Small systems at RHIC: a brief overview

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GHP 2021
The Internet
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Quick outline

- Identified particles
- Thermal photons
- Flow correlations
  —Small systems beam energy scan
  —Small systems geometry scan

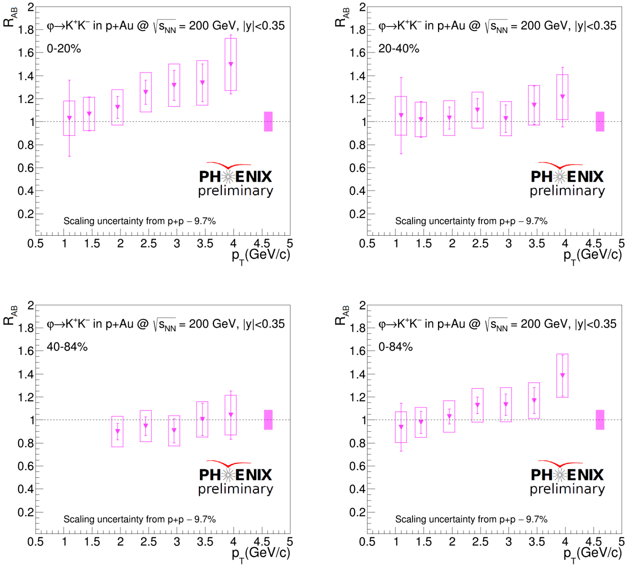
Intermission

Identified particles

Reminder: the nuclear modification factor is

$$R_{AB} = \frac{\text{Yield in AB collisions}}{\text{Yield in pp collisions} \cdot \text{Number of binary collisions}}$$

Identified hadron nuclear modification factors in p+Au



ϕ meson in p+Au

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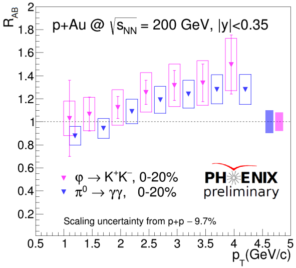
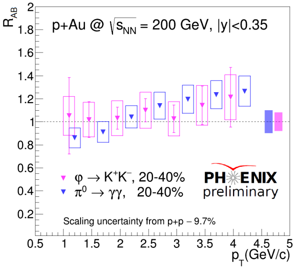
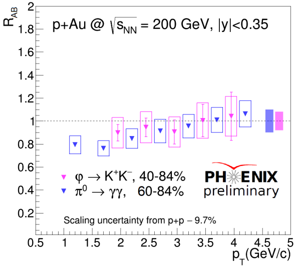
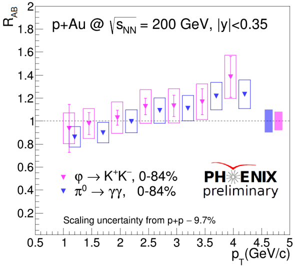






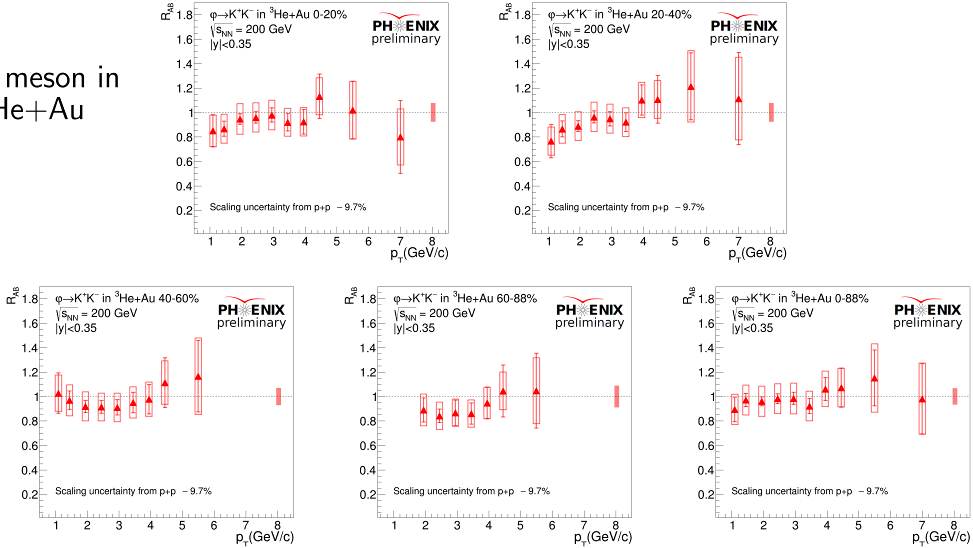


ϕ meson in p+Au

ϕ shows similar modification to π^0 in p+Au despite different mass and strangeness content

Identified hadron nuclear modification factors in ^{3}He+Au

ϕ meson in ^{3}He+Au



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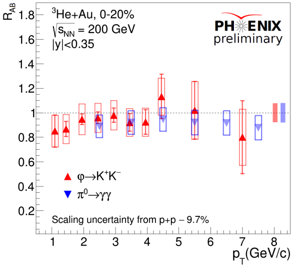

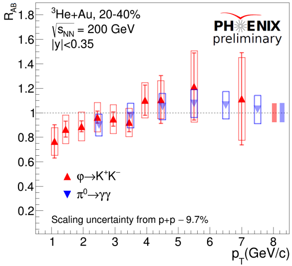

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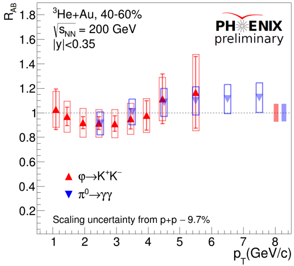
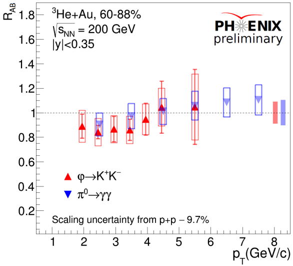
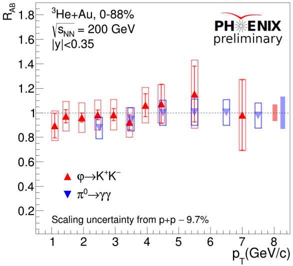
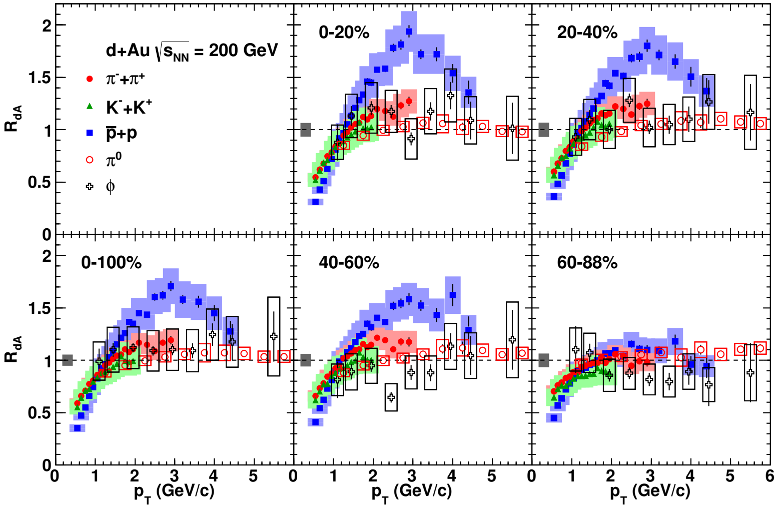






Particle species dependence of "Cronin enhancement"

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



π^+, π^-, π^0,

K^+, K^-,

p, $\bar{p}$,

ϕ

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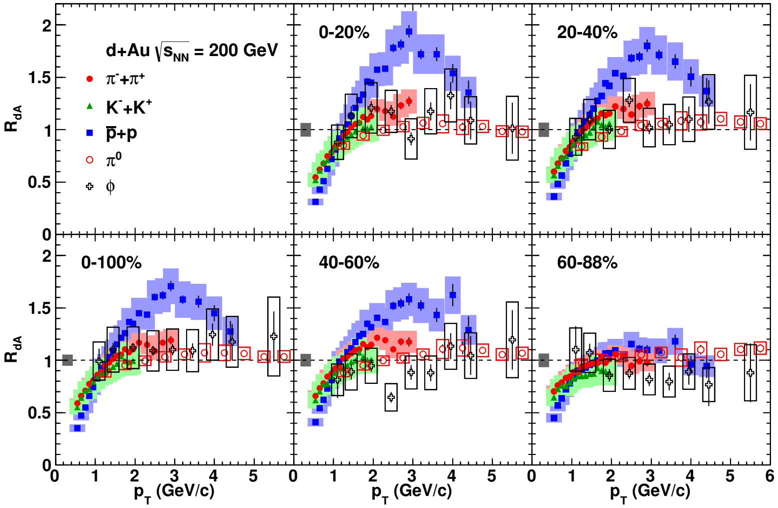

π^+, π^-, π^0,

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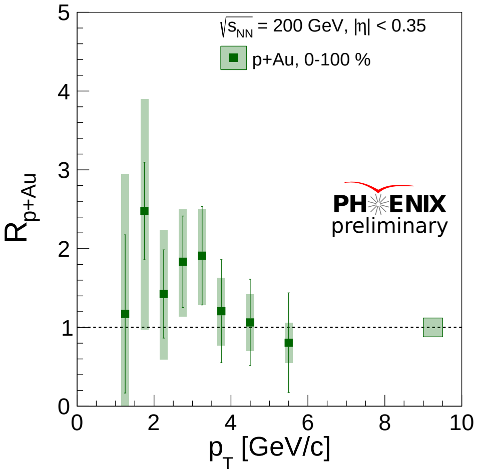
ϕ

Baryons strongly different from mesons, as found in large systems

Intermission

Thermal photons

Nuclear modification of photons



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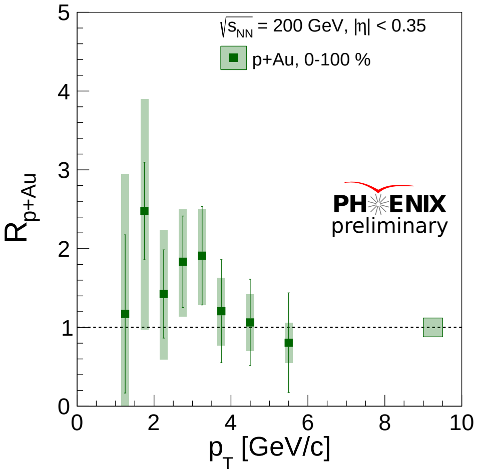
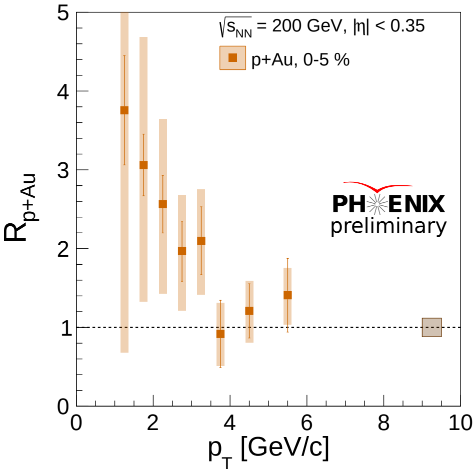
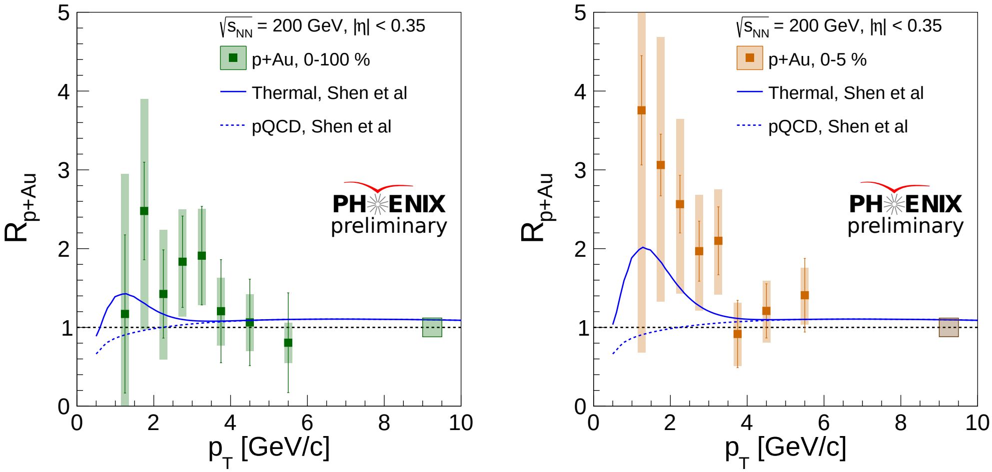




- Thermal photons in p+Au?

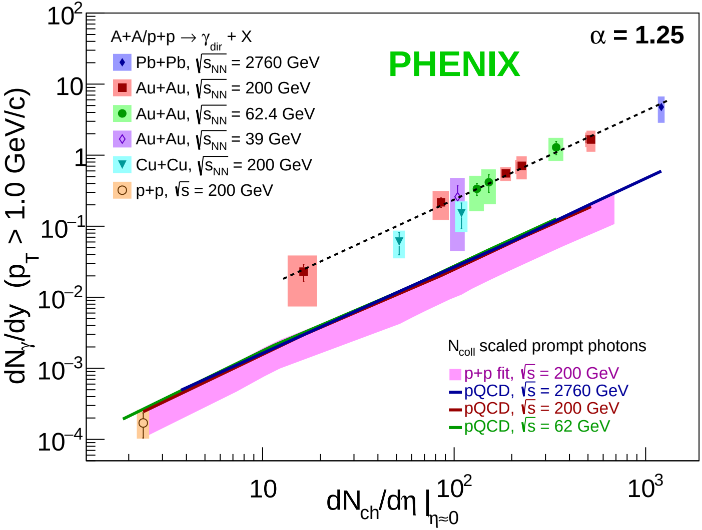
Nuclear modification of photons



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

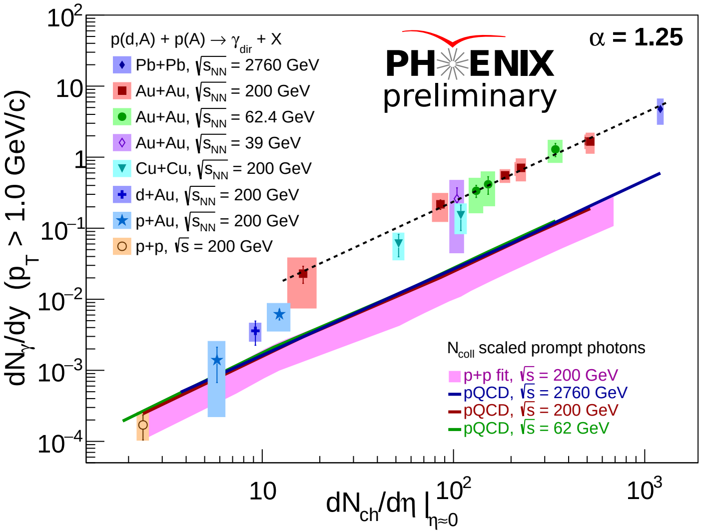
Photon yields

PHENIX, Phys. Rev. Lett. 123, 022301 (2019)



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, indicating a possible turn-on of thermal photons

Intermission

Flow correlations

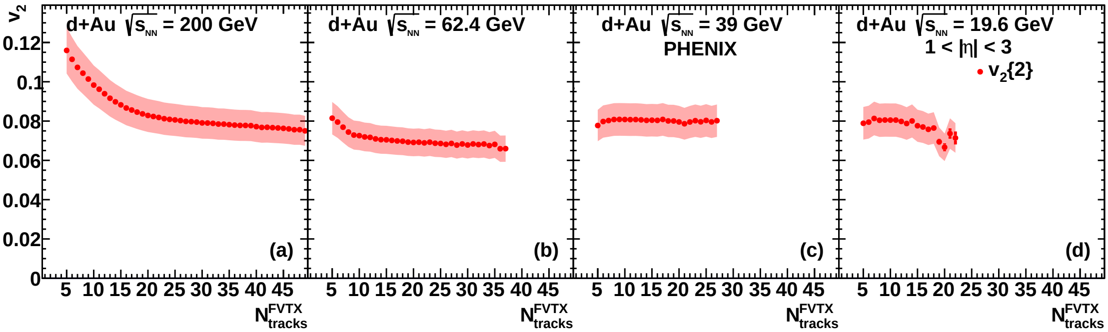
Reminder: we study flow via Fourier decomposition of the angular distribution of particles in the transverse plane

$$\frac{dN}{d\varphi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos n\varphi \qquad v_n = \langle \cos n\varphi \rangle$$

d+Au beam energy scan

PHENIX, Phys. Rev. Lett. 120, 062302 (2018)

200 GeV 62.4 GeV 39 GeV 19.6 GeV



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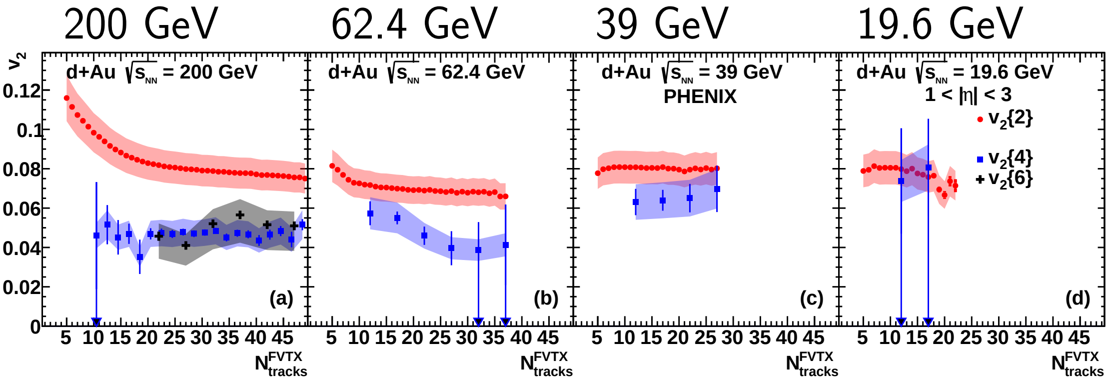

- Measurement of $v_2\{6\}$ in d+Au at 200 GeV and $v_2\{4\}$ in d+Au at all energies

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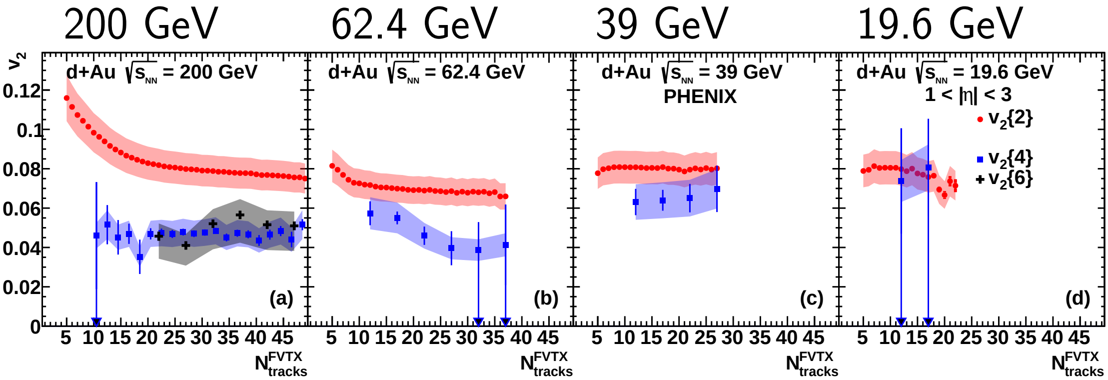
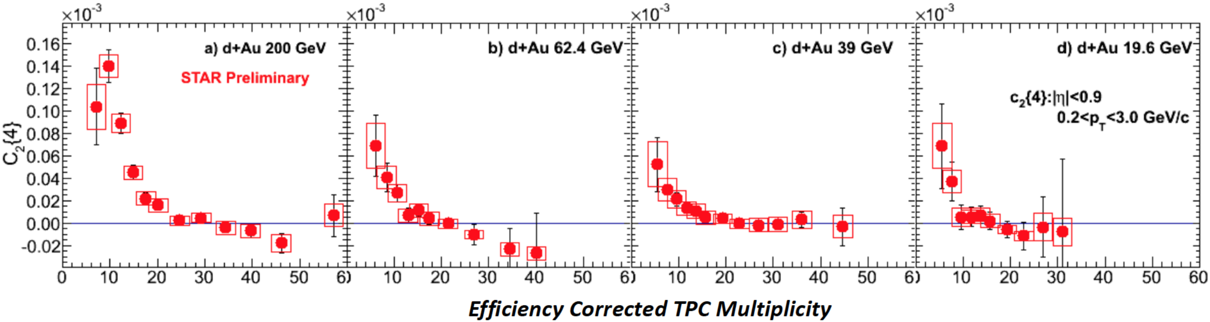


- Measurement of $v_2\{6\}$ in d+Au at 200 GeV and $v_2\{4\}$ in d+Au at all energies
- Multiparticle correlations can be a good indicator of collectivity

d+Au beam energy scan

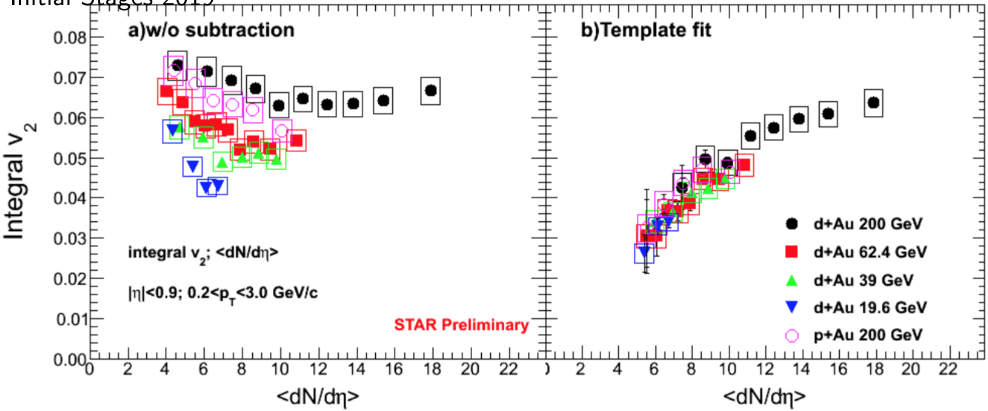
STAR, Initial Stages 2019



- STAR sees negative $c_2\{4\}$ in d+Au, qualitatively consistent with PHENIX
- The differences in kinematics between the two experiments are important

d+Au beam energy scan

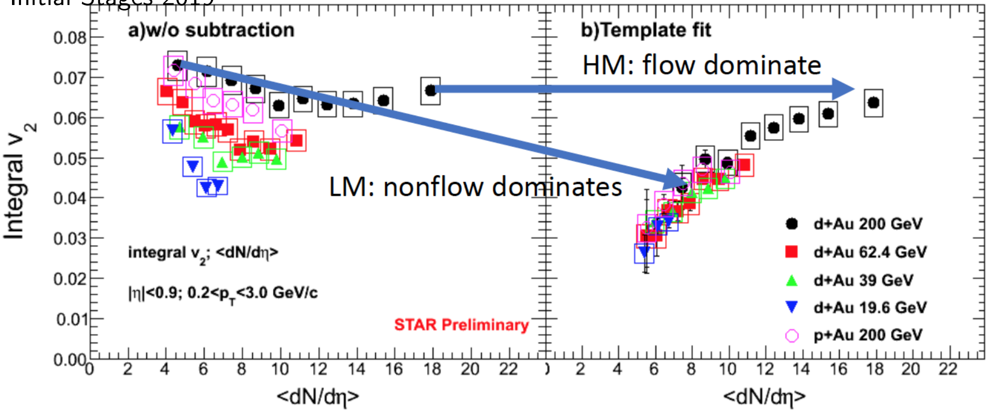
STAR, Initial Stages 2019



- STAR $v_2\{2\}$ qualitatively like PHENIX (important: different kinematics)

d+Au beam energy scan

STAR, Initial Stages 2019



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- High multiplicity dominated by collective flow

d+Au beam energy scan

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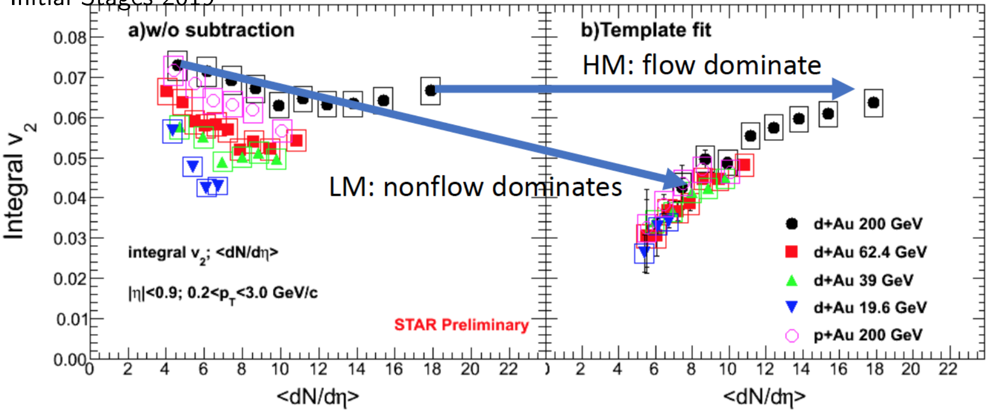
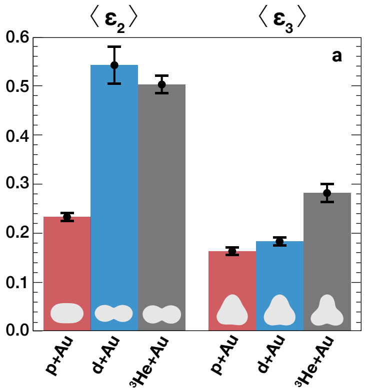
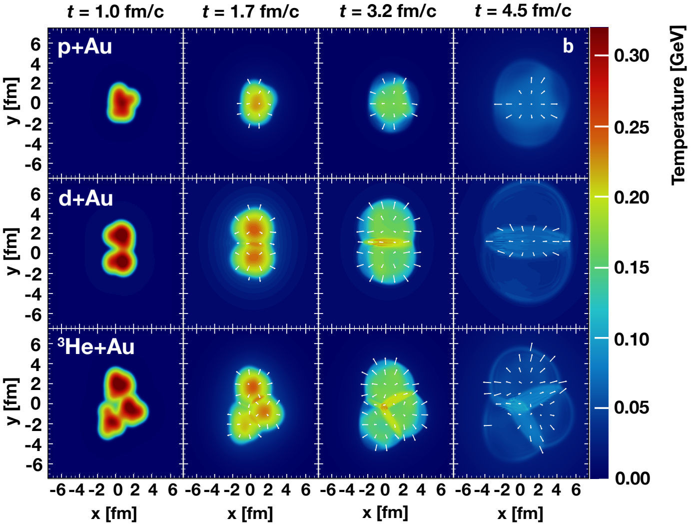


- STAR $v_2\{2\}$ qualitatively like PHENIX (important: different kinematics)
- High multiplicity dominated by collective flow
- One needs to be careful about assumptions in nonflow subtraction methods —See S. Lim et al, Phys. Rev. C 100, 024908 (2019)

Small systems geometry scan

PHENIX, Nat. Phys. 15, 214–220 (2019)





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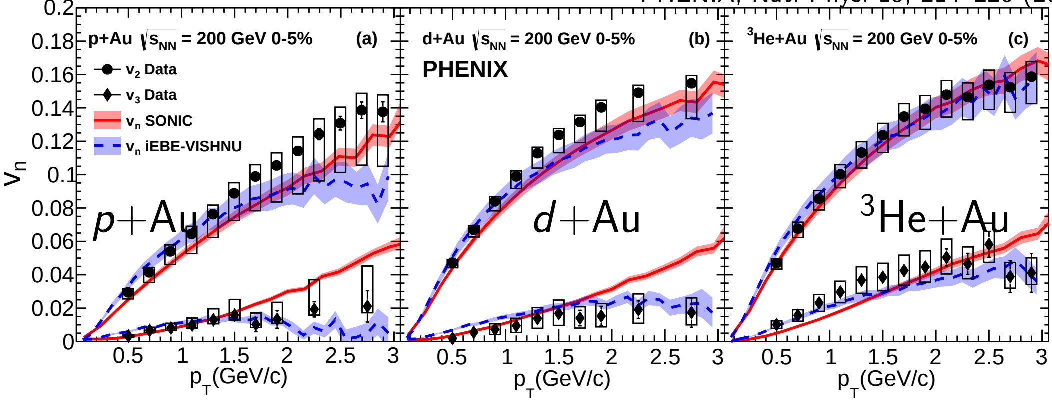

- v_2 and v_3 vs p_T predicted or described very well by hydrodynamics in all three systems
  —All predicted (except v_2 in d+Au) in J.L. Nagle et al, PRL 113, 112301 (2014)
  —v_3 in p+Au and d+Au predicted in C. Shen et al, PRC 95, 014906 (2017)

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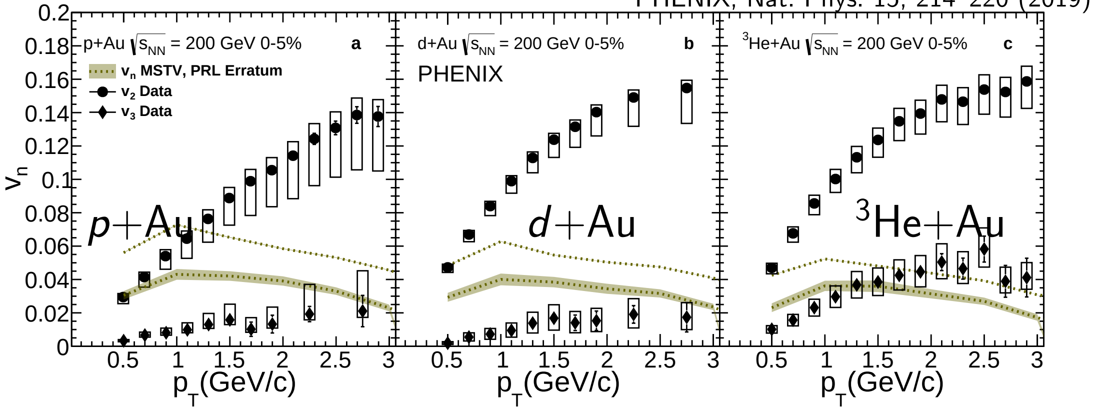

- Initial state effects alone do not describe the data —Phys. Rev. Lett. 123, 039901 (Erratum) (2019)

Small systems geometry scan

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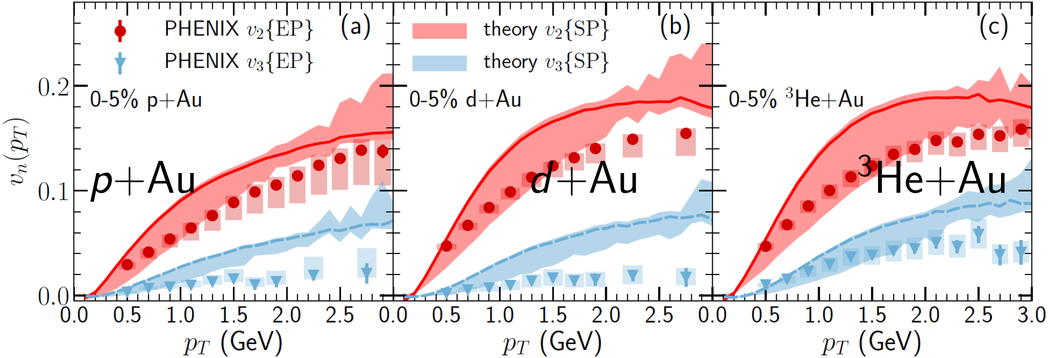
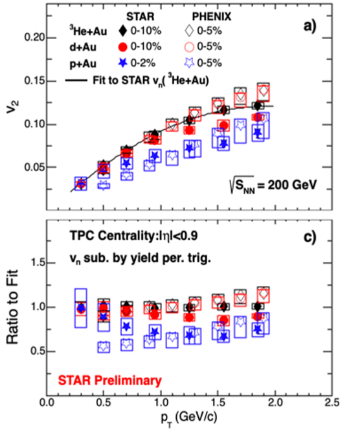


- Important to include initial state effects
  —B. Schenke et al, Phys. Lett. B 803, 135322 (2020)

Comparisons with STAR

STAR, Quark Matter 2019



Good agreement between STAR and PHENIX for v_2

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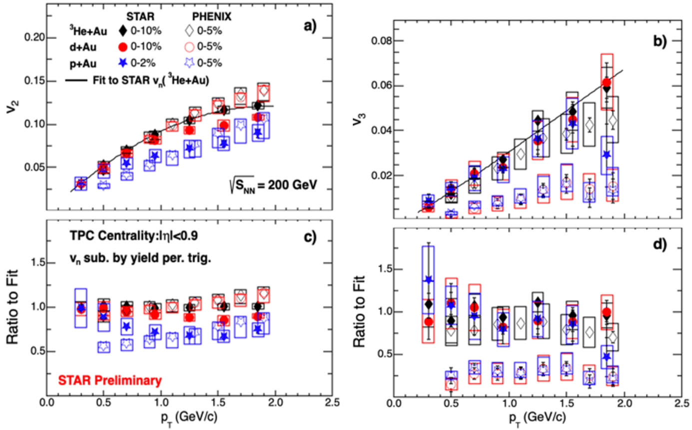
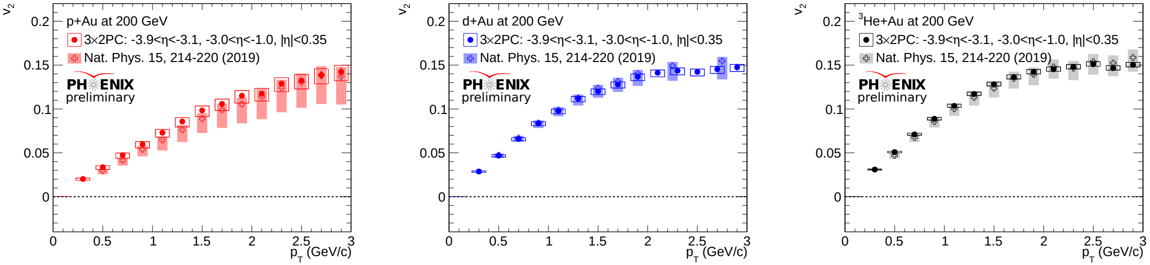


Good agreement between STAR and PHENIX for v_2

Large discrepancy between STAR and PHENIX for v_3

PHENIX data update



- PHENIX has completed a new analysis confirming the results published in Nature Physics
- All new analysis using two-particle correlations with event mixing instead of event plane method
  —Completely new and separate code base
  —Very different sensitivity to key experimental effects (beam position, detector alignment)

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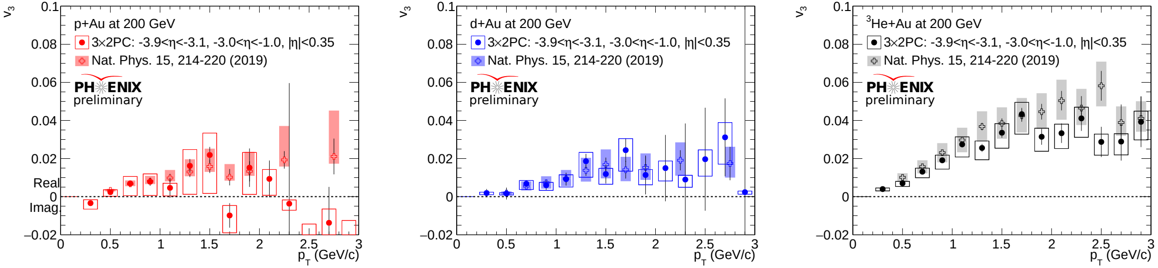

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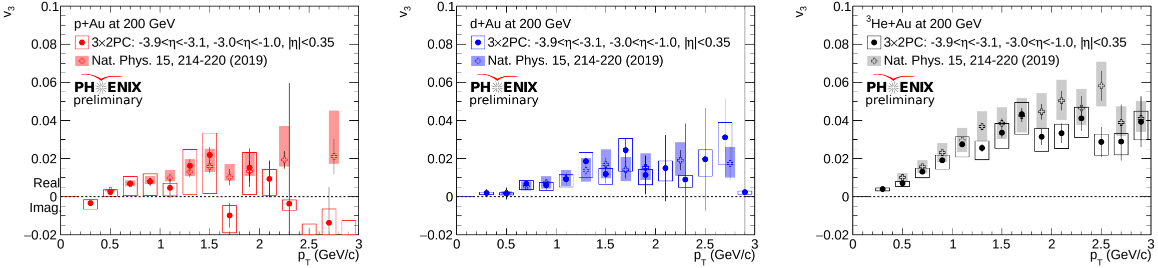

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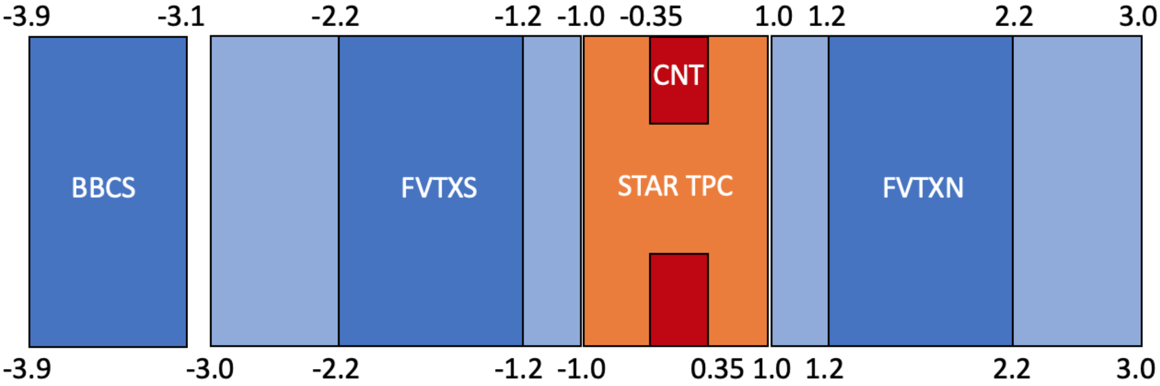
- All new analysis using two-particle correlations with event mixing instead of event plane method
  —Completely new and separate code base
  —Very different sensitivity to key experimental effects (beam position, detector alignment)
- It's essential to understand the two experiments have very different detector acceptances
  —STAR-PHENIX discrepancy may actually reveal interesting physics!

Summary

- Identified particles in small systems
  —Minimal sensitivity to mass and strangeness
  —Strong sensitivity to baryon vs meson
  —Hadronization (likely via parton coalescence) plays a key role in system dynamics and observables
- Photons in small systems
  —Excess in photon R_{pA} at low p_T may indicate presence of thermal photons
  —Scaled photon yields may show turn-on of thermal photons from p+p to small systems to large systems
- Flow correlations in small systems
  —Long term understanding of collective and hydrodynamical behavior of heavy ion data
  —Geometry and fluctuations play essential roles in observables
  —Collective behavior seen in small systems, predicted and described by hydro

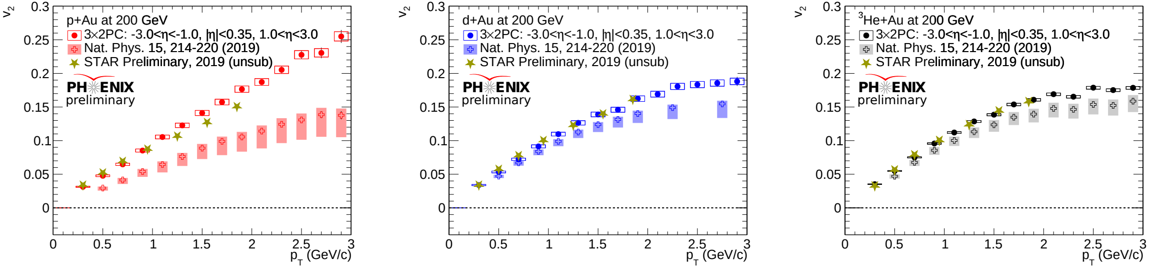
Extra material

STAR and PHENIX detector comparison



- The PHENIX Nature Physics paper uses the BBCS-FVTXS-CNT detector combination
  —This is very different from the STAR analysis
- We can try to use FVTXS-CNT-FVTXN detector combination to better match STAR
  —Closer, and "balanced" between forward and backward, *but still different*

More STAR and PHENIX data comparisons



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  —Both experiments' results confirmed, so differences need to be understood in terms of physics

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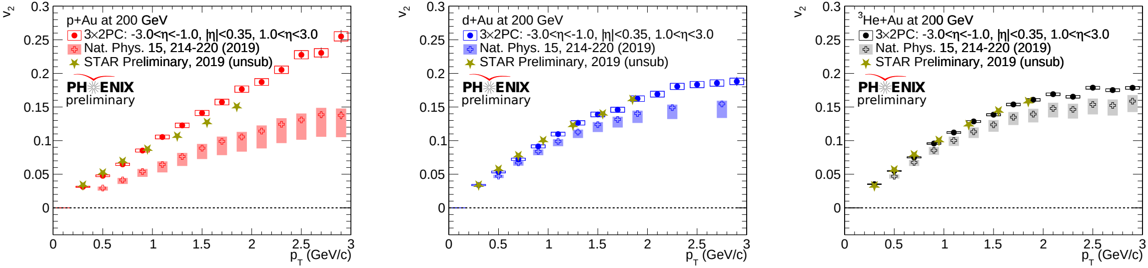

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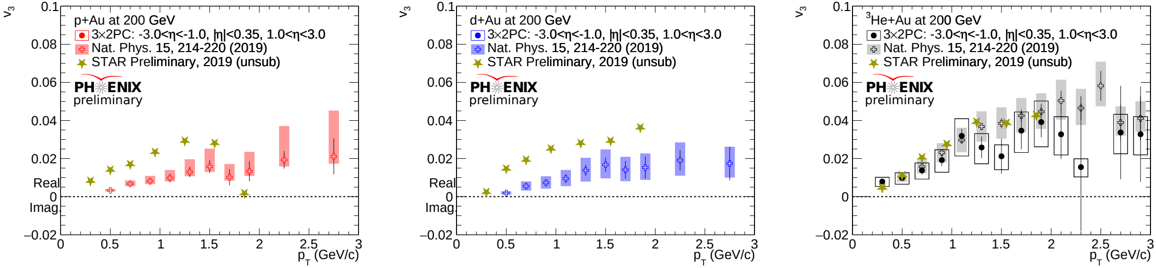

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- Strikingly different results for v_3
  —Rather different physics for the two different pseudorapidity acceptances
  —Decorrelation effects much stronger for v_3 than v_2

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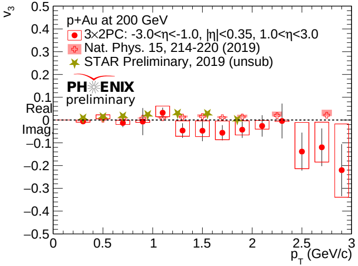

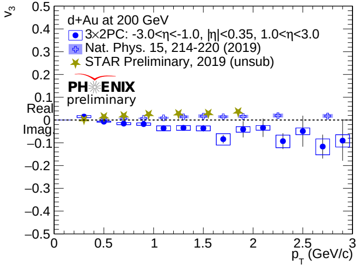

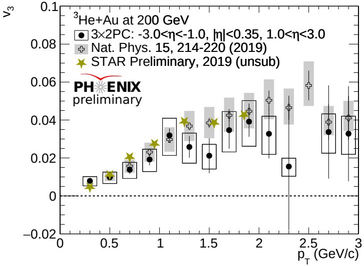

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Initial eccentricities

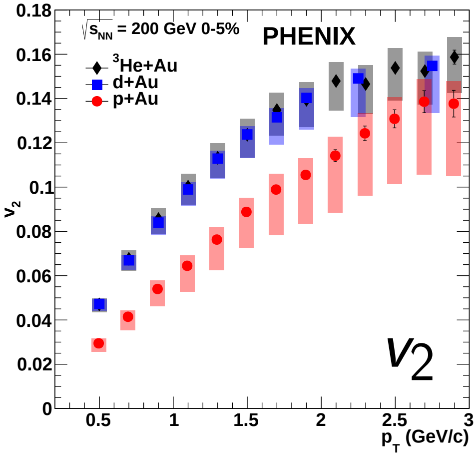
Table compiled by J.L. Nagle

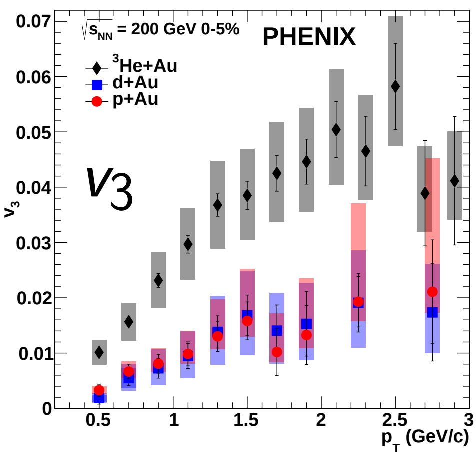
System	Nagle Nucleons w/o NBD fluctuations	Welsh Nucleons w/ NBD fluctuations	Welsh Quarks w/ NBD and Gluon fluctuations	IPGlasma w/ Nucleons t=0	IP-Glasma w/ 3 Quarks t=0
ε_2 p+Au	0.23	0.32	0.38	**0.10**	**0.50**
ε_2 d+Au	0.54	0.48	0.51	**0.58**	**0.73**
ε_2 ^{3}He+Au	0.50	0.50	0.52	**0.55**	**0.64**
ε_3 p+Au	0.16	0.24	0.30	**0.09**	**0.32**
ε_3 d+Au	0.18	0.28	0.31	**0.28**	**0.40**
ε_3 ^{3}He+Au	0.28	0.32	0.35	**0.34**	**0.46**

- Nagle et al: `https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.113.112301`
- Welsh et al: `https://journals.aps.org/prc/abstract/10.1103/PhysRevC.94.024919`
- IP-Glasma run by S. Lim using publicly available code (thanks to B. Schenke)

Small systems geometry scan

PHENIX, Nat. Phys. 15, 214–220 (2019)

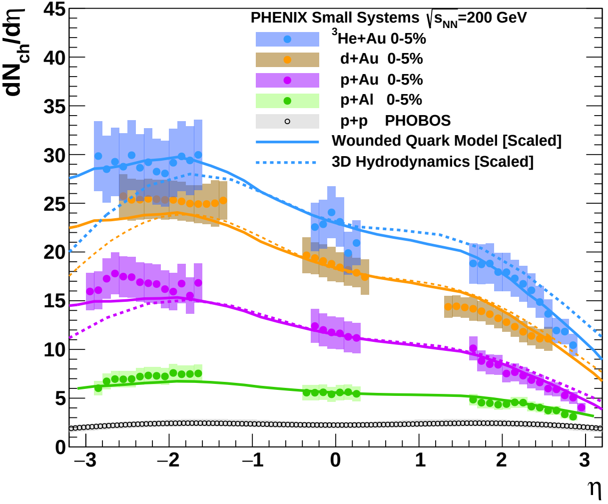




- v_2 and v_3 ordering matches ε_2 and ε_3 ordering in all three systems
  —Collective motion of system translates the initial geometry into the final state

Longitudinal dynamics in small systems

Phys. Rev. Lett. 121, 222301 (2018)



p+Al, p+Au, d+Au, ^{3}He+Au

Good agreement with wounded quark model
(M. Barej et al, Phys. Rev. C 97, 034901 (2018))

Good agreement with 3D hydro
(P. Bozek et al, Phys. Lett. B 739, 308 (2014))

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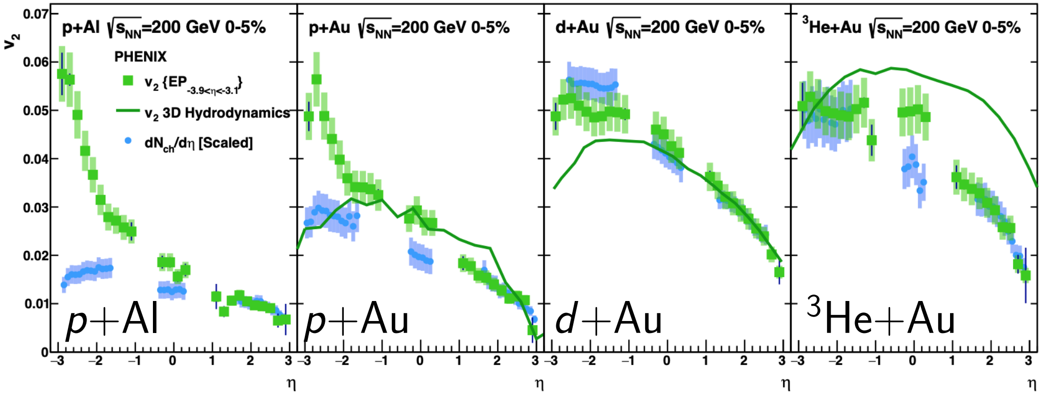

- v_2 vs η in p+Al, p+Au, d+Au, and ^{3}He+Au
- Good agreement with 3D hydro for p+Au and d+Au (Bozek et al, PLB 739, 308 (2014))

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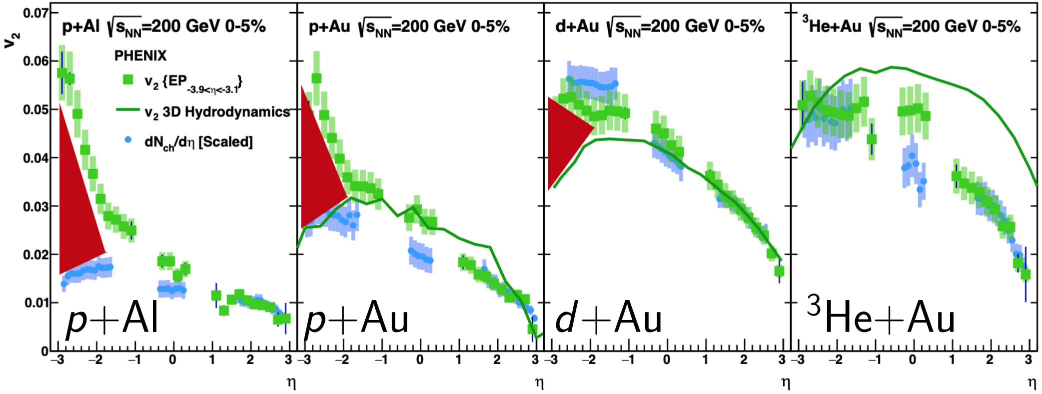

- v_2 vs η in p+Al, p+Au, d+Au, and ^{3}He+Au
- Good agreement with 3D hydro for p+Au and d+Au (Bozek et al, PLB 739, 308 (2014))
- Prevalence of nonflow near the EP detector ($-3.9 < \eta < -3.1$)

Longitudinal dynamics in small systems

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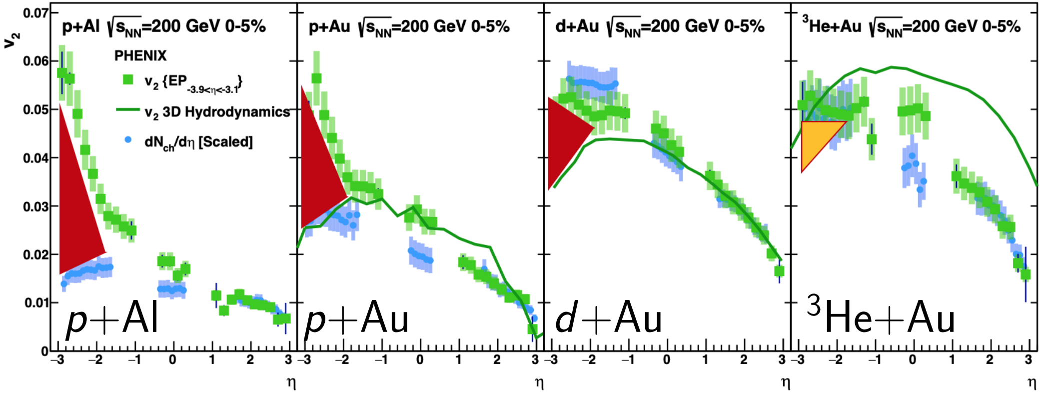

- v_2 vs η in p+Al, p+Au, d+Au, and ^{3}He+Au
- Good agreement with 3D hydro for p+Au and d+Au (Bozek et al, PLB 739, 308 (2014))
- Prevalence of nonflow near the EP detector ($-3.9 < \eta < -3.1$)