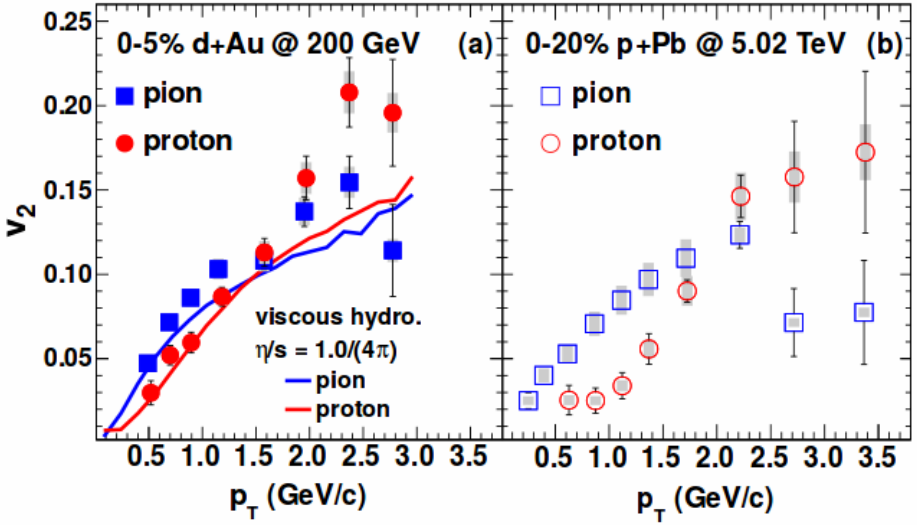
Exploiting Intrinsic Triangular Geometry in Relativistic $He^3 + Au$ Collisions to Disentangle Medium Properties

J. L. Nagle, A. Adare, S. Beckman, T. Koblesky, J. Orjuela Koop, D. McGlinchey, P. Romatschke[1], and J. Carlson, J. Lynn, M. McCumber[2]

[1]University of Colorado Boulder and [2]Los Alamos National Laboratory

RHIC/AGS Users Meeting 2014

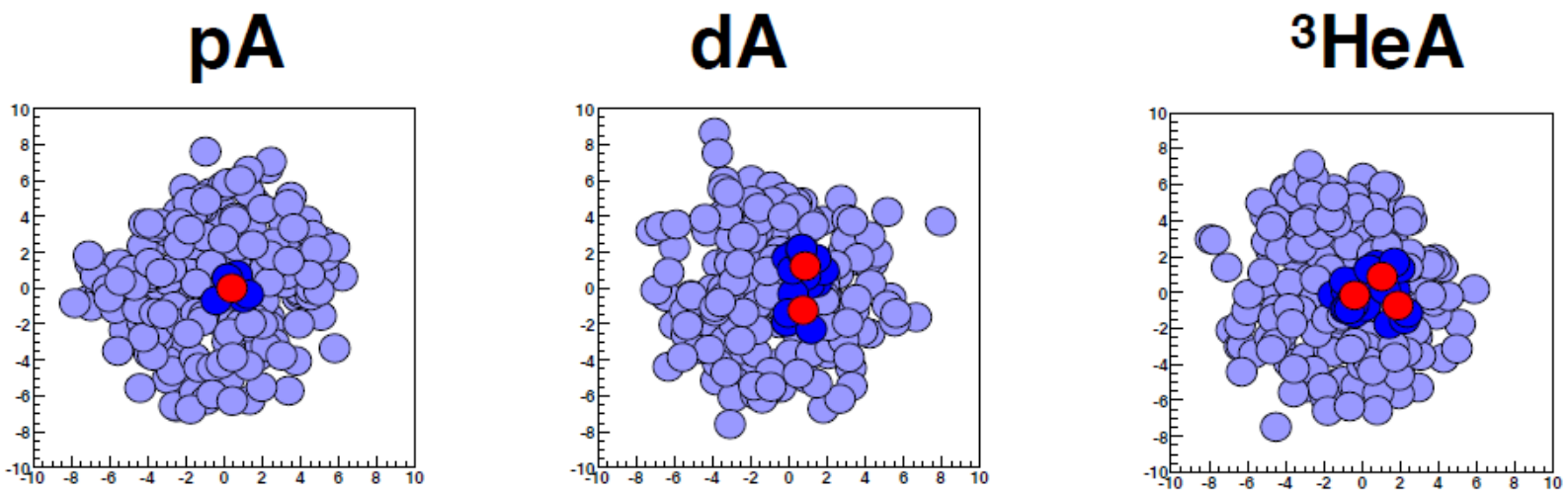
Studying Initial Geometry in Small Systems



arXiv:1404.7461

- Results in $p(d)$+A collisions at the LHC and RHIC indicate "flow" in small systems.
- Experimental results of v_2 and v_3 well described by viscous hydrodynamics.
- Measuring v_n in multiple small systems - p+Au, d+Au, and $He^3 + Au$ - can help disentangle initial anisotropy and viscous damping

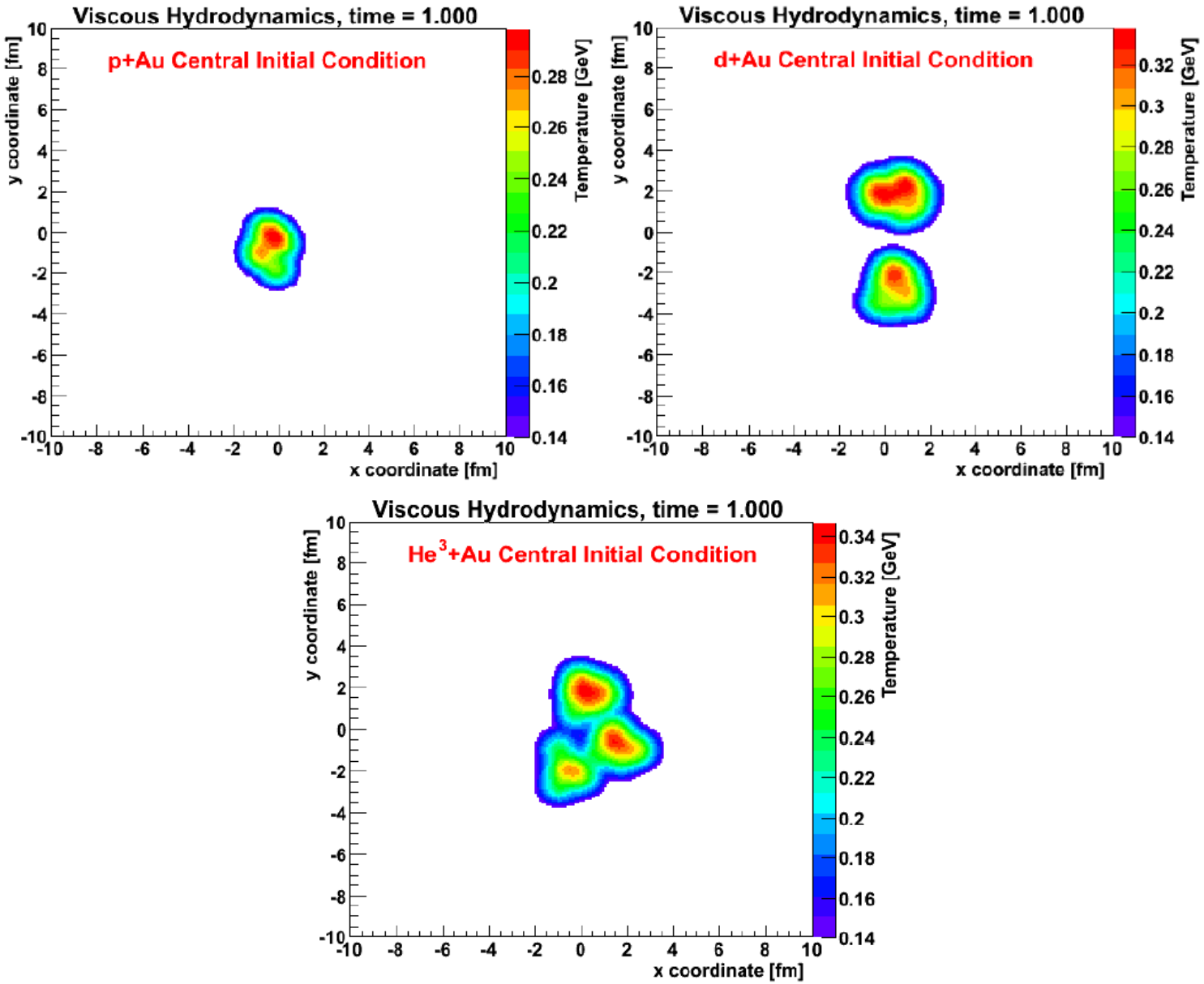
Initial Geometry in p+Au, d+Au, and $He^3 + Au$



A. Sickles, QM14

- Use Woods-Saxon for nucleon positions in Au nucleus
- Use Hulthen wavefunction for d
- Use Green's function Monte Carlo calculations *[Carlson & Schiaville, 1998]* for nucleon positions in He^3
- Calculate positions of participating nucleons using Glauber model
- Each participating nucleon deposits energy in the form of a Gaussian with $\sigma = 0.4$ fm

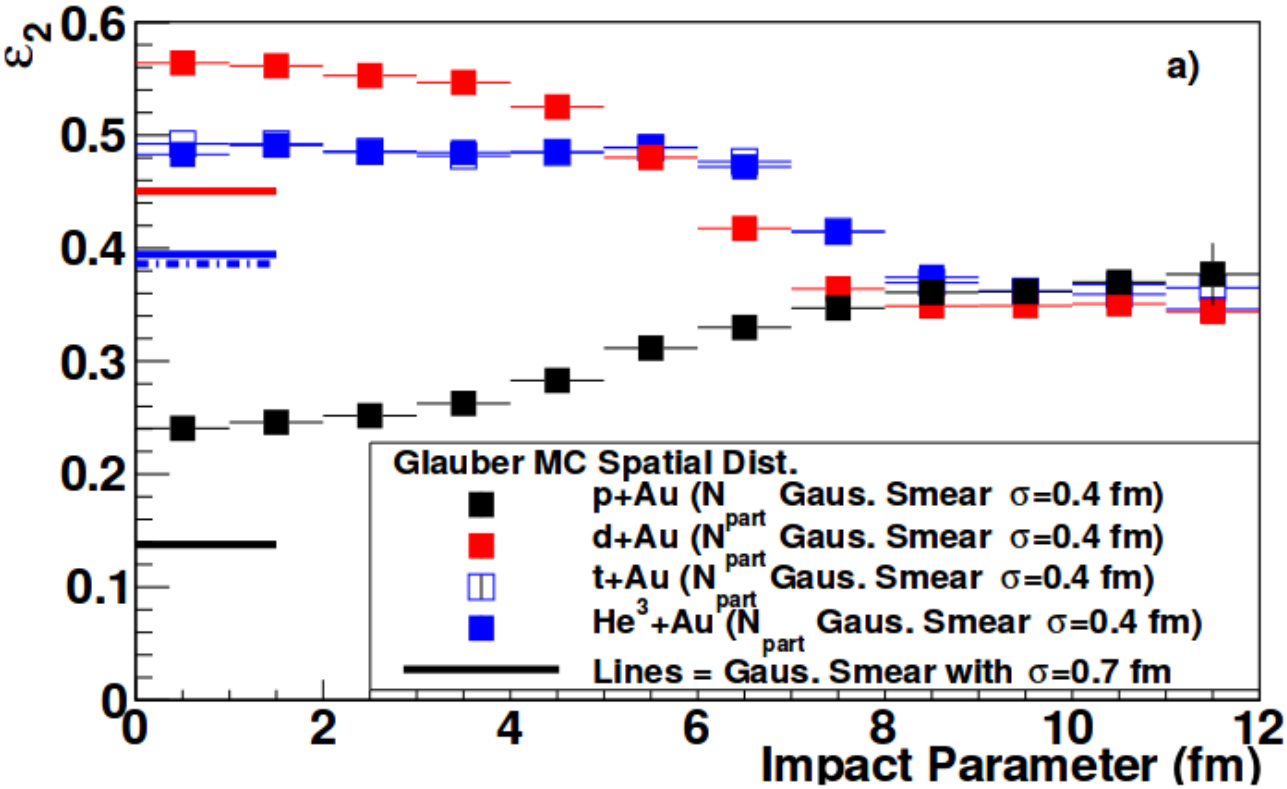
Initial Geometry in p+Au, d+Au, and $He^3 + Au$



Initial Geometry in p+Au, d+Au, and $He^3 + Au$

Initial spatial anisotropy - ϵ_2

arXiv:1312.4565

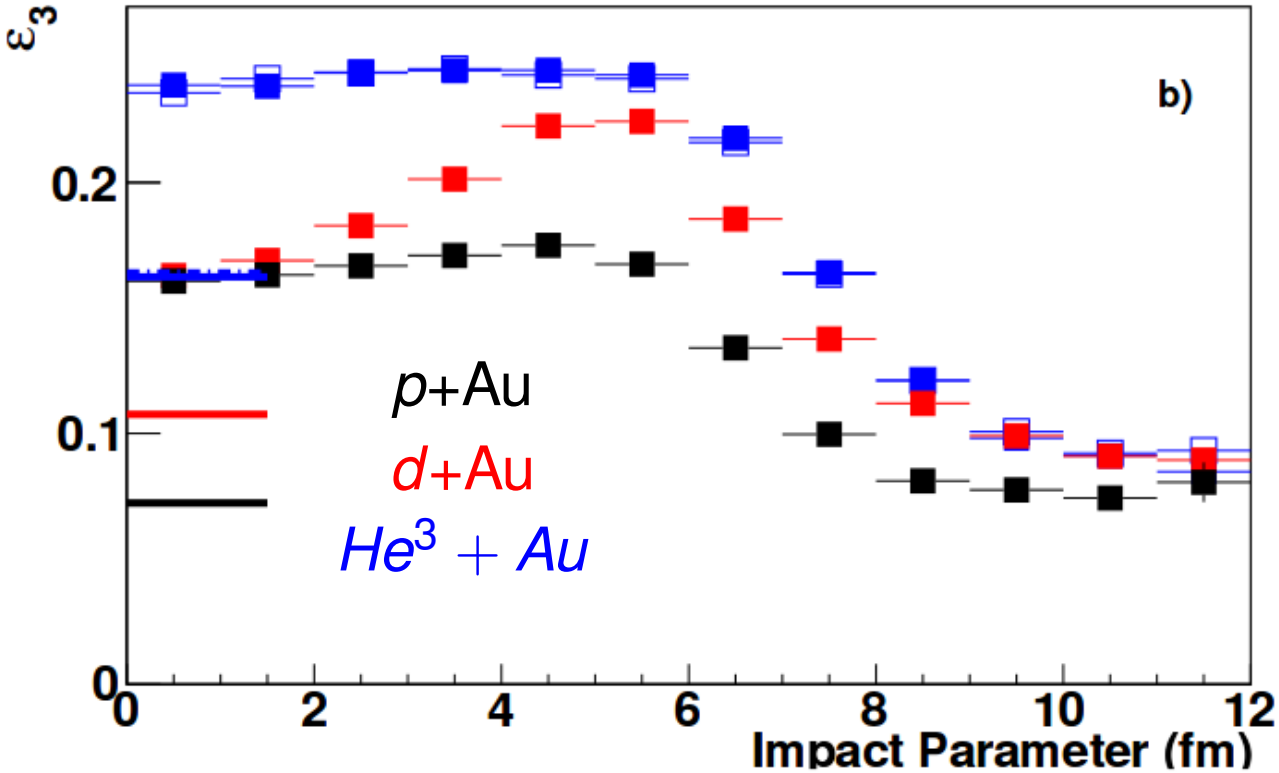


Largest ϵ_2 in d+Au

Initial Geometry in p+Au, d+Au, and $He^3 + Au$

Initial spatial anisotropy - ϵ_3

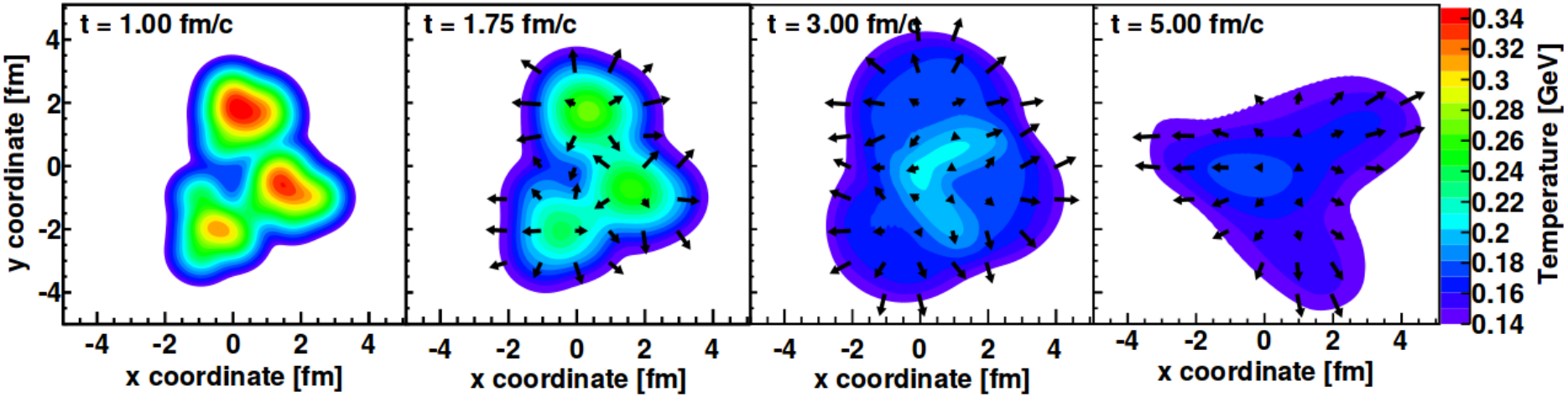
arXiv:1312.4565



Largest ϵ_3 in $He^3 + Au$

Spatial → Momentum Conversion via Viscous Hydro

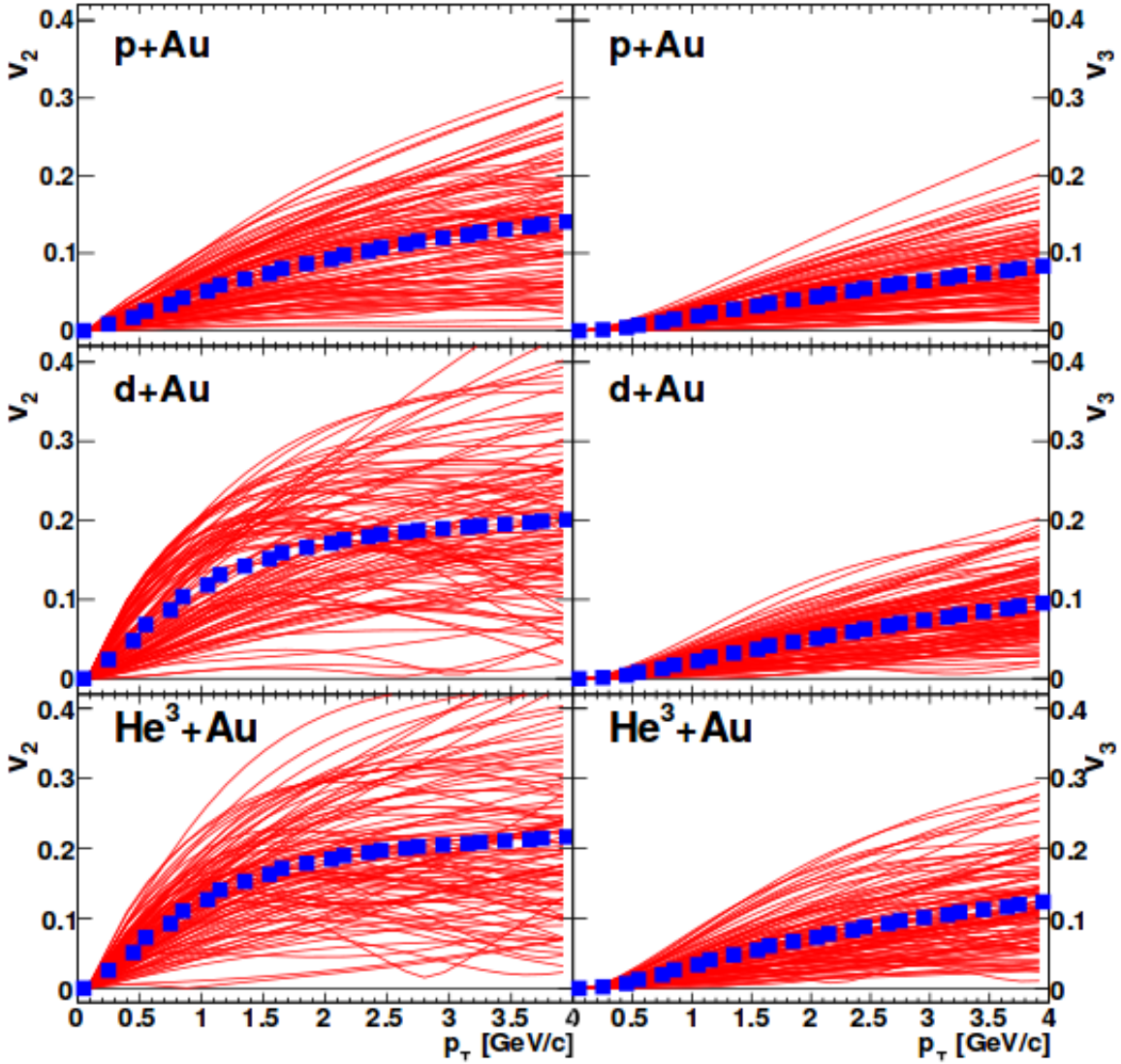
arXiv:1312.4565



Standard viscous hydro (vh2+1, Luzum/Romatschke) - well tested

Primordial Pions - v_2 & v_3

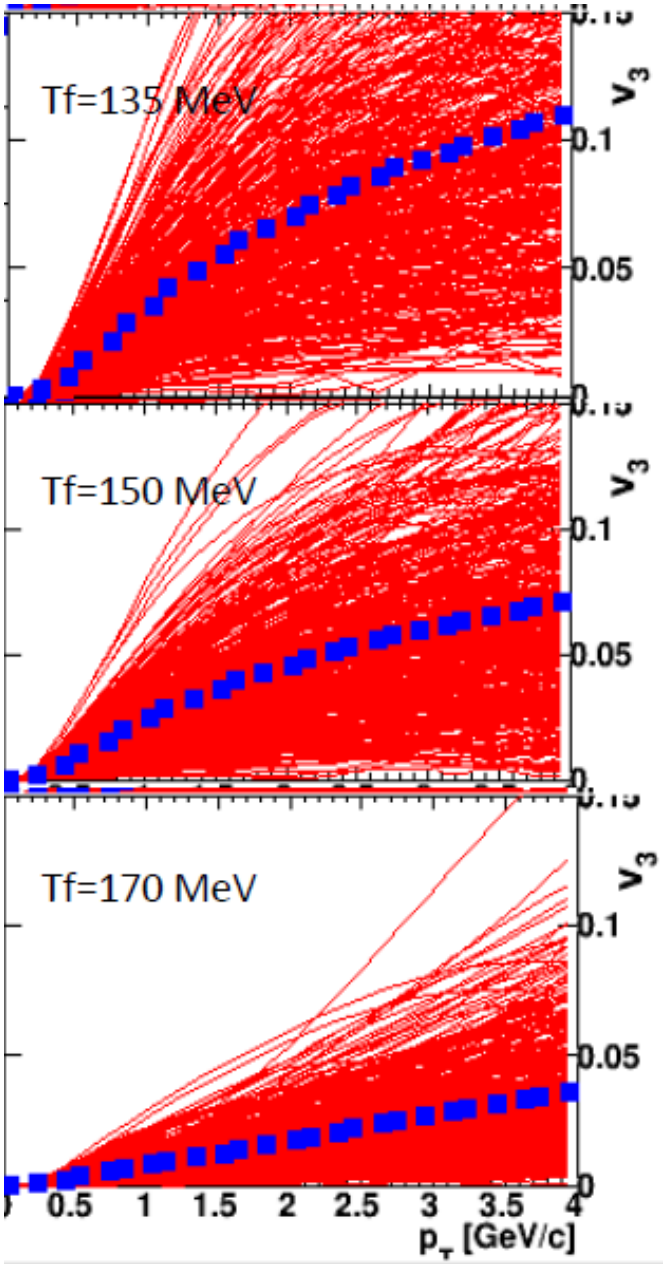
arXiv:1312.4565



pure hydro
100 events
$\eta/s = 1/4\pi$
$\tau_0 = 1$ fm/c
$T_f = 150$ MeV/c
high multiplicity
event average

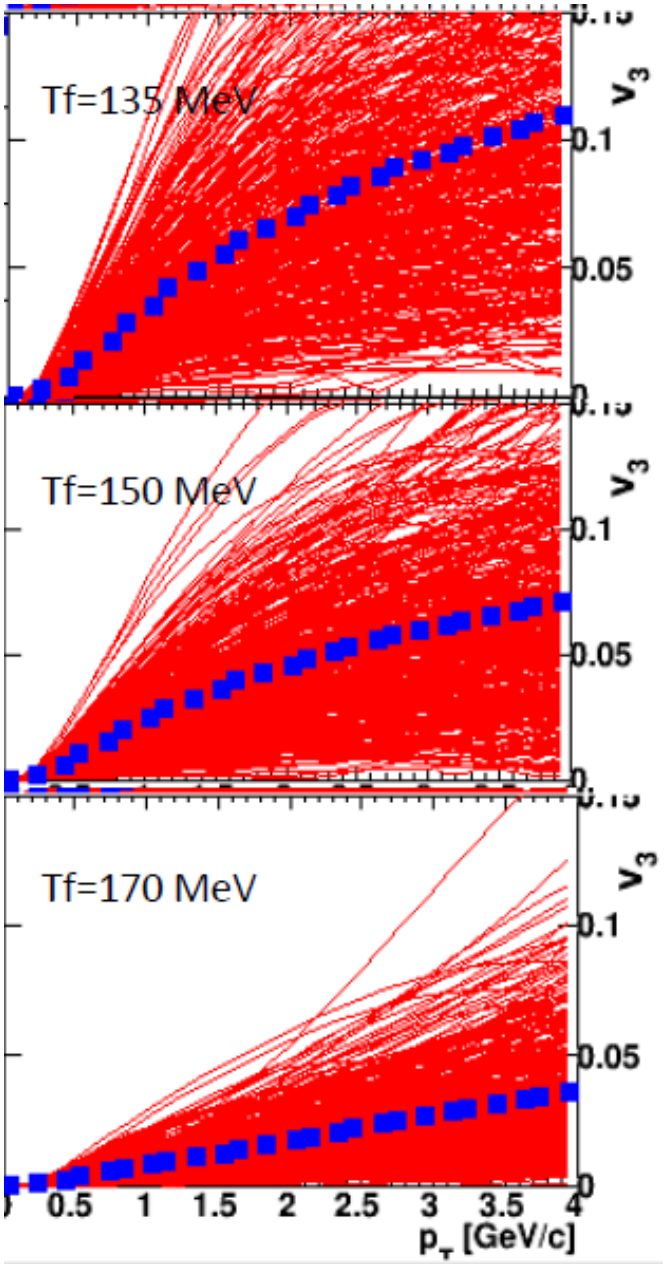
d+Au Consistent with P. Bozek's results

$He^3 + Au$ - T_f Dependence



Strong T_f dependence in **pure hydro** - if system does not live long enough, triangularity not fully translated into v_3.

$He^3 + Au$ - T_f Dependence

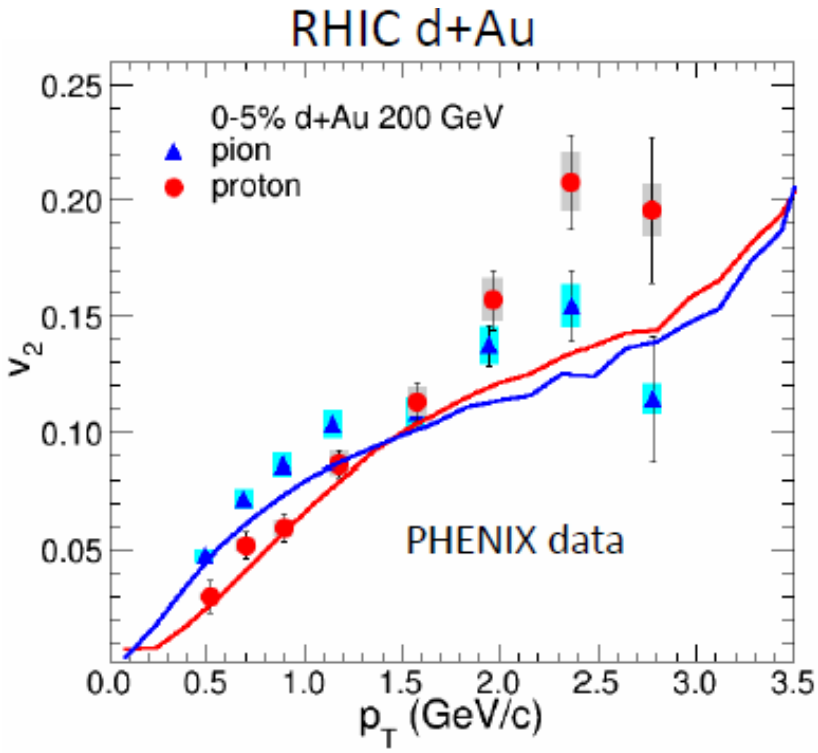


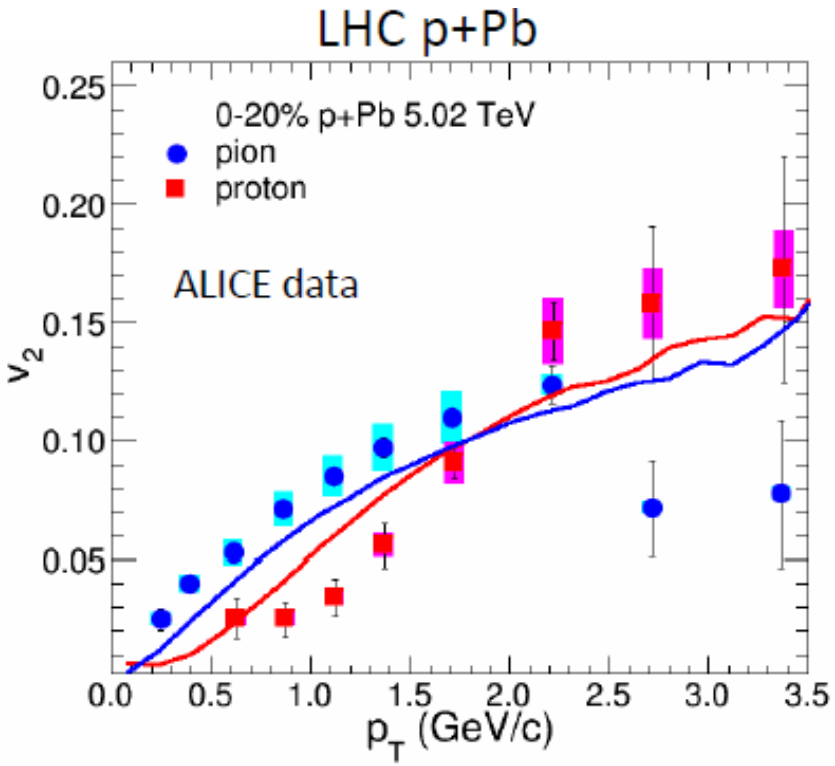
Strong T_f dependence in **pure hydro** - if system does not live long enough, triangularity not fully translated into v_3.

Add hadron cascade after hydro with T_f=170 MeV transition.

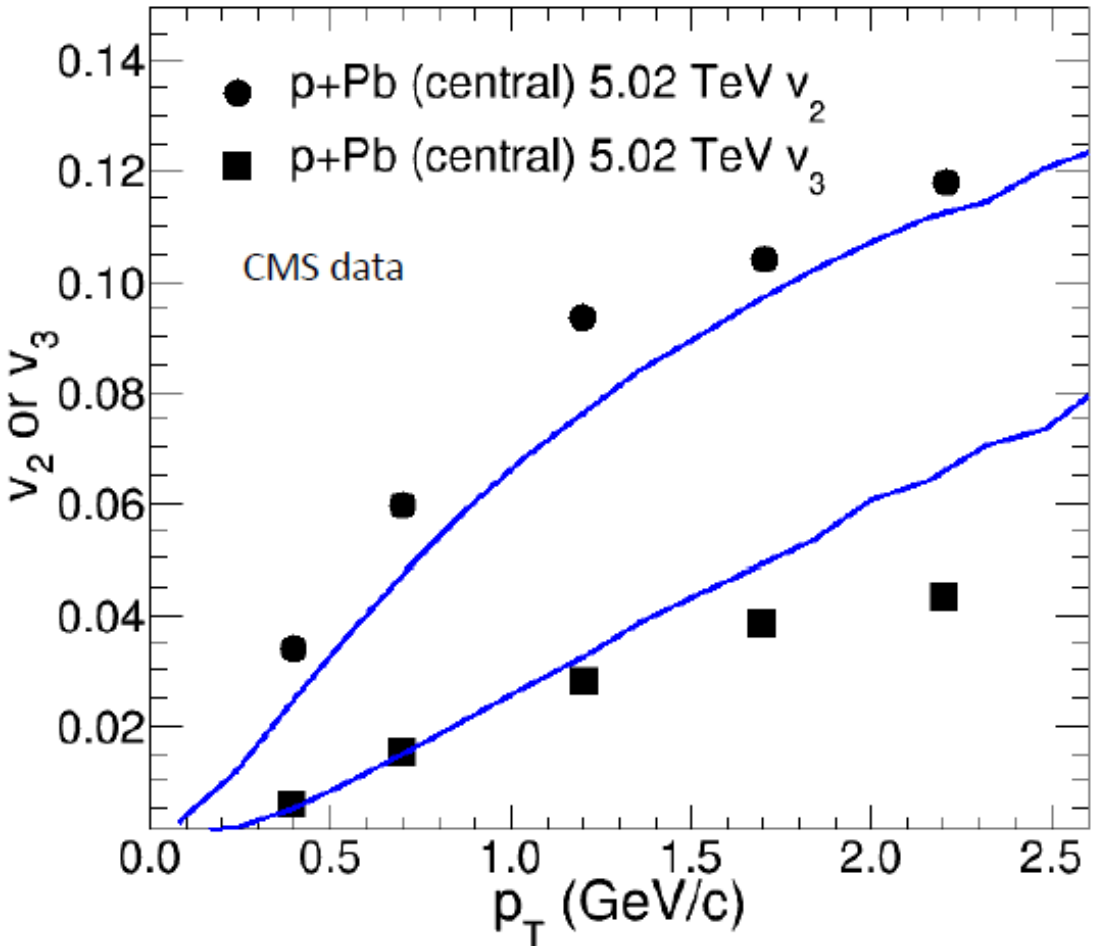
Hydro+Cascade Model vs. Data

hydro $\eta/s = 1/4\pi$**,** $\tau_0 = 0.5$ **fm/***c***, T**$_{freeze}$**=170 MeV, then cascade** and the right initial energy deposited, gives reasonable comparisons to RHIC (*d*+Au) and LHC (*p*+Pb) v_2 results.





Hydro+Cascade Model vs. Data



Model gives reasonable agreement to LHC v_2 and v_3 results in p+Pb

Break-down of Hydro?

Results depend sensitively on:

- Initial equilibrium energy
- Freeze out temperature
- large momentum/pressure gradients

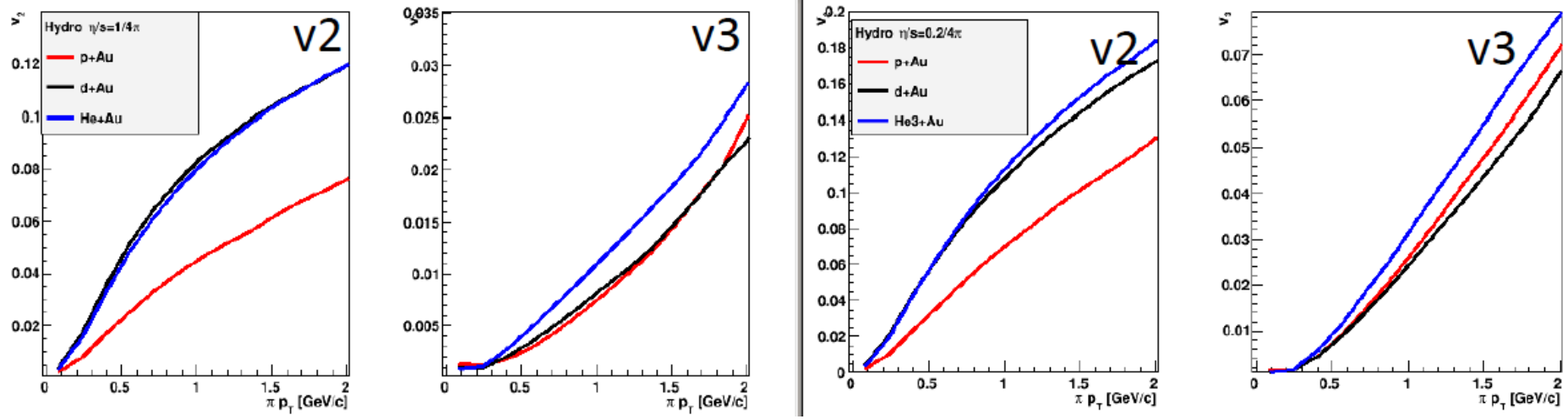
some concern that this shows hydro breaks down and is no longer applicable

However: Hydro still provides reasonable agreement to measured data!

Results for p+Au, d+Au, and $He^3 + Au$

Full viscous hyrdro (T_f=170 MeV) + hadronic cascade

Hydro $\eta/s = 1/4\pi$ | Hydro $\eta/s = 0.2/4\pi$



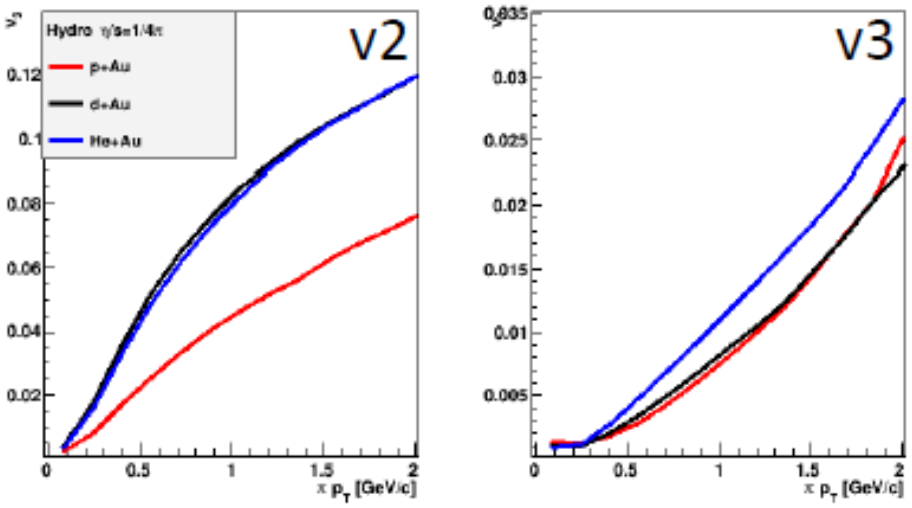
Ordering between systems is preserved.

v_3 sensitive to η/s

Results for p+Au, d+Au, and $He^3 + Au$

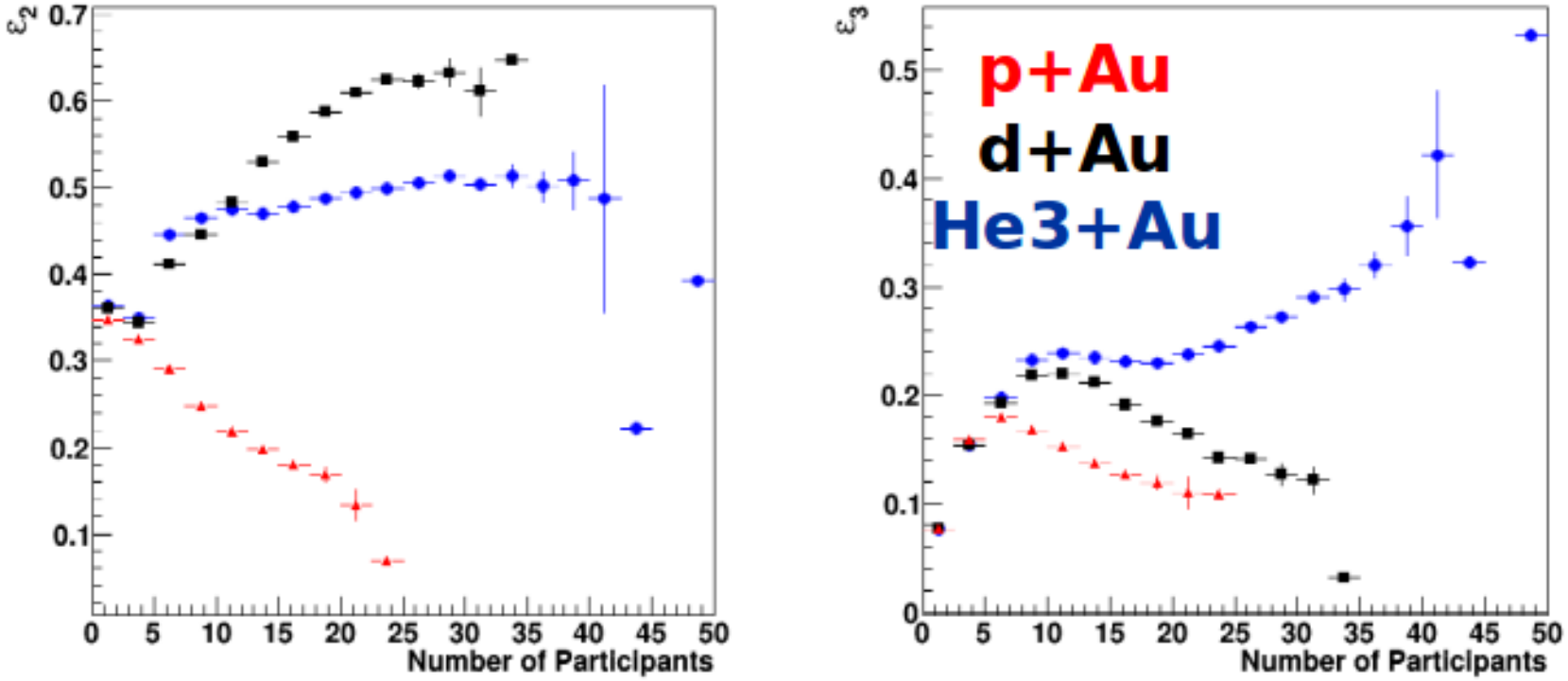
Full viscous hyrdro (T_f=170 MeV) + hadronic cascade

T_f=170 MeV + cascade, $\eta/s = 1/4\pi$



For $\eta/s = 1/4\pi$, $He^3 + Au$ v_3 at $p_T = 2$ GeV is 3% instead of the 7% quoted in arXiv:1312.4565 (pure hydro).

Boosting v_3: Ultra-Central Collisions



Can boost the initial spatial anisotropy by measuring more central events.

Alternative Approach - Event Generators

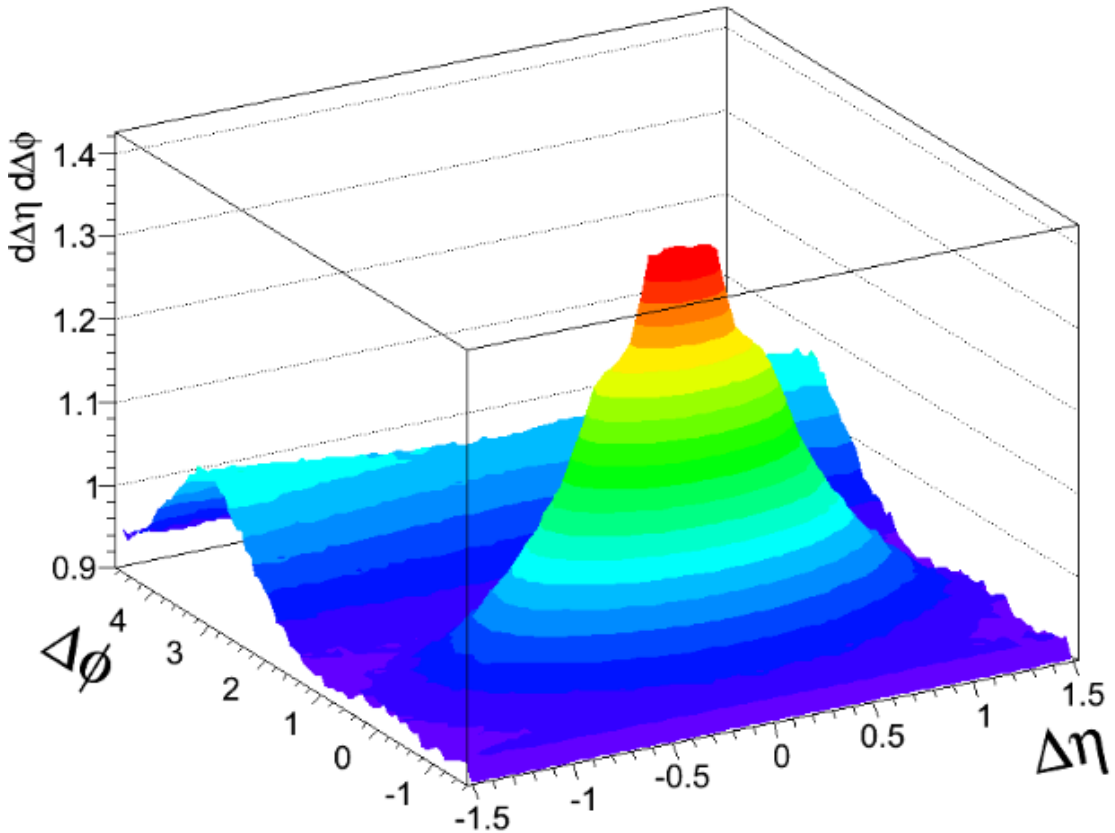
- Recent paper by Ma & Bzdak [arXiv:1404.4129] investigates azimuthal correlations in $p + p$ and p+Pb within AMPT and finds reasonable agreement with LHC data.
- What about $He^3 + Au$?
- Begin investigations using HIJING and AMPT (performed by J. Orjuela Koop)
- **Note:** Neither HIJING or AMPT use full He^3 wavefunction.

Azimuthal Correlations in $He^3 + Au$ - HIJING

HIJING

$He^3 + Au$ @ 200 GeV, $0 \leq b\ [\mathrm{fm}] \leq 2$

$1 \leq p_T\ [\mathrm{GeV/c}] \leq 2$, $|\eta| < 1$



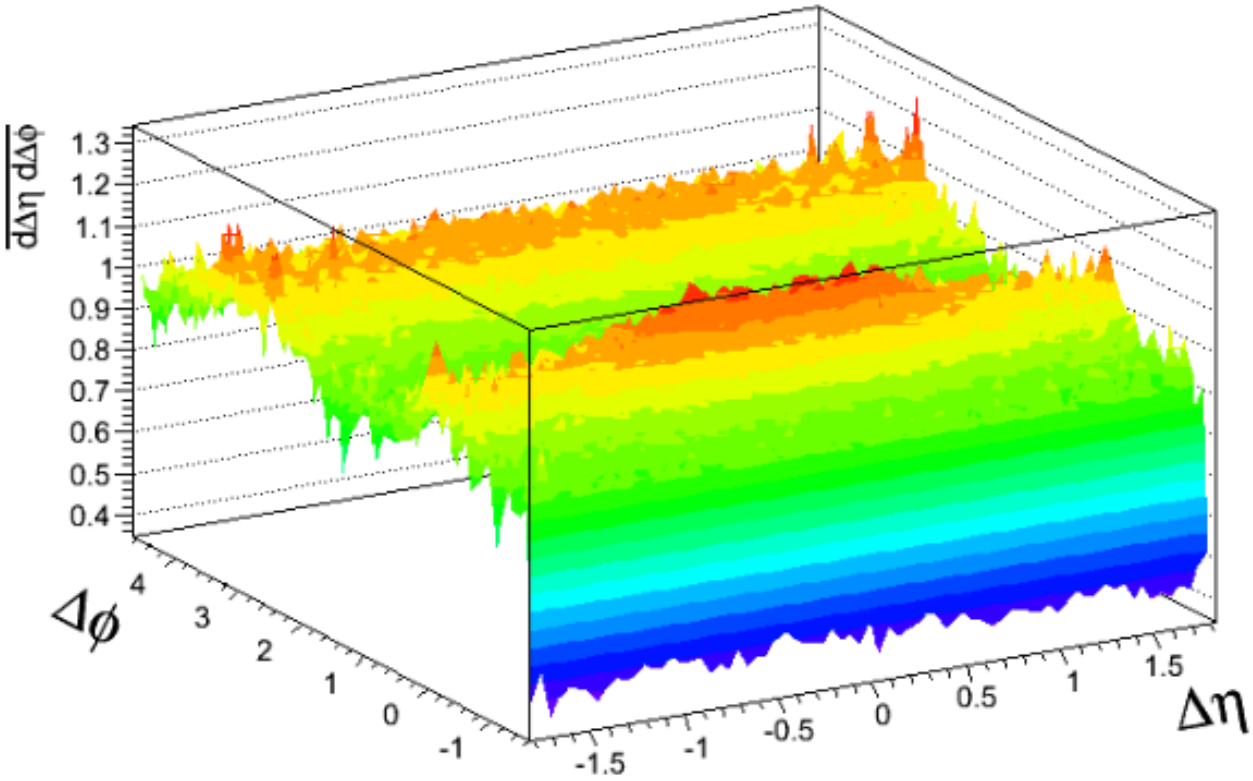
Only jet correlations, no final state rescattering in HIJING

Azimuthal Correlations in $He^3 + Au$ - AMPT

AMPT

$He^3 + Au$ @ 200 GeV, $0 \leq b$ [fm] ≤ 2

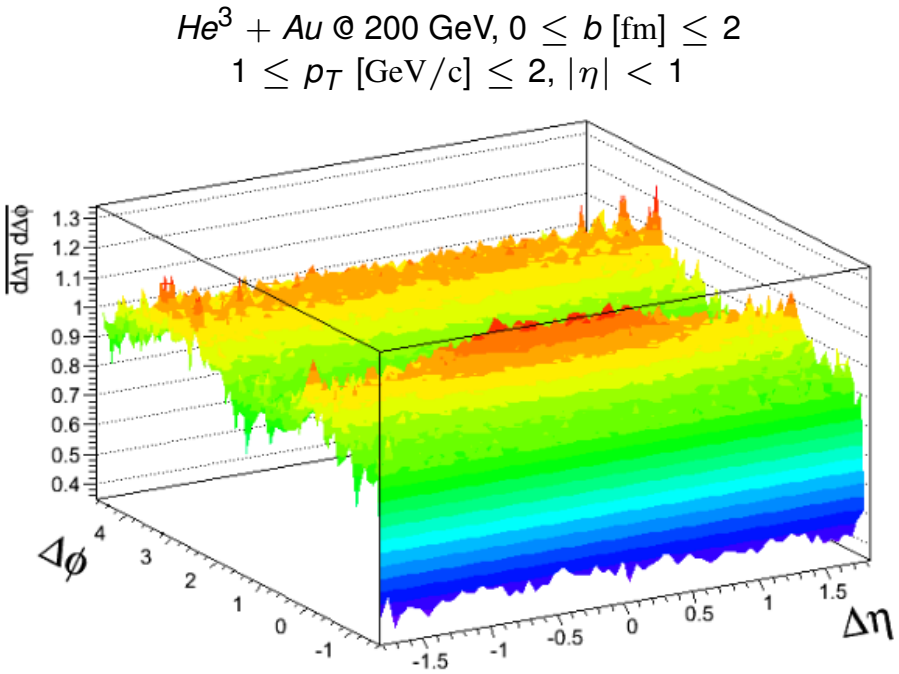
$1 \leq p_T$ [GeV/c] ≤ 2, $|\eta| < 1$

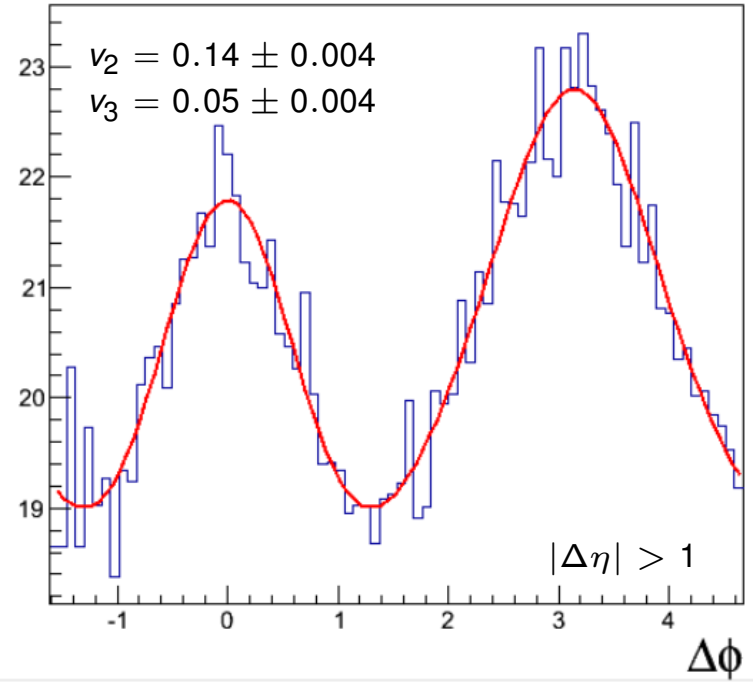


Large away-side ridge in AMPT

Extracting v_n from AMPT

String melting on, not full He^3 wavefunction

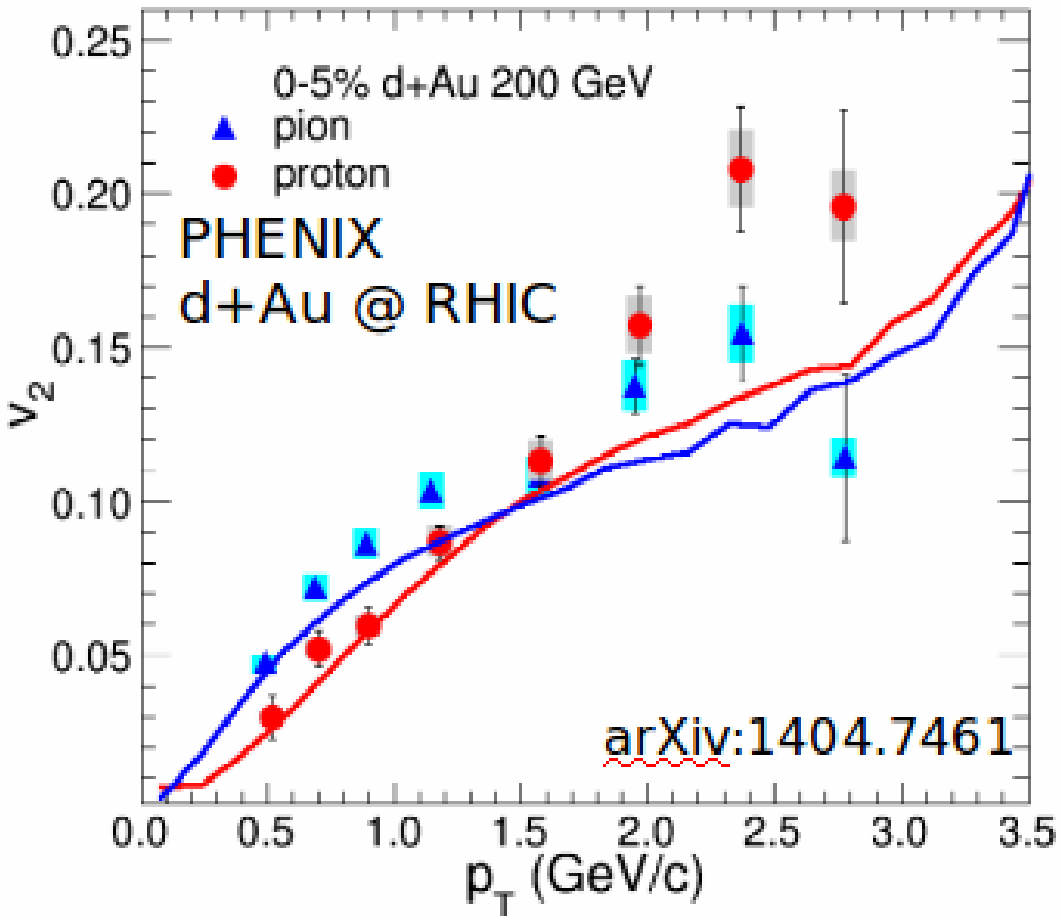




Clear ridge visible.

Extracted v_3 values similar to those from hydro+cascade.

What can we expect from RHICs $He^3 + Au$ running?



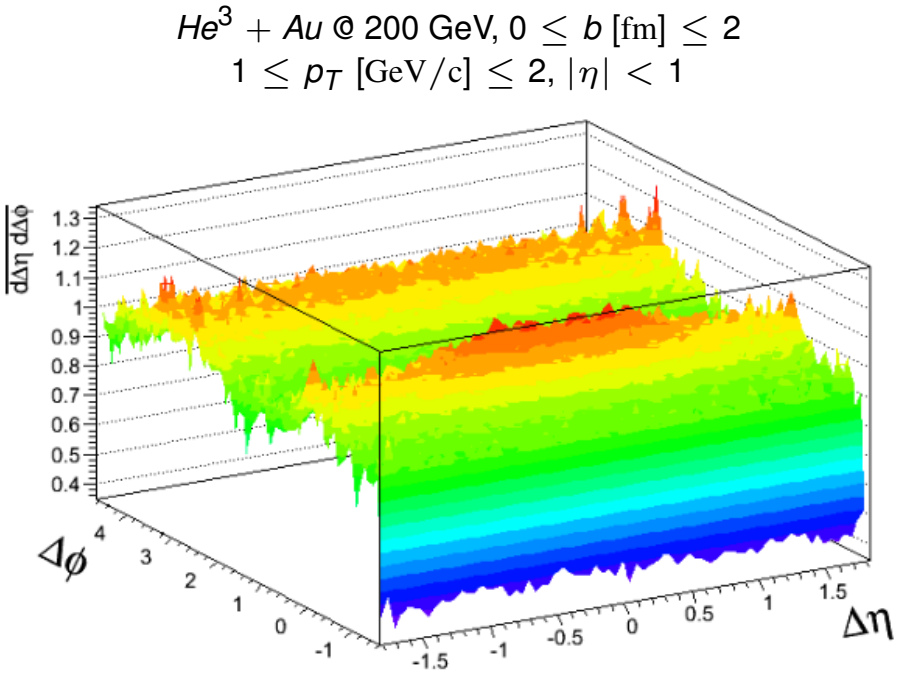
This analysis used 1.6 billion MB *d*+Au events.

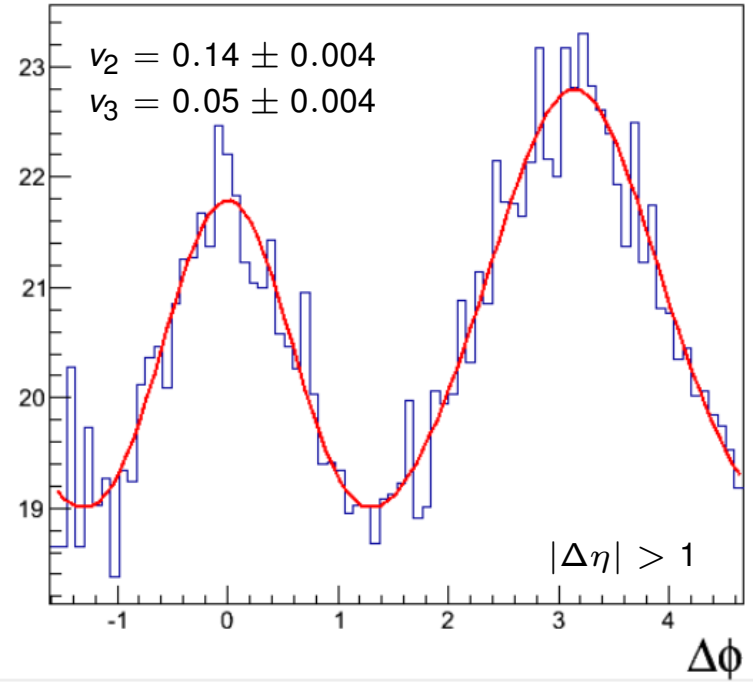
In 10 days of physics running, PHENIX will sample 2.6 billion MB events.

Will be able to sample 4x more with central event trigger.

What can we expect from RHICs $He^3 + Au$ running?

String melting on, not full He^3 wavefunction





Results are from 2M central AMPT events (full 2π acceptance). PHENIX should record $\approx$ 130M 5% central events in 10 days of $He^3 + Au$ running, without central event trigger.

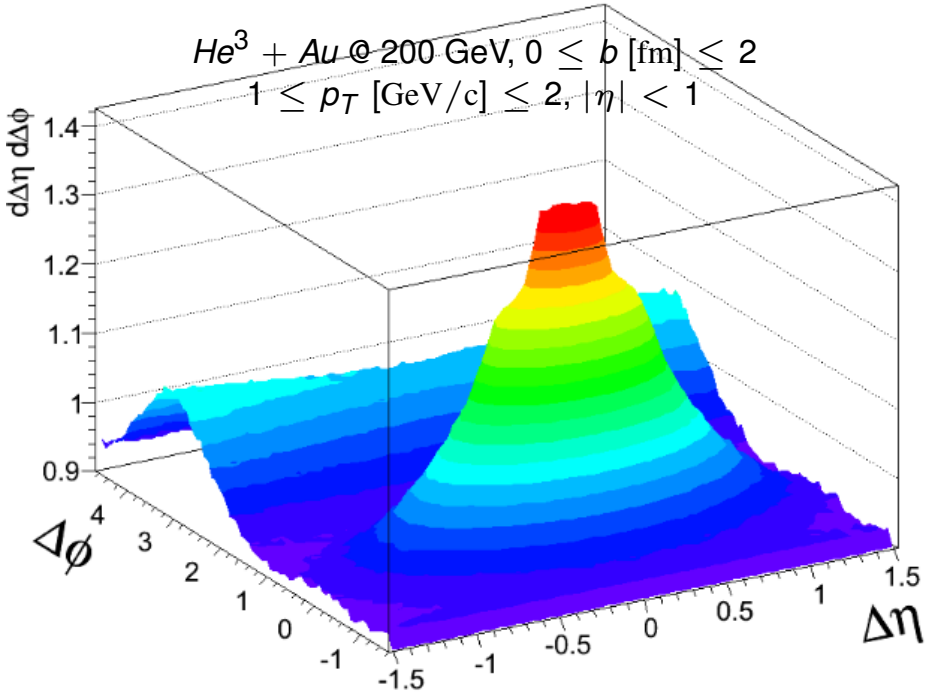
Conclusions

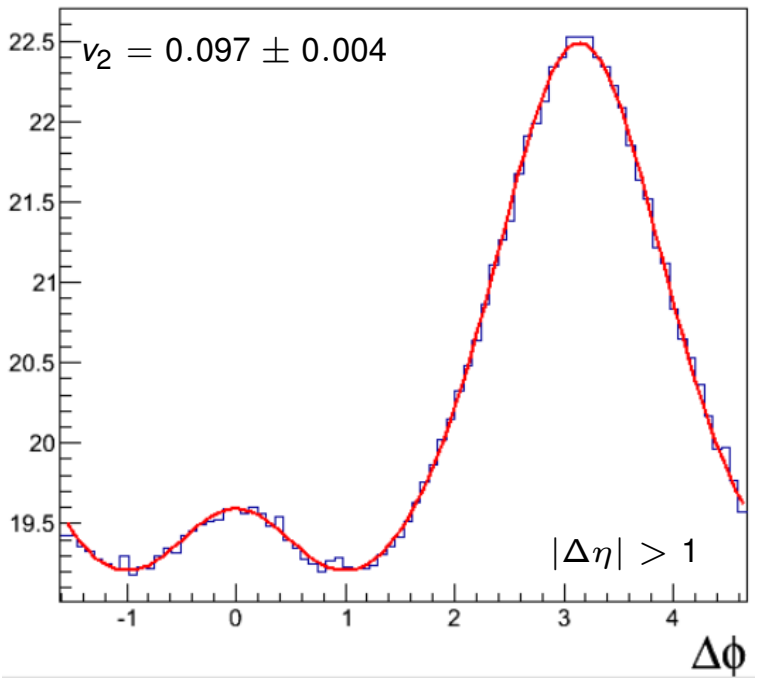
- Comparing p+Au, d+Au, and $He^3 + Au$ may help unfold initial state / medium ambiguities
- Hydro + cascade describes experimental v_2 & v_3 results in d+Au and p+Pb
- Predictions for $He^3 + Au$ show modest v_2 and small, but measurable v_3
- v_3 signal can be boosted by measuring more central events
- Azimuthal correlations clearly seen in AMPT, with similar v_3 values compared to hydro + cascade
- RHIC is currently running $He^3 + Au$ - eagerly await experimental results

Thank You!

What can we expect from RHICs $He^3 + Au$ running?

No flow in HIJING, not full He^3 wavefunction





Results are from 350M central HIJING events (full 2π acceptance). PHENIX should record $\approx$ 130M 5% central events in 10 days of $He^3 + Au$ running, without central event trigger.