Elliptic and triangular flow of light nuclei in Au+Au collisions in the BES-II energies using the STAR detector

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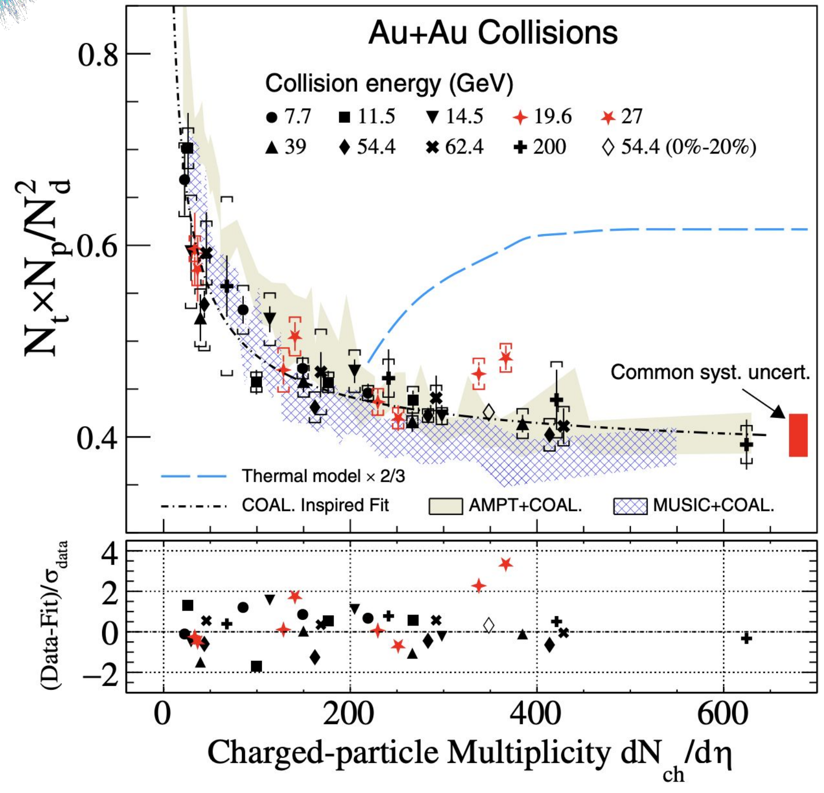
STAR Presentations: https://drupal.star.bnl.gov/STAR/presentations

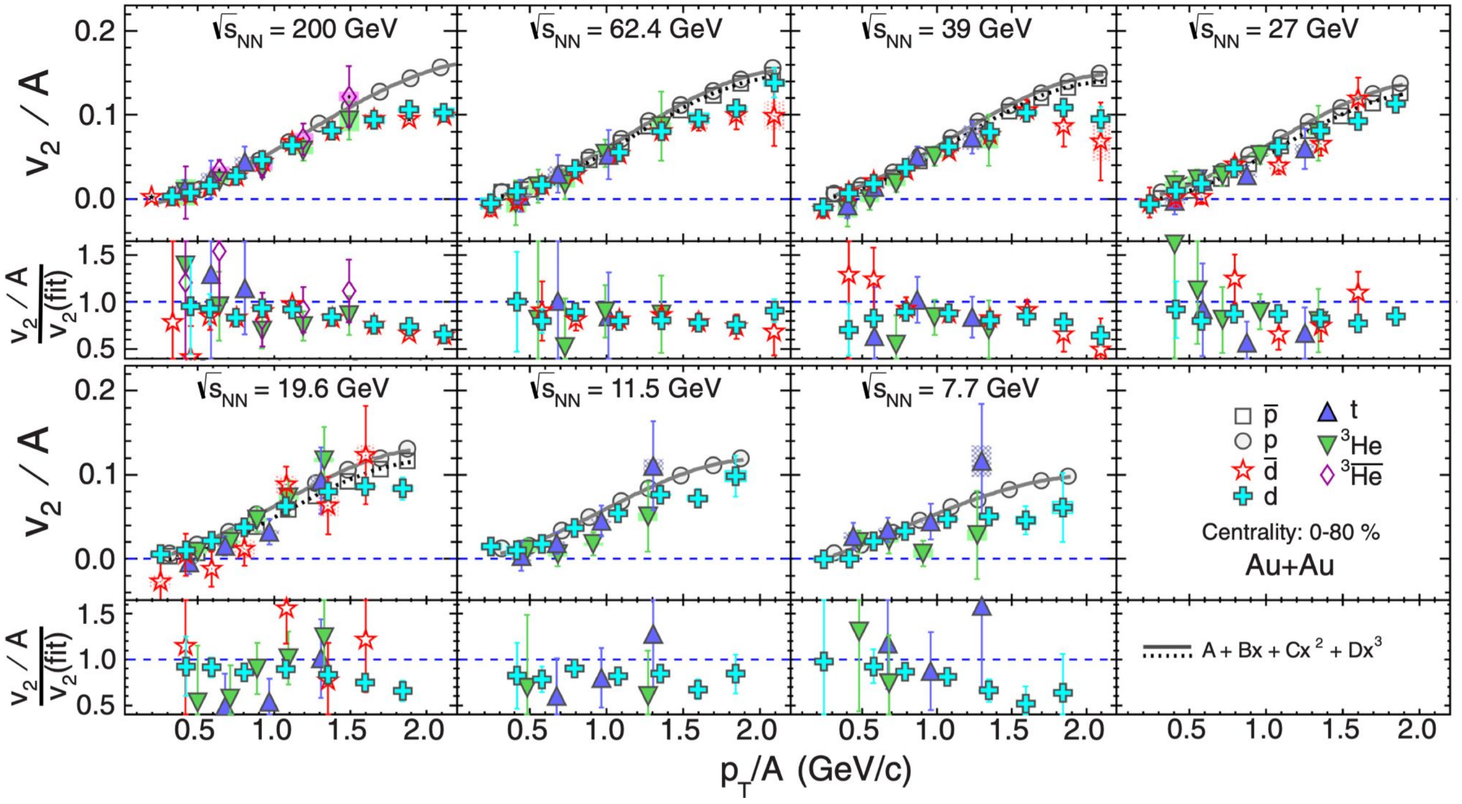
Outline

- Motivation
- The STAR experiment
- Analysis details
- Results
  - Elliptic flow of light nuclei
  - Triangular flow of light nuclei
- Summary and Outlook

Motivation



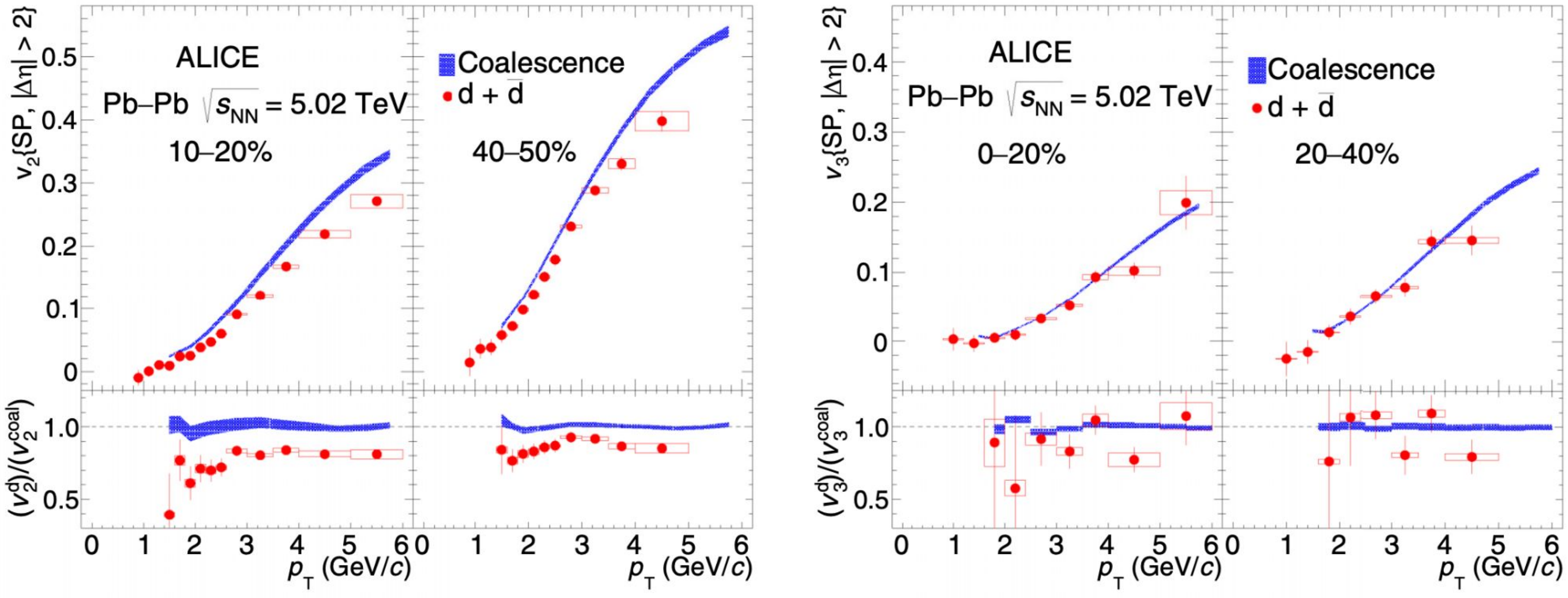
STAR, PRL 130, 202301 (2023)



STAR, PRC 94, 034908 (2016)

- ➢ **Coalescence model**: Light nuclei are formed in the later stages of heavy-ion collision by the coalescence of protons and neutrons
- ➢ Recent measurements indicate **coalescence model** can reproduce light nuclei yields/ratios
- ➢ v_2/A of light nuclei was observed to be close to v_2 of protons for p_T/A < 1.5 GeV/c in BES-I data → Supporting **coalescence model**
- ➢ Higher statistics dataset in BES-II program will allow us to revisit and better understand the production mechanism of light nuclei

Motivation



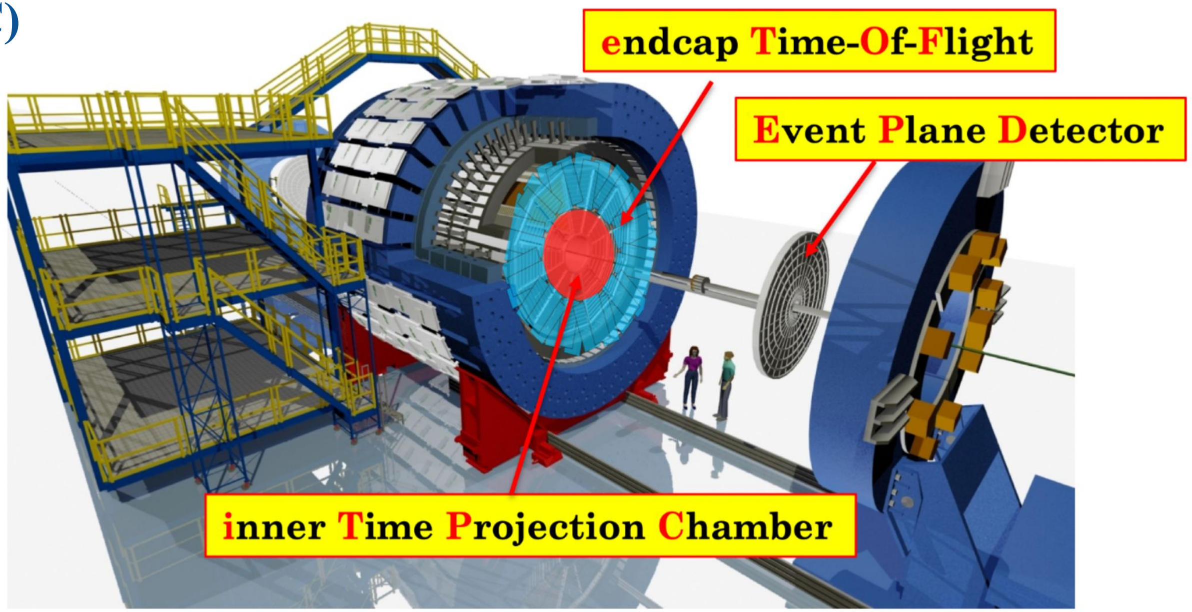
ALICE, PRC 102, 055203 (2020)

$$v_{2(3),d}(p_T) = \frac{2v_{2(3),p}(p_T/2)}{1 + 2v^2_{2(3),p}(p_T/2)}$$

- At LHC energies:
  - v_2 was observed to deviate from mass number scaling by 20-30%
  - v_3 was observed to exhibit mass number scaling although with large uncertainties
- High statistics data in BES-II energies enables us to study mass number scaling of higher order flow harmonics at STAR energies

The STAR Experiment

- Particle identification is performed using
  - *dE/dx* information from **Time Projection Chamber (TPC)**
  - m^2 information from **Time of Flight (TOF)**
- BES-II upgrades:
  - **iTPC**: Large pseudorapidity coverage ($|\eta| < 1.5$)
  - **Endcap Time of Flight (eTOF)**: $-1.6 < \eta < -1.1$
  - **Event Plane Detector (EPD)**: $2.1 < |\eta| < 5.1$
  - Improved particle detection capabilities
  - Better track momentum and event plane resolution
- Datasets
  - **BES-II**: Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27, and 54.4 GeV



JINST 15 C07040 (2020)

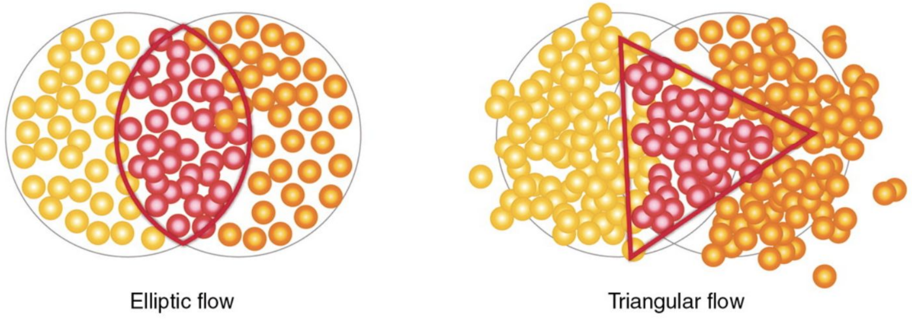
Analysis Method

➢ The particle azimuthal distribution can be written as:

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty} 2v_n\cos(n(\phi-\Psi_n))\right)$$

$$v_n = \langle\cos(n(\phi-\Psi_n))\rangle$$

v_2: Elliptic flow v_3: Triangular flow



Science 337, 310 (2012)

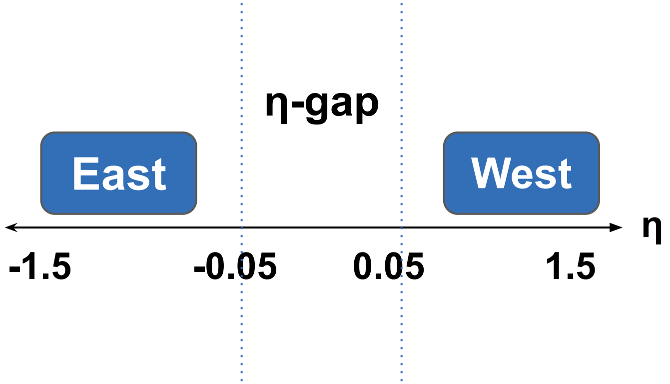
➢ n^{th} harmonic plane is calculated using the Q-vector:

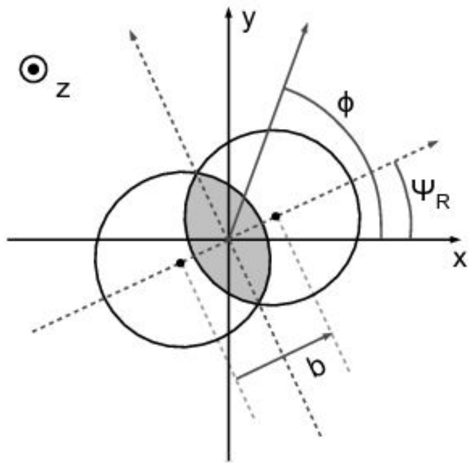
$$Q_n\cos(n\Psi_n) = \sum_i w_i\cos(n\phi_i)$$

$$Q_n\sin(n\Psi_n) = \sum_i w_i\sin(n\phi_i)$$

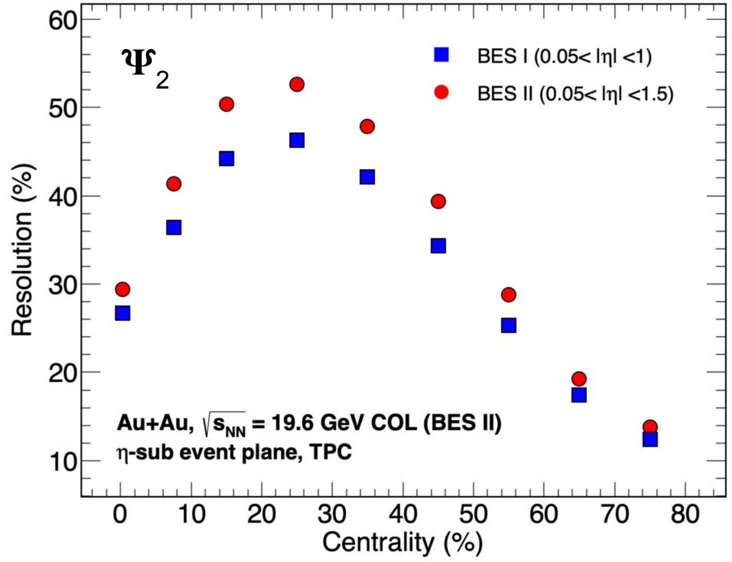
$$\Psi_n = \left(\tan^{-1}\frac{\sum_i w_i\sin(n\phi_i)}{\sum_i w_i\cos(n\phi_i)}\right)/n$$

➢ η-sub event plane method is used



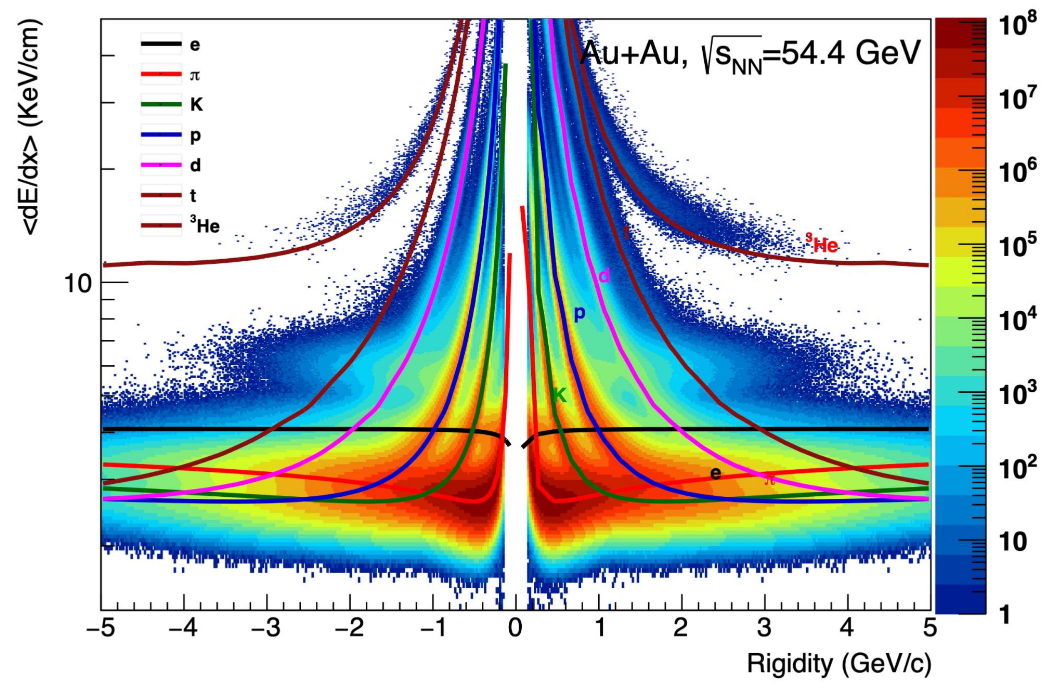


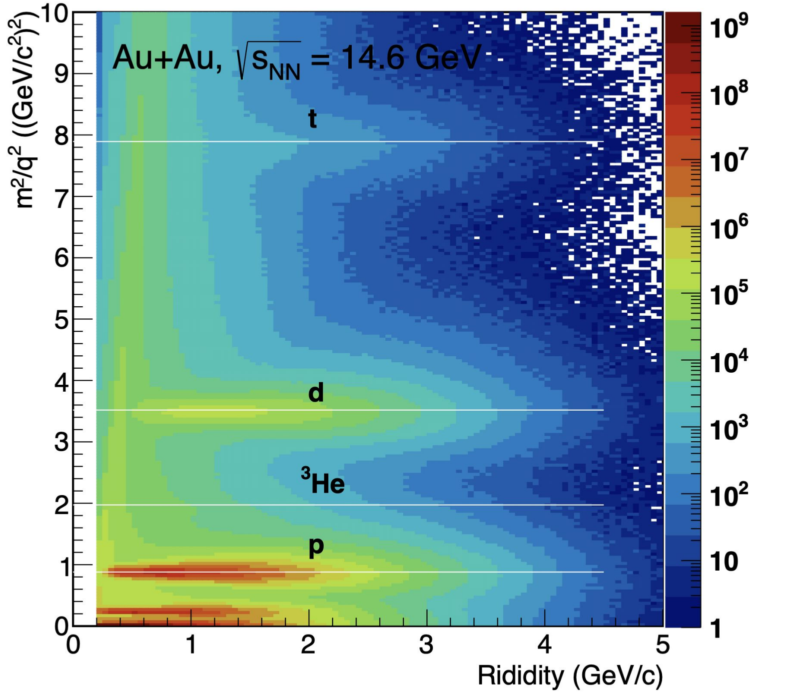
CMS, PRC 87 014902 (2013)



➢ **~10% improvement of resolution from BES-I owing to higher TPC acceptance and track momentum resolution**

Light nuclei identification





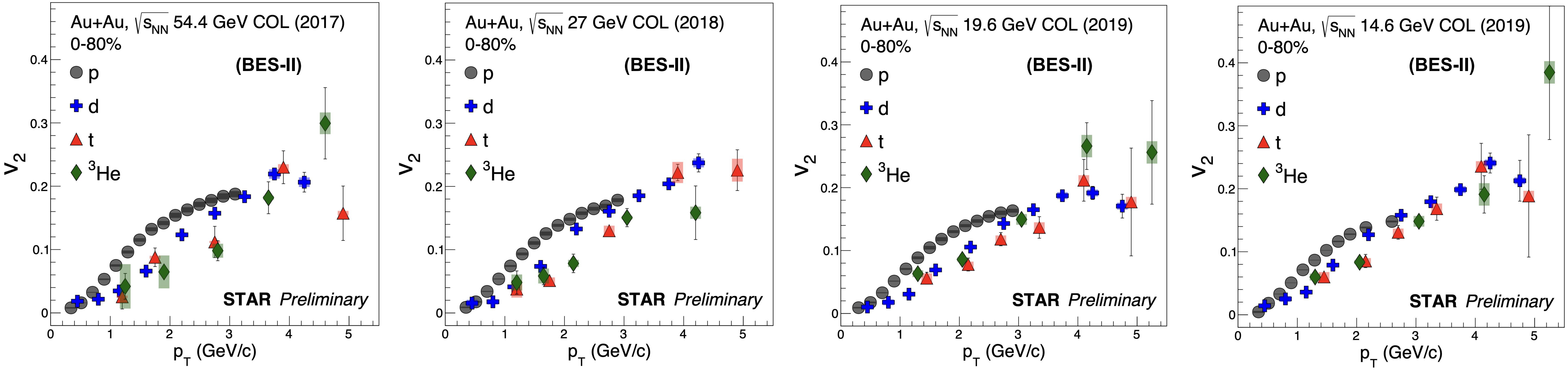
	Proton	Deuteron	Triton	Helium-3
Identification using	m^2-distribution	z-distribution	z-distribution	z-distribution
To increase purity of the signal	$\lvert n\sigma \rvert < 3.0$	$2.8 < m^2 < 4.2$ $(GeV/c^2)^2$	$6.3 < m^2 < 9.5$ $(GeV/c^2)^2$	--

$$z_i = \ln\left(\frac{<dE/dx>_{measured}}{<dE/dx>_{i,theory}}\right)$$

$$m^2 = p^2\left(\frac{1}{\beta^2} - 1\right)$$

Elliptic flow of light nuclei

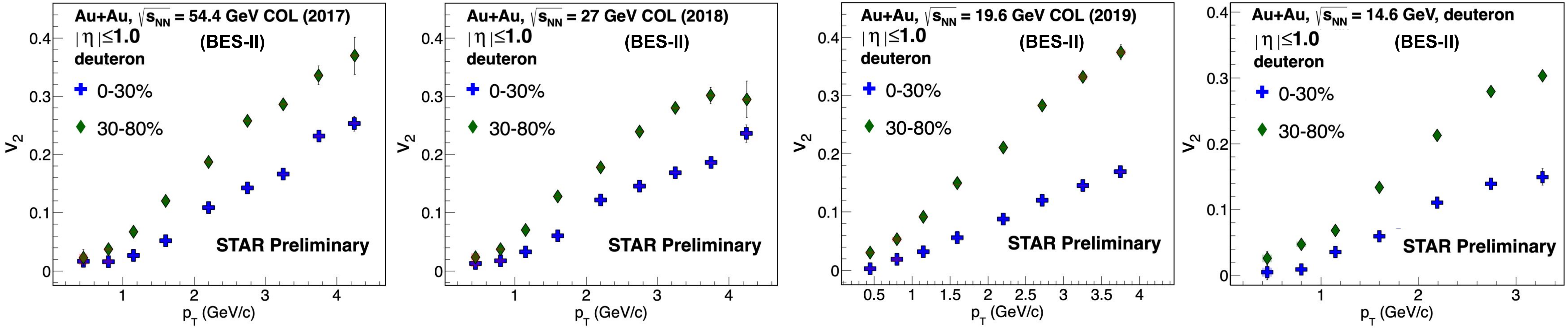
Elliptic flow (v_2)



- ➢ v_2 of light nuclei increases with increasing p_T for all collision energies in the measured p_T range
- ➢ v_2 shows mass ordering at low p_T between 1-2 GeV/c
- ➢ Statistical errors have reduced significantly compared to BES-I results

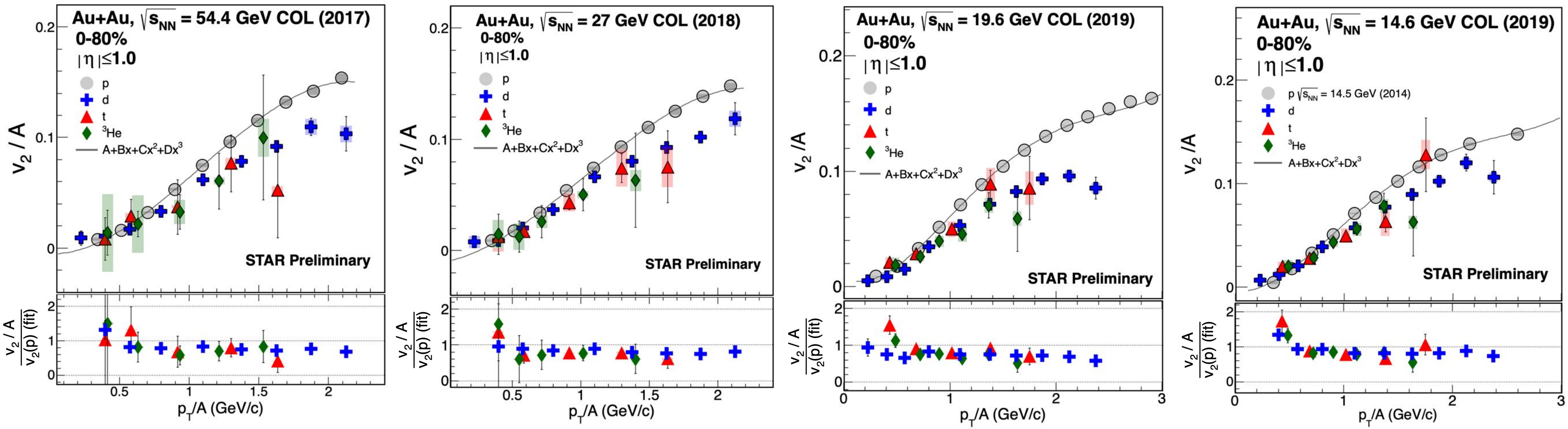
Proton v_2: PRC 93, 014907 (2016); PRC 88, 014902 (2013); PLB 827, 137003 (2022)

Centrality dependence of v_2



- ➢ v_2 of *d* shows a strong centrality dependence
- ➢ Peripheral collisions have relatively larger v_2 due to their larger initial spatial anisotropy

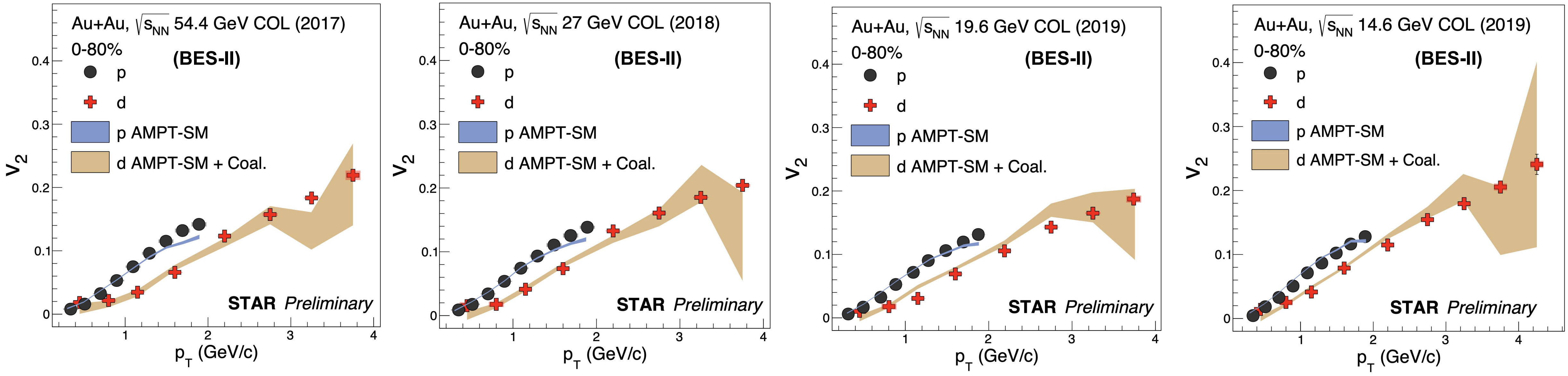
Mass number scaling of v_2



- ➢ Systematic deviation of around 20-30% from mass number scaling is observed for all light nuclei in measured energies

Proton v_2: PRC 93, 014907 (2016); PRC 88, 014902 (2013); PLB 827, 137003 (2022)

Comparison with AMPT+Coal.



- ➢ AMPT-SM model with a coalescence afterburner is in good agreement with $v_2(p_T)$ of *d*

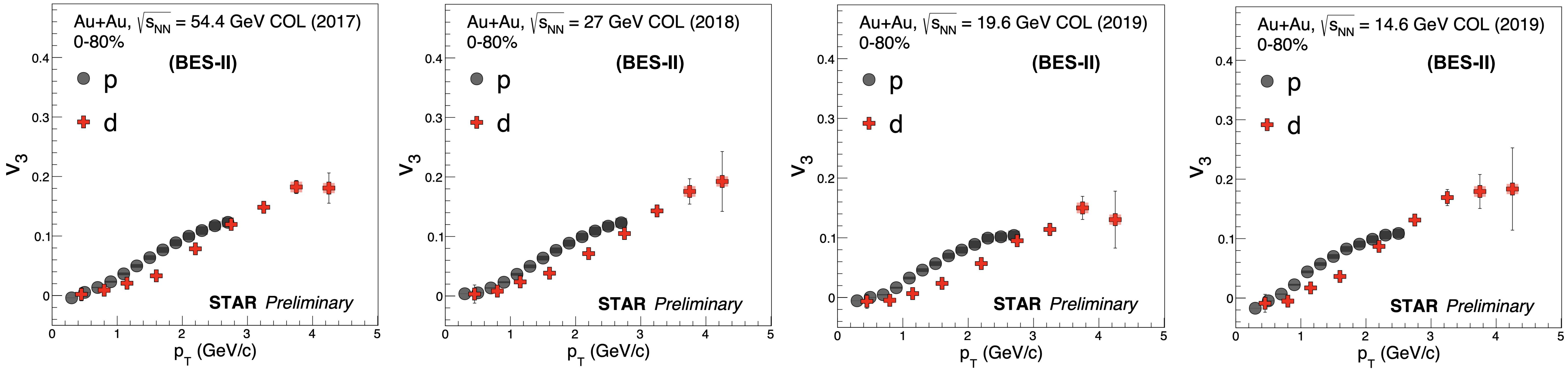
PRC 72, 064901 (2005)

Nucl. Phys. A 729 (2003) 809–834

Proton v_2: Phys. Rev. C 93, 014907 (2016); Phys. Rev. C 88, 014902 (2013); Phys. Lett. B 827, 137003 (2022)

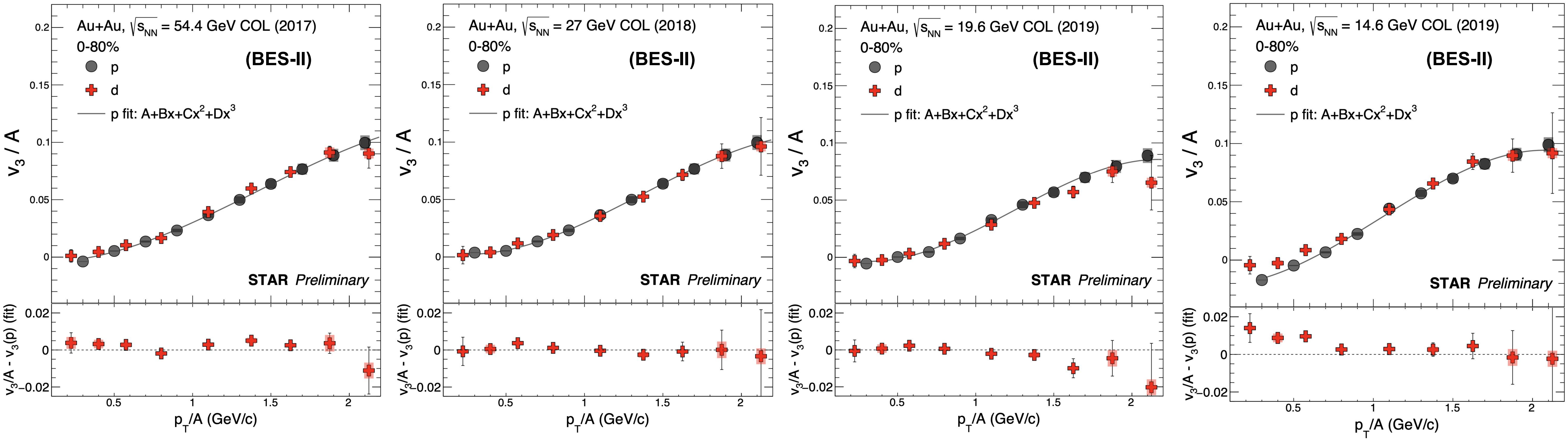
Triangular flow of light nuclei

Triangular flow (v_3)



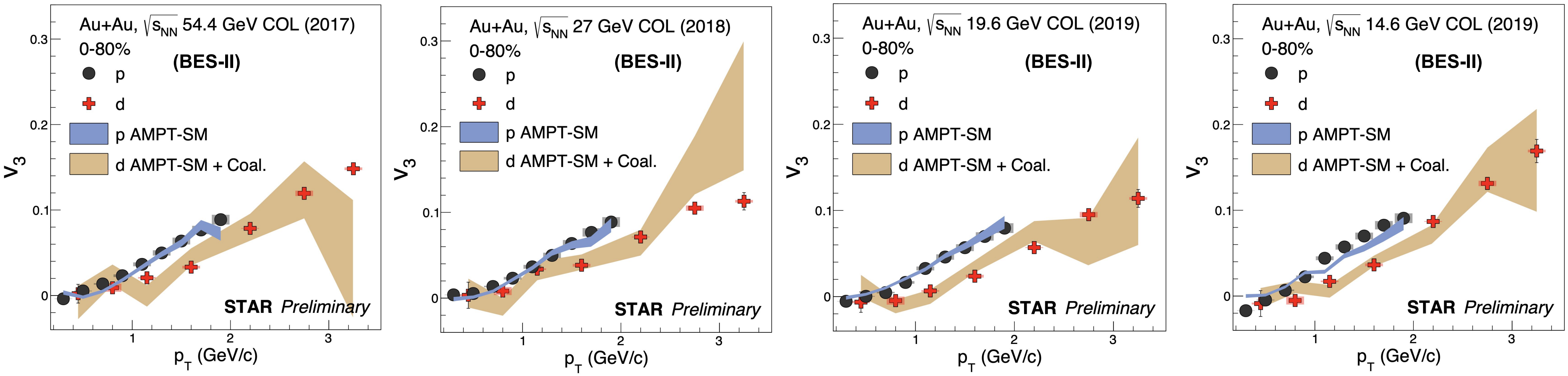
- ➢ v_3 of *p* and *d* increases with increasing p_T for all collision energies in the measured p_T range
- ➢ v_3 shows mass ordering at low p_T between 1-2 GeV/c

Mass number scaling of v_3



➢ $v_3(p_T)$ of *d* shows a good agreement with mass number scaling within ~10%

Comparison with AMPT+Coal.



- AMPT-SM model with a coalescence afterburner is in good agreement with $v_3(p_T)$ of *d*

PRC 72, 064901 (2005)

Nucl. Phys. A 729 (2003) 809–834

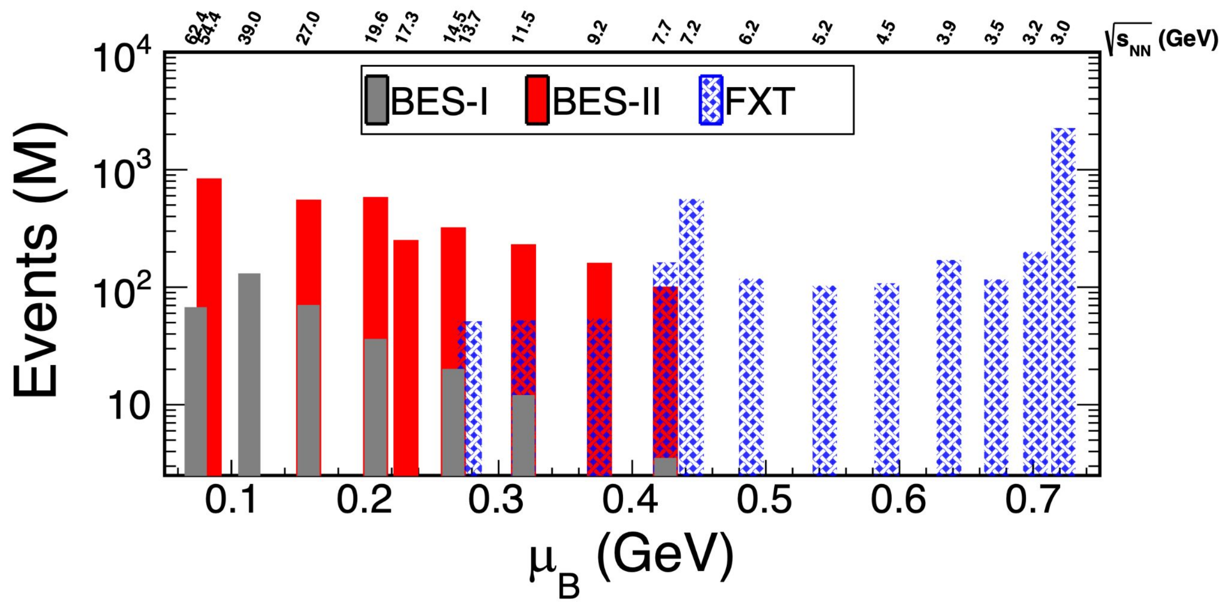
Summary

- $v_2(p_T)$ of *d*, *t*, and ^3He is measured in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27, and 54.4 GeV (COL)
  - Clear centrality dependence is observed for *d* for all collision energies
  - 20-30% deviation of light nuclei v_2 from mass number scaling is observed
  - AMPT+Coal. seems to well describe the v_2 of *d*
- $v_3(p_T)$ of *p* and *d* is measured in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27, and 54.4 GeV (COL)
  - v_3 of *d* shows a good agreement with mass number scaling
  - AMPT+Coal. seems to well describe the v_3 of *d*

Elliptic and Triangular flow measurements suggest coalescence to be the dominant mechanism of light nuclei production in heavy-ion collisions

Outlook

- We will extend the analysis to the remaining BES-II energies (**Au+Au, $\sqrt{s_{NN}}$ = 7.7, 9.2, 11.5, and 17.3 GeV**)
- Stay tuned for more exciting results on light nuclei from BES II energies



Other light (hyper-)nuclei flow results from STAR at QM 2023

Chengdong's talk (#666): First observation of $v_1(y)$ and $v_2(y)$ of light (hyper-)nuclei in FXT energies

Xiaoyu's talk (#632), Sharang's poster (#414): Event plane correlated directed ($v_1\{\Psi_1\}$) and triangular ($v_3\{\Psi_1\}$) flow of light nuclei in FXT energies

Thank you