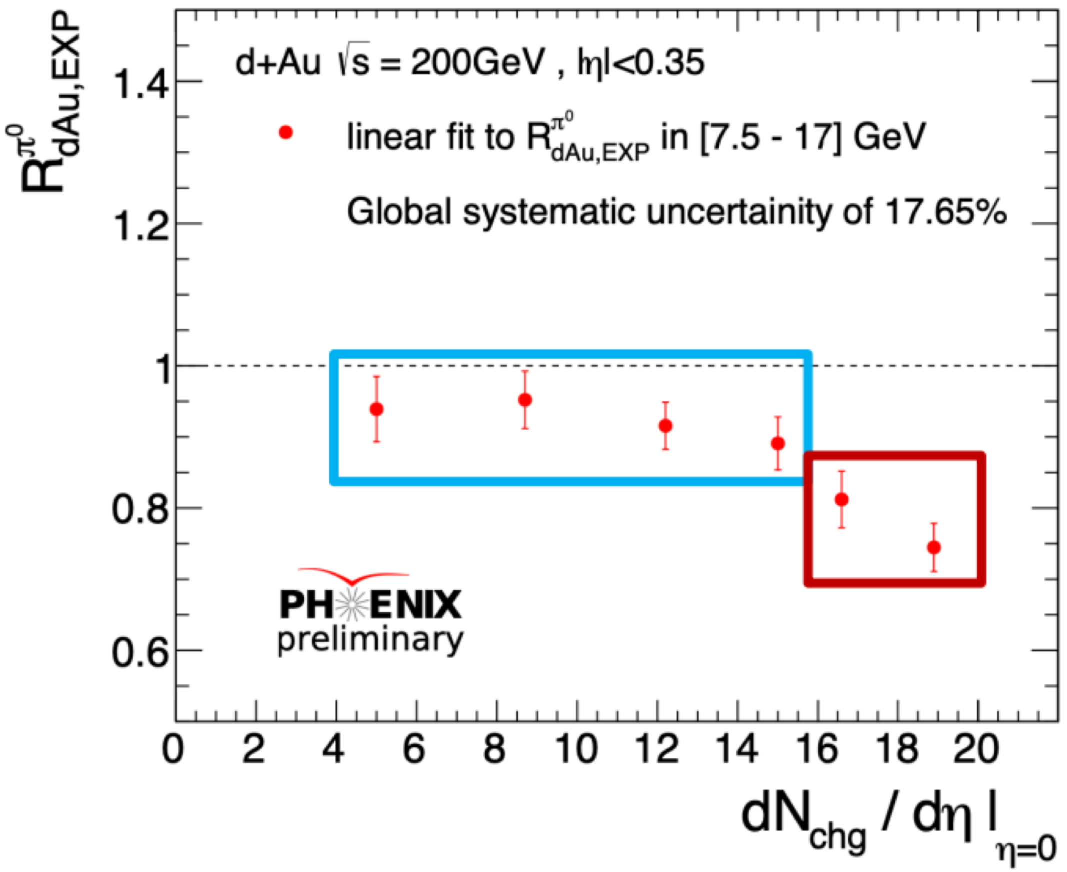
Even γ R_{dAu} shows the enhancement at most peripheral, amount of that matches that of π^0 R_{dAu} .

→ Introduce experimentally determined N_{coll}

$$\langle N_{coll}^{exp} \rangle = \frac{\left(\frac{d^2N^\gamma}{dp_T d\eta}\right)_{dAu}}{\left(\frac{d^2N^\gamma}{dp_T d\eta}\right)_{pp}}$$

π^0 R_{dAu} with experimental N_{coll}

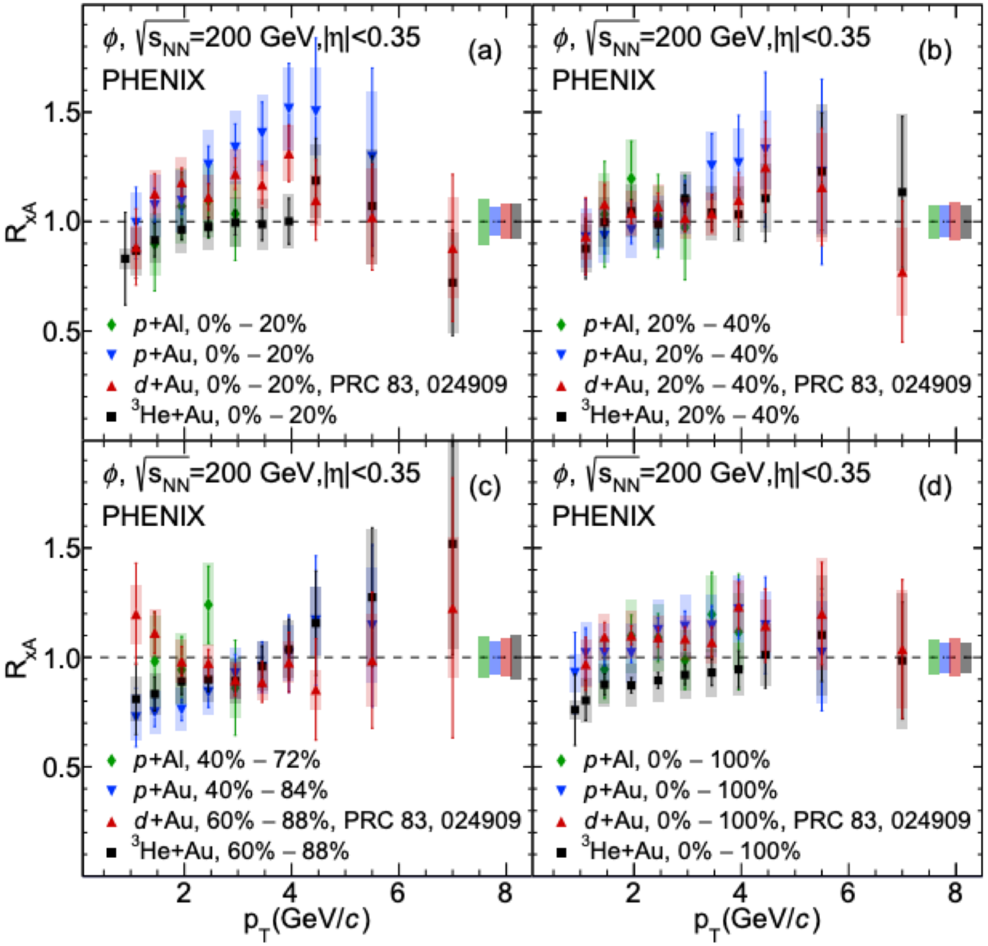




- After the correction, π^0 R_{dAu} with p_T integrated [7.5-17 GeV/c] is less than 1 for all measured centralities.
- It shows suppression in central collisions clearly. → QGP-like matter ?

ϕ R_{xA} in p+Al, p+Au, d+Au and ^{3}He+Au

arXiv:2203.06087



*The normalization uncertainty from p+p is about 9.7%.

At MB
- R_{xA} are ~1 within large uncertainties.

At 0-20 %
- Ordering is observed:
  ^{3}He+Au < d+Au < p+Au
  → Same as π^0 R_{xA}

ϕ R_{xA} in p+Al, p+Au, d+Au and ^{3}He+Au

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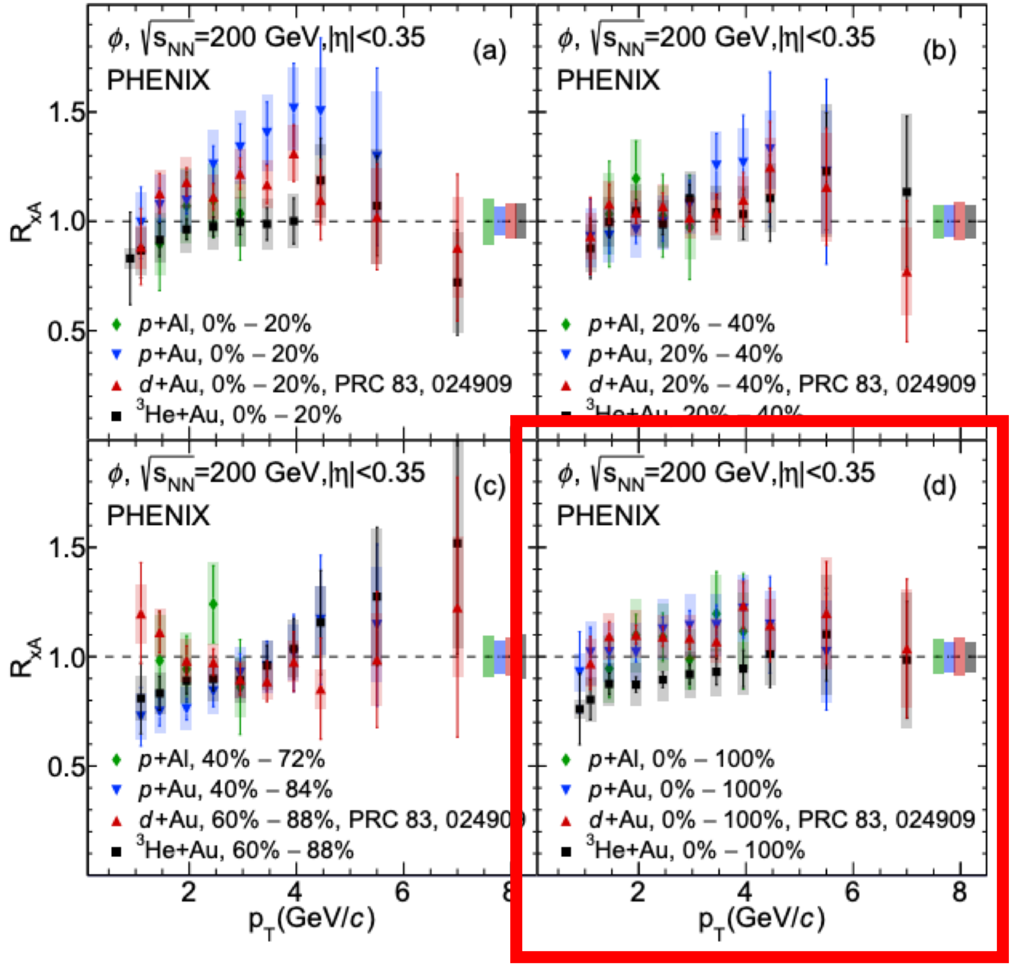

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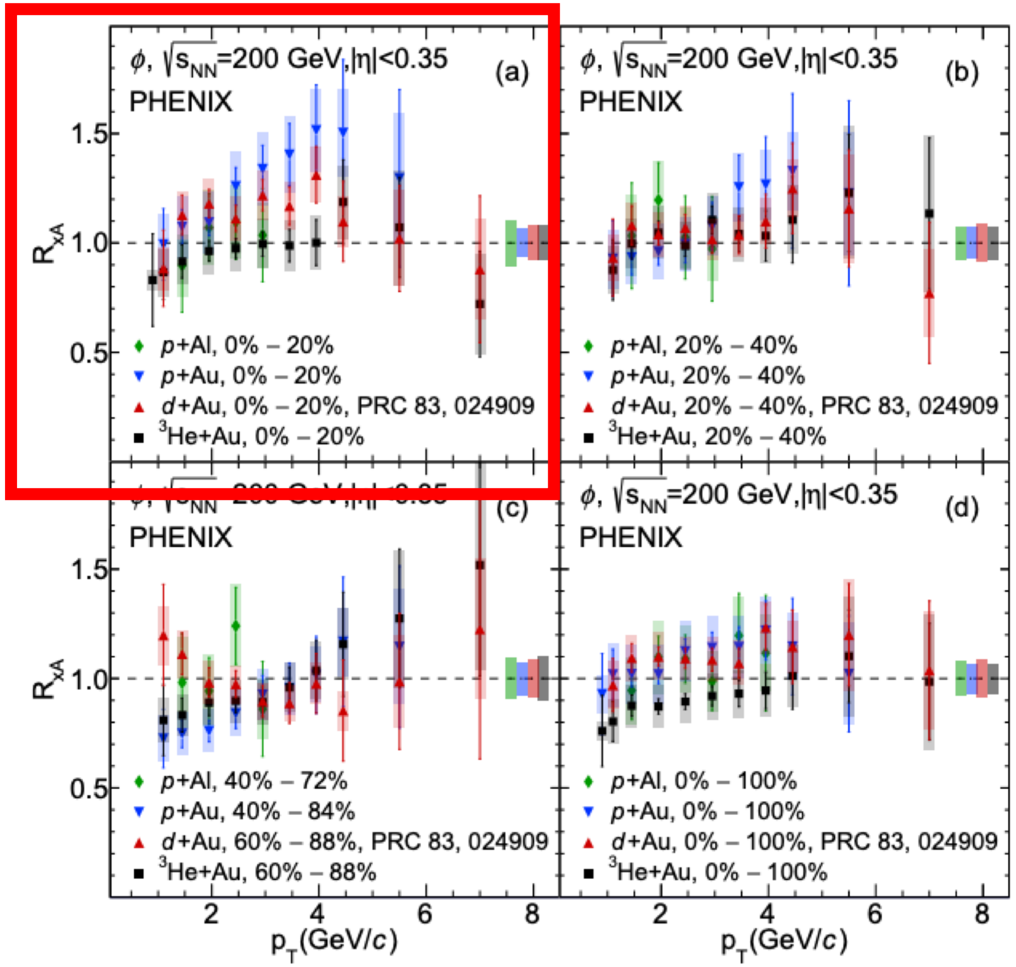

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At 0-20 %

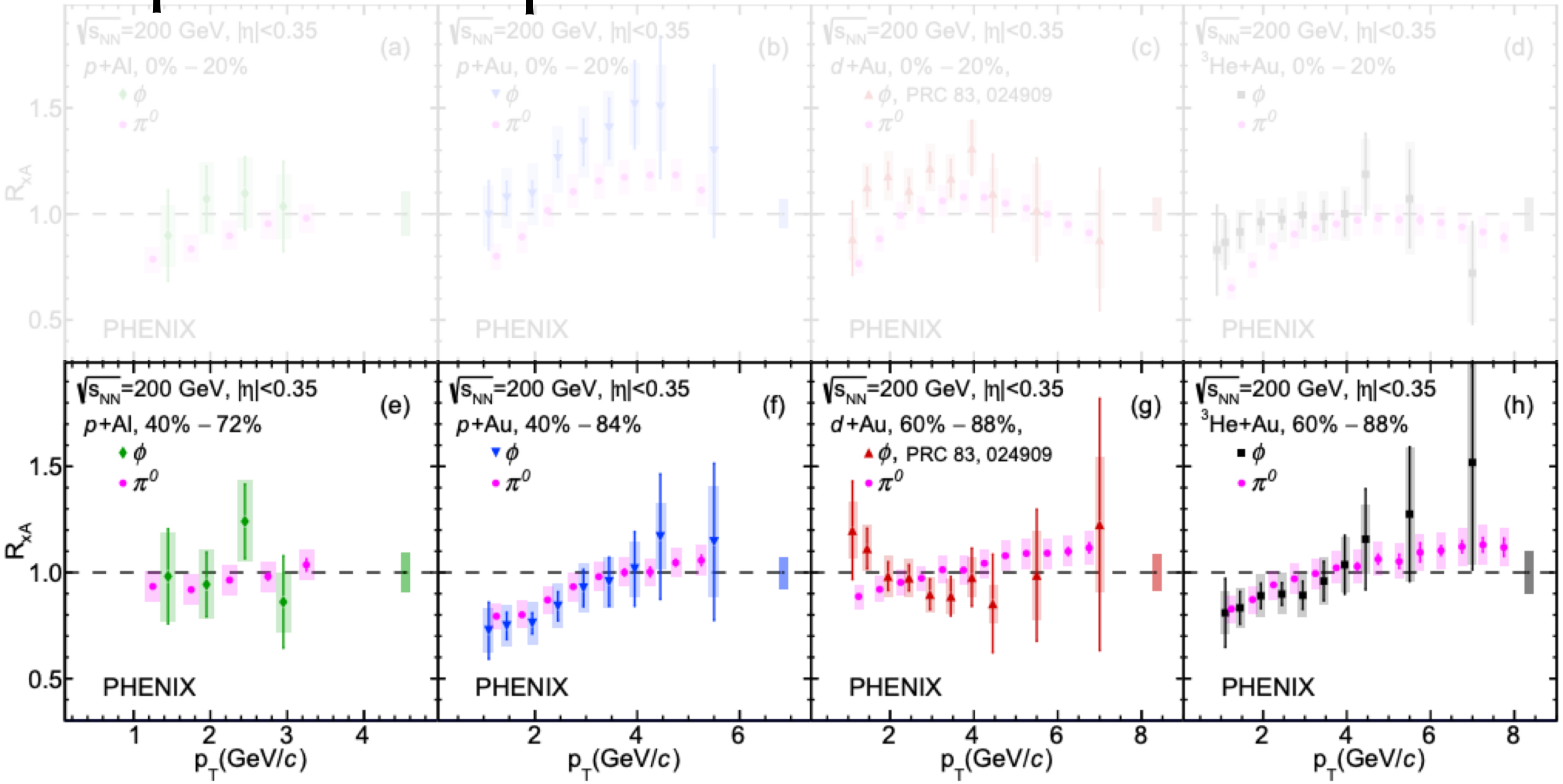
- Ordering is observed: ^{3}He+Au < d+Au < p+Au

→ Same as π^0 R_{xA}

Comparison of ϕ to π^0 R_{xA}

arXiv:2203.06087

pAl pAu dAu ^{3}HeAu

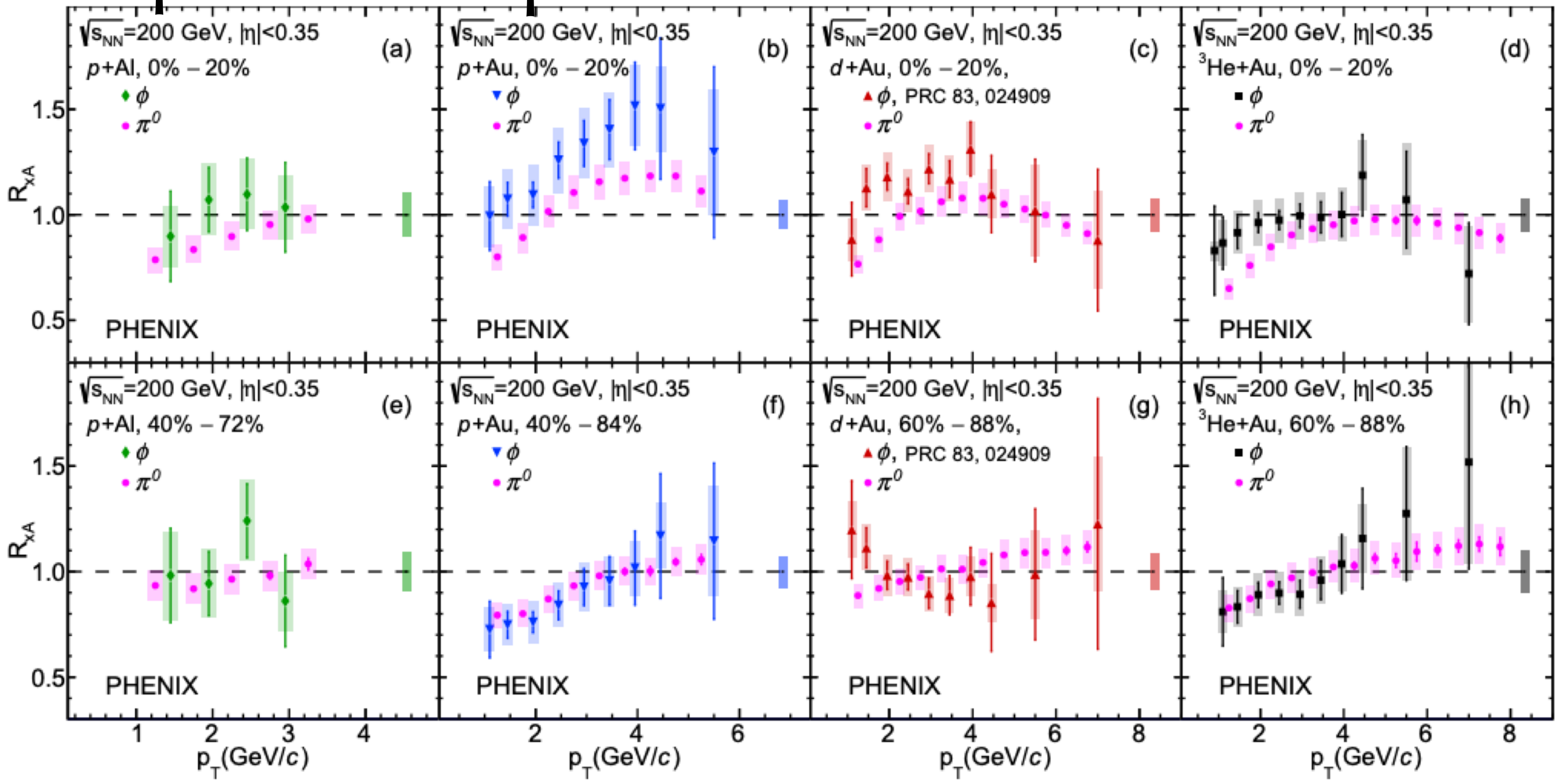


Peripheral:
ϕ to π^0 agree well.

Comparison of ϕ to π^0 R_{xA}

arXiv:2203.06087

pAl pAu dAu ^{3}HeAu



Central:
Strangeness enhancement ?

Peripheral:
ϕ to π^0 agree well.

The ϕ meson R_{xA} seems to be higher than π^0 R_{xA} in central collision possibly due to strangeness enhancement.
→ Cannot be concluded due to the large uncertainty.

J/ψ R_{AB} in p+Au and ^{3}He+Au

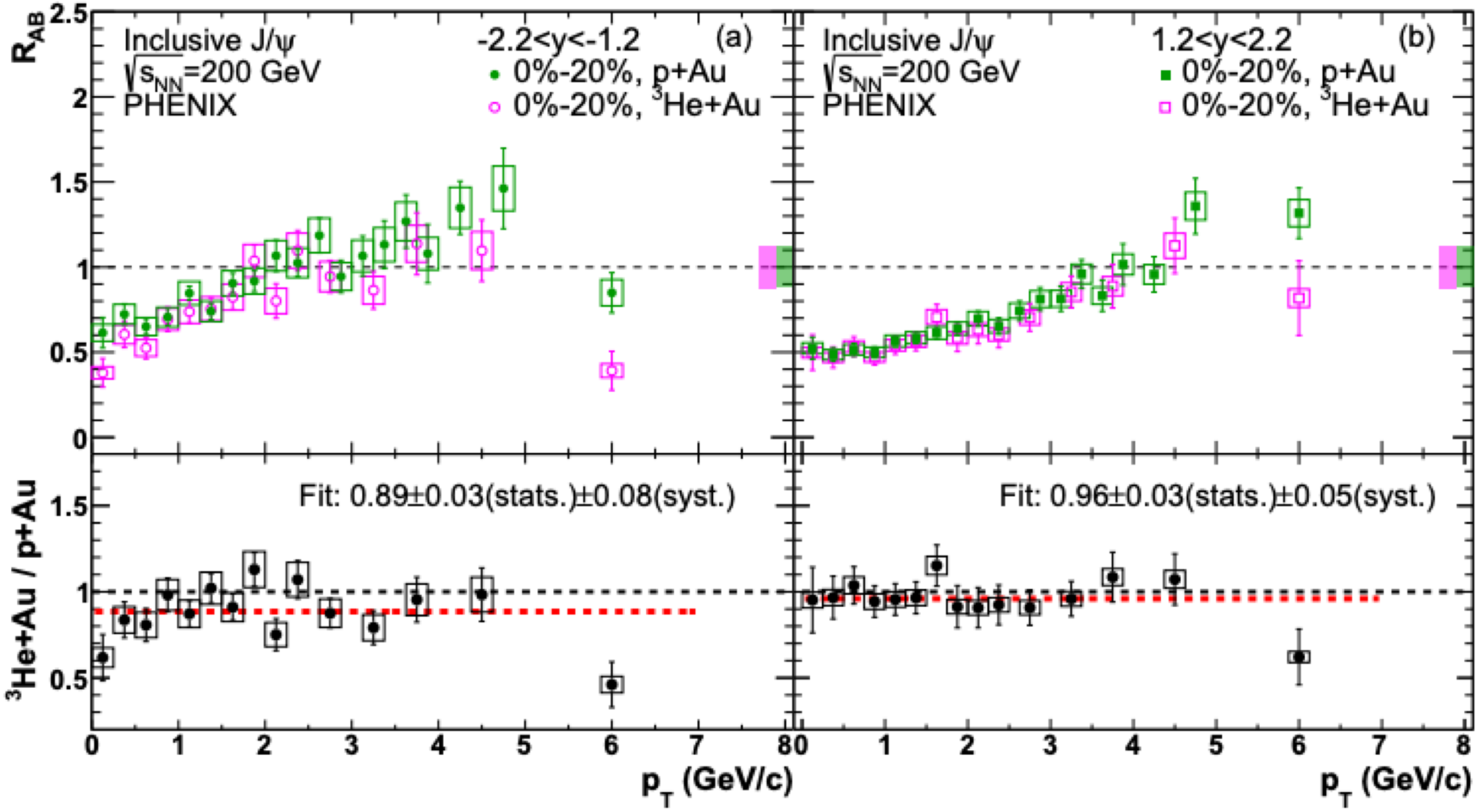
PRC 102, 014902 (2020)

backward

Au-going

forward

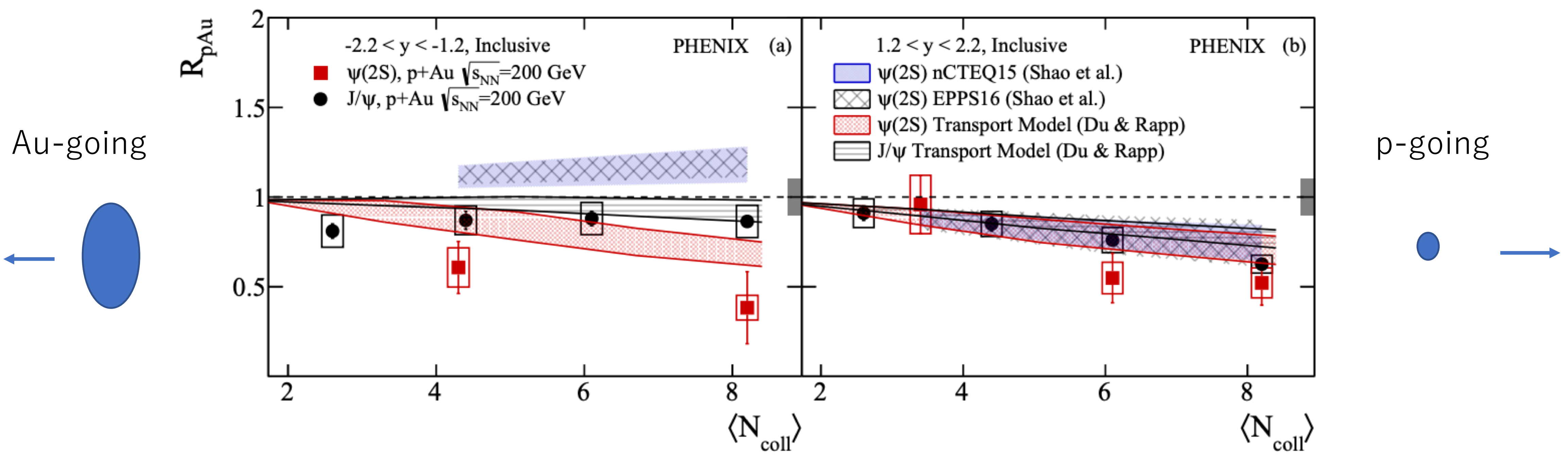
p/^{3}He-going



- CNM effects seem to be dominant.
- Small final effect at Au-going side(bkwd) while no final effect at p/^{3}He-going side(fwd)

Comparison of J/ψ to ψ(2S) R_{pAu} in p+Au

arXiv:2202.03863



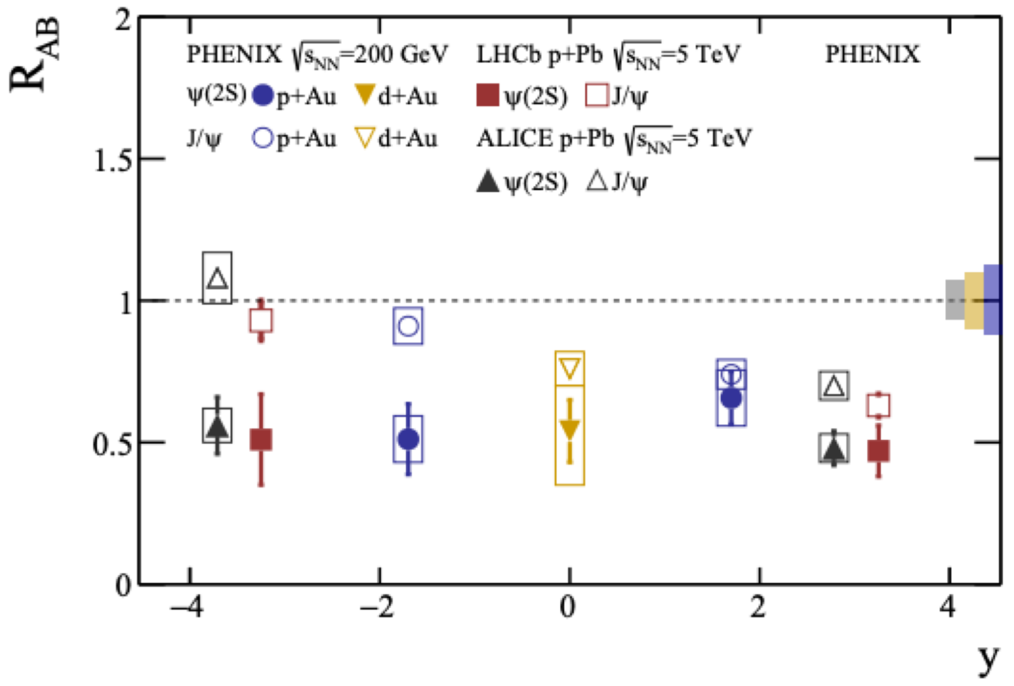
- Similar suppression is observed at p(d)-going side(fwd).
- Only ψ(2S) suppress at Au-going side but not J/ψ.
- Transport-model describes the relative modification well but underpredicts the suppression for ψ(2S).

→ The suppression of ψ(2S) seems to be due to the final state effects.

J/ψ, ψ(2S) R_{AB} at RHIC and LHC

arXiv:2202.03863

Au-going

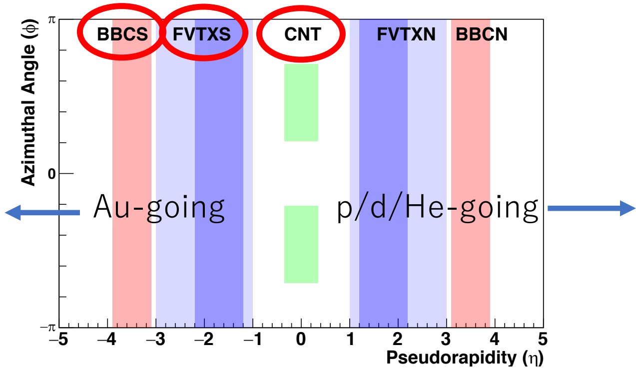


p/d-going

- No significant difference between PHENIX,ALICE and LHCb.

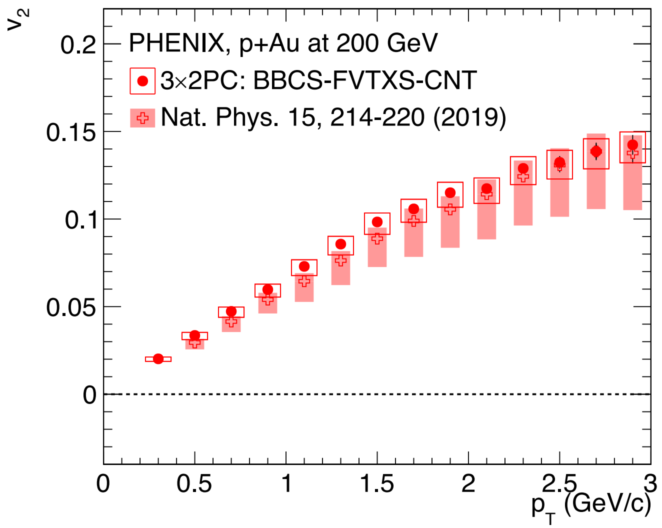
→ No energy dependence. Very similar final effect are observed.

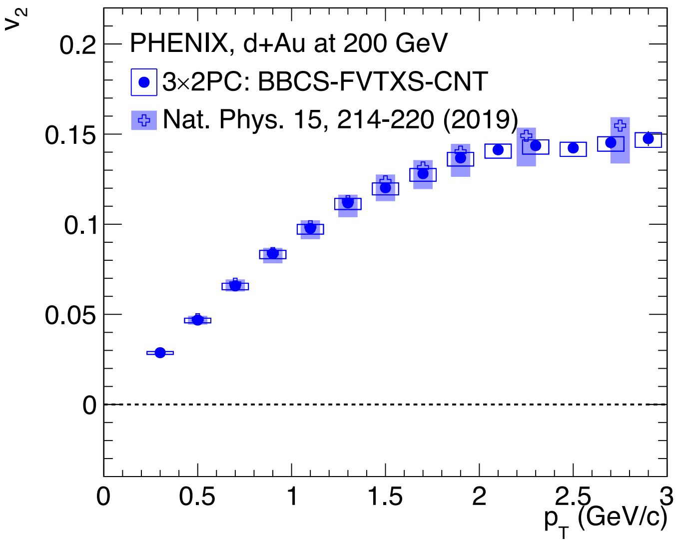
v_2 with 3x2PC at small systems

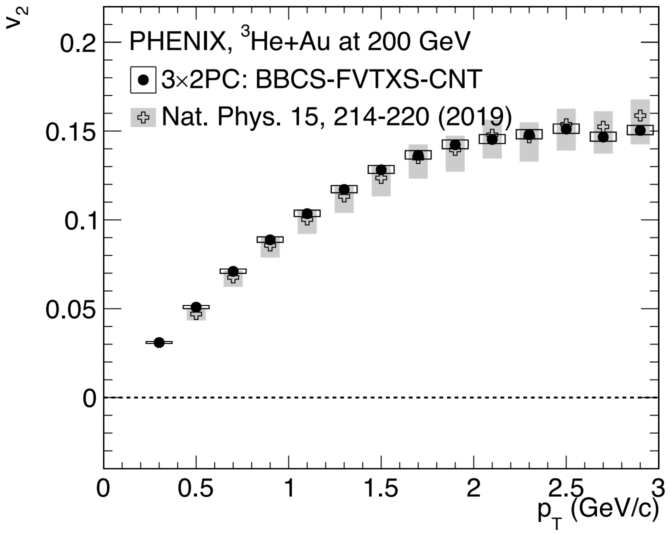


PRC 105, 024901 (2022)

BBCS-FVTXS-CNT
Acceptance combination is same as Nat. Phys



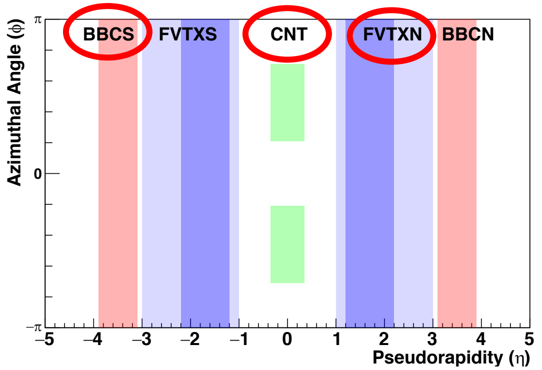




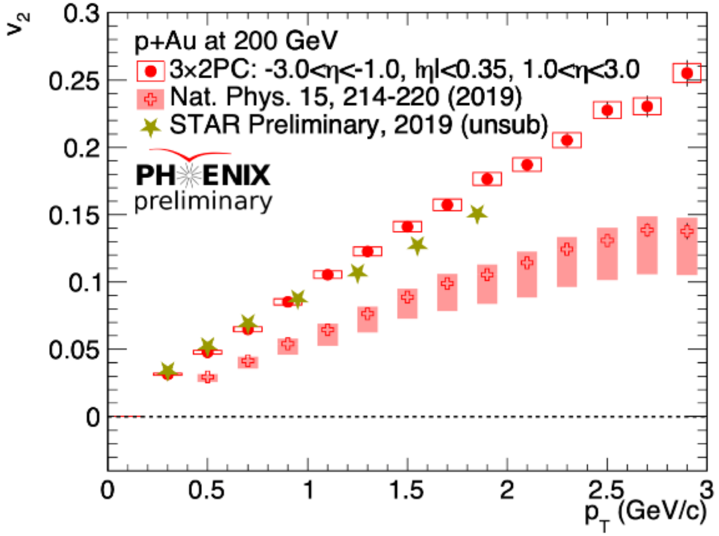
- Combination of 3 detectors (BBCS-FVTXS-CNT) are used for 2PC method to obtain v_2.
- The 3x2PC results confirm the PHENIX Nature Physics results.

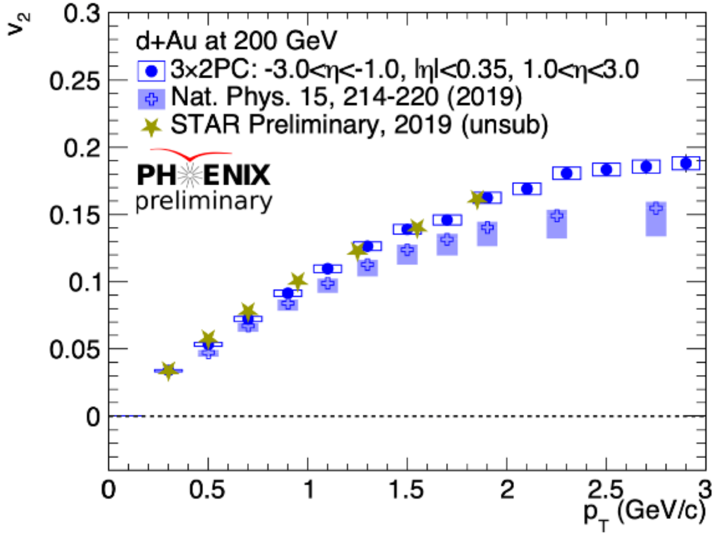
  → Consistent with the QGP droplet picture.

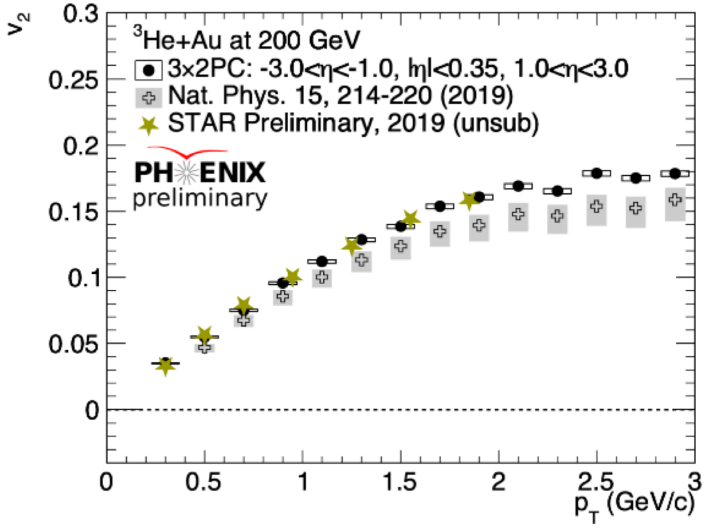
v_2 with 3x2PC at small systems



PRC 105, 024901 (2022)

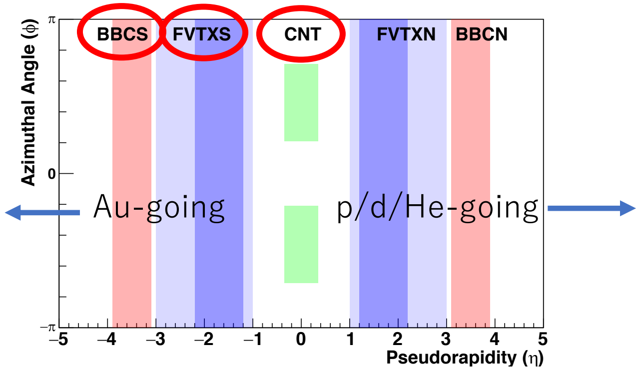






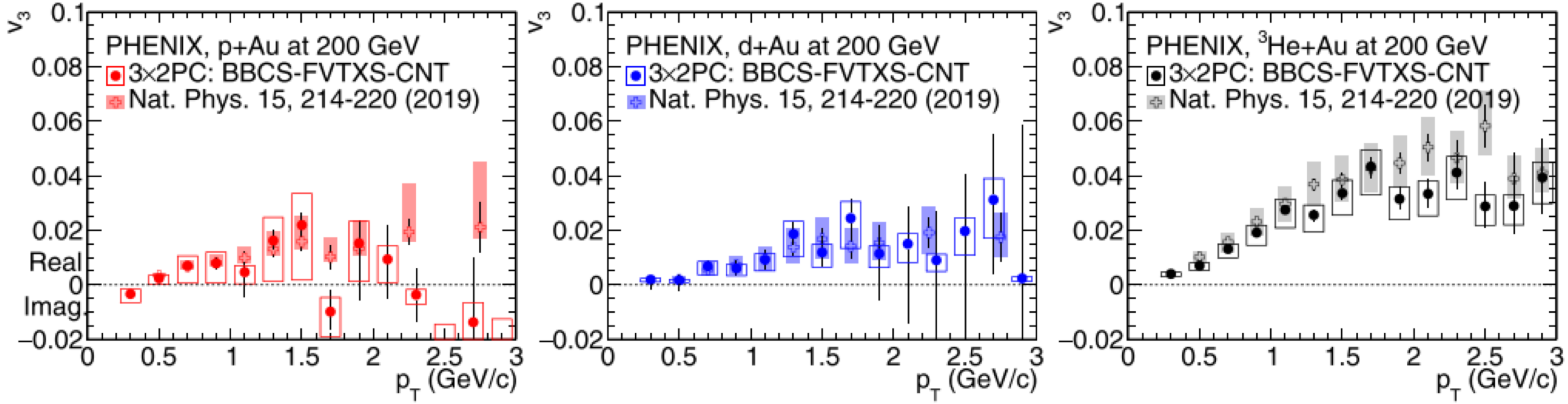
- Forward –Backward combination including more non flow gives larger v_2 than Backward – Backward combination (Nat. Phys).
- Rapidity selection is very important to understand the flow in small systems.
  - This explains the differences between STAR and PHENIX results.

v_3 with 3x2PC at small systems



PRC 105, 024901 (2022)

BBCS-FVTXS-CNT Acceptance combination is same as Nat. Phys

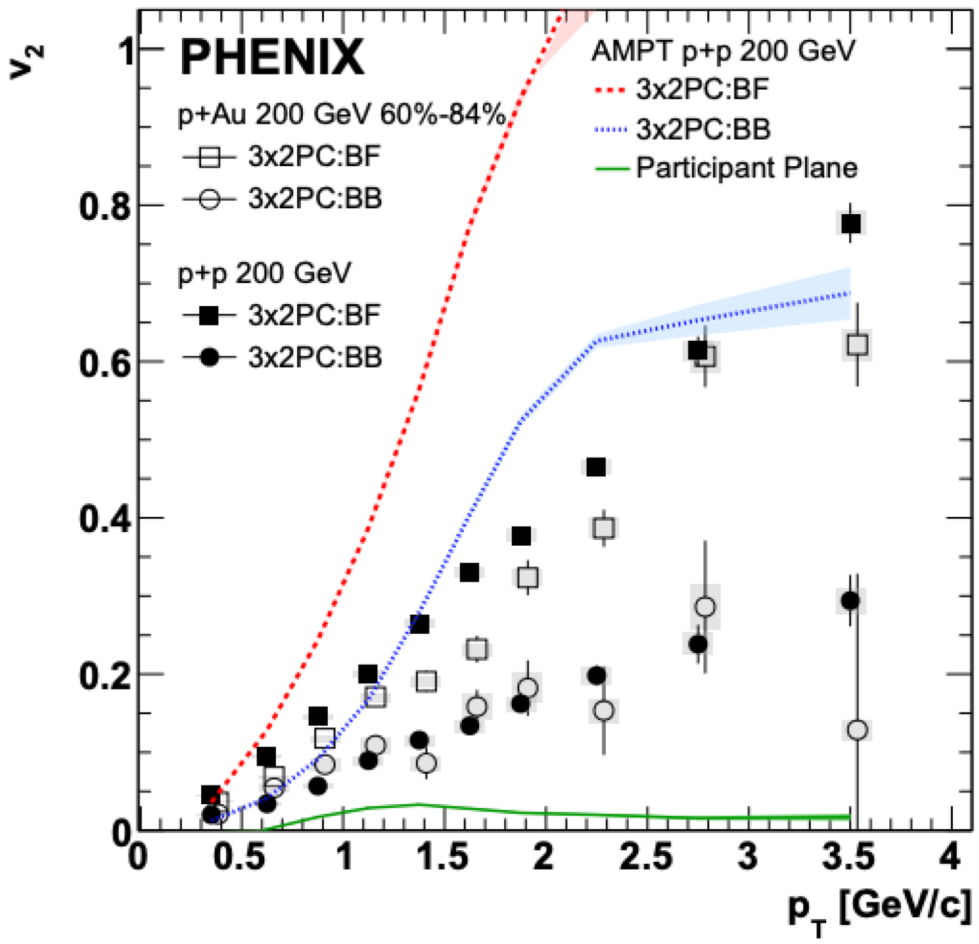


- v_3 is also obtained with same 3x2PC method as v_2.
- The 3x2PC results confirm the PHENIX Nature Physics results.

  → Consistent with the QGP droplet picture.

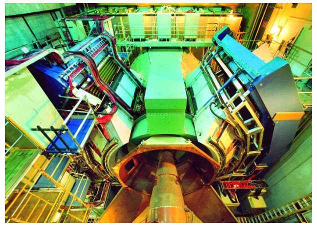
More detailed study for v_2 at small systems with 3x2PC

arXiv:2203.09894



- Systematic study of v_2 on small systems (p+Au, d+Au, $_3$He+Au, from peripheral to central) are conducted.
- v_2 at p+p is also measured.
  - Non-zero v_2
  - v_2\{BB\} and v_2\{BF\} shows difference.
- AMPT w sm doesn't reproduce v_2 quantitatively but show the difference of v_2\{BB\} and v_2\{BF\}.

Summary



PHENIX data in pAl, pAu, dAu and ^{3}HeAu at $\sqrt{s_{NN}}$=200GeV have been analyzed.

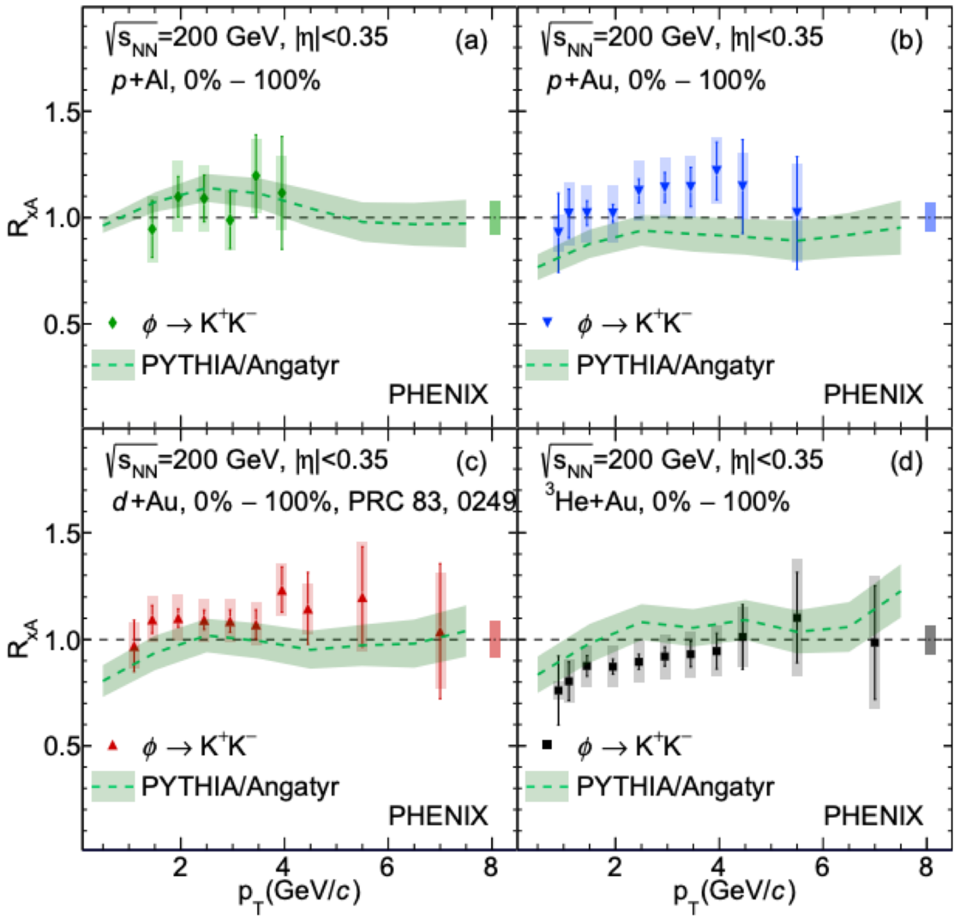
- ϕ to π^0 R_{xA}
  - Cronin effect and radial flow qualitatively explains the results.
  - Suppression is observed at central
  - Strangeness enhancement is not observed clearly so far in any small system. Need more precise study.
- J/ψ R_{AB} and $\psi(2S)$ in dAu at forward/backward
  - Small final effect for J/ψ R_{AB} at Au-going side is seen.
  - $\psi(2S)$ suppress at Au-going side but not J/ψ.
  - RHIC and LHC agrees well.
- v_2 and v_3
  - Previous v_2 and v_3 results are confirmed
  - 3x2PC describes the possible differences with different combination of 3 detectors.
  - Rapidity selection changes v2 a lot.
  - v2 for mid and peripheral centralities are also measuered.
  - Non-zero v2 at 3x2PC methods are observed.

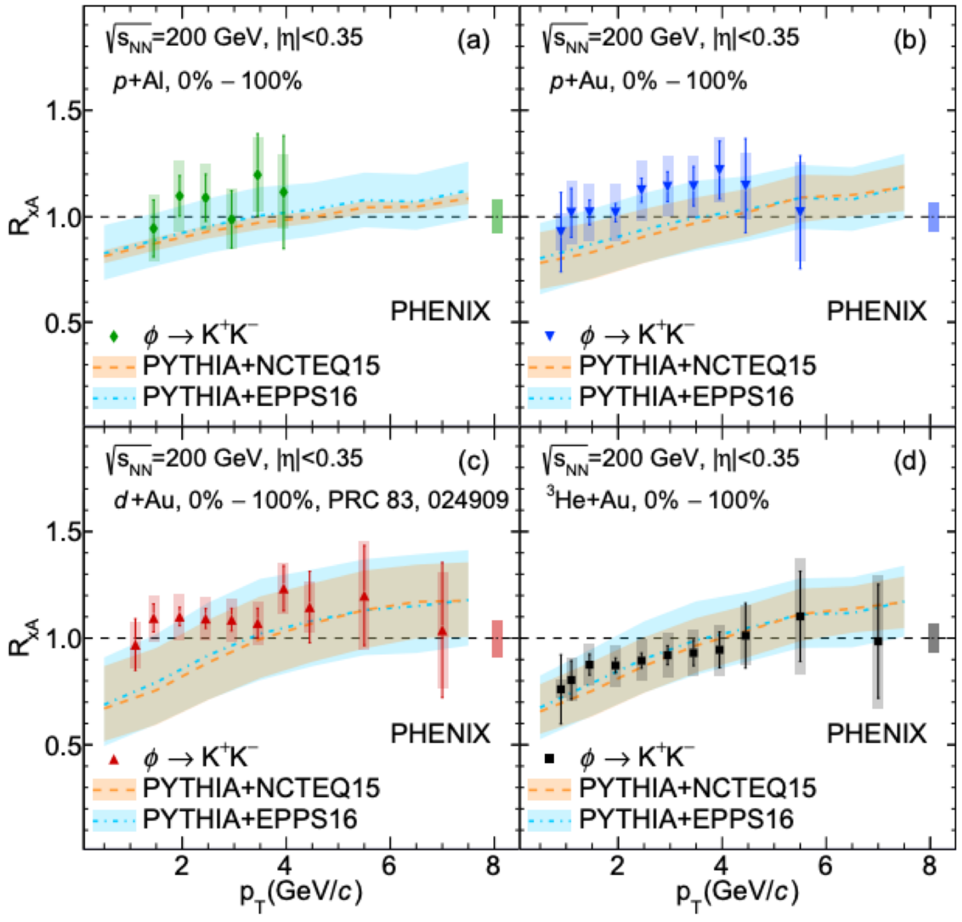
→ π^0 R_{xA} and v_2 results shows the central collisions in the small system except p+p seem to create QGP-like matter at RHIC energy but not exactly same as large system.

Back Up

arXiv:2203.06087

Comparison with model calculations



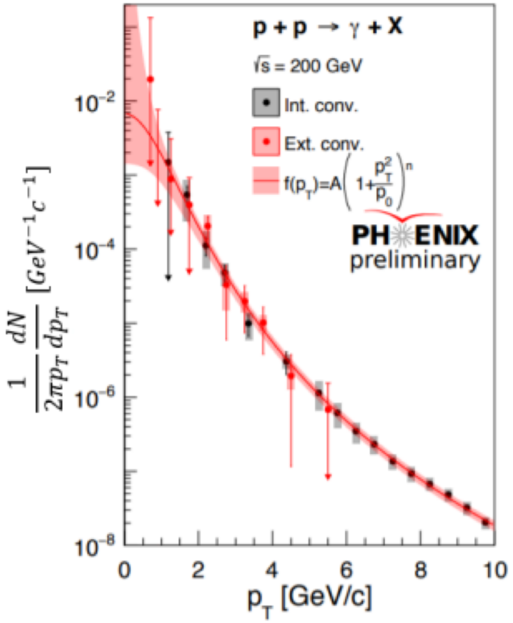


Non of these model calculations can explain all data simultaneously.

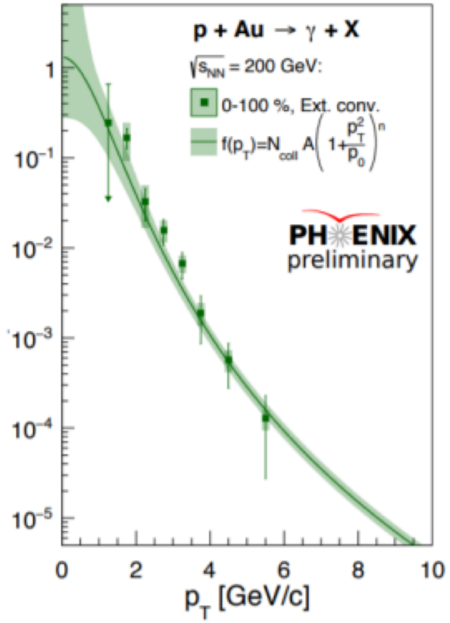
Direct photon enhancement with system size

arXiv:2203.17187

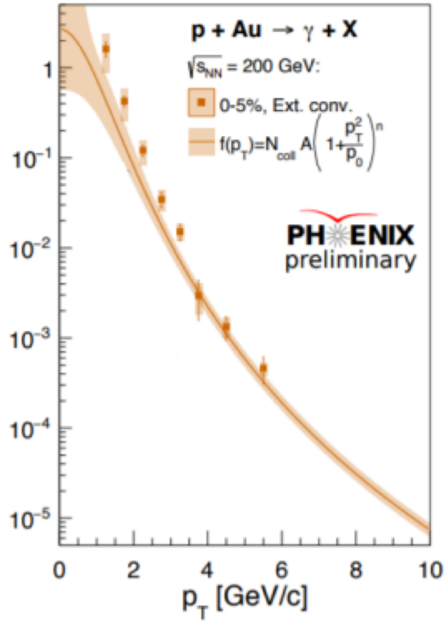
pp



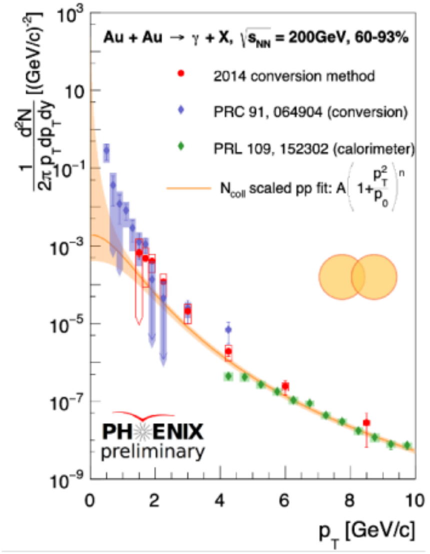
pAu



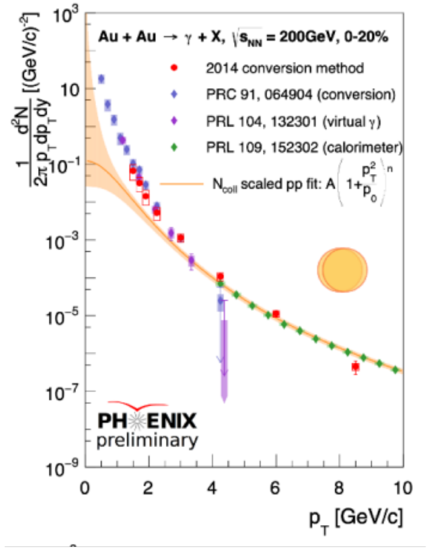
pAu 0-5%



AuAu 60-93%



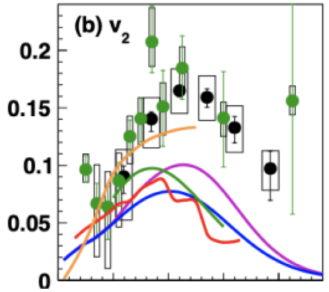
AuAu 0-20%



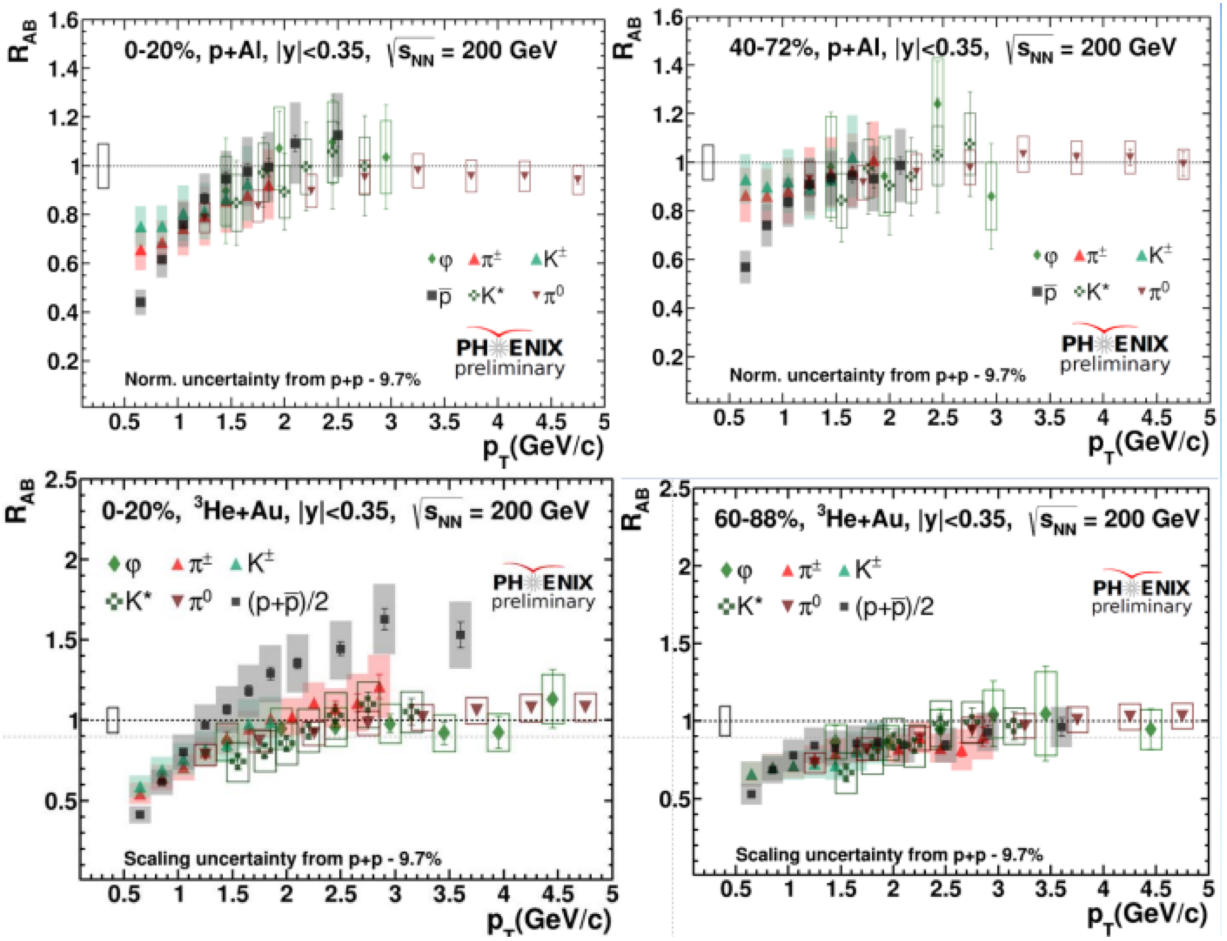
Larger system has more enhancement at low p_T and it may be seen at pAu most central. → relate to QGP size?

Direct photon puzzle together with large v2 emissions.

→ might be hadronization photons ??



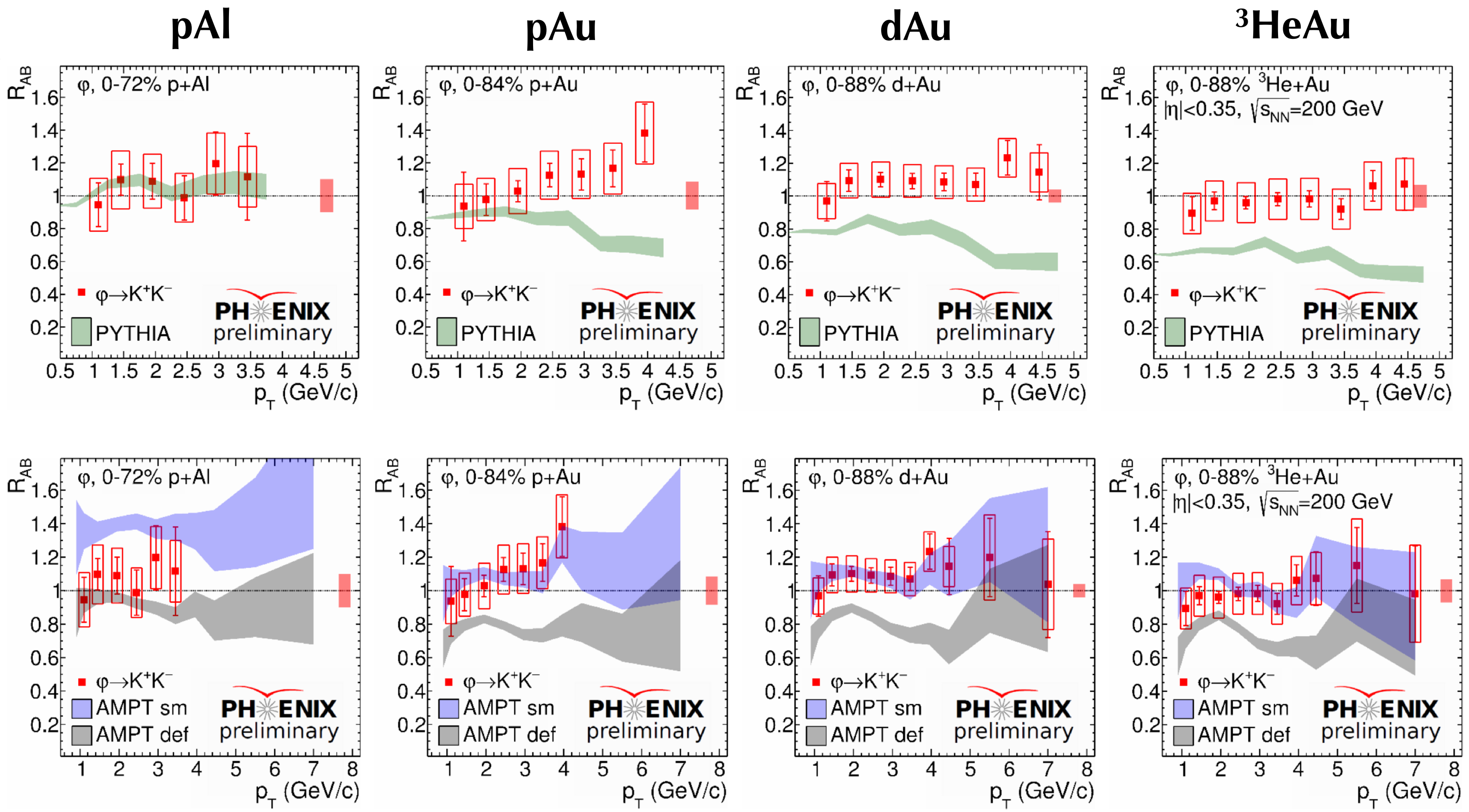
K^{*0}, ϕ and π^0 R_{AB} in pAl and ^{3}HeAu



K^{*0}, ϕ and π^0 all agree well.
- Strangeness enhancement is not observed clearly.

Proton shows enhancement at 0-20% in ^{3}He+Au.
→ Qualitatively agrees with Radial flow/Recombination

φ R_{AB} in pAl, pAu, dAu, and ^{3}HeAu



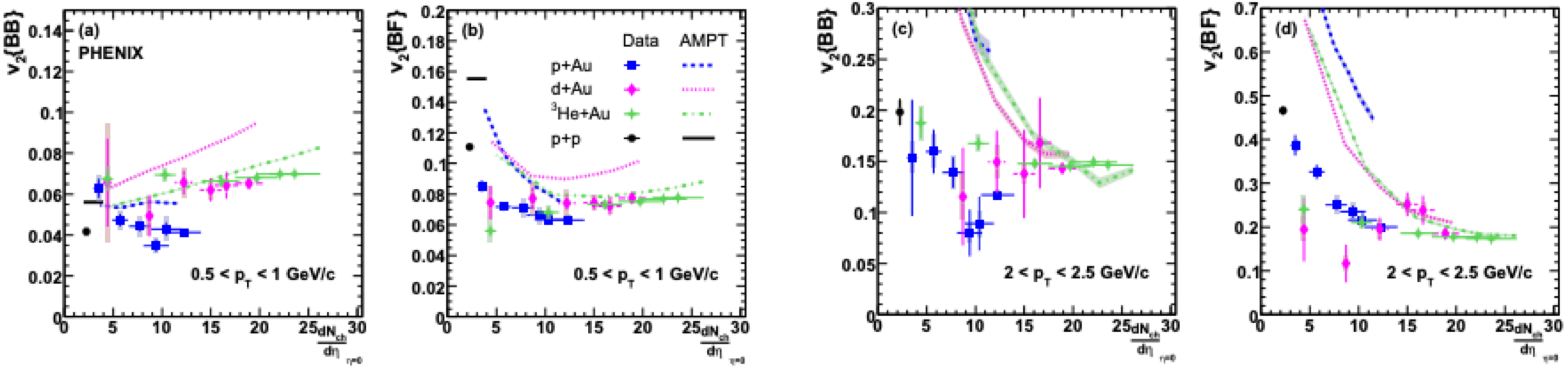
PYTHIA reproduce φ R_{AB} in pAl but underestimate it in pAu, dAu and ^{3}HeAu.

AMPT def (w/o coalessense) agree with φ R_{AB} in pAl while AMPT sm (w coalessense) reproduce it well in pAu, dAu and ^{3}HeAu.

Dominant production process seems to change between pAl and pAu.

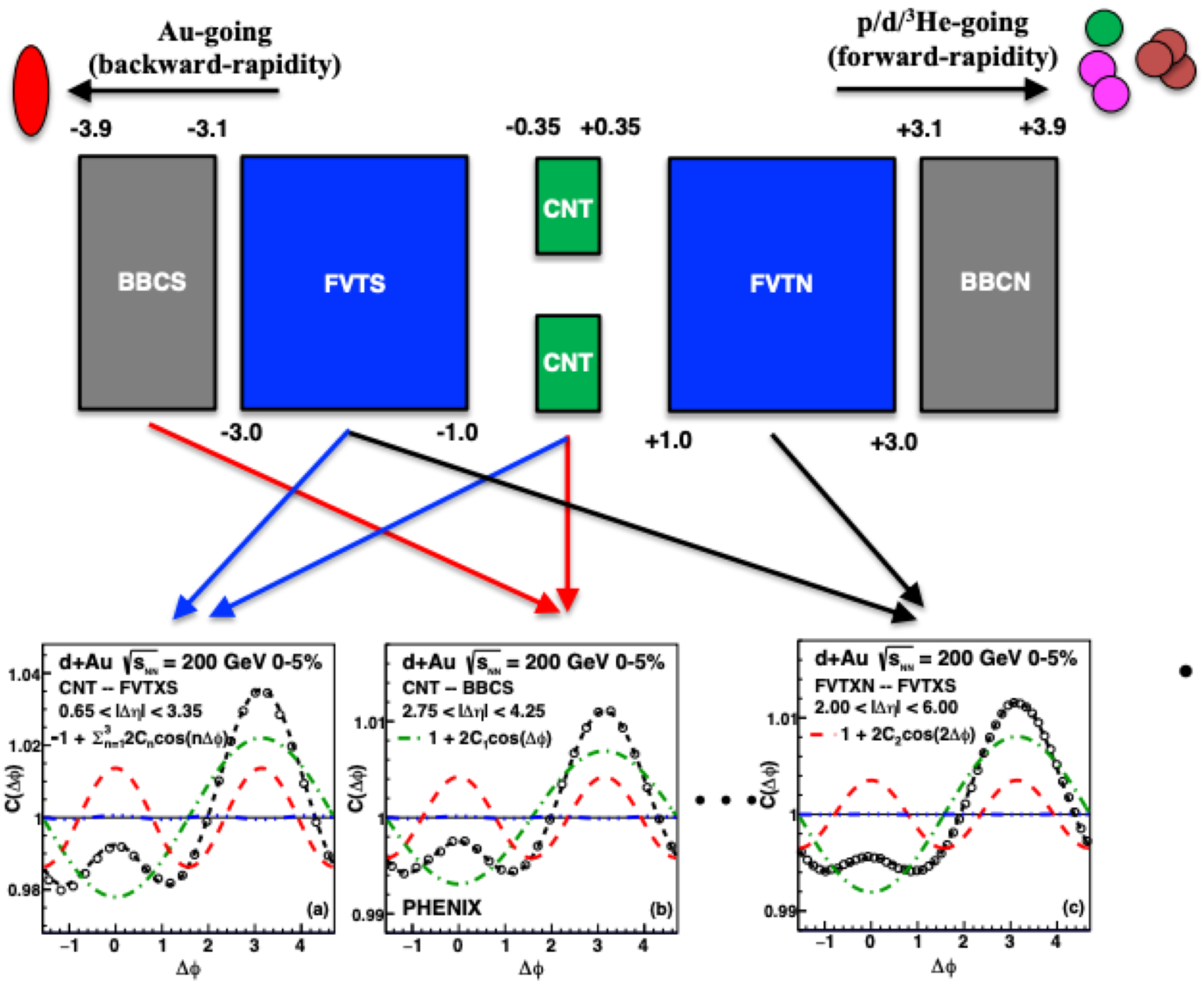
More detailed study for v_2 at small systems

arXiv:2203.09894



- v2{BB} has no smooth connection around dN/dη ~10.
- AMPT-model calculations don't reproduce the qualitative trends of v_2\{BB\} while it shows some agreement for the trends of v_2\{BF\}.

v_n with 3x2PC method



- **Advantage of 2PC :** Cancelling out possible detector and beam optics effects by the event-mixing technique

- Combine three 2PCs to obtain v_n due to the asymmetric collision systems

$$v_n^{A} = \sqrt{\frac{C_n^{AB} \times C_n^{AC}}{C_n^{BC}}} \qquad C_n^{AB} = \langle \cos n\Delta\phi \rangle$$

A, B, C : kinematic ranges

- Measure mid-rapidity v_n with the following rapidity combinations
  - Mid-Back(-3.9<η<–3.1)-Back(-3.0< η <-1.0) : BB
    - Acceptance combination used in the Nature analysis
  - Mid-Back (-3.0< η <-1.0)-For (1.0< η <3.0) : BF

Borrow from Takahito Todoroki's talk at sQM.