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STAR

Directed Flow of Light and Hyper-Nuclei at 3 GeV Au+Au collisions in STAR

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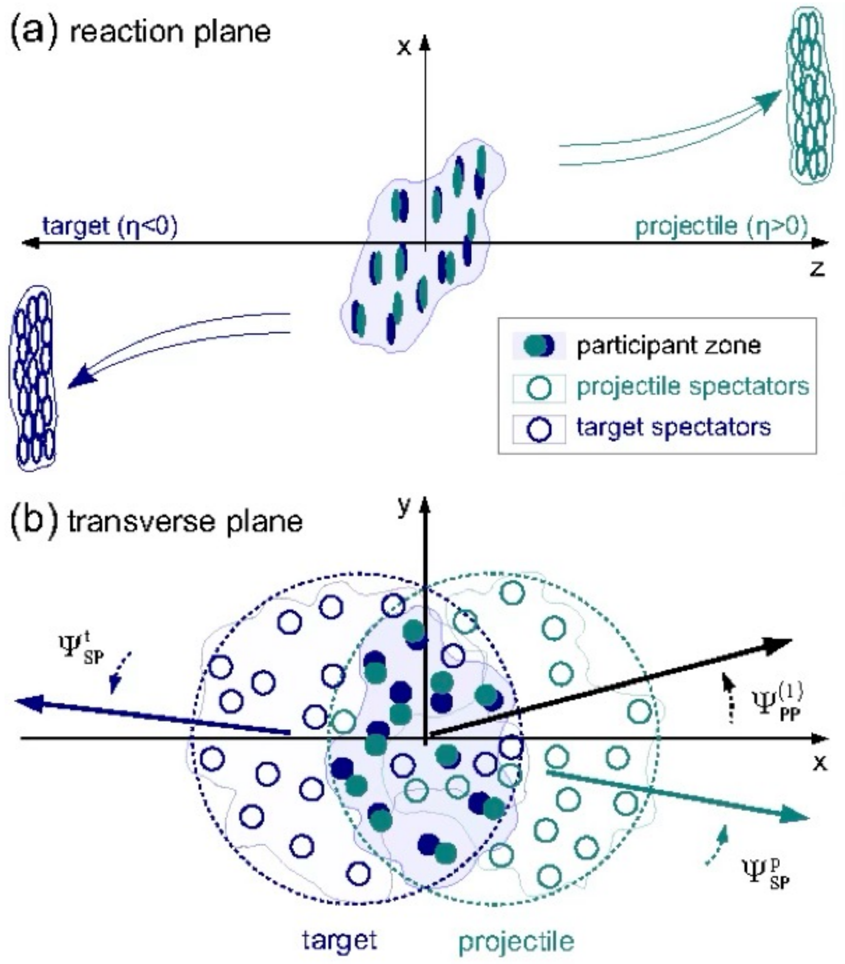
Outline

1. Introduction
2. Datasets and Particle Reconstruction
3. Directed Flow of light nuclei and hyper-nuclei
4. Summary and Outlook

Directed Flow



B.Abelev et al. Phys. Rev. Lett. **111**, 232302(2013)

- Directed flow is the collective sideways motion of particles produced in heavy-ion collisions.

- It reflects the first harmonic azimuthal anisotropy relative to the reaction plane.

$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\phi - \psi_{RP})))$$

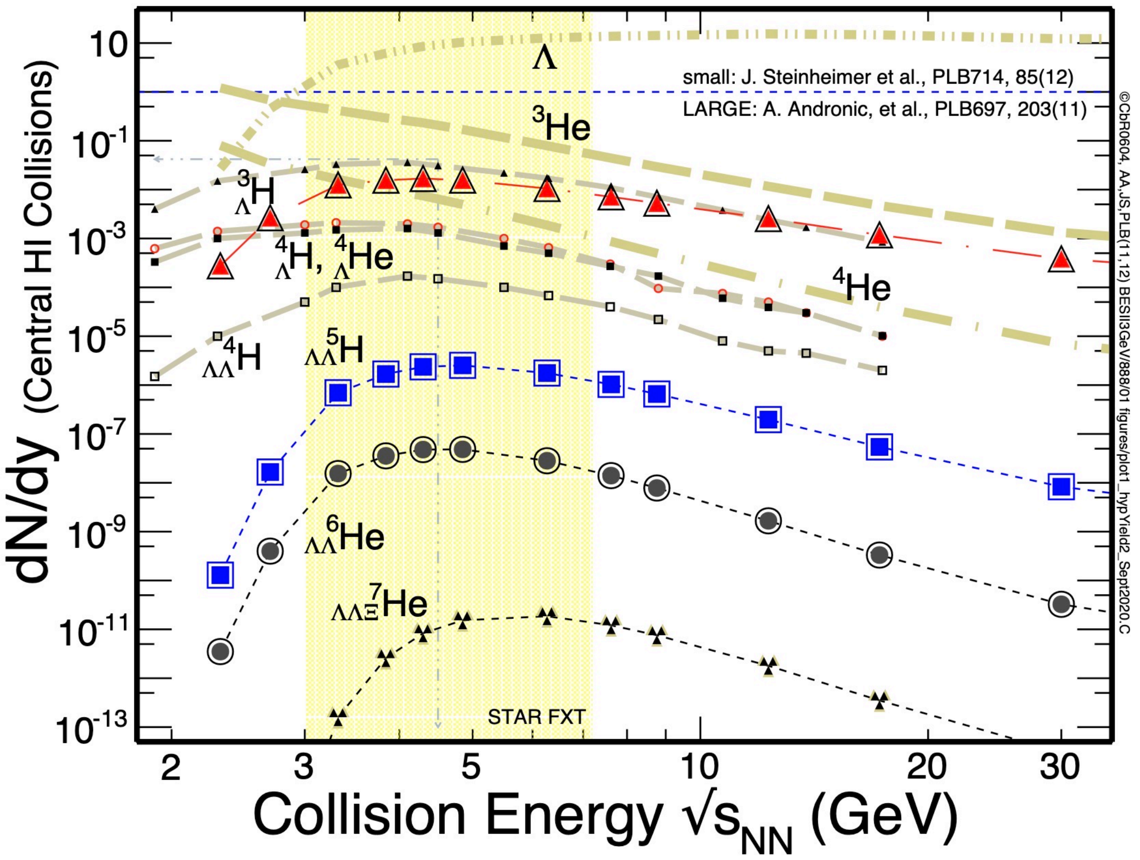
- Directed flow: $v_1 = \langle \cos(\phi - \psi_{RP}) \rangle$

- Probes the Equation of State (EOS) of nuclear matter under high baryon density region.

- Reveals the properties of dense baryonic matter created in heavy-ion collisions.

Production of Light Nuclei and Hyper-Nuclei

Thermal model calculation results



1) Light nuclei and hyper-nuclei production is enhanced in the high baryon density region.

2) Properties of light nuclei and hyper-nuclei provide important information about nucleon-nucleon (N-N) and hyperon-nucleon (Y-N) interactions.

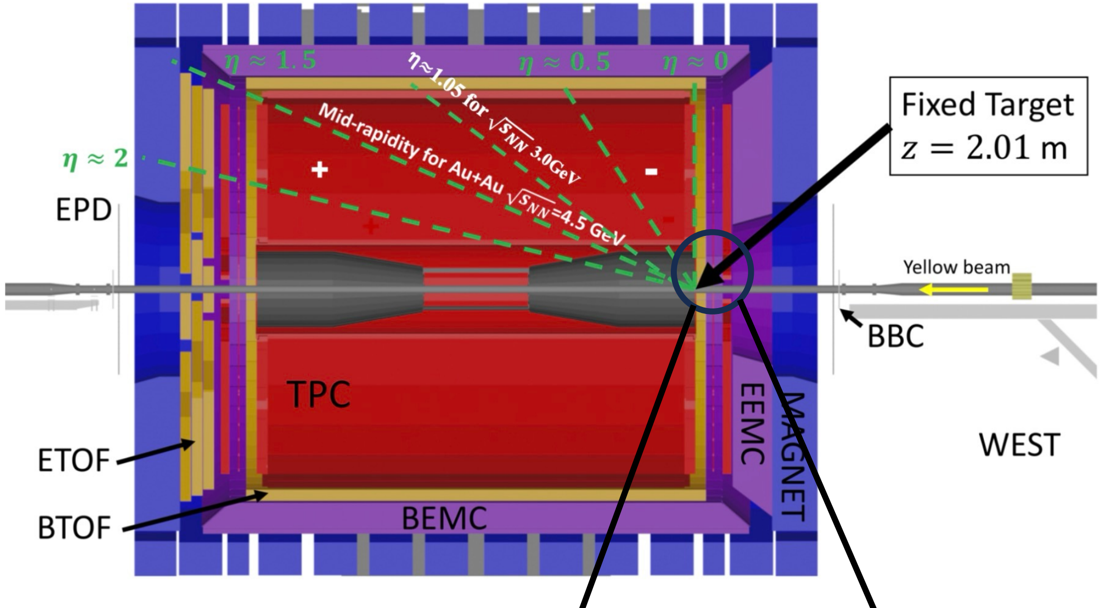
3) Directed flow helps reveal the production mechanisms of both light nuclei and hyper-nuclei.

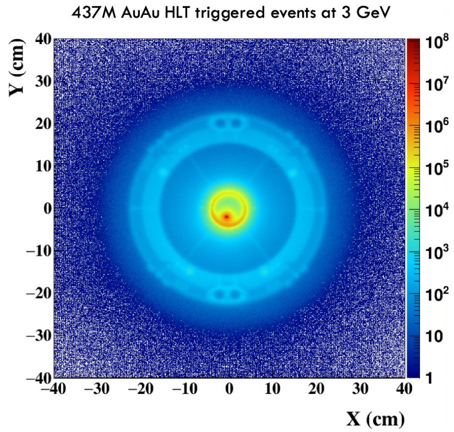
[1] A. Andronic et al, Phys. Lett. B **697**, 203(2011)

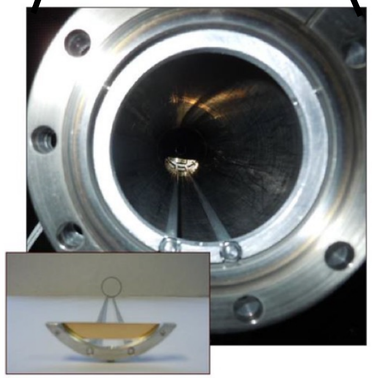
[2] J. Steinheimer et al. Phys. Lett. B **714**, 85(2012)

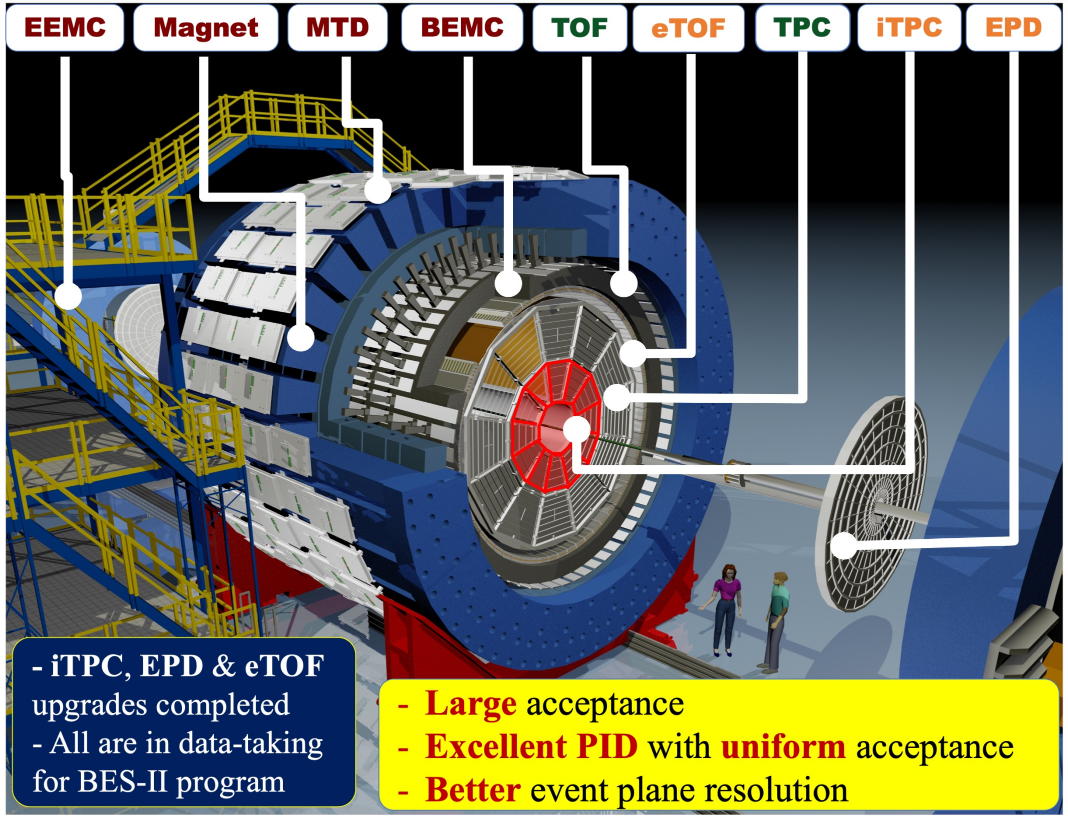
STAR BES-II

Fixed target mode ($\sqrt{s_{NN}}$ = 3.0– 13.7 GeV)









- iTPC, EPD & eTOF upgrades completed
- All are in data-taking for BES-II program

- **Large** acceptance
- **Excellent PID** with **uniform** acceptance
- **Better** event plane resolution

- STAR BES-II
  - 10× statistics compared to BES-I.
  - This analysis: $\sqrt{s_{NN}}$ = 3.0 GeV (baryon chemical potential is 720 MeV).

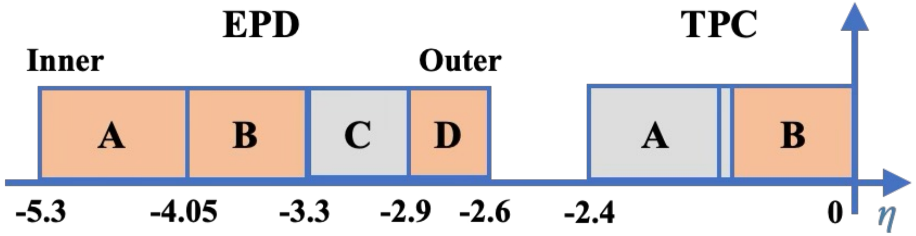
Dataset and Event Plane Reconstruction

DataSet	Analyzed Events	Target rapidity	Primary vertex cuts
$\sqrt{s_{NN}}$ = 3.0 GeV (2021)	~1.97B	-1.045	$(V_x + 0.47)^2 + (V_y + 2)^2 < 4\ cm^2$ $198 < V_z < 202$ cm

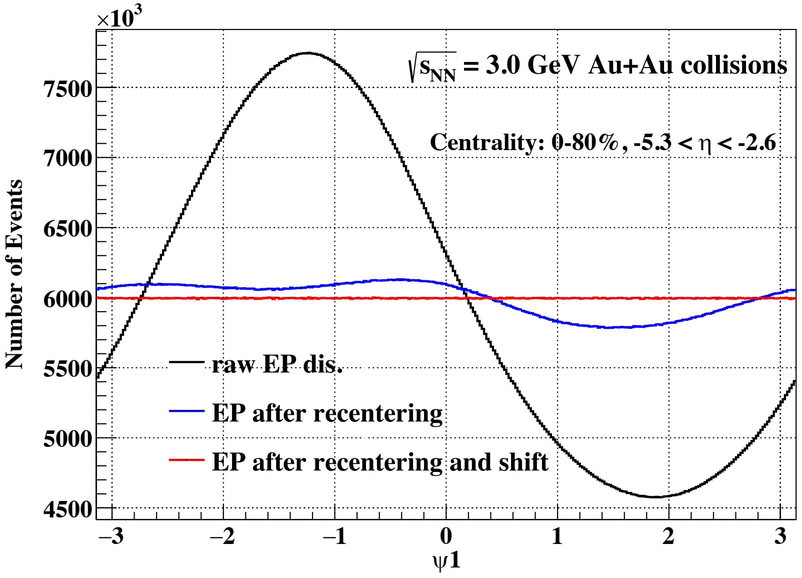
❖ Event Plane Reconstruction

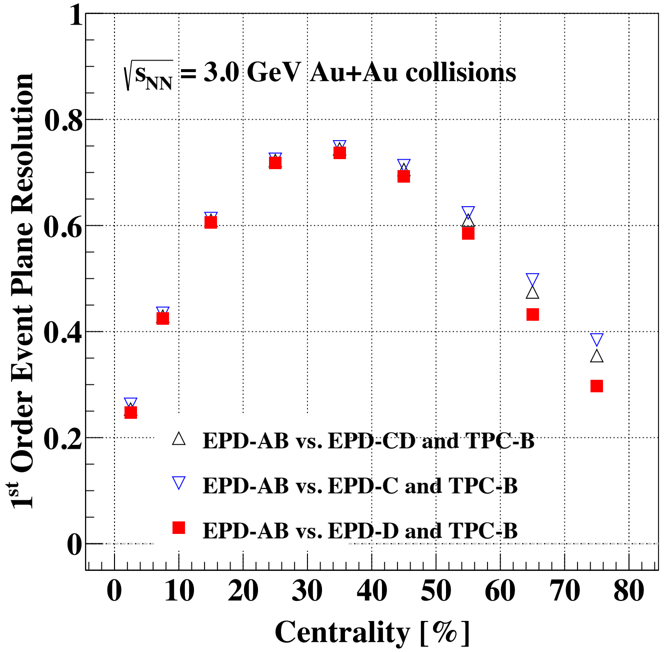
- Reconstruction method: Q-vector method.
- Calibration: recentering and shift.
- EP resolution: three sub-events method

$$\langle\cos(\psi_1^a - \psi_r)\rangle = \sqrt{\frac{\langle\cos(\psi_1^a - \psi_1^b)\rangle\langle\cos(\psi_1^a - \psi_1^c)\rangle}{\langle\cos(\psi_1^b - \psi_1^c)\rangle}}$$



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

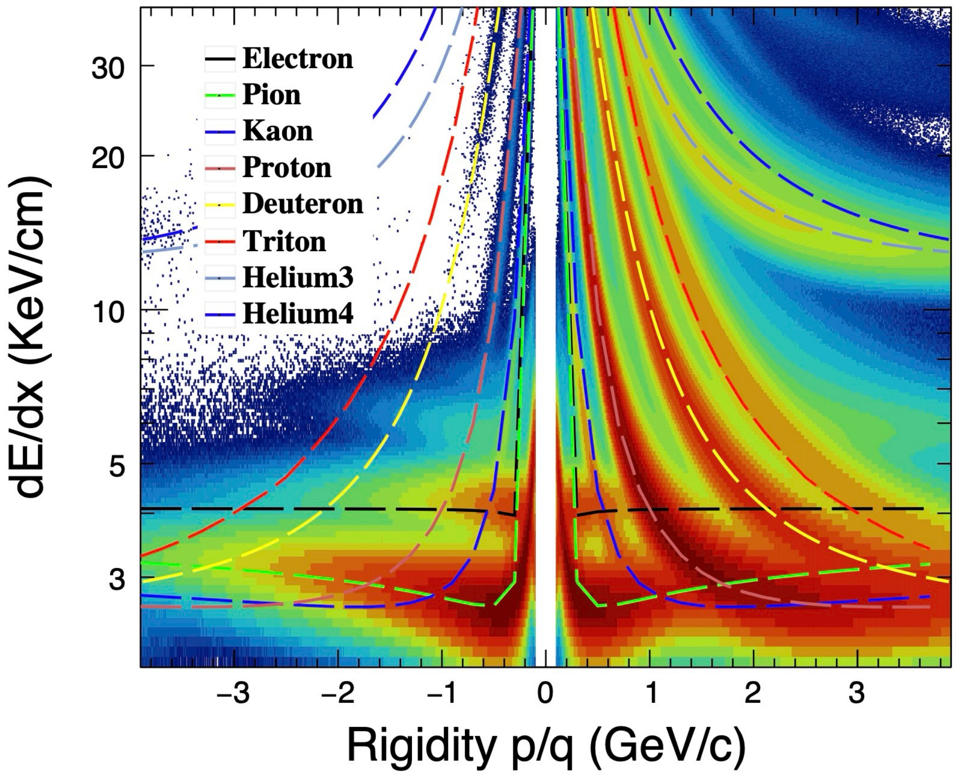


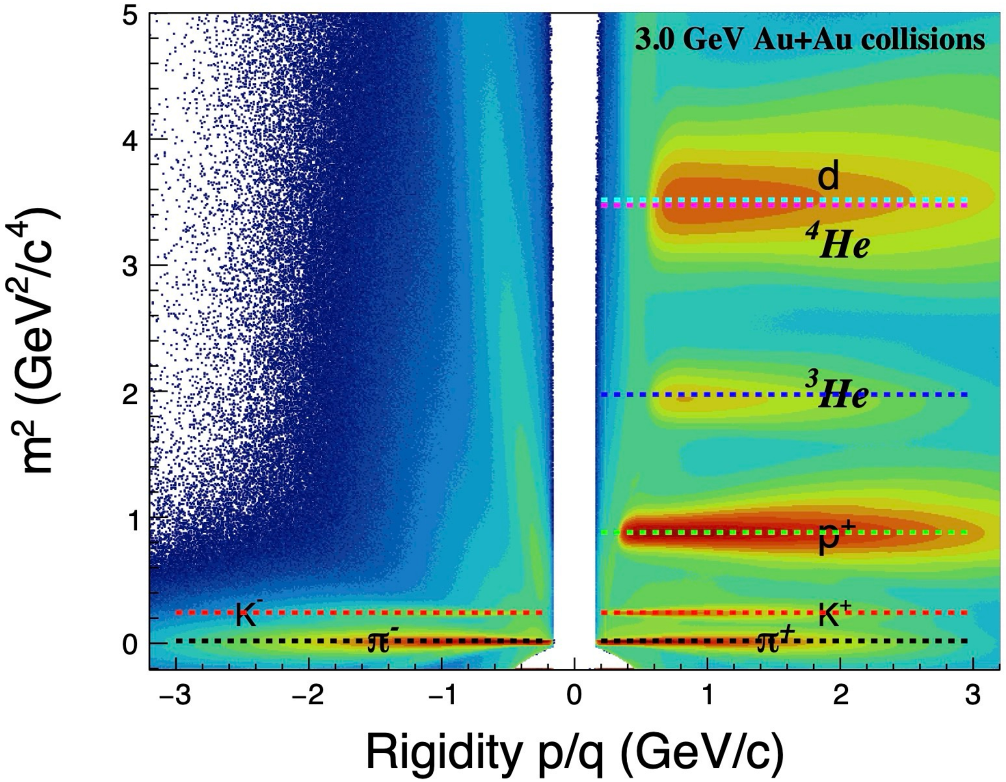


➢ High event plane resolution achieved at $\sqrt{s_{NN}}$ = 3.0 GeV.

➢ EPD-AB is selected for v_1 extraction

Particle Identification

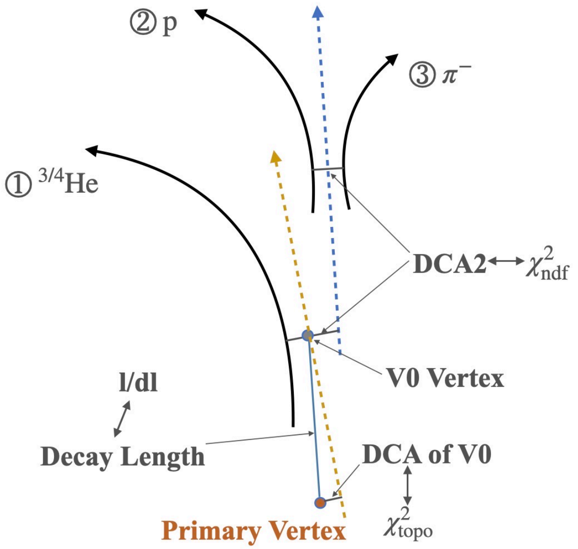




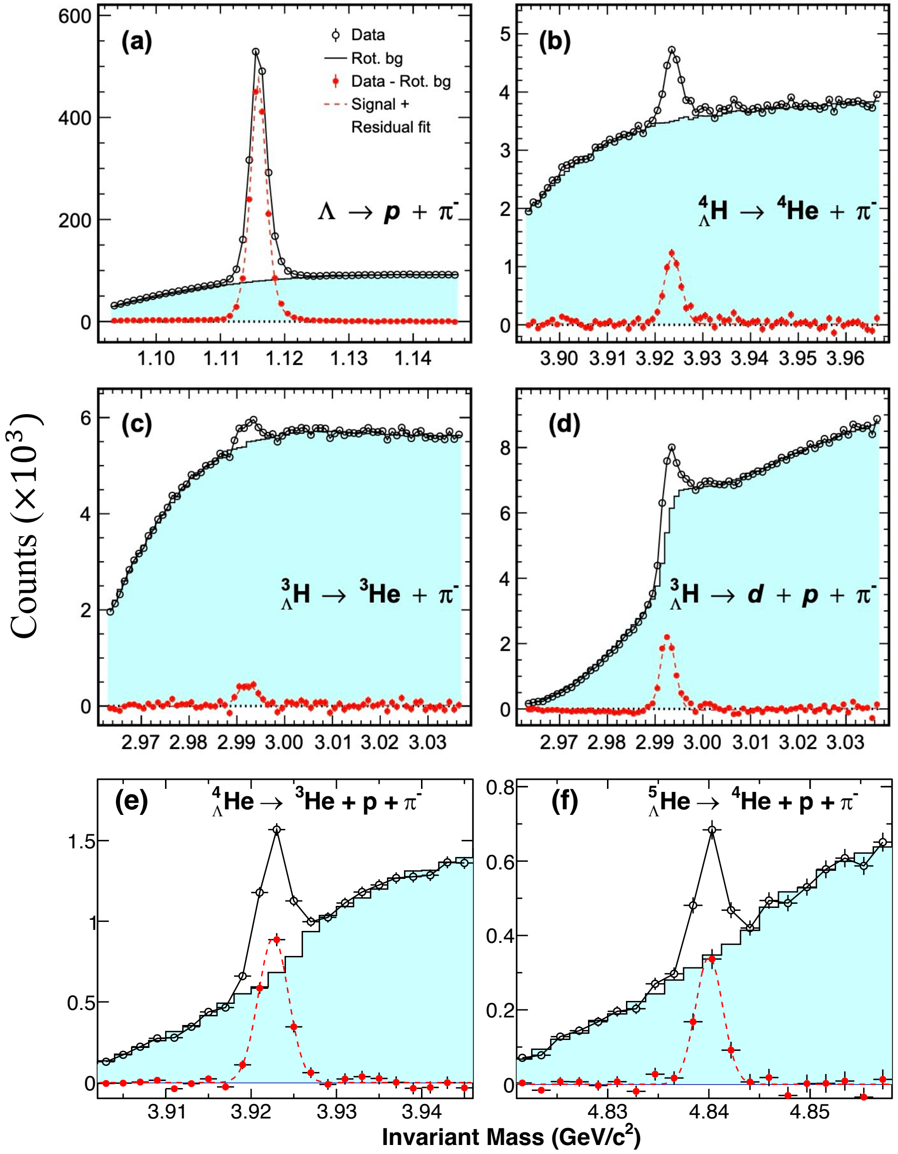
- The TPC enables excellent particle identification at low momentum through ionization energy loss (dE/dx) measurements.
- The TOF detector improves particle separation at higher momentum by providing squared mass (m^2) information.

Hyper-Nuclei Reconstruction

Decay Topology



- Hypernuclei are reconstructed using the KFParticle package, which applies a Kalman filter method to enhance signal significance.
- Clear signals are observed in the invariant mass spectra. The $^5_\Lambda$He is observed for the first time with a significance of ~14.



Run18

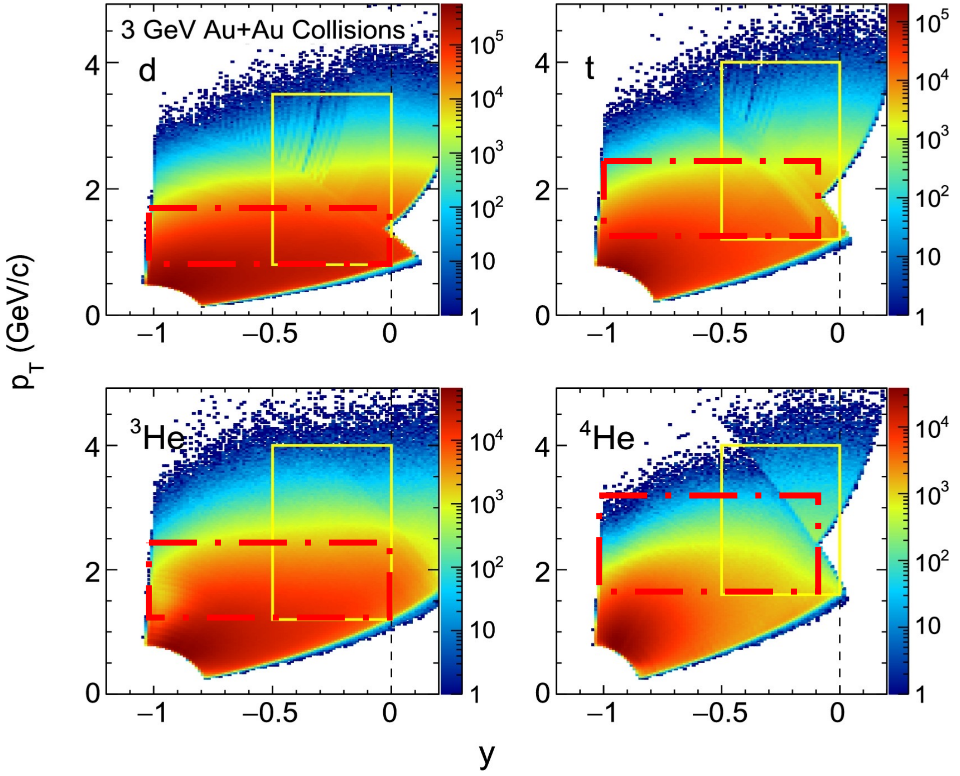
Run21

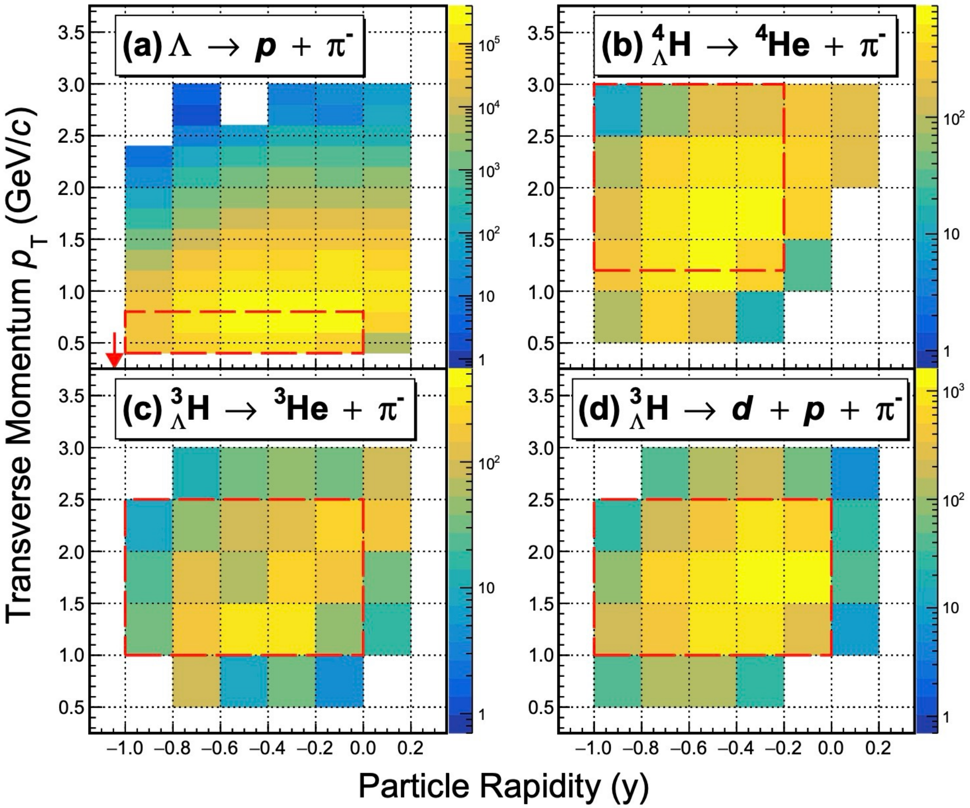
[1] Gorbunov and I. Kisel, Reconstruction of decayed particles based on the Kalman filter. CBM-SOFT-note-2007-003, 7 May 2007

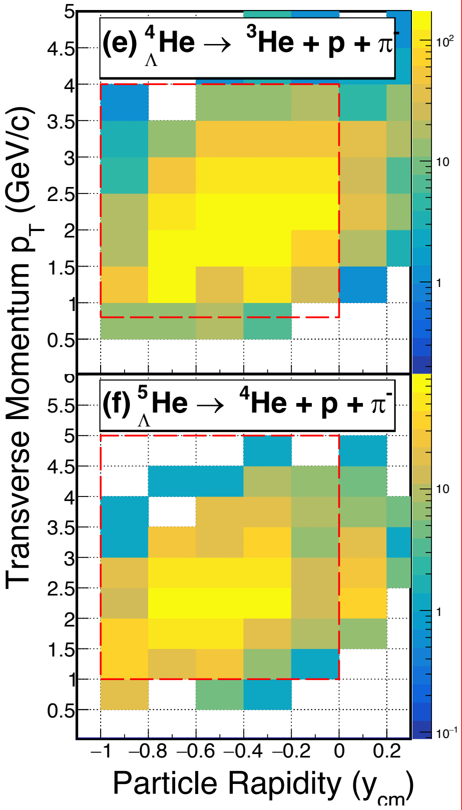
[2] KF Particle Finder: M. Zyzak, Dissertation thesis, Goethe University of Frankfurt, 2016.

Light Nuclei and Hyper-Nuclei Acceptance

From Xionghong He's talk: 17:55 Mon.







- ❑ Signal yields are extracted using a bin counting method.

[1] Abdallah, M.S. *et al.*, Phys.Lett.B **827**, 136941, 2022.
[2] Aboona, Bassam *et al.*, Phys.Rev.Lett. **130**, 212301, 2023.

- ❑ The directed flow of light nuclei and hyper-nuclei is calculated within the p_T and y range, marked by red dashed boxes.

Directed Flow v_1 Extraction

Extract v_1 with InvMass Method:

- Calculate the mean azimuthal angle relative to the event plane, $\cos[n(\phi - \psi_m)]$, as a function of M_{inv}

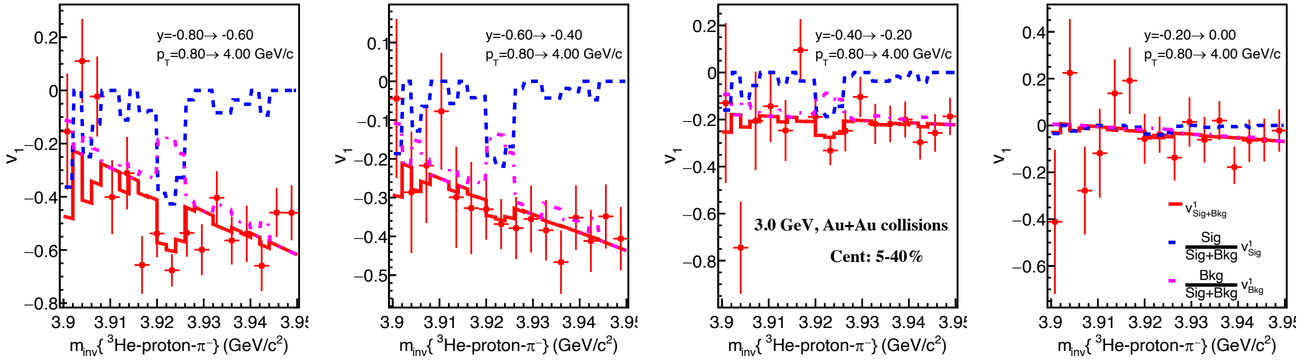
$$v_n^{S+B}(M_{inv}) = \langle \cos[n(\phi - \psi_m)]_{inv} \rangle$$
$$= v_n^S \frac{S}{S+B}(M_{inv}) + v_n^B(M_{inv}) \frac{B}{S+B}(M_{inv})$$

  Here, S is the signal yield peaked at the M_{inv} of the particle, B is the background yield, v_n^S, v_n^B and v_n^{S+B} are the v_n for signal, background and the total particles, respectively.

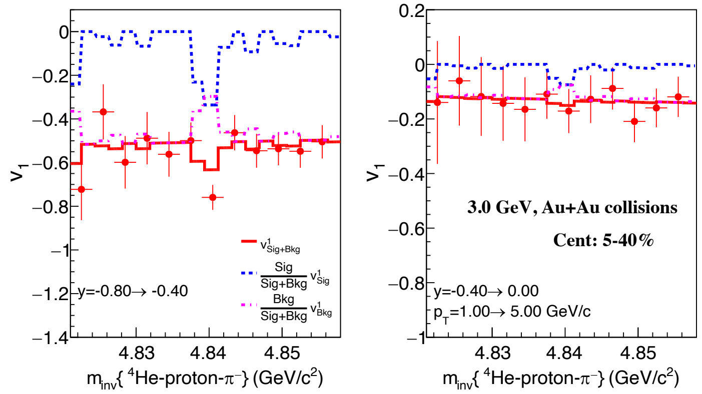
- v_n^B is parameterized as a first order polynomial $v_n^B = p_0 + p_1 M_{inv}$. v_n^S can be obtained as a free parameter of the fit.
- Add $1/R_n$ as a weight when filling the histograms of $\cos[n(\phi - \psi_m)]$ as a function of M_{inv}.

H. Masui et al., Nucl. Instrum. Methods Phys. Res. A **833**, 181 (2016)

$^4_\Lambda He$

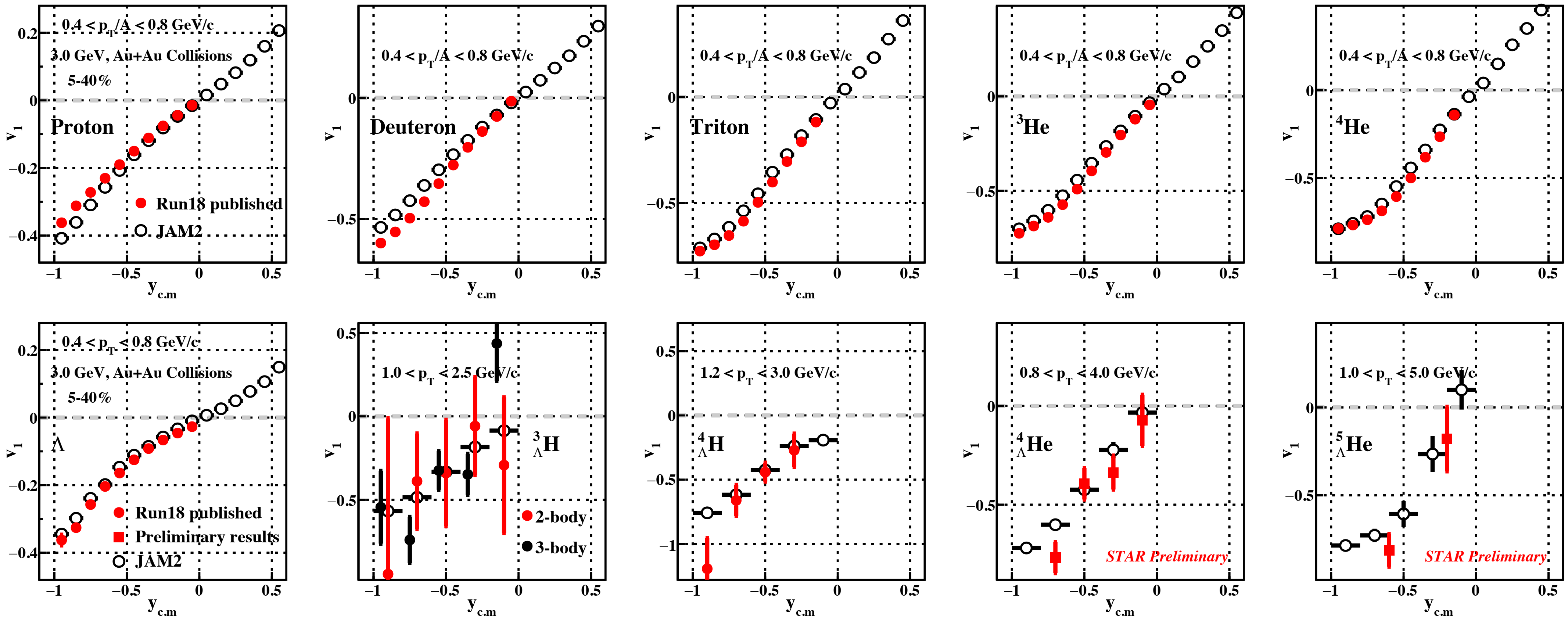


$^5_\Lambda He$



Fitting function: $v_1 = p_0 * \frac{S}{S+B} + (p_1 + p_2 * M_{inv}) * \frac{B}{S+B}$

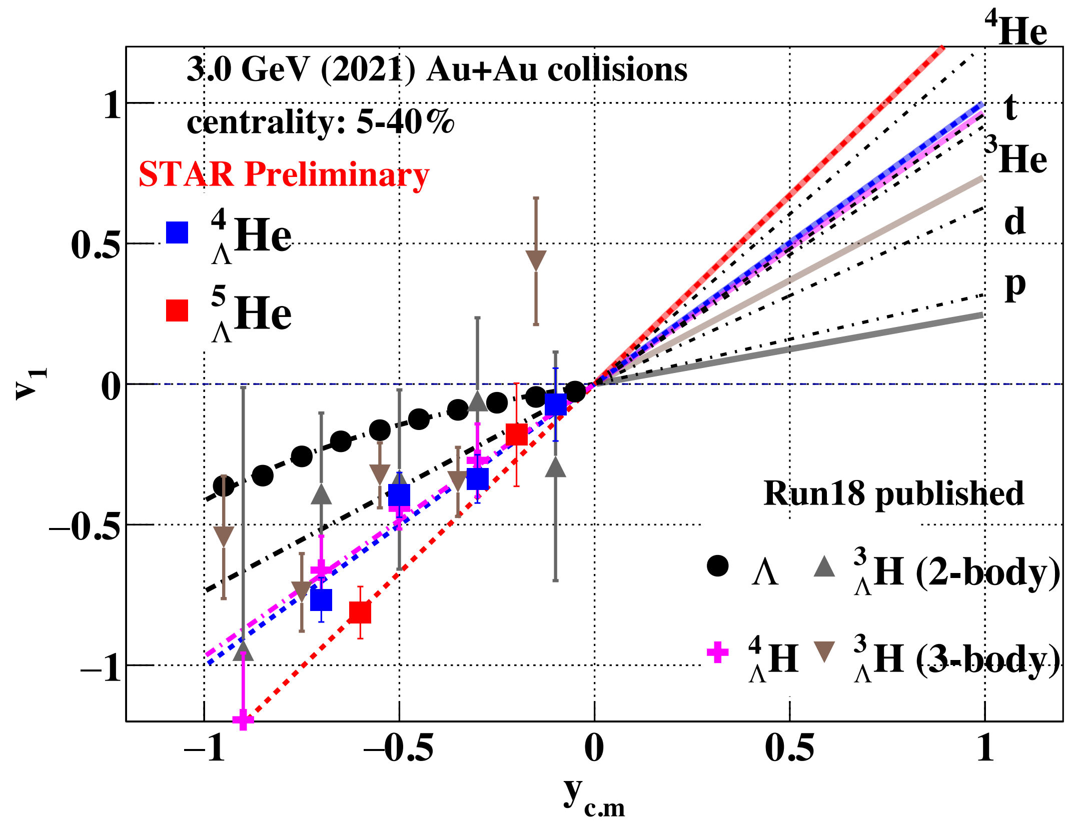
Light Nuclei and Hyper-Nuclei Directed Flow v_1



- Hadronic transport model (JAM2 mean field (κ = 380 MeV) + Coalescence) calculations describes the observed v_1 as a function of rapidity well for both light nuclei and hyper-nuclei.

[1] Abdallah, M.S. *et al.*, Phys.Lett.B **827**, 136941, 2022.
[2] Aboona, Bassam *et al.*, Phys.Rev.Lett. **130**, 212301, 2023.
[3] Y.Nara *et al.*, Phys.Rev.C **106**, 044902, 2022.

Particle Mass Dependence



- The v_1 slope is extracted by fitting the $v_1(y)$ distribution with a polynomial function, where p_0 corresponds to the v_1 slope at mid-rapidity ($dv_1/dy|_{y=0}$)

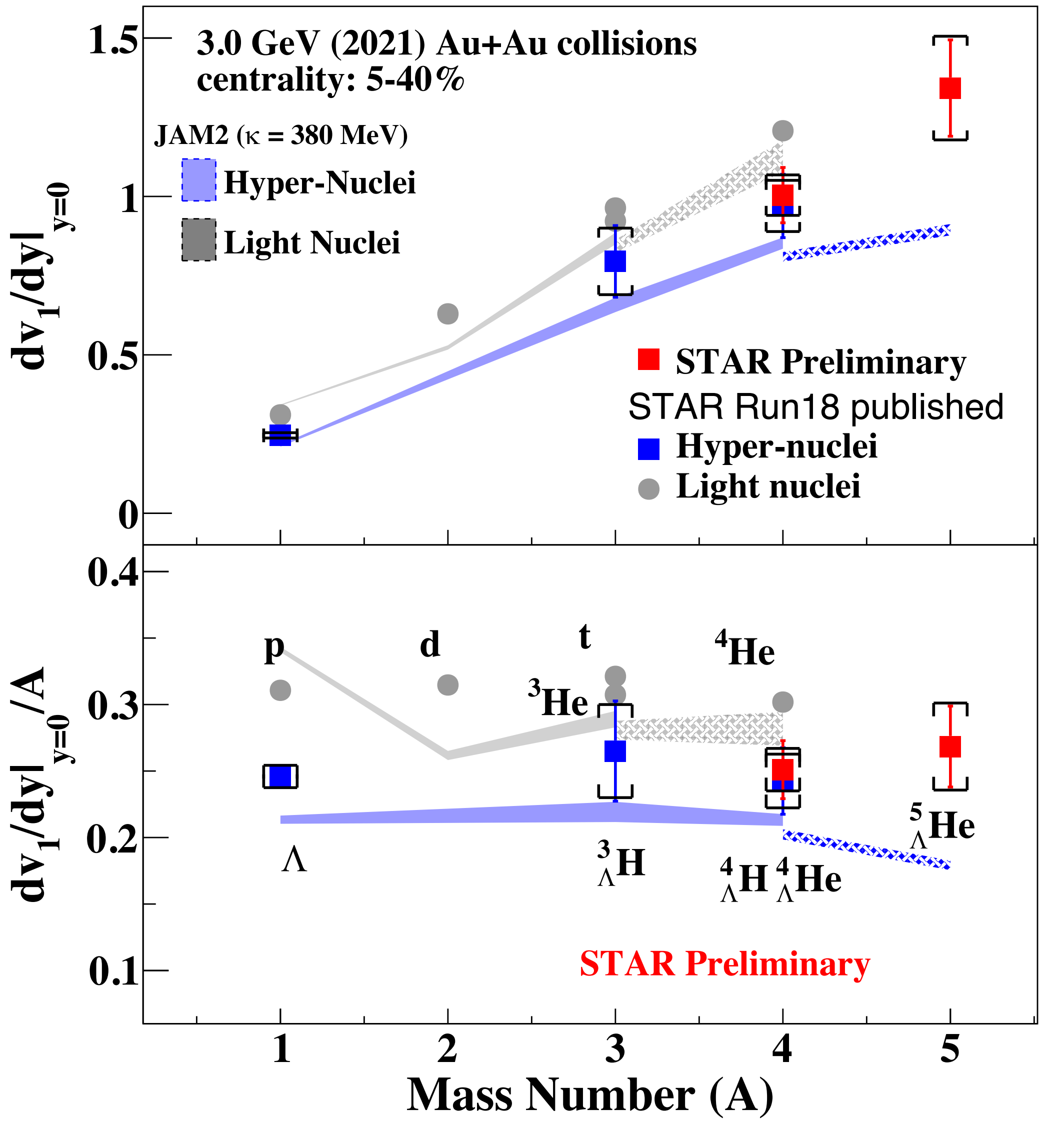
Hyper-Nuclei	Fitting Function
Λ	$v_1(y) = p_0 \cdot y + p_1 \cdot y^3$
$^{3}_{\Lambda}$H, $^{4}_{\Lambda}$H, $^{4}_{\Lambda}$He, $^{5}_{\Lambda}$He	$v_1(y) = p_0 \cdot y$

Light-Nuclei	Fitting Function
p, d, t, ^{3}He, ^{4}He	$v_1(y) = p_0 \cdot y + p_1 \cdot y^3$

- In mid-central collisions, the directed flow (v_1) of both light nuclei and hyper-nuclei increases with rapidity, and its slope at mid-rapidity becomes larger with increasing mass number (A).
- This mass ordering reflects the collective motion of the constituent nucleons or hyperons, which is consistent with a coalescence picture.

[1] Abdallah, M.S. *et al.*, Phys.Lett.B **827**, 136941, 2022.
[2] Aboona, Bassam *et al.*, Phys.Rev.Lett. **130**, 212301, 2023.

Particle Mass Dependence



- The directed flow v_1 of light nuclei exhibits nucleon mass scaling, whereas that of hyper-nuclei is consistent with Λ hyperon mass scaling .

- The JAM2+coalescence model generally describes the experimental data.
  - The JAM2 + coalescence model slightly underestimates the data.

[1] Abdallah, M.S. *et al.*, Phys.Lett.B **827**, 136941, 2022.
[2] Aboona, Bassam *et al.*, Phys.Rev.Lett. **130**, 212301, 2023.
[3] Y.Nara *et al.*, Phys.Rev.C **106**, 044902, 2022.

Summary

1) Presented the directed flow (v_1) of light nuclei and hyper-nuclei in 3.0 GeV Au+Au collisions.

2) The v_1 of light and hyper-nuclei increases with mass number (A), indicating a clear mass ordering.

3) The JAM2 + coalescence model generally describes the experimental data, although it slightly underestimates the measurements.

Outlook:

1) Analyze v_1 of other hyper-nuclei (Λ, ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$) using the 2-billion-event dataset (Run21) in 3.0 GeV Au+Au collisions to achieve larger acceptance and improved precision.

2) Extract v_2 of hyper-nuclei from the 2-billion-event dataset in 3.0 GeV Au+Au collisions.

Thank you for your attention!