Azimuthal Anisotropy of Particles from Small Asymmetric Systems Measured in PHENIX at the RHIC

Carlos Pérez Lara (SBU), for the *PHENIX* collaboration

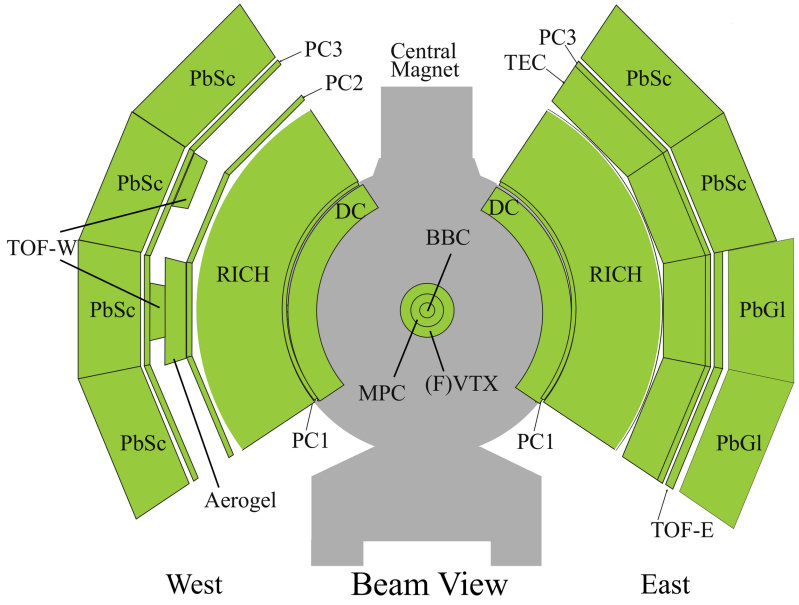
Abstract:
The study of azimuthal anisotropy of particles produced in Heavy Ion collisions provides strong constrains to the evolution of the strongly coupled QCD medium and its event-by-event geometry fluctuations. The strength and predominance of these observables have long been identified as a manifestation of a strong collective behaviour in the formed medium.
However recent measurements of non-zero anisotropy in small systems both at RHIC and LHC have posed new questions: How small can a system be and still present collective effects? Are there other mechanisms different from collectivity that could give rise to such high degree of anisotropy?
Experimentally we can address these questions by a systematic study of azimuthal correlations for different collision systems. These studies are being pursued by the PHENIX experiment profiting from the different beam configurations in the RHIC during the last years. In this talk I will present the latest results from PHENIX on azimuthal anisotropy obtained from a variety of collisional systems and using different techniques.

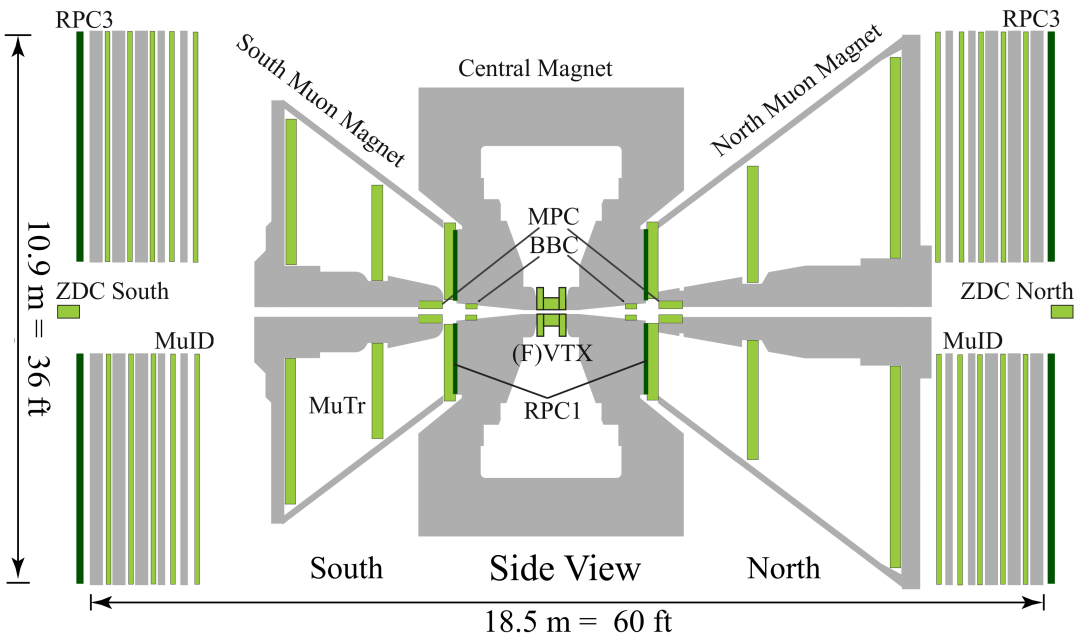
Contents

- The ridge in p+Au and ^{3}He+Au @ 200 GeV
- v_2 (PID) p+Au d+Au and ^{3}He+Au @ 200 GeV
- v_3 d+Au and ^{3}He+Au @ 200 GeV
- d+Au v_2 @ 200, 64, 39 and 20 GeV

The PHENIX Detector

2012 - 2016





Detector(s)	Azimuthal	Pseudorapidity	Description
DC+PC	partial	|eta| < 0.35	Full Tracking; pt measurement
Fvtx	full	1 < |eta| < 3	Silicon strip multilayers
BBC	full	3 < |eta| < 3.9	Quartz Cherenkov radiator
MPC	full	3.1 < |eta| < 3.9	PbWO4 electromagnetic calorimeter

p+Au ^{3}He+Au / p+p

2PC

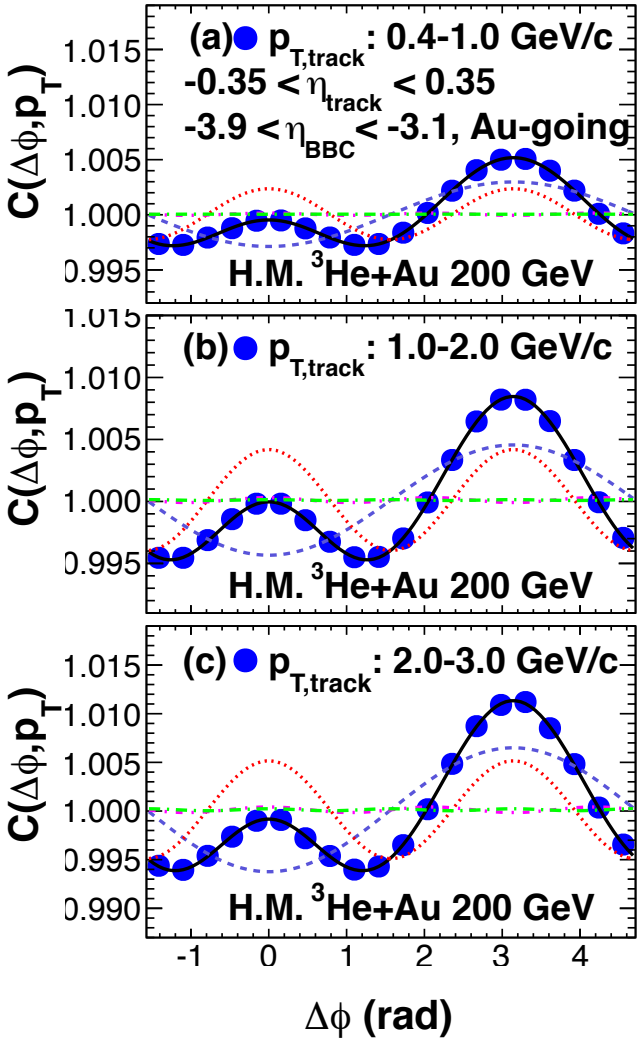
2 Particle Correlation Function

Track-BBC pairs: $$S(\Delta\phi, p_T) = \frac{d\left(\omega_{PMT}\, N^{track\,(p_T)-PMT}\right)}{d\Delta\phi}$$

$$C(\Delta\phi, p_T) = \frac{S(\Delta\phi, p_T)}{M(\Delta\phi, p_T)} \frac{\int_0^{2\pi} M(\Delta\phi, p_T)\, d\Delta\phi}{\int_0^{2\pi} S(\Delta\phi, p_T)\, d\Delta\phi}$$

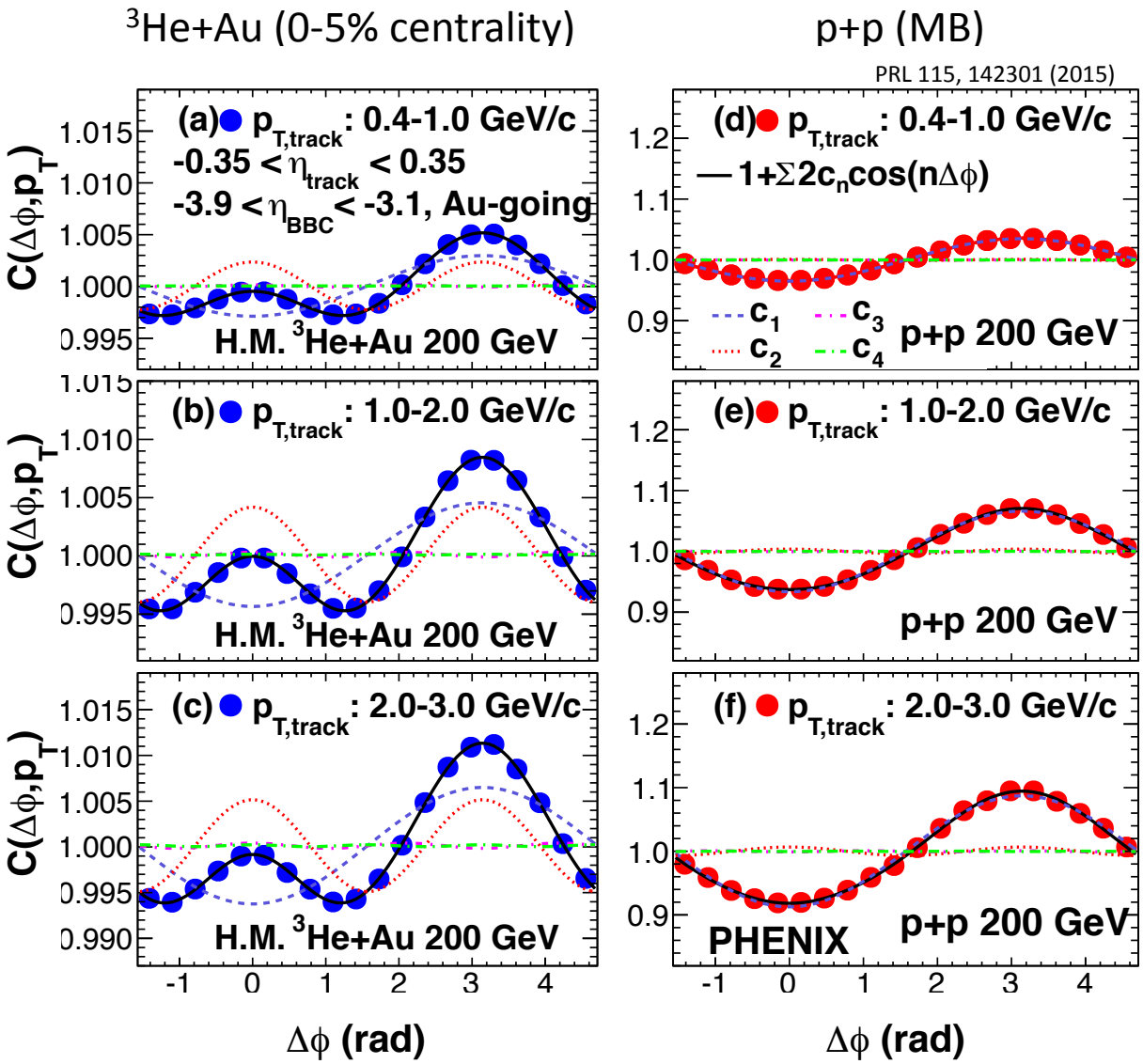
^{3}He+Au

^{3}He+Au (0-5% centrality)



Clear ridge manifest

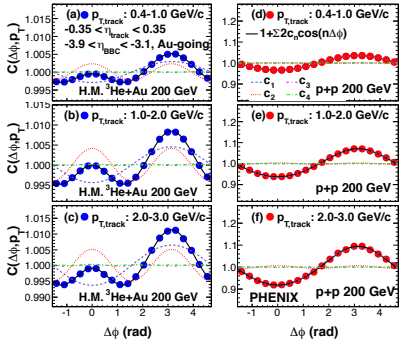
^{3}He+Au



c_n components extracted from both central ^{3}He+Au and M.B. p+p

^{3}He+Au

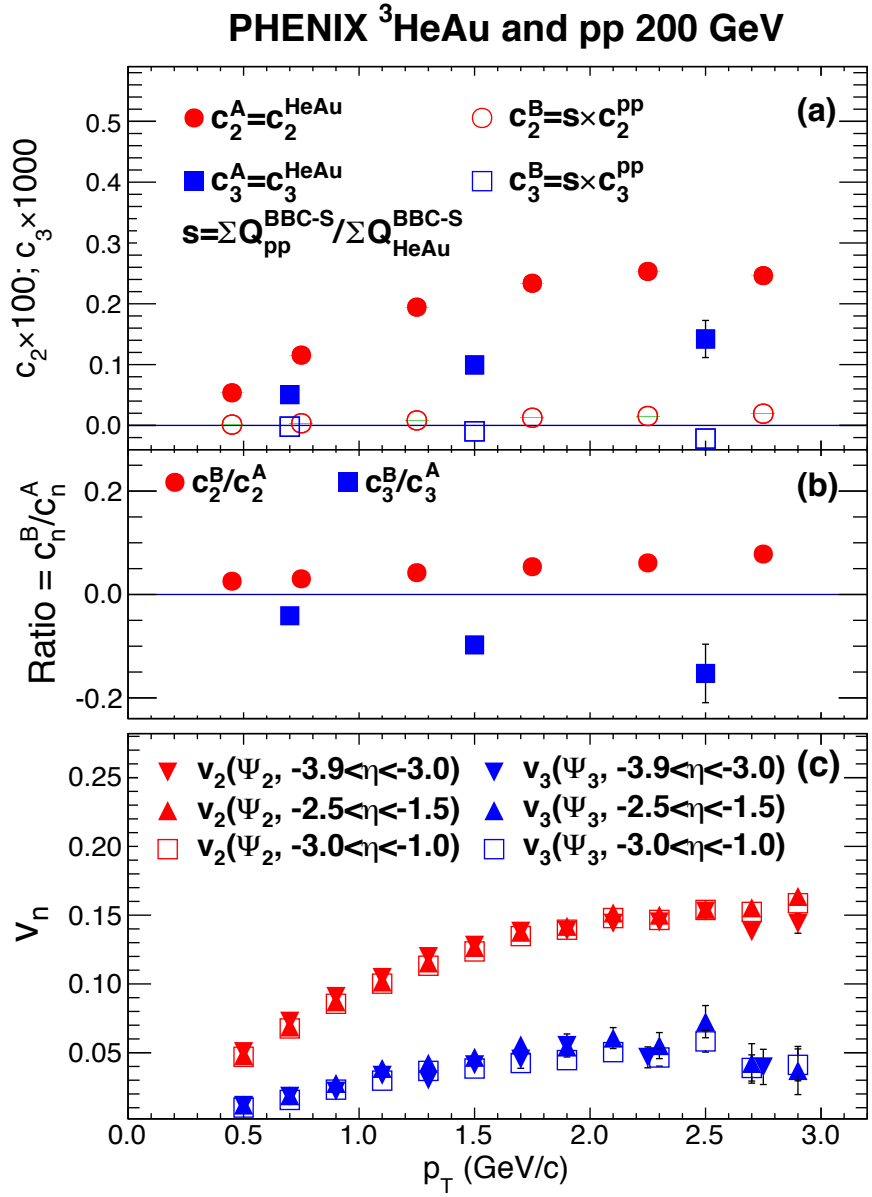
PRL 115, 142301 (2015)



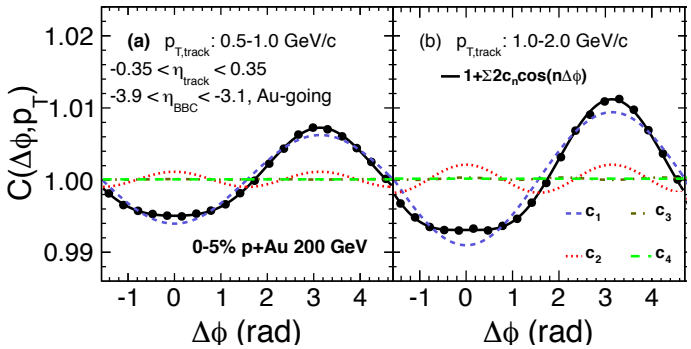
c_n from p+p are scaled to ^{3}He+Au based on charge from BBC-S

Ratio quantifies p+p component: Jets, decay, …

p+p component changes with p_T, but is below 7% for c_2 and below 15% for c_3 for this pt range



p+Au



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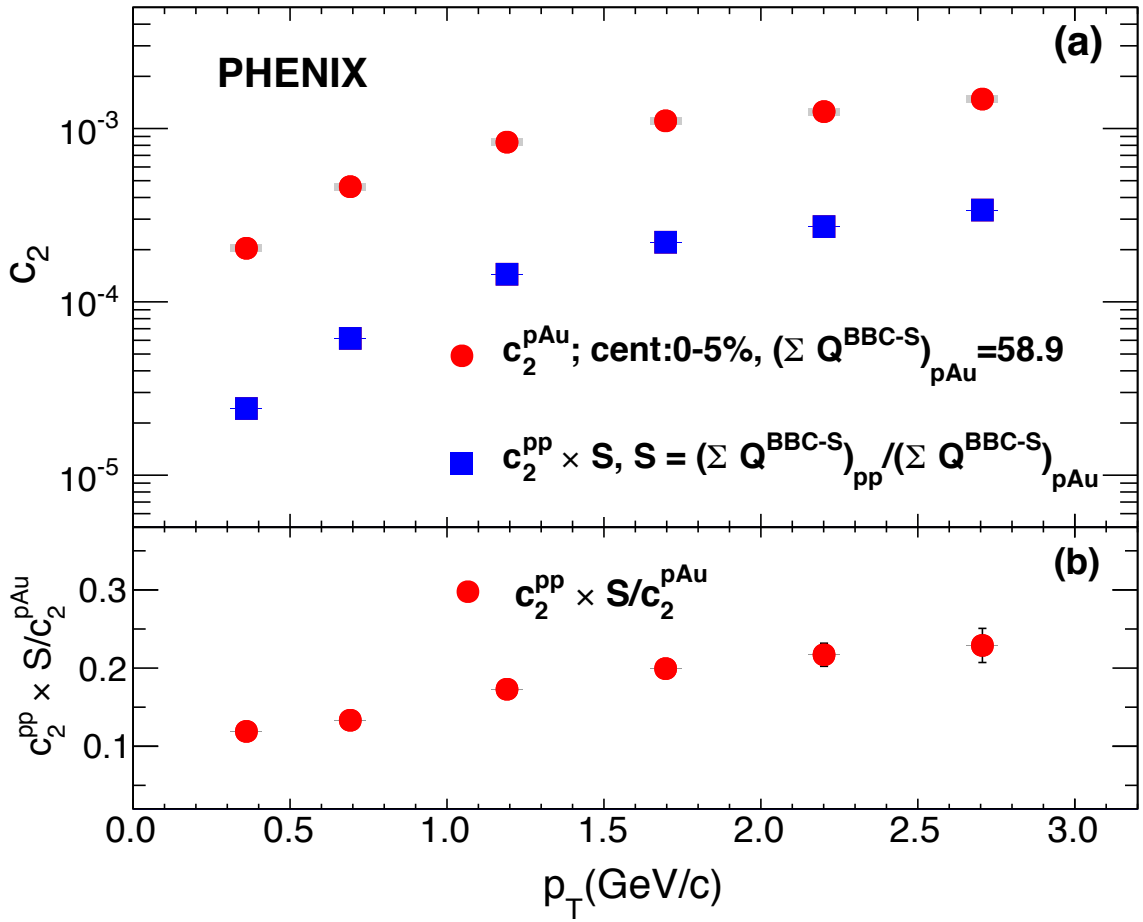
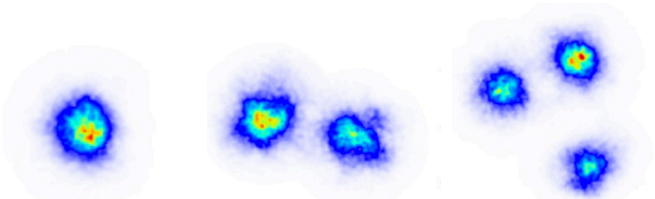


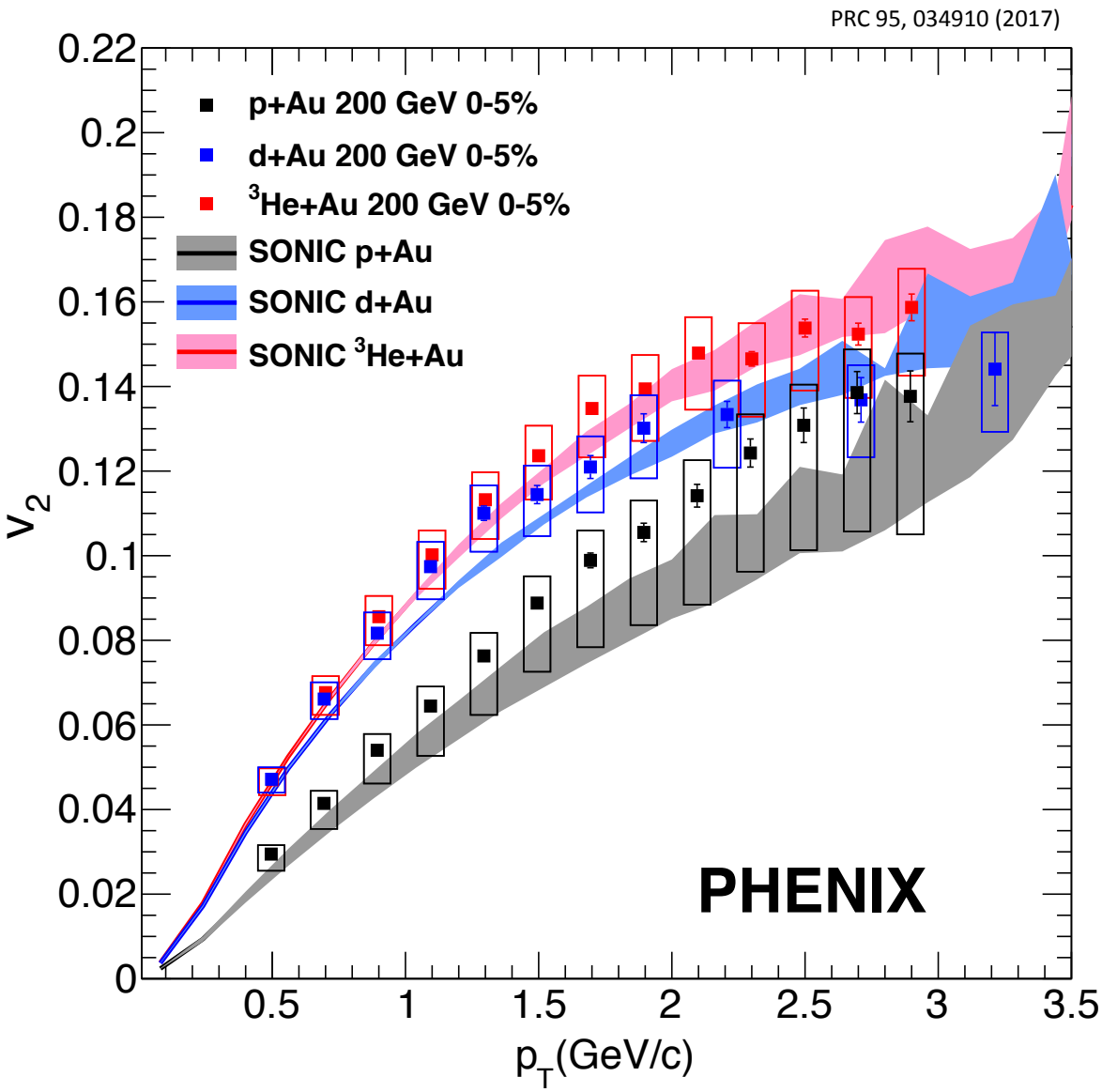
Similarly, the p+Au c_2 ratio increases with p_T and was found to be much larger (up to 23%)



p+Au d+Au ^{3}He+Au : Initial Geometry Dependence

V2 {EP}

v_2 in p+Au, d+Au, ^{3}He+Au @ 200 GeV



Data is well described by hydrodynamic model over all pt for all different collision systems

v_2 in p+Au, d+Au, ^{3}He+Au @ 200 GeV

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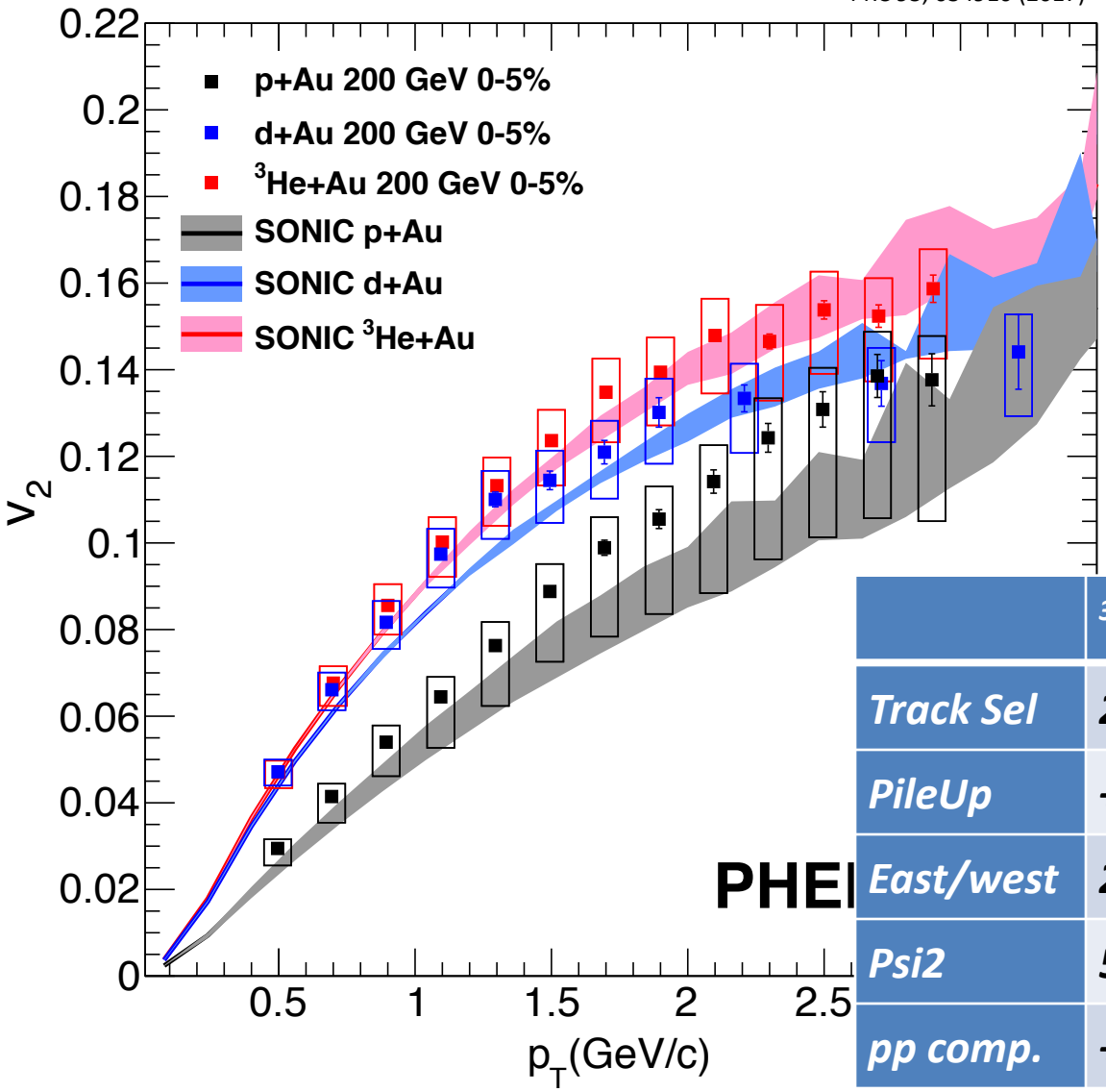

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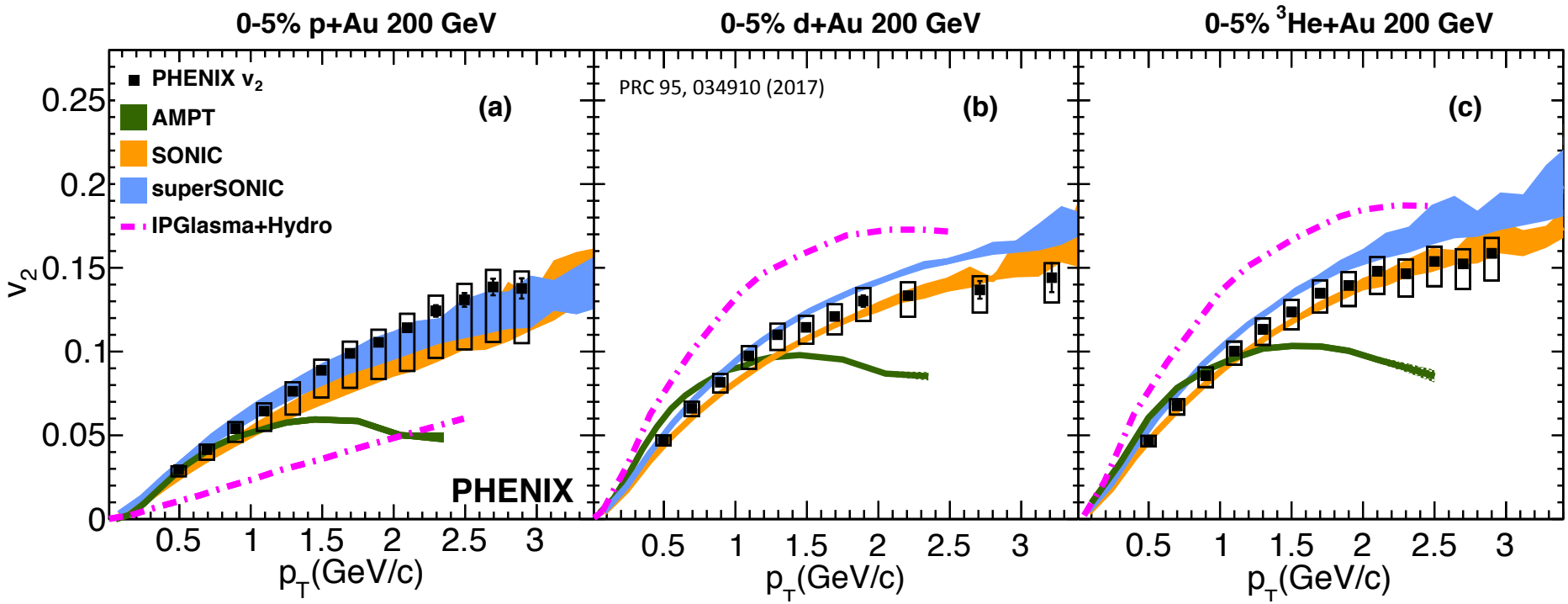
Systematic Uncertainties

	^{3}He+Au('14)	d+Au ('08)	p+Au('15)
Track Sel	2%	2%	2%
PileUp	+5% -0%	+5% -0%	+4% -0%
East/west	2%	3%	5%
Psi2	5%	5%	3%
pp comp.	+0% -7%	+0 -10%	+0% -23%

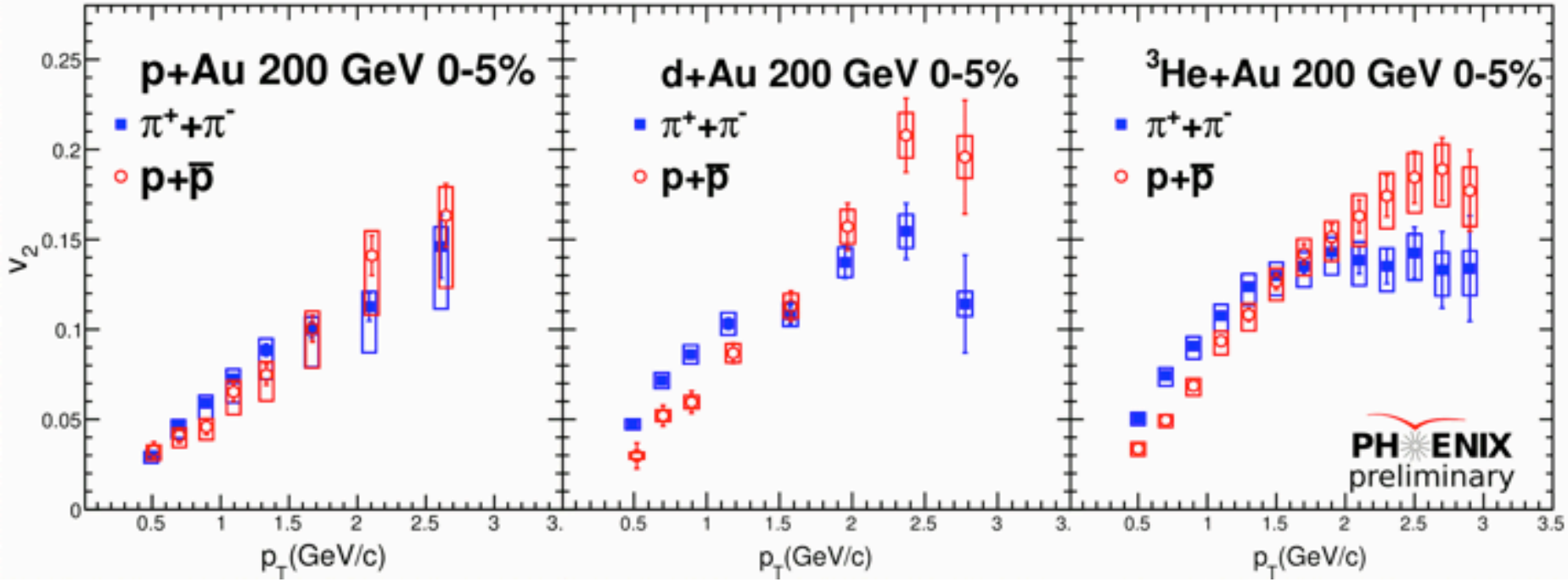
v_2 in p+Au, d+Au, ^{3}He+Au @ 200 GeV



AMPT describes data well below 1.2 GeV/c

IPGlasma+Hydro does not simultaneously describe the three systems

v_2 in p+Au, d+Au, ^{3}He+Au @ 200 GeV



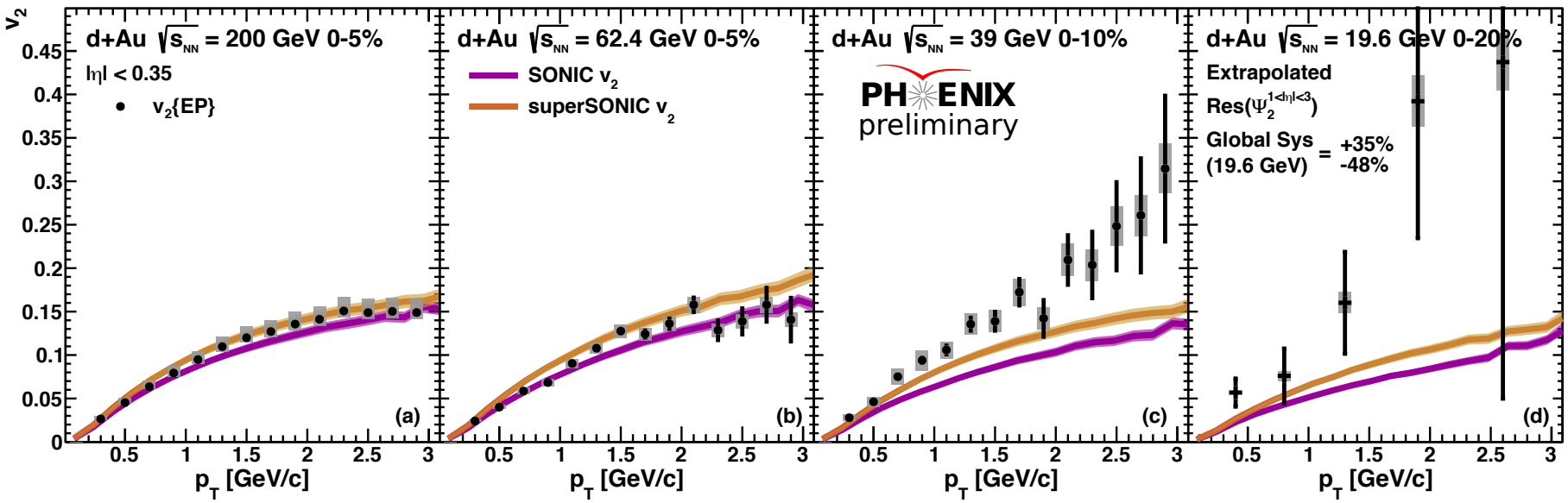
Mass ordering was found in all three systems

Strength of mass scaling is small in p+Au

d+Au Energy Scan

V2 {EP}

d+Au @ 200, 62, 39 and 20 GeV



v_2 in 200 and 62 GeV well described by (super)SONIC over all pt

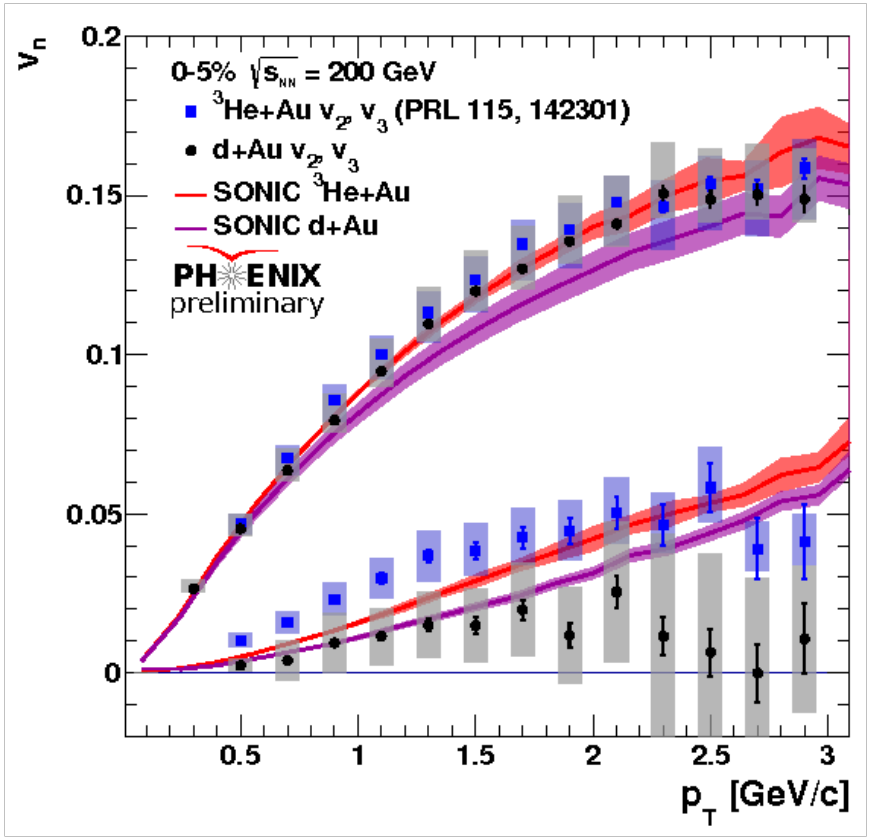
v_2 in 39 and 20 GeV beyond pt > 1 GeV/c is much higher than prediction from hydro models: purely nonflow?

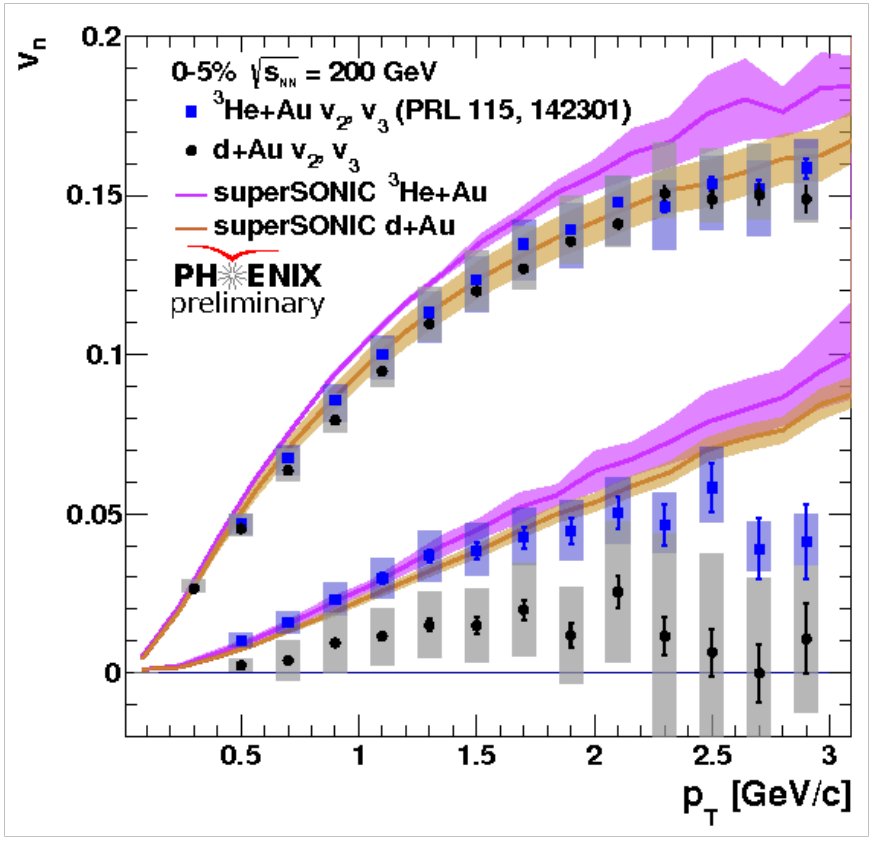
no nonflow component assigned yet

d+Au ^{3}He+Au @200 GeV : handle on pre-equilibrium stage?

V3 {EP}

v_2 and v_3 for d+Au and ^{3}He+Au @ 200 GeV





Large v_3 difference between the two systems challenges inclusion of pre-equilibrium stage

Summary

- SONIC (Glauber initial geometry + viscous hydro with eta/s=0.8 + hadronic phase) can reproduce v_2 results for all system sizes and energies.
  - Supports initial geometry driven v_2
- AMPT (partonic + hadronic transport model) reproduces well v_2 results for all system sizes and energies below pt < 1.0 GeV/c
- Mass scaling in v_2 in the three systems at 200 GeV
- v_3 for d+Au and ^{3}He+Au helps constrain pre-equilibrium stage

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Other interesting results left out due to lack of time
- v2(EP) for p+Al at 200 GeV
- v2{2} and v2{4} for d+Au at BES
- Cumulants for p+Au and d+Au at 200 GeV

@200 GeV

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

Summary

@200, 62, 39, 20 GeV

d+Au

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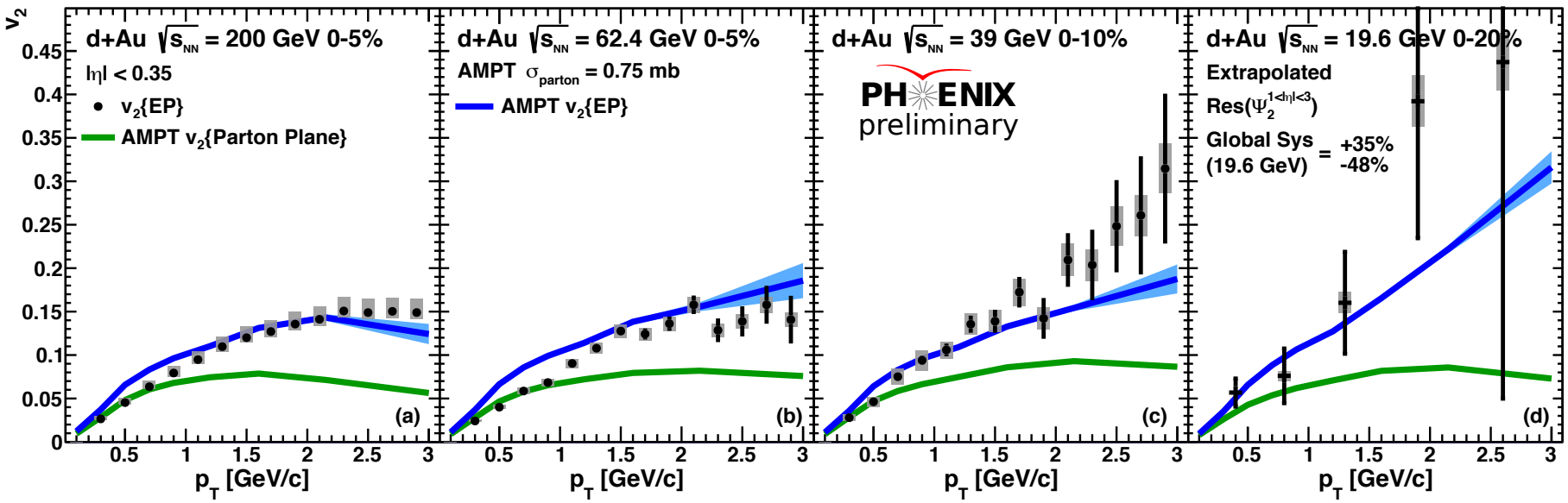
Dank U wel!

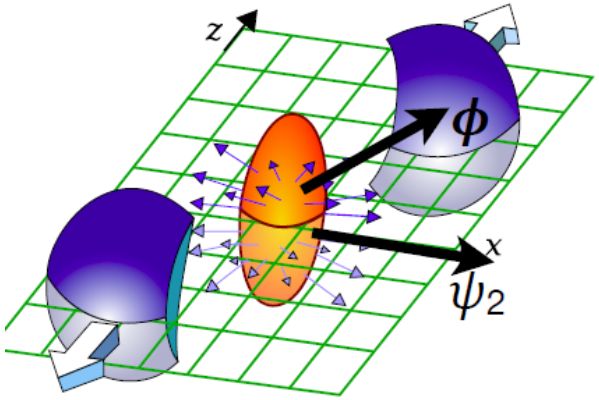
BACKUP SLIDES

d+Au @ 200, 62, 39 and 20 GeV



- v_2 in 200 and 62 GeV well described by (super)SONIC over all pt
- v_2 in 39 and 20 GeV beyond pt > 1 GeV/c is much higher than prediction from hydro models
- AMPT suggests that high v_2 for pt > 1.0 GeV/c may come from remanent nonflow component

Event Plane method



$$v_2 = \frac{\langle \mathrm{Cos}\ 2\ (\phi - \psi_2) \rangle}{\mathrm{Res}\ \psi_2}$$

Psi$_2$ resolution for most central (0-5%) collisions

	^{3}He+Au ('14)	d+Au ('08)	p+Au ('15)	d+Au ('16)
BBC-S	***0.110***	***0.113***	***0.062***	***0.107 - 0.049 - 0.024***
FVTX-S	***0.274***	***—***	***0.171***	***0.240 - 0.135 - 0.073***
MPC-S		***0.151***		

200 GeV

200 - 64 - 39 GeV

Centrality Selection based on BBC (Au going direction)

p+Au @ 200 GeV

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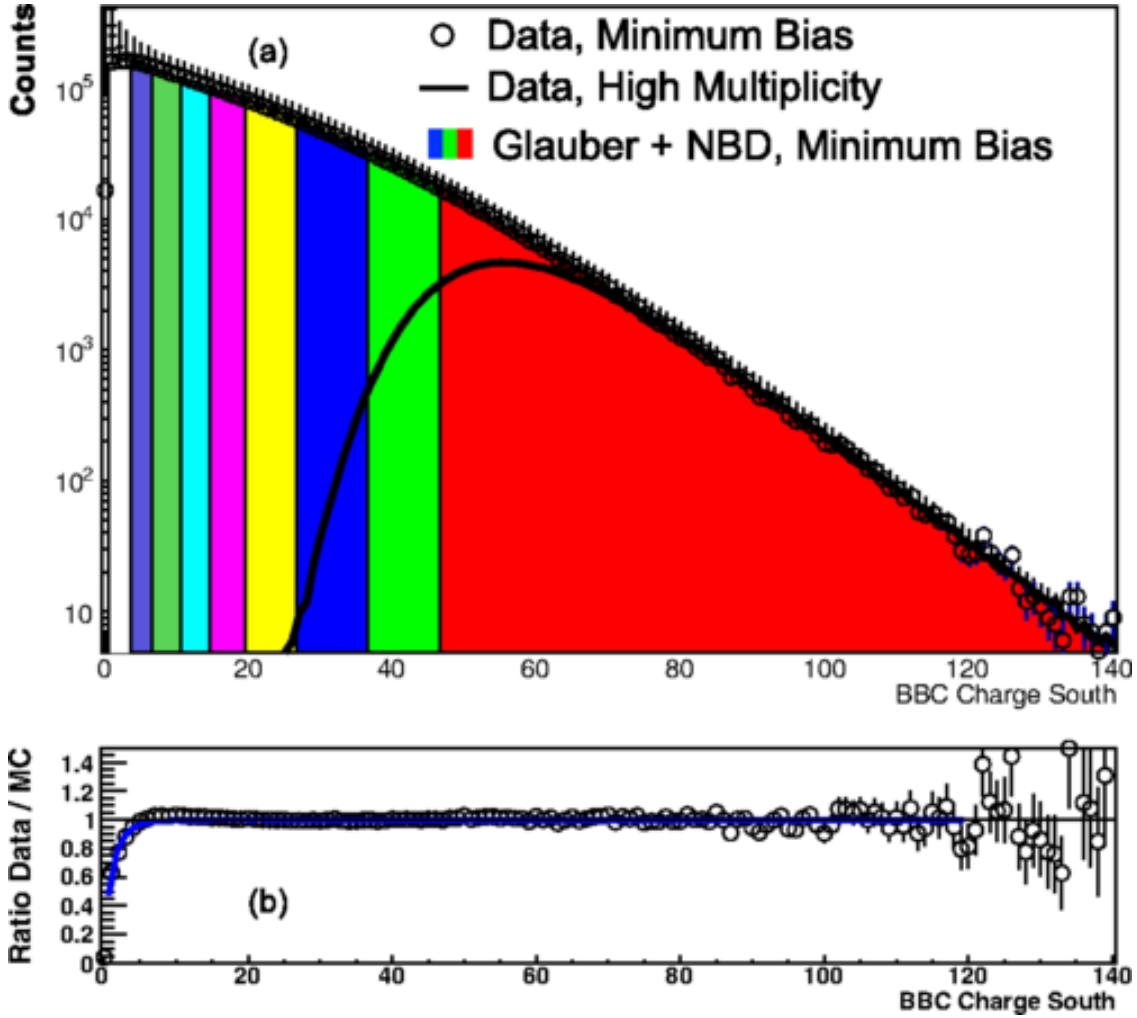
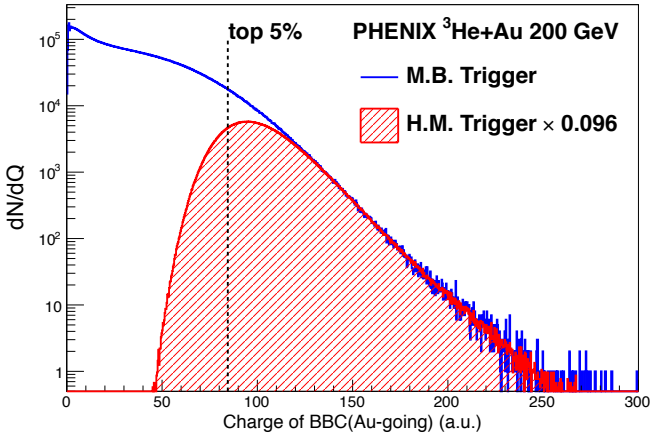
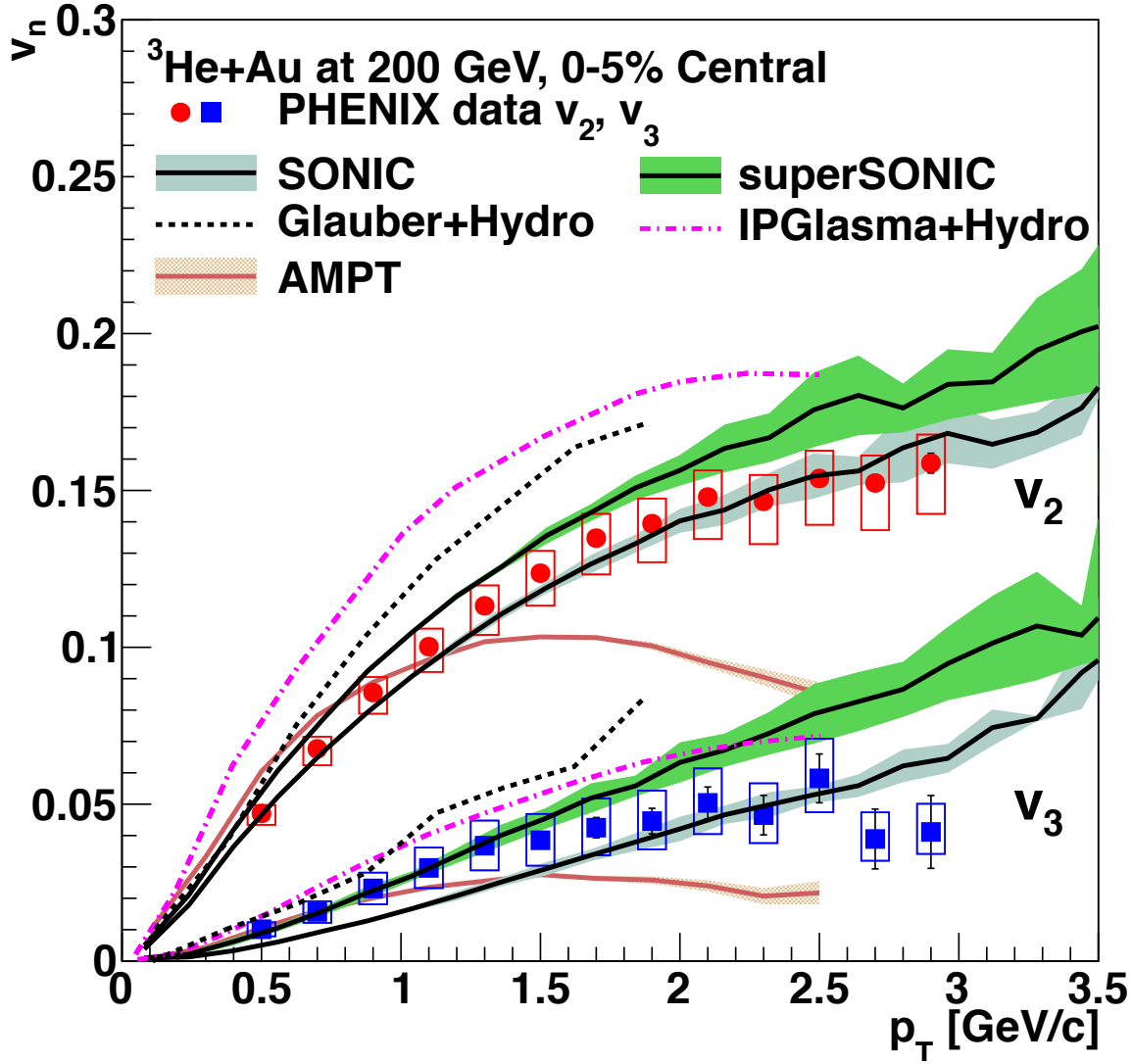


^{3}He+Au @ 200 GeV

PRL 115, 142301 (2015)

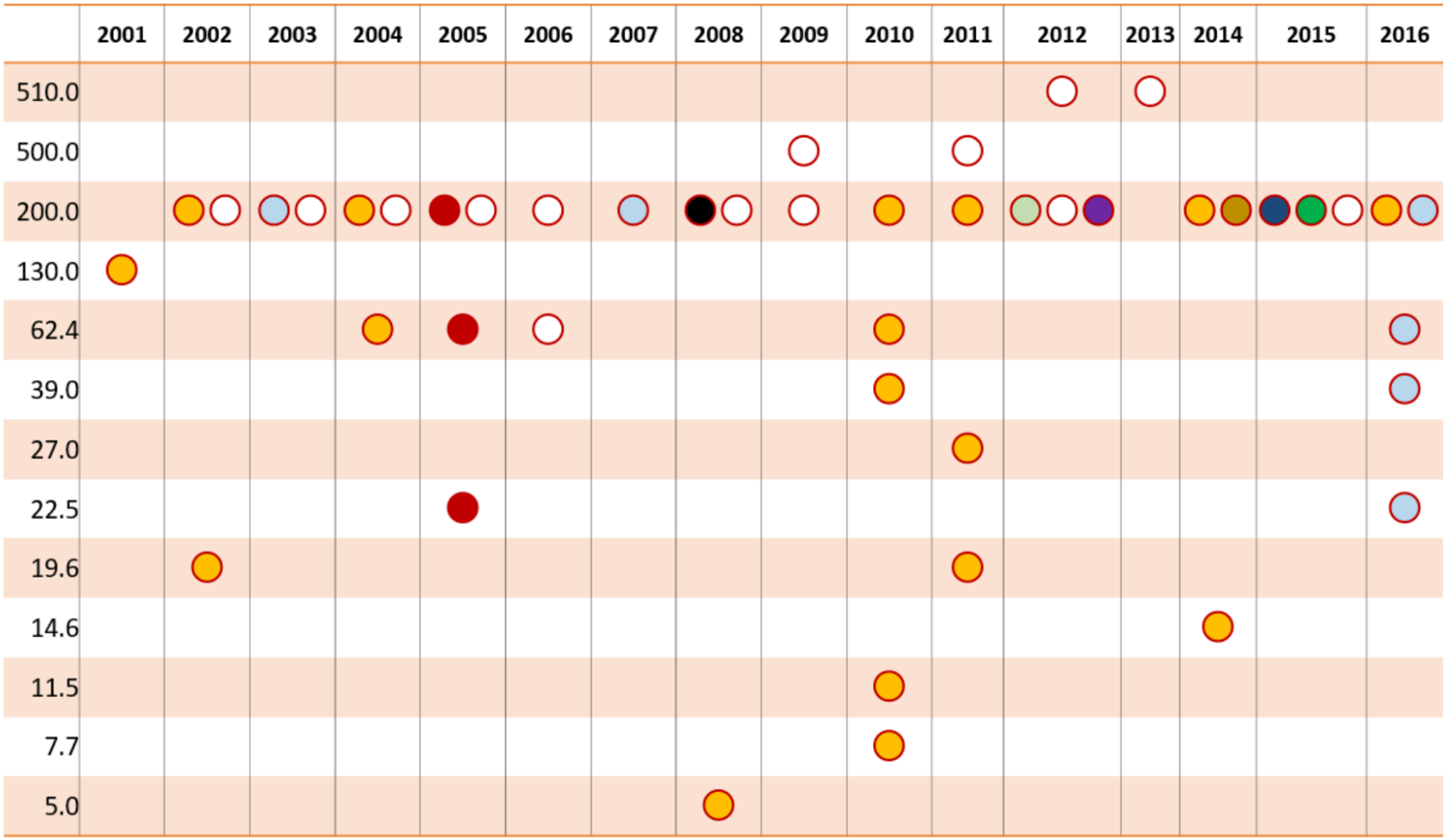


v2 and v3 He+Au @ 200 GeV



- (Super)SONIC describes (fairly) well v2 over all pt
- SuperSONIC describes v3 well at low pt. Stronger pre equilibrium sensitivity?
- AMPT reproduces v3 below 1.2 GeV
- IPGlasma+Hydro (no hadronic phase) overshoots data

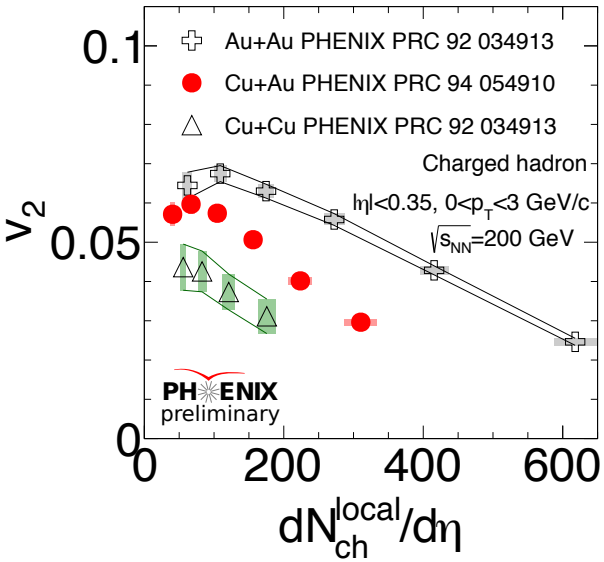
PHENIX runs at a glance



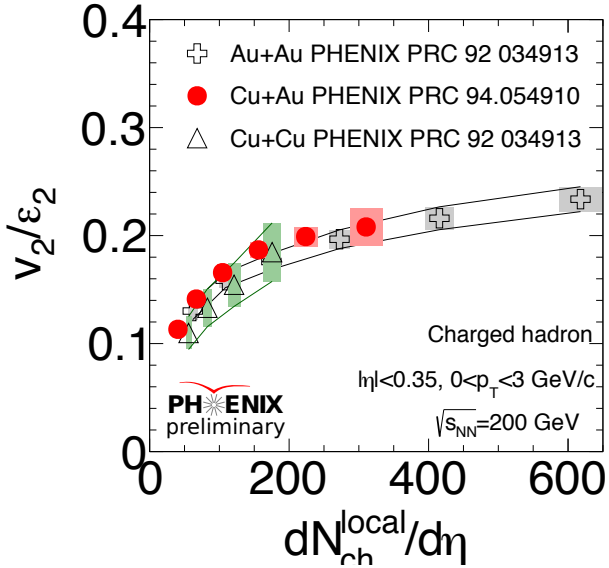
○ p+p ● Au+Au ● d+Au ● Cu+Cu ● U+U ● Cu+Au ● He+Au ● p+Au ● p+Al

See details at http://www.rhichome.bnl.gov/RHIC/Runs/

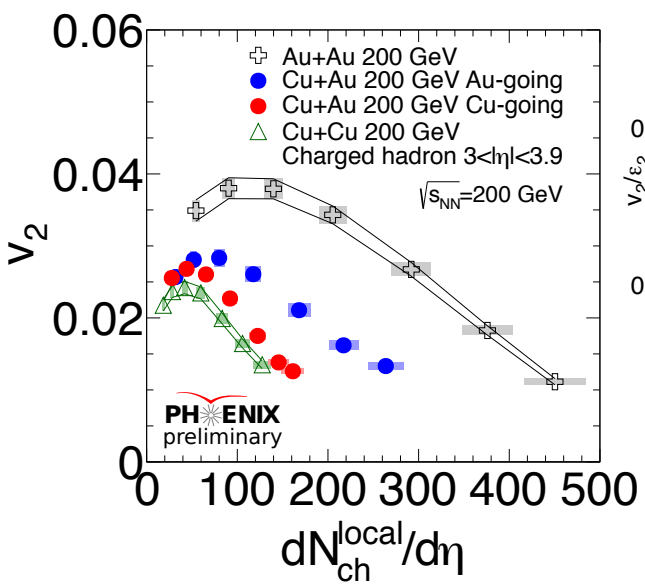
Initial eccentricity over a large eta range

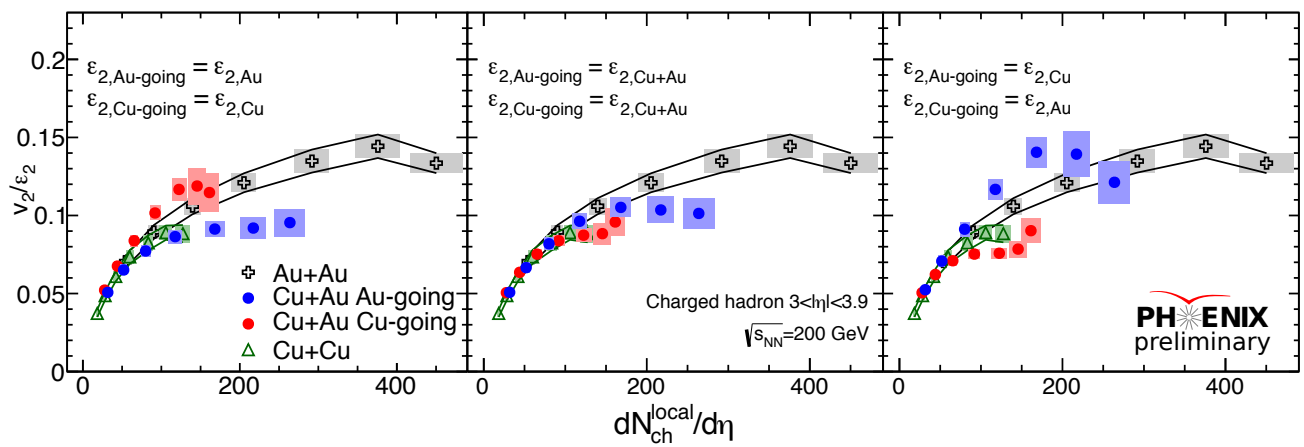


v2 scaling with Epsilon2 at midrapidity



v2 scaling with Epsilon2 for asymmetric systems at forward/backward rapidities





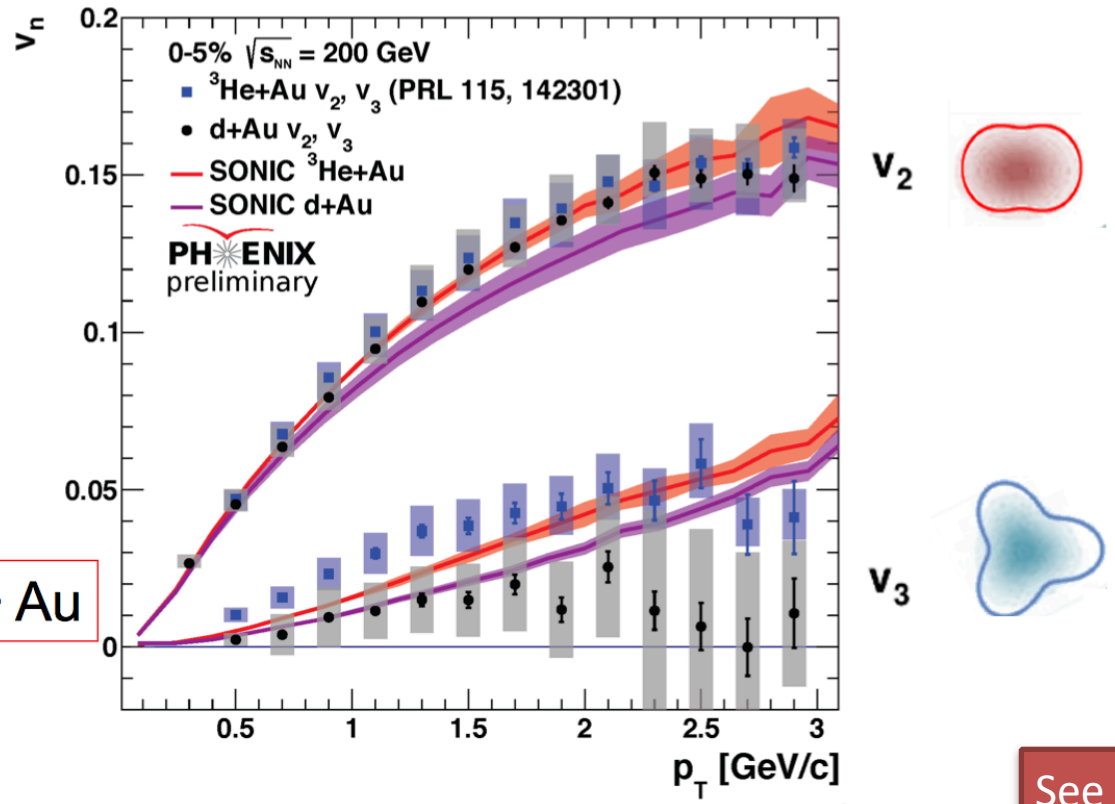
See flash talk at QM17 by Hiroshi Nakagomi

Recent results from v3 in d+Au presented in QM17

Triangular flow at 200 GeV in different systems: insights about the role of preflow

v_2 in d/^{3}He+ Au
Nearly identical

v_3 smaller in d+ Au



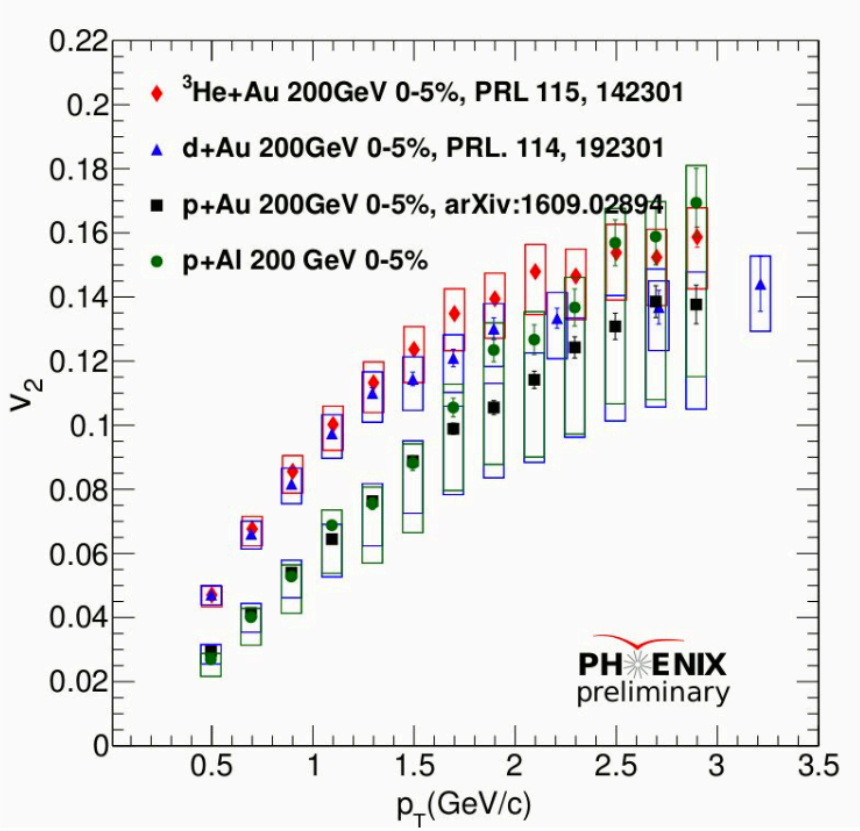
- Trends well described with hydro without preflow

See talk at QM17 by Julia Velkovska

PHENIX Julia Velkovska, QM 2017 15

Recent results for v2 in p+Al presented at QM17

Charged v_2 Comparison between systems



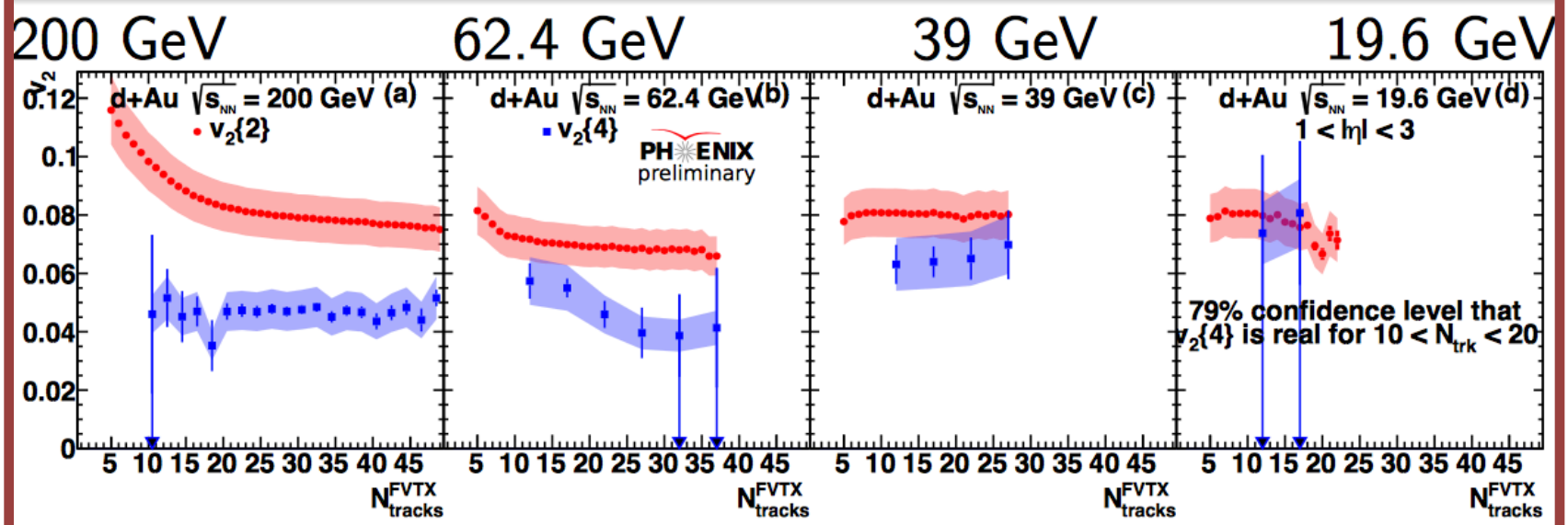
	Epsilon2
He+Au	*0.50*
d+Au	*0.54*
p+Au	*0.23*
p+Al	*0.30*

- $v_2(^3\text{HeAu}) \sim v_2(\text{dAu}) > v_2(\text{pAu}) \sim v_2(\text{pAl})$
- Geometry control works!

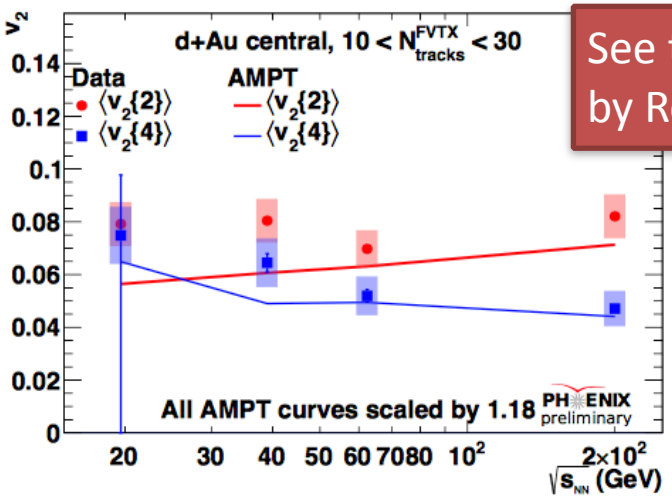
See talk at QM17 by Qiao Xu

Recent results from v2{2} and v2{4} in d+Au for BES presented at QM17

$v_2\{2\}$ and $v_2\{4\}$ in the d+Au beam energy scan



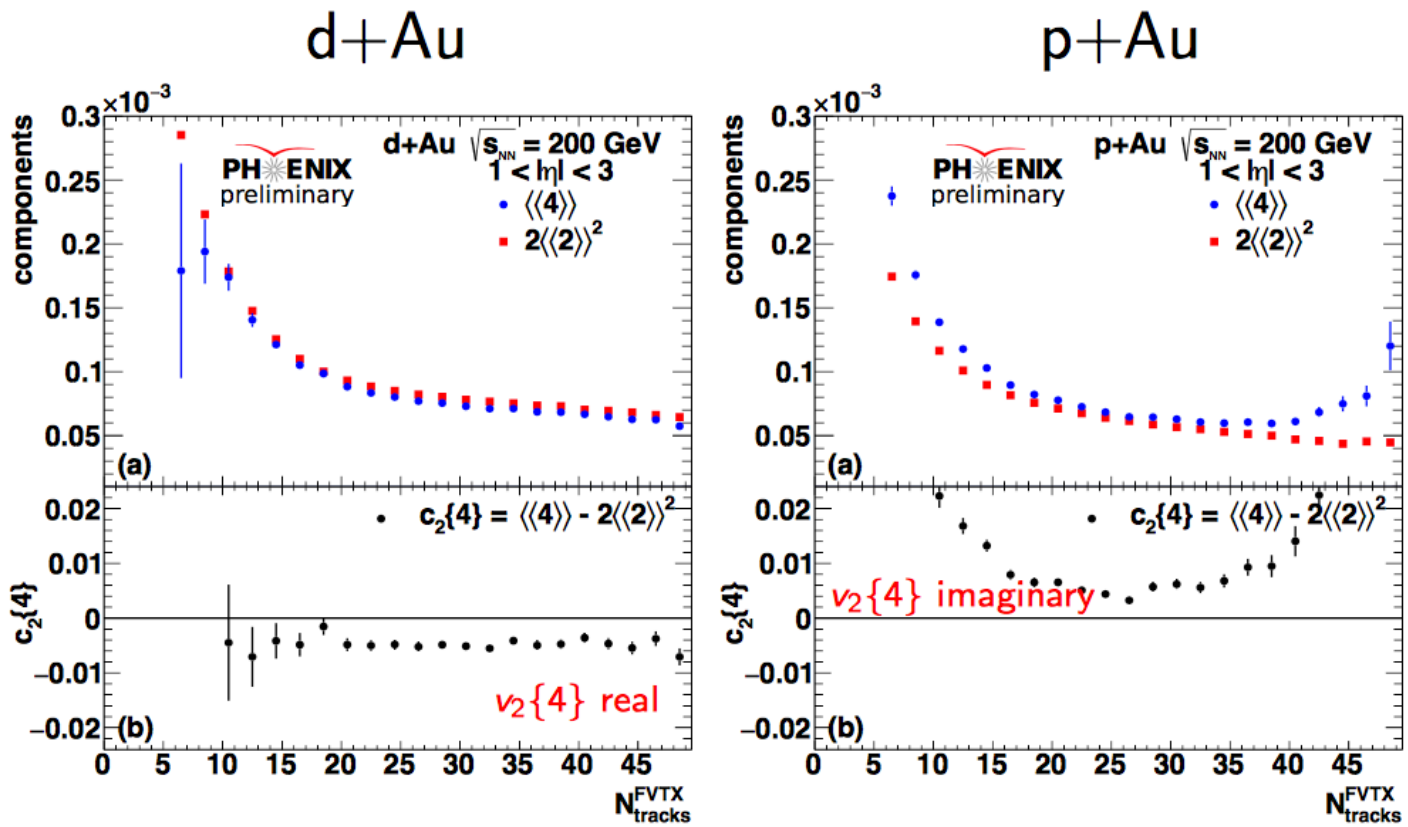
- Select $10 < N_{tracks}^{FVTX} < 30$, integrate
- Trend of $v_2\{2\}$ and $v_2\{4\}$ merging as $\sqrt{s_{NN}}$ is lowered
- AMPT sees the same trend



See talk at QM17 by Ron Belmont

Recent results from cumulants in p+Au and d+Au presented at QM17

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



- Real $v_2\{4\}$ in d+Au, imaginary $v_2\{4\}$ in p+Au
- Fluctuations could dominate in the p+Au ($v_2\{4\} = \sqrt{v_2^2 - \sigma^2}$)

See talk at QM17 by Ron Belmont