QUARK GLUON PLASMA DROPLETS WITH THREE DIFFERENT GEOMETRIES

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for the PHENIX Collaboration

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Based on: arXiv:1807.11928, PRL 121 (2018) 222301
arXiv:1805.02973, Nature Physics, v15 (2019) (3)

RHIC geometry scan
p/d/^{3}He+Au: v_2, v_3
Hydrodynamic predictions
CGC postdictions
QGP droplets engineered
Summary

Based on M. Csanád's PHENIX talk at Zimányi 2018, Sylvia Morrow's talk at DNP-JSPS18 talk and Xiao Qu's talk at WWND 2019

Nature Physics Editorial: QGP, drop by drop

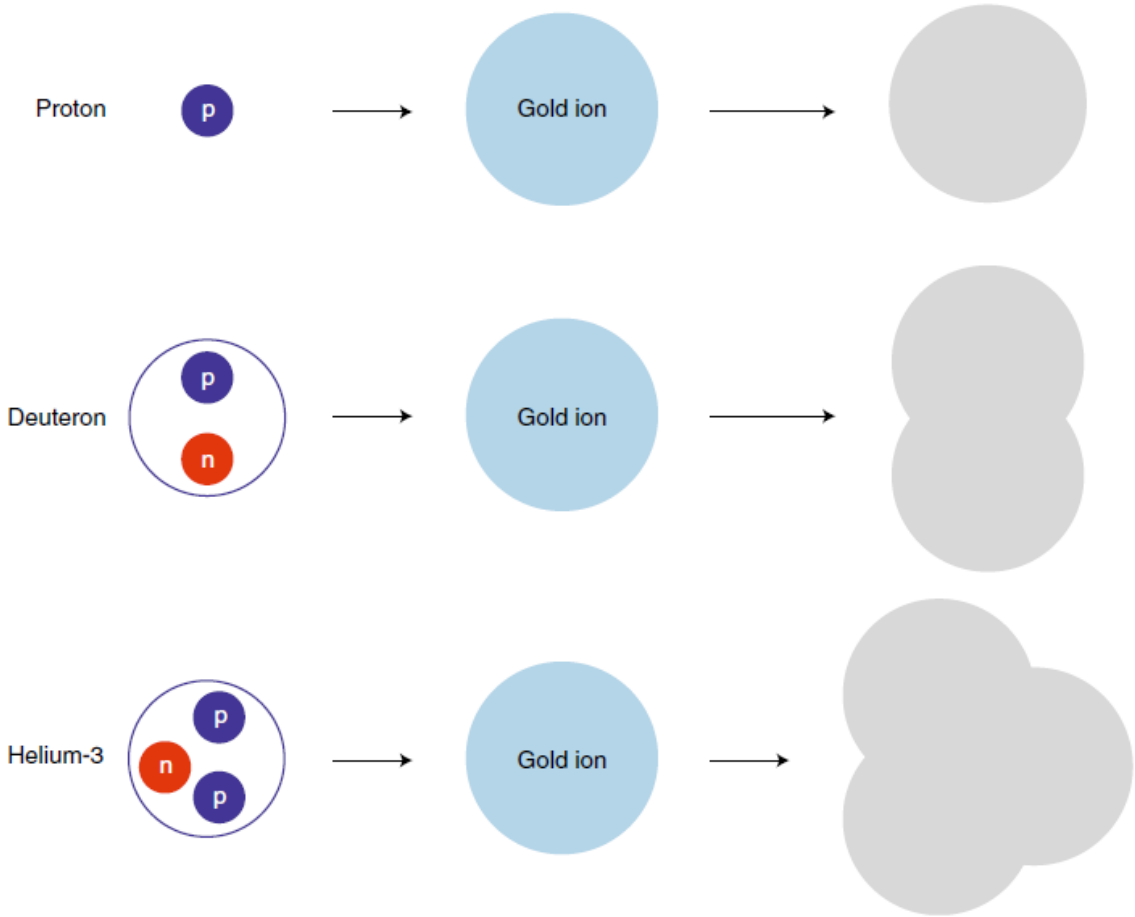
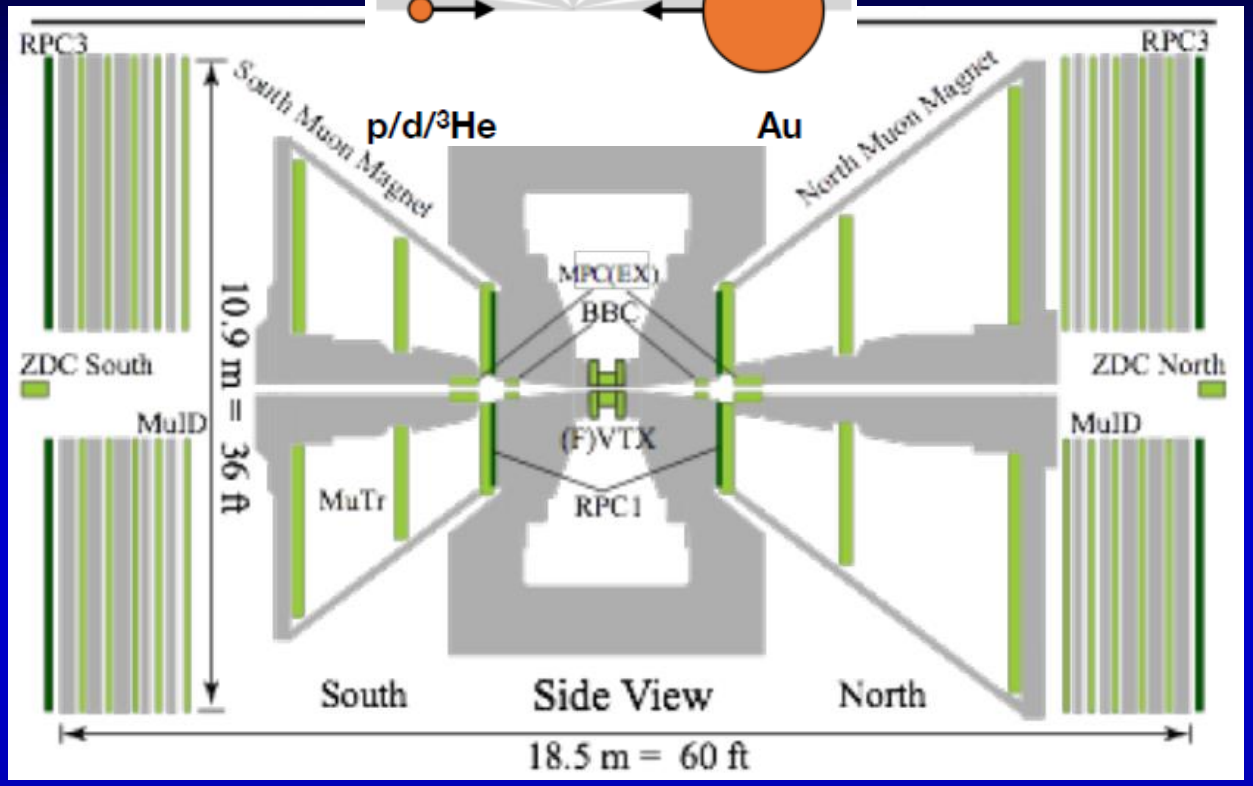
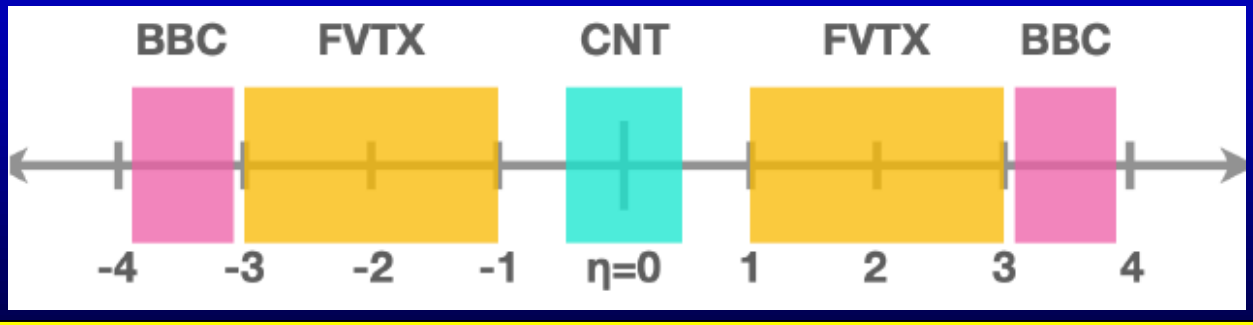


Fig. 1 | Quark–gluon plasma. Adding the plasma drop by drop by using proton–gold (top), deuteron–gold (middle) and helium-3–gold (bottom) collisions in the hydrodynamics picture.

https://www.nature.com/articles/s41567-018-0375-6

PHENIX DETECTOR SYSTEM



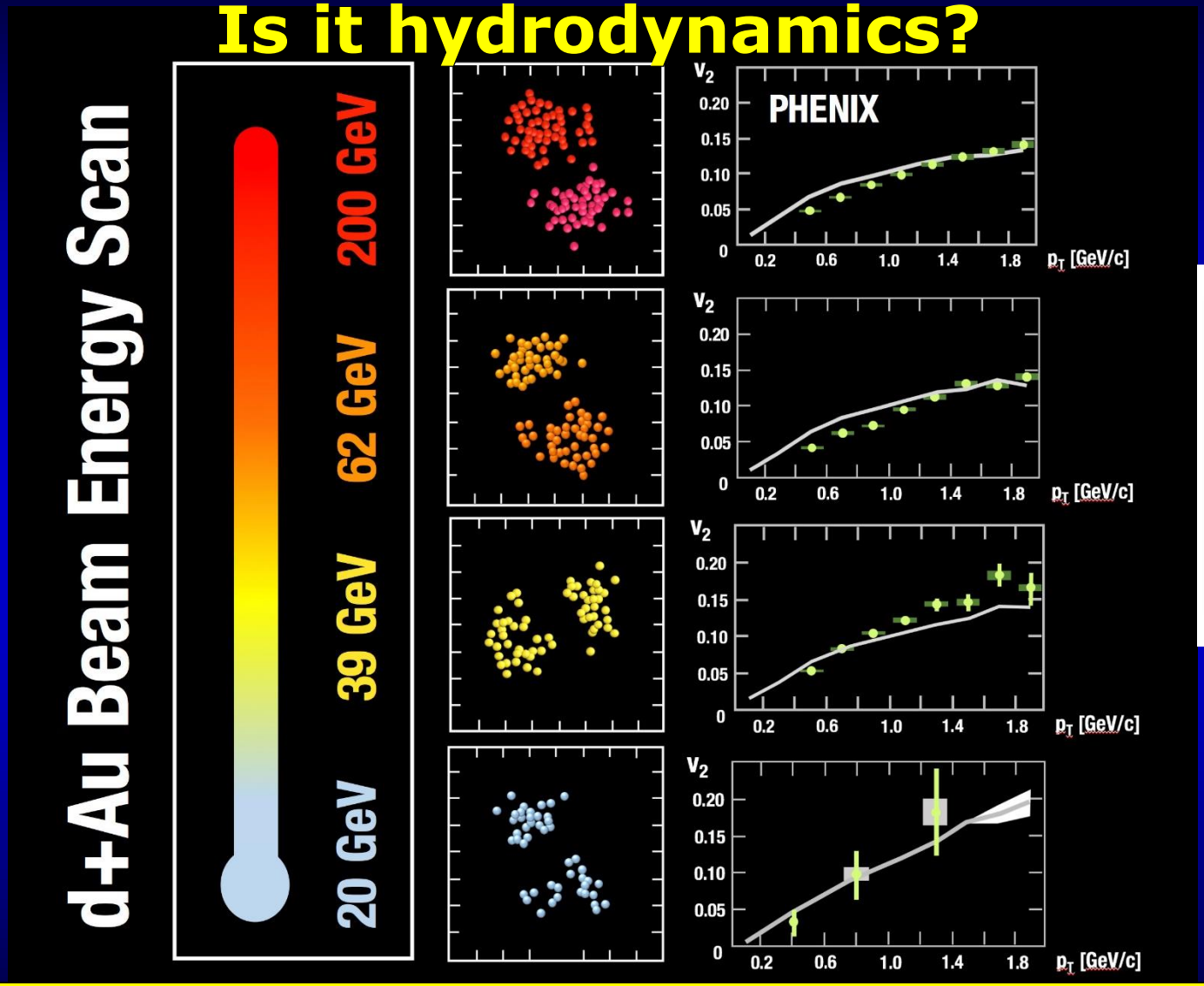


$$\eta \equiv -\ln\left(\tan\frac{\theta}{2}\right)$$

CNT: Charged particle tracking, central arm
FVTX: Charged p. tracking, event plane; BBC: event plane, centrality

BEAM ENERGY SCAN: CAN WE TURN IT OFF?

Is it hydrodynamics?

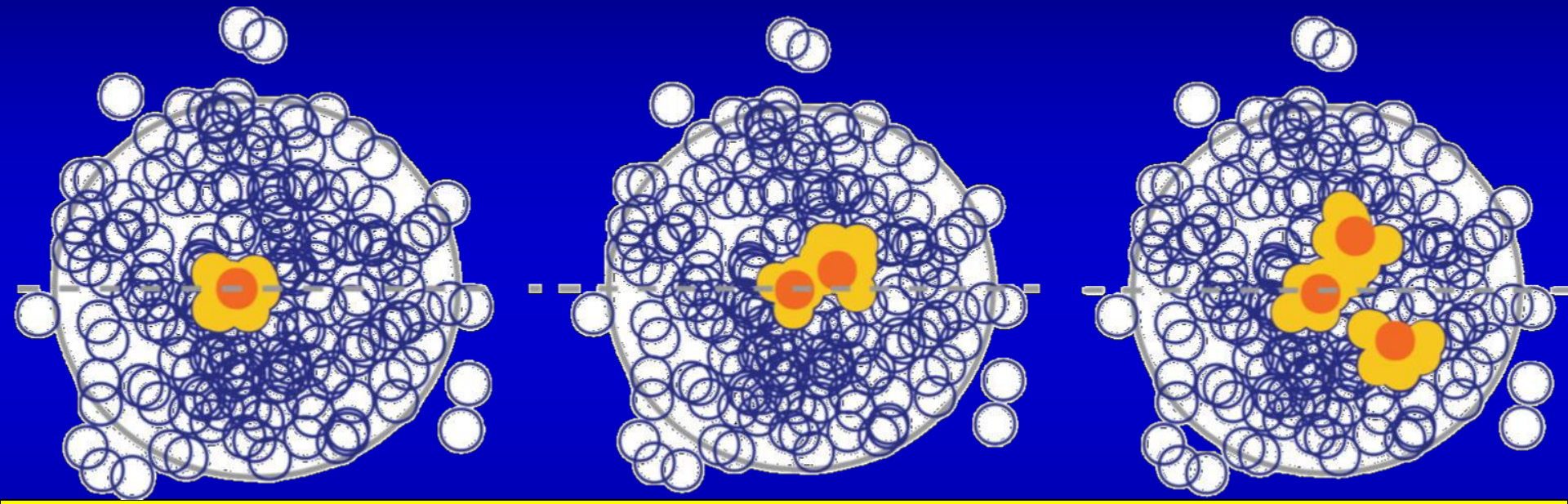


RHIC operations: versatility.

Beam energy scan x geometry scan, for d+Au: 19.6 ≤ √s ≤ 200 GeV

GEOMETRY SCAN: 3 DIFFERENT SHAPES

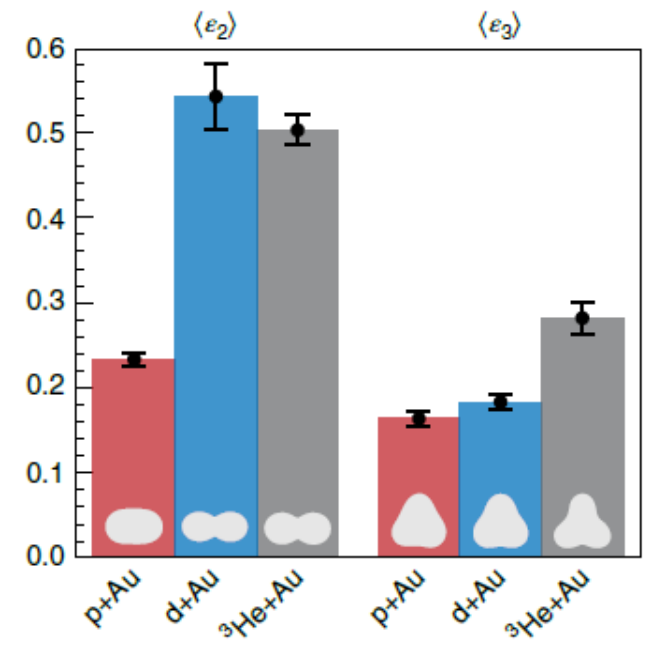
Is it hydrodynamics?



RHIC operations: versatility.
Geometry scan: p+Au, d+Au and ^{3}He+Au at $\sqrt{s}$ =200 GeV

p+Au	d+Au	^{3}He+Au
2015	2016	2014

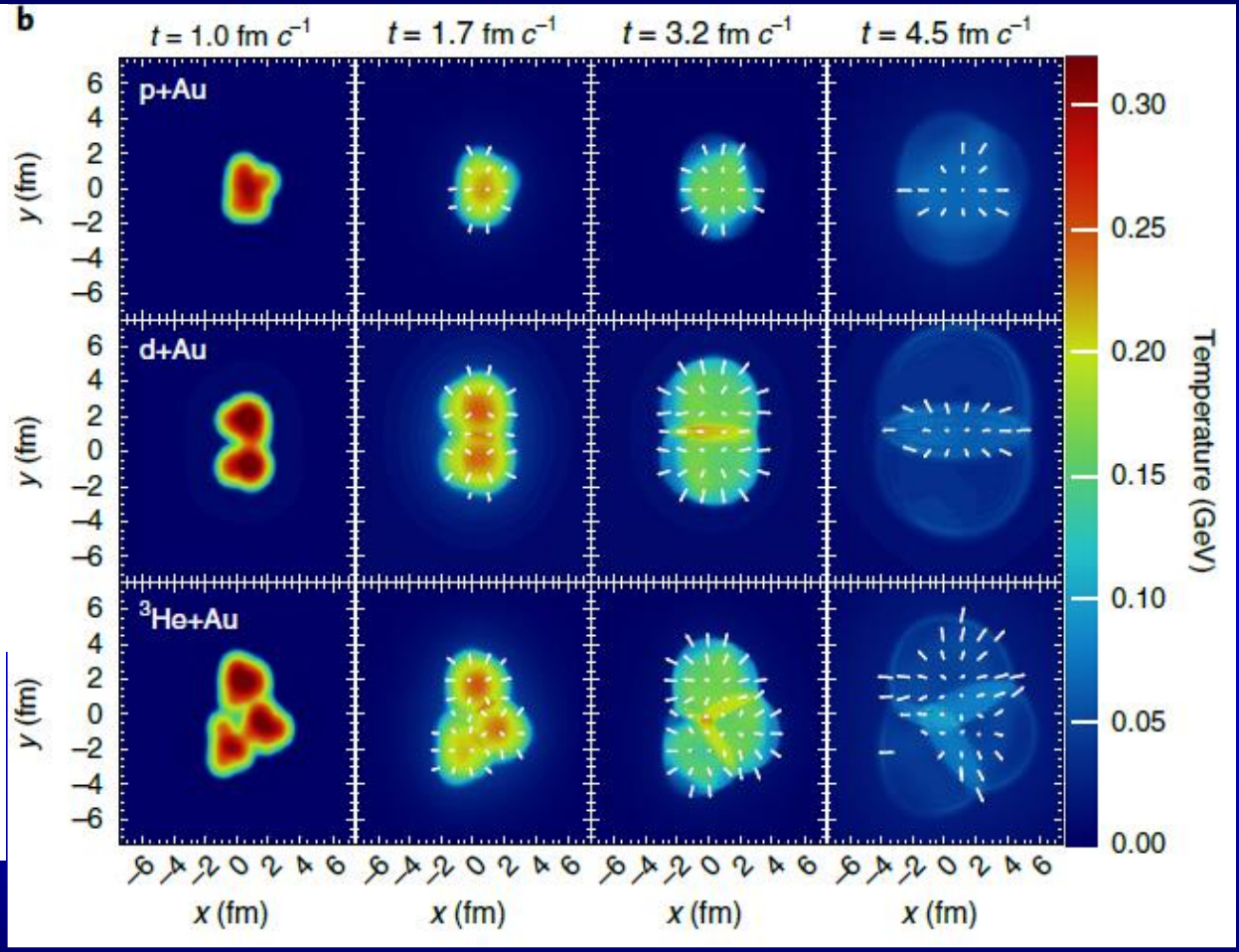
GEOMETRY SCAN: 3 DIFFERENT SHAPES
Is it hydrodynamics?



$$\varepsilon_2^{p+\mathrm{Au}} < \varepsilon_2^{d+\mathrm{Au}} \approx \varepsilon_2^{^3\mathrm{He}+\mathrm{Au}}$$

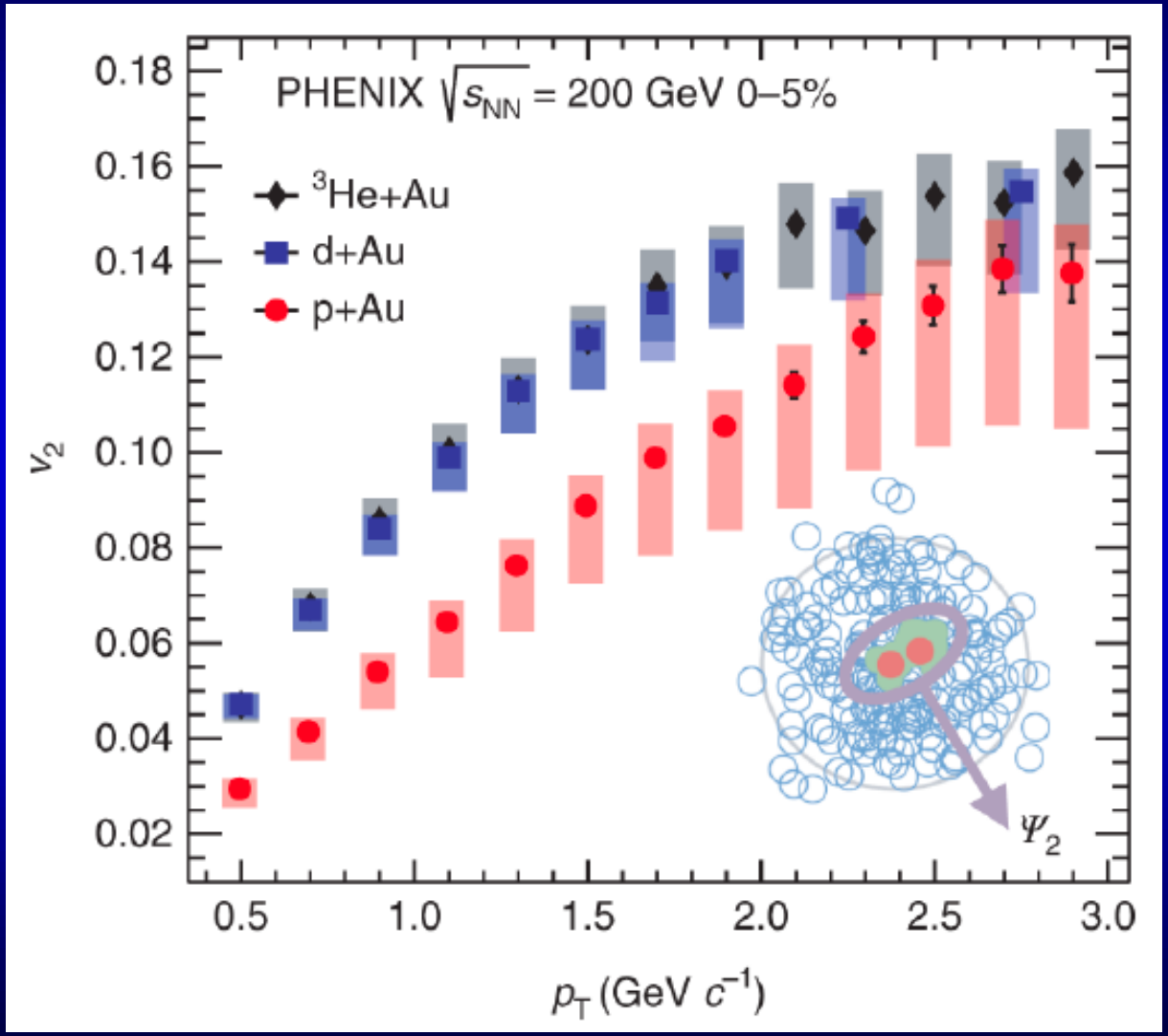
$$\varepsilon_3^{p+\mathrm{Au}} \approx \varepsilon_3^{d+\mathrm{Au}} < \varepsilon_3^{^3\mathrm{He}+\mathrm{Au}}$$

$$\varepsilon_n = \frac{\sqrt{\langle r^n \cos(n\phi)\rangle^2 + \langle r^n \sin(n\phi)\rangle^2}}{\langle r^n \rangle}$$



Hydrodynamics (SONIC, lQCD EoS, 1+2d):
Different initial geometry /energy deposition translated by ∇p
to *different* final state momentum space correlations

GEOMETRY SCAN: v_2 RESULTS
Is it hydrodynamics?



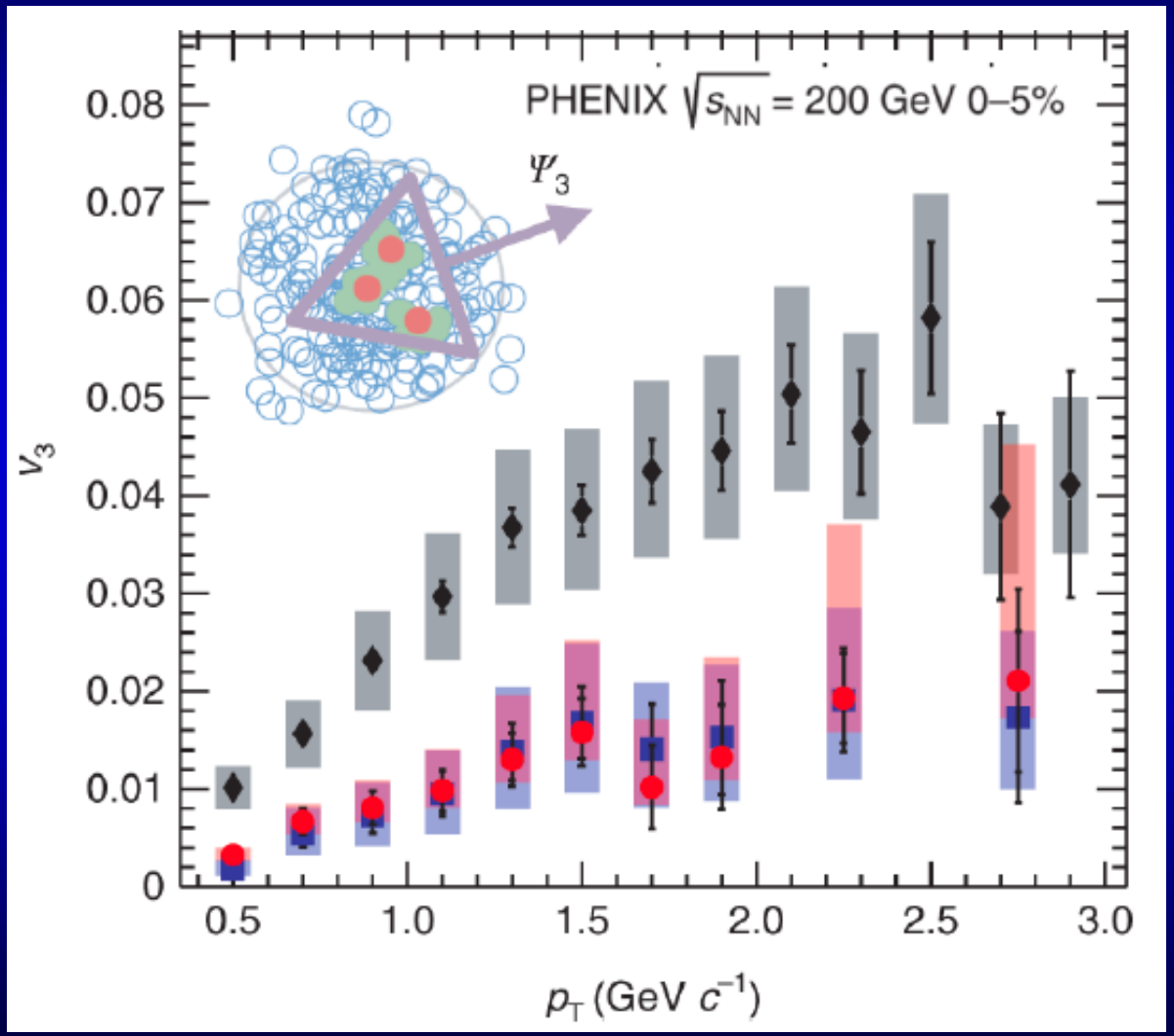
$$\varepsilon_2^{p+\mathrm{Au}} < \varepsilon_2^{d+\mathrm{Au}} \approx \varepsilon_2^{^3\mathrm{He}+\mathrm{Au}}$$

$$v_2^{p+\mathrm{Au}} < v_2^{d+\mathrm{Au}} \approx v_2^{^3\mathrm{He}+\mathrm{Au}}$$

v_2 RESULTS CONSISTENT WITH HYDRO ORDERING

https://www.nature.com/articles/s41567-018-0360-0

GEOMETRY SCAN: v_3 RESULTS
Is it hydrodynamics?



$$\varepsilon_3^{p+\mathrm{Au}} \approx \varepsilon_3^{d+\mathrm{Au}} < \varepsilon_3^{^3\mathrm{He}+\mathrm{Au}}$$

$$v_3^{p+\mathrm{Au}} \approx v_3^{d+\mathrm{Au}} < v_3^{^3\mathrm{He}+\mathrm{Au}}$$

v_3 RESULTS CONSISTENT WITH HYDRO ORDERING

https://www.nature.com/articles/s41567-018-0360-0

GEOMETRY SCAN: v_2 RESULTS
Is it hydrodynamics?

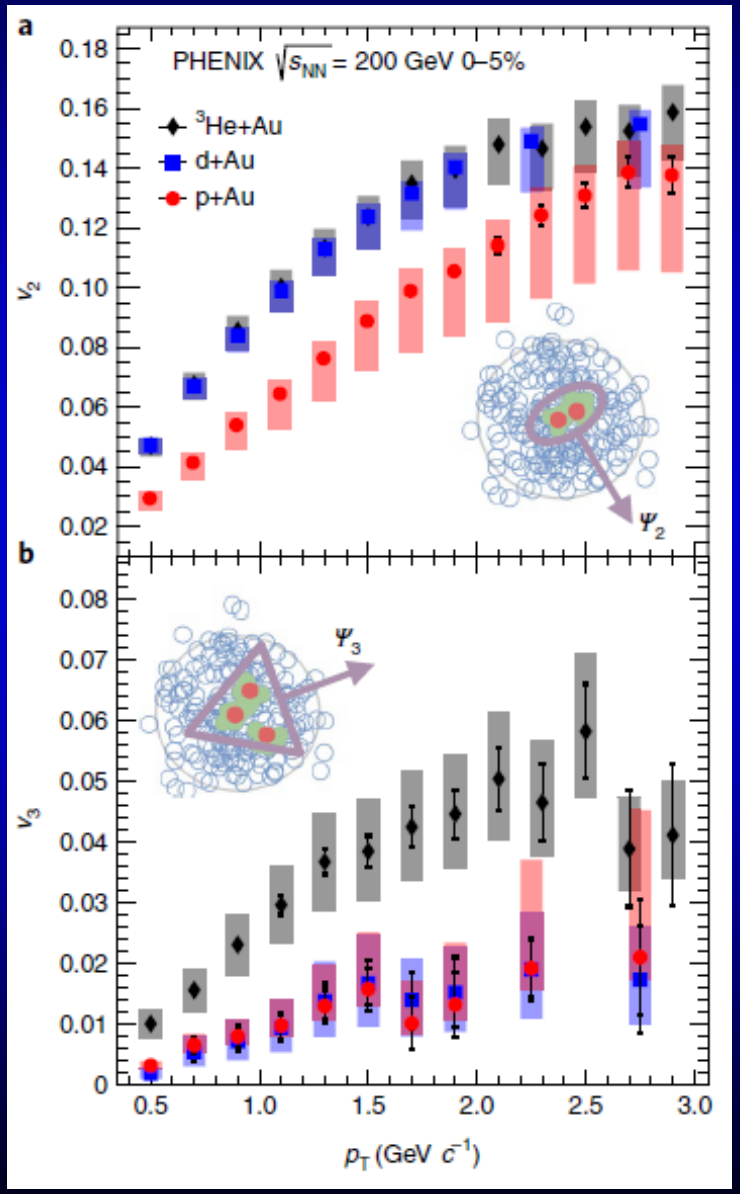
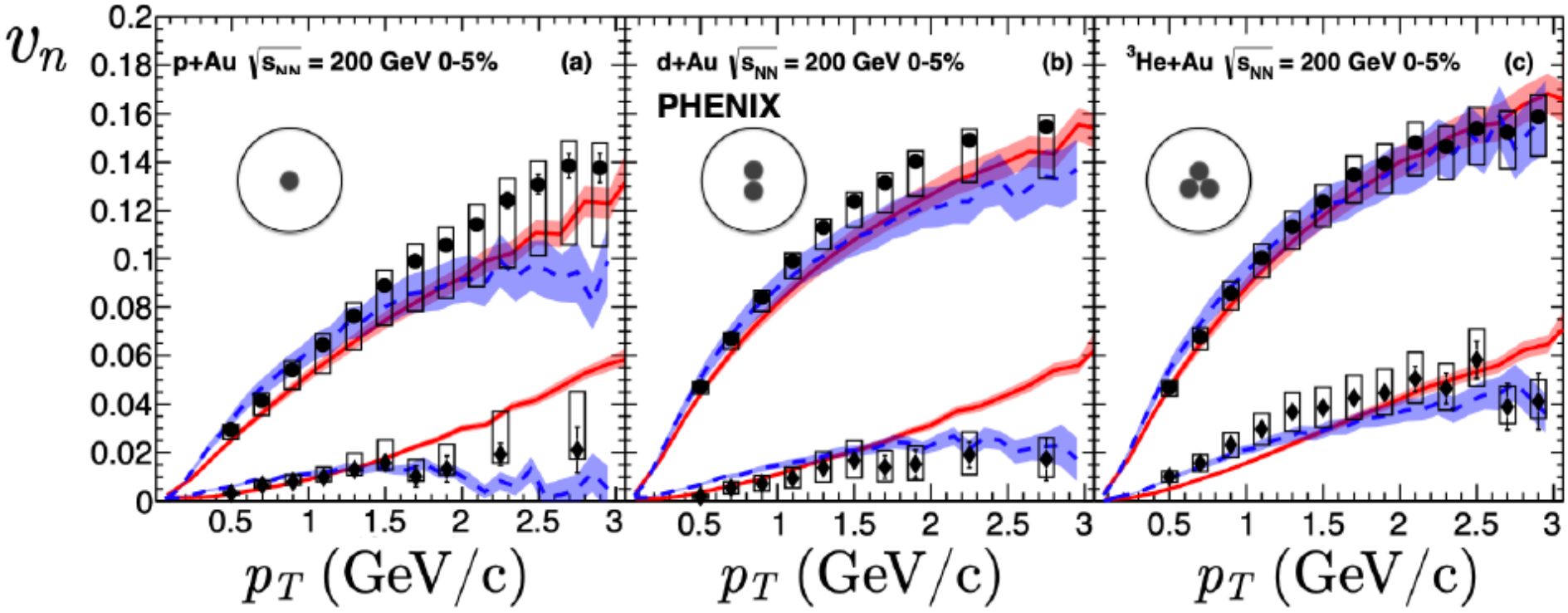


Fig. 2 | Measured $v_n(p_T)$ in three collision systems. a, Measurements of $v_2(p_T)$ in the 0–5% most central p+Au, d+Au and ^{3}He+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. A d+Au event from a MC Glauber model is inset with the elliptic symmetry plane angle, ψ_2, depicted. **b**, Measurements of $v_3(p_T)$ in the 0–5% most central p+Au, d+Au and ^{3}He+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. A ^{3}He+Au event from a MC Glauber model is inset with the triangular symmetry plane angle, ψ_3, depicted. Each point in **a**,**b** represents an average over p_T bins of width 0.2 GeV c^{-1} to 0.5 GeV c^{-1}. The vertical lines (boxes) represent one standard deviation statistical (systematic) uncertainties.

v_2, v_3 Results CLEARLY NOT inconsistent with hydro ordering

What about quantitative tests and/or alternative explanations?

GEOMETRY SCAN VS HYDRO PREDICTIONS

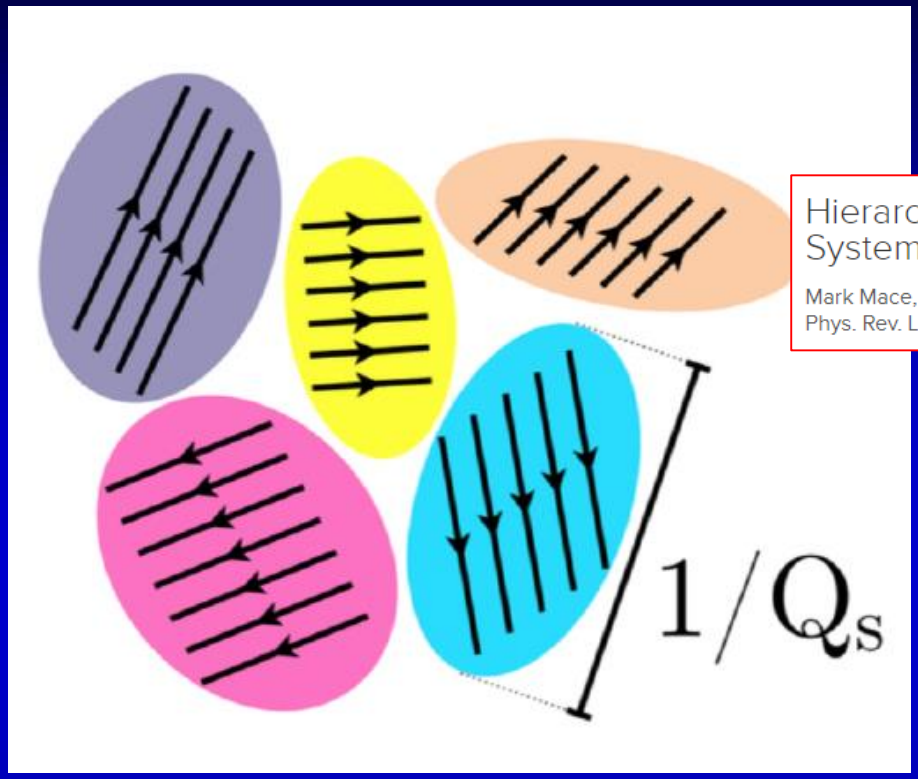


- v_2 Data
- v_3 Data
- v_n SONIC *Eur. Phys. J. C 75, 15 (2015)*
- v_n iEBE-VISHNU *PRC 95, 014906 (2017)*

- Both use η/s=0.08, MC Glauber initial conditions, 2+1D viscous hydrodynamic evolution
- Different hadronic rescattering packages

v_2, v_3 : Data within syst errors quantitatively consistent with *2 different* detailed hydro model predictions: SONIC/iEBE-VISHNU

ALTERNATIVE EXPLANATION: SATURATION?



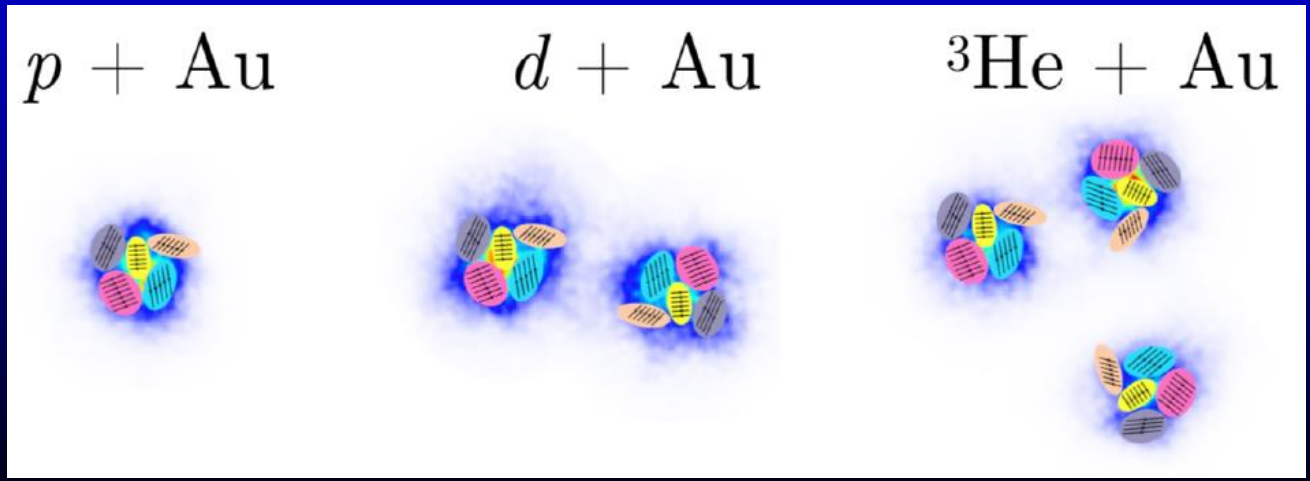
https://arxiv.org/abs/1805.09342 (MSTV)

Hierarchy of Azimuthal Anisotropy Harmonics in Collisions of Small Systems from the Color Glass Condensate

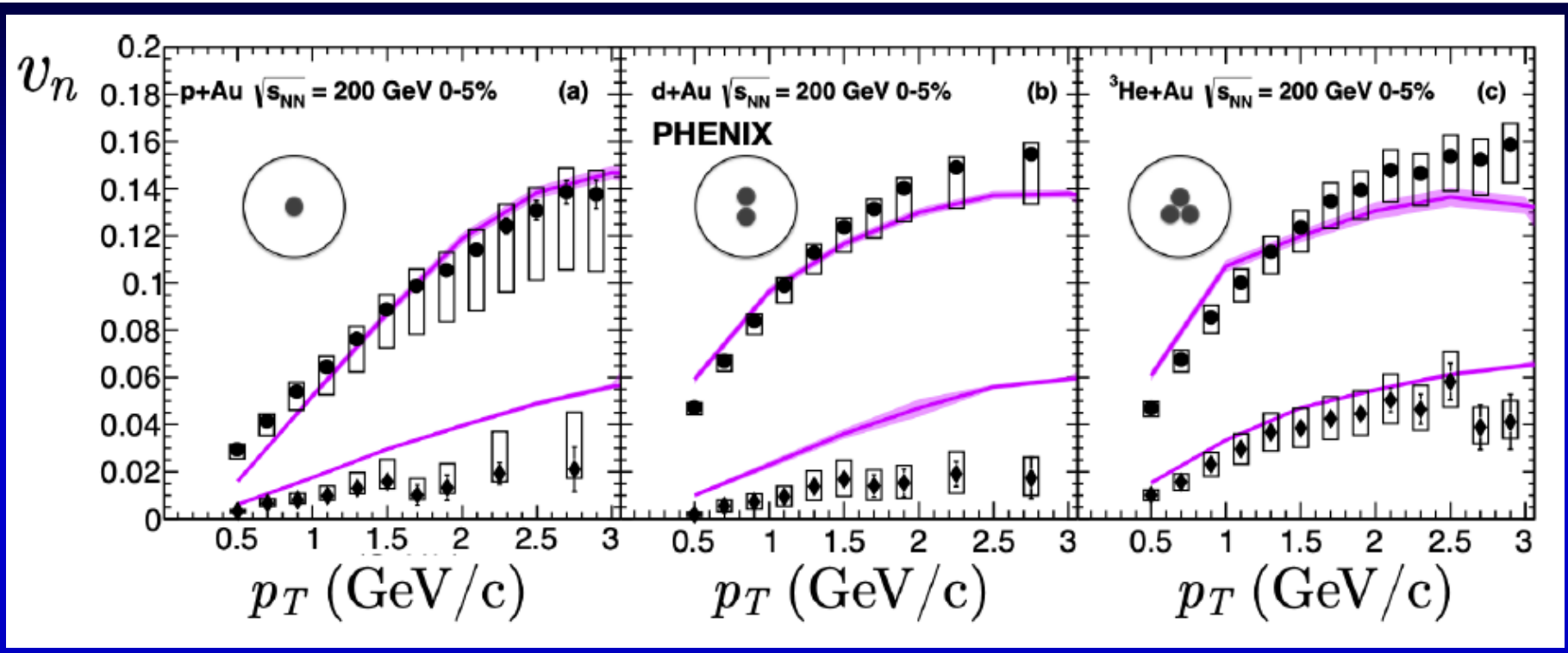
Mark Mace, Vladimir V. Skokov, Prithwish Tribedy, and Raju Venugopalan
Phys. Rev. Lett. **121**, 052301 – Published 31 July 2018

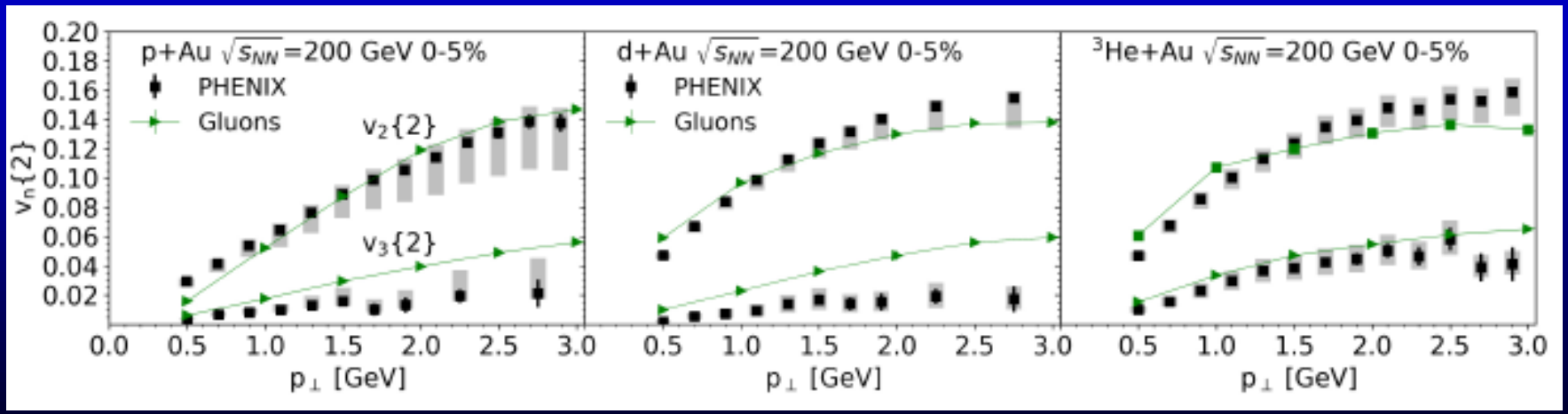
$$v_n^{p+\mathrm{Au}} > v_n^{d+\mathrm{Au}} > v_n^{^3\mathrm{He}+\mathrm{Au}}$$

Domains not resolved individually
Q_s (deuteron) > Q_s (proton) (Q_s = saturation scale)

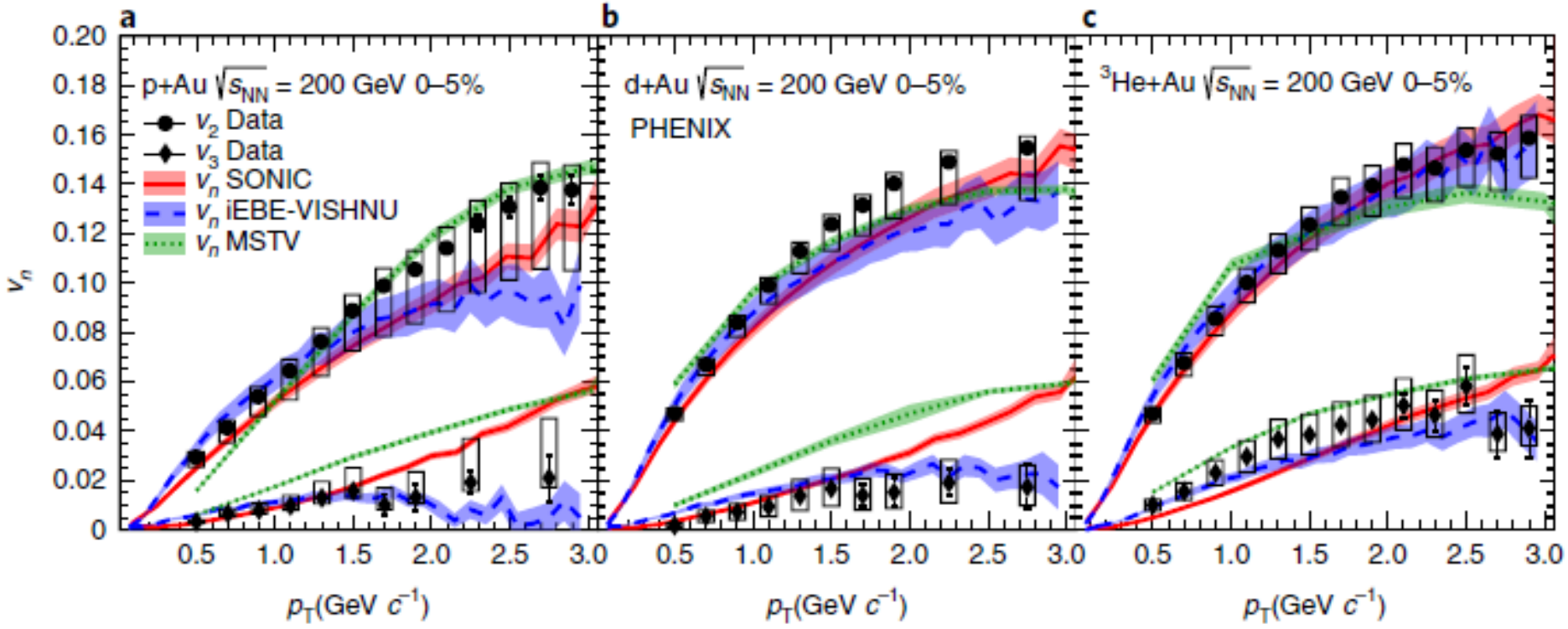


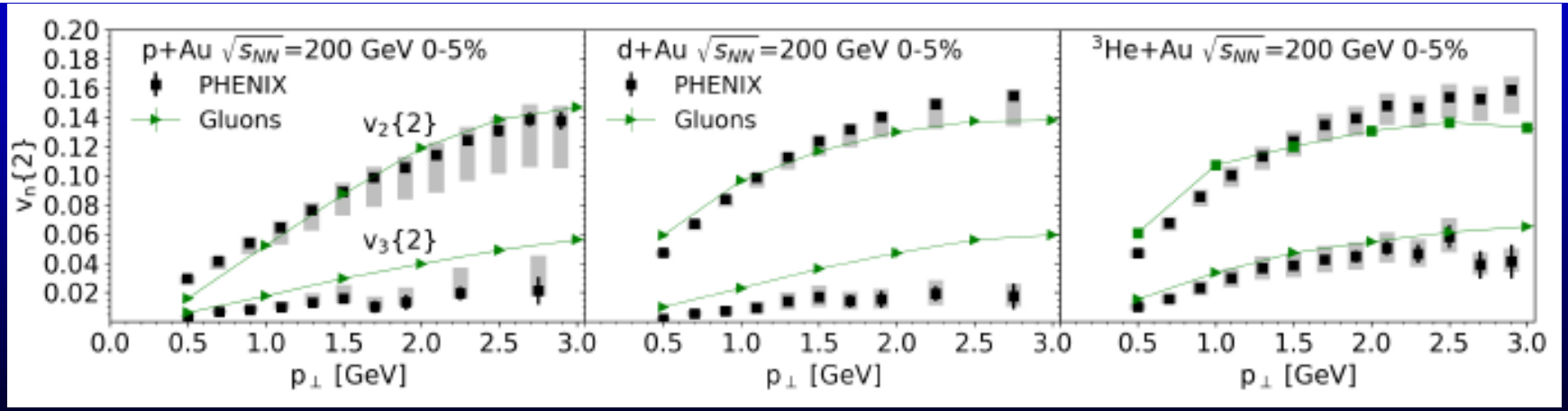
GEOMETRY SCAN VS MSTV CGC SATURATION





GEOMETRY SCAN VS GLUON SATURATION

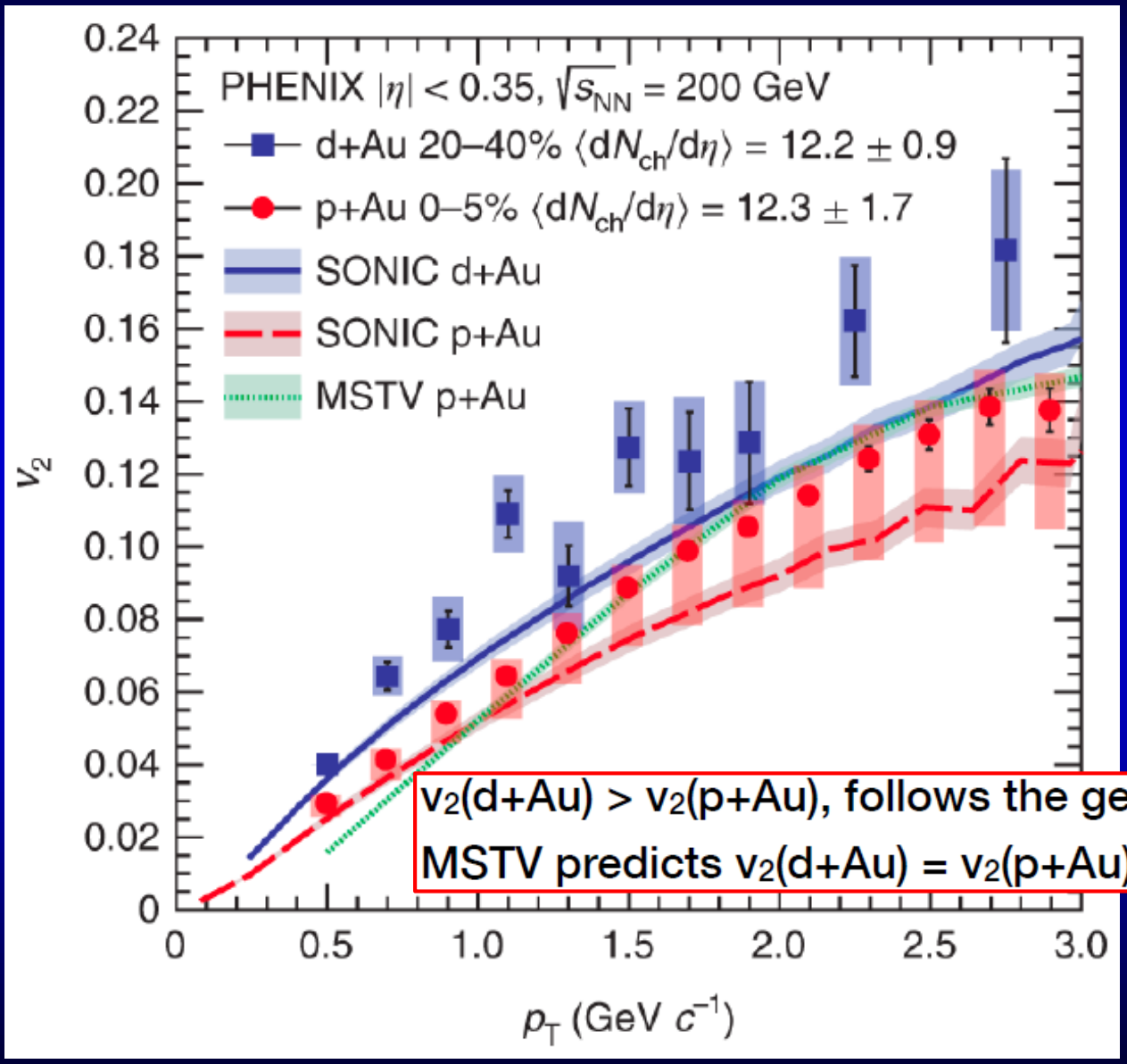




MSTV – CGC model misses geometry in $v_3(p_t)$

https://arxiv.org/abs/1805.09342 (MSTV)

CROSS-CHECK ON MVST - CGC



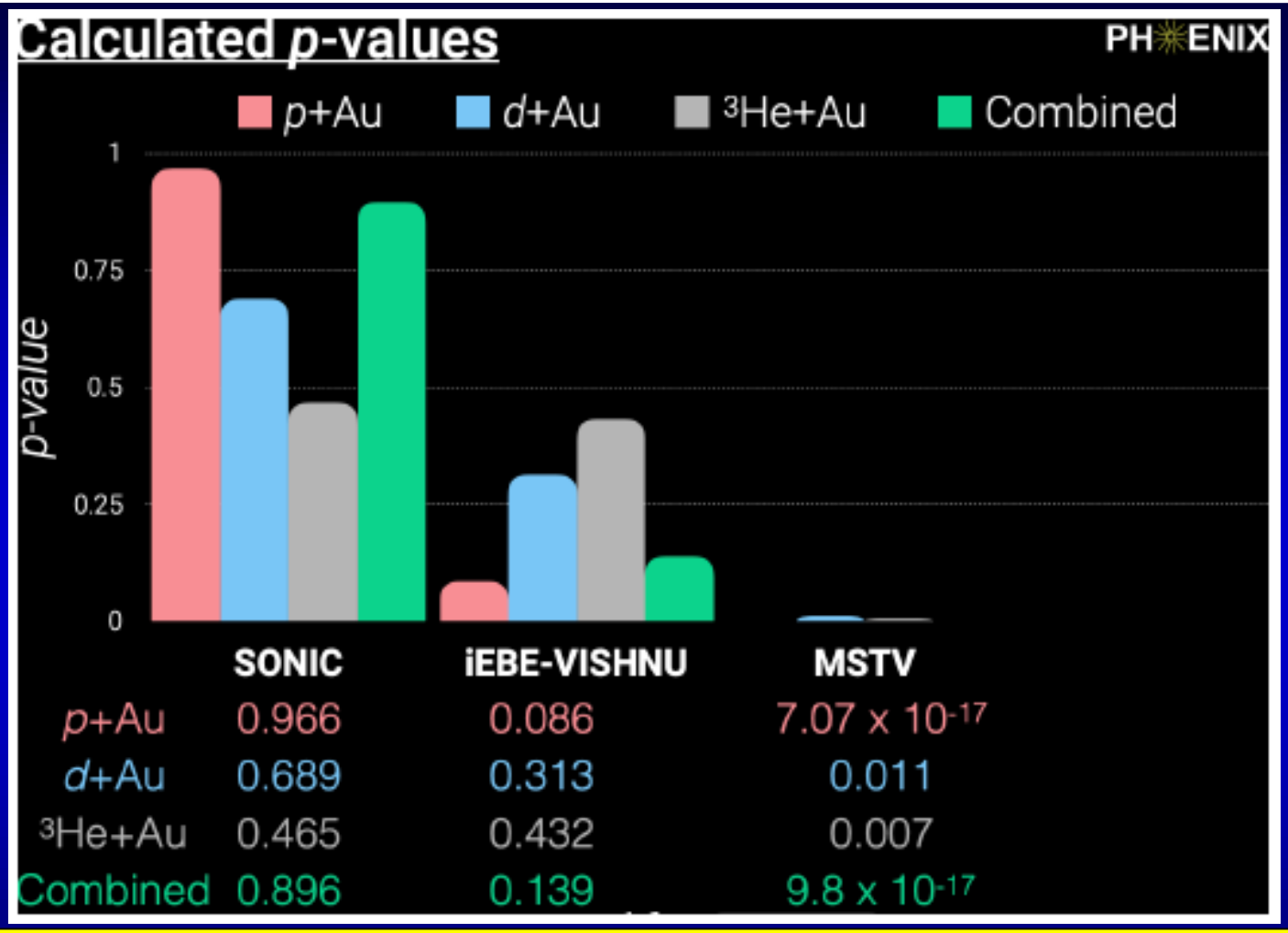
d+Au 20-40% $(dN/d\eta = 12.2 \pm 0.9)$
PRC 96, 064905 (2017)

p+Au 0-5% $(dN/d\eta = 12.3 \pm 1.7)$
PRC 95, 034910 (2017)

v_2(d+Au) > v_2(p+Au), follows the geometry

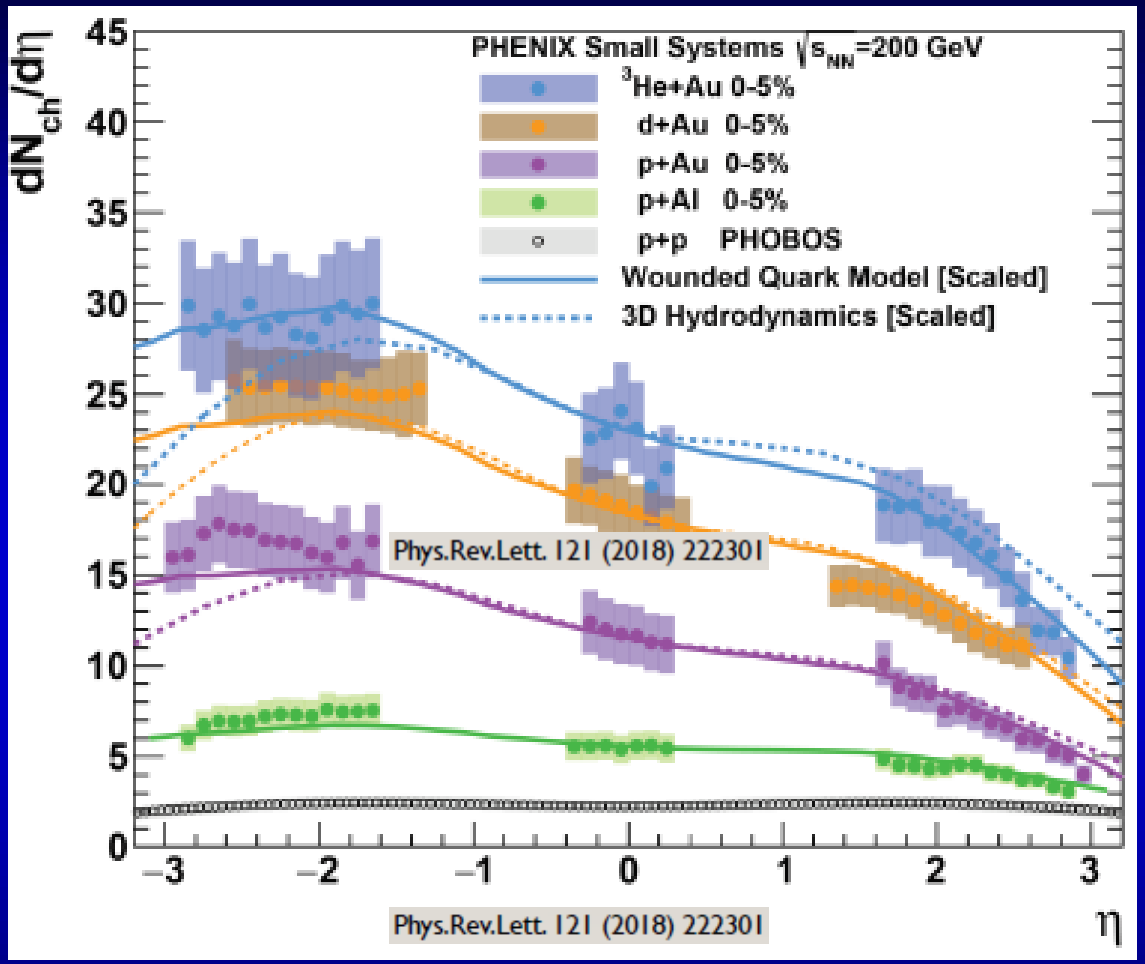
MSTV predicts v_2(d+Au) = v_2(p+Au) at same event multiplicity

SIGNIFICANCE ANALYSIS



p-value: probability that the model describes the data
Hydrodynamic models (SONIC, iEBE-VISHNU, lQCD EoS, 1+2d)
MSTV: Gluon saturation, Color Glass Condensate

FORWARD PARTICLE PRODUCTION



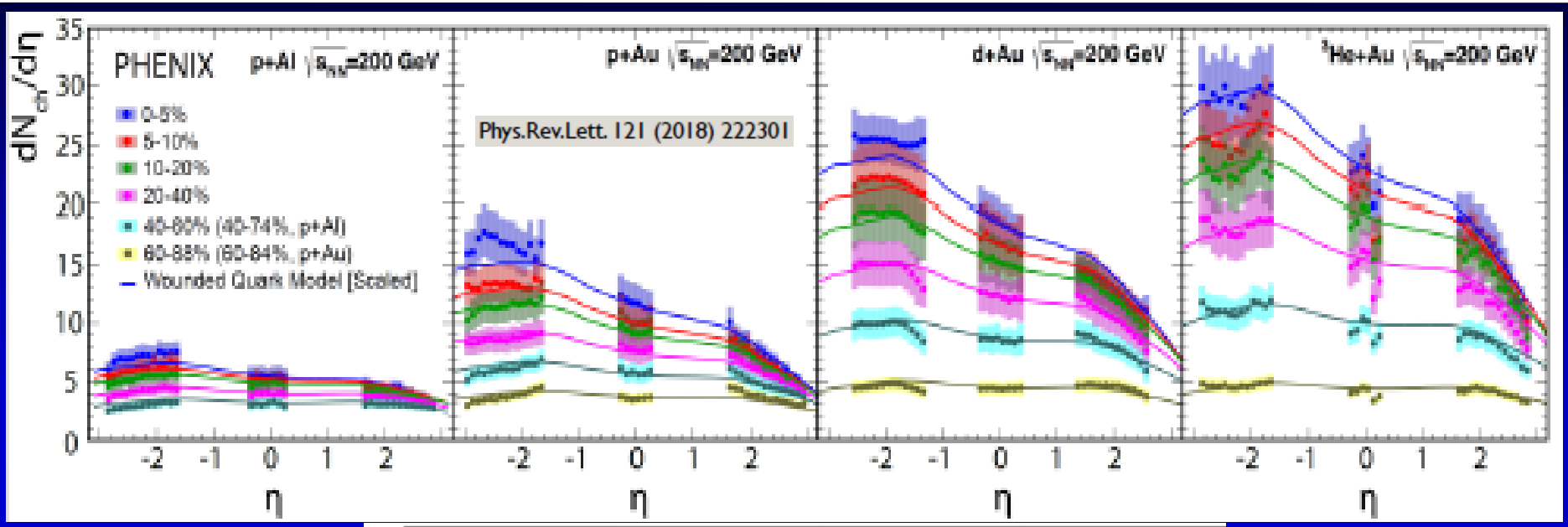
Wounded quark model (WQM) works for dn/dη

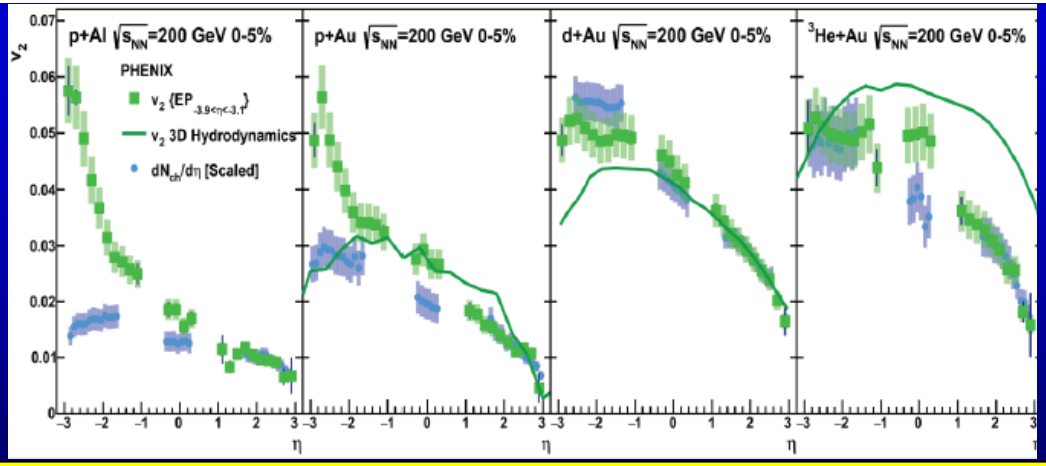
3d hydrodynamic models also describe qualitatively dn/dη

WQM: Barej, Bzdak, Gutowski, PRC 97 (2018) 034901

3d hydro: Bozek, Broniowski, PLB 739, 304 (2014)

DETAILES OF FORWARD PRODUCTION





Wounded quark model (WQM) OK for centrality of dn/dη

v_2(h) scales approximately with dn/dη

WQM: Barej, Bzdak, Gutowski, PRC 97 (2018) 034901

SUMMARY AND CONCLUSIONS

RHIC: versatility

Geometry and beam energy scan

PHENIX: Perfect fluid of sQGP, drop-by-drop in p/d/^{3}He+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

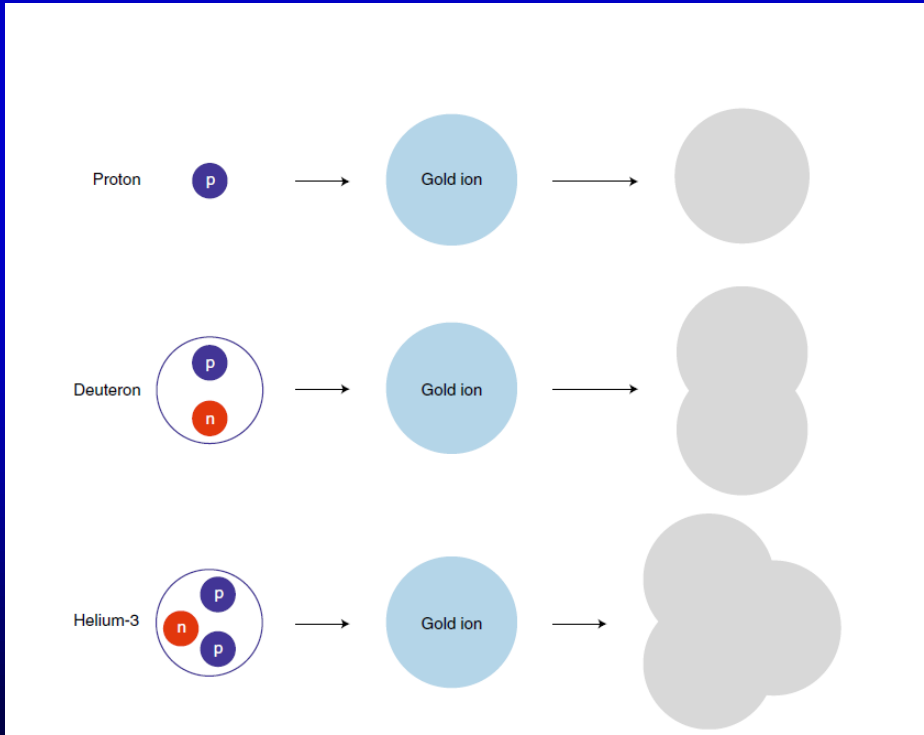
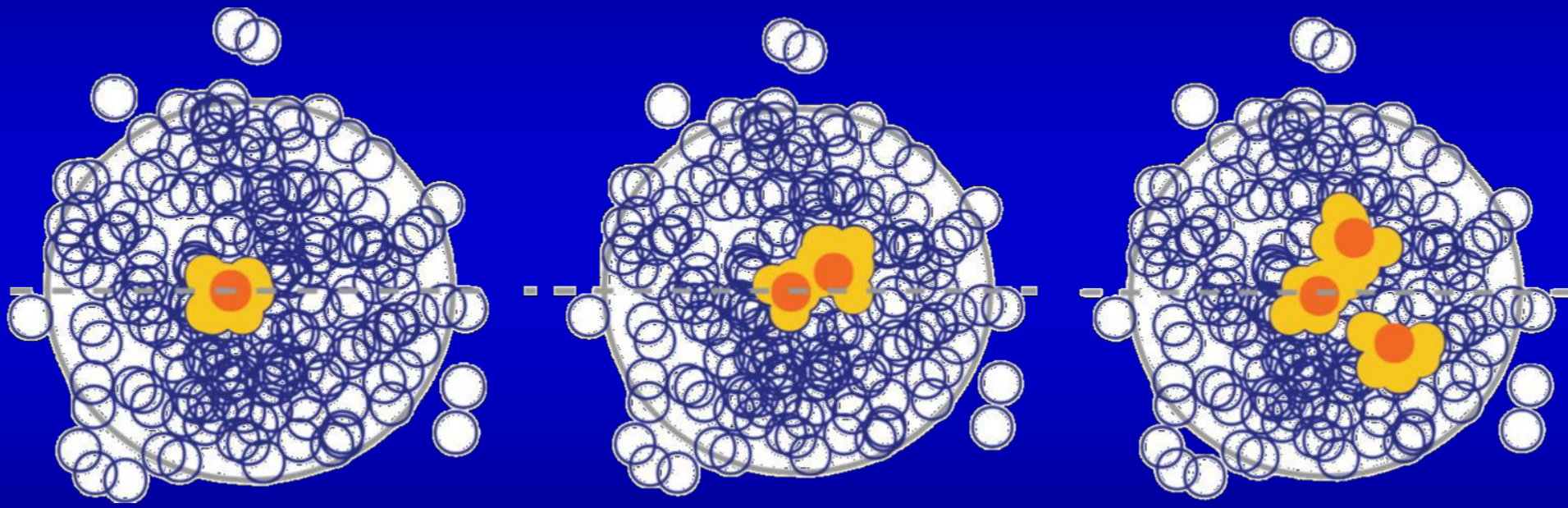


Fig. 1 | Quark-gluon plasma. Adding the plasma drop by drop by using proton-gold (top), deuteron-gold (middle) and helium-3-gold (bottom) collisions in the hydrodynamics picture.

Thank you for your attention!

Questions?



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