

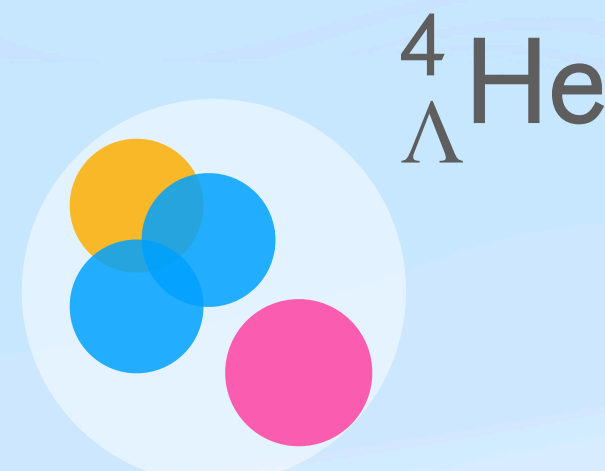
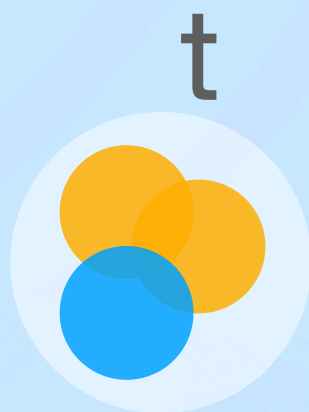


New Hypernuclei Measurements from STAR

n

p

Λ

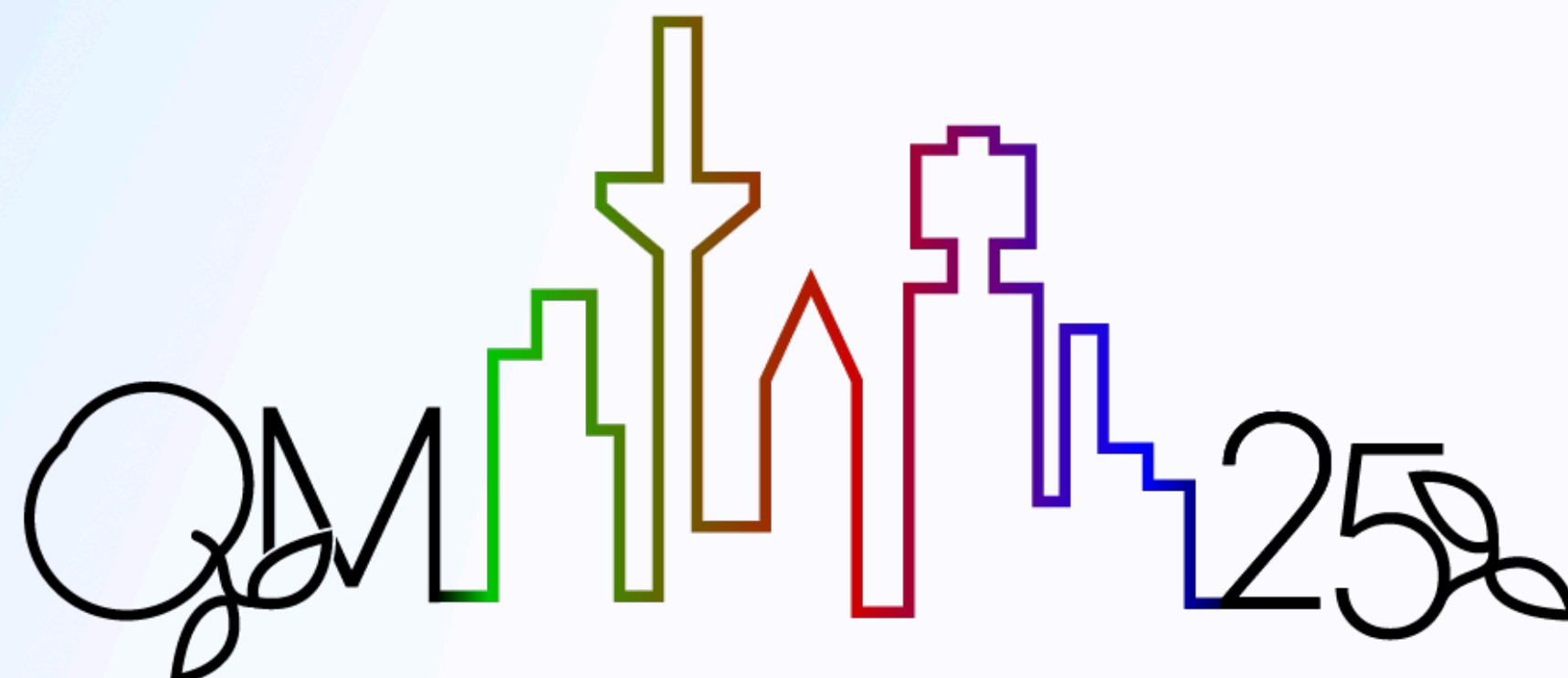


Outline

1. Introduction
2. Yields and Yield Ratios
3. Transverse Momentum Distribution
4. Collective Flow
5. Summary and Outlook

*Yingjie Zhou for the STAR Collaboration
CCNU, GSI*

Quark Matter 2025, Frankfurt, Germany



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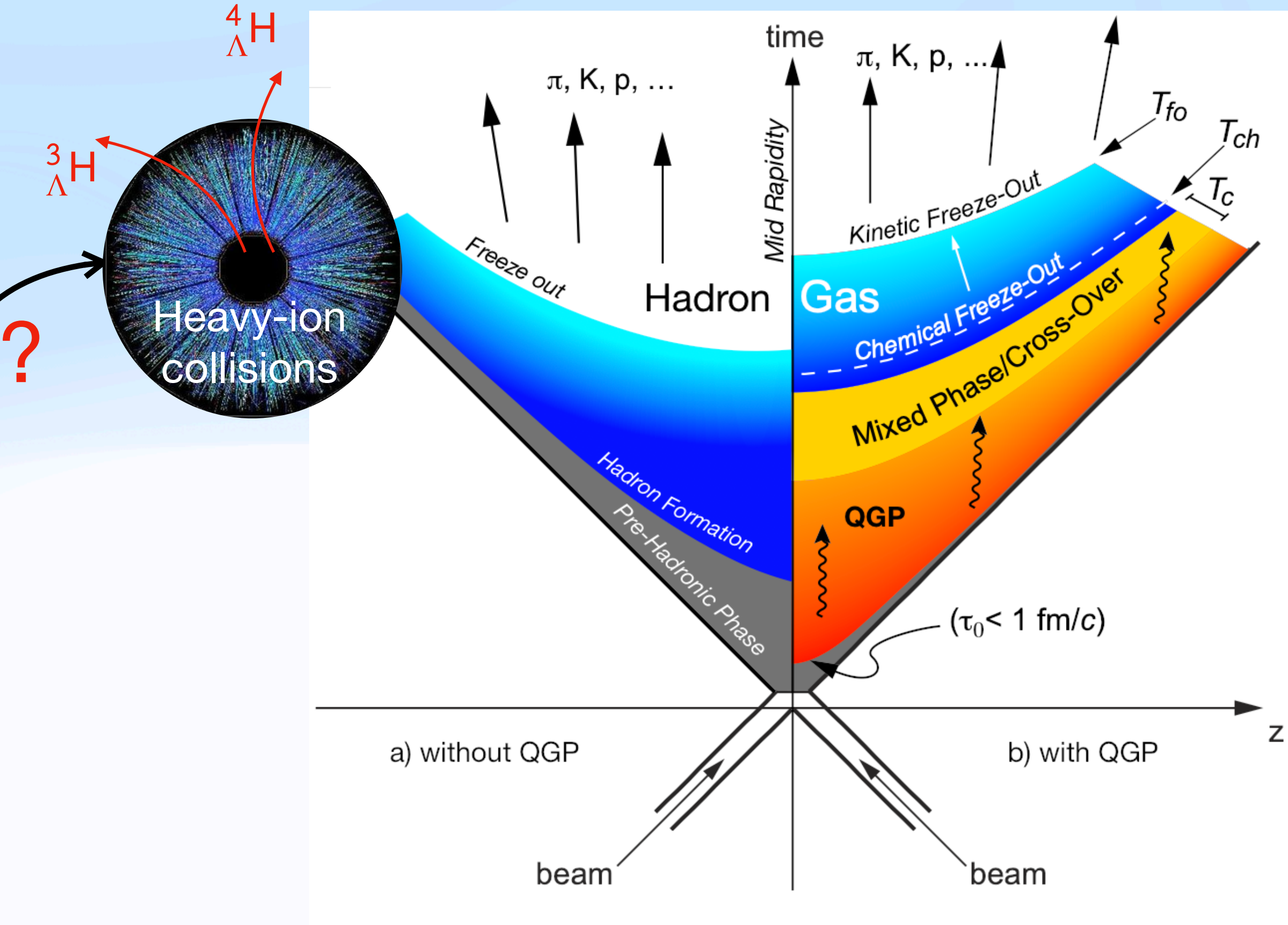
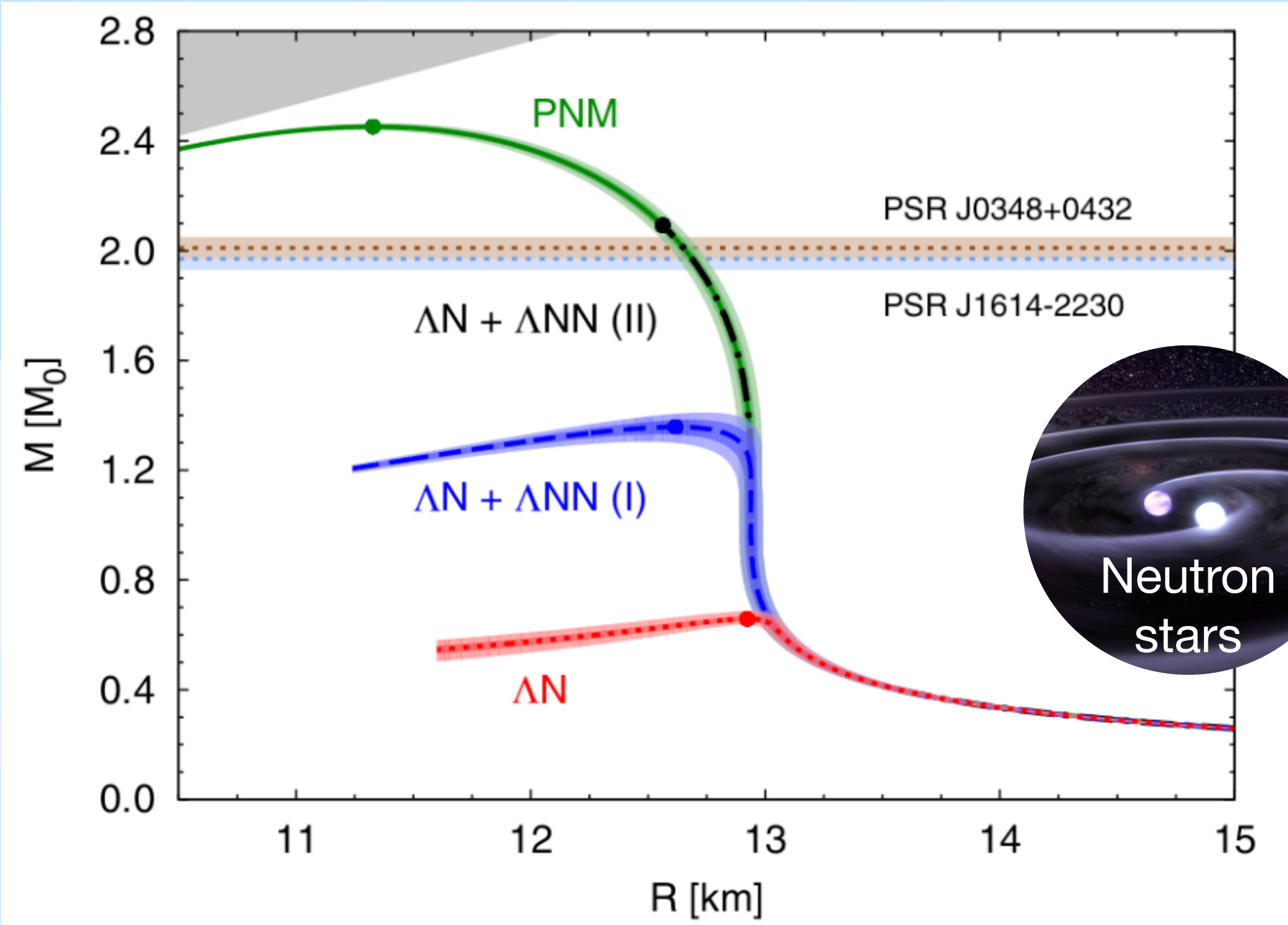
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Hypernuclei and Hyperon-Nucleon (Y-N) Interaction

- **Hyperon Puzzle:** difficulty to reconcile the measured masses of neutron stars with the presence of hyperons in their interiors
- Hypernuclei have been measured in heavy-ion collisions over a broad range of baryon densities

D. Lonardoni et al., PRL 114, 092301 (2015)



- Density dependent YN, YNN interactions are essential for solving the hyperon puzzle
- Can hypernuclei production be used to constrain the in-medium Y-N interaction?

Hypernuclei Production Mechanisms

When are nuclei produced in a heavy-ion collision?

1. Thermal models

- Hadrons and (hyper-)nuclei are treated equally
- Yields are predicted with thermal equilibrium assumptions

✗ Y–N dynamics have minimal impact on final yield

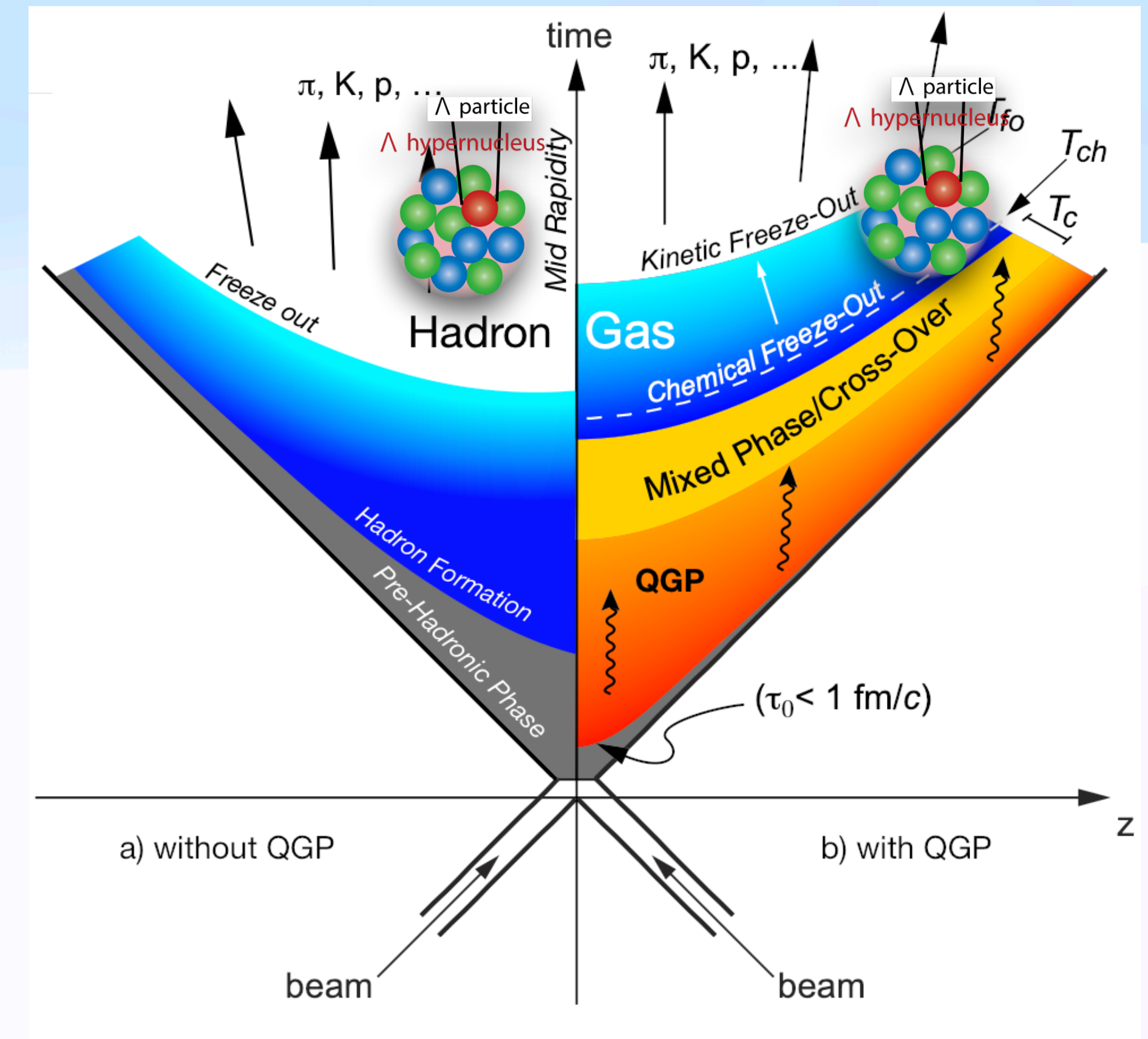
2. Coalescence model

- (Hyper-)nuclei formation after kinetic freeze-out
- Nucleon coalescence
 - Wigner function
 - Emission source size and nuclear radius

✓ In-medium Y–N interactions modify freeze-out phase space, affecting coalescence and hypernuclei yields

Nuclear matter production

*Need a solid understanding in **hypernuclei production mechanisms** before we can use them to probe the in-medium Y–N*



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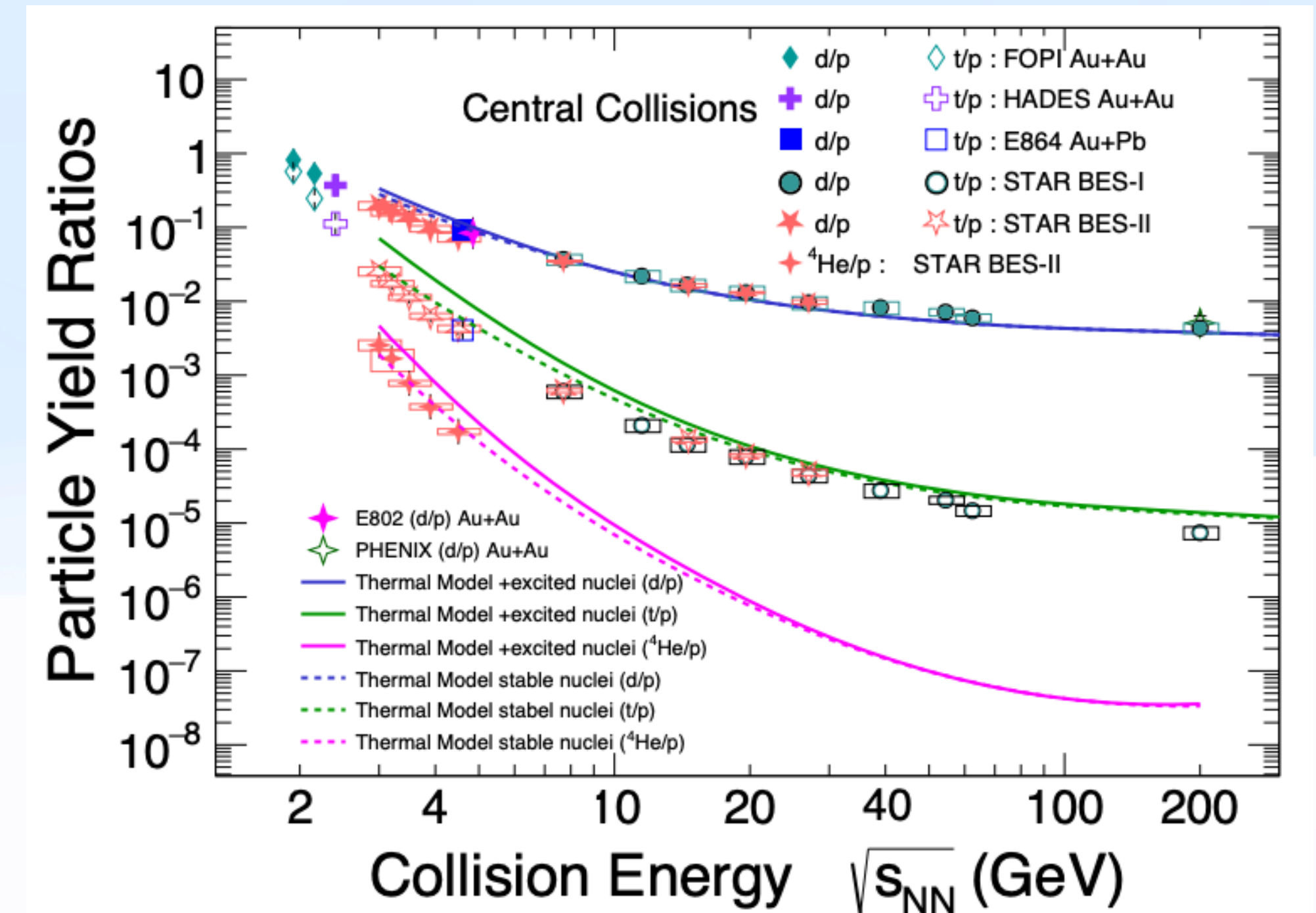
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What have we learnt from light nuclei production?

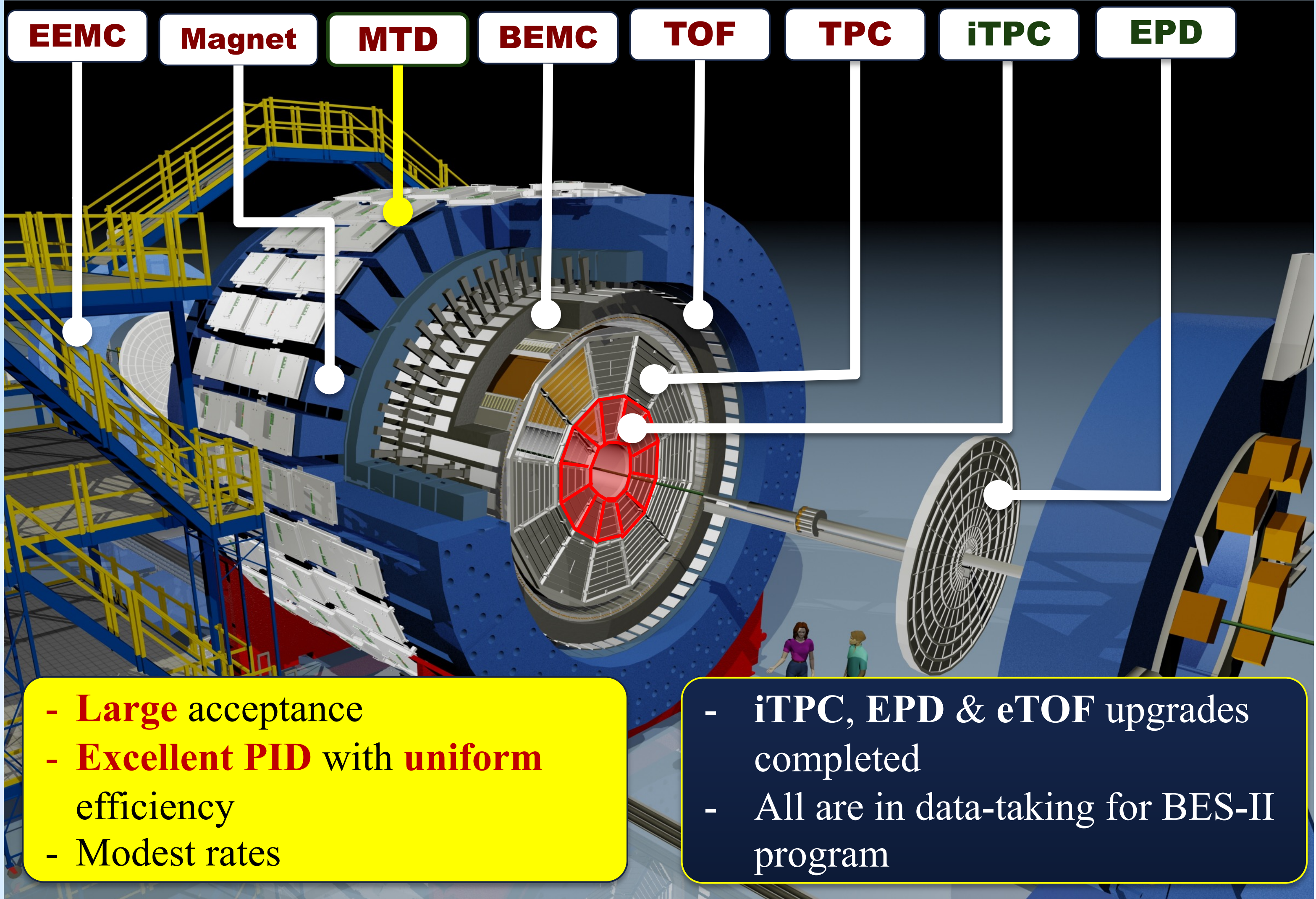
See poster by Liubing Chen (xx/xx)



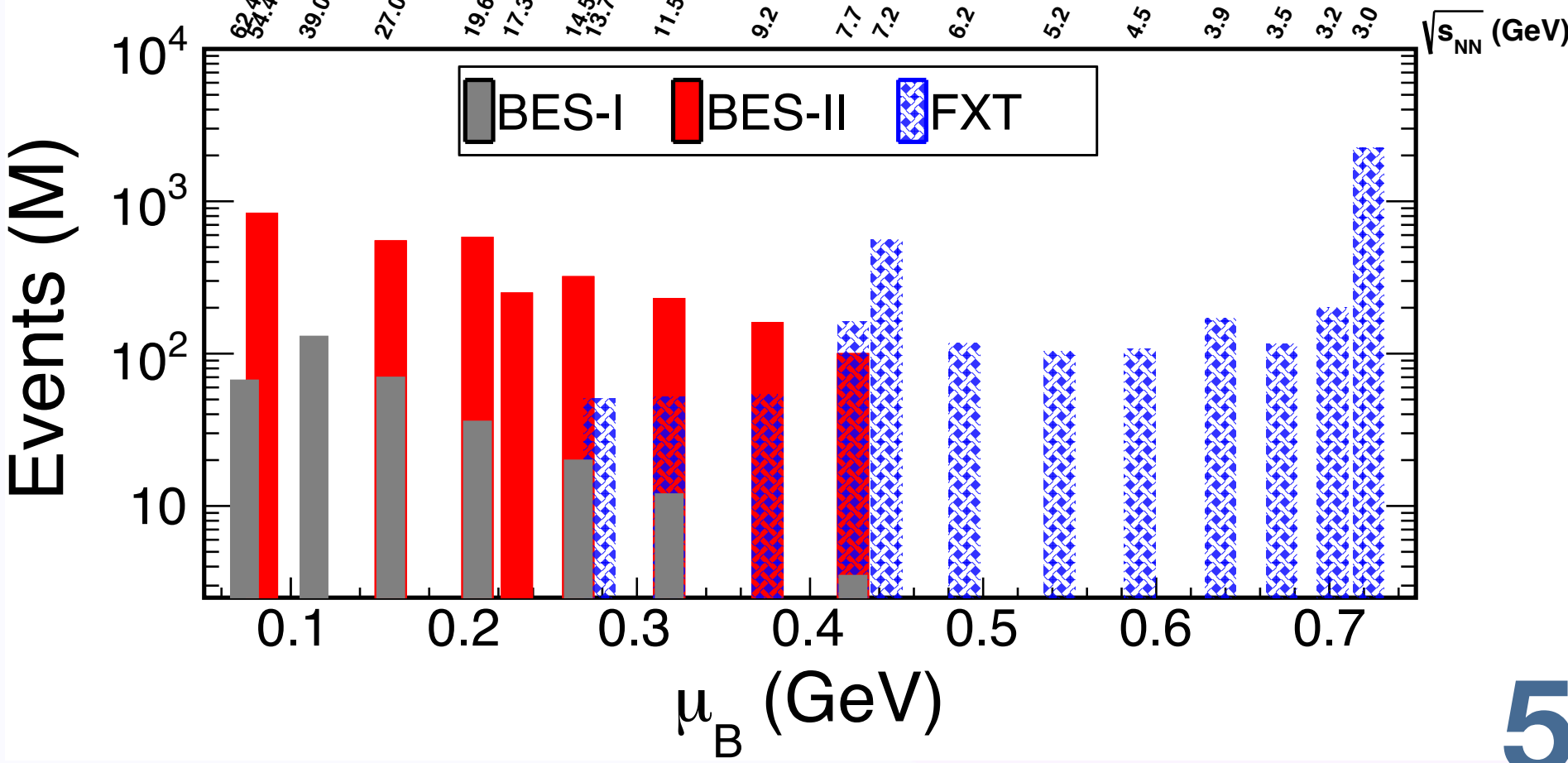
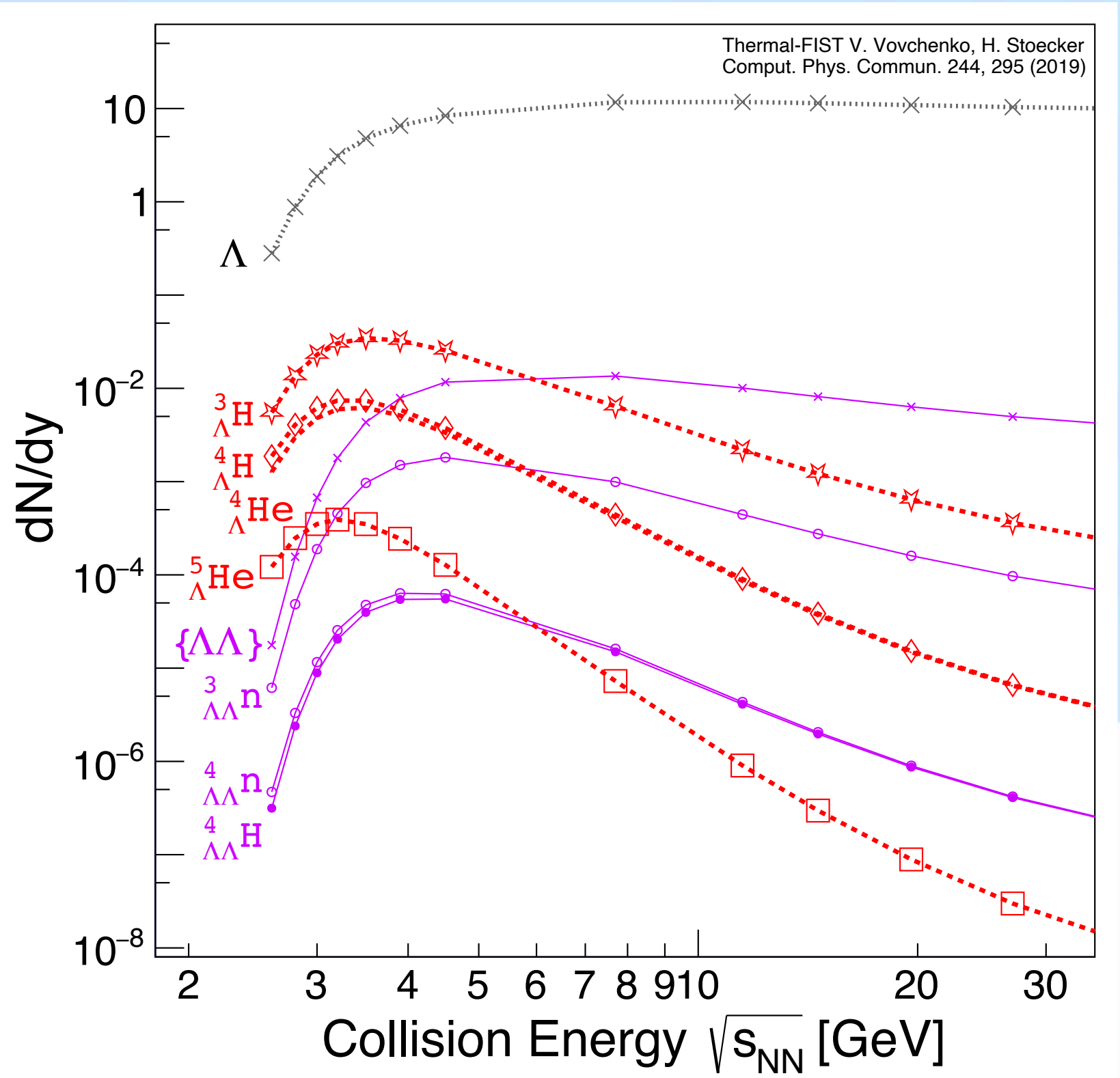
- d/p is fairly well described by thermal model, but t/p , $^4\text{He}/p$ is overestimated

Recent nuclei measurements poses challenges for thermal model

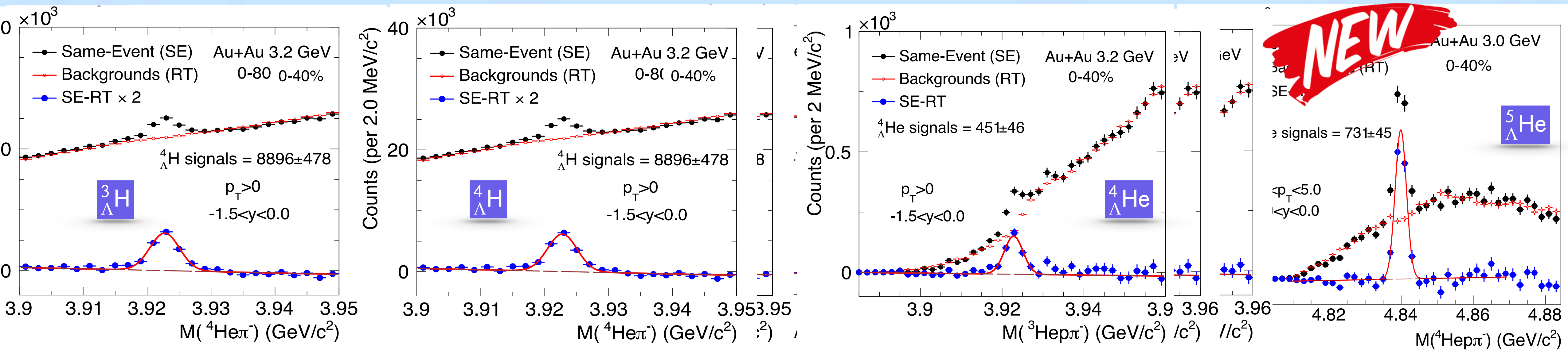
STAR and Beam Energy Scan



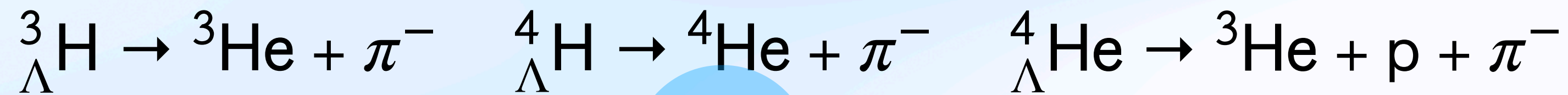
- RHIC BES-II offers great opportunity for hypernuclei measurements



Hypernuclei reconstruction



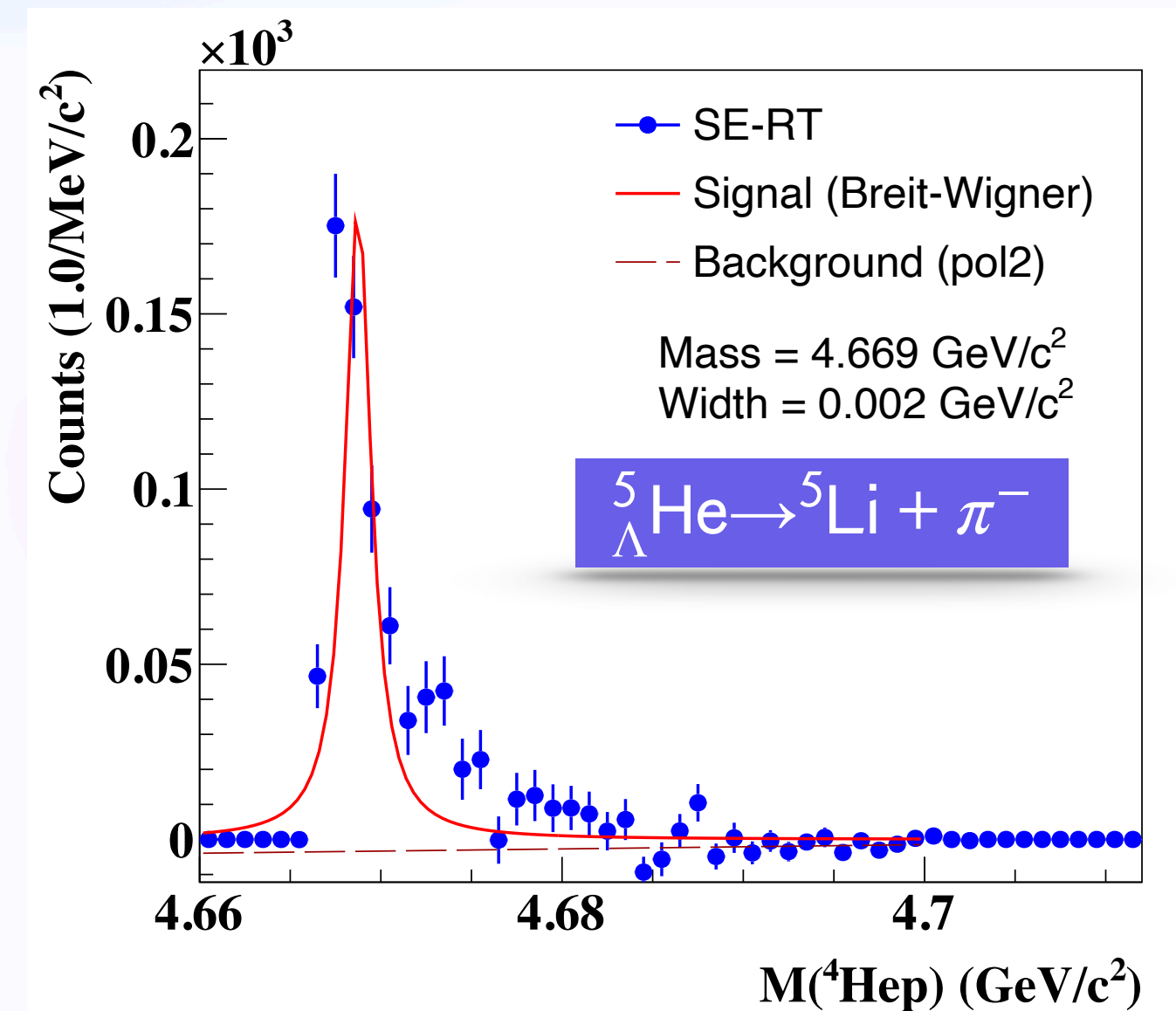
- Hypernuclei are reconstructed using the following decay channels:



Helps to constrain Λ -N and Λ NN

H. Le et al., PRL 134, 072502 (2025)
A. Jinno et al., PRC 110, 014001 (2024)

- Combinatorial background estimated via rotating fragments tracks or event mixing
- Efficiency correction using a **data-driven** GEANT simulation
 - To account for the decay kinematics of ${}^4_{\Lambda}\text{He}$, ${}^5_{\Lambda}\text{He}$, the three-body decay phase space is weighted according to the Dalitz plot from data



Hypernuclei p_T Spectra and Rapidity

- Measurements cover different energies

- $^3_{\Lambda}\text{H}$ in Au+Au collisions at **3-27 GeV**, Au+Au collisions at **200 GeV**

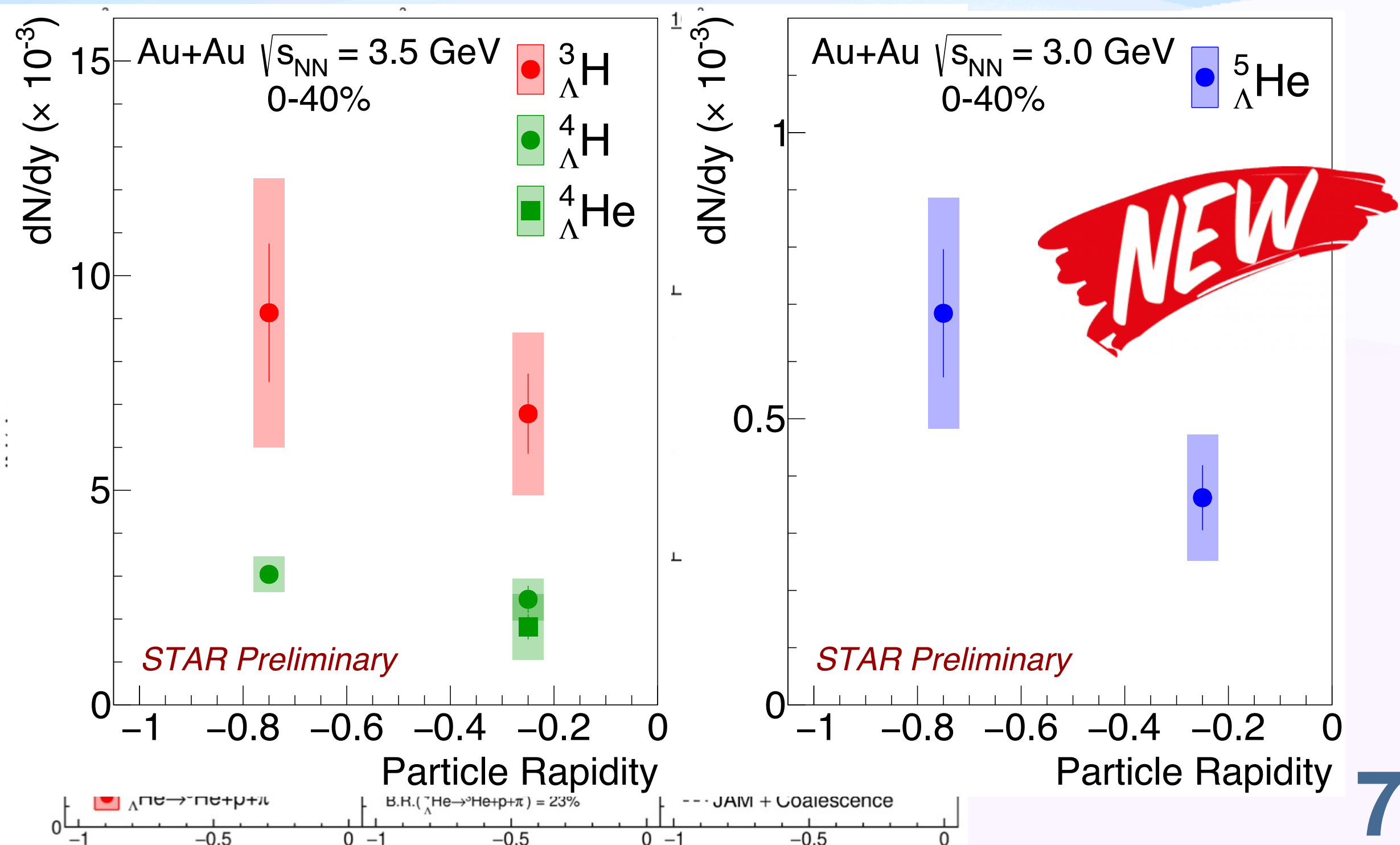
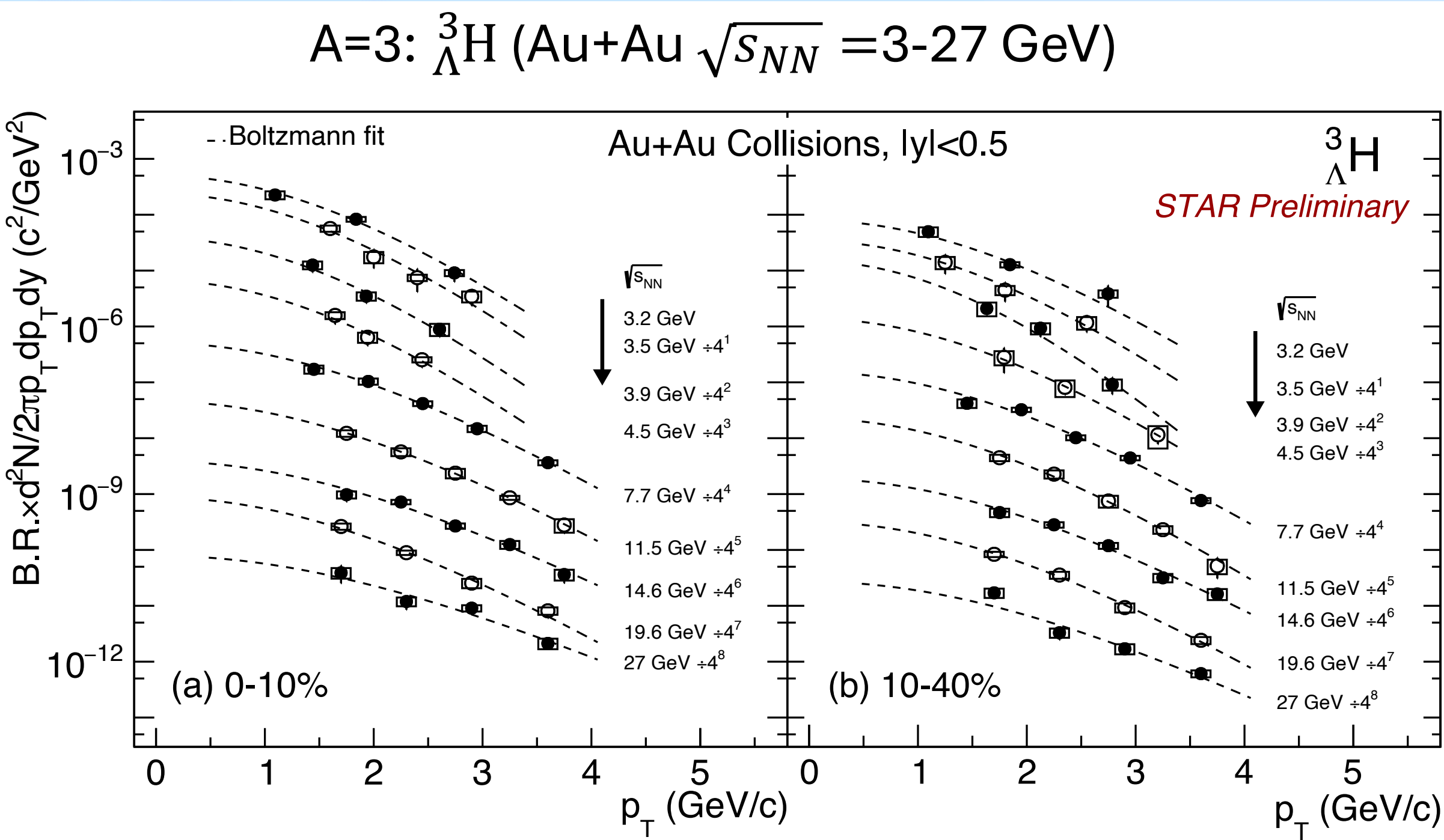


- $^4_{\Lambda}\text{H}$, $^4_{\Lambda}\text{He}$ in Au+Au collisions at **3-3.5 GeV**

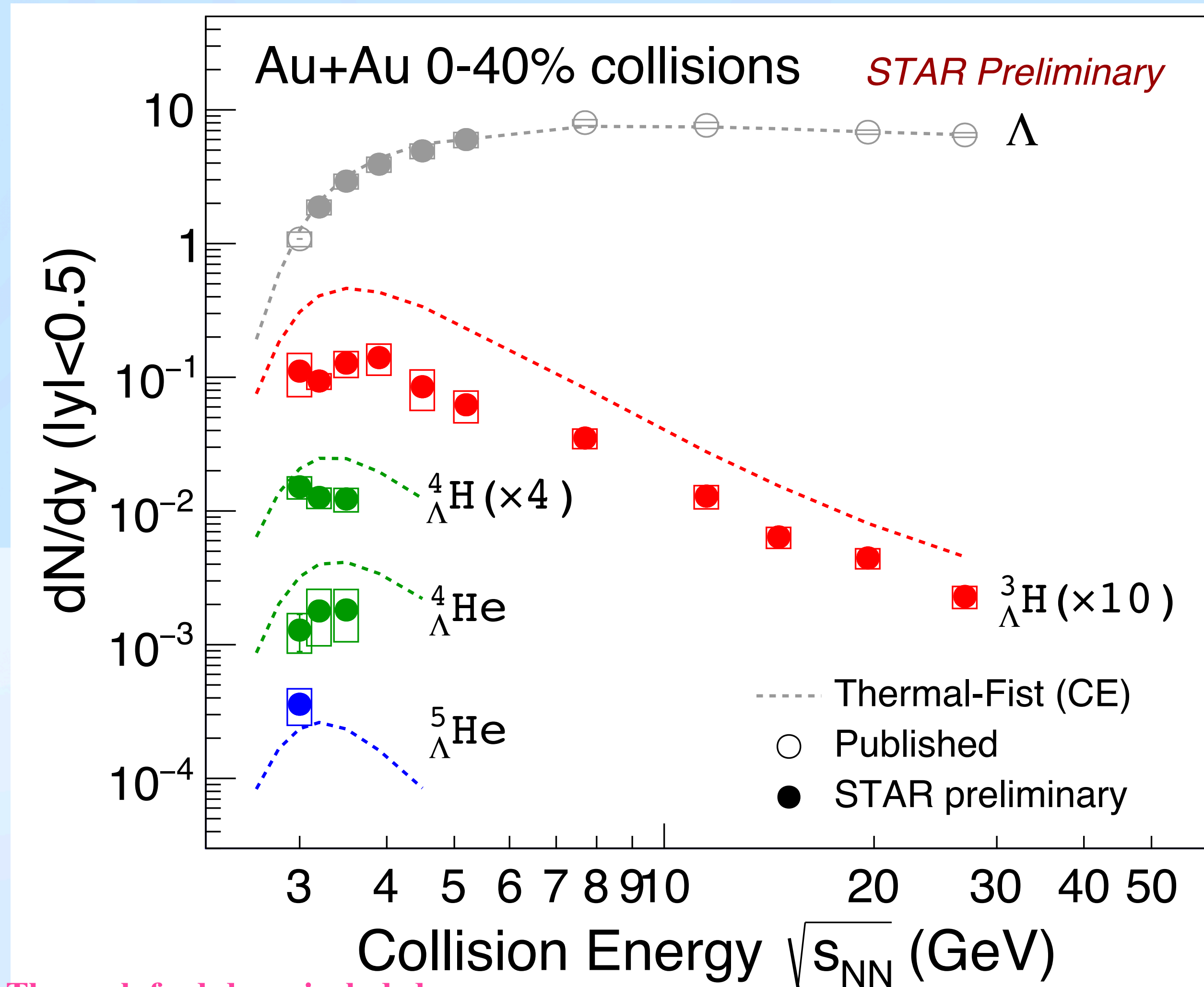
- $^5_{\Lambda}\text{He}$ in Au+Au collisions at **3 GeV**

- Significant hypernuclei production at target rapidity, more pronounced for heavier hypernuclei
Spectator matter matters at target rapidity

A. S. Botvina et al., PRC 84, 064904 (2011)



Excitation Function



Thermal: feed-down included

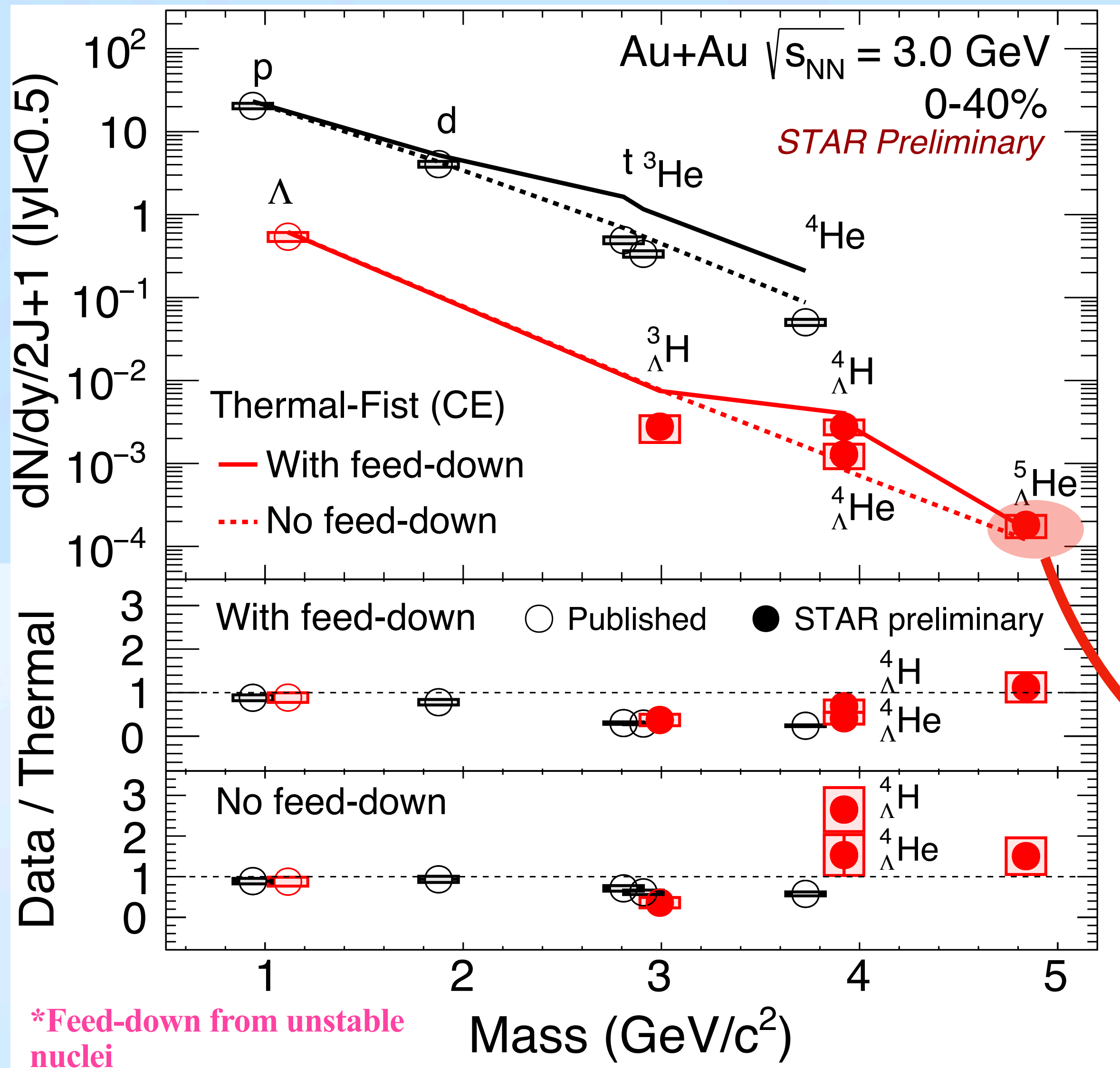
- ${}^3_{\Lambda}\text{H}$ plateaus at $\sqrt{s_{NN}} = 3\text{-}4$ GeV
- Similar trend for ${}^4_{\Lambda}\text{H}$ and ${}^4_{\Lambda}\text{He}$

Interplay between increasing baryon production and stronger strangeness canonical suppression towards low energies

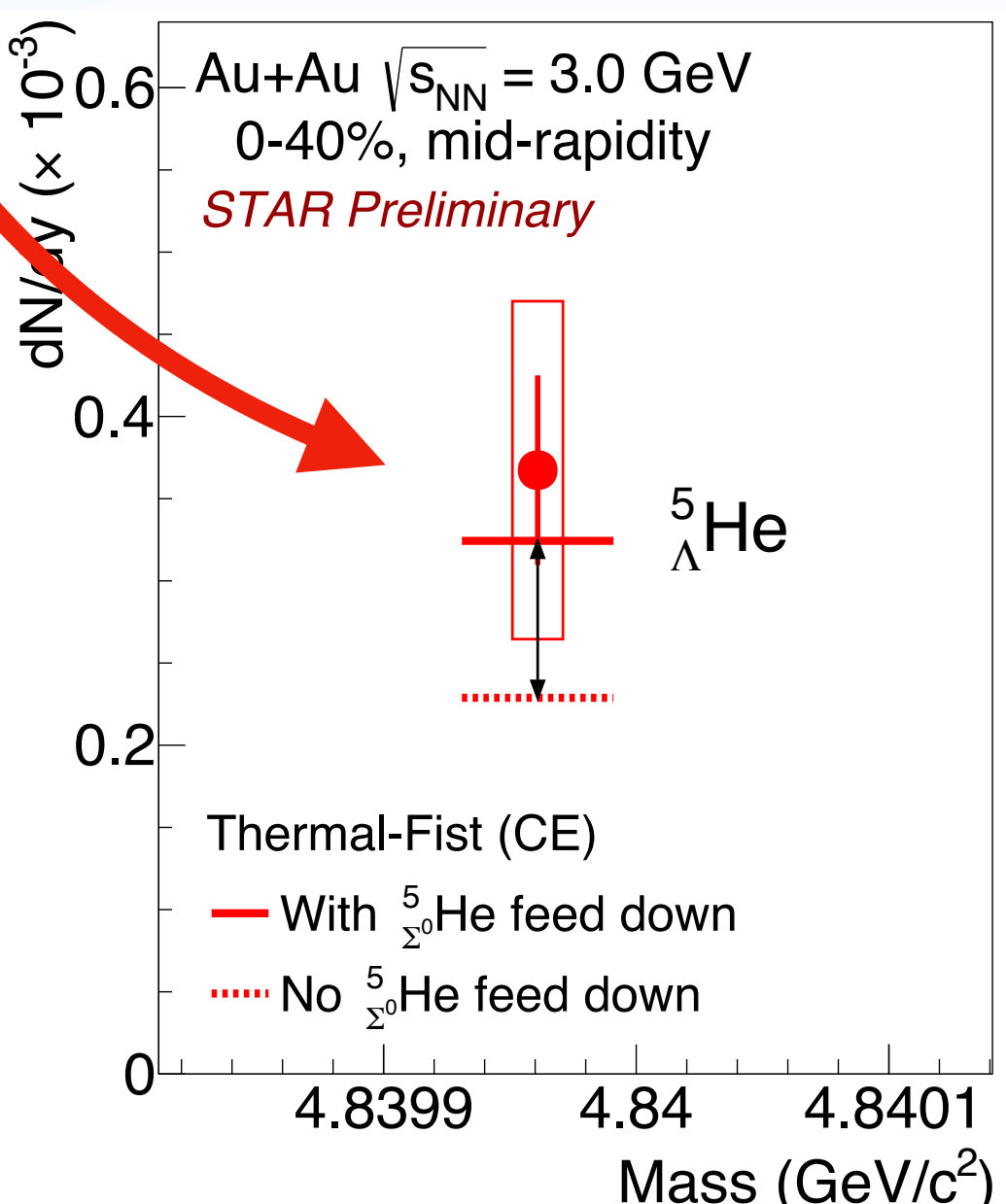
*Establishes **low energy** collision experiments as a promising tool to study **exotic strange matter***

- Thermal describes Λ , **over-estimate** ${}^3_{\Lambda}\text{H}$, ${}^4_{\Lambda}\text{H}$, and ${}^4_{\Lambda}\text{He}$, slightly **under-estimate** ${}^5_{\Lambda}\text{He}$

Comparison to Thermal Model at 3 GeV



- Thermal model predicts approx. exponential dependence of yields/(2J+1) vs A
- Light nuclei overestimated by thermal with feed-down from unstable nuclei
- Evidence of the formation of $^4_{\Lambda}H$ and $^4_{\Lambda}He$ excited states

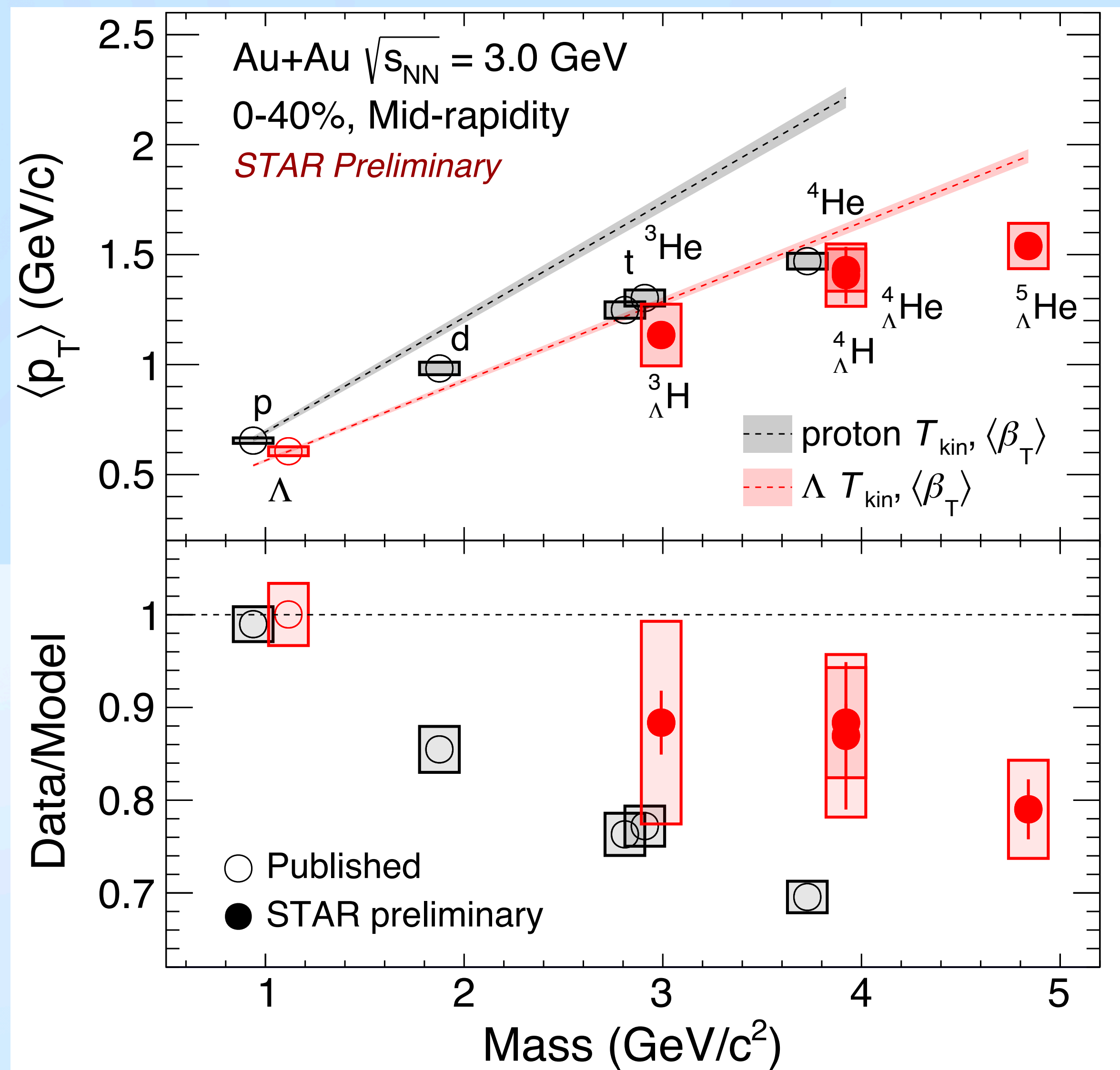


- Possible feed down from $^5_{\Sigma^0}He \rightarrow ^5_{\Lambda}He + \gamma$

STAR, PRC 110, 054911 (2024)
STAR, PRL 128, 202301 (2022)
STAR, JHEP **2024** (2024)139

J. Johnstone et al., J. Phys. G 8, L105 (1982)

Mean Transverse Momentum at 3 GeV



Blast wave function fit

$$\frac{d^2N}{2\pi p_T dp_T dy} = A \int_0^R r dr m_T \times I_0\left(\frac{p_T \sinh \rho(r)}{T_{kin}}\right) K_1\left(\frac{m_T p \cosh \rho(r)}{T_{kin}}\right)$$

T_{kin} : kinetic freeze-out temperature

$\langle \beta_T \rangle$: average transverse radial flow velocity, $\rho = \tanh^{-1} \beta_r$

n: the exponent of flow velocity profile, n=1

Hydrodynamic-inspired Blast-Wave model: assumes particles are emitted thermally from an expanding source with a common $\langle \beta_T \rangle$ and T_{kin}

- Vary the mass to construct the blast-wave prediction using p(Λ) freeze-out parameters

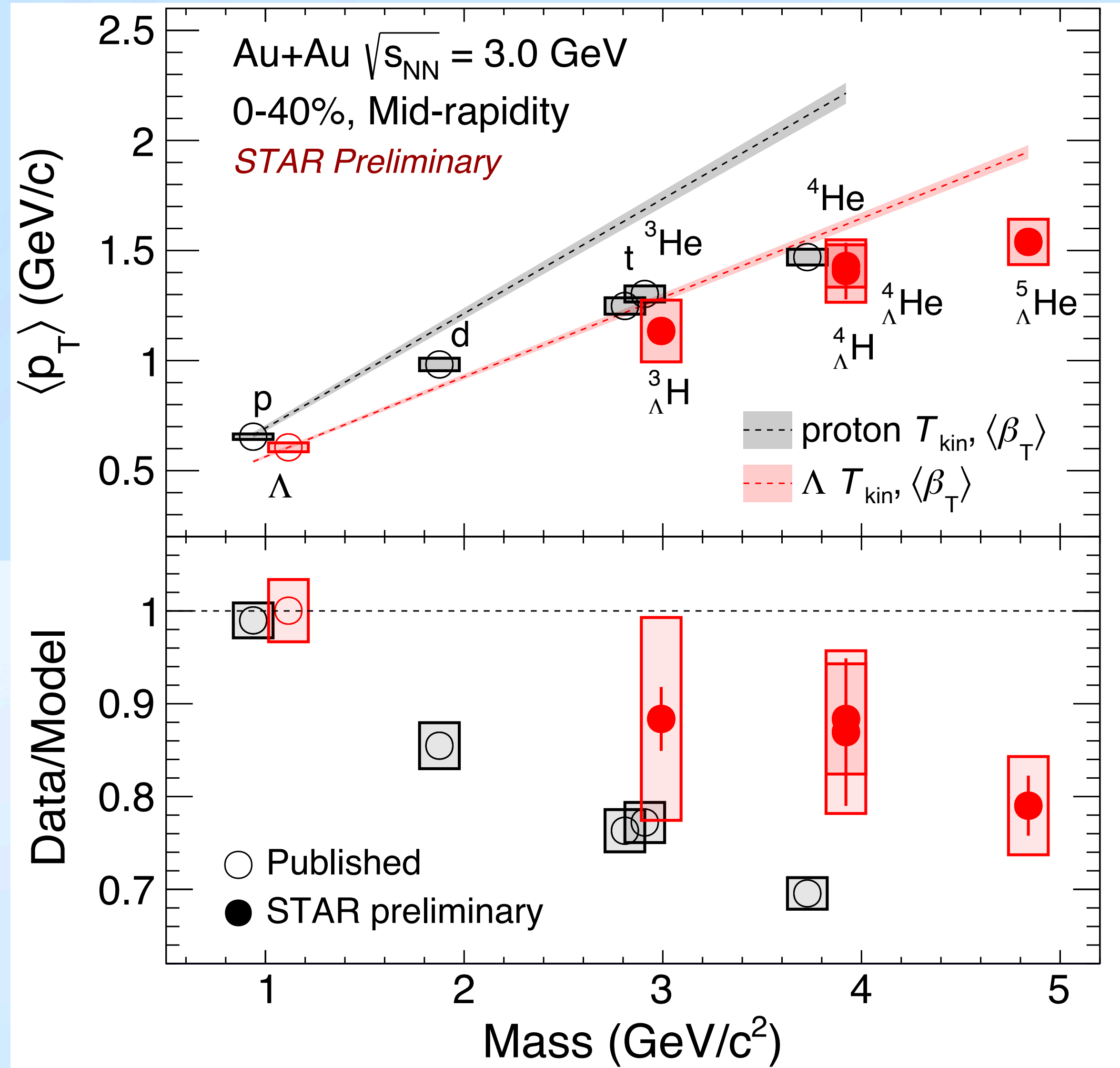
E. Schnedermann et al., PRC 48, 2462 (1993)
PLB 794, 50–63 (2019)

- Light nuclei and hypernuclei deviate from the full hydrodynamic picture

Coalescence scenario?

STAR, PRC 110, 054911 (2024)
STAR, PRL 128, 202301 (2022)
STAR, JHEP **2024** (2024)139

Mean Transverse Momentum at 3 GeV

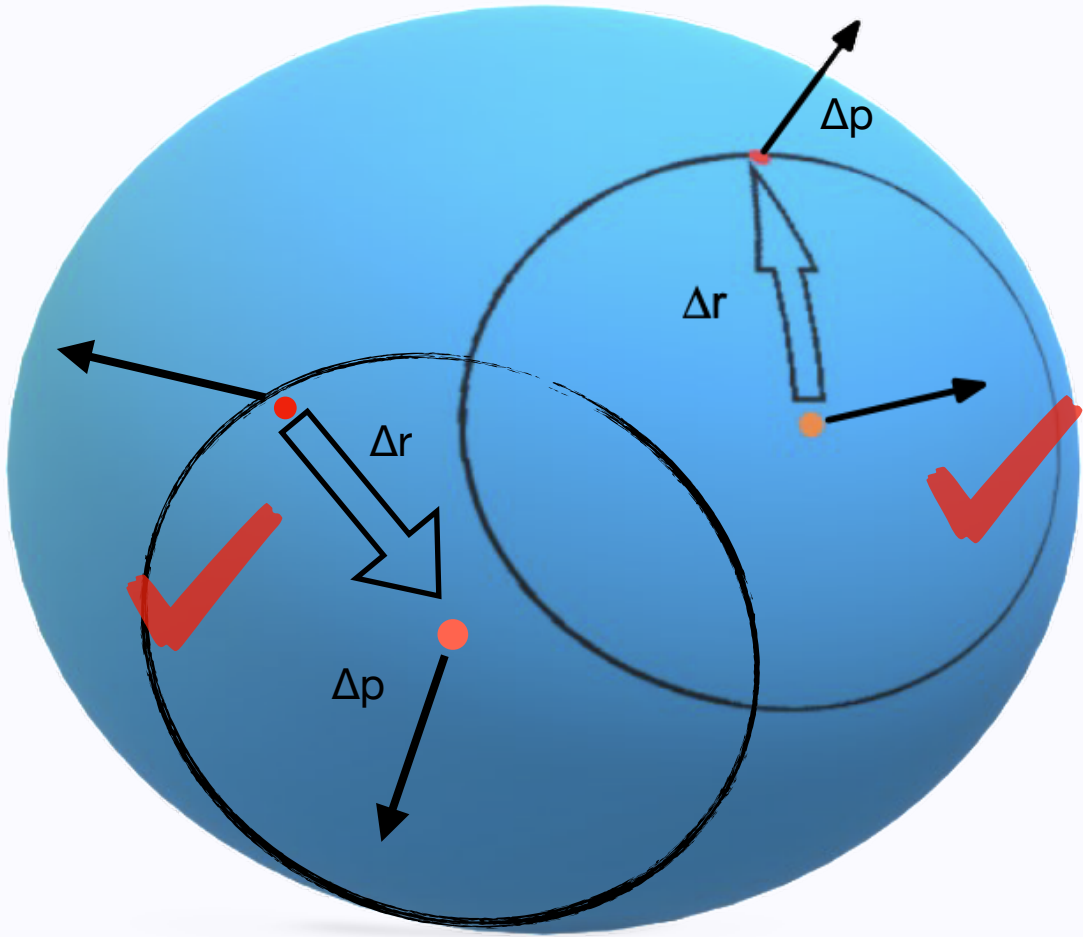


STAR, PRC 110, 054911 (2024)
STAR, PRL 128, 202301 (2022)
STAR, JHEP **2024** (2024)139

Coalescence scenario: nuclei formed at a later stage after kinetic freeze-out

- Light nuclei and hypernuclei deviate from the full hydrodynamic picture
 1. Less correlated nucleons coalesce to nuclei, leading to smaller $\langle p_T \rangle$ than if perfectly aligned
 2. Heavier (hyper)nuclei $\rightarrow$ Large deviation from blast wave ansatz

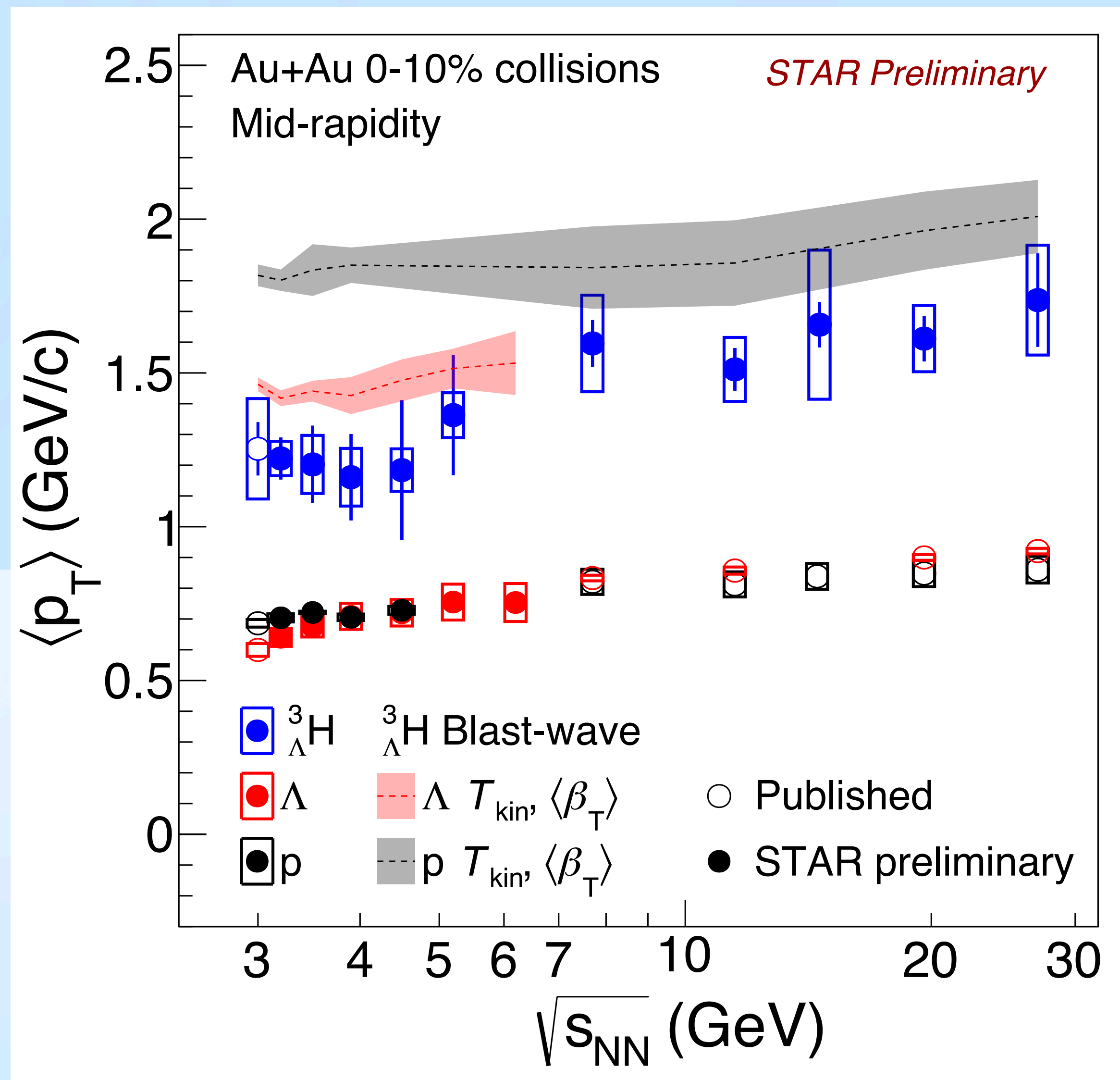
A. I. Sheikh et al., PRC 106, 054907 (2022)



Small effective volume
nucleon's r and p are less correlated

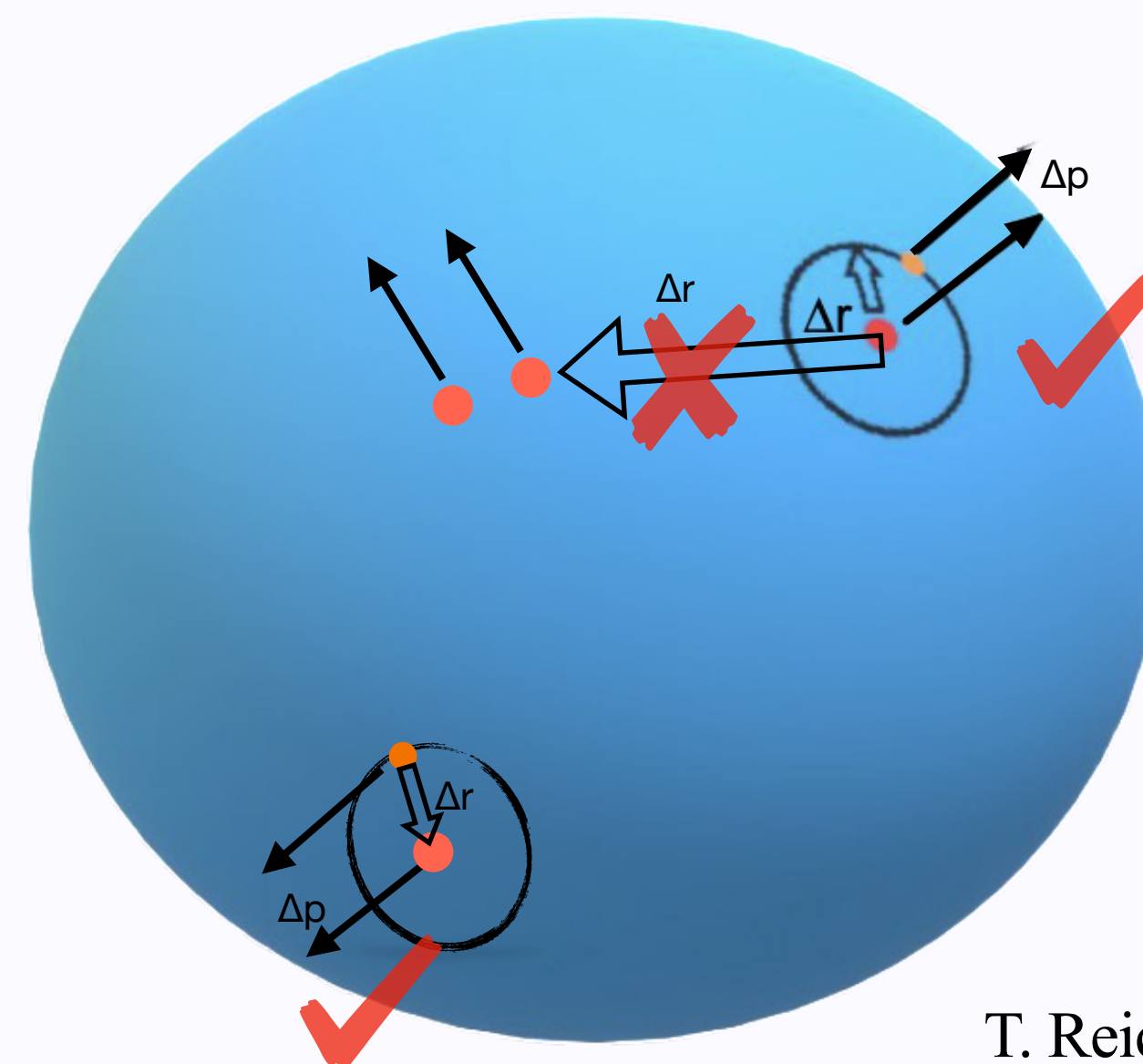
T. Reichert, SQM 2022, slides (2022)

Mean Transverse Momentum v.s. Collision Energy



- At $\sqrt{s_{NN}} \geq 7.7$ GeV, ${}^3_{\Lambda}H$ $\langle p_T \rangle$ tends to approach the blast-wave prediction with proton freeze-out parameters
- Likely due to larger effective volume, where nucleons that eventually coalesce are more likely to be aligned in space and momentum

Suggests a different effective volume at $\sqrt{s_{NN}} \geq 7.7$ GeV, with an noticeable change between 4.5 and 7.7 GeV

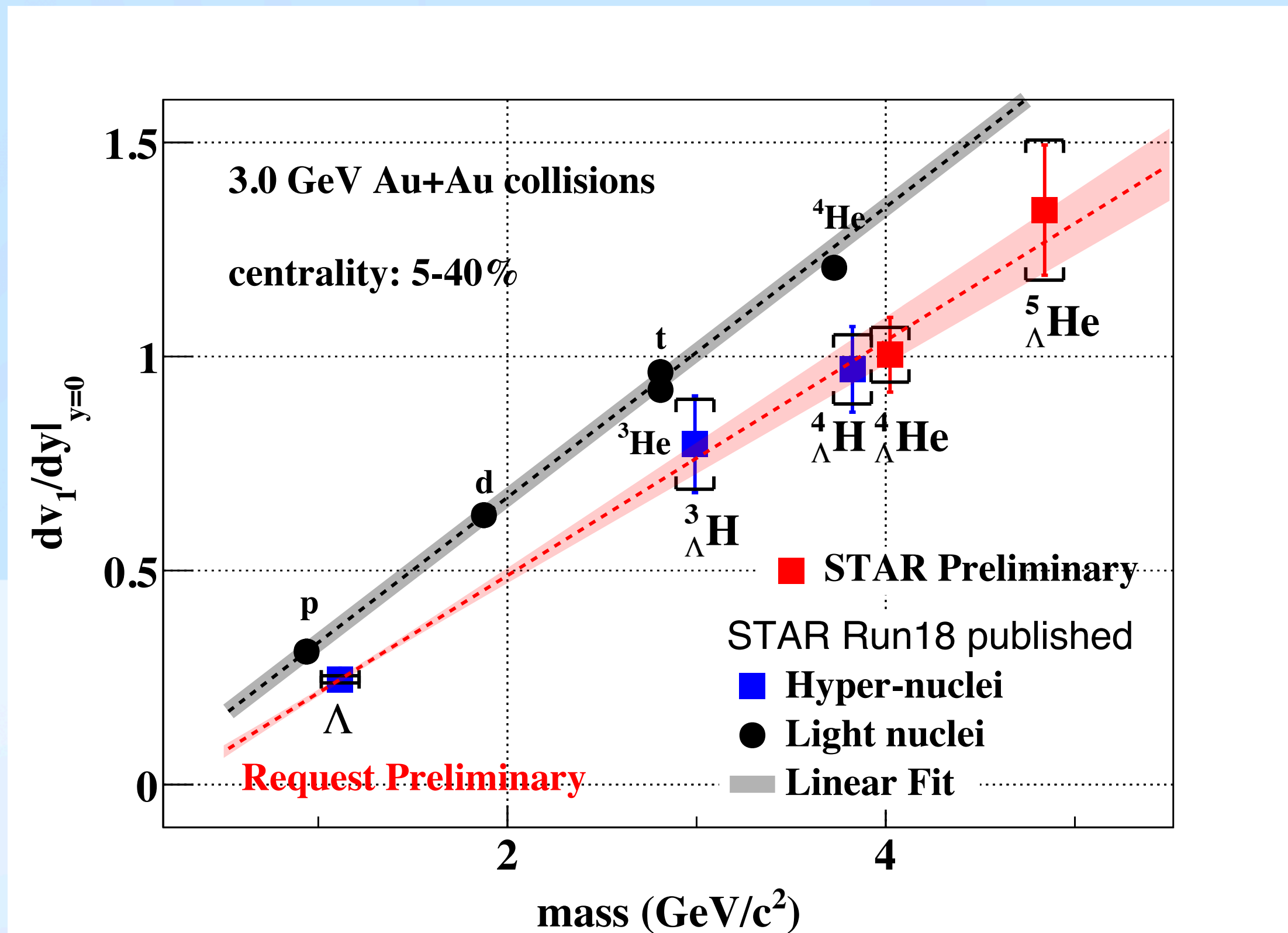


Large effective volume nucleon's r and p are correlated

STAR, PRC 110, 054911 (2024)
STAR, PRL 128, 202301 (2022)
STAR, JHEP **2024** (2024)139

Collective Flow at 3 GeV

See poster by Junyi Han (xx/xx)



- Directed flow of hypernuclei follows mass scaling
- Qualitatively consistent with coalescence formation of hypernuclei

Summary and Outlook

- Hypernuclei measurement from STAR BES-II at $\sqrt{s_{NN}} = 3\text{-}27$ GeV
 1. **First measurement of $A = 5$ hypernuclei yield and directed flow in Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV**
 2. Thermal model overestimates ${}^3_{\Lambda}\text{H}$, ${}^4_{\Lambda}\text{H}$, and ${}^4_{\Lambda}\text{He}$, and slightly underestimates ${}^5_{\Lambda}\text{He}$
 3. Mean transverse momentum tends to be lower than hydrodynamic-inspired blast-wave model at $\sqrt{s_{NN}} < 7.7$ GeV

Consistent with coalescence picture: weaker space and momentum correlation among coalescing nucleons in a smaller effective volume at low collision energies
 4. Collective flow qualitatively consistent with coalescence model

Outlook:

- High statistics 3 GeV FXT data: more precise measurement of $A < 5$ hypernuclei, ${}^5_{\Lambda}\text{He}$ dalitz plot, search for heavier hypernuclei ($A > 5$), double- Λ hypernuclei,
➔ Further constrain production mechanism, structure of hypernuclei, and YN, YY, YNN interactions