Measurement of azimuthal anisotropy of light nuclei produced in heavy-ion collisions at RHIC

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Outline

- **Introduction & motivation**
- **STAR experiment at RHIC**
- **Results**
- **Summary**

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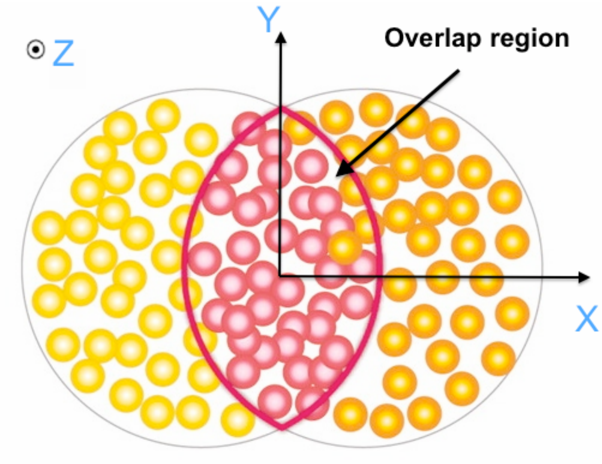
Azimuthal anisotropy

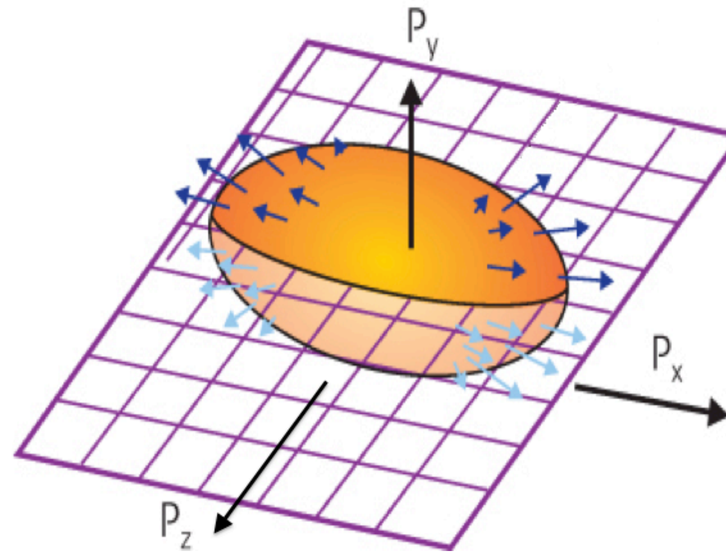


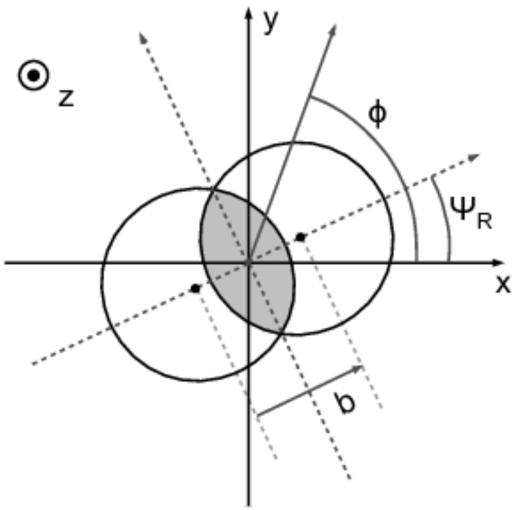
Interactions

↓

Pressure (P)

$$y > x \longrightarrow \frac{\partial P}{\partial x} > \frac{\partial P}{\partial y}$$





Azimuthal distribution of produced particles can be described as a Fourier series. The second order coefficient,

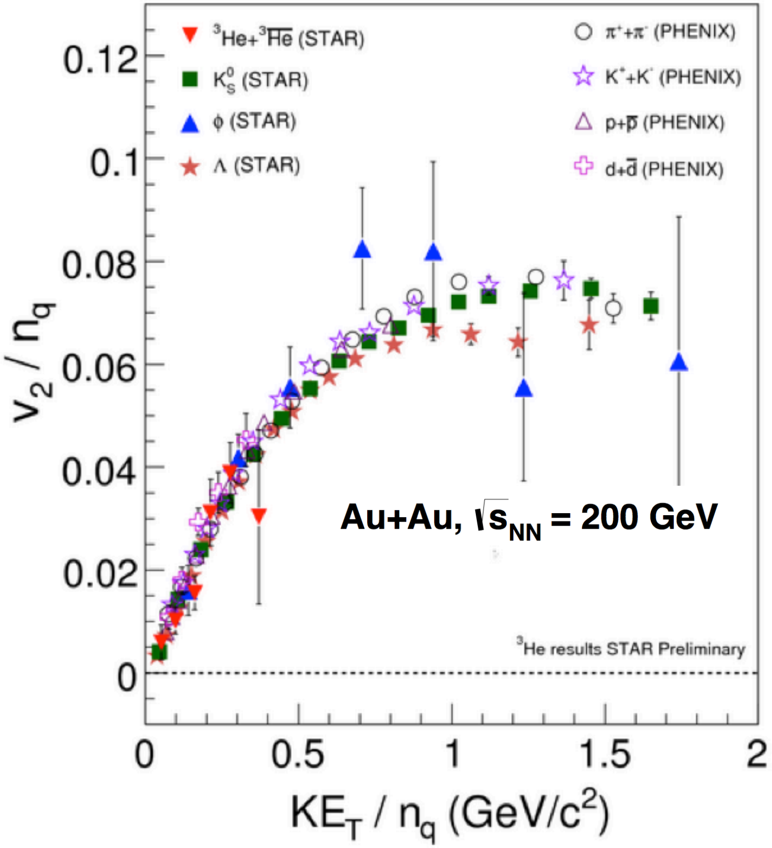
$$v_2 = \langle \cos(2(\phi - \psi_R)) \rangle = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle$$

- Sensitive to early times in the evolution of the system

An estimate of ψ_R, namely Event Plane (ψ_2), is calculated using produced particles in mid-rapidity.

A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C 58, 1671 (1998)

Motivation



✓ hadron v_2 show constituent quark (NCQ) scaling.

➢ Nuclei are expected to form at a later stage due to their low binding energy

→ *Can we expect mass number scaling of nuclei v_2 ?*

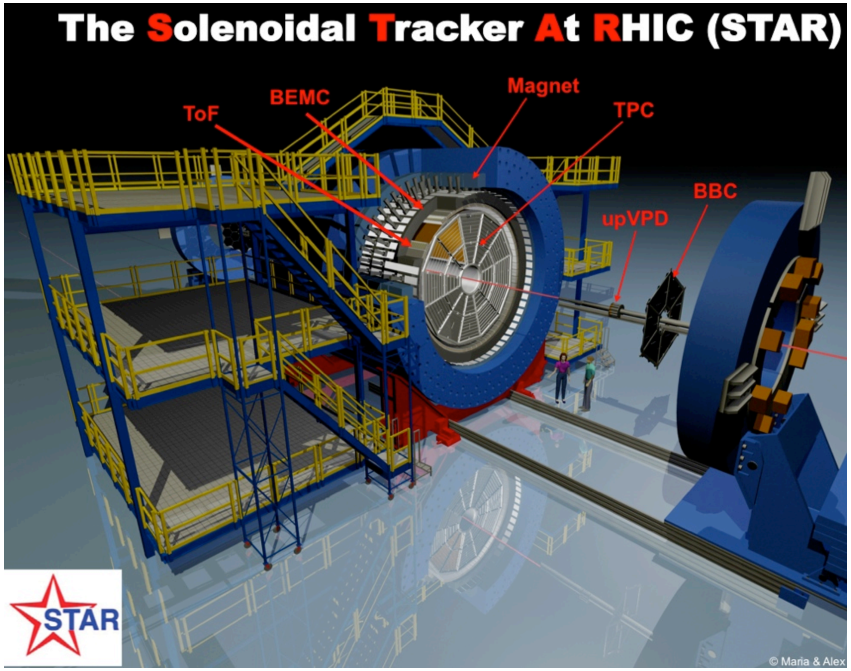
→ *How does nuclei and anti-nuclei v_2 compare?*

→ *Is there any centrality dependence of nuclei v_2 ?*

J. I. Kapusta, Phys. Rev. C 21, 1301 (1980)
R. Scheibl, U. Heinz, Phys. Rev. C 59, 1585 (1999)
D. Molnár, S. A. Voloshin, Phys. Rev. Lett. 91, 92301 (2003)

Figure ref: Phys. Rev. C 75, 054906 (2007), Phys. Rev. Lett. 99, 112301 (2007), Phys. Rev. Lett. 98, 162301 (2007)

The STAR experiment



1. **Time Projection Chamber (TPC)**
   pseudo-rapidity window: $-1.0 < \eta < 1.0$
   full azimuthal coverage.
   M Anderson *et al.* , NIM, A 499, 624 (2003)

2. **Time of Flight (ToF)**
   pseudo-rapidity window: $-0.9 < \eta < 0.9$
   full azimuthal coverage.
   W. J. Llope *et al.* , NIM, B 241, 306 (2005)

Using TPC and ToF *π, K, p* can be identified up to p_T ~3.0 GeV/c.

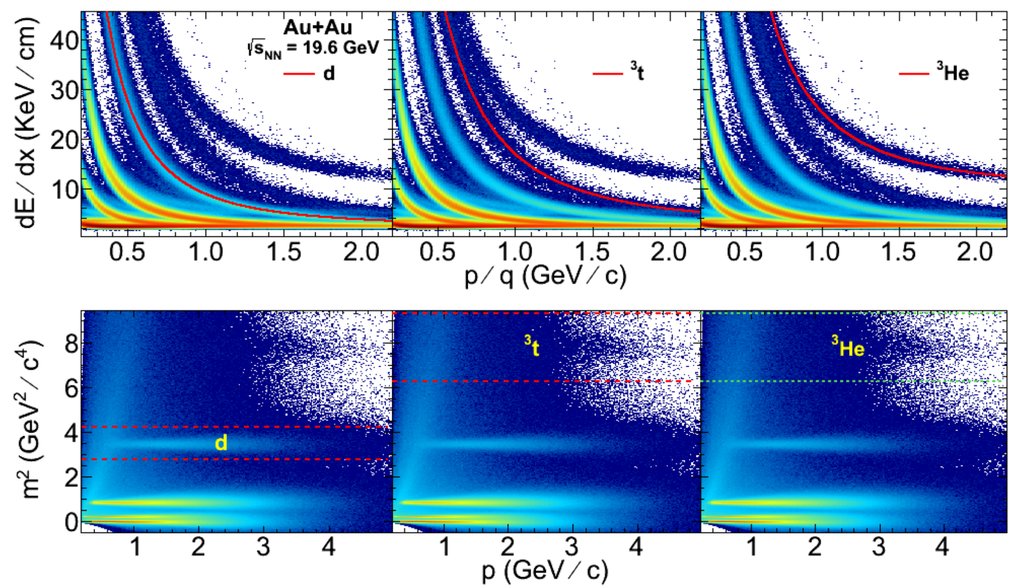
Phys. Rev. C 88, 014902 (2013)

Light nuclei identification using TPC

d, dbar, triton: p_T ~1.0 GeV/c, and ^{3}He up to 4.5 GeV/c.

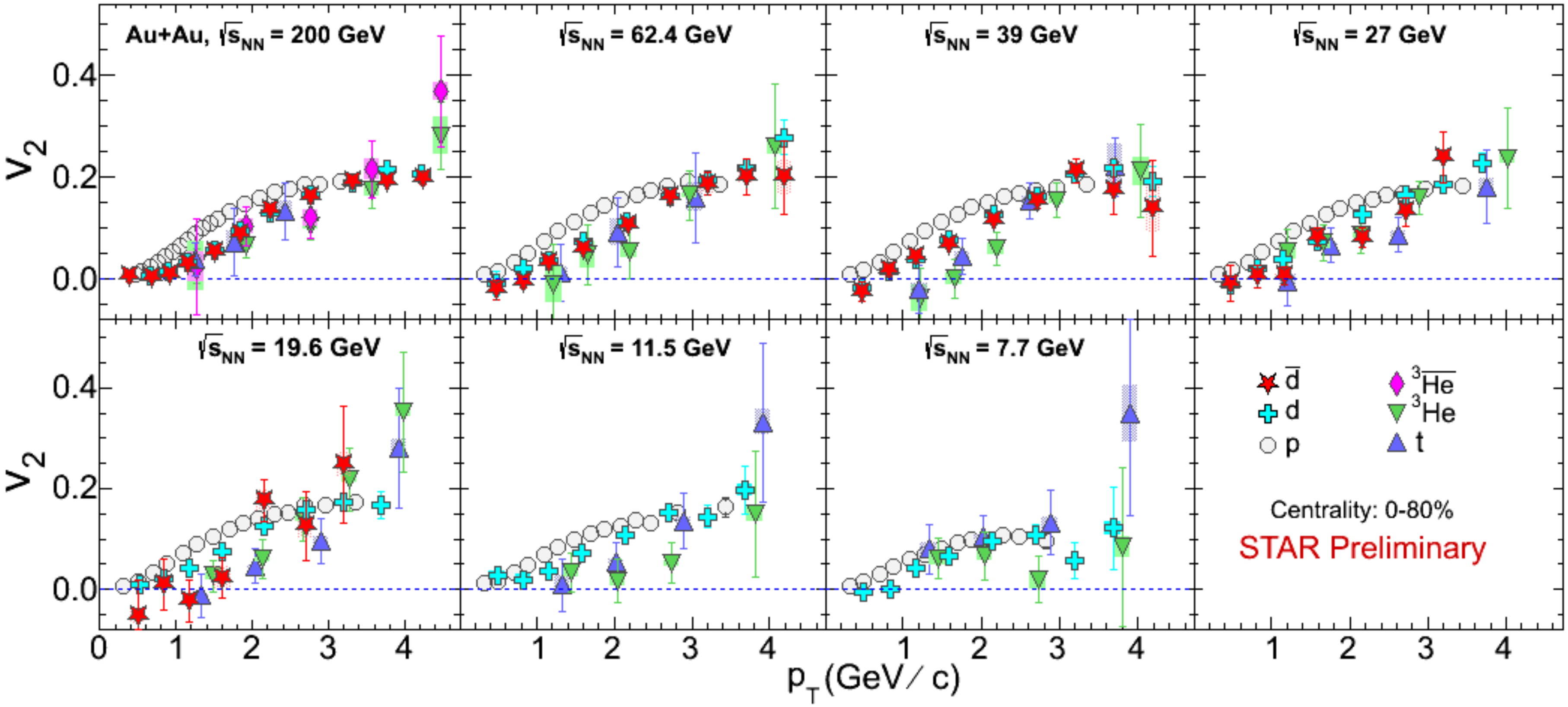
Light nuclei identification using ToF

d, dbar, triton: p_T ~4.0 GeV/c.



Theoretical dE/dx values: H. Bichsel, NIM, A 562, 154 (2006)

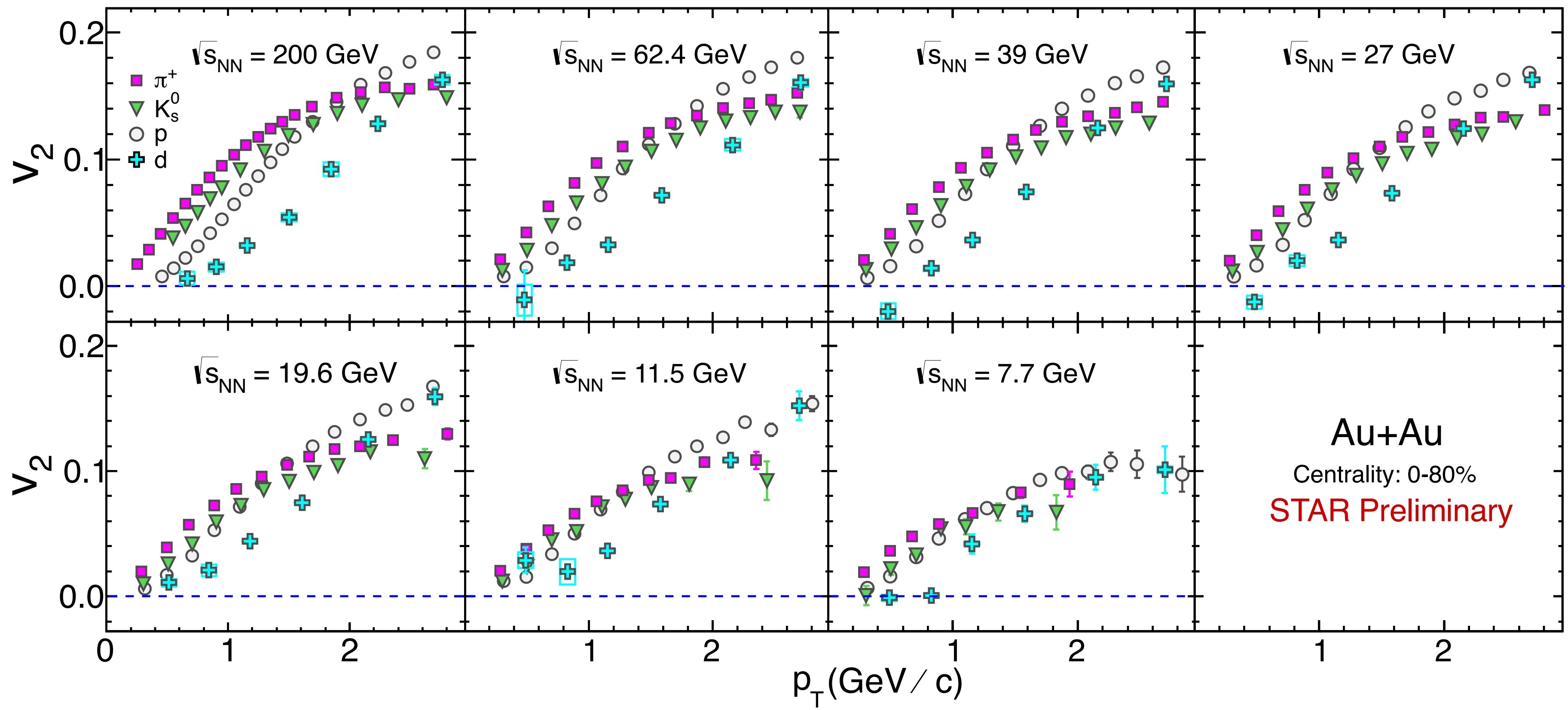
Measurement of nuclei v_2



- ✓ Elliptic flow of *d*, *$\bar{d}$*, *t*, *^3He*, *$^3\overline{He}$* measured at mid-rapidity.
- ✓ η sub-event plane method was used with η-gap = 0.1
- ✓ some particles not plotted at lower beam energies due to statistical limitations

proton v_2 from Phys. Rev. C 88, 014902 (2013)

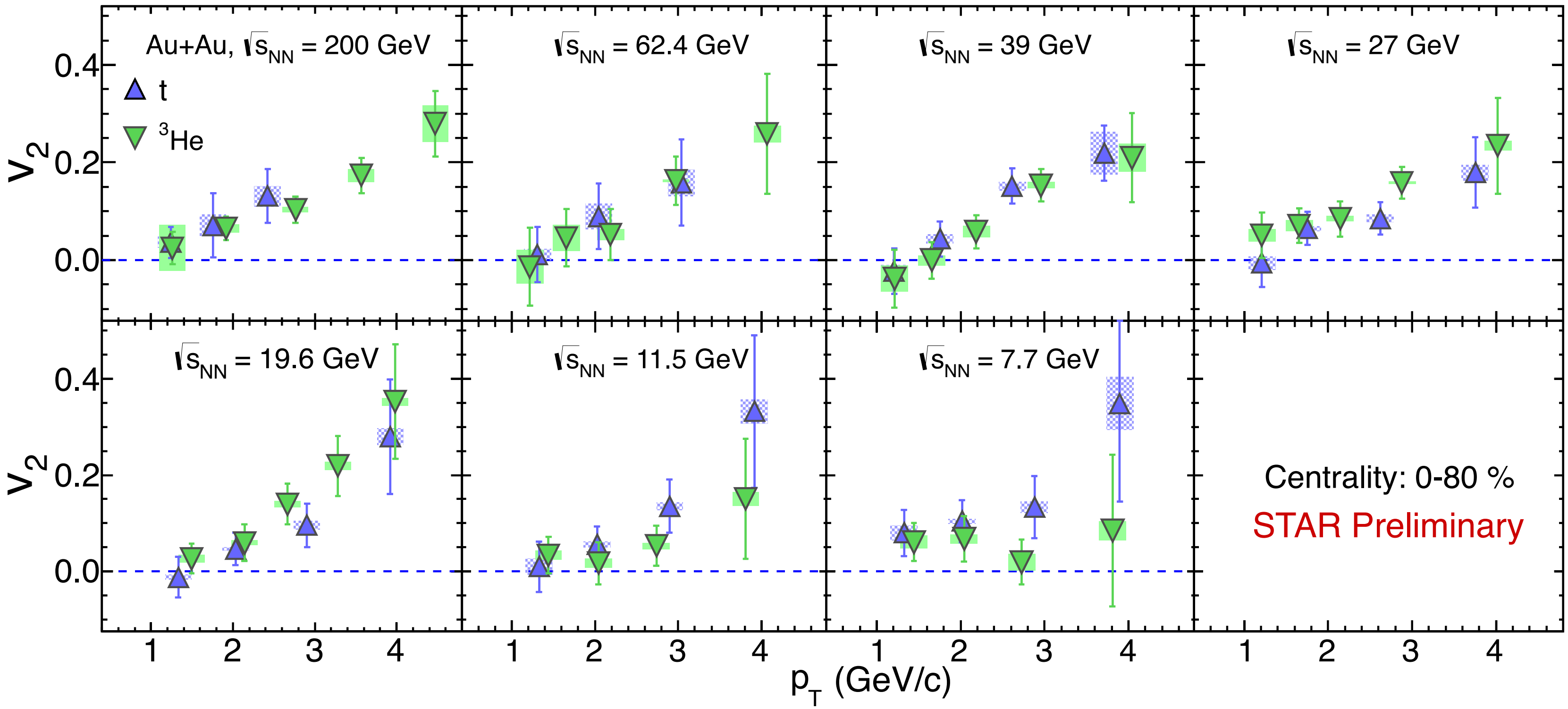
Mass ordering of v_2



→ *Nuclei v_2 shows mass ordering at low p_T similar to hadrons*

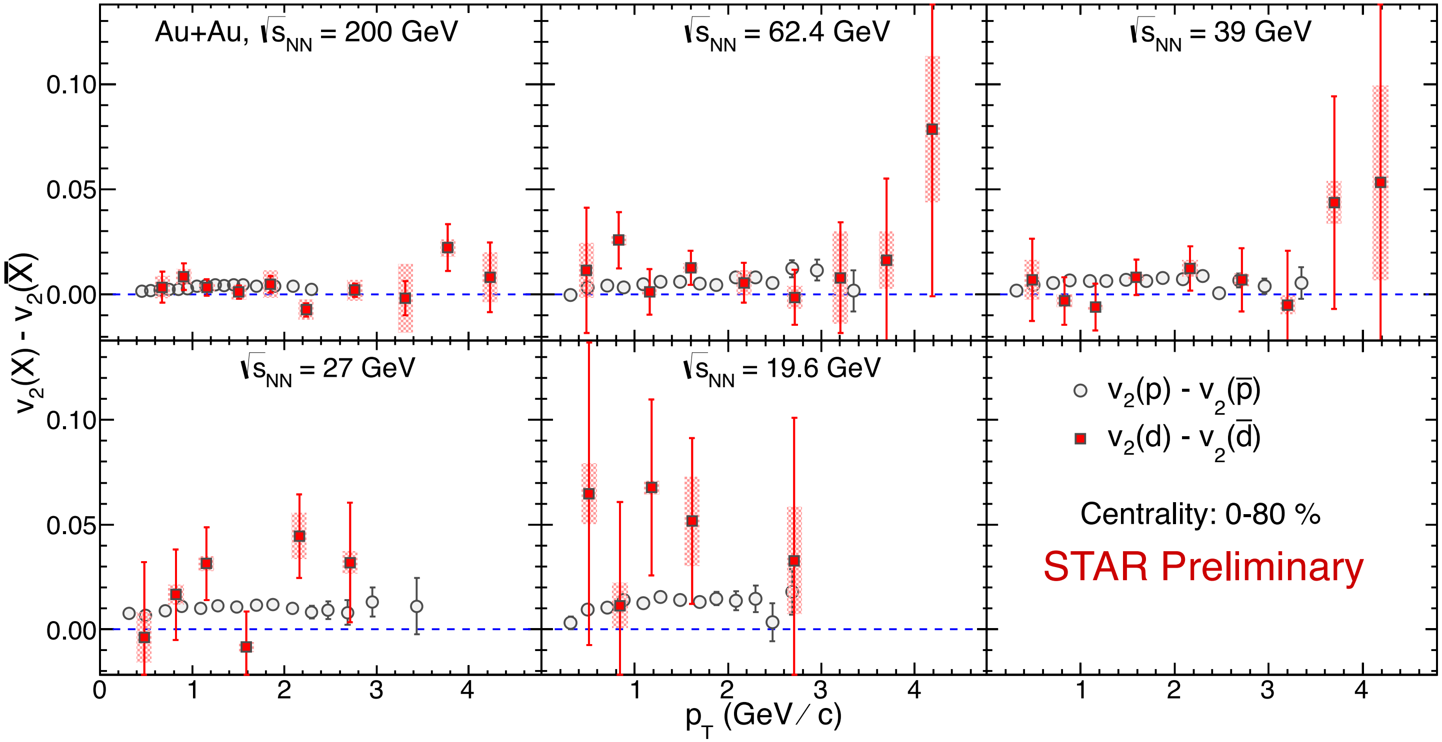
hadron v_2 from Phys. Rev. C 88, 014902 (2013)

v_2 of triton (t) and ^3He



→ *v_2 of t and ^3He are of similar magnitude (within uncertainty)*

v_2 of particles and anti-particles

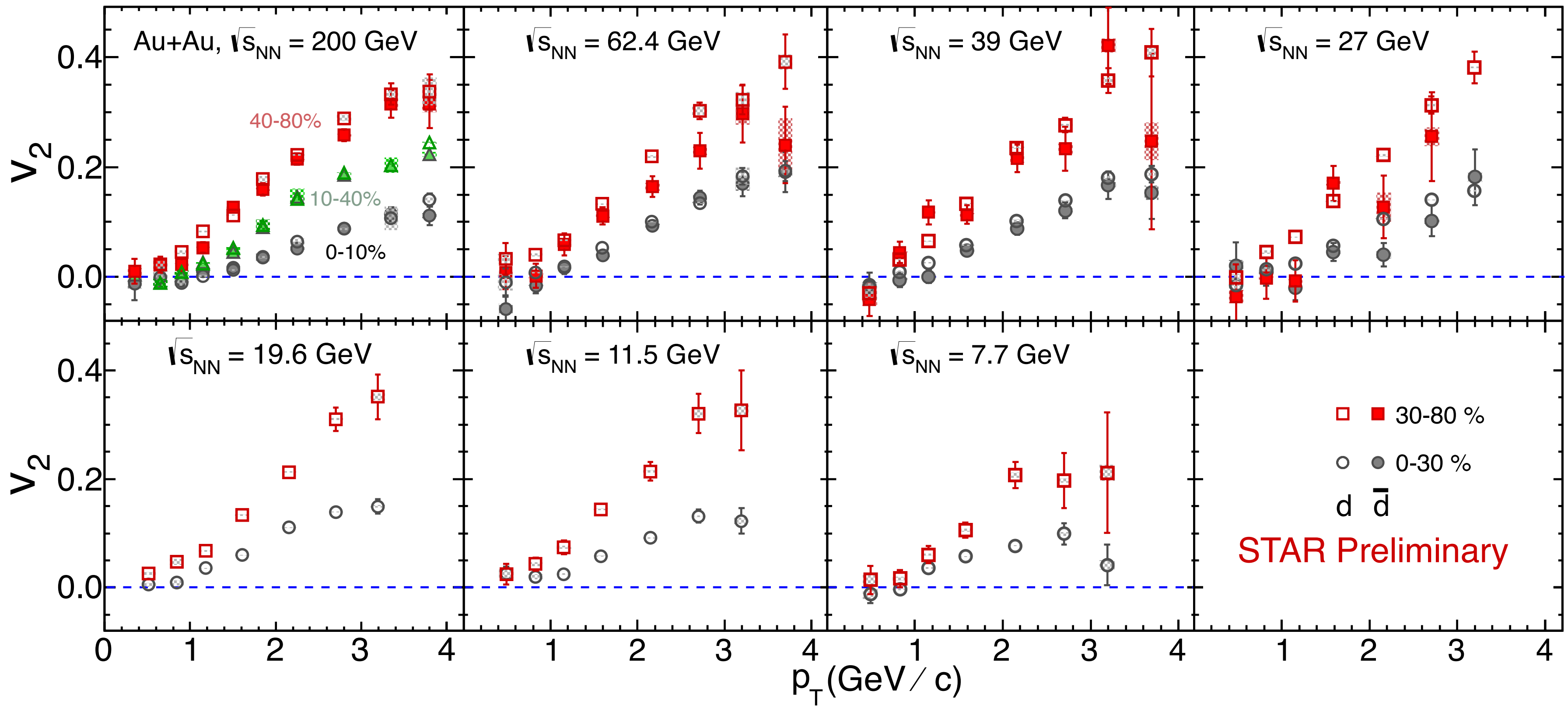


→ *Nuclei and anti-nuclei shows similar magnitude of difference in v_2*

→ *The v_2 difference between particle and anti-particle become larger as collision energy decreases, though errors are large at low energies.*

→ *Statistics for anti-nuclei at beam energies below 19.6 GeV is too low to check this consistency.*

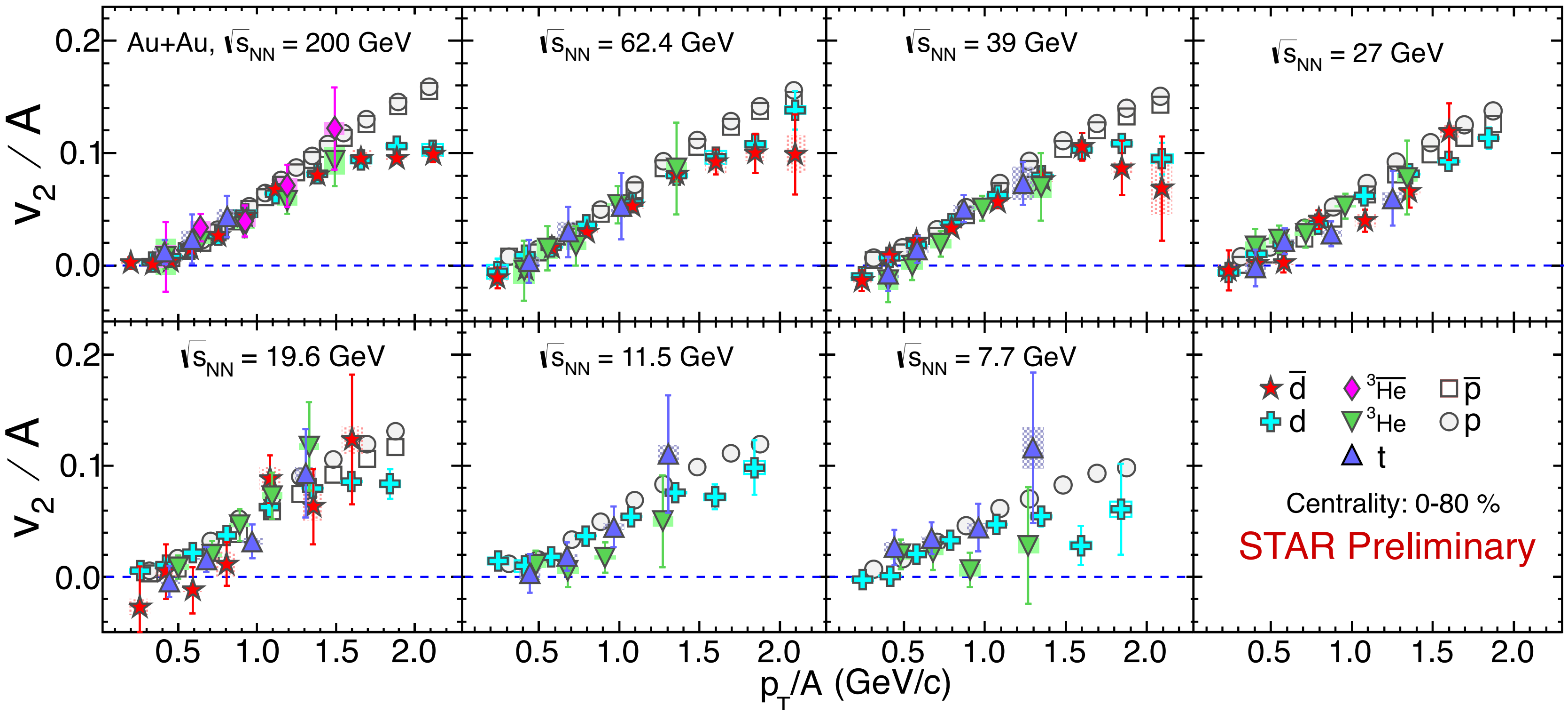
Centrality dependence of nuclei v_2



→ *Nuclei v_2 shows centrality dependence for all energies*

→ *antiparticles not shown where statistically limited*

Mass number scaling of v_2

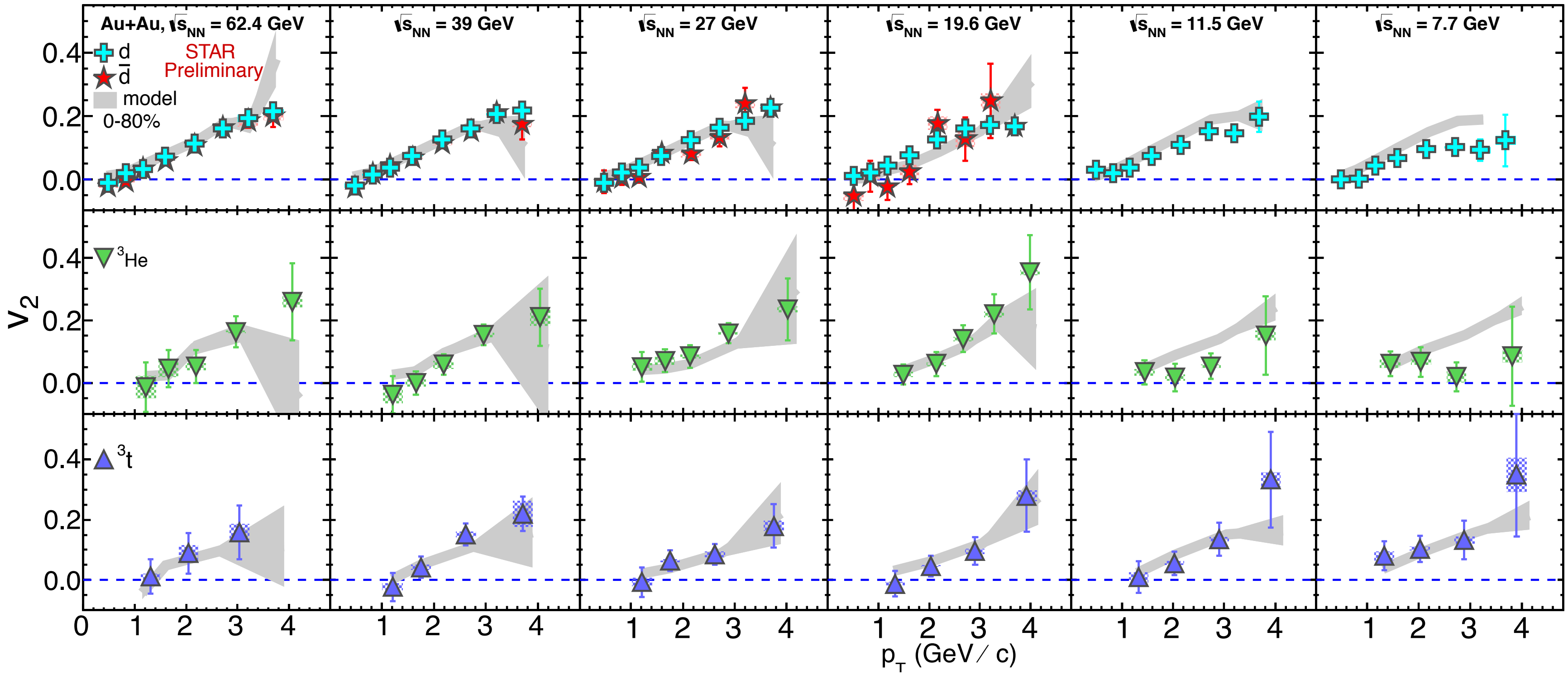


Nuclei v_2 show mass number scaling for p_T /A ~1.5 GeV/c for all beam energies

→ *Support the general idea that nuclei are formed by coalescence of nucleons*

(anti-) proton v_2 from Phys. Rev. C 88, 014902 (2013)

Coalescence model results



Coalescence model agrees with data

→ *Another indication of coalescence of nucleons to form nuclei*

- ✓ Probability for producing a nucleus is given by the overlap of nucleon phase-space distribution with the Wigner phase-space function of nucleons inside the nuclei.
- ✓ Nucleon phase space information used from a transport (AMPT) model.

R. Mattiello et al. Phys. Rev. Lett. 74, 2180 (1995), L. W. Chen et al. Phys. Rev. C 68, 017601 (2003)
AMPT model: Zi-Wei Lin et al. Phys. Rev. C 72, 064901 (2005)

Summary

(A) New Measurement presented:

✓ Energy ($\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27, 39, 62.4 and 200 GeV) and centrality dependence of nuclei v_2 presented.

(B) Observation and Physics conclusion:

1. Nuclei v_2 versus p_T shows a clear centrality dependence and mass ordering when compared with identified hadrons at all beam energies studied

→ *Mass ordering of v_2 occurs naturally according to hydrodynamic theory of heavy-ion collisions.*

2. Nuclei v_2 versus p_T shows mass number scaling up to p_T/A = 1.5 GeV/c

→ *Supports the physics picture of coalescence of nucleons as the dominant mechanism for light nuclei production.*

→ *Results from AMPT+Coalescence calculation are consistent with data.*

Thanks..

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Back up: NCQ scaling

particle

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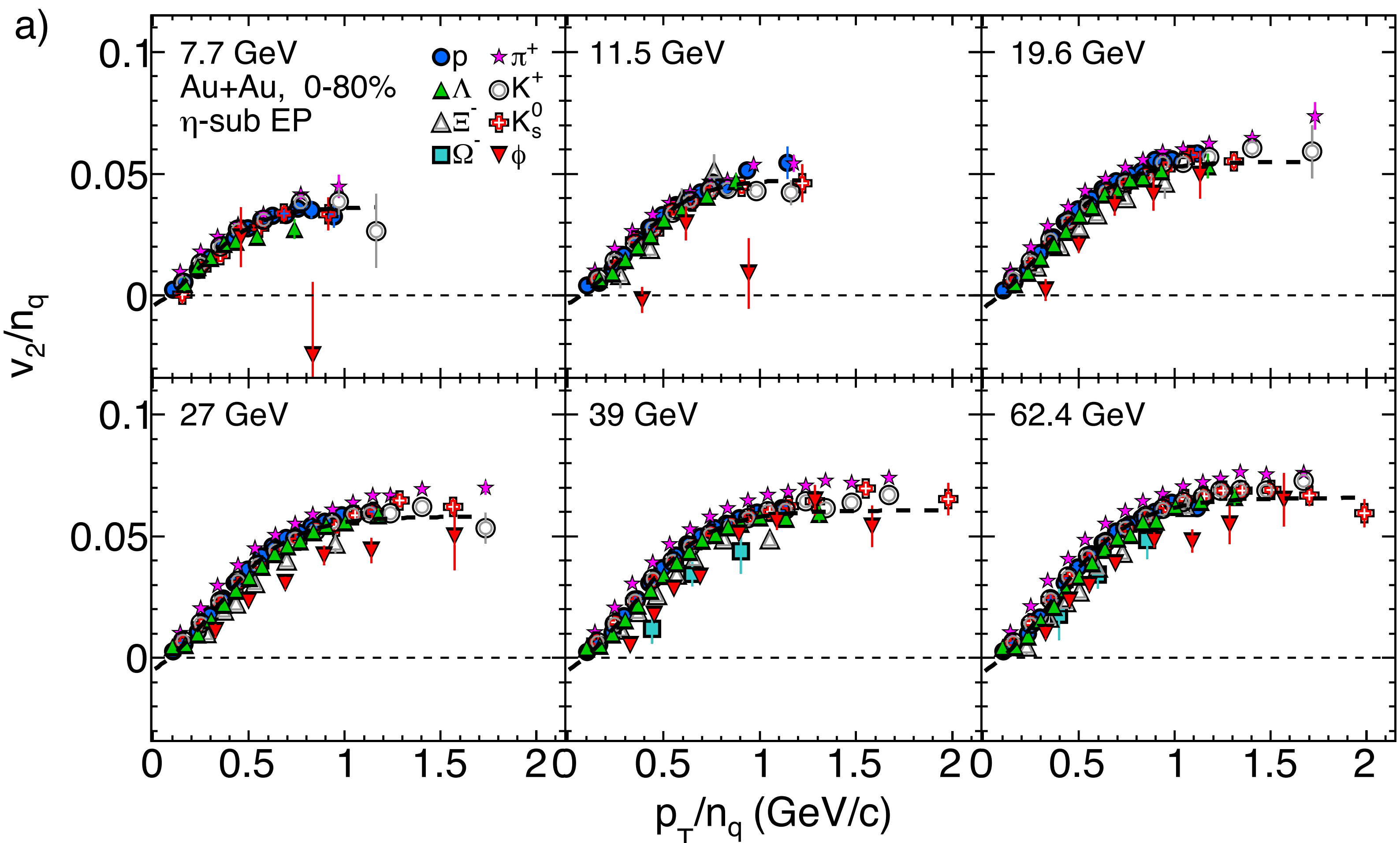

Back up: $(m_T - m_0)/n_q$ scaling

particle

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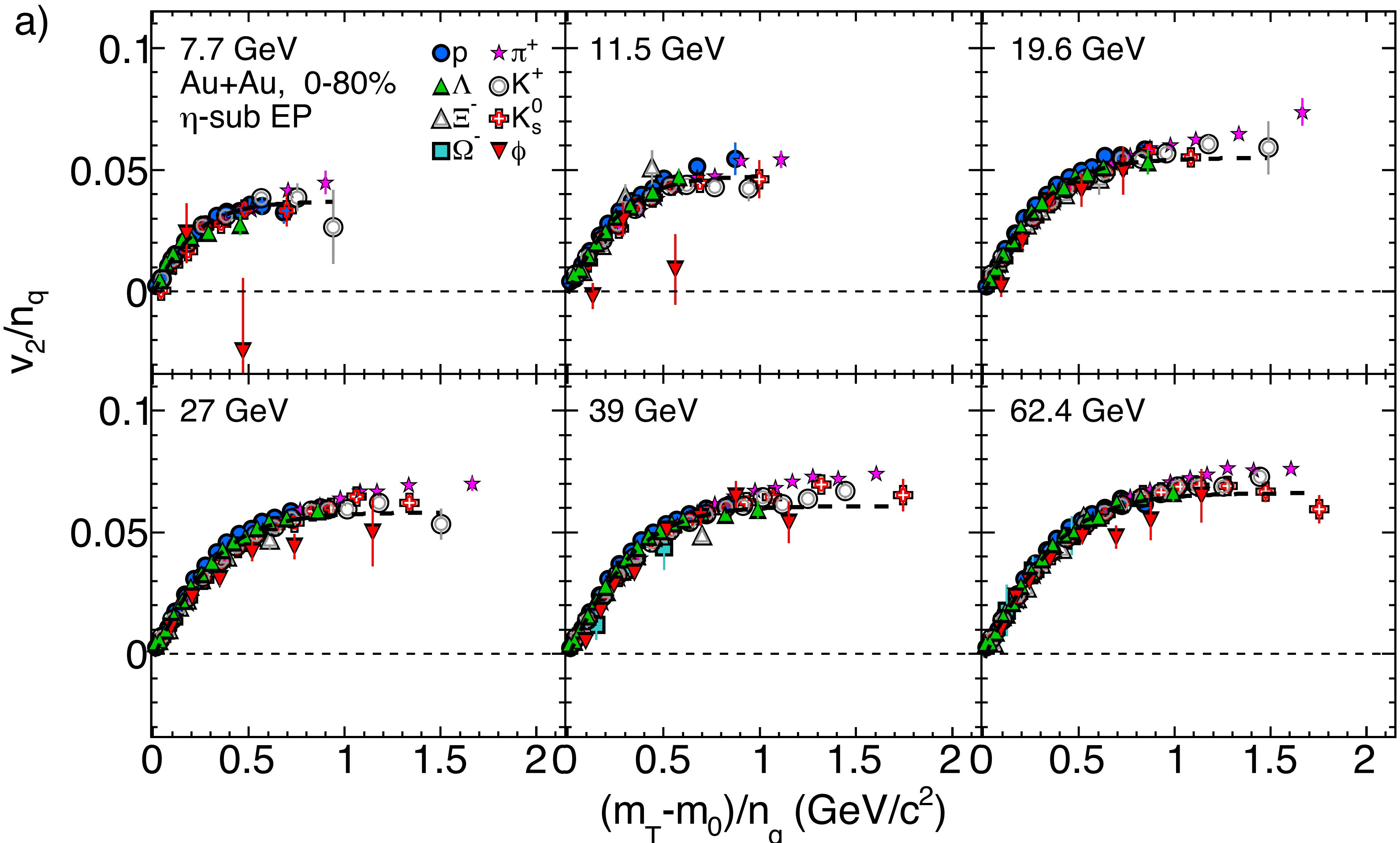
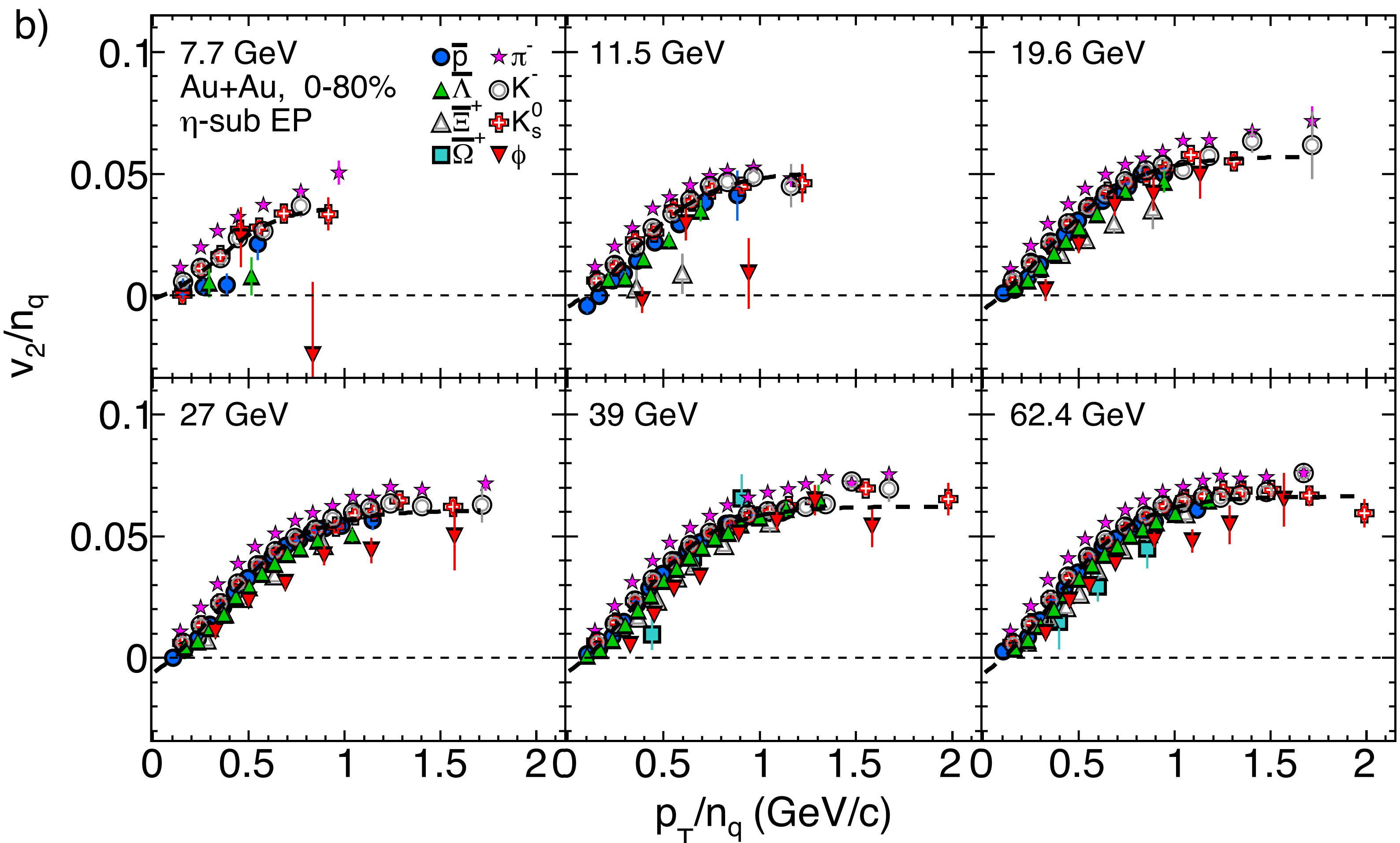


Back up: NCQ scaling

anti-particle

Phys. Rev. C 88, 014902 (2013)



Back up: $(m_T - m_0)/n_q$ scaling

anti-particle

Phys. Rev. C 88, 014902 (2013)