Geometry engineering, longitudinal dynamics, and droplets of quark-gluon plasma

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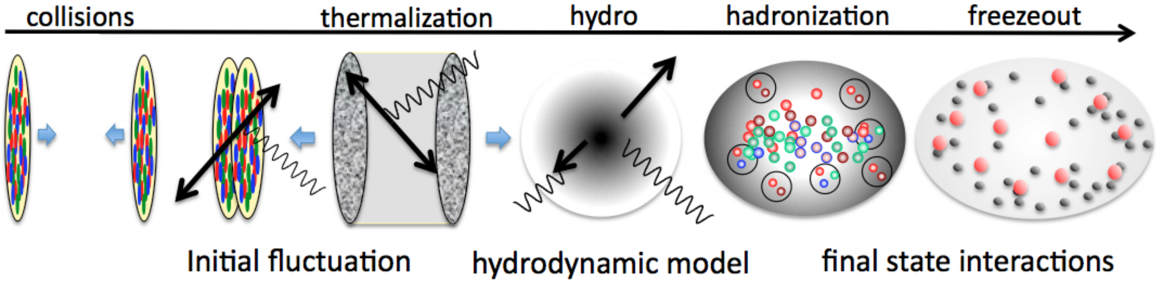
University of North Carolina at Greensboro

BNL Seminar
2 November 2021

Quick outline

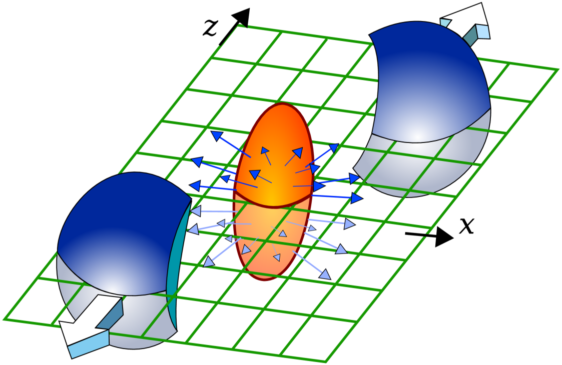
- Brief overview of the standard model of heavy ion collisions (the hydro paradigm)
- Small systems beam energy scan
- Small systems geometry scan
- A quick look outside RHIC

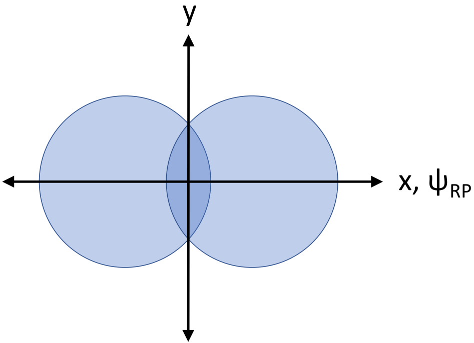
Standard model of heavy ion physics



Based on developments in hydro theory over the last few years, we might replace "thermalization" with "hydrodynamization"

Azimuthal anisotropy measurements

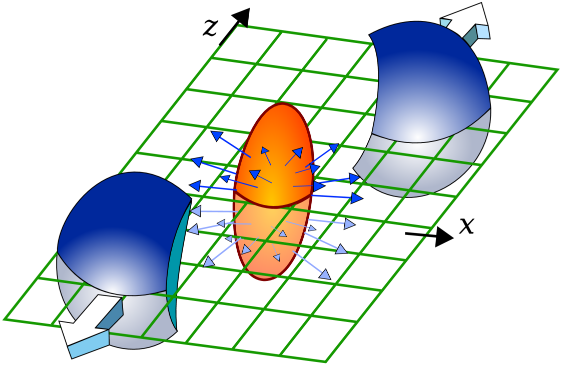


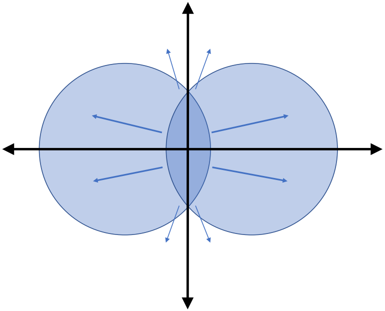


$$\frac{dN}{d\varphi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos n\varphi \qquad v_n = \langle \cos n\varphi \rangle \qquad \varepsilon_n = \frac{\sqrt{\langle r^n \cos n\varphi \rangle + \langle r^n \sin n\varphi \rangle}}{\langle r^n \rangle}$$

- Hydrodynamics translates initial shape (including fluctuations) into final state distribution

Azimuthal anisotropy measurements





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

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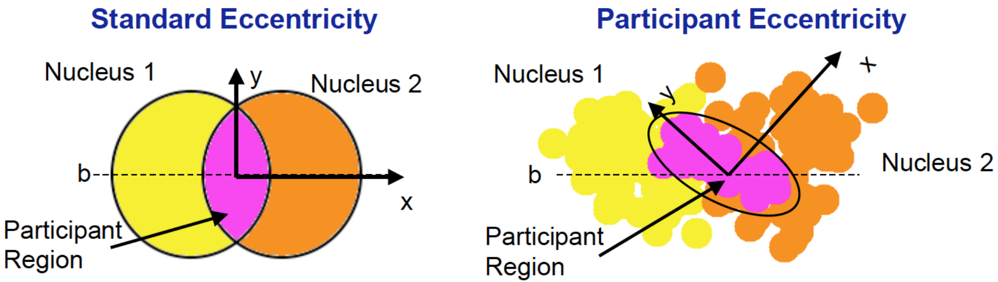
Important discovery in 2005

PHOBOS Plenary, Quark Matter 2005 (see also Phys.Rev.C 77, 014906 (2008))



A nucleus isn't just a sphere

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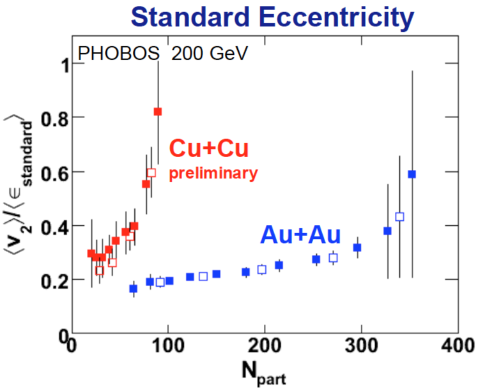

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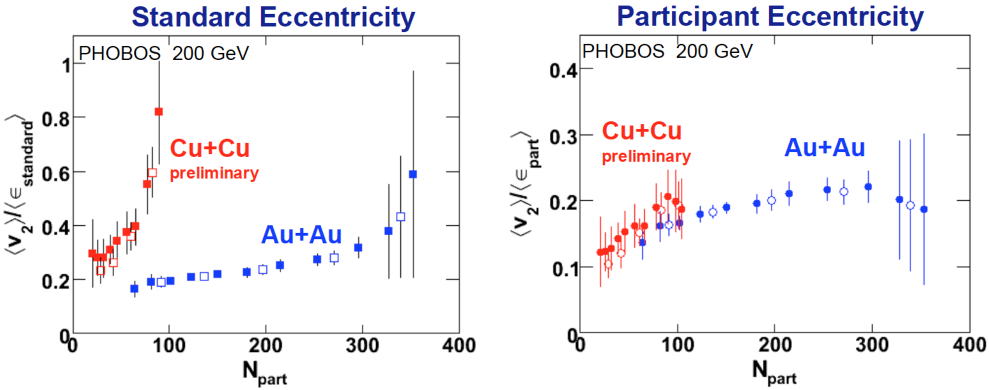


A nucleus isn't just a sphere

Important discovery in 2005

R. Andrade et al, Eur. Phys. J. A 29, 23-26 (2006)

NeXSPheRIO results on elliptic flow at RHIC and connection with thermalization

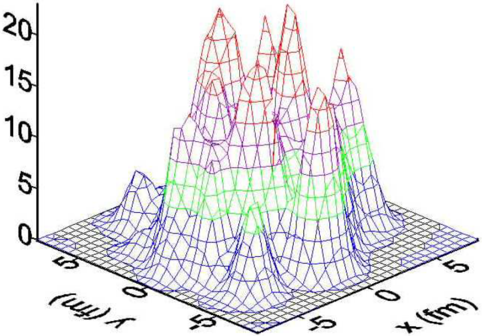
R.Andrade[1], F.Grassi[1], Y.Hama[1], T.Kodama[2], O.Socolowski Jr.[3], and B.Tavares[2]

[1] Instituto de Física, USP,
C. P. 66318, 05315-970 São Paulo-SP, Brazil

[2] Instituto de Física, UFRJ,
C. P. 68528, 21945-970 Rio de Janeiro-RJ , Brazil

[3] CTA/ITA,
Praça Marechal Eduardo Gomes 50, CEP 12228-900 São José dos Campos-SP, Brazil

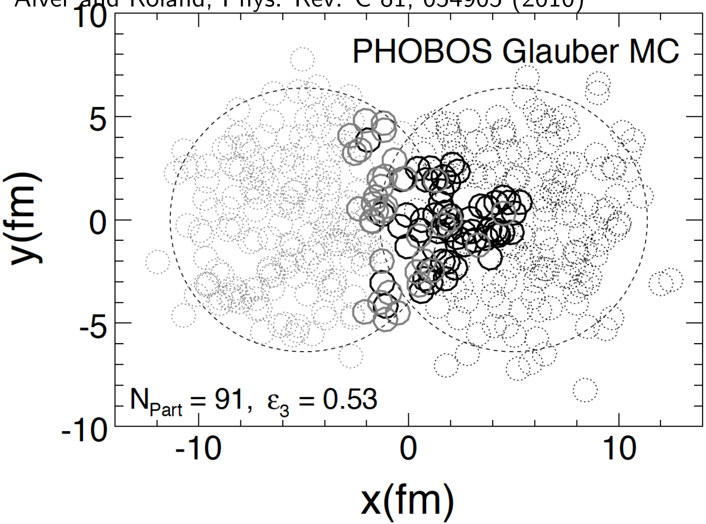
Received 1 January 2004



Worth noting that lumpy initial conditions were predicted some time in 2003

Important discovery in 2010

Alver and Roland, Phys. Rev. C 81, 054905 (2010)



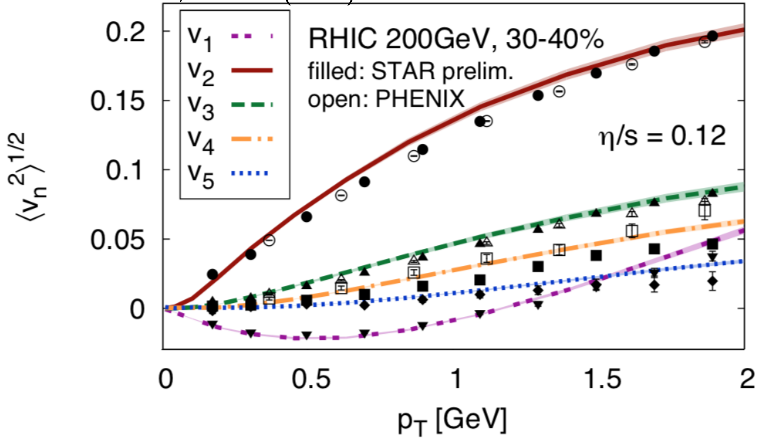
Nucleon fluctuations can produce non-zero ε_n for odd n

Symmetry planes ψ_n can be different for different harmonics

$$\varphi = \phi_{lab} - \psi_n$$

Data and theory for v_n

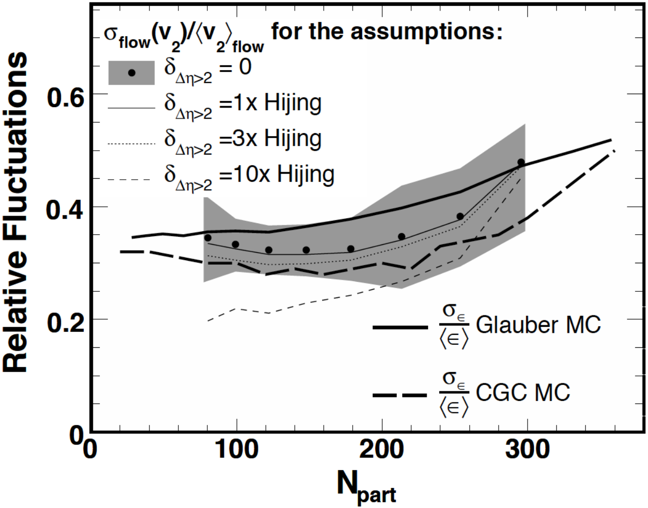
Gale et al, Phys. Rev. Lett. 110, 012302 (2013)



$$\frac{dN}{d\varphi} \propto 2v_1 \cos\varphi + 2v_2 \cos 2\varphi + 2v_3 \cos 3\varphi + 2v_4 \cos 4\varphi + 2v_5 \cos 5\varphi$$

Fluctuations in large systems

PHOBOS, Phys. Rev. C 81, 034915 (2010)



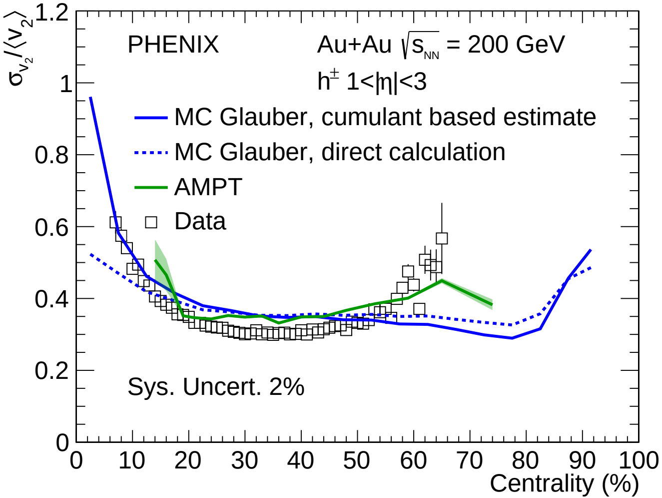
Fluctuations should also be translated, so measure $\sigma_{v_2}/\langle v_2\rangle$

$|\eta| < 1$

Generally good agreement with models of initial geometry

Fluctuations in large systems

PHENIX, Phys. Rev. C 99, 024903 (2019)



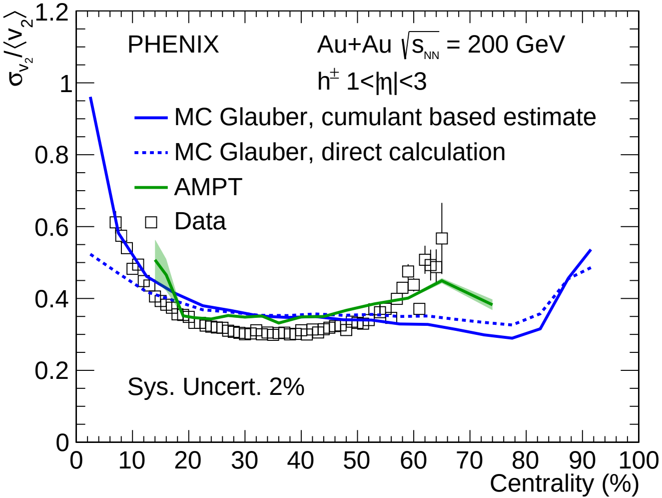
Fluctuations should also be translated, so measure $\sigma_{v_2}/\langle v_2 \rangle$

$1 < |\eta| < 3$

Generally good agreement with models of initial geometry

Fluctuations in large systems

PHENIX, Phys. Rev. C 99, 024903 (2019)



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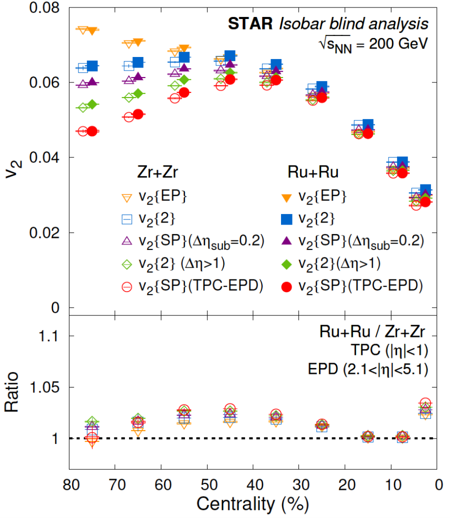
$1 < |\eta| < 3$

Central: breakdown of small-variance limit (assumed in data and solid line)

Peripheral: non-linearity in hydro response (e.g. J. Noronha-Hostler et al Phys. Rev. C 93, 014909 (2016))

Geometry engineering and nuclear structure

STAR, arXiv:2109.00131



Exquisite new data from STAR shows percent-level sensitivity to nuclear structure

J. Jia, arXiv:2109.00604 proposes to use flow and nuclear structure to inform each other

Intermission

Small systems

A brief history of heavy ion physics

- 1980s and 1990s—AGS and SPS... QGP at SPS!
- Early 2000s—QGP at RHIC! No QGP at SPS. d+Au as control.
- Mid-late 2000s—Detailed, quantitative studies of strongly coupled QGP. d+Au as control.
- 2010—Ridge in high multiplicity p+p (LHC)! Probably CGC!
- Early 2010s—QGP in p+Pb!
- Early 2010s—QGP in d+Au!
- Mid 2010s to present—QGP almost everywhere

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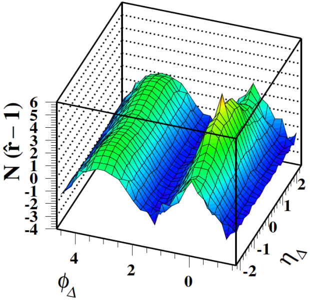
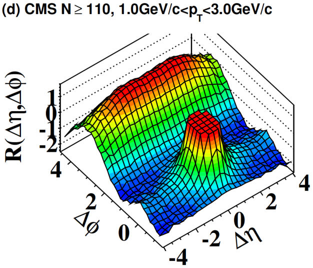
"Twenty years ago, the challenge in heavy ion physics was to find the QGP. Now, the challenge is to not find it." —Jürgen Schukraft, QM17

The ridge is a signature of flow

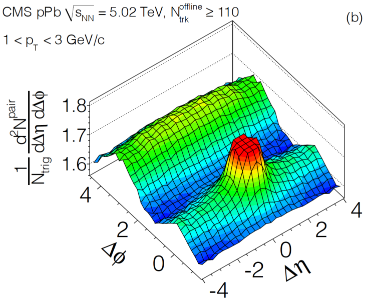
STAR, PRC 73, 064907 (2006)



CMS, JHEP 1009, 091 (2010)



CMS, PLB 718, 795 (2013)

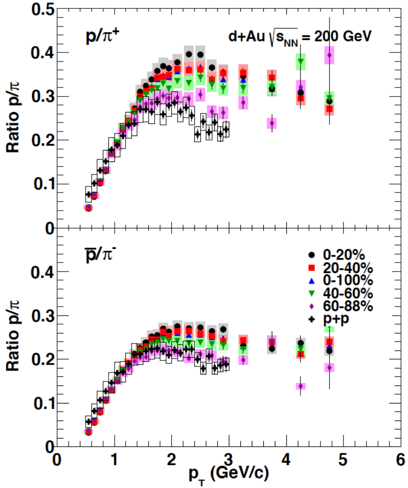


Extended structure away from near-side jet peak interpreted as collective effect due to presence of QGP

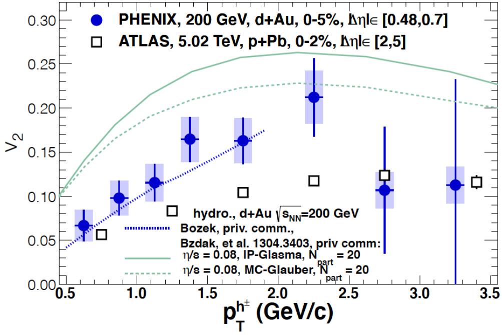
- First discovered by STAR in Au+Au in 2004 (PRC 73, 064907 (2006) and PRL 95, 152301 (2005))
- Realized by STAR to be flow in 2009 (PRL 105, 022301 (2010))
- First found in small systems by CMS (JHEP 1009, 091 (2010) and PLB 718, 795 (2013))

First results at RHIC

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



PHENIX, Phys. Rev. Lett. 111, 212301 (2013)



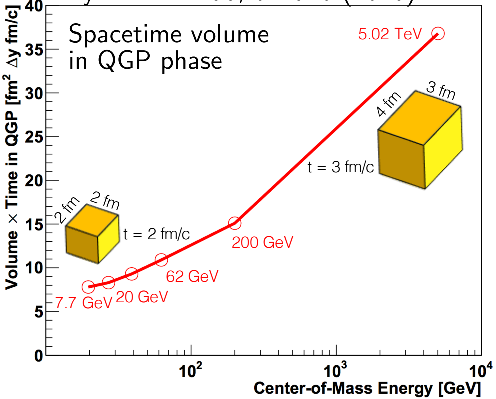
- Right around the same time as the *p*+Pb ridge:
  —First paper measuring v_2 in *d*+Au at RHIC
  —Measurement of baryon enhancement in *d*+Au

Intermission

Small systems beam energy scan

Testing hydro by controlling system size and life time

J.D. Orjuela Koop et al
Phys. Rev. C 93, 044910 (2016)

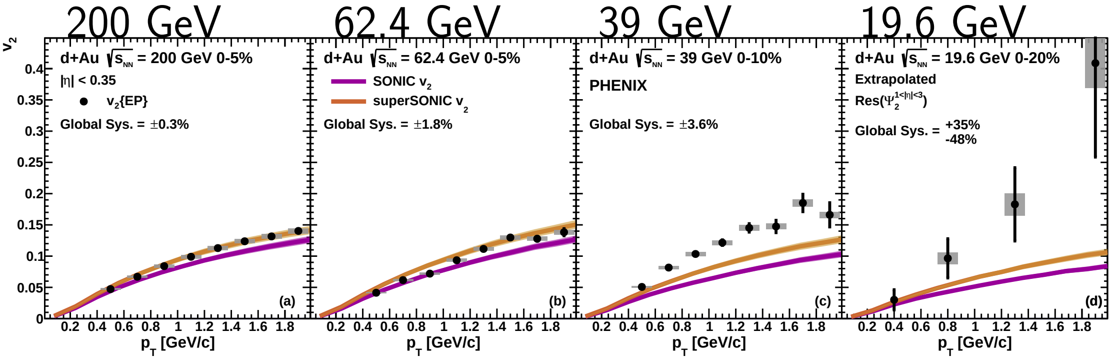


Geometry in d+Au collisions dominated by deuteron shape, thus largely independent of collision energy

Spacetime volume of system in QGP phase decreases with decreasing collision energy

d+Au beam energy scan

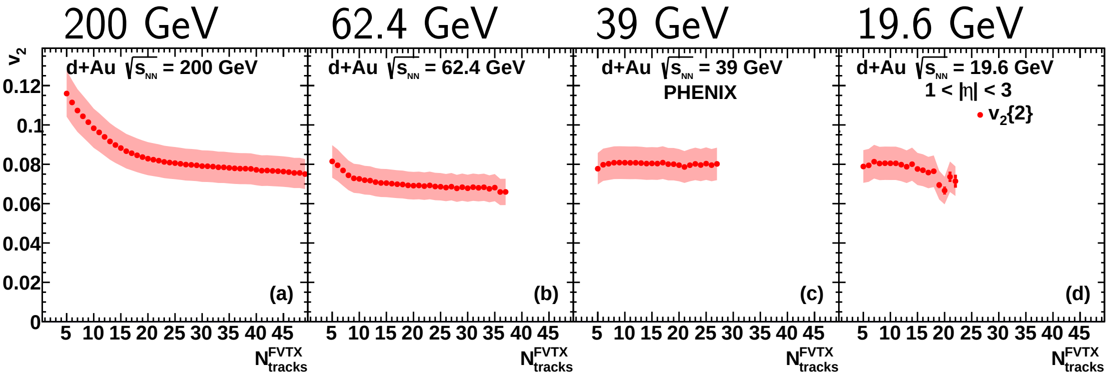
PHENIX, Phys. Rev. C 96, 064905 (2017)



- Hydro theory agrees with higher energies very well, underpredicts lower energies
- Likely need different EOS for lower energies; influence of conserved charges likely more important at lower energies (see e.g. J. Noronha-Hostler et al, 1911.10272, 1911.12454)
- Nonflow likelier to be an issue due to lower multiplicity at lower energies

d+Au beam energy scan

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



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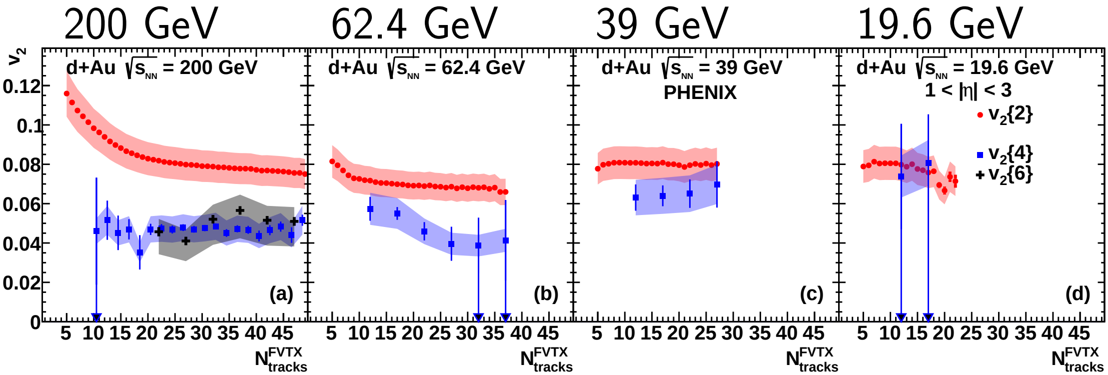

- Measurement of $v_2\{6\}$ in d+Au at 200 GeV and $v_2\{4\}$ in d+Au at all energies

d+Au beam energy scan

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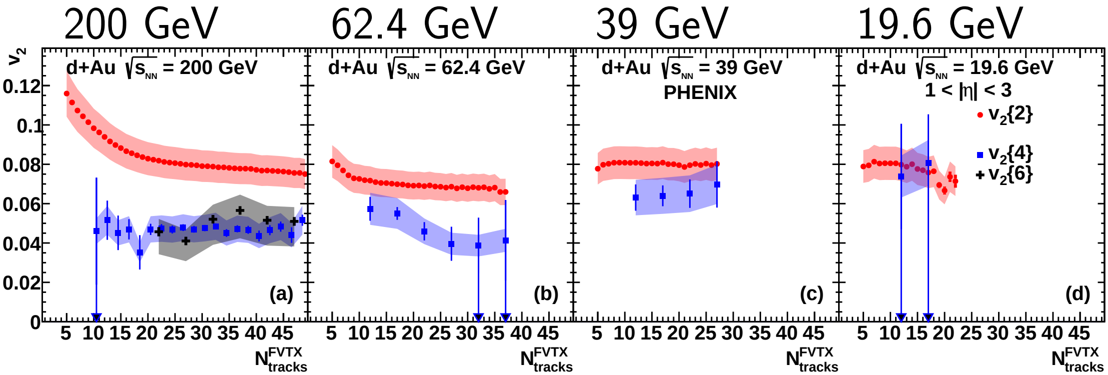
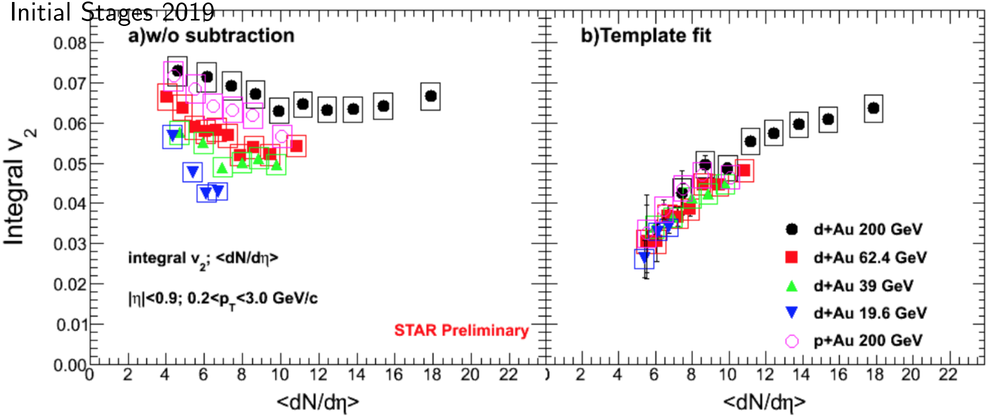


- Measurement of $v_2\{6\}$ in d+Au at 200 GeV and $v_2\{4\}$ in d+Au at all energies
- Multiparticle correlations can be a good indicator of collectivity, but beware caveats

d+Au beam energy scan

STAR, Initial Stages 2019



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

d+Au beam energy scan

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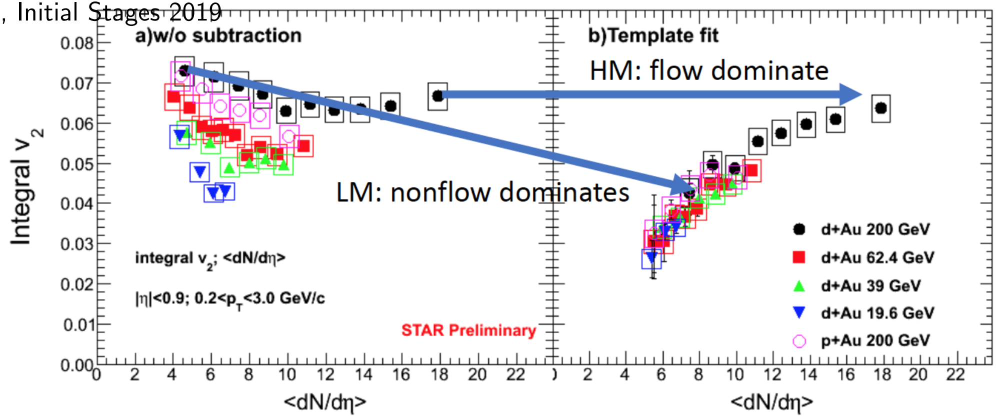

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d+Au beam energy scan

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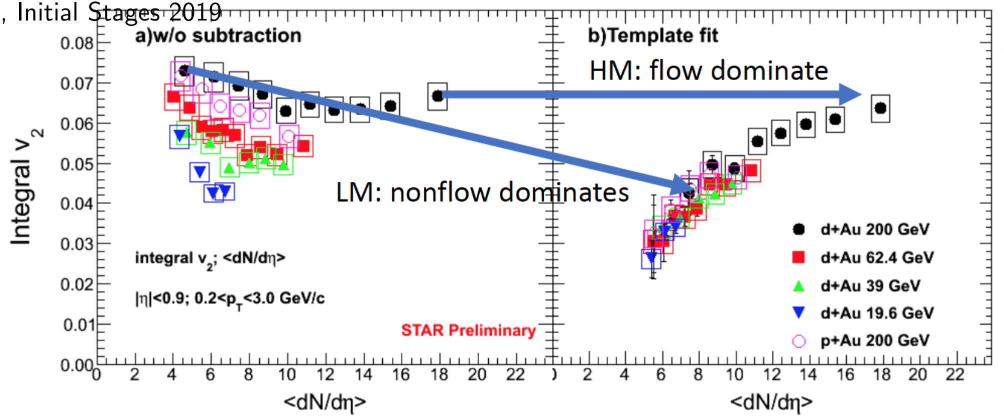
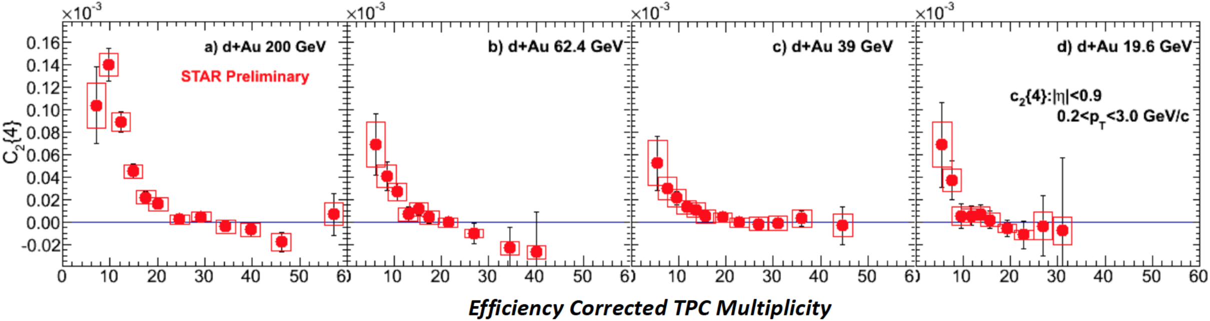


- STAR $v_2\{2\}$ qualitatively like PHENIX (important: different kinematics)
- High multiplicity dominated by collective flow
- One needs to be careful about assumptions in nonflow subtraction methods
  —See S. Lim et al, Phys. Rev. C 100, 024908 (2019)

d+Au beam energy scan

STAR, Initial Stages 2019



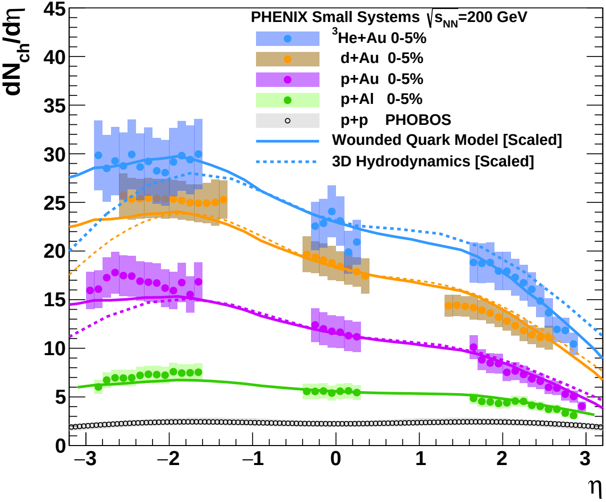
- STAR sees negative $c_2\{4\}$ in d+Au, qualitatively consistent with PHENIX
- The differences in kinematics between the two experiments are important

Intermission

Pseudorapidity dependence in small systems as a prelude to the geometry scan

Pseudorapidity dependence in small systems

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



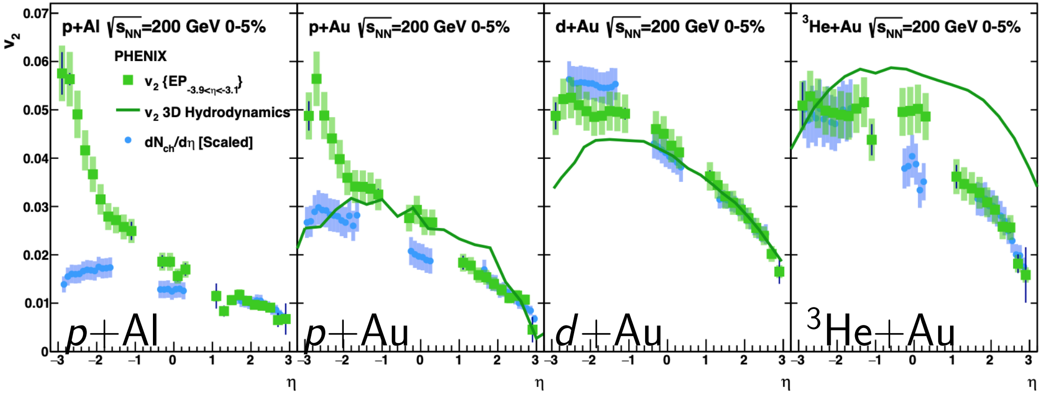
p+Al, *p*+Au, *d*+Au, ^{3}He+Au

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))

Pseudorapidity dependence in small systems

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



- 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))

Pseudorapidity dependence in small systems

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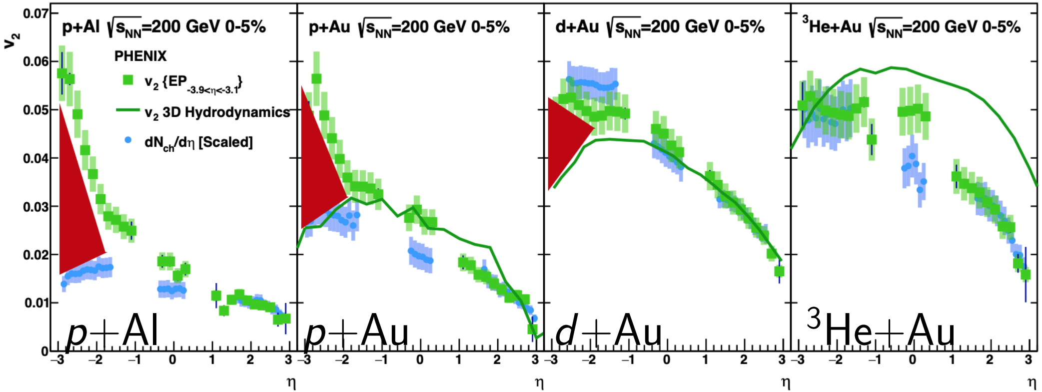

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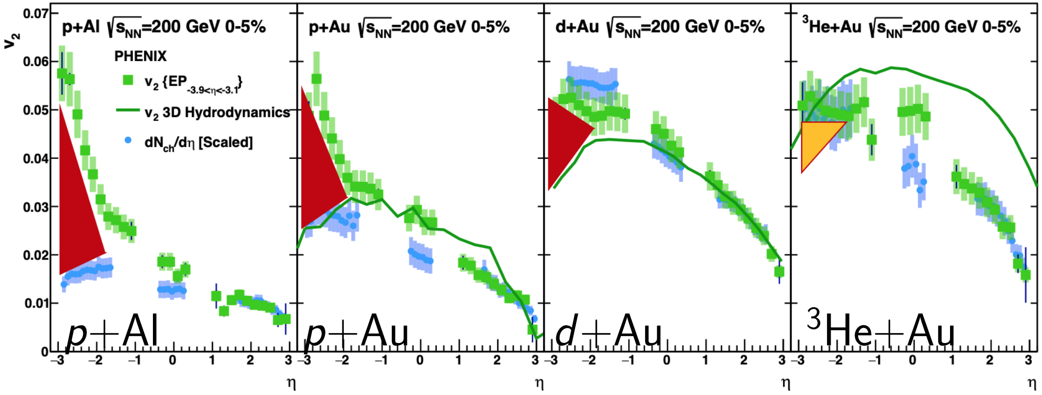
- Prevalence of nonflow near the EP detector ($-3.9 < \eta < -3.1$)

Pseudorapidity dependence in small systems

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



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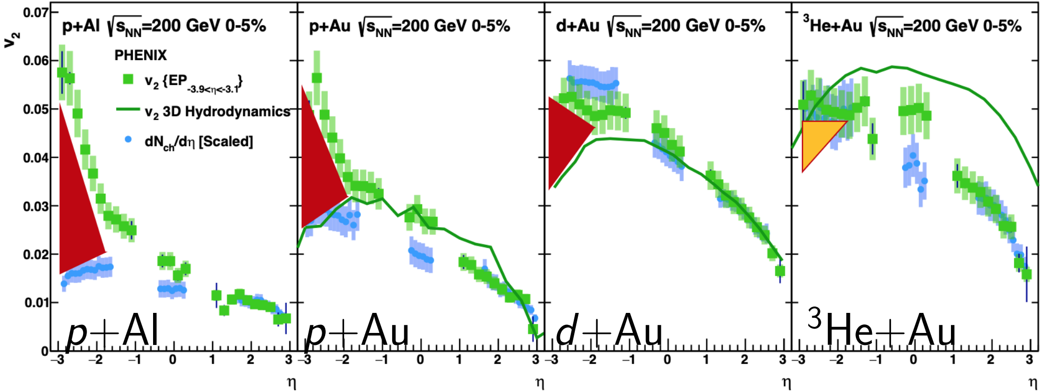

- It would be nice to know $v_3(\eta)$, but very hard to measure

Intermission

Small systems geometry scan

Testing hydro by controlling system geometry

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Exploiting Intrinsic Triangular Geometry in Relativistic $^{3}\mathbf{He} + \mathbf{Au}$ Collisions to Disentangle Medium Properties

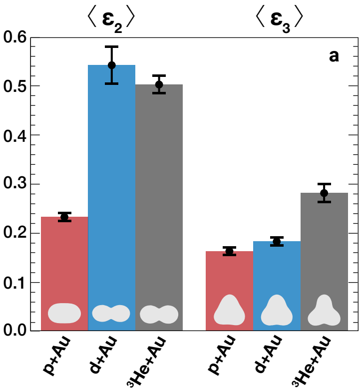
J. L. Nagle, A. Adare, S. Beckman, T. Koblesky, J. Orjuela Koop, D. McGlinchey, P. Romatschke, J. Carlson, J. E. Lynn, and M. McCumber

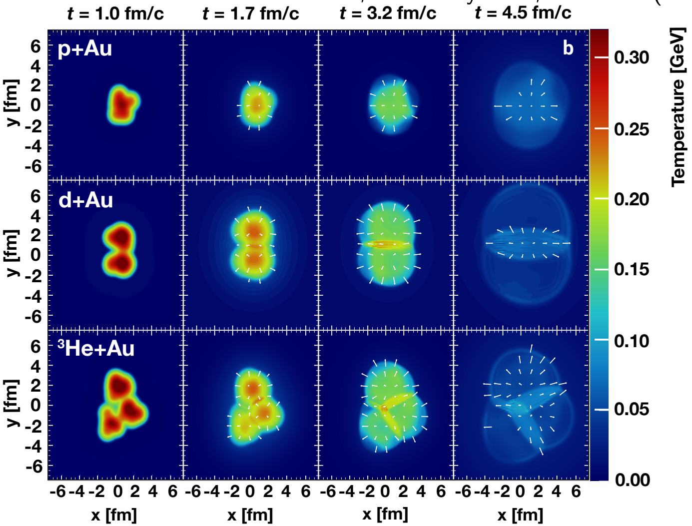
Phys. Rev. Lett. **113**, 112301 – Published 12 September 2014

- Collective motion translates initial geometry into final state distributions
- To determine whether small systems exhibit collectivity, we can adjust the geometry and compare across systems
- We can also test predictions of hydrodynamics with a QGP phase

Testing hydro by controlling system geometry

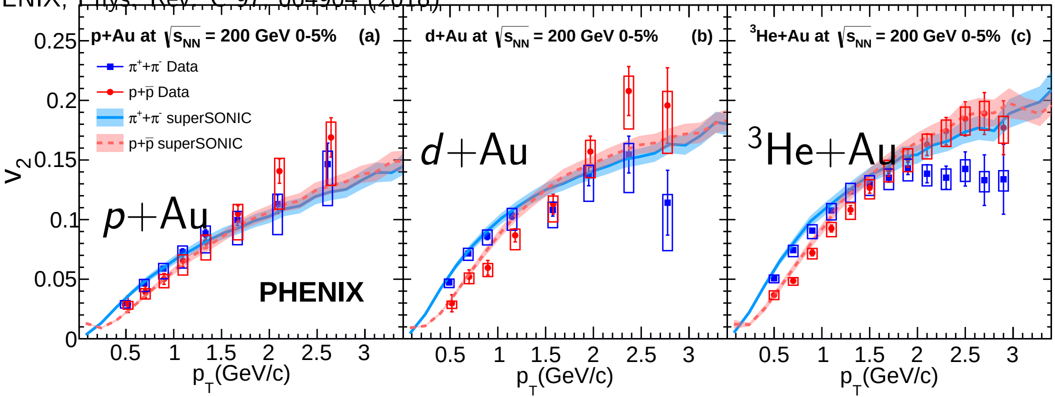
PHENIX, Nat. Phys. 15, 214–220 (2019)





Small systems geometry scan

PHENIX, Phys. Rev. C 97, 064904 (2018)



- Identified particle v_2 vs p_T in p+Au, d+Au, and ^{3}He+Au
  - —Low p_T mass ordering well-described by hydro
  - —Hydro doesn't have enough splitting at mid-p_T (hadronization by Cooper-Frye)

Small systems geometry scan

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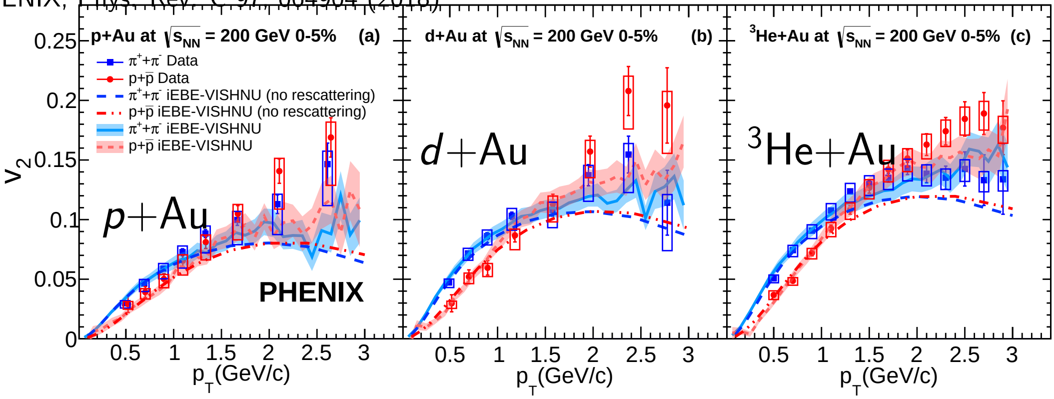

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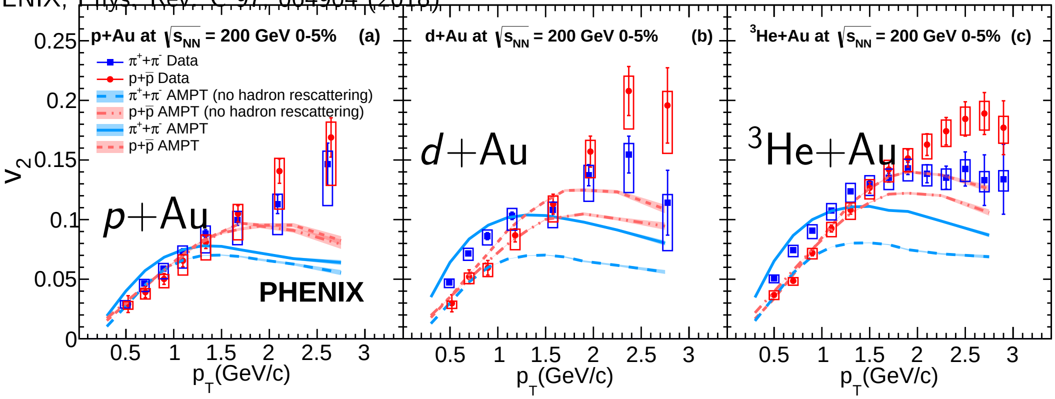
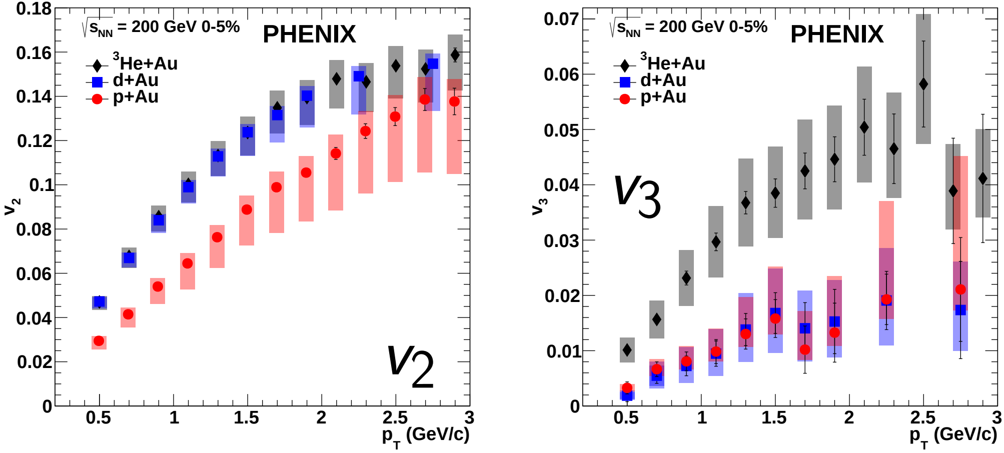


- Identified particle v_2 vs p_T in p+Au, d+Au, and ^{3}He+Au
  - —Low p_T mass ordering well-described by hydro
  - —Hydro doesn't have enough splitting at mid-p_T (hadronization by Cooper-Frye)
- AMPT gets mid-p_T separation because of the more realistic hadronization (coalescence)

Testing hydro by controlling system geometry

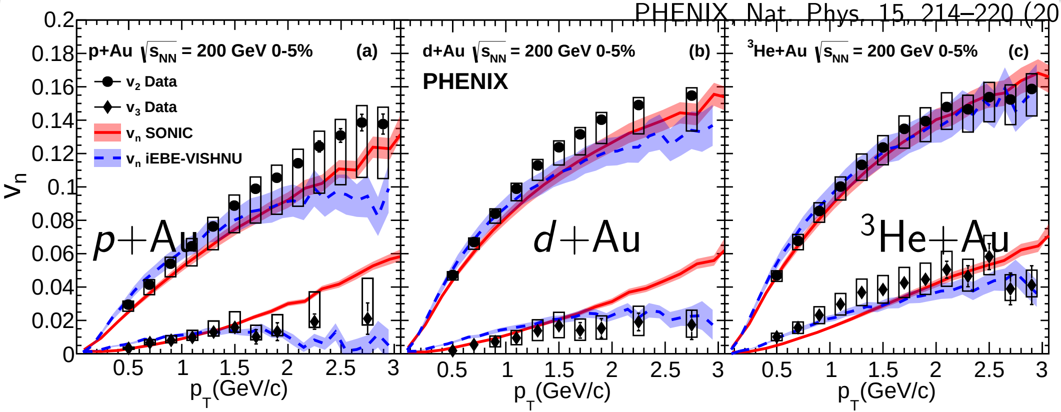
PHENIX, Nat. Phys. 15, 214–220 (2019)



- 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

Testing hydro by controlling system geometry

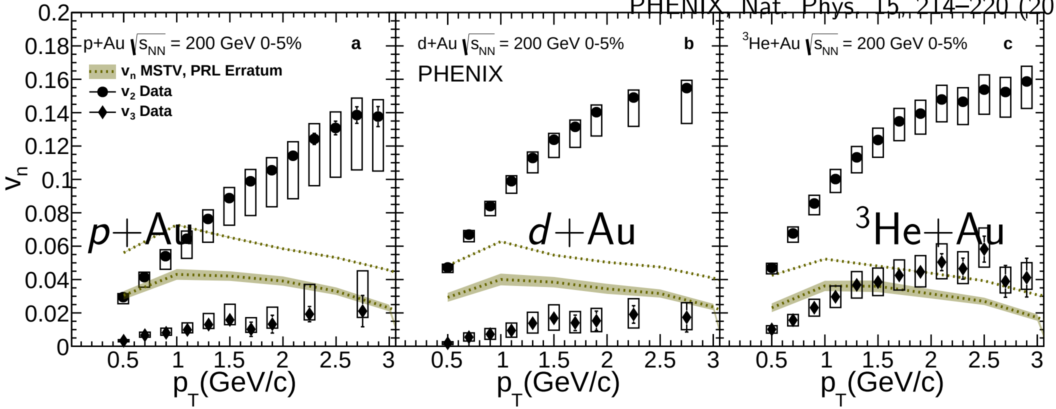
PHENIX, Nat. Phys. 15, 214–220 (2019)



- 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)

Testing hydro by controlling system geometry

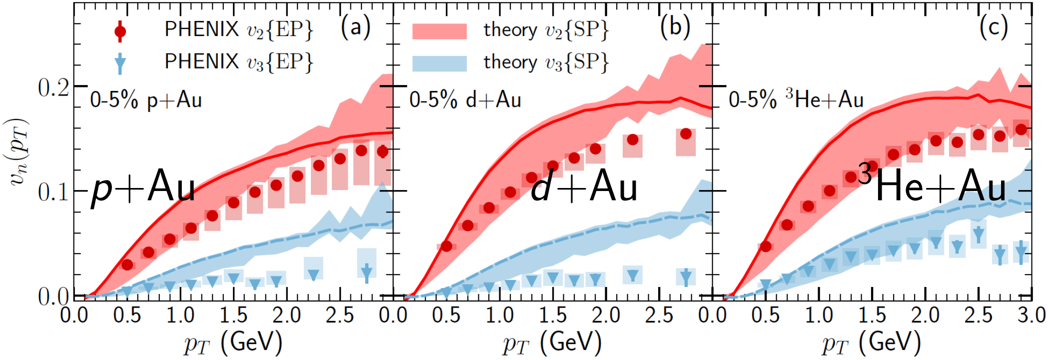
PHENIX, Nat. Phys. 15, 214–220 (2019)



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

Testing hydro by controlling system geometry

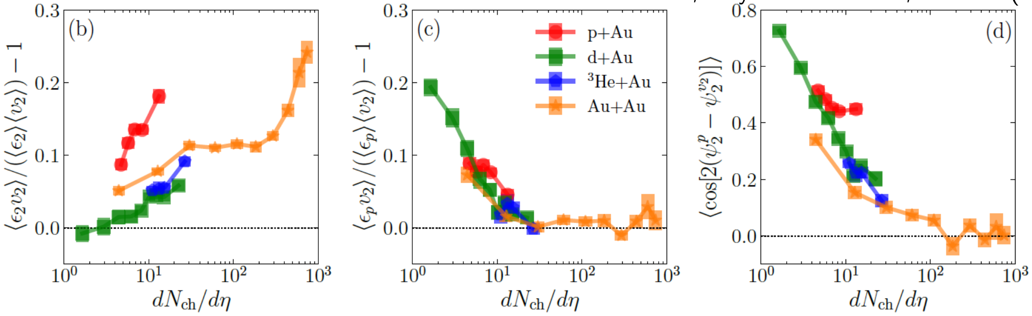
PHENIX, Nat. Phys. 15, 214–220 (2019)



- 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)

How important are initial state effects?

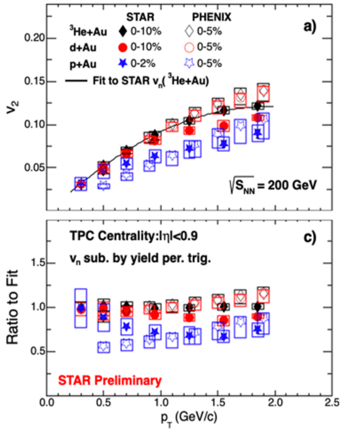
B. Schenke et al, Phys. Lett. B 803, 135322 (2020)



- 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 $\psi_2^{v_2}$

Comparisons with STAR

STAR, Quark Matter 2019



Good agreement between STAR and PHENIX for v_2

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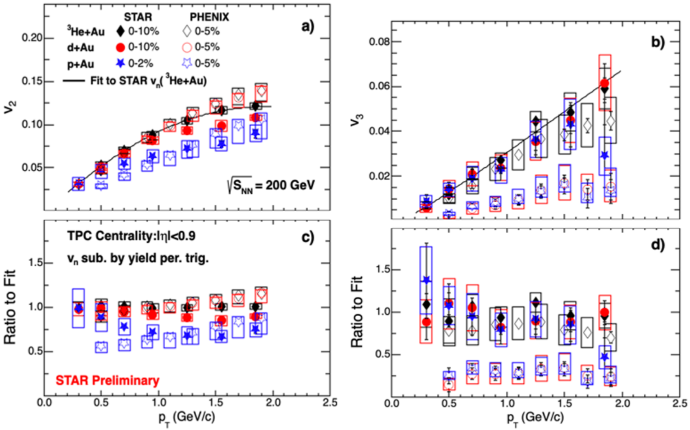
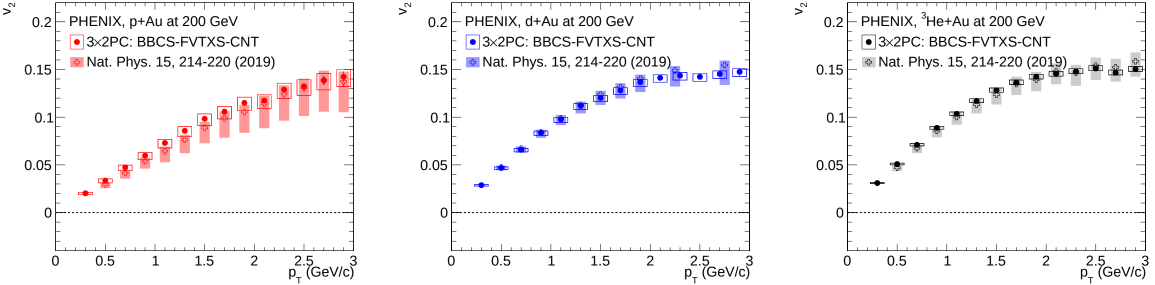


Good agreement between STAR and PHENIX for v_2

Large discrepancy between STAR and PHENIX for v_3

PHENIX data update

PHENIX, arXiv:2107.06634 (submitted to Phys. Rev. C)



- 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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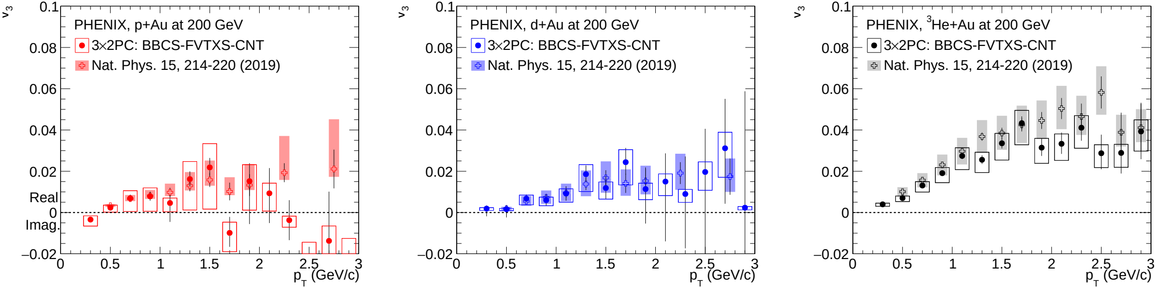

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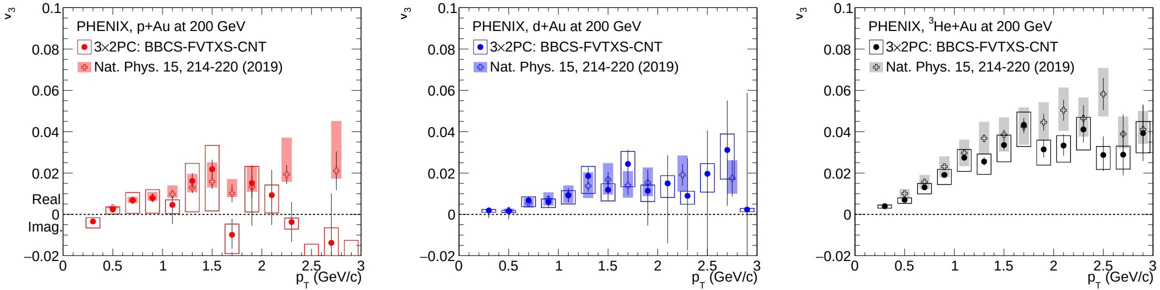
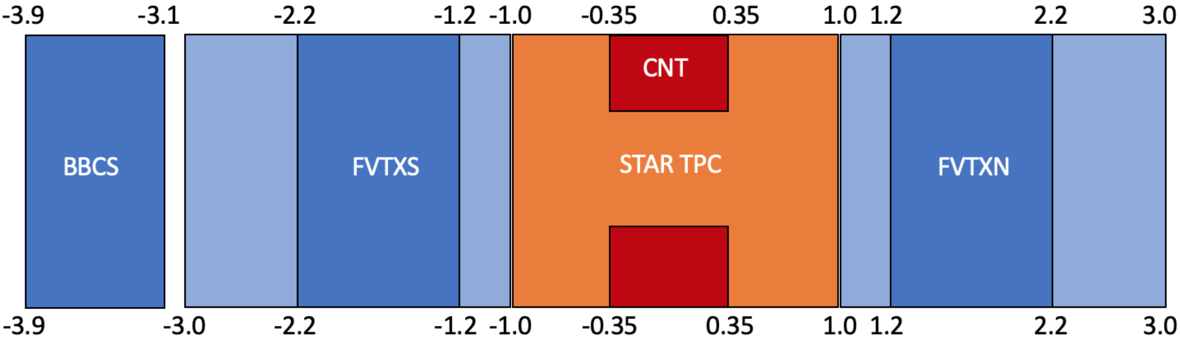


- PHENIX has completed a new analysis confirming the results published in Nature Physics
- All new analysis using two-particle correlations with event mixing instead of event plane method
  —Completely new and separate code base
  —Very different sensitivity to key experimental effects (beam position,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

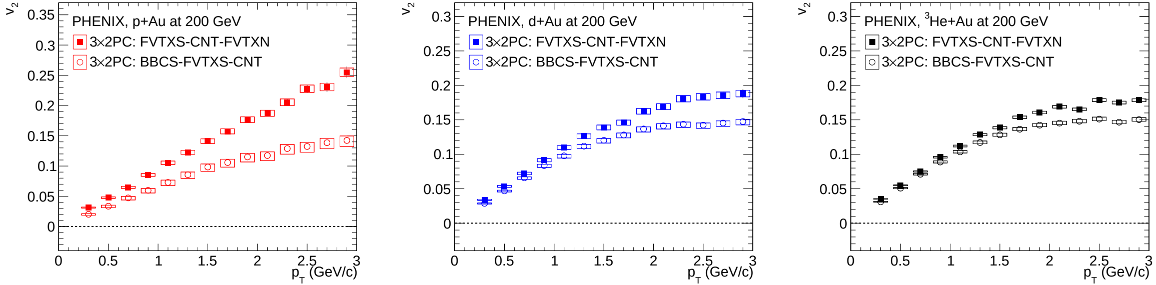
STAR and PHENIX detector comparison



- 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

PHENIX, arXiv:2107.06634 (submitted to Phys. Rev. C)



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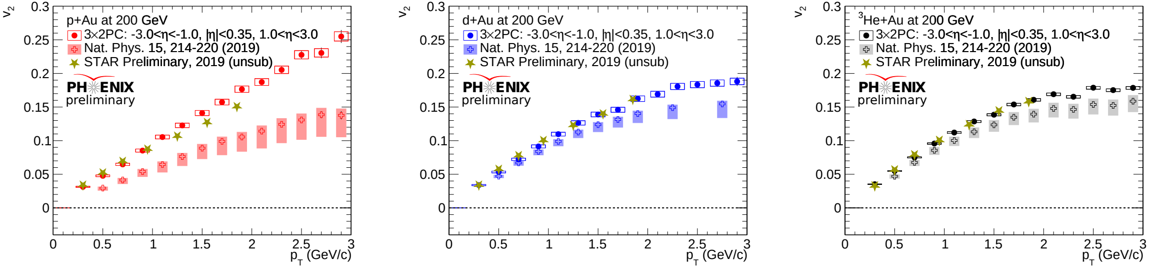

- Good agreement with STAR for v_2
  —Similar physics for the two different pseudorapidity acceptances

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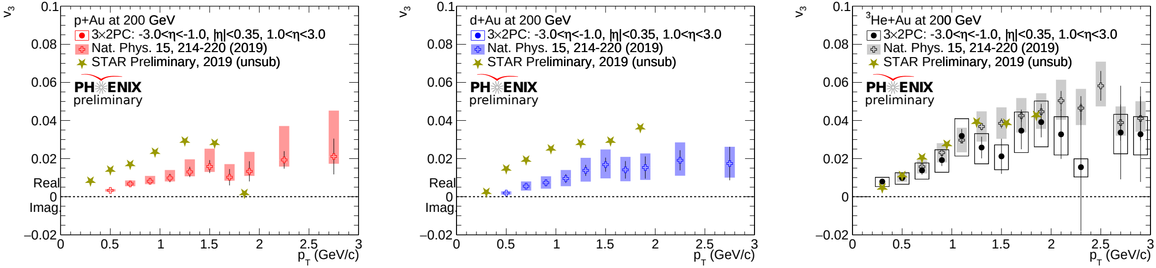

- Good agreement with STAR for v_2
  —Similar physics for the two different pseudorapidity acceptances
- Strikingly different results for v_3
  —Rather different physics for the two different pseudorapidity acceptances
  —Longitudinal effects much stronger for v_3 than v_2

More STAR and PHENIX data comparisons

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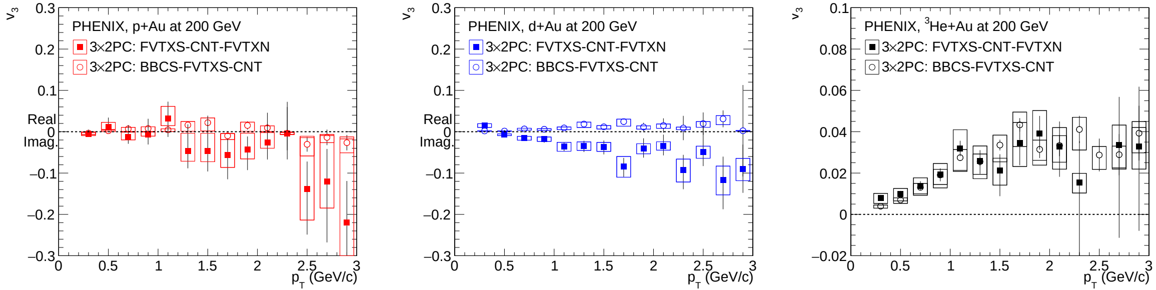

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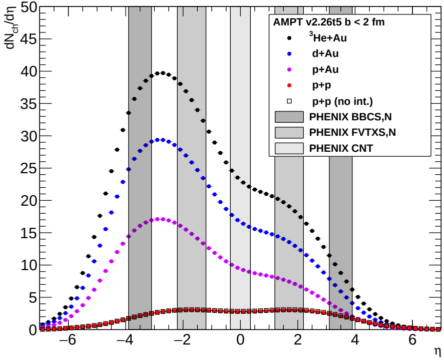
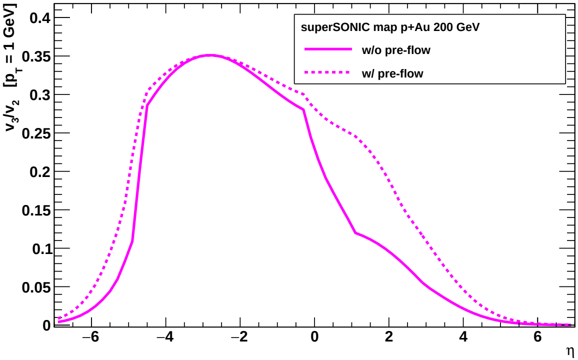
Pseudorapidity dependence in small systems

J.L. Nagle et al, arXiv:2107.07287 (submitted to PRC)



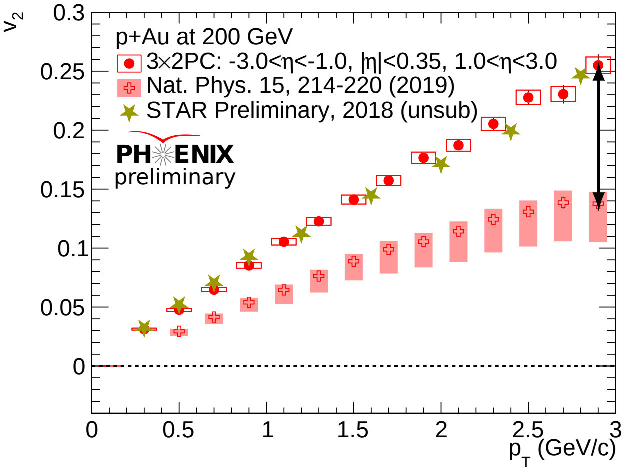


- $dN_{ch}/d\eta$ from AMPT, $v_3(\eta)$ from (super)SONIC
- The likely much stronger pseudorapidity dependence of v_3 compared to v_2 is an essential ingredient in understanding different measurements

Intermission

Understanding the non-flow contributions

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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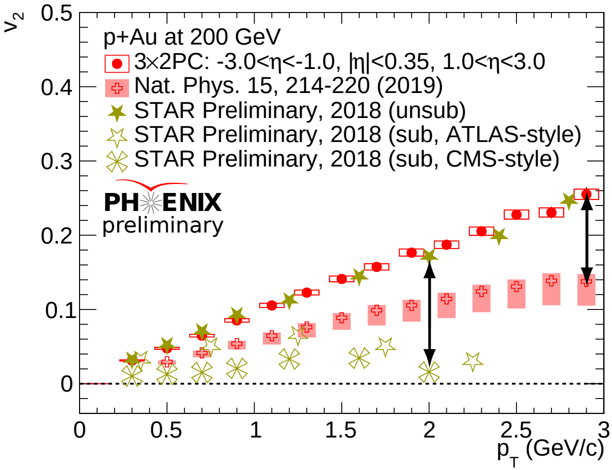
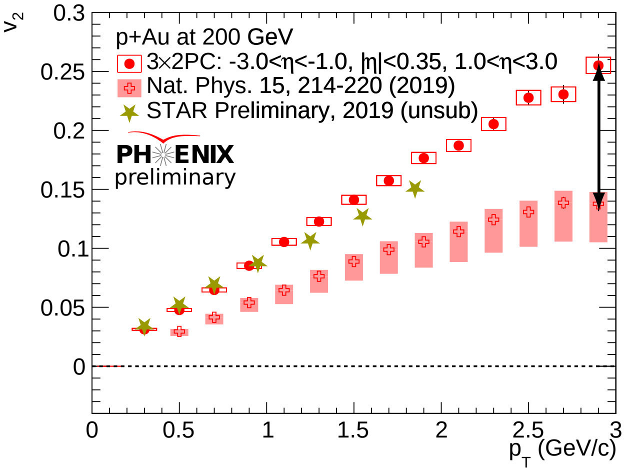


- The large difference between the PHENIX published and STAR preliminary in this case is nonflow
- PHENIX suppresses nonflow via kinematic selection
- STAR applies non-flow subtraction procedure
- One needs to be careful about the risk of over-subtraction methods—S. Lim et al, Phys. Rev. C 100, 024908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

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



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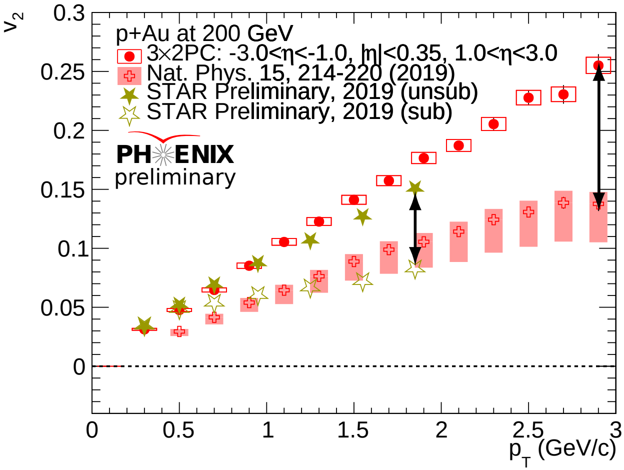


- The large difference between the PHENIX published and STAR preliminary in this case is nonflow
- PHENIX suppresses nonflow via kinematic selection
- STAR applies non-flow subtraction procedure
- Considerable improvement in nonflow subtraction in STAR 2019 preliminary, reasonable agreement with PHENIX

Additional non-flow studies using published data tables

- To enable additional study, the new PHENIX publication (arXiv:2017.06634, sub'd to PRC) includes the complete set of $\Delta\phi$ correlations and extracted coefficients c_1, c_2, c_3, c_4

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*

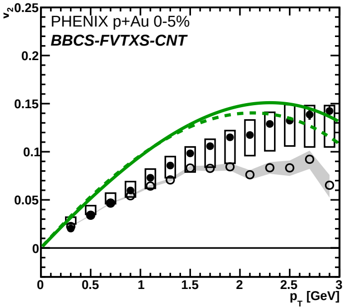
(Dated: July 16, 2021)

https://arxiv.org/abs/2107.07287

- To enable additional study, the new PHENIX publication (arXiv:2017.06634, sub'd to PRC) 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, arXiv:2107.07287 (submitted to PRC)



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

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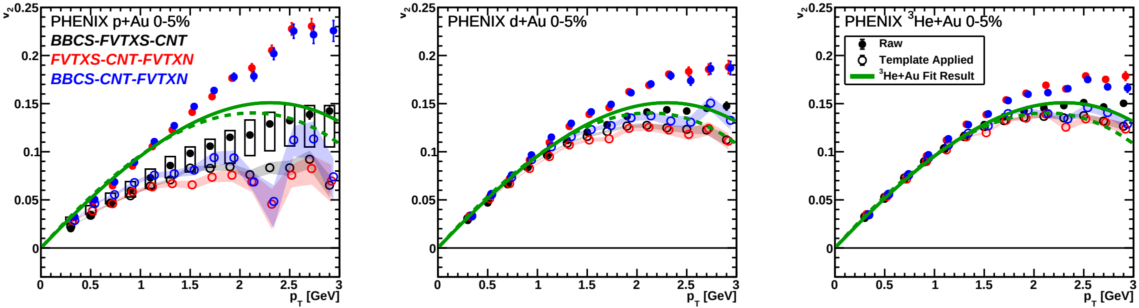

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- The FVTXS-CNT-FVTXN combination has more non-flow, and the subtraction does much more
- That the three different combinations all line up after non-flow subtraction seems to lend some credence thereto, but one must be careful...

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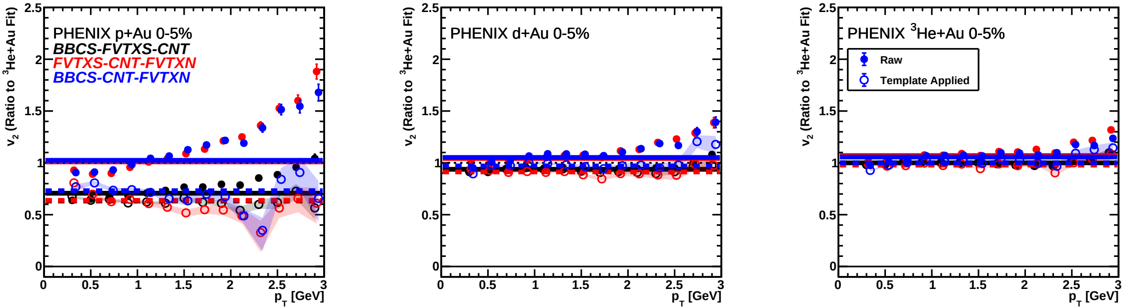

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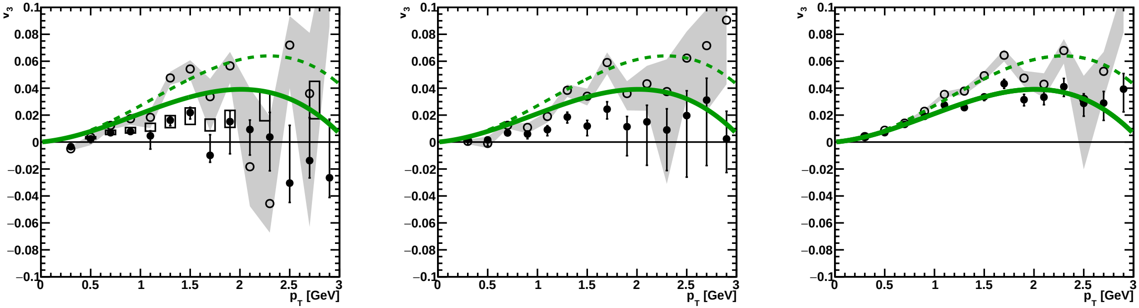

- There's a larger relative change for v_3 compared to v_2, but the smaller value of v_3 makes the non-flow subtraction more sensitive to non-closure

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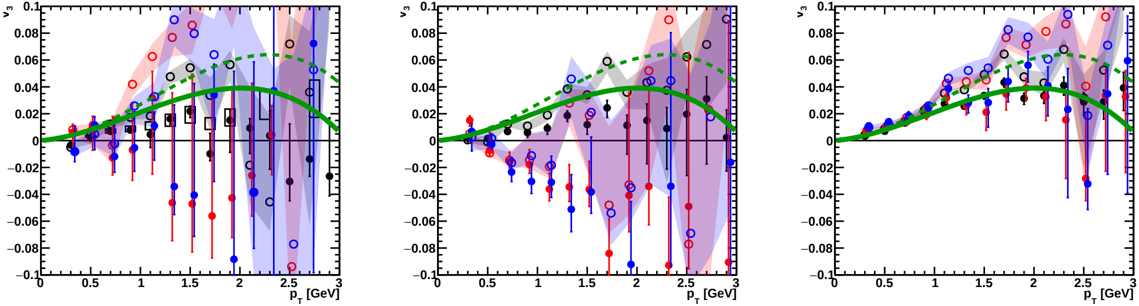

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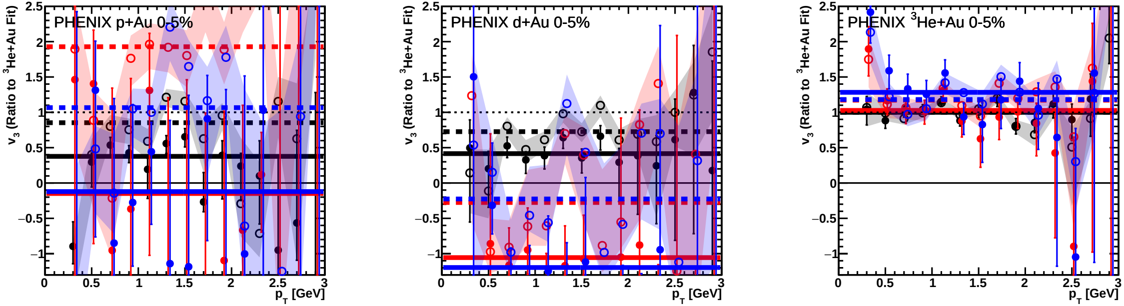

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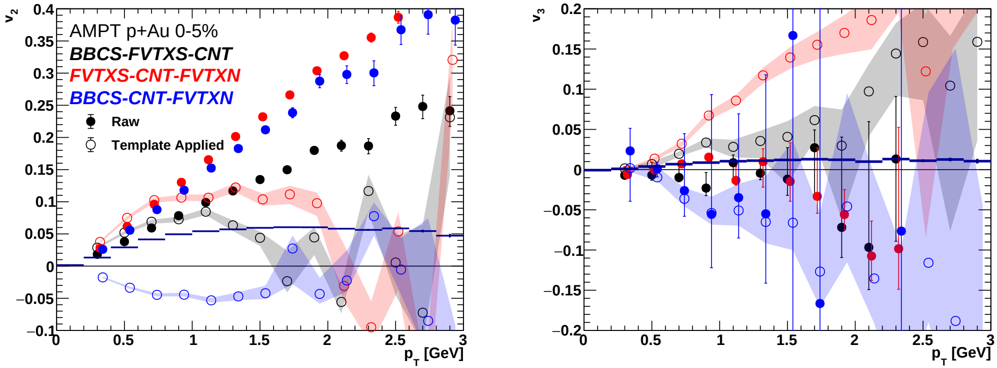

- Closure is considerably violated in AMPT

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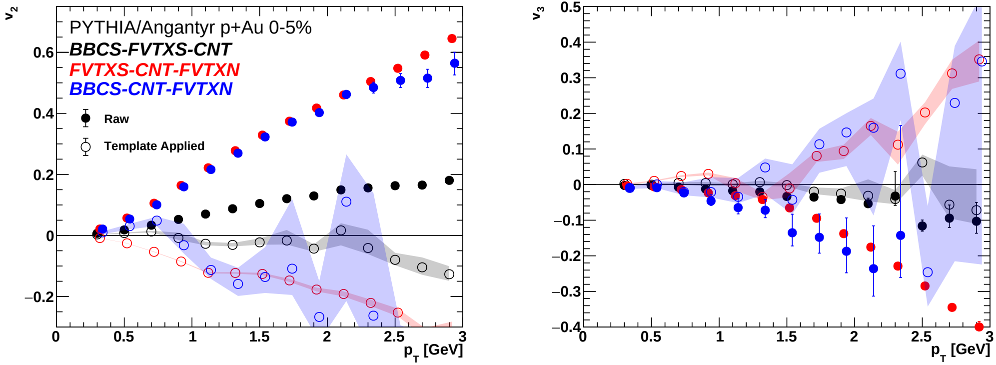

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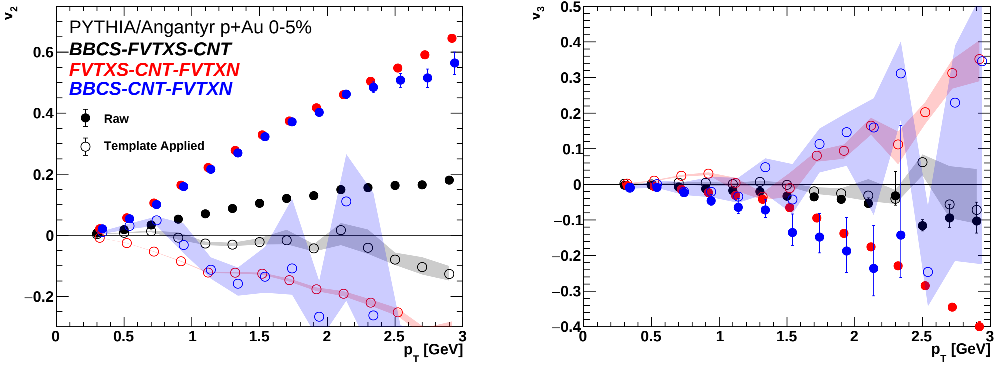
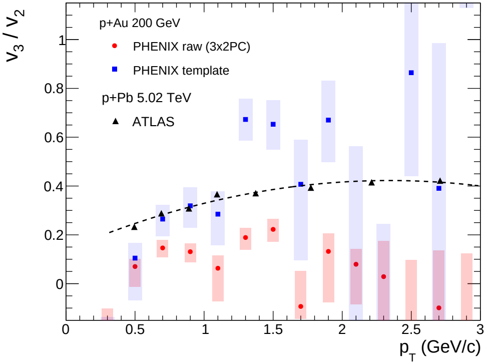


- Closure is considerably violated in AMPT and PYTHIA/Angantyr
- Since AMPT has too much non-flow and PYTHIA doesn't have any flow, the degree of overcorrection in real data is likely not as bad as it is with these generators

Additional non-flow studies using published data tables

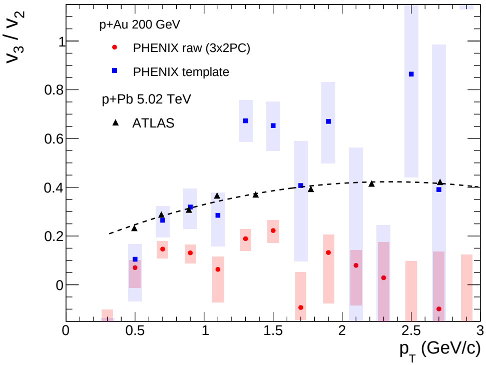
J.L. Nagle et al, arXiv:2107.07287 (submitted to PRC)

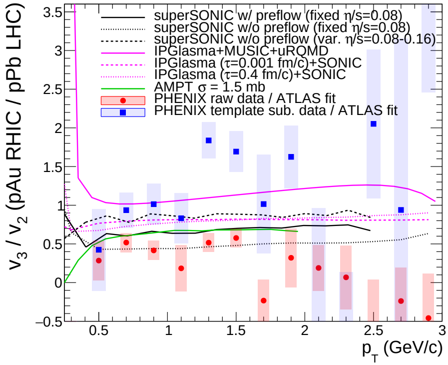


- The standard PHENIX v_3/v_2 is lower than the ATLAS, while the non-flow corrected is above

Additional non-flow studies using published data tables

J.L. Nagle et al, arXiv:2107.07287 (submitted to PRC)





- 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

Additional non-flow studies using published data tables

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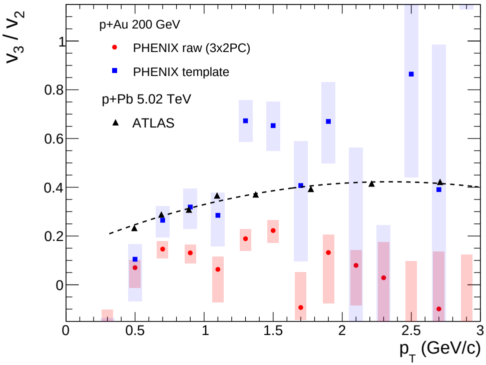
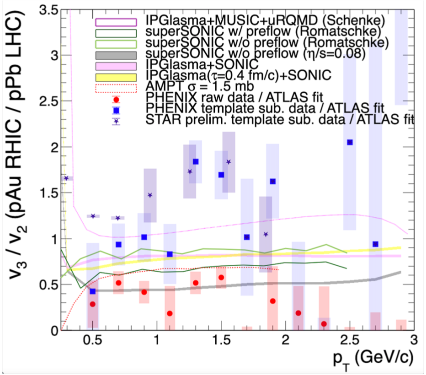
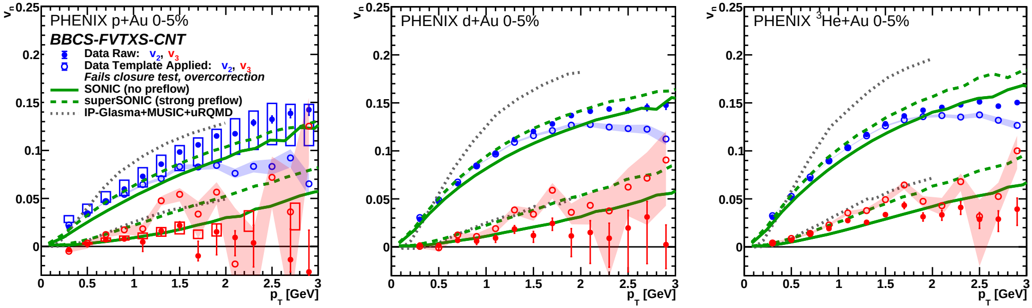




- The standard PHENIX v_3/v_2 is lower than the ATLAS, while the non-flow corrected is above
- The ratio is expected to be lower for lower collision energies in almost all physics scenarios
  —Lower energy, shorter lifetime, more damping of higher harmonics
- The STAR v_3/v_2 is very similar to the non-flow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

Additional non-flow studies using published data tables

J.L. Nagle et al, arXiv:2107.07287 (submitted to PRC)



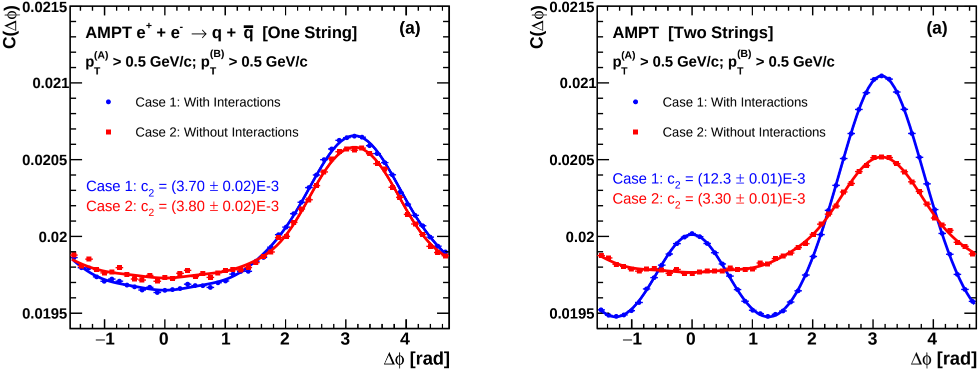
- Since the template method over-corrects the raw BBCS-FVTXS-CNT v_3, the truth is likely in between
- A firm understanding of this could shed a lot of light on various physics scenarios...

Intermission

Extremely small systems

Extremely small systems in AMPT

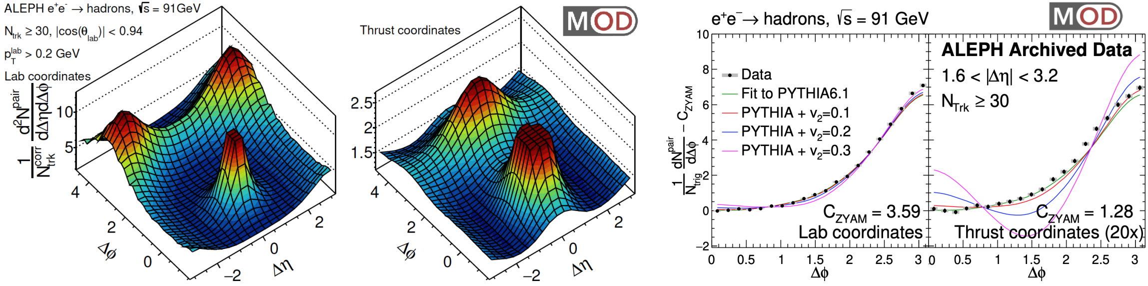
J.L. Nagle et al, Phys. Rev. C 97, 024909 (2018)



- A single color string ($e^{+}+e^{-}$ collisions) shows no sign of collectivity
- Two color strings shows collectivity
  —In AMPT, $p+p$ has two strings and $p/d/^{3}$He+Au have more

Extremely small systems at LEP

Badea et al, Phys. Rev. Lett. 123, 212002 (2019)

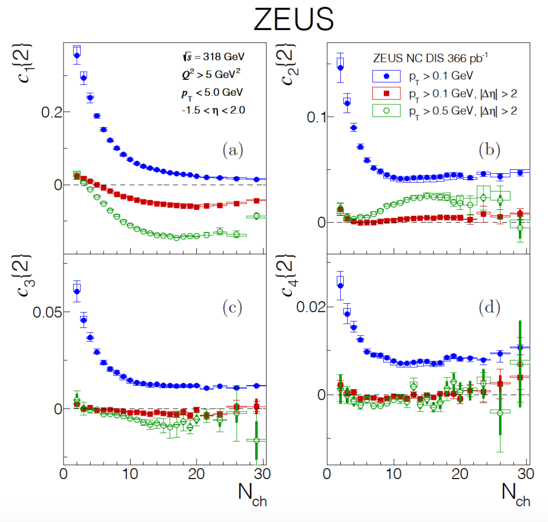


No apparent collectivity in ALEPH $e^{+}+e^{-}$ data

- Brought up as a possibility in e.g. P. Romatschke, EPJC 77, 21 (2017)
- Not expected in parton escape picture (see previous slide)
- Not expected (below $\sqrt{s} \approx 7$ TeV) in e.g. P. Castorina et al, EPJA 57, 111 (2021)

Extremely small systems at HERA and the EIC

Abt et al, JHEP 04, 070 (2020)



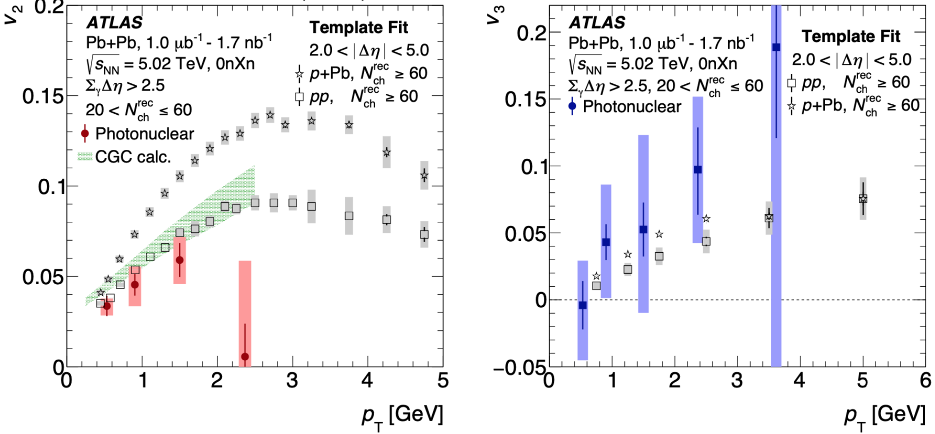
"The correlations observed here do not indicate the kind of collective behaviour recently observed at the highest RHIC and LHC energies in high-multiplicity hadronic collisions."

No collectivity in $e{+}p$ collisions at HERA →
Not likely to find collectivity in $e{+}p$ collisions at EIC
But what about $e{+}A$ collisions?

Considerable interest in this topic within EIC community (see talks by R. Milner, E. Ferreiro, others...)

Extremely small systems at the LHC

ATLAS, Phys. Rev. C 104, 014903 (2021)



- Observation of collectivity in photonuclear collisions
- Collective picture: photon fluctuates into a vector meson (e.g. ρ), not so different from p+Pb
- Initial state picture: CGC calculation in good agreement, further investigation needed

Brief summary and outlook

- Long term understanding of collective and hydrodynamical behavior in large systems
- Geometry and fluctuations play essential roles in observables
- Many successful predictions for both the small systems beam energy scan and the small systems geometry scan from hydrodynamics
  —Pushing the envelope for regimes of applicability of hydro
  —Driving theoretical developments in hydro
- Some notable challenges
  —Small systems cumulants (including long-known sign issue in $p+p$ at LHC)
  —Longitudinal dynamics (STAR-PHENIX geometry scan, $dN_{ch}/d\eta$, $v_2(\eta)$,...)
  —Need for more realistic hadronization
- Plenty of great opportunities in the future
  —More geometry scans, including but limited to more isobars
  —Extremely small systems at future colliders, e.g. EIC

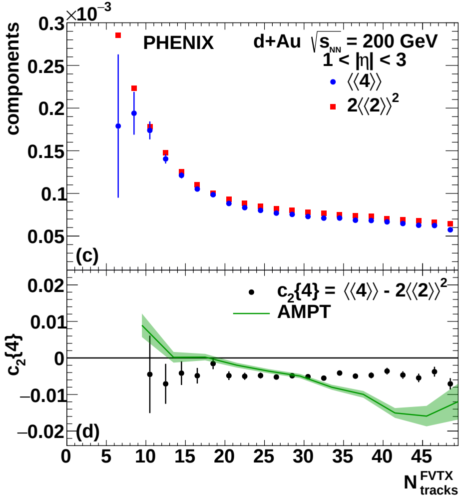
Extra material

Components and cumulants in p+Au and d+Au at 200 GeV

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

$$v_2\{4\} = (-c_2\{4\})^{1/4}$$

Negative $c_2\{4\}$ means real $v_2\{4\}$



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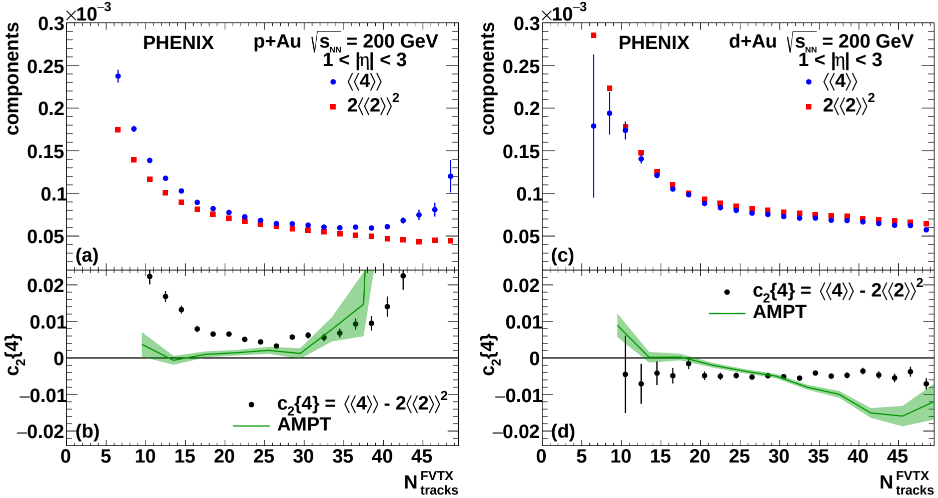
Phys. Rev. Lett. 120, 062302 (2018)



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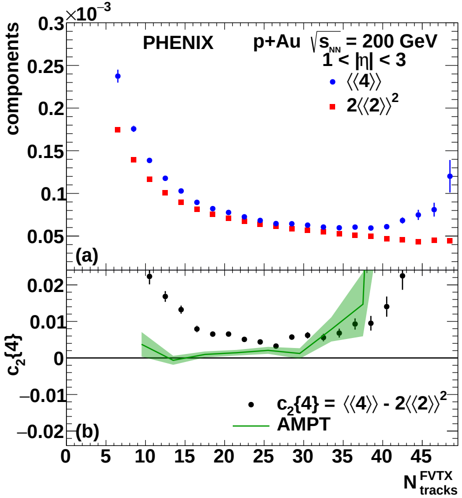
Phys. Rev. Lett. 120, 062302 (2018)

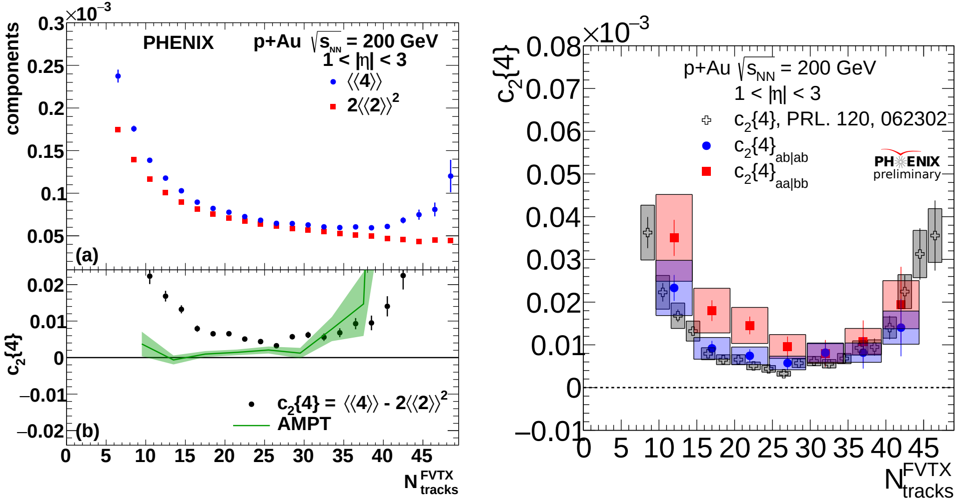


$c_2\{4\}$ is positive in p+Au

Can we blame this on nonflow?

Components and cumulants in p+Au and d+Au at 200 GeV

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

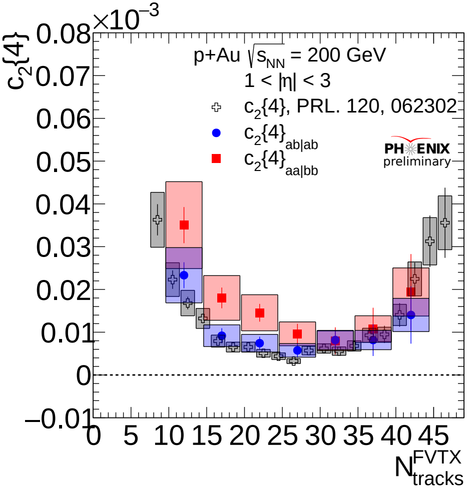


Components and cumulants in p+Au and d+Au at 200 GeV

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

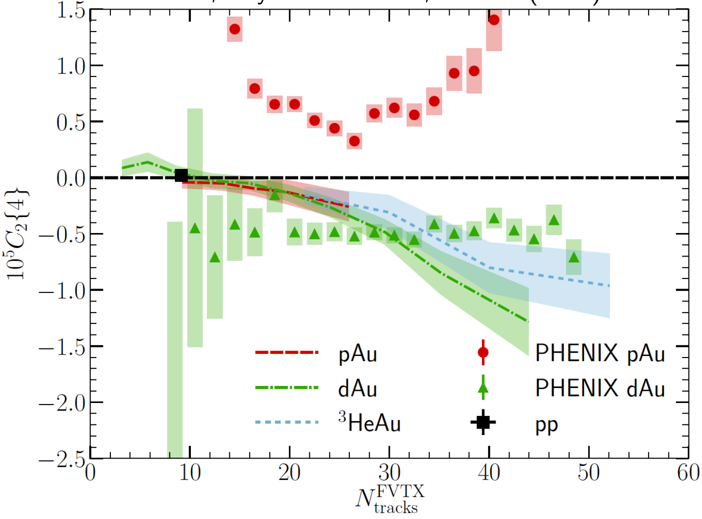
Use of subevents further suppresses nonflow

Positive $c_2\{4\}$ in p+Au doesn't seem to be related to nonflow



Cumulants in p+Au and d+Au at 200 GeV

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



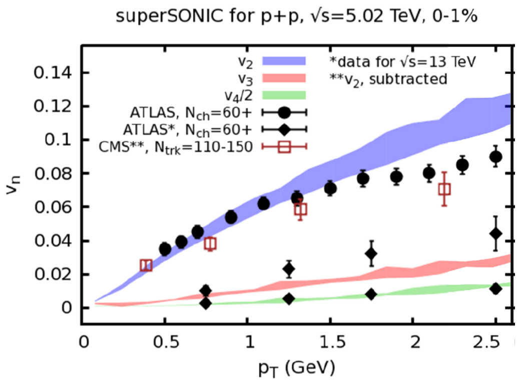
Cumulants are computationally expensive in hydro theory, so not as well-studied

This particular calculation doesn't show the strong geometry dependence seen in the data

Important to note this is 2+1D hydro, so the kinematics can't match the data

$p+p$ collisions at the LHC

Weller & Romatschke, PLB 774, 351 (2017)

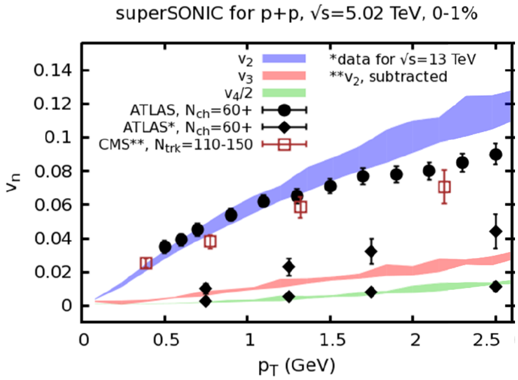


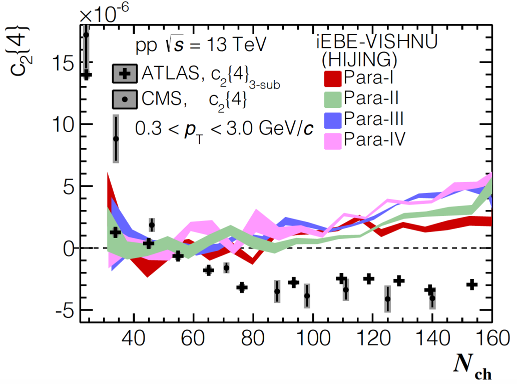
- Hydro does a good job of $v_n\{2\}$...

$p+p$ collisions at the LHC

Weller & Romatschke, PLB 774, 351 (2017)

W. Zhao et al, PLB 780, 495 (2018)





- Hydro does a good job of $v_n\{2\}$...
- ...but hydro cannot even get the correct sign of $c_2\{4\}$

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)

Intermission

Can we turn the QGP off?

Let's have a look at *extremely* small systems