Recent Results from PHENIX

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Introduction

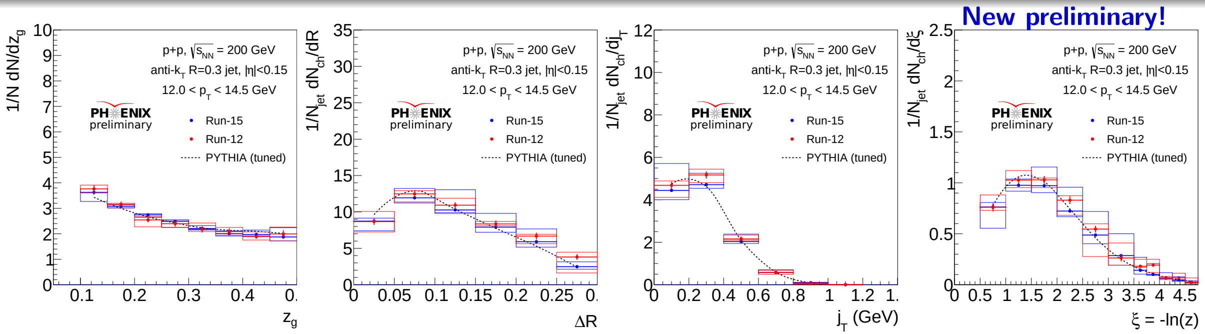
PHENIX at SQM22

- Rachid Nouicer, PHENIX Probing QCD Matter Through Heavy Flavor and Quarkonium at RHIC, PA-HF 2022-06-15 at 9am KST
- László Kovács, Charge kaon femtoscopy with Lévy sources in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions at PHENIX, POS-BLK-21
- Krista Smith, J/ψ in small systems with PHENIX, POS-HF-14

PHENIX papers recently submitted

- arXiv:2203.17058 Charm and bottom quark production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
- arXiv:2203.17187 Non-prompt direct photon production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
- arXiv:2203.12354 Low-p_T direct-photon production in Au+Au collisions at 39 and 62.4 GeV
- arXiv:2203.09894 Measurements of second-harmonic Fourier coefficients from azimuthal anisotropies in p+p, p+Au, d+Au, and ^{3}He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
- arXiv:2203.06087 Study of ϕ meson production in in p+Al, p+Au, d+Au, and ^{3}He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
- arXiv:2202.03863 Measurement of $\psi(2S)$ nuclear modification at backward and forward rapidity in p+p, p+Al, and p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

Jet substructure in $p+p$



Jet splitting function

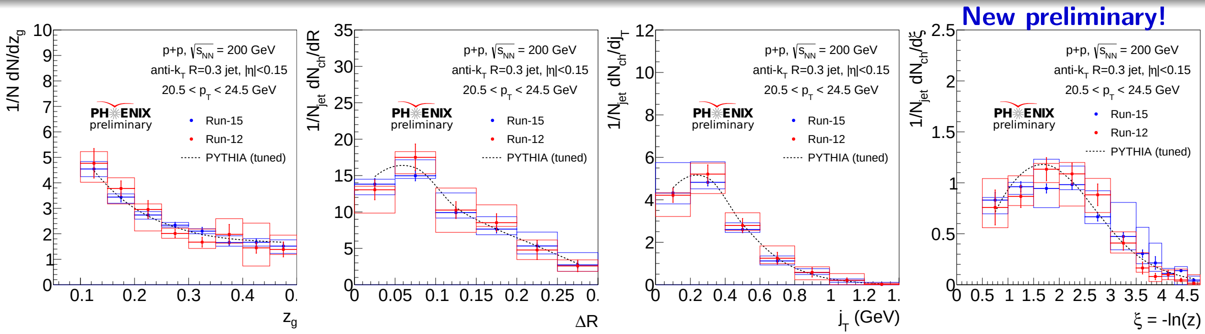
Radial profile

Transverse fragmentation

Longitudinal fragmentation

- New analysis of jet substructure
  —$R = 0.3$
  —$12.0\ \text{GeV}/c < p_T < 14.5\ \text{GeV}/c$
- Analysis ongoing with p+Au, results coming soon!

Jet substructure in $p+p$



Jet splitting function

Radial profile

Transverse fragmentation

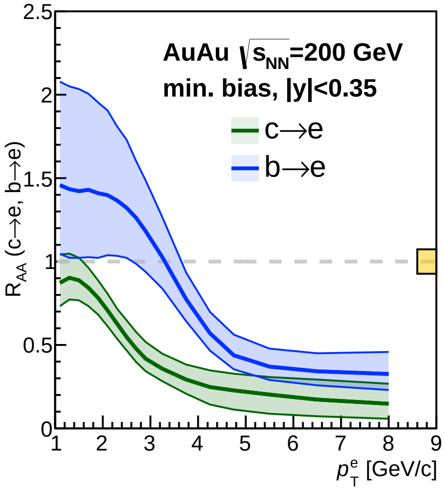
Longitudinal fragmentation

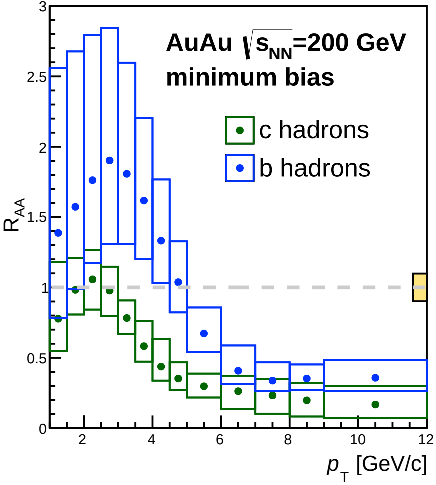
- New analysis of jet substructure
  - —$R = 0.3$
  - —20.5 GeV$/c$ $<$ p_T $<$ 24.5 GeV$/c$
- Analysis ongoing with p+Au, results coming soon!

c and *b* in large systems

arXiv:2203.17058 (submitted to Phys. Rev. C)

Recently submitted!





- Bottom shows less suppression than charm

c and *b* in large systems

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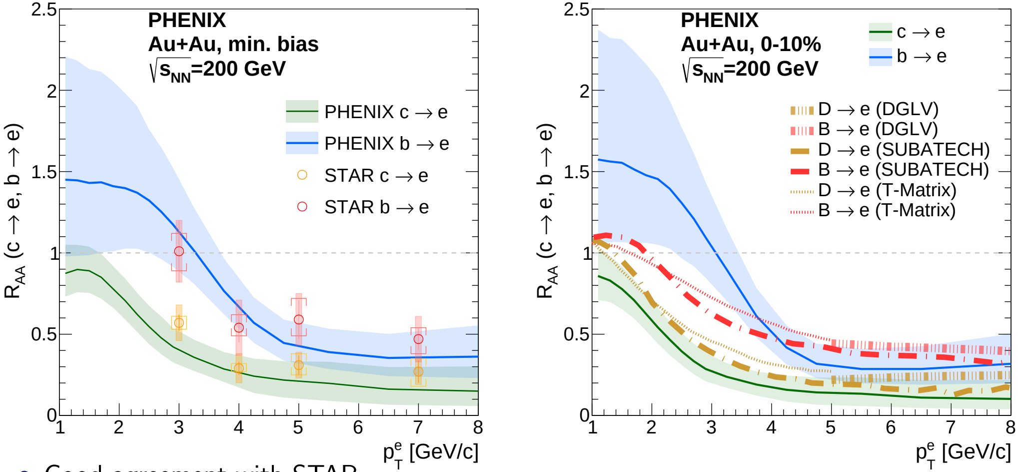
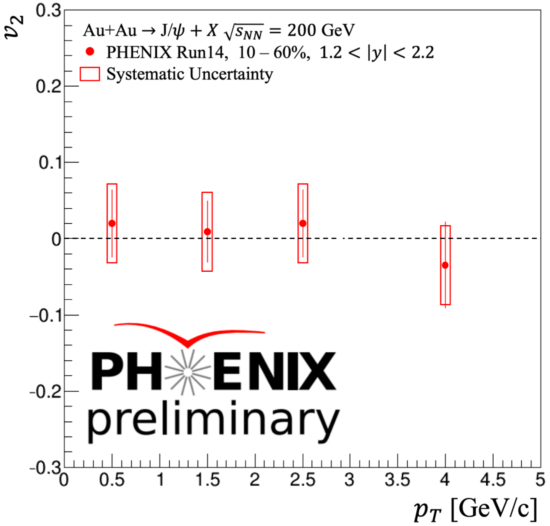


- Good agreement with STAR
- Good agreement with models (all p_T for c, $p_T > 4$ GeV/c for b)

J/ψ v_2 in large systems

New preliminary!

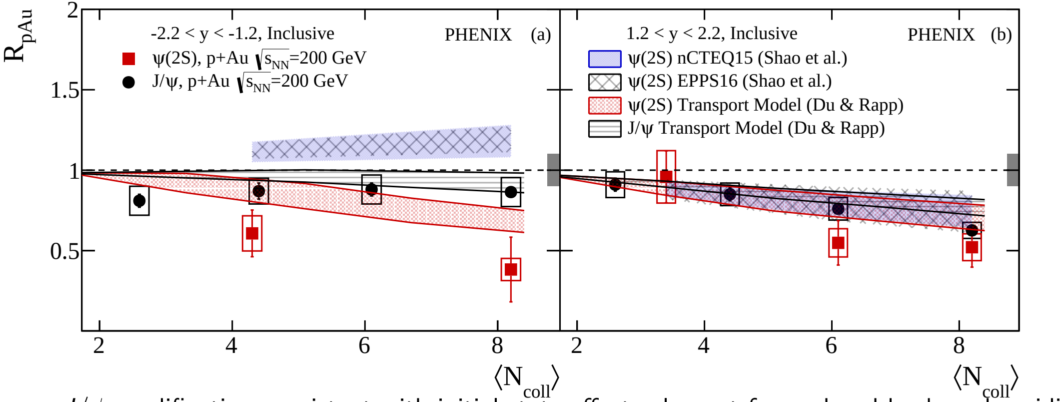


J/ψ v_2 is consistent zero at forward rapidity, different from the LHC results

May indicate absence of charmonium regeneration in the forward rapidity region at RHIC energies

J/ψ and $\psi(2S)$ in small systems

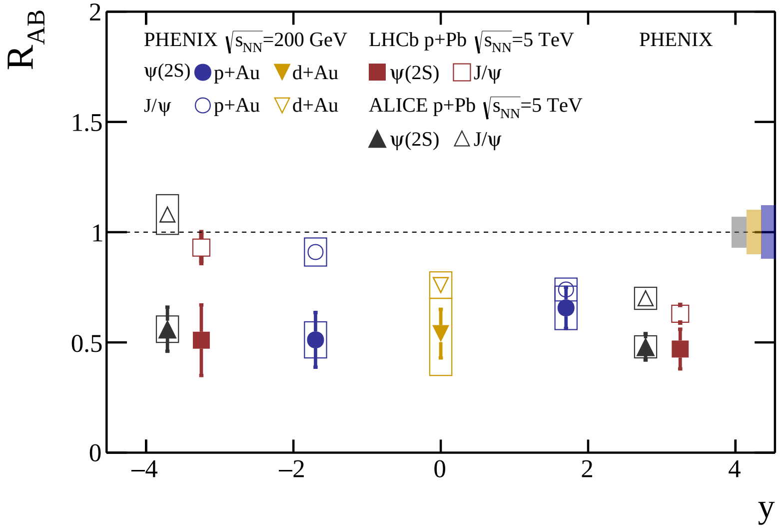
arXiv:2202.03863 (submitted to Phys. Rev. C) **Recently submitted!**



- J/ψ modification consistent with initial state effects alone at forward and backward rapidity
- $\psi(2S)$ modification indicates presence of final state effects at backward rapidity
  —Presence of co-movers? QGP?

J/ψ and $\psi(2S)$ in small systems

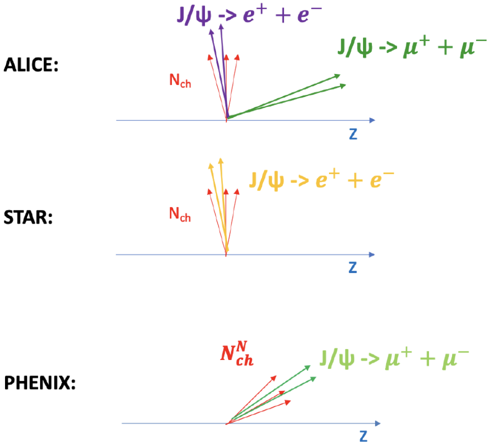
arXiv:2202.03863 (submitted to Phys. Rev. C) **Recently submitted!**

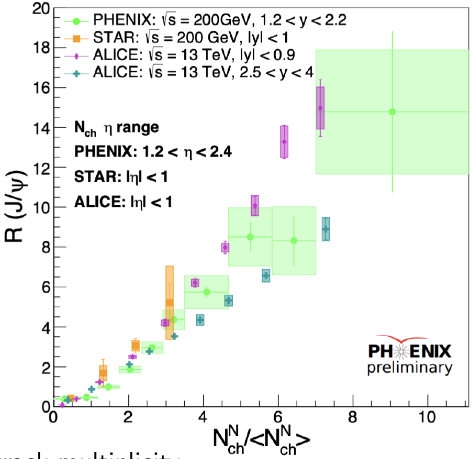


Similar patterns for J/ψ and $\psi(2S)$ found at RHIC and LHC

J/ψ yield in $p+p$

New preliminary!





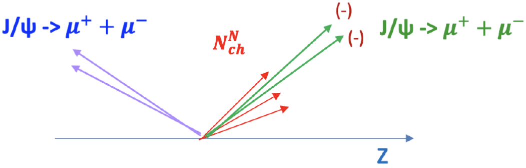
- J/ψ yield exhibits large dependence on local track multiplicity —Usually attributed to multi-parton interactions

J/ψ yield in $p+p$

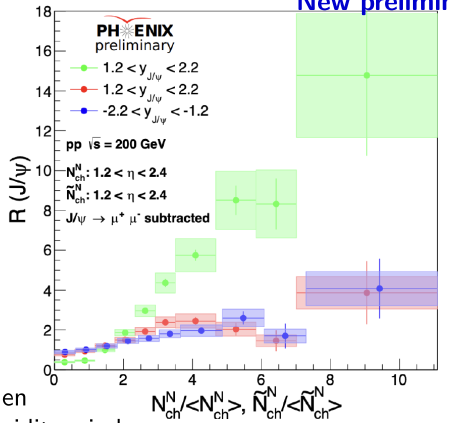
J/ψ and tracks in the same rapidity

J/ψ and tracks in the opposite rapidity

J/ψ and tracks in the same rapidity, tracks from J/psi removed from track count



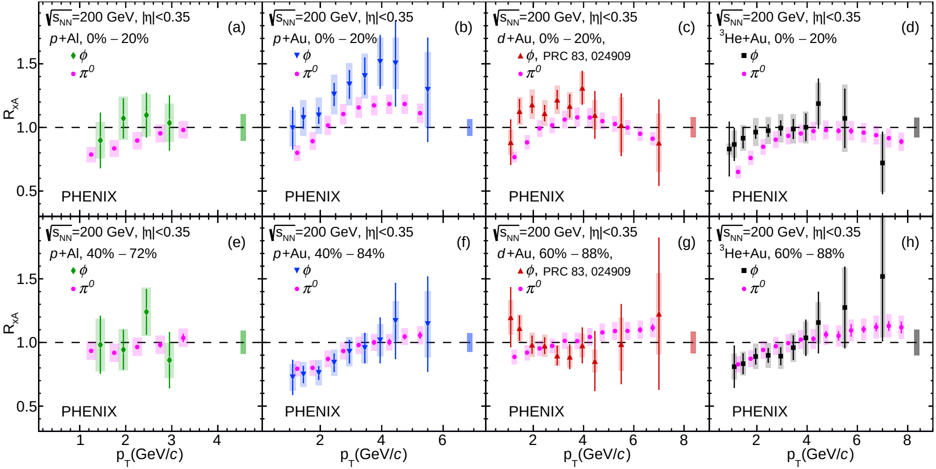
New preliminary!



- J/ψ yield vs multiplicity significantly reduced when
  —Looking at J/ψ and multiplicity in separate rapidity windows
  —Looking at J/ψ and multiplicity in the same rapidity window but removing the $\mu^+\mu^-$ from the multiplicity
- Important implications for MPI picture

ϕ meson in small systems

arXiv:2203.06087 (submitted to Phys. Rev. C) **Recently submitted!**



- ϕ similar to π^0 with a few hints of a slight enhancement relative to π^0

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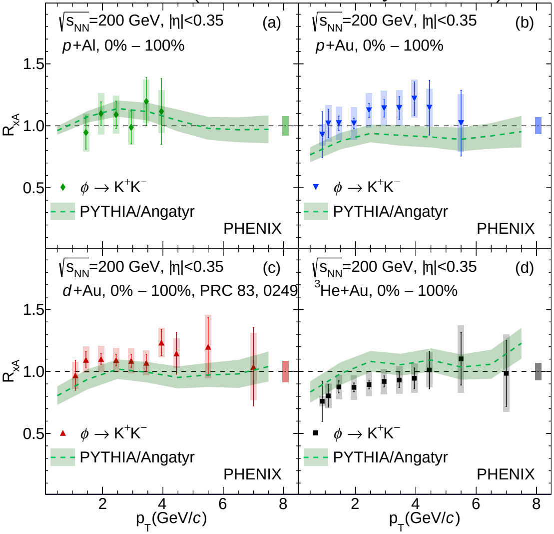

ϕ nuclear modification reasonably well-described by PYTHIA/Angantyr, but overall system size ordering is missed

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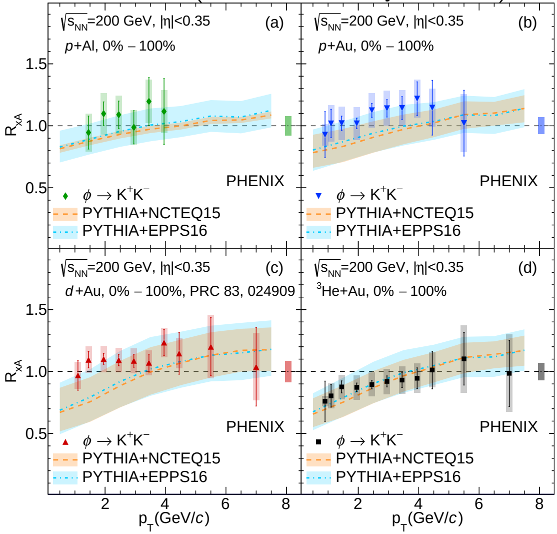


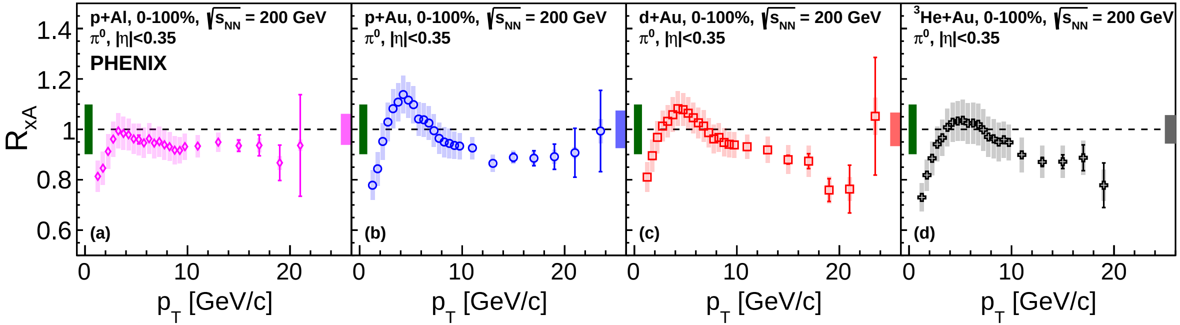
ϕ nuclear modification reasonably well-described by PYTHIA/Angantyr, but overall system size ordering is missed

Also reasonably well-described by PYTHIA with nPDFs, but overall system size ordering is missed

Nuclear modification of π^0 in small systems

Phys. Rev. C 105, 064902 (2022)

Recently published!



- Minimum bias collisions shown
- Cronin enhancement at intermediate p_T
  —Lighter target shows smaller enhancement (p+Al $<$ p+Au)
  —Heavier projectile shows smaller enhancement (^{3}He+Au $<$ d+Au $<$ p+Au)

Nuclear modification of π^0 in small systems

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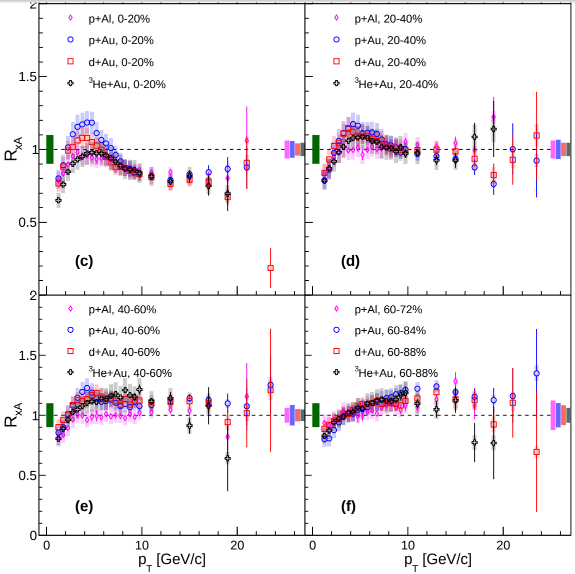
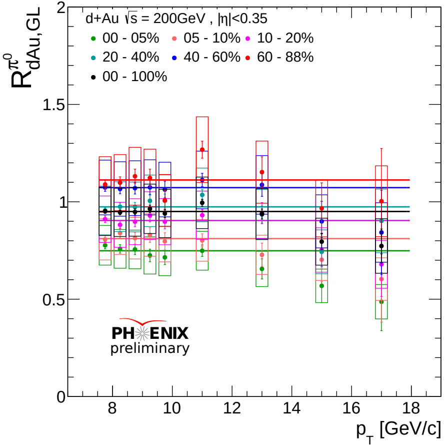


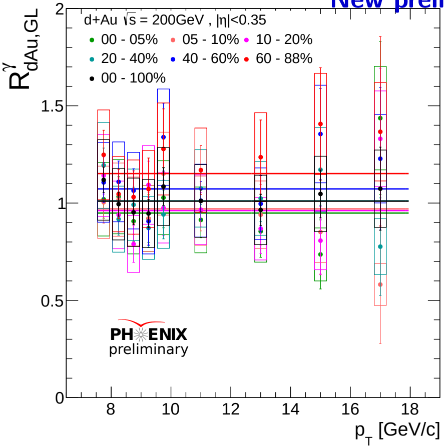
Considerable centrality dependence—suppression in central, enhancement in peripheral

Peripheral enhancement not new, but still difficult to understand...

Direct photons and π^0 in small systems

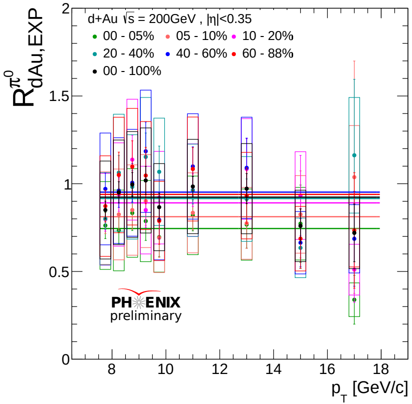
New preliminary!



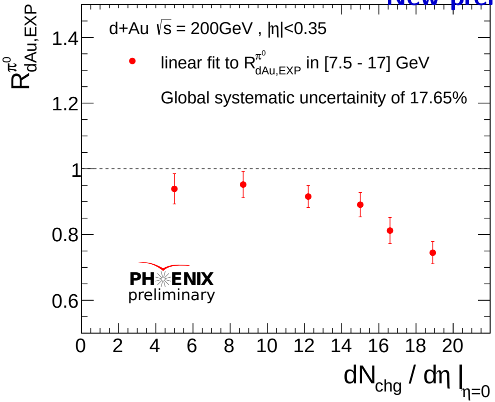


- Long-known (and somewhat mysterious) centrality dependence of R_{dA} of π^0
- New measurement of direct photons shows similar centrality dependence, but should be unity—mean free path ∼50 times larger than nuclear size

Direct photons and π^0 in small systems



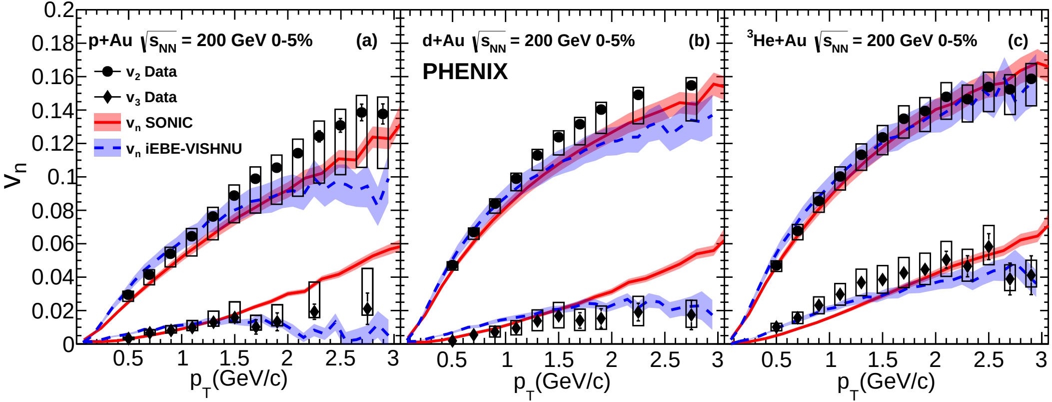
New preliminary!



- Can use non-modification of photons to correct for bias in N_{coll} determination
- Resolves a decade-long mystery of apparent enhancement in peripheral collisions
- Small but non-negligible suppression in central collisions
  —EMC effect? QGP?

v_n in small systems

Nat. Phys. 15, 214–220 (2019)



- v_2 and v_3 vs p_T predicted or described very well by hydrodynamics in all three systems
  —All predicted (except v_2 in d+Au) in J.L. Nagle et al, PRL 113, 112301 (2014)
  —v_3 in p+Au and d+Au predicted in C. Shen et al, PRC 95, 014906 (2017)

v_n in small systems

Phys. Rev. C 105, 024901 (2022)

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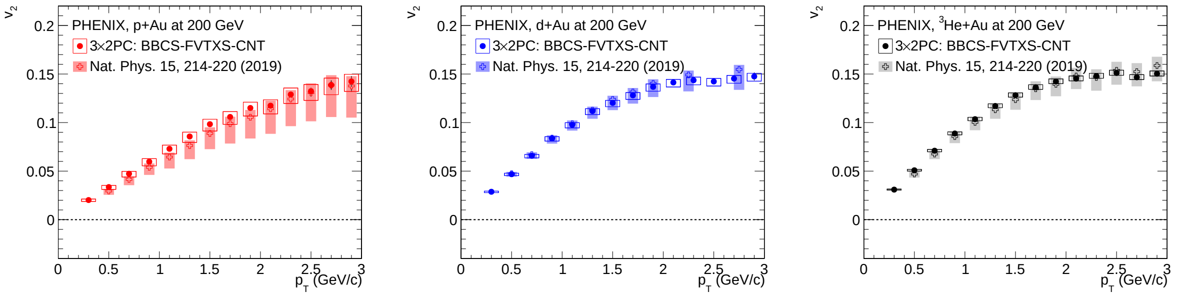

- All new analysis using two-particle correlations with event mixing instead of event plane method used in Nature Physics publication
  —Very different sensitivity to key experimental effects (beam position, detector alignment)
- Uses same detector combination as used in Nature Physics publication

v_n in small systems

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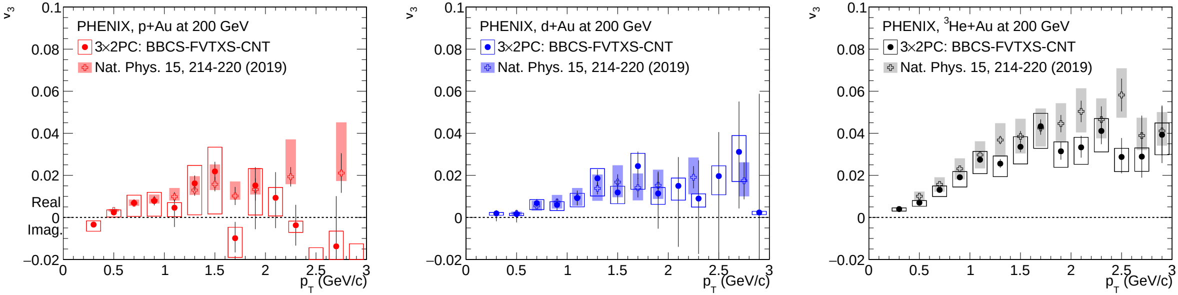

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v_2 in small systems

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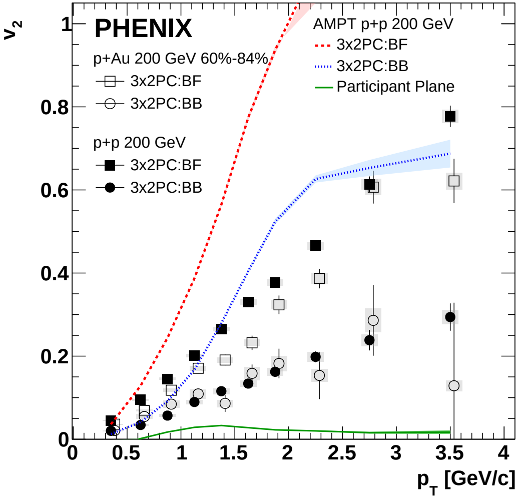
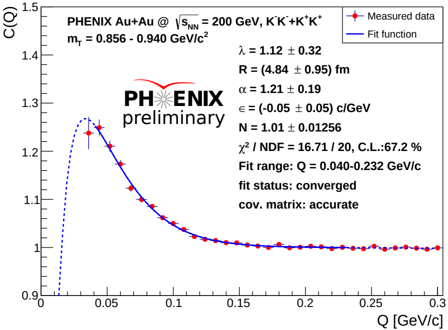


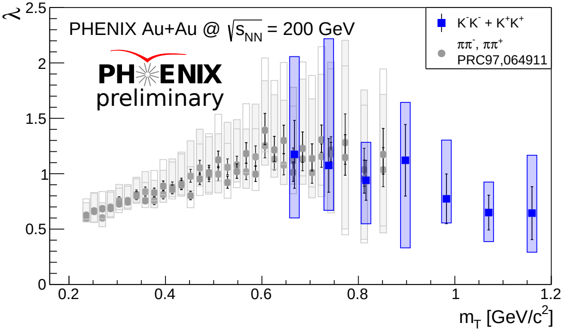
Systematic study of v_2 in small systems
—p+p, p+Au, d+Au, ^{3}He+Au
—Centrality dependence
—Multiple detector combinations

AMPT exhibits little or no collectivity but large v_2 due to non-flow correlations
Also shows similar relative pattern between backward-backward (BB) and backward-forward (BF)

Kaon femtoscopy in large systems

New preliminary!





- Femtoscopy with $K^{\pm}$ and assuming Lévy source
- λ describes strength of correlation
- α describes shape of distributions—$\alpha = 2$ is Gaussian, $\alpha = 1$ is Cauchy
- R is width parameter (similar to but not same as standard Gaussian radius)

Kaon femtoscopy in large systems

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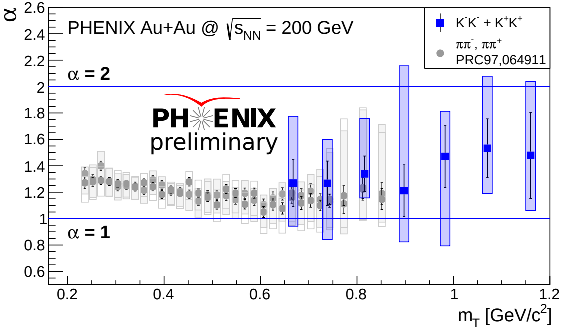

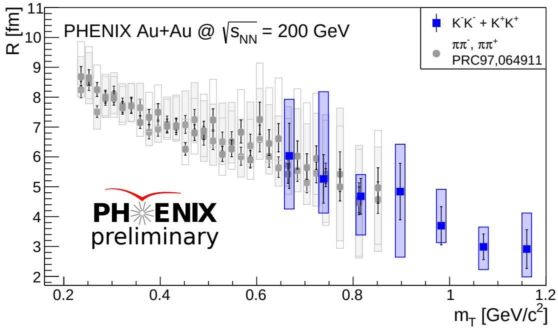

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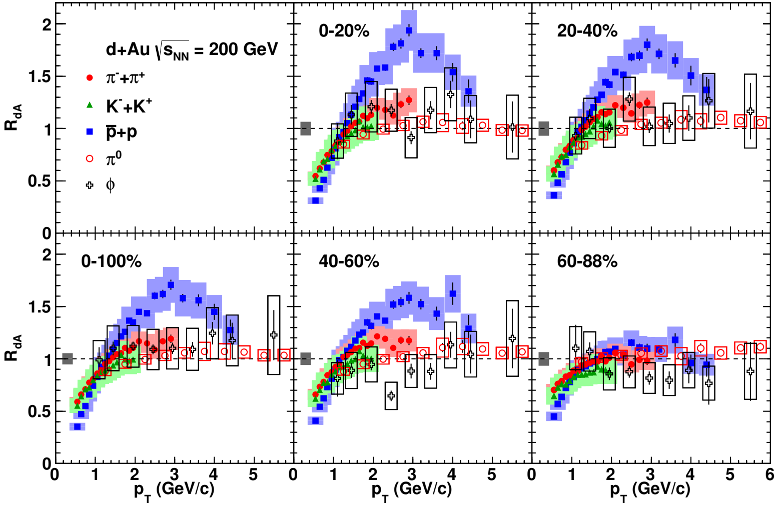
Brief summary and outlook

- Jet substructure measurements done in p+p, p+Au and Cu+Au coming soon
- Evidence of final state effects in charmonium production in small systems at RHIC
- Evidence of centrality determination bias in high-p_T particle R_{xA} in small systems, can use direct photons to correct for this bias
  —No enhancement in peripheral collisions
  —Suppression in central collisions
- Comprehensive set of small systems flow measurements
- New results on femtoscopy with charged kaons
- Many more interesting and important measurements from PHENIX coming soon!

Extra material

Particle species dependence of "Cronin enhancement"

PHENIX, Phys. Rev. C 88, 024906 (2013)



π^+, π^-, π^0,

K^+, K^-,

p, $\bar{p}$,

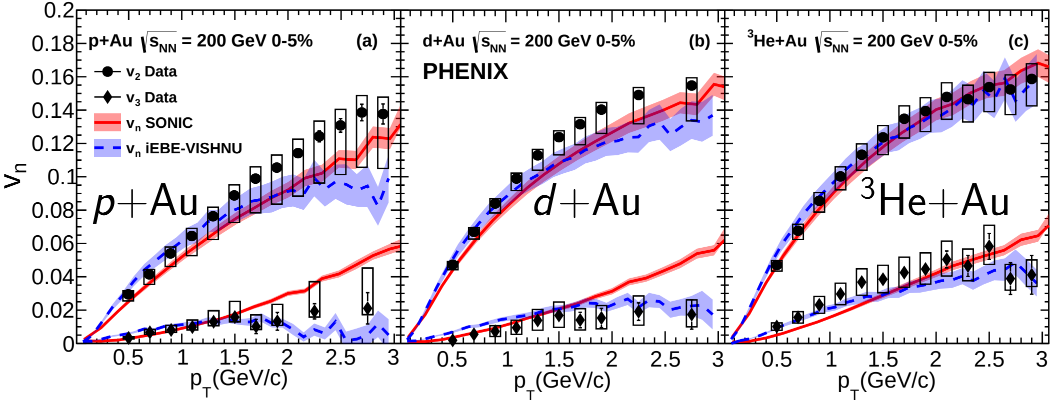
ϕ

Protons much more strongly modified than pions

ϕ mesons similar to pions

v_n in small systems

Nat. Phys. 15, 214–220 (2019)



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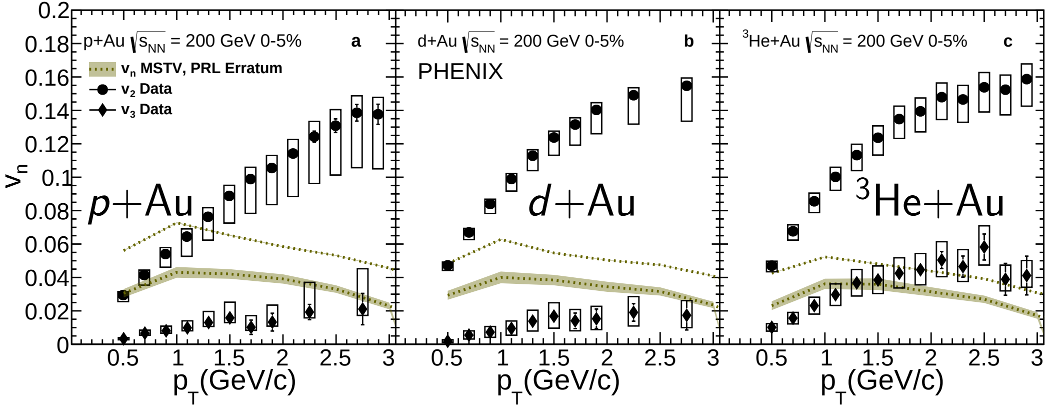
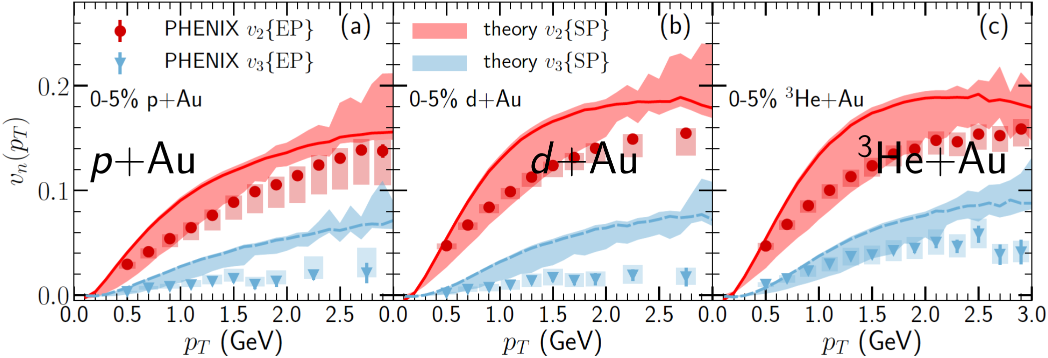


- Initial state effects alone do not describe the data
  —Phys. Rev. Lett. 123, 039901 (Erratum) (2019)

v_n in small systems

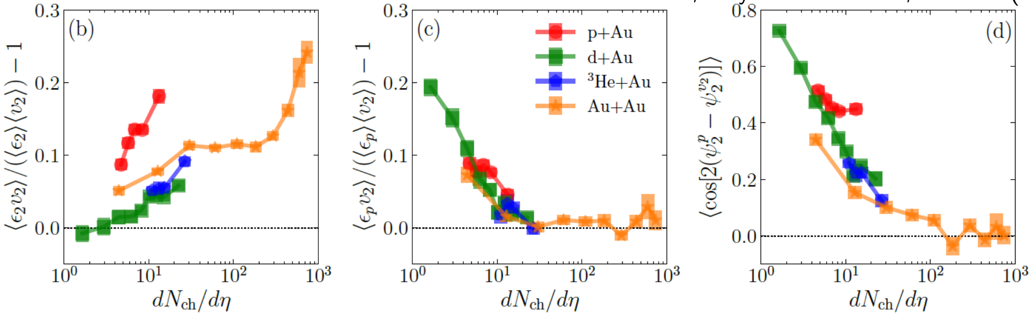
Nat. Phys. 15, 214–220 (2019)



- Inclusion of initial state effects is important, but not a big contribution for central collisions —B. Schenke et al, Phys. Lett. B 803, 135322 (2020)

v_n in small systems

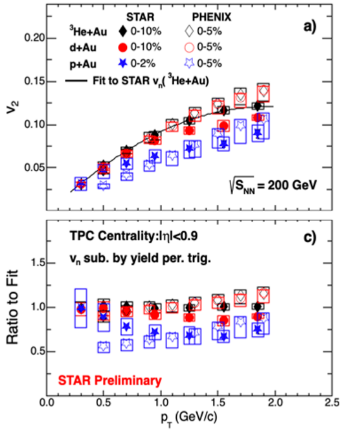
B. Schenke et al, Phys. Lett. B 803, 135322 (2020)



- For central p+Au, modest correlation between ε_p and v_2 but fairly strong correlation between ψ_2^p and $\psi_2^{v_2}$
- For central d+Au and ^{3}He+Au, no correlation between ε_p and v_2, modest correlation between ψ_2^p and $\psi_2^{v_2}$

v_n in small systems

STAR, Quark Matter 2019



Good agreement between STAR and PHENIX for v_2

v_n in small systems

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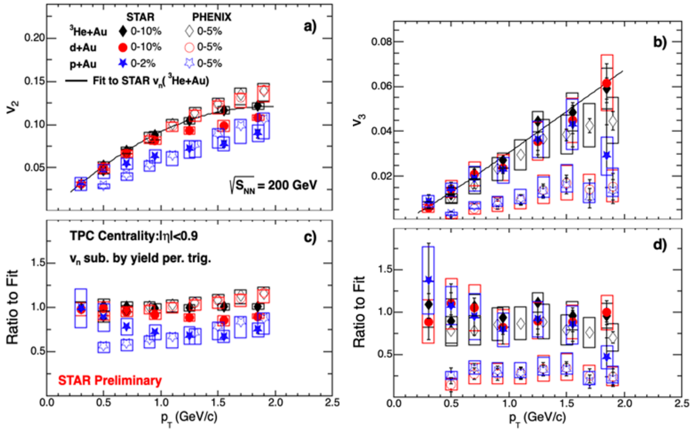
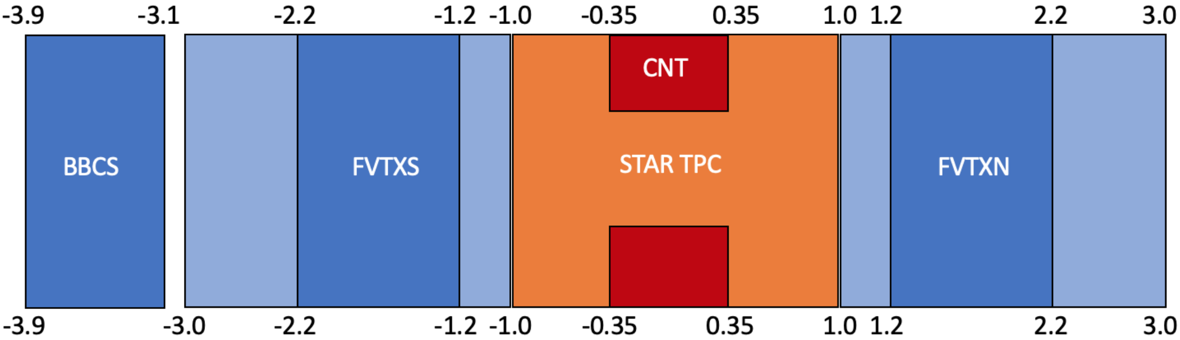


Good agreement between STAR and PHENIX for v_2

Large discrepancy between STAR and PHENIX for v_3

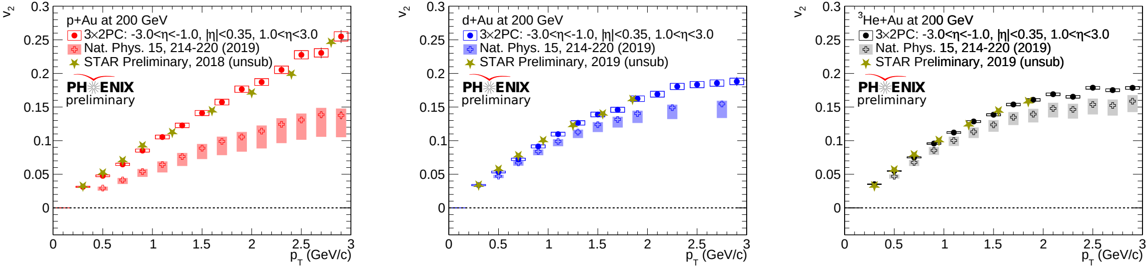
v_n in small systems



- The PHENIX Nature Physics paper uses the BBCS-FVTXS-CNT detector combination
  —Very different kinematic acceptance compared to STAR
- We can try to use FVTXS-CNT-FVTXN detector combination to better match STAR
  —Closer, and "balanced" between forward and backward

v_n in small systems

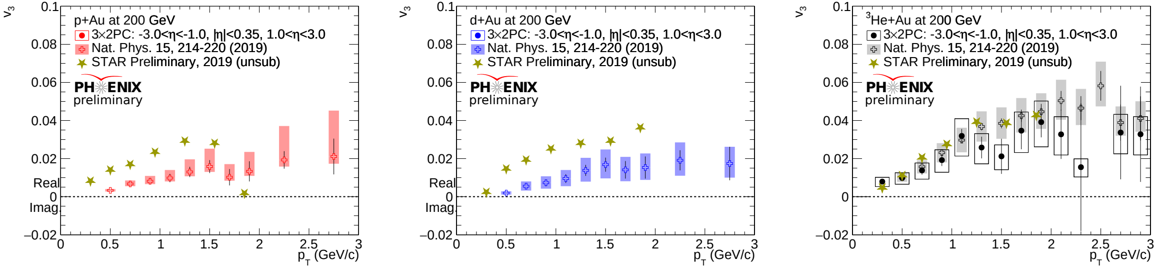
Phys. Rev. C 105, 024901 (2022)



- Good agreement with STAR for v_2
  —Similar physics for the two different pseudorapidity acceptances

v_n in small systems

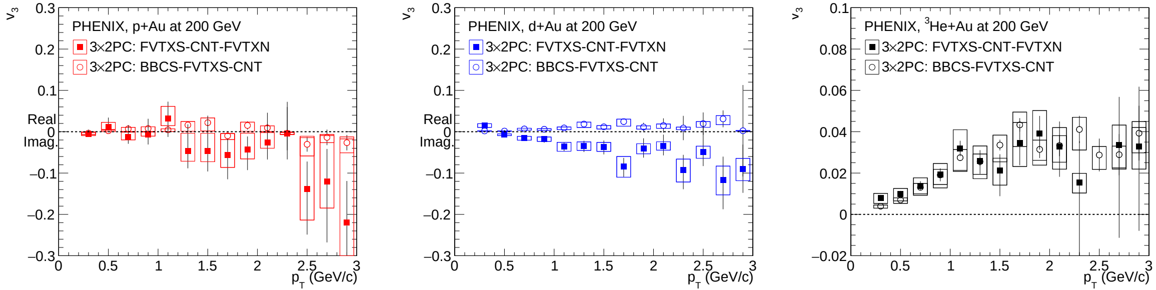
Phys. Rev. C 105, 024901 (2022)



- Good agreement with STAR for v_2
  —Similar physics for the two different pseudorapidity acceptances
- Strikingly different results for v_3
  —Rather different physics for the two different pseudorapidity acceptances
  —Longitudinal effects much stronger for v_3 than v_2

v_n in small systems

Phys. Rev. C 105, 024901 (2022)



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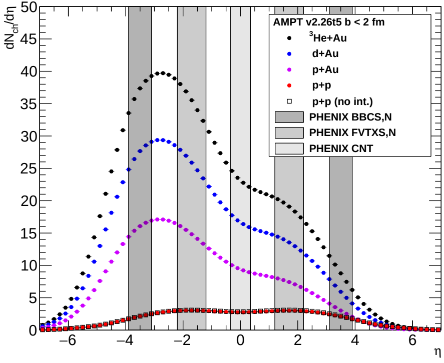
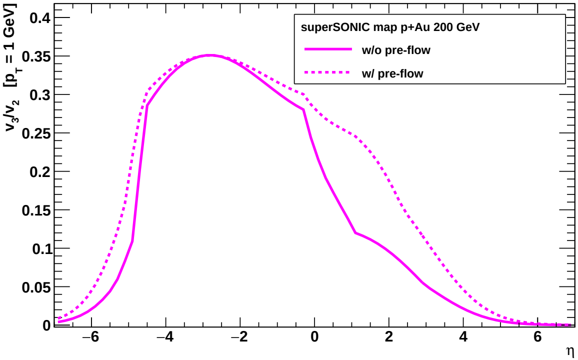
v_n in small systems

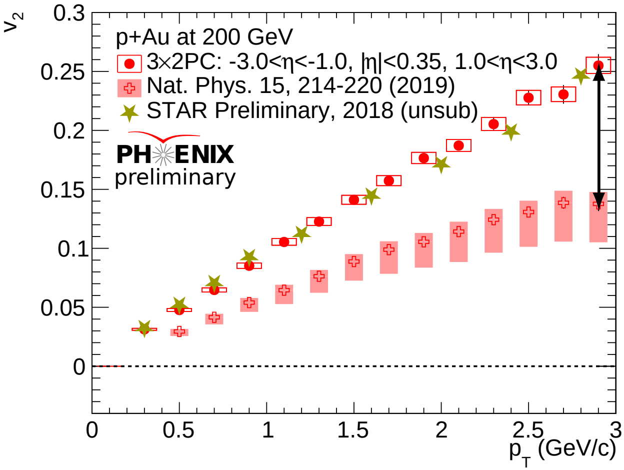
J.L. Nagle et al, Phys. Rev. C 105, 024906 (2022)





- $dN_{ch}/d\eta$ from AMPT, $v_3(\eta)$ from (super)SONIC
- The likely much stronger pseudorapidity dependence of v_3 compared to v_2 is an essential ingredient in understanding different measurements

Understanding the nonflow contribution: v_2 in p+Au as a case study



- The large difference between the PHENIX published and STAR preliminary in this case is nonflow
- PHENIX suppresses nonflow via kinematic selection

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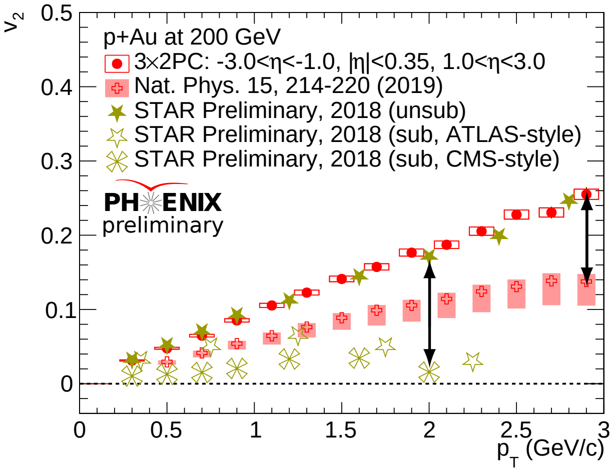
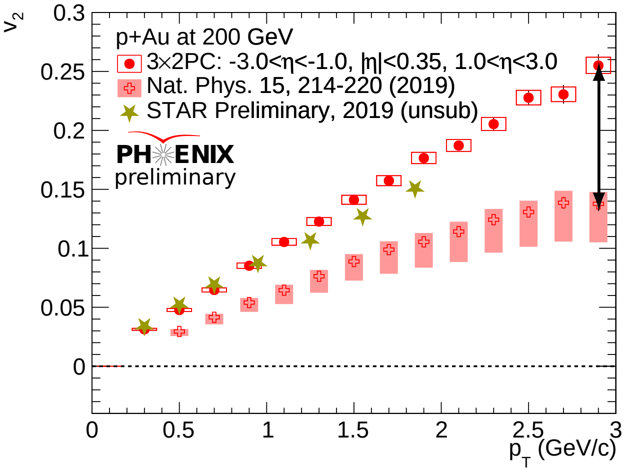


- The large difference between the PHENIX published and STAR preliminary in this case is nonflow
- PHENIX suppresses nonflow via kinematic selection
- STAR applies non-flow subtraction procedure
- One needs to be careful about the risk of over-subtraction methods—S. Lim et al, Phys. Rev. C 100, 024908 (2019)

Understanding the nonflow contribution: v_2 in p+Au as a case study



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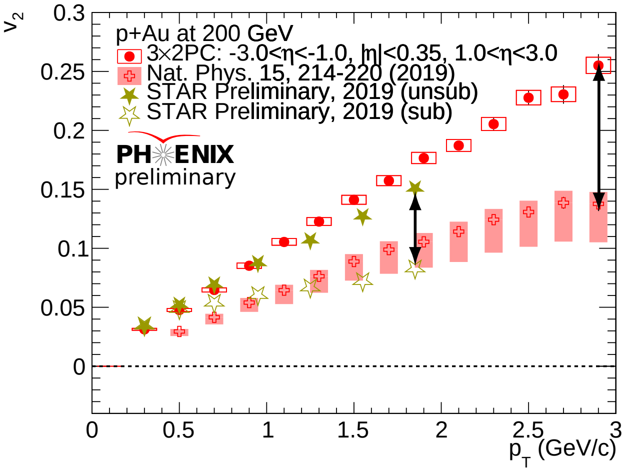
Understanding the nonflow contribution: v_2 in p+Au as a case study



- The large difference between the PHENIX published and STAR preliminary in this case is nonflow
- PHENIX suppresses nonflow via kinematic selection
- STAR applies non-flow subtraction procedure
- Considerable improvement in nonflow subtraction in STAR 2019 preliminary, reasonable agreement with PHENIX

Additional non-flow studies using published data tables

Checking Non-Flow Assumptions and Results via PHENIX Published Correlations in p+p, p+Au, d+Au, ^{3}He+Au at $\sqrt{s_{NN}}$ = 200 GeV

J.L. Nagle,[1] R. Belmont,[2] S.H. Lim,[3] and B. Seidlitz[1]

[1] *University of Colorado, Boulder, Colorado 80309, USA*
[2] *University of North Carolina, Greensboro, North Carolina 27413, USA*
[3] *Pusan National University, Busan, 46241, South Korea*

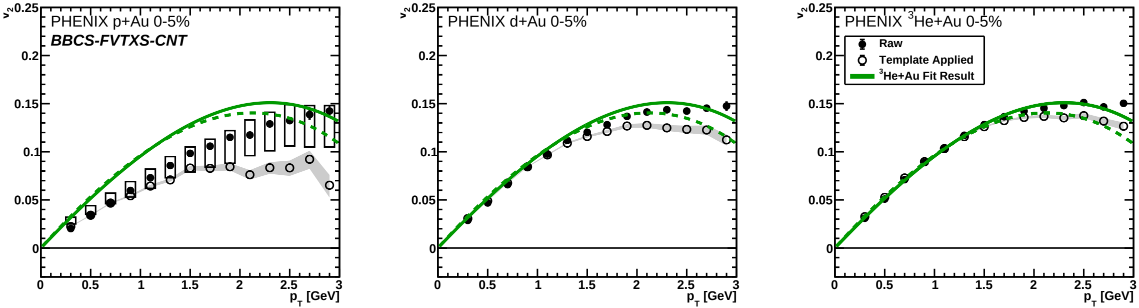
(Dated: July 16, 2021)

https://arxiv.org/abs/2107.07287

- To enable additional study, the new PHENIX publication (Phys. Rev. C 105, 024901 (2022)) includes the complete set of $\Delta\phi$ correlations and extracted coefficients c_1, c_2, c_3, c_4
- A new paper uses these data tables to explore non-flow subtraction of these data as well as to assess the degree of (non-)closure of non-flow subtraction methods

Additional non-flow studies using published data tables

J.L. Nagle et al, Phys. Rev. C 105, 024906 (2022)



- The BBCS-FVTXS-CNT combination minimizes non-flow, so subtraction doesn't make too much difference

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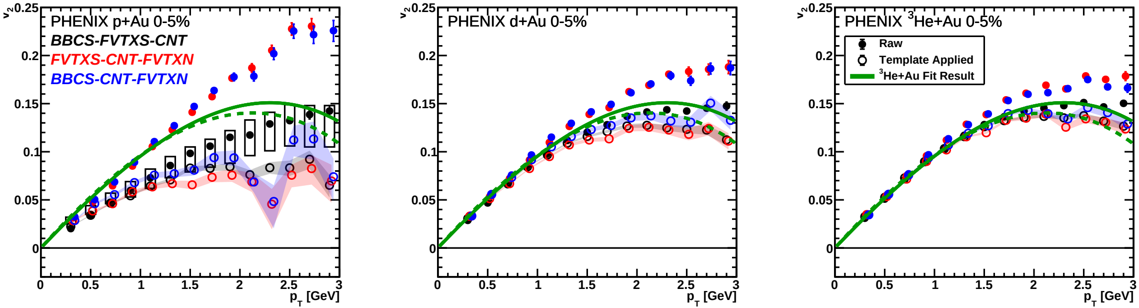

- The BBCS-FVTXS-CNT combination minimizes non-flow, so subtraction doesn't make too much difference
- The FVTXS-CNT-FVTXN combination has more non-flow, and the subtraction does much more
- That the three different combinations all line up after non-flow subtraction seems to lend some credence thereto, but one must be careful...

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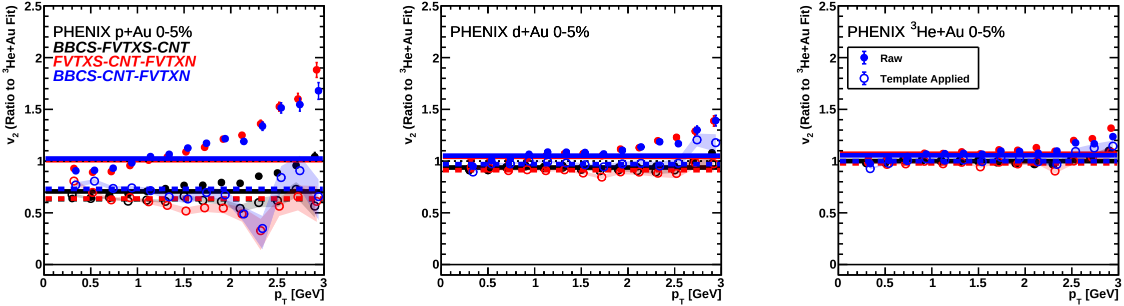

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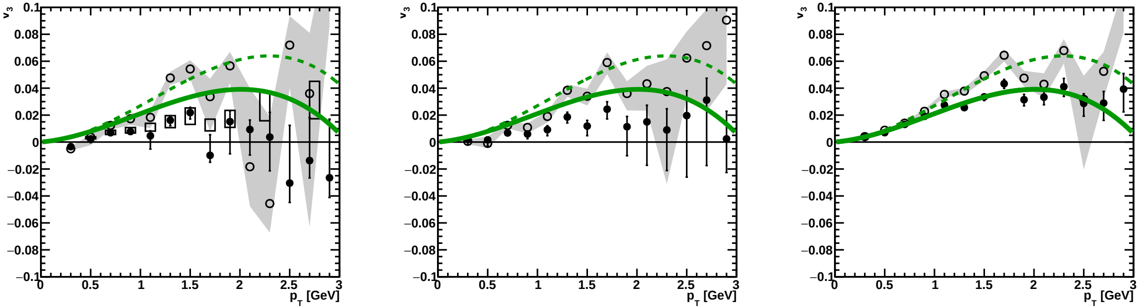

- There's a larger relative change for v_3 compared to v_2, but the smaller value of v_3 makes the non-flow subtraction more sensitive to non-closure

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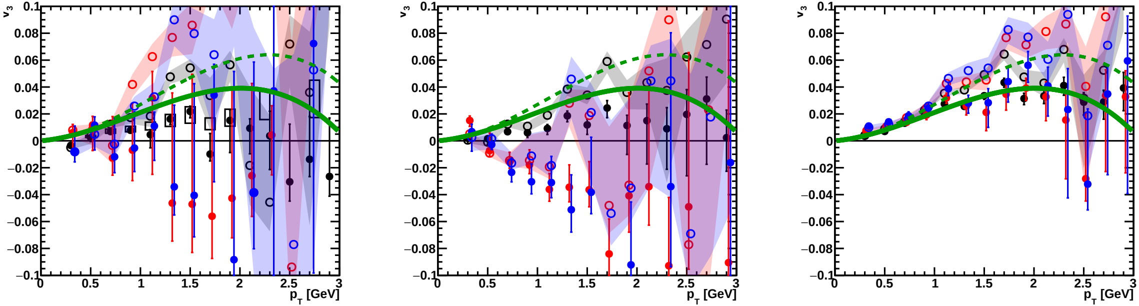

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- For the combinations with more non-flow, where the v_3 is imaginary in p+Au and d+Au, the non-flow subtraction is completely uncontrolled

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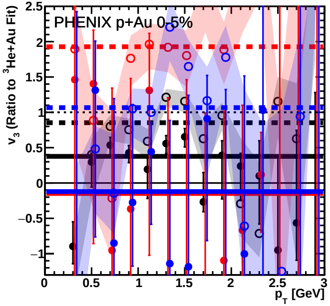

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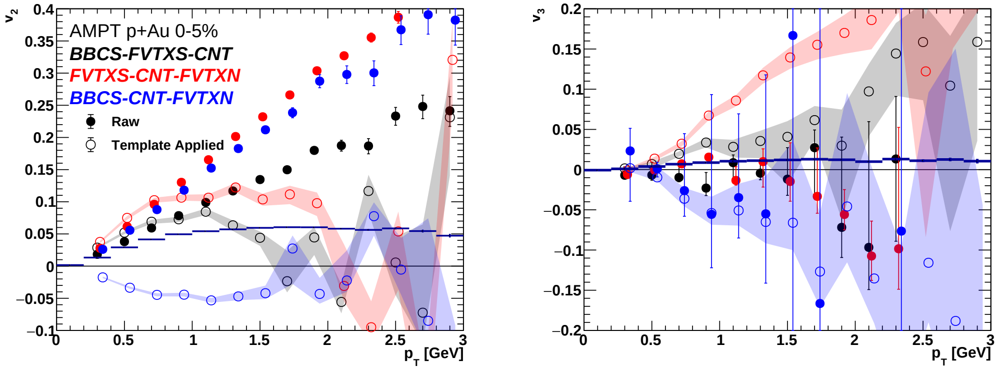

- Closure is considerably violated in AMPT

Additional non-flow studies using published data tables

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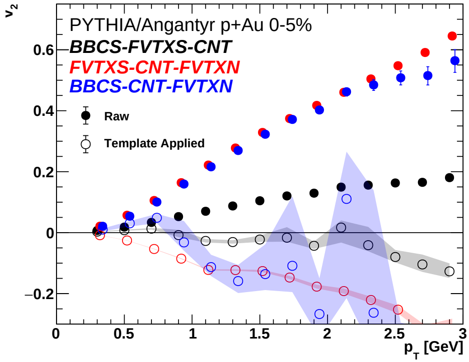

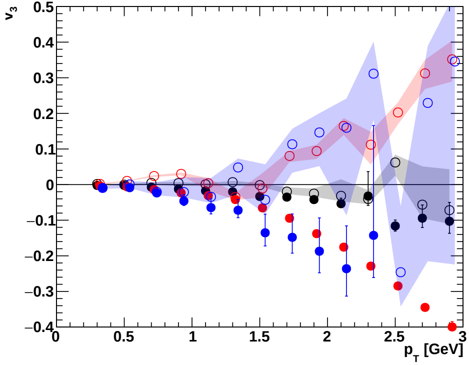

- Closure is considerably violated in AMPT and PYTHIA/Angantyr

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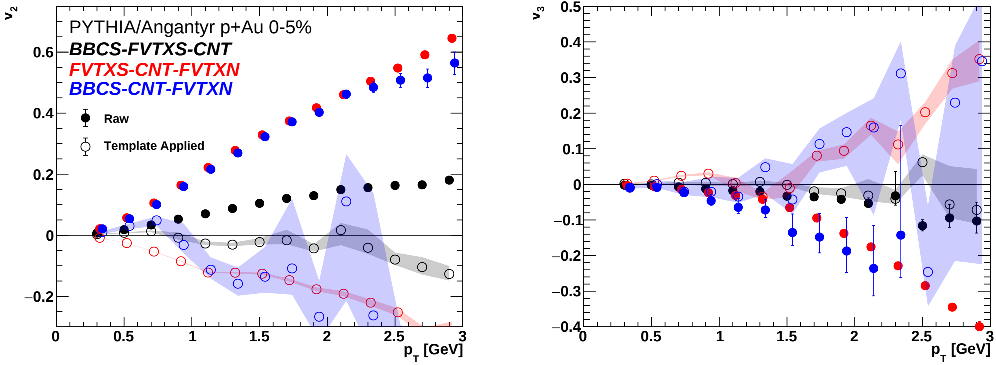

- Closure is considerably violated in AMPT and PYTHIA/Angantyr
- Since AMPT has too much non-flow and PYTHIA doesn't have any flow, the degree of overcorrection in real data is likely not as bad as it is with these generators

Additional non-flow studies using published data tables

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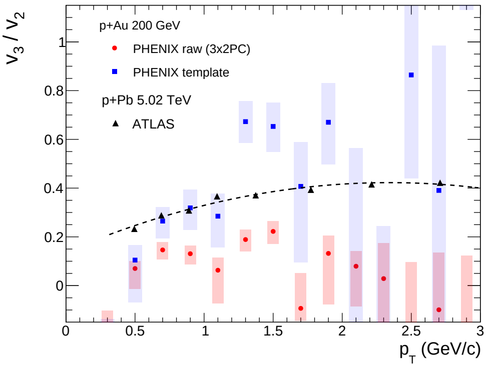

- The standard PHENIX v_3/v_2 is lower than the ATLAS, while the non-flow corrected is above

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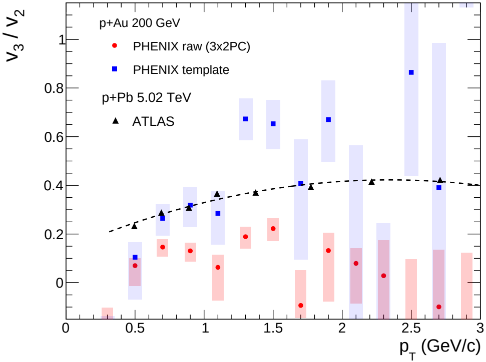
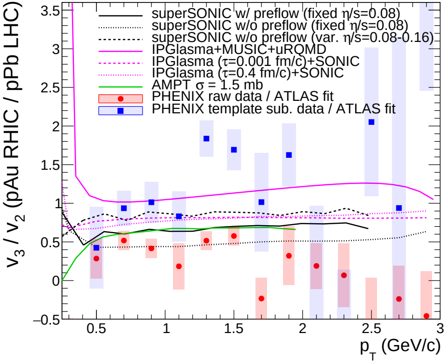
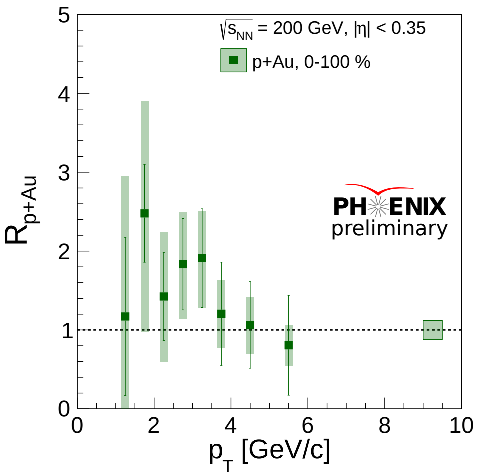




- The standard PHENIX v_3/v_2 is lower than the ATLAS, while the non-flow corrected is above
- The ratio is expected to be lower for lower collision energies in almost all physics scenarios
  —Lower energy, shorter lifetime, more damping of higher harmonics

Photons in small systems



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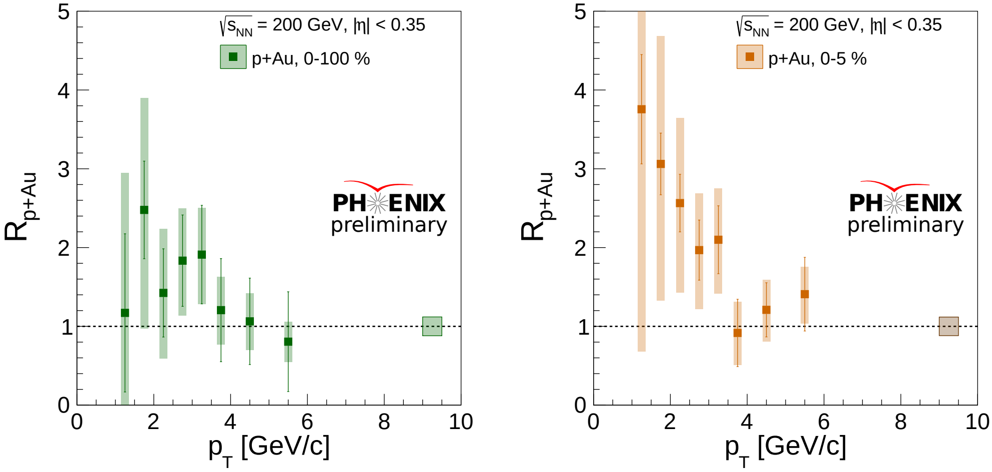
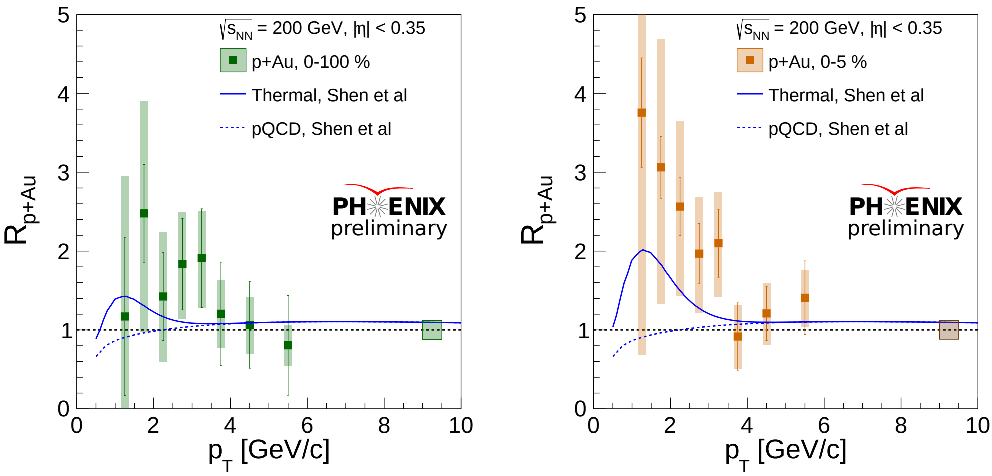


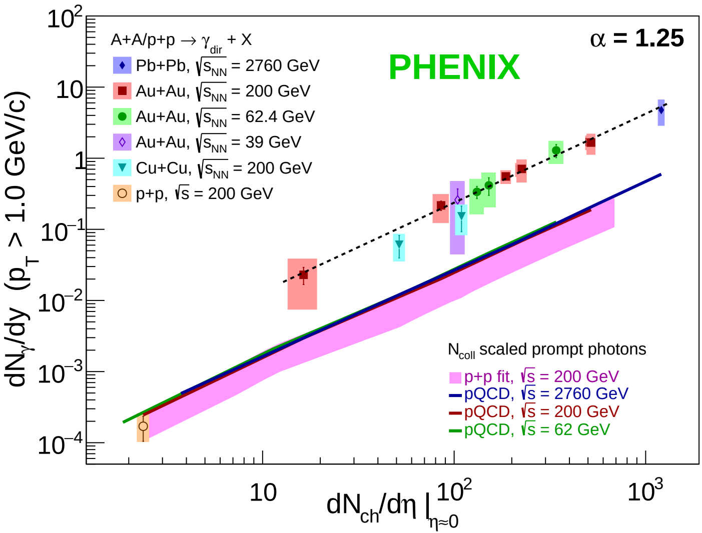
- Thermal photons in p+Au?

Photons in small systems



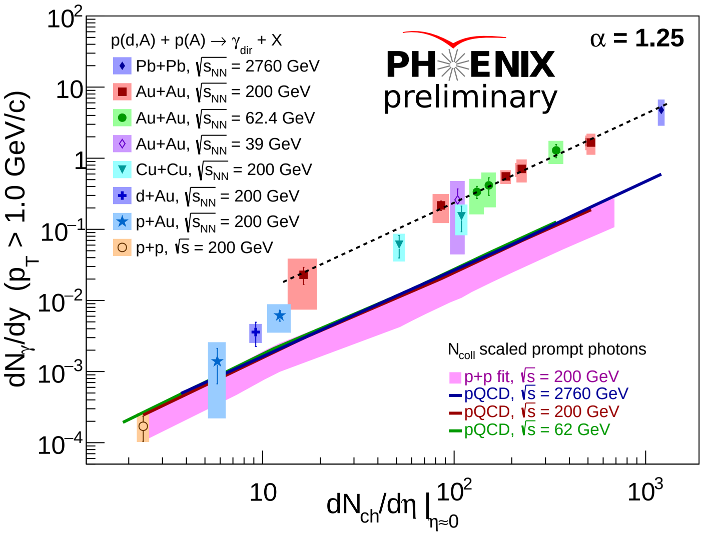
- Thermal photons in p+Au? Theory from Phys. Rev. C 95, 014906 (2017)

Photon yields



Common scaling for Au+Au and Pb+Pb at different energies; very different from N_{coll}-scaled $p+p$

Photon yields



Common scaling for Au+Au and Pb+Pb at different energies; very different from N_{coll}-scaled p+p

p+Au and d+Au in between