Collective flow of light nuclei and hyper-nuclei in Au+Au collisions at $\sqrt{s_{NN}}$ = 3, 14.6, 19.6, 27, and 54.4 GeV using the STAR detector

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Outline

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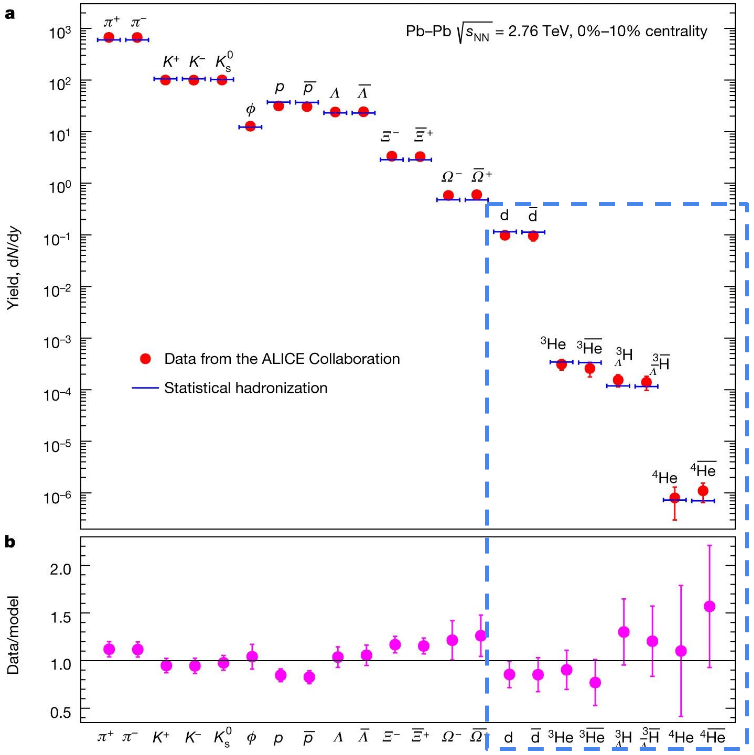
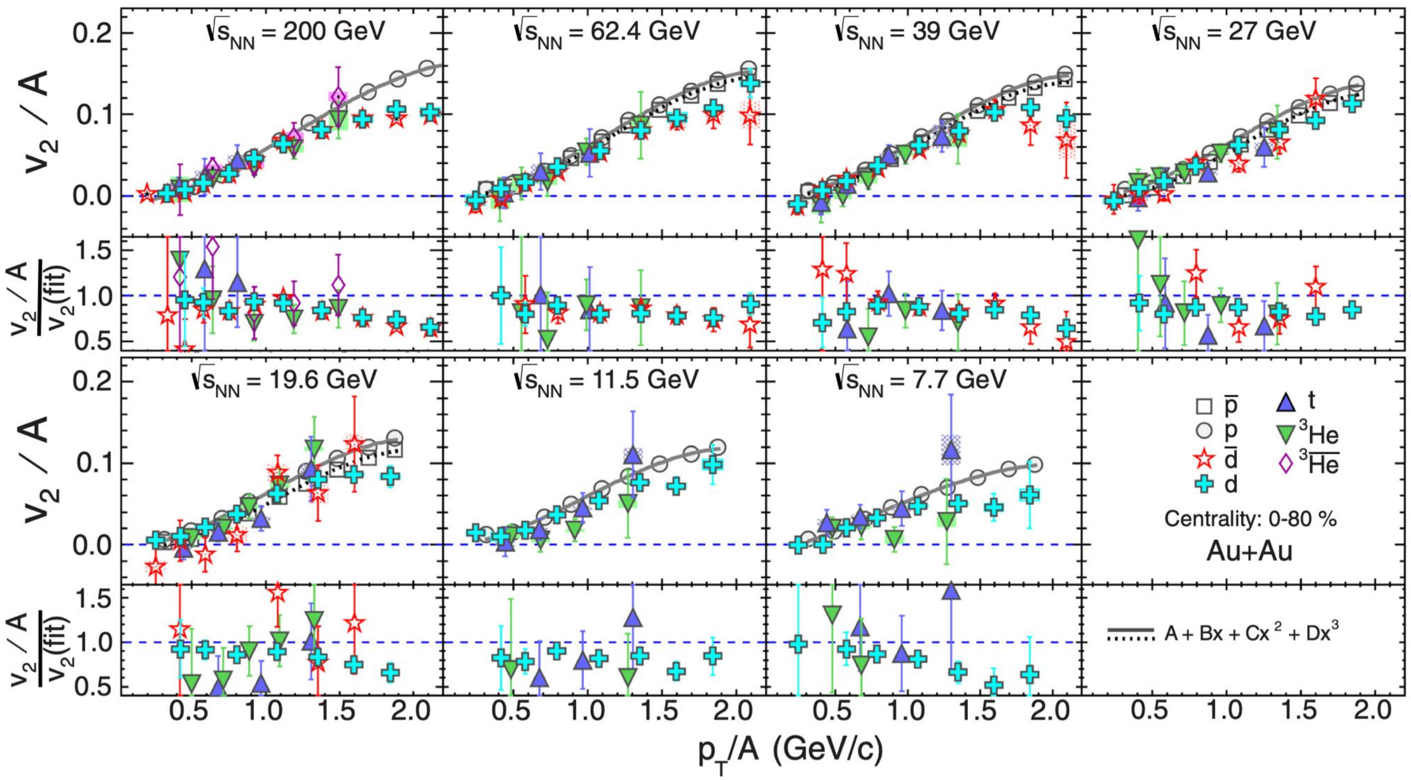
- ★ The STAR experiment
- ★ Analysis method
- ★ Results
    - ○ Elliptic flow of light nuclei
    - ○ Directed flow of light (hyper-)nuclei
- ★ Summary

Motivation



Nature 561, 321–330 (2018)



STAR, PRC 94, 034908 (2016)

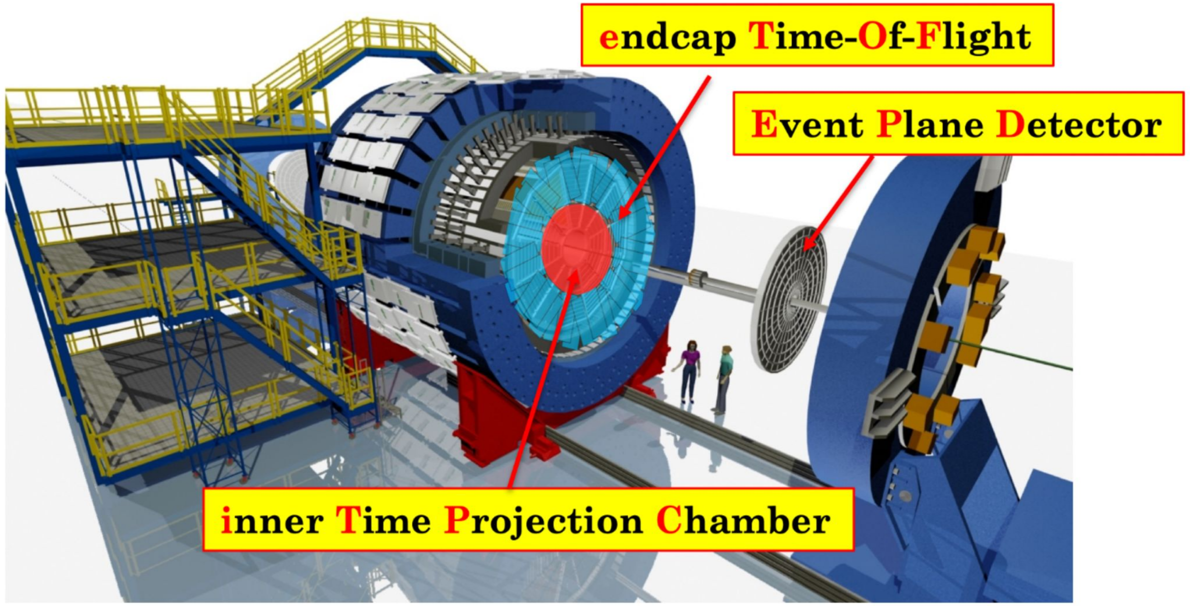
★ Light (hyper-)nuclei production in heavy-ion collisions can be explained either by the **thermal model** or the **final-state coalescence** of nucleons

★ 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

★ Higher statistics dataset in BES-II program will allow us to revisit and better understand the production mechanism of light (hyper-)nuclei

The STAR experiment

- ★ **Solenoidal Tracker at RHIC (STAR)** is one of the large detector systems at RHIC consisting of several sub-detectors
- ★ dE/dx information from **Time Projection Chamber (TPC)** and m^2 information from **Time of Flight (TOF)** are used for particle identification
- ★ Upgrade to **iTPC**
  - Large acceptance ($|\eta| < 1.5$)
  - Better track resolution
- ★ **Event Plane Detector (EPD)**: $2.1 < |\eta| < 5.1$



JINST 15 C07040 (2020)

- ★ Datasets:
  - **BES II:** Au+Au collisions at $\sqrt{s_{NN}}$ = 3 (FXT), 14.6, 19.6, 27, and 54.4 GeV (COL)

Analysis method

★ The particle azimuthal distribution can be written as:

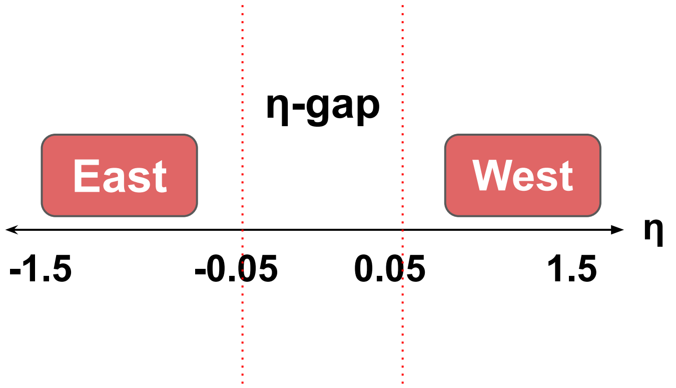
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos(n(\phi-\Psi_R))\right) \qquad v_n = \langle \cos[n(\phi-\psi_R)] \rangle$$

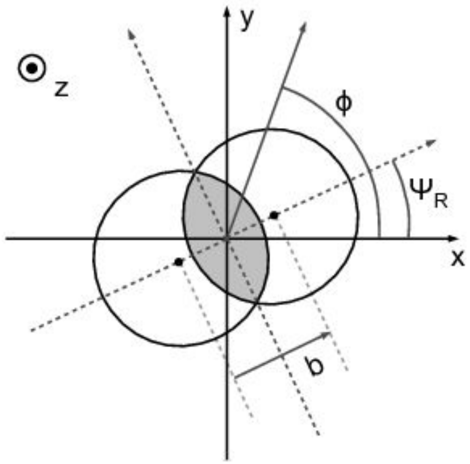
v_1: Directed flow $\qquad$ v_2: Elliptic flow

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

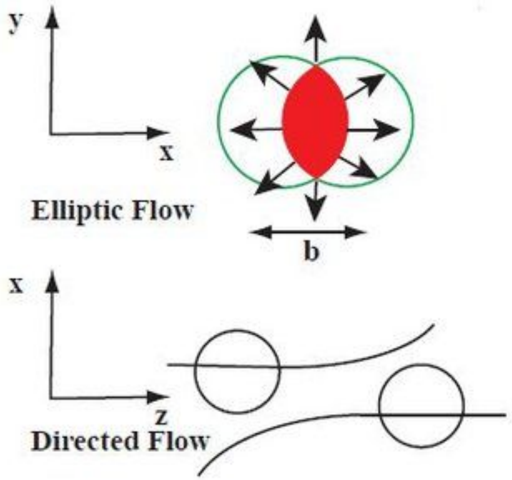
$$Q_n \cos(n\Psi_n) = \sum_i w_i \cos(n\phi_i)$$
$$Q_n \sin(n\Psi_n) = \sum_i w_i \sin(n\phi_i)$$
$$\Psi_n = \left(\tan^{-1}\frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)}\right)/n$$

★ η-sub event plane method is used

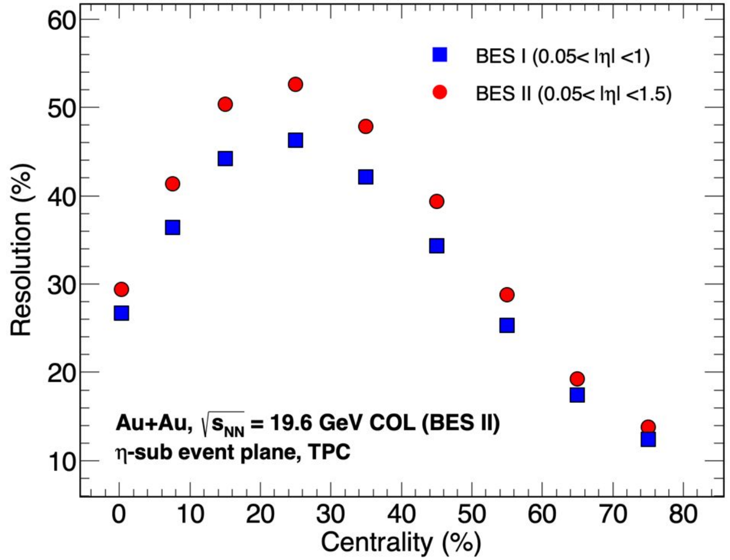




CMS, PRC 87 014902 (2013)



STAR, PRL 103, 251601 (2009)



We observe an improvement of resolution by ~10% from BES I owing to higher TPC acceptance and track resolution

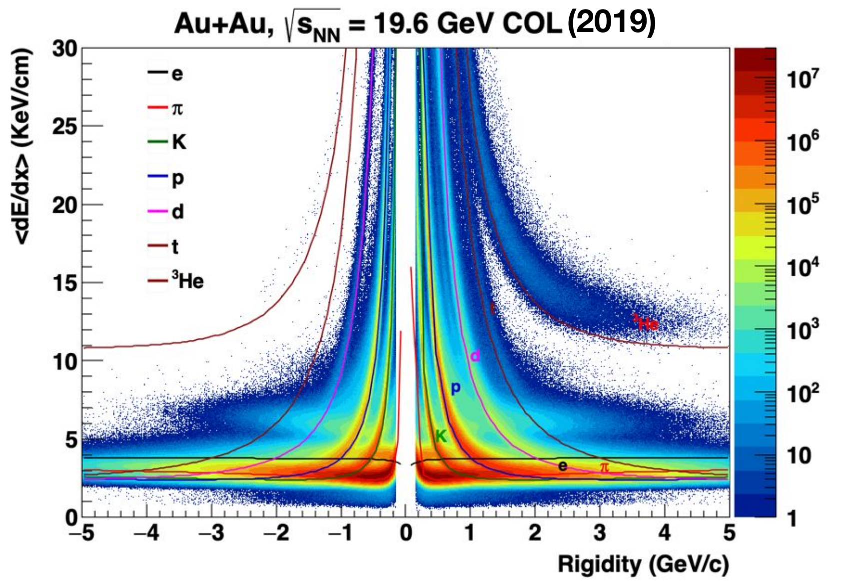
Particle identification

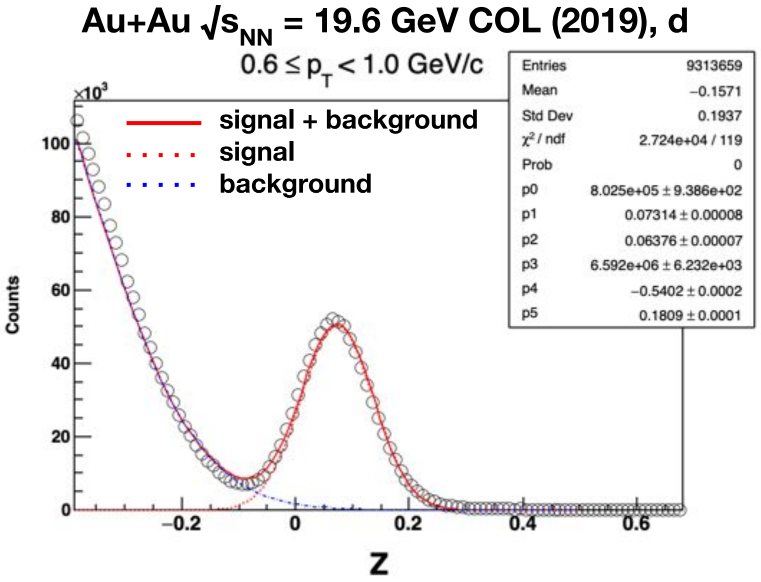
★ Particles are identified using **dE/dx information from TPC** in the range $|\eta| \leq 1.0$

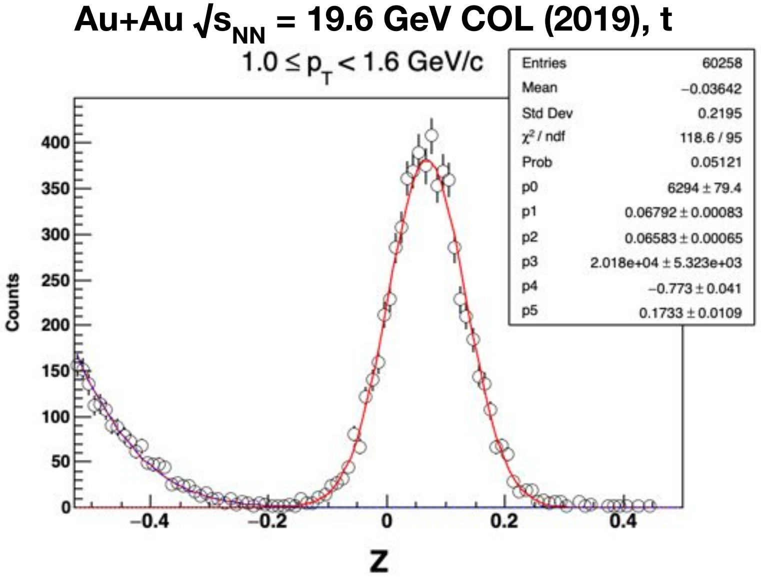
$$z_i = \ln\left(\frac{\langle dE/dx\rangle_{measured}}{\langle dE/dx\rangle_{theory}}\right)$$

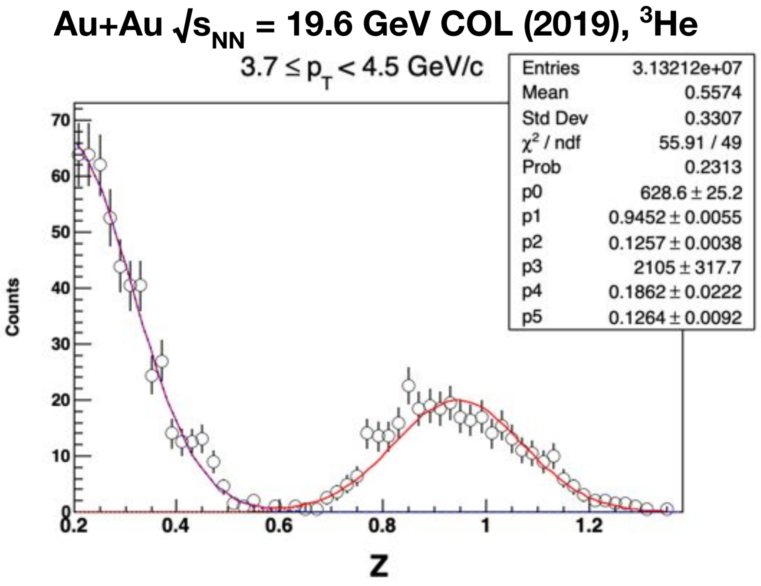
★ $\langle dE/dx \rangle_{theory}$ is calculated using Bichsel function

★ Double Gaussian fit is done to calculate yield in each p_T and $\phi-\Psi_2$ bin



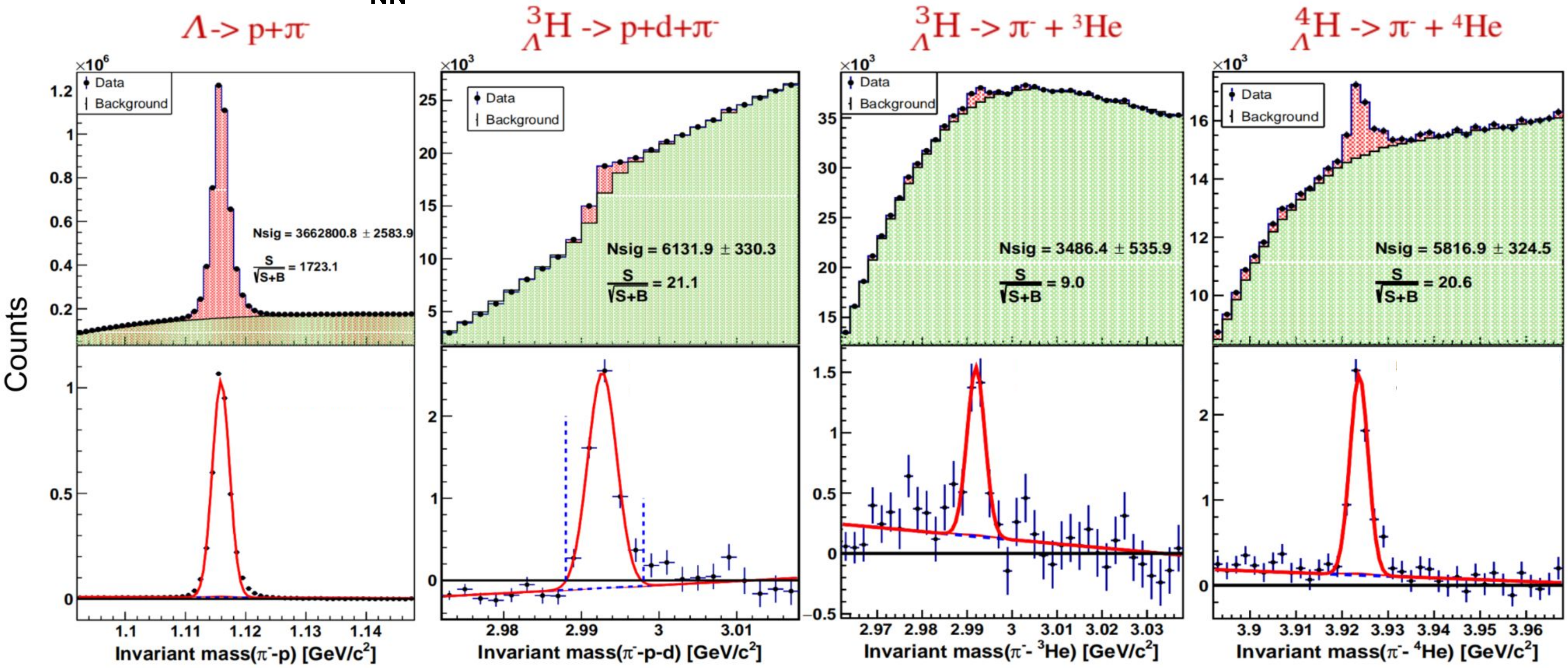






Particle identification

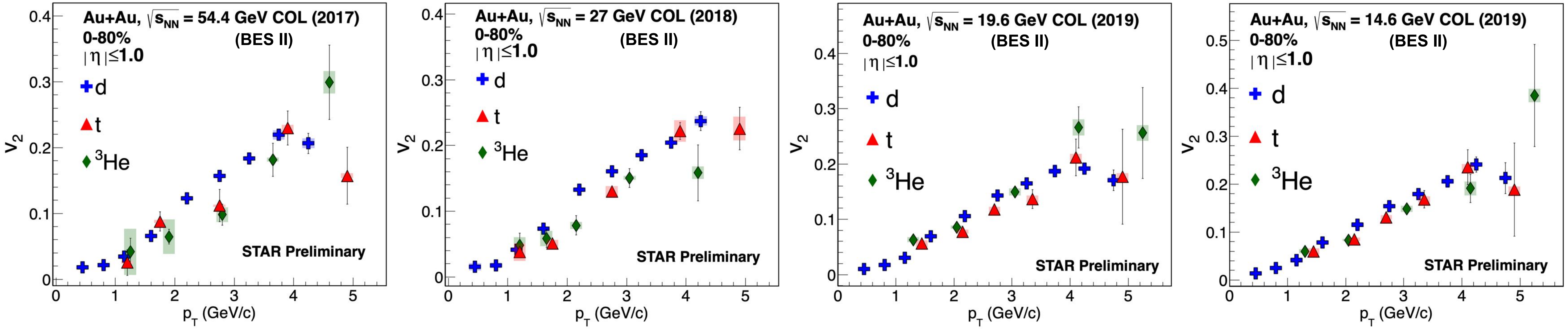
$\sqrt{s_{NN}}$ = 3 GeV (FXT) Au+Au Collisions at RHIC (BES II)



KFParticle package has been used for signal reconstruction

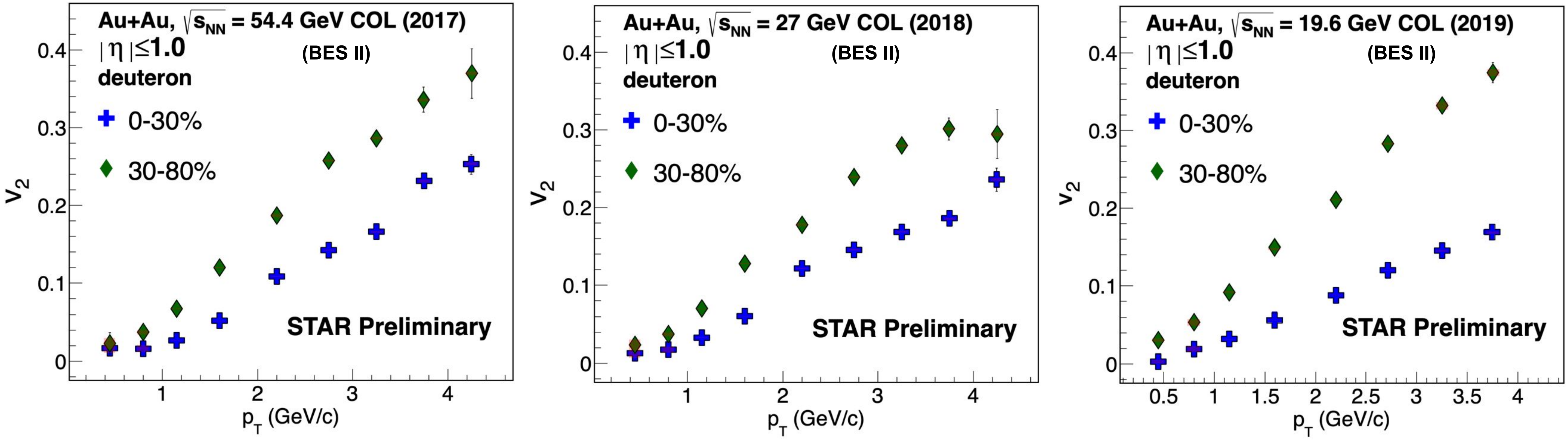
I. Kisel (CBM), J. Phys. Conf. Ser. 1070, 012015 (2018)

Elliptic flow (v_2)



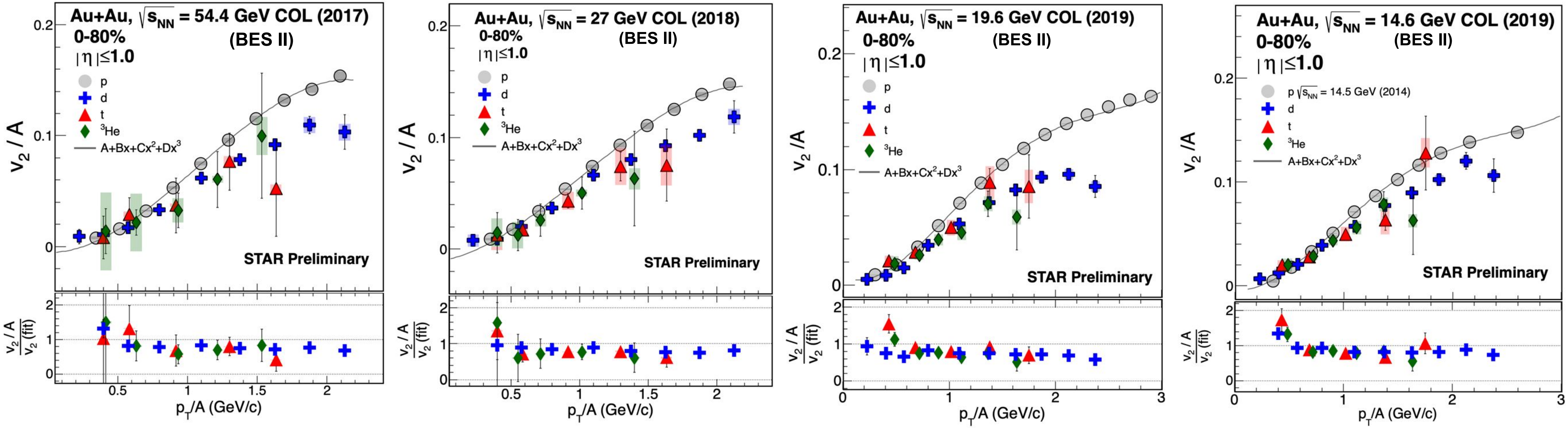
- The $v_2(p_T)$ for all nuclei species increases with increasing p_T for all collision energies
- Statistical errors have reduced significantly compared to the BES I results

Centrality dependence



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

Mass number scaling

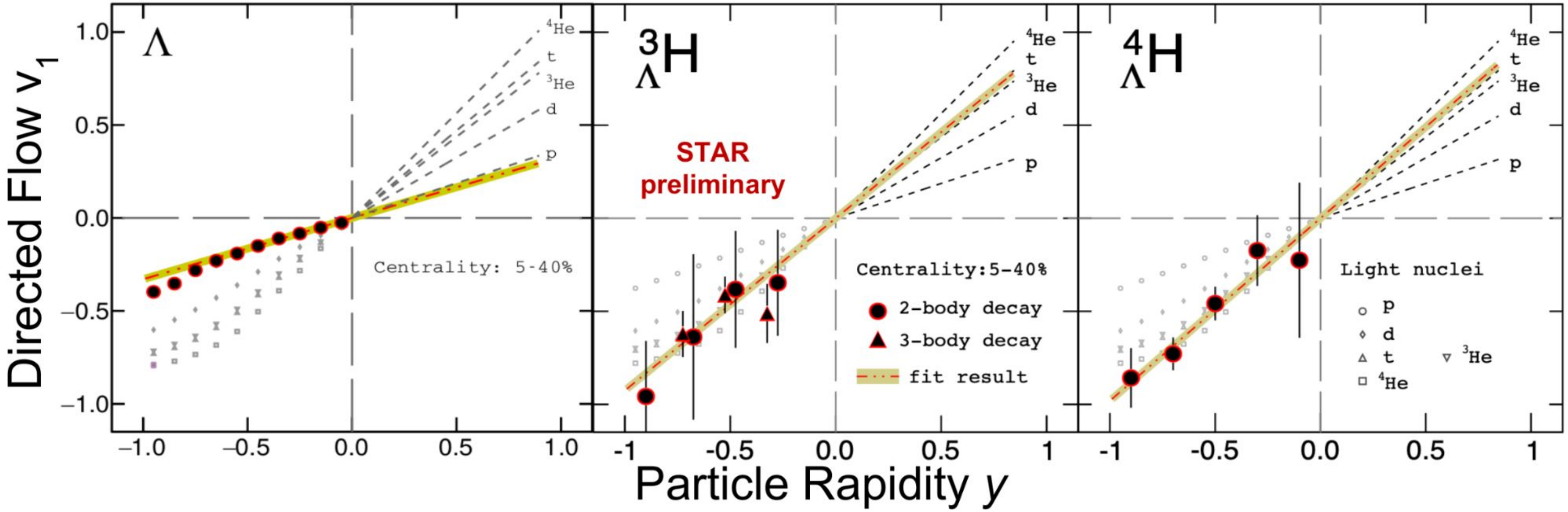


- A systematic deviation of around 20-30% from mass number scaling is observed for all light nuclei species at all measured energies

STAR, PRC 93, 014907 (2016)

Directed flow (v_1) vs rapidity

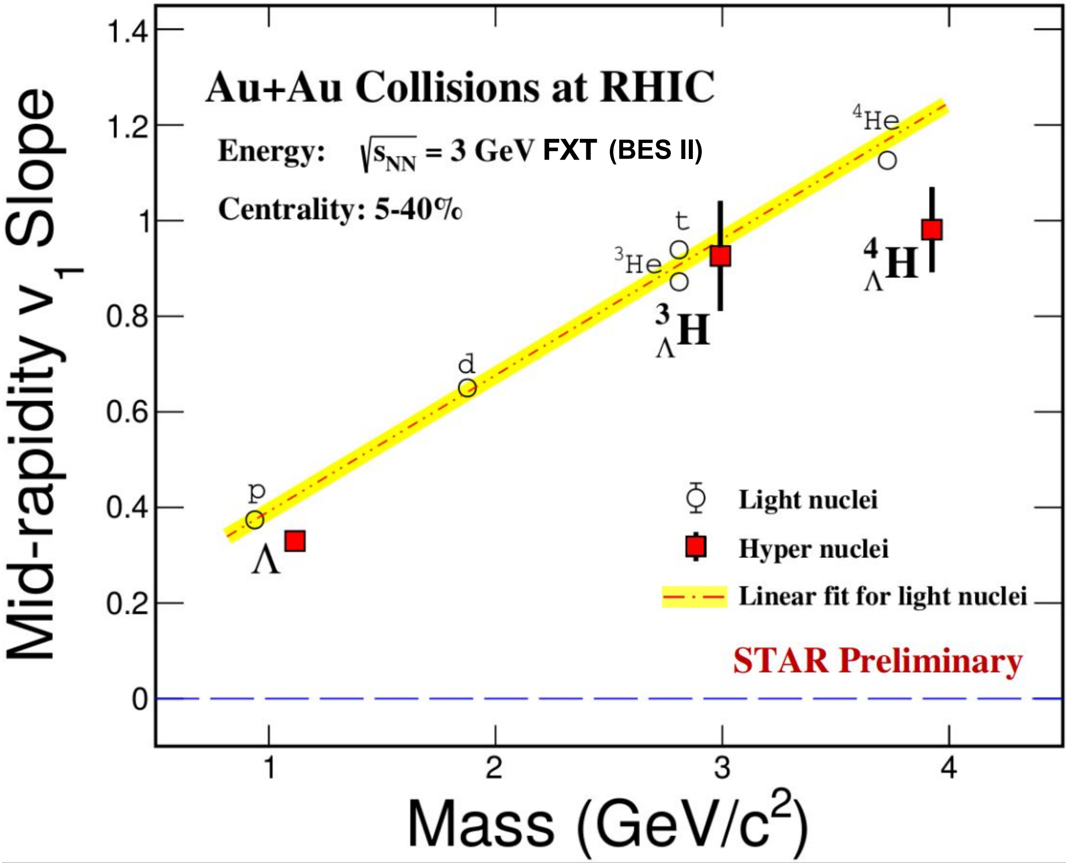
$\sqrt{s_{NN}}$ = 3 GeV (FXT) Au+Au Collisions at RHIC (BES II)



- **First observation of hyper-nuclei directed flow (v_1) in high-energy heavy-ion collisions**
- **Hyper-nuclei v_1 seems to follow the mass number scaling**

STAR, PLB 827 136941 (2022)

v_1-slope vs particle mass



Within statistical uncertainties, the slopes of v_1 of hypernuclei seem to follow the mass number scaling

STAR, PLB 827 136941 (2022)

Summary

- ★ v_2 of d, t, and ^{3}He is measured in Au+Au collisions at $\sqrt{s_{NN}}$= 14.6, 19.6, 27 and, 54.4 GeV (COL)
  - 20-30% deviation of light nuclei v_2 from mass number scaling is observed
  - Clear centrality dependence is observed for deuterons for all collision energies
- ★ v_1 of Λ, ${}^{3}_{\Lambda}H$, and ${}^{4}_{\Lambda}H$ is presented in Au+Au collisions at $\sqrt{s_{NN}}$= 3 GeV (FXT)
  - Rapidity dependence of hyper-nuclei v_1 is measured
  - v_1 of hyper-nuclei shows mass number scaling

Outlook

- ★ Stay tuned for more exciting results on (hyper-)nuclei from BES II energies

Thank you