Collision Energy Dependence of Hypertriton Production in Au+Au Collisions at RHIC

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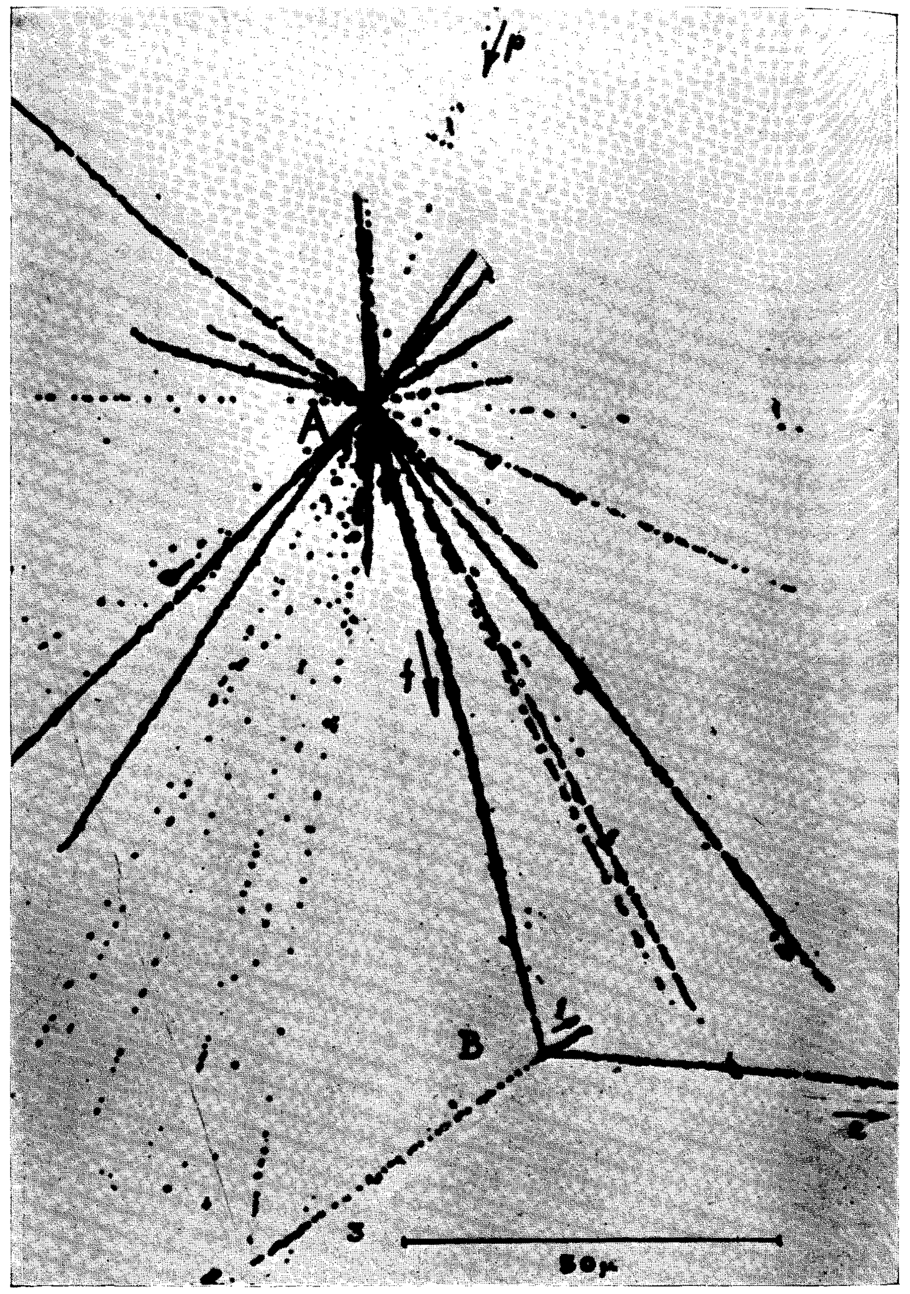
Introduction: hypernuclei

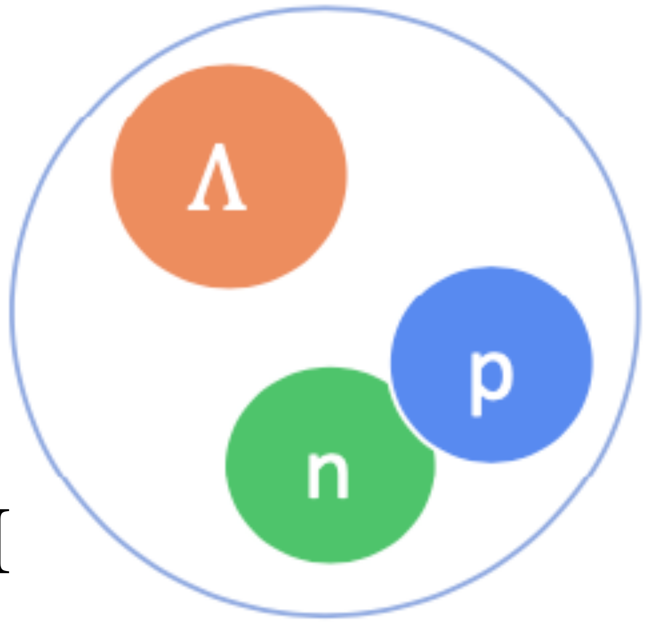
- Hypernuclei: bound nuclear systems of non-strange and strange baryons

—Natural hyperon-baryon correlation system



The first discovery of hypernucleus by Marian Danysz (right) and Jerzy Pniewski (left) in 1952

M. Danysz, J. Pniewski, Philos. Mag. 44 (1953) 348.

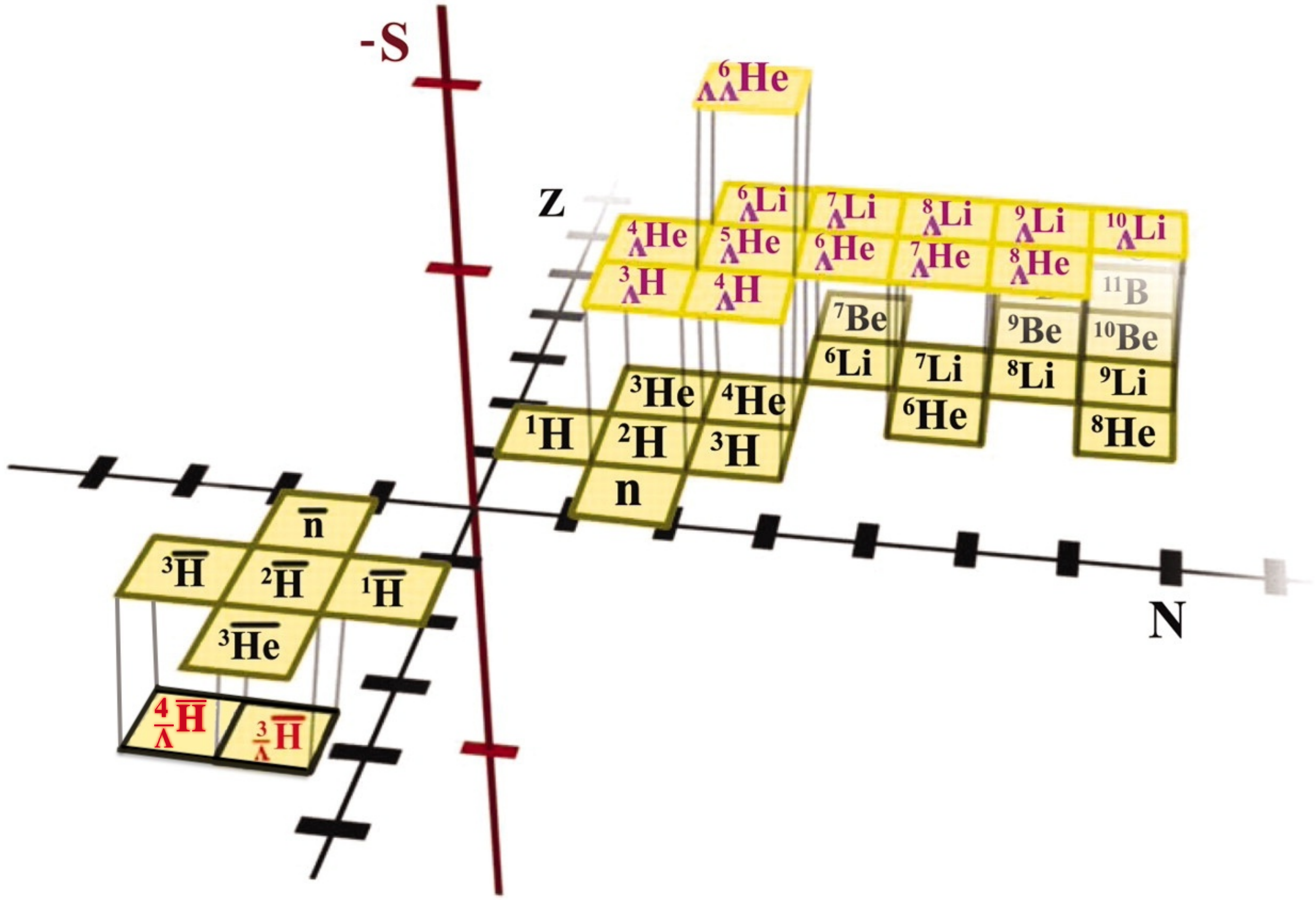


$^{3}_{\Lambda}H$

lightest hypernucleus

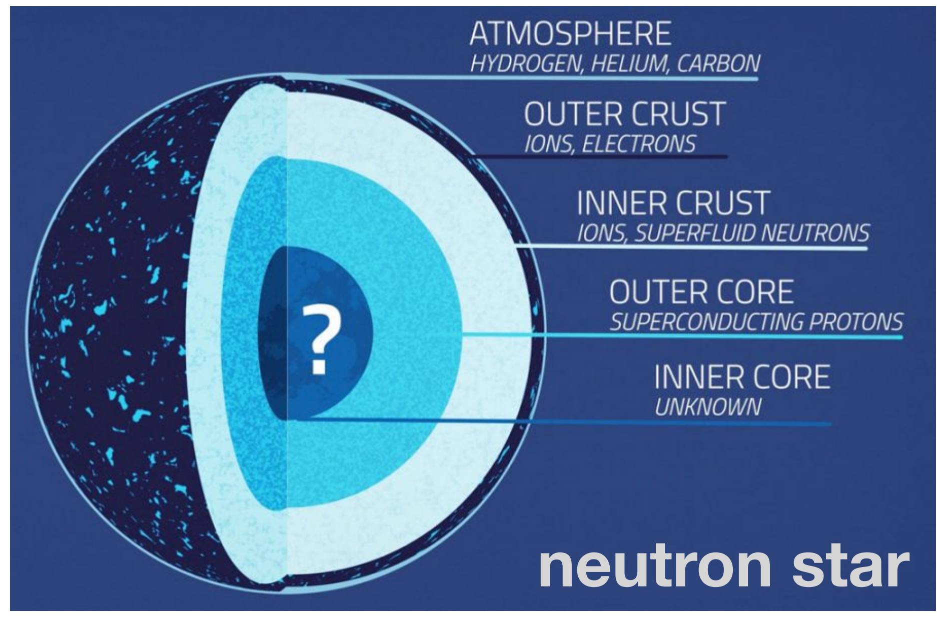
$B_{\Lambda} \sim 0.15\text{MeV}$

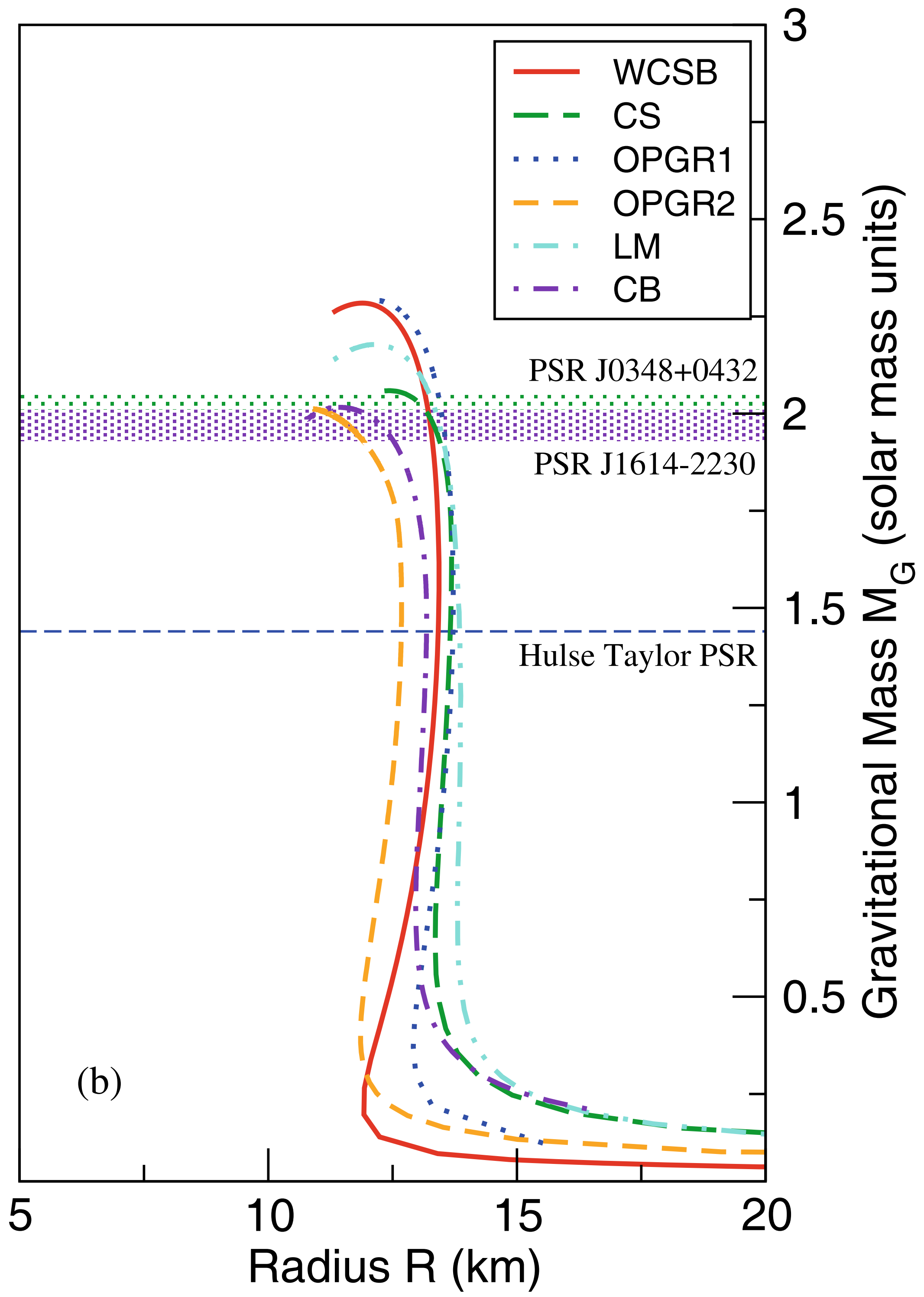
RMS radius $5 \sim 10$ fm



Introduction: YN interaction in dense matter

- Hypernuclei serve as a laboratory to study the hyperon–nucleon (YN) interaction
  - YN interaction is essential in probing dense inner core of neutron star
    - **Hyperon puzzle**: do hyperons exist in the dense inner core of neutron stars?
      - No direct method to probe inner core
        - Rely on theoretical models compared with observations
      - Lack of experimental data of YN, YNN, YY interactions to constrain theoretical models of the dense matter equation of state (EoS)



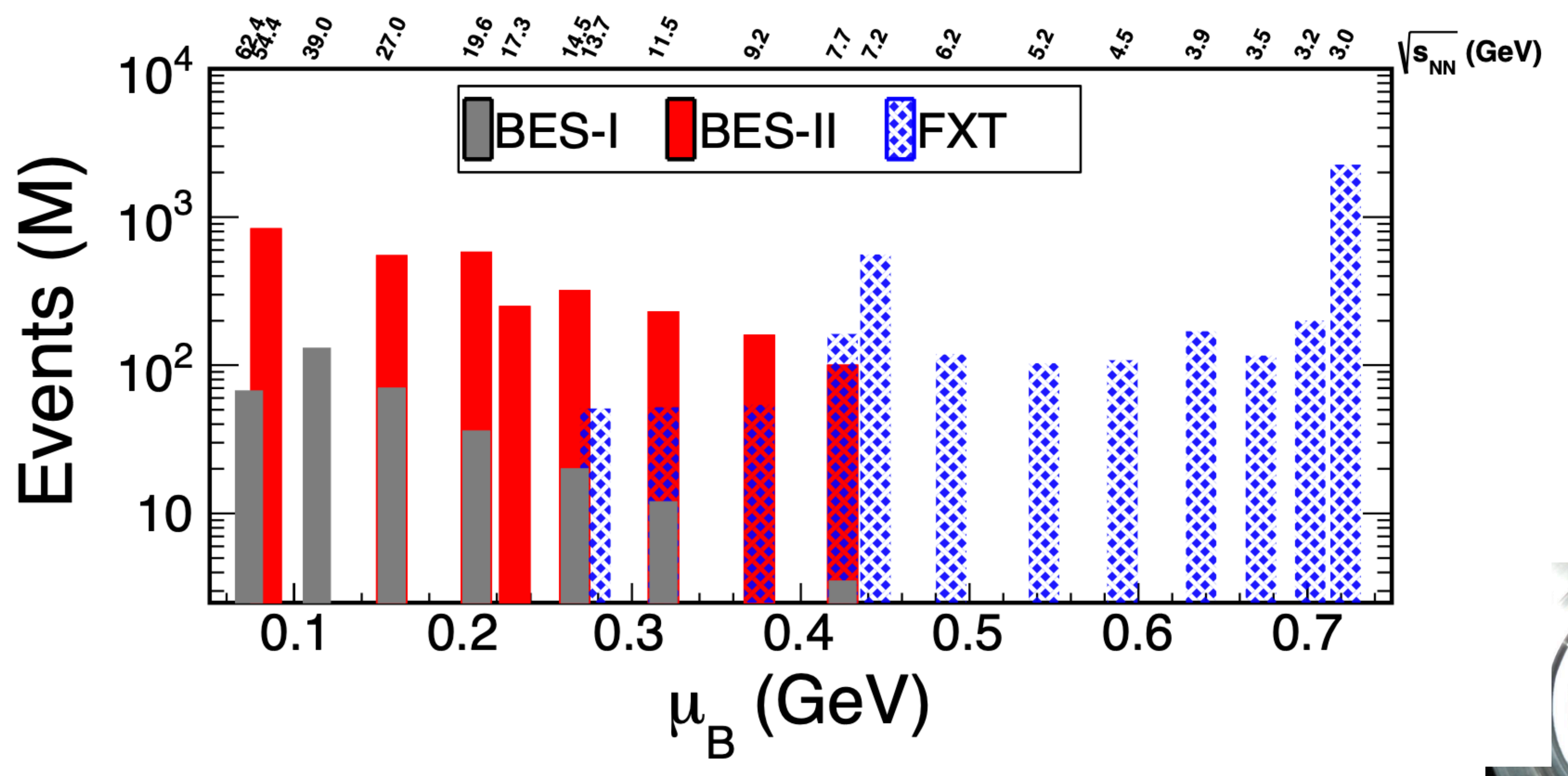


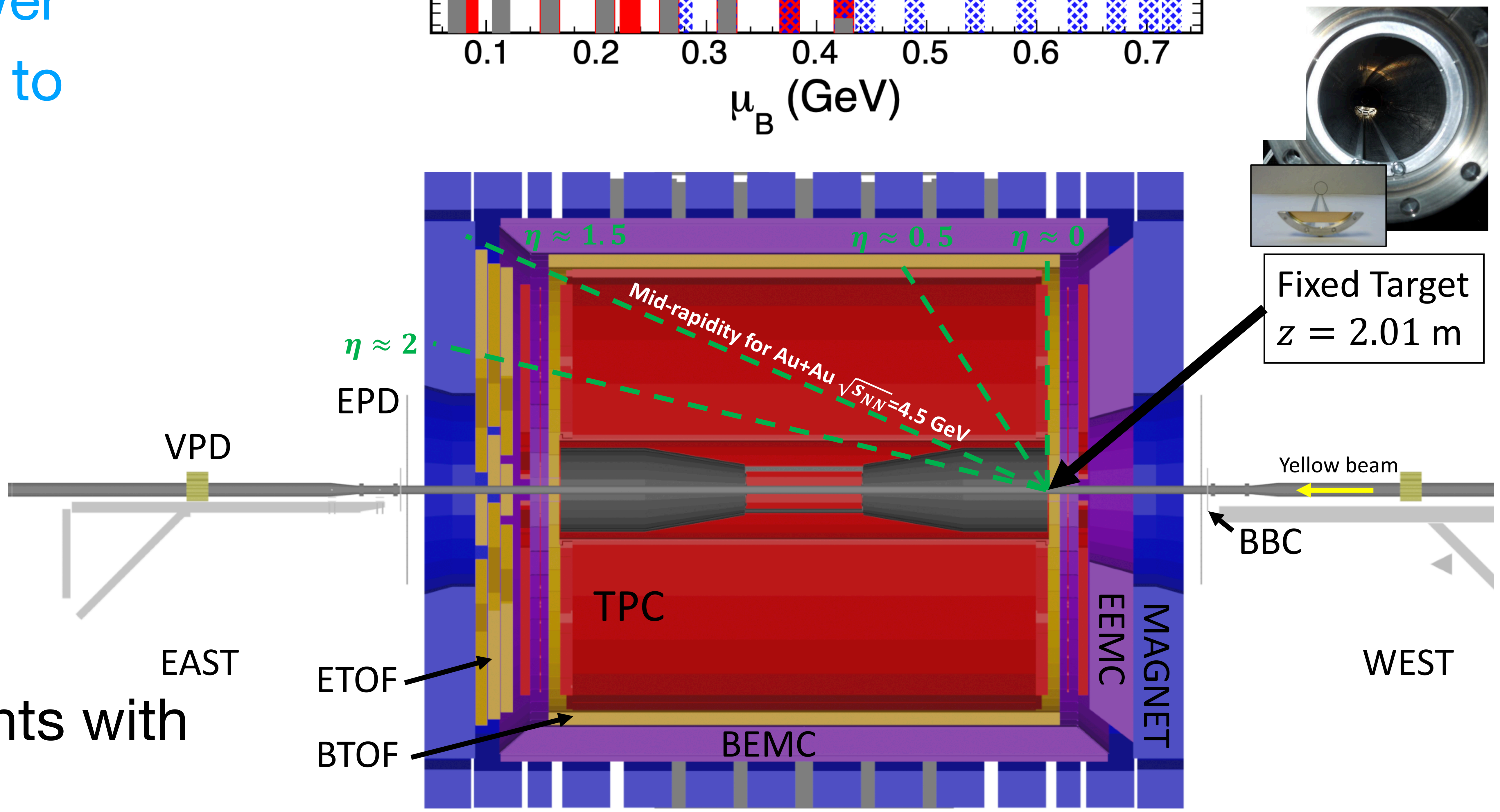
D. Chatterjee, Eur. Phys. J. A 52 (2016) 29

Introduction: RHIC BES-II

- RHIC beam energy scan Phase II (BES-II): 2017 - 2021
  - Specific focus on low $\sqrt{s_{NN}}$
    - Include fixed target (FXT) mode to reach lower energies, increase μ_B range from ~400 MeV to ~700 MeV
  - High statistics data
  - Improve systematics
    - Detector upgrade: iTPC, EPD, eTOF

— Enhances the capability of various measurements with excellent precision



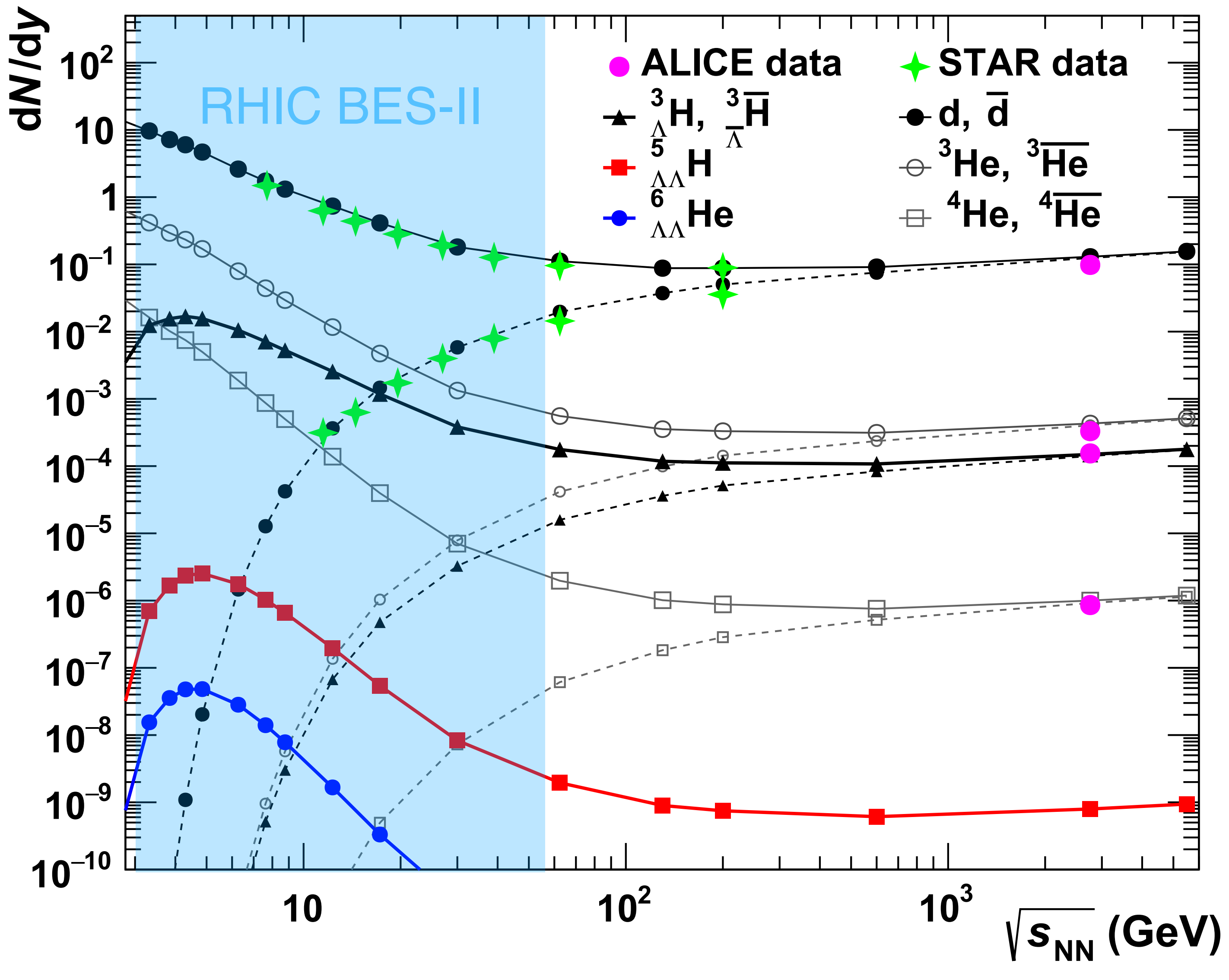


Introduction: hypernuclei in HI collisions

Production mechanism of hypernuclei is still not well understood.

Hypernuclei formation process in relativistic heavy-ion (HI) collisions

can be studied through measurements related to **spectra and collective flow.**

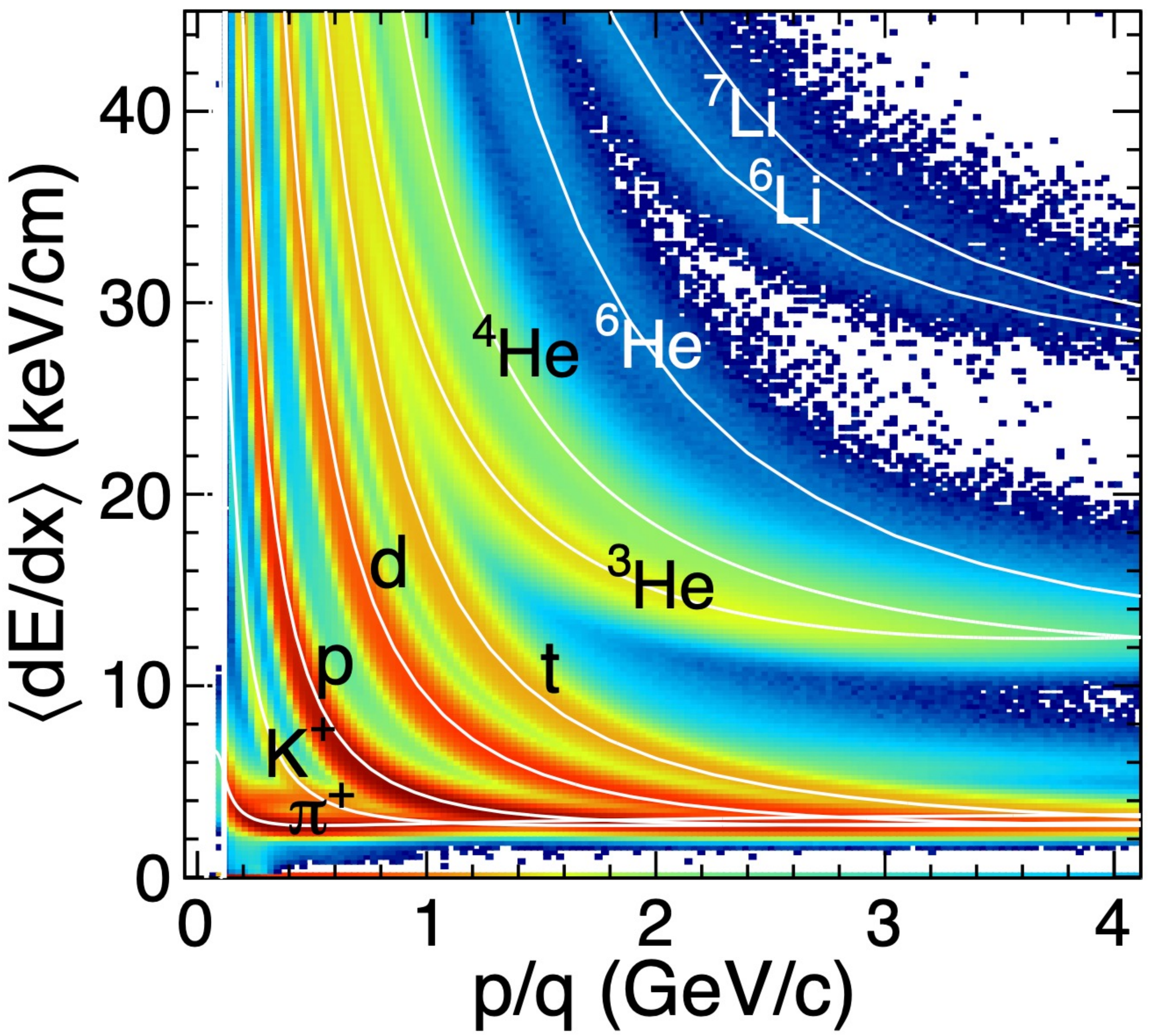


- Hypernuclei measurements are scarce in HI collision experiments
- At **low beam energies**, hypernuclei production is expected to be **enhanced** due to high baryon density

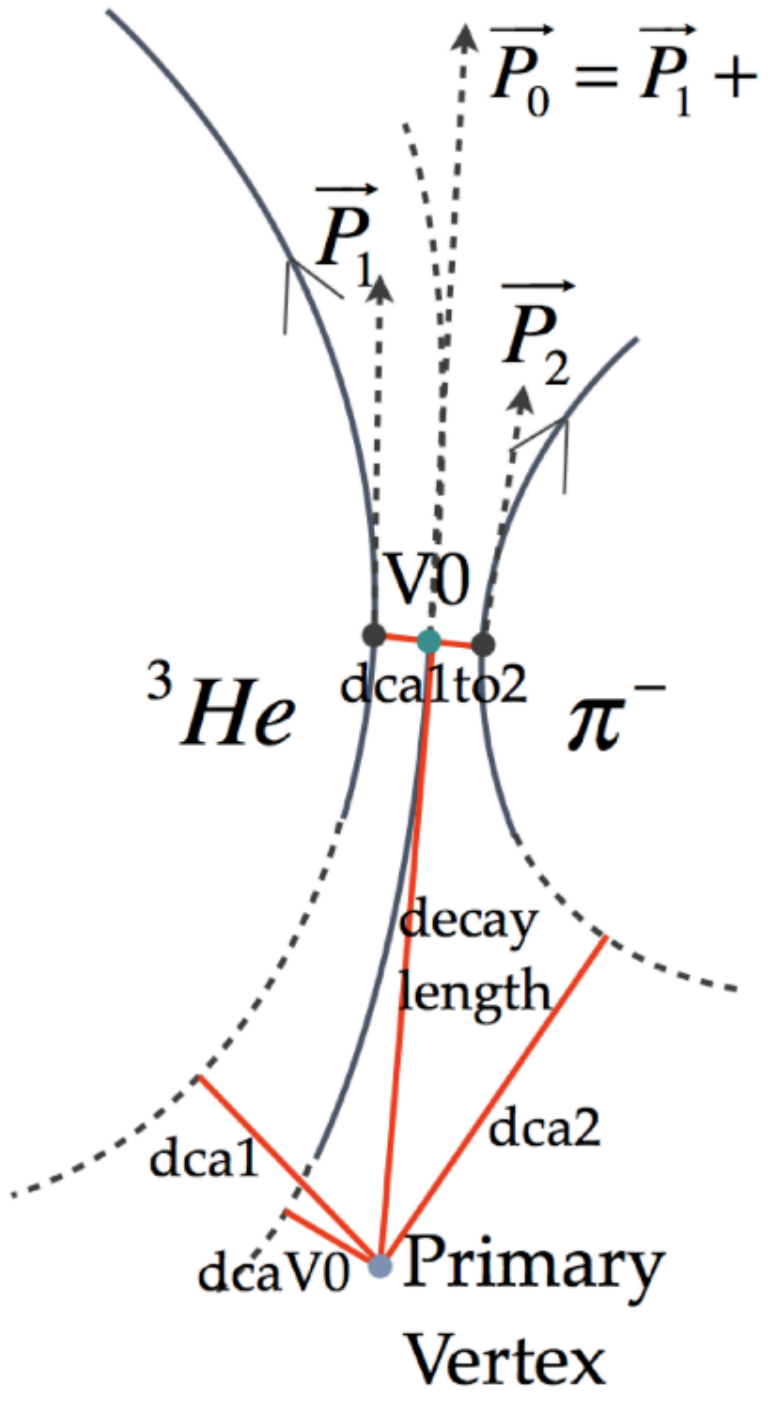
RHIC BES-II offers great opportunity for hypernuclei measurements.

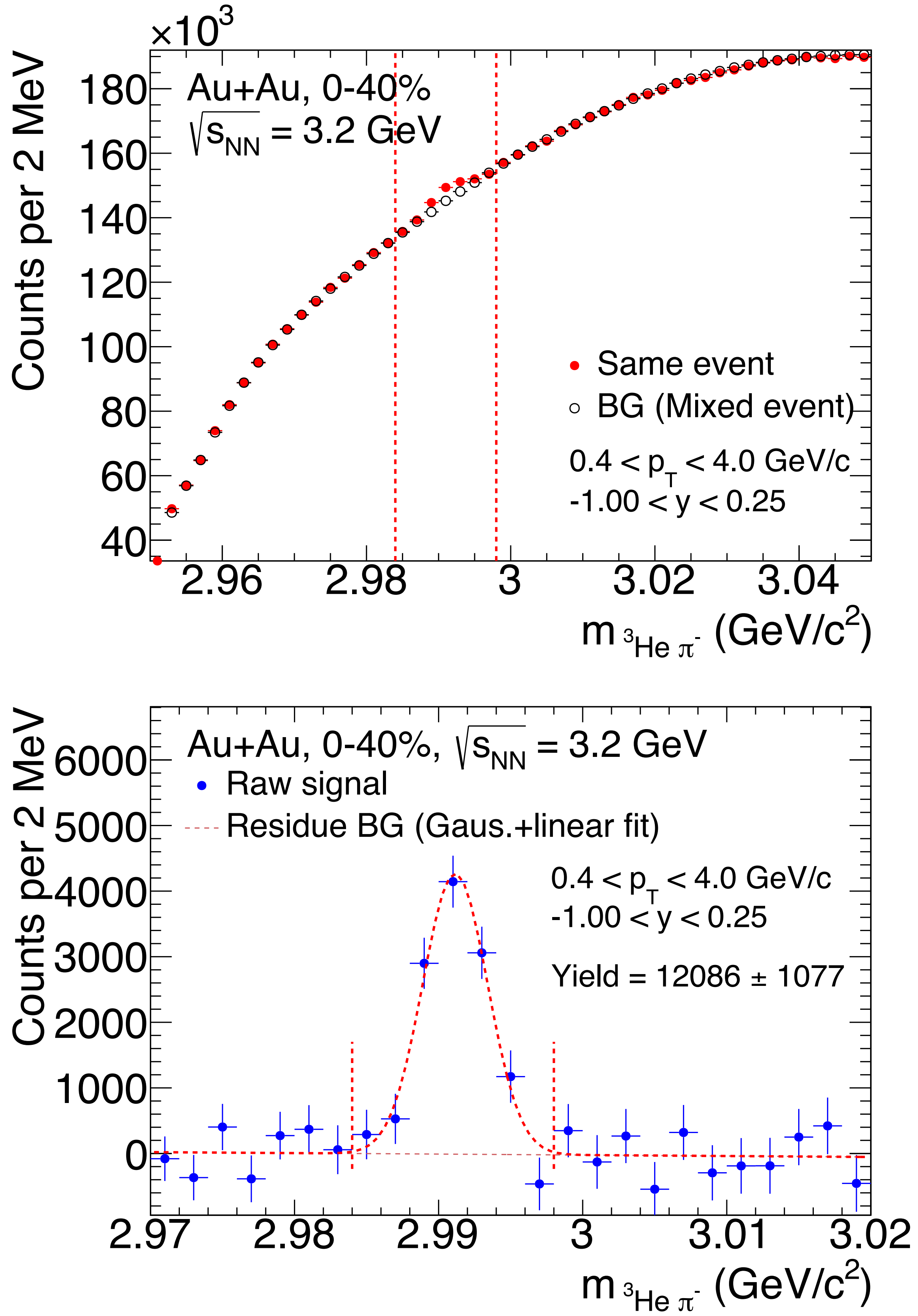
B. Dönigus, Eur. Phys. J. A (2020) 56:280
A. Andronic et al. PLB (2011) 697:203–207

$^{3}_{\Lambda}H$ reconstruction



$^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$:

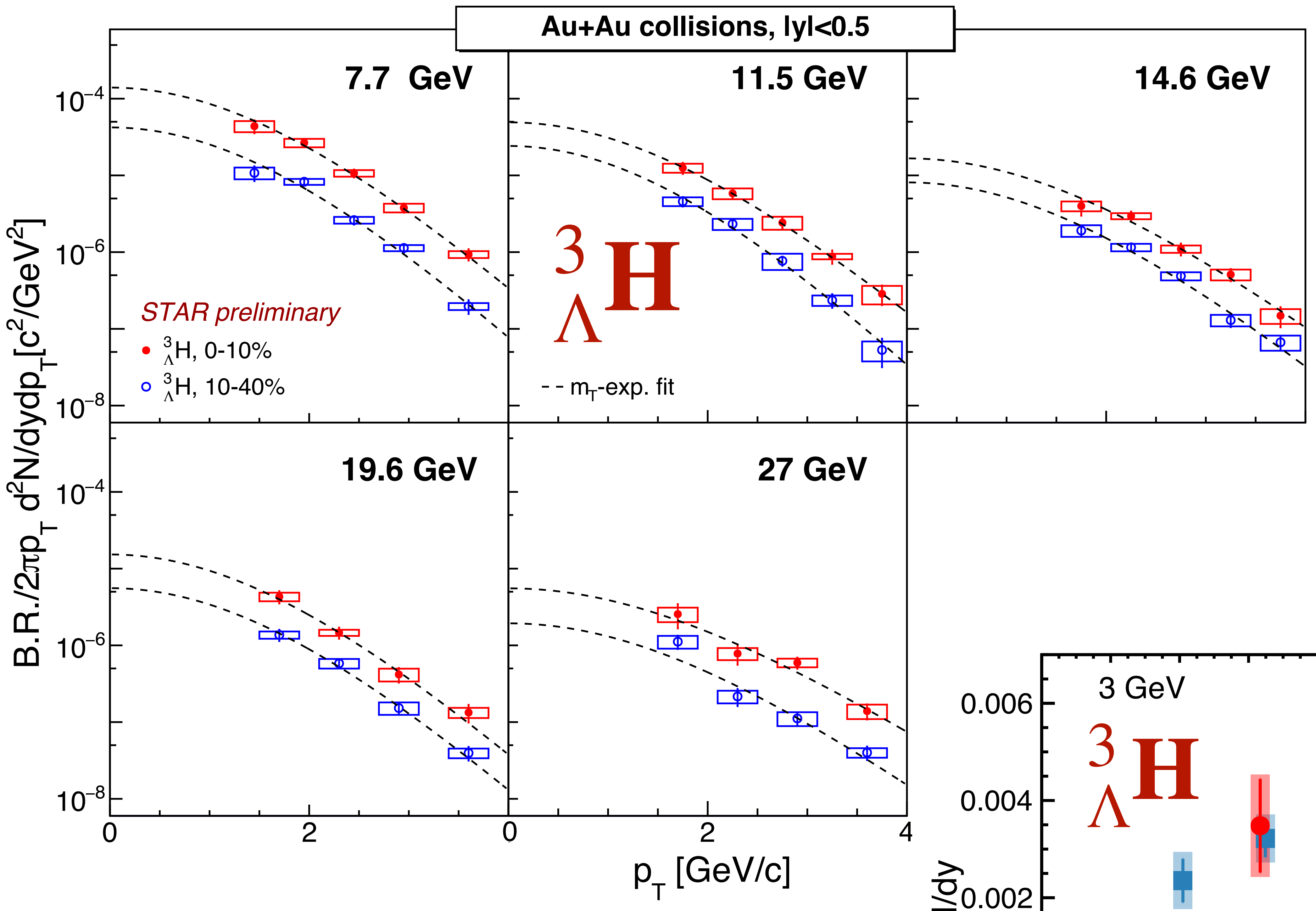




- Reconstruction channel: $^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$
- Particle identification from energy loss measurement using TPC
- KF particle package is used for signal reconstruction

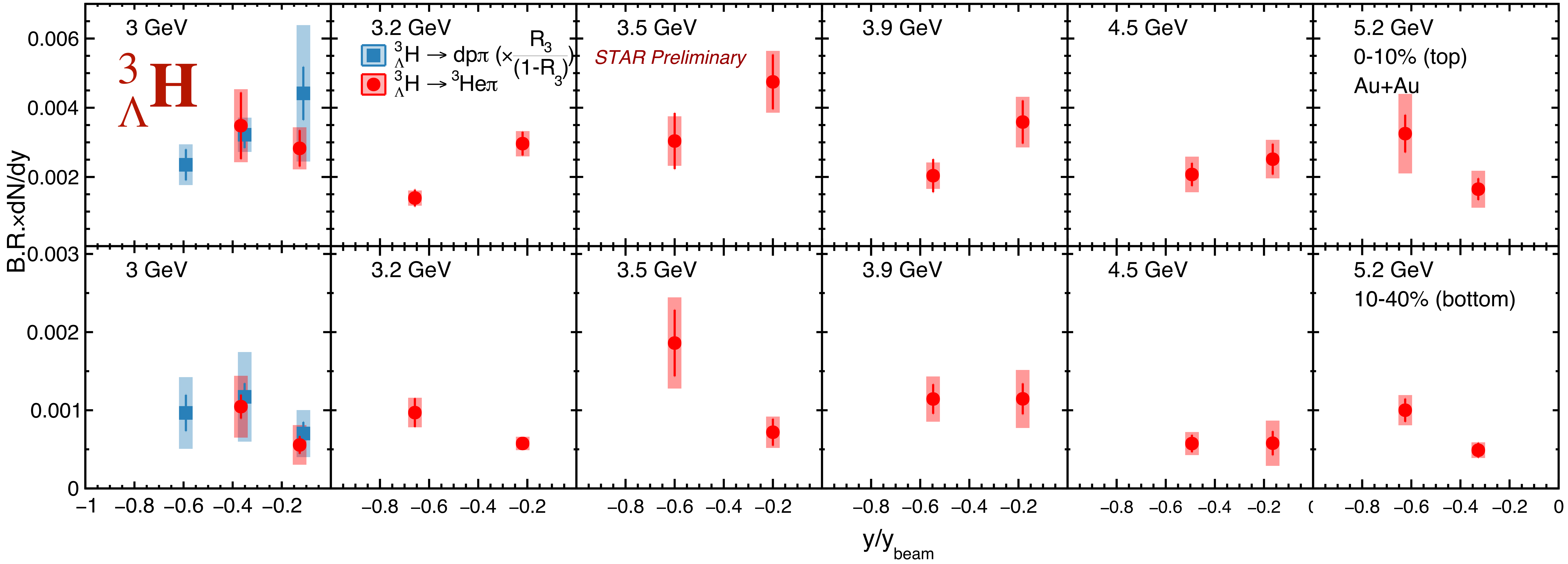
XY. Ju et al. Nucl.Sci.Tech. 34 (2023) 10, 158

${}^{3}_{\Lambda}H$ rapidity and p_T spectra

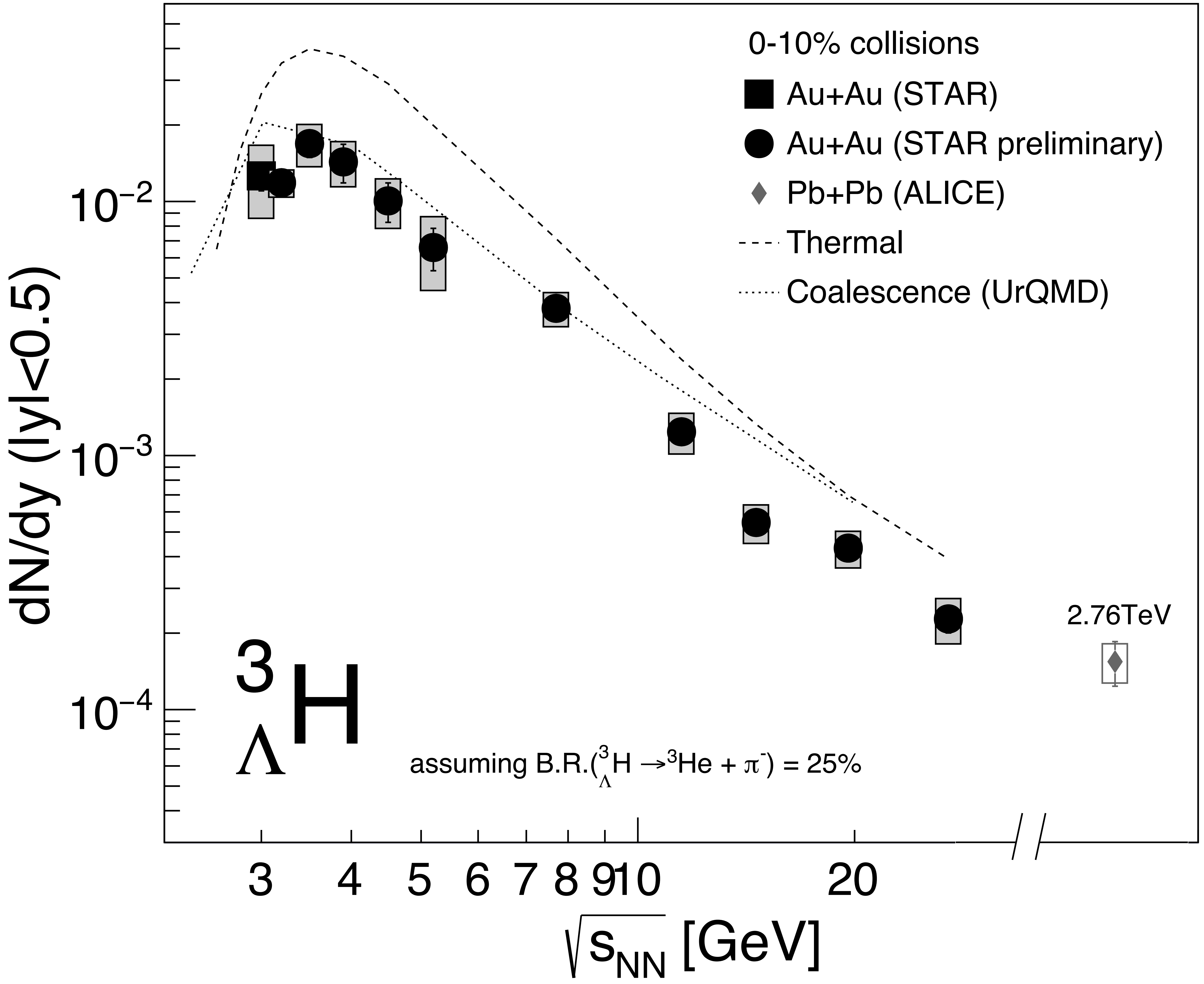


- Measurements cover 11 different energies

Collider: 7.7, 11.5, 14.6, 19.6, 27 GeV
Fixed Target: 3.0, 3.2, 3.5, 3.9, 4.5, 5.2 GeV



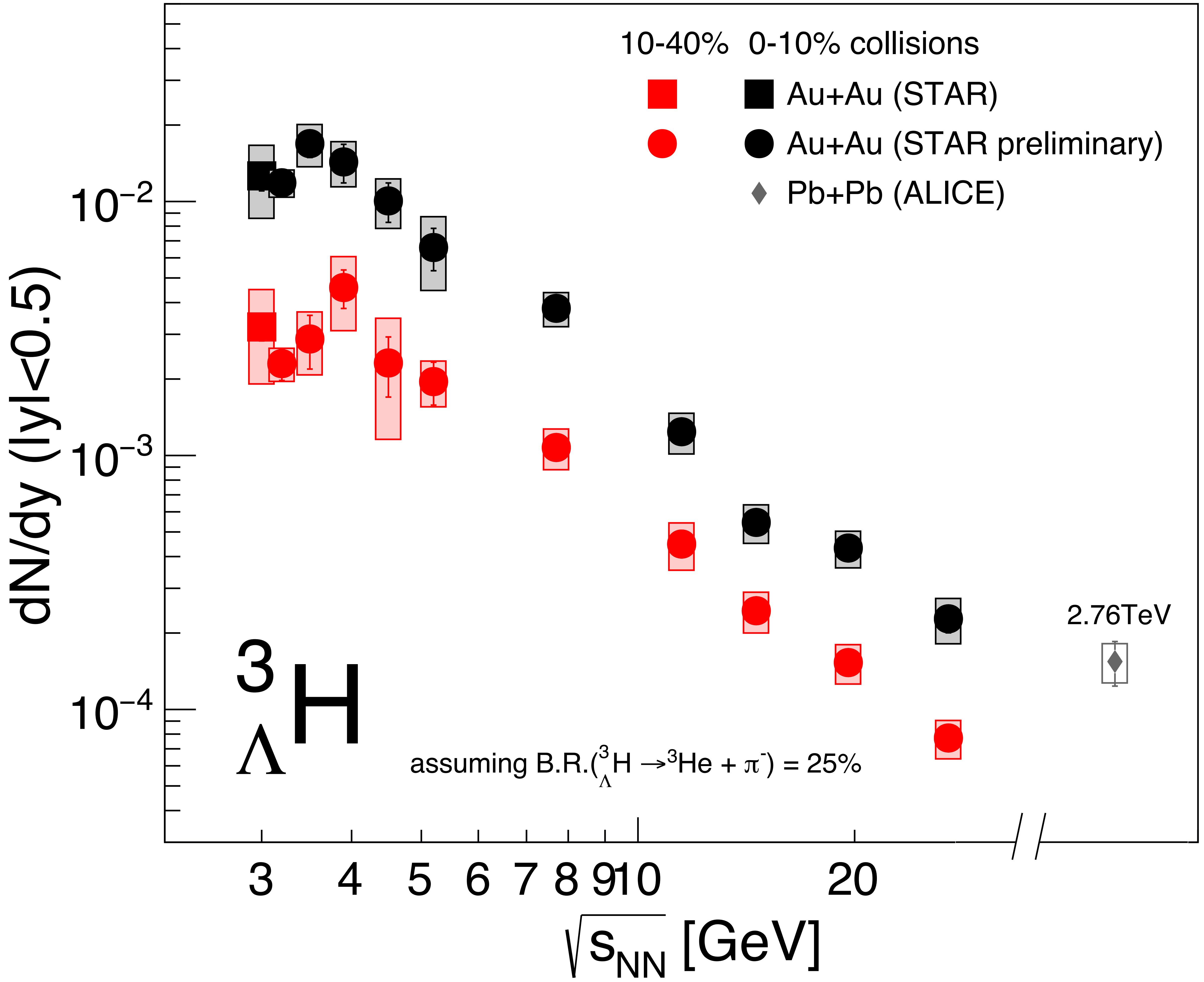
Energy dependence of ${}^{3}_{\Lambda}H$ production



STAR, PRL 128 (2022) 202301
ALICE, PLB 754 (2016) 360
T. Reichert, et al, PRC 107 (2023) 014912

- Yields increase strongly from $\sqrt{s_{NN}}$ = 27 GeV to ~4 GeV
- Peak at 3-4 GeV
- Hadronic transport + coalescence models qualitatively describe the data
- Thermal model overestimates the data

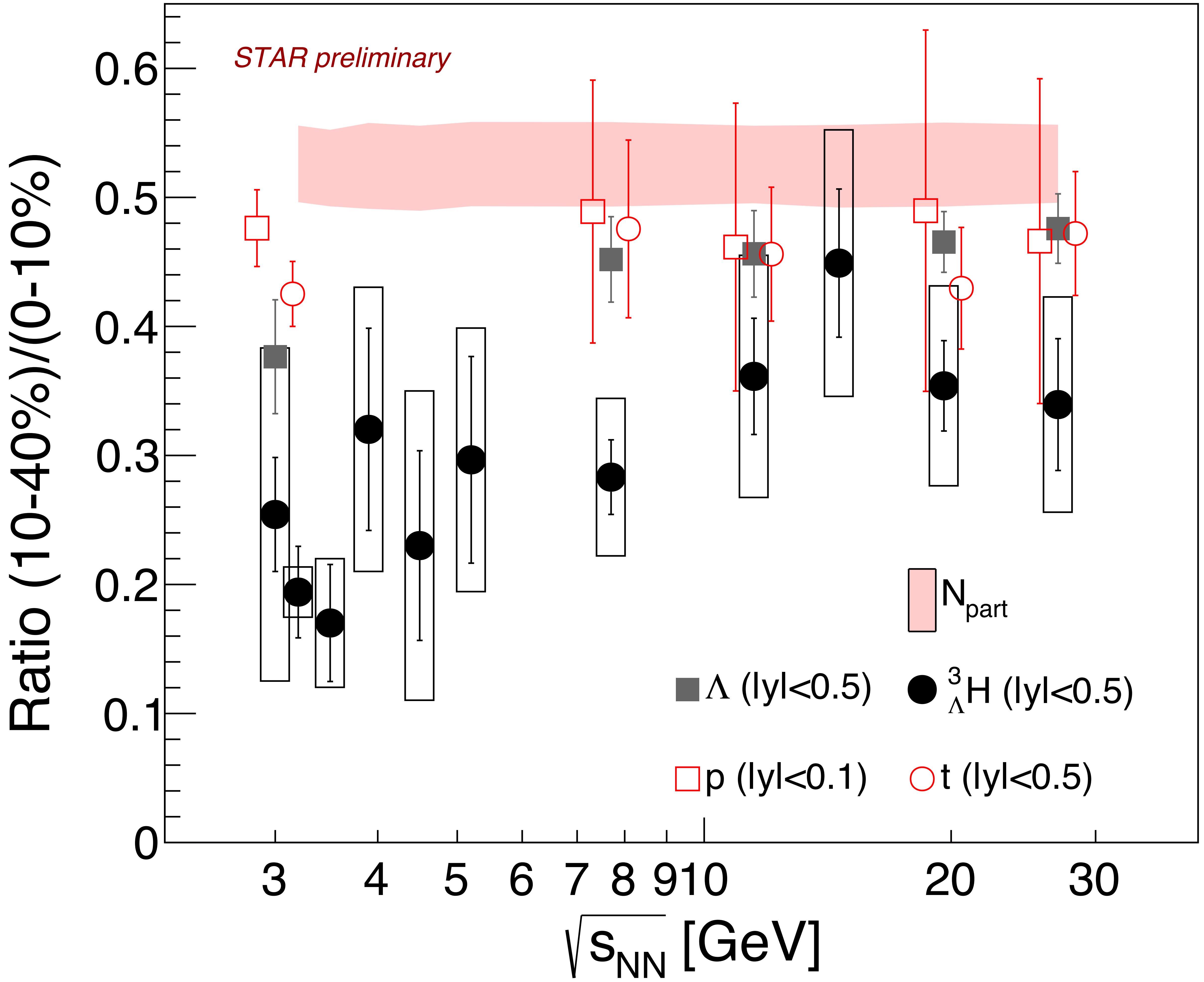
Centrality dependence of $^{3}_{\Lambda}H$ production



- Similar trend in central (0-10%) and mid-central (10-40%) collisions

STAR, PRL 128 (2022) 202301
ALICE, PLB 754 (2016) 360

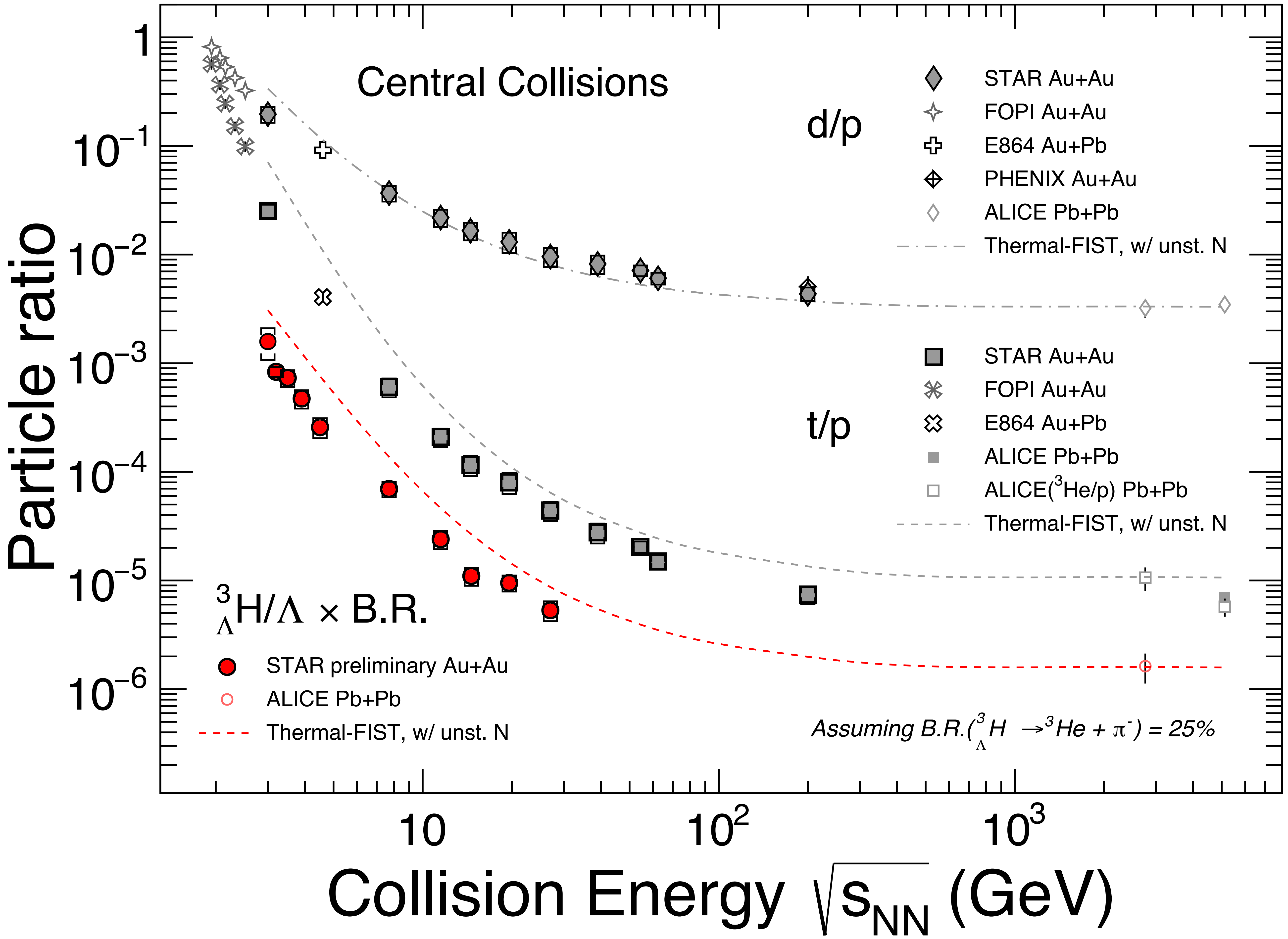
Centrality dependence of ${}^{3}_{\Lambda}\mathrm{H}$ production



- Suppression of mid-central/central ${}^{3}_{\Lambda}\mathrm{H}$ yield ratio w.r.t $\mathrm{N_{part}}$, seems more apparent below $\sqrt{s_{NN}}$ = 7.7 GeV

- ${}^{3}_{\Lambda}\mathrm{H}$ yield ratio tends to increase more steeply than proton, Λ, triton at low energies

Nuclei-to-hadron ratios

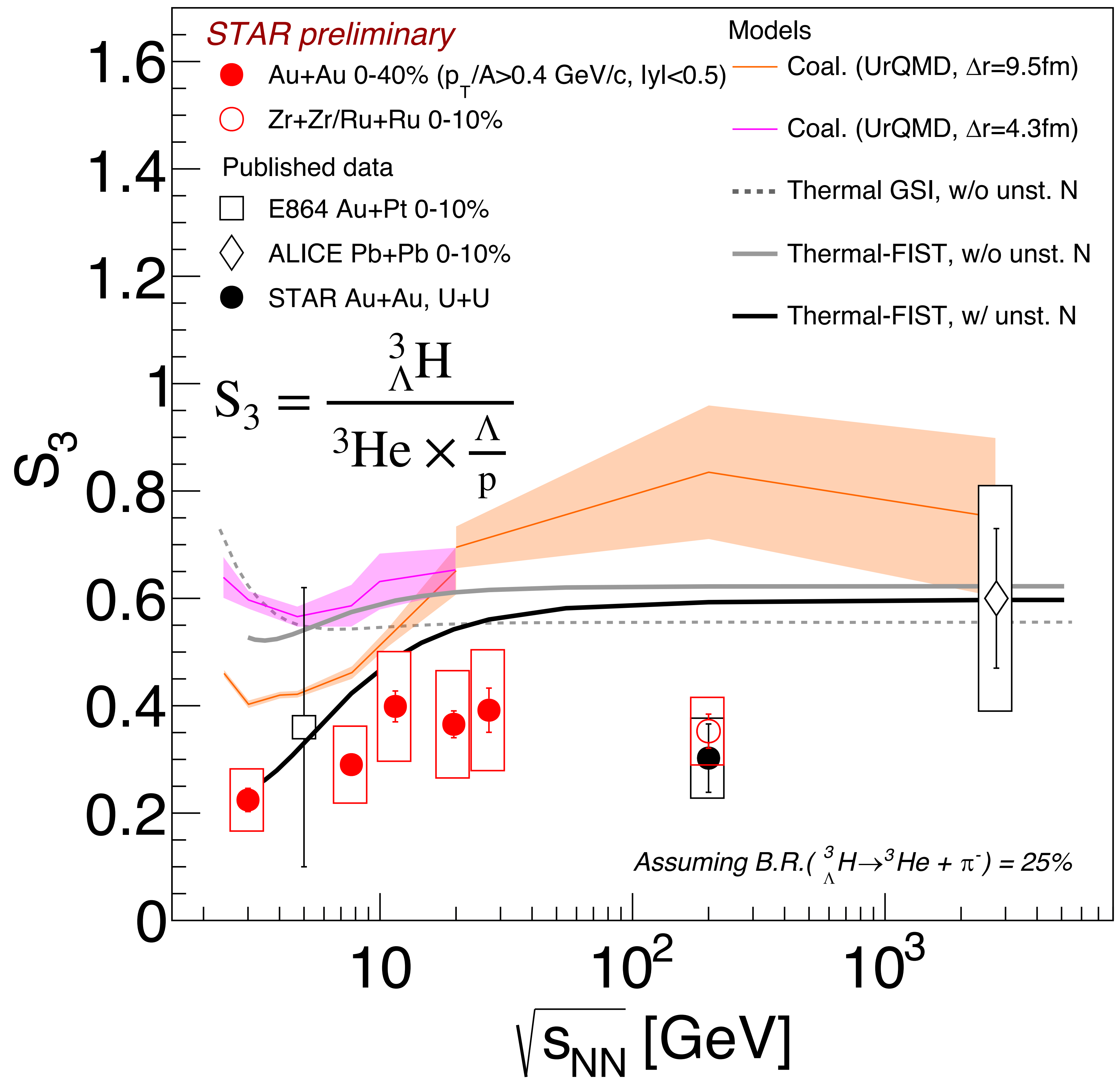


STAR, PRL 130 (2023) 202301
STAR, arXiv: 2311.11020
T. Reichert, et al, PRC 107 (2023) 014912

- Thermal model assumes that chemical freeze-out of light/hypernuclei happens at same time with hadrons
  - Particle yield ratio is independent of volume. $^3_\Lambda\mathrm{H}/\Lambda$ yield ratio is dependent of strangeness correlation length
- d/p consistent with thermal model
- $^3_\Lambda\mathrm{H}/\Lambda$, as well as t/p, overestimated by thermal model by a factor of ~2

Suggest $^3_\Lambda\mathrm{H}$ and t yields are not in equilibrium and fixed at chemical freeze-out simultaneously with other hadrons

Energy dependence of strangeness population factor S_3

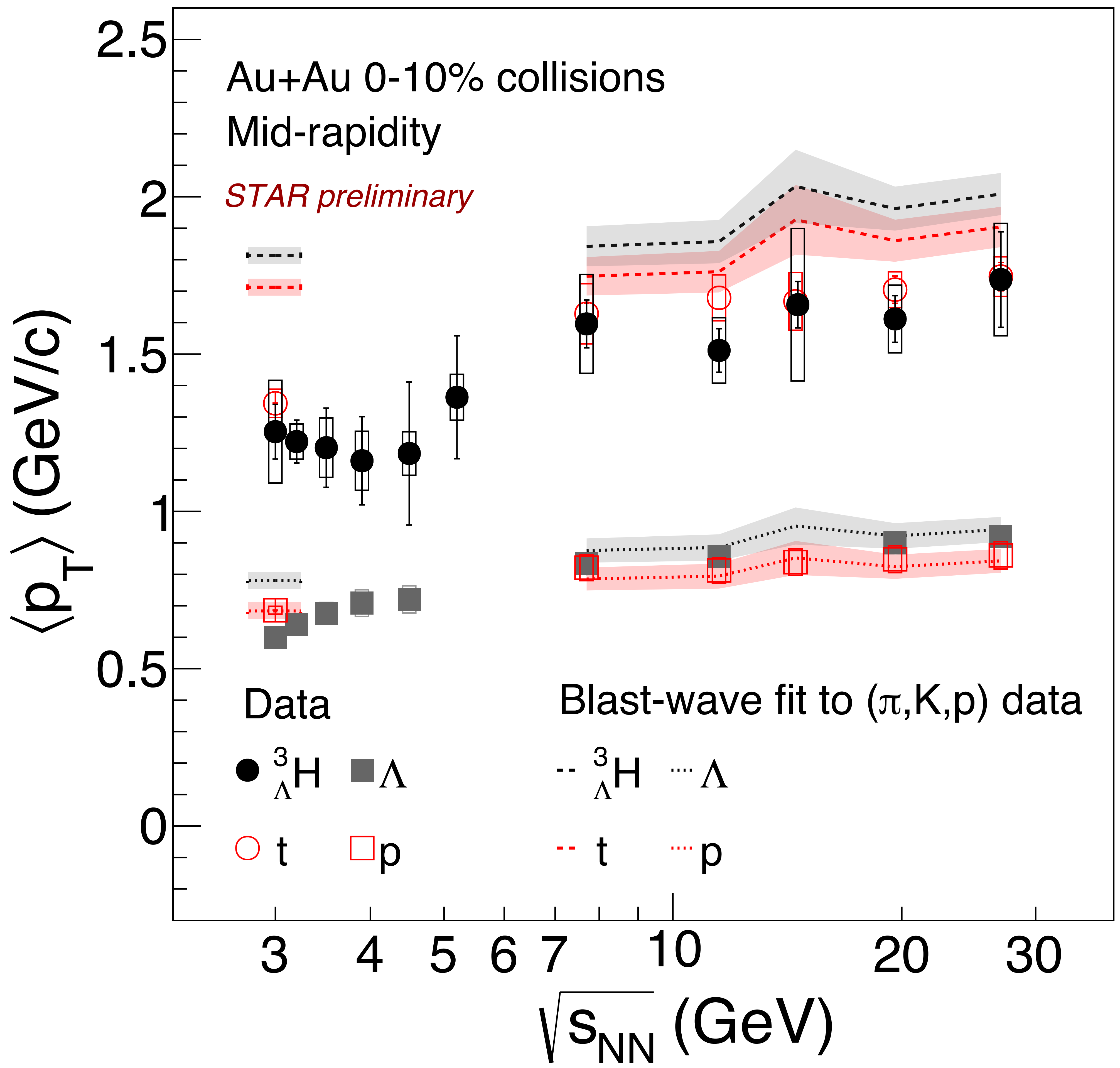


- A prominent enhancement of S_3 was proposed as a probe for deconfinement S. Zhang et al. PLB 684 (2010) 224–227
- Data shows a mild increasing trend from $\sqrt{s_{NN}}$ = 3.0 GeV to 2.76 TeV
- For coalescence(UrQMD) models, the energy dependence is sensitive to the **source radius** (Δr). Data favor larger radius.
  - Due to the difficulty in forming ${}^3_\Lambda H$ of large radius in small systems
- Thermal-FIST, which includes **feed-down** from unstable nuclei to stable p, ${}^3He$, describes the S_3 data better
  - Possible feed-down should be accounted

STAR, Science 328 (2010) 58
STAR, arXiv: 2310.12674
ALICE, PLB 754 (2016) 360
E864, PRC 70 (2004) 024902

A. Andronic et al, PLB 697 (2011) 203 (Thermal (GSI))
S. Zhang, PLB 684 (2010) 224 (Coal.+AMPT)
T. Reichert, et al, PRC 107 (2023) 014912 (UrQMD, Thermal-FIST)

Energy dependence of ${}^{3}_{\Lambda}\mathrm{H}$ $\langle p_T \rangle$



- Similar $\langle p_T \rangle$ for ${}^{3}_{\Lambda}\mathrm{H}$ and t
- Hint of ${}^{3}_{\Lambda}\mathrm{H}$ and t $\langle p_T \rangle < \langle p_T \rangle^{BW}$ at $\sqrt{s_{NN}}$ > 7.7 GeV
  - Blast-wave fit using measured kinetic freeze-out parameters from light hadrons (π, K, p)

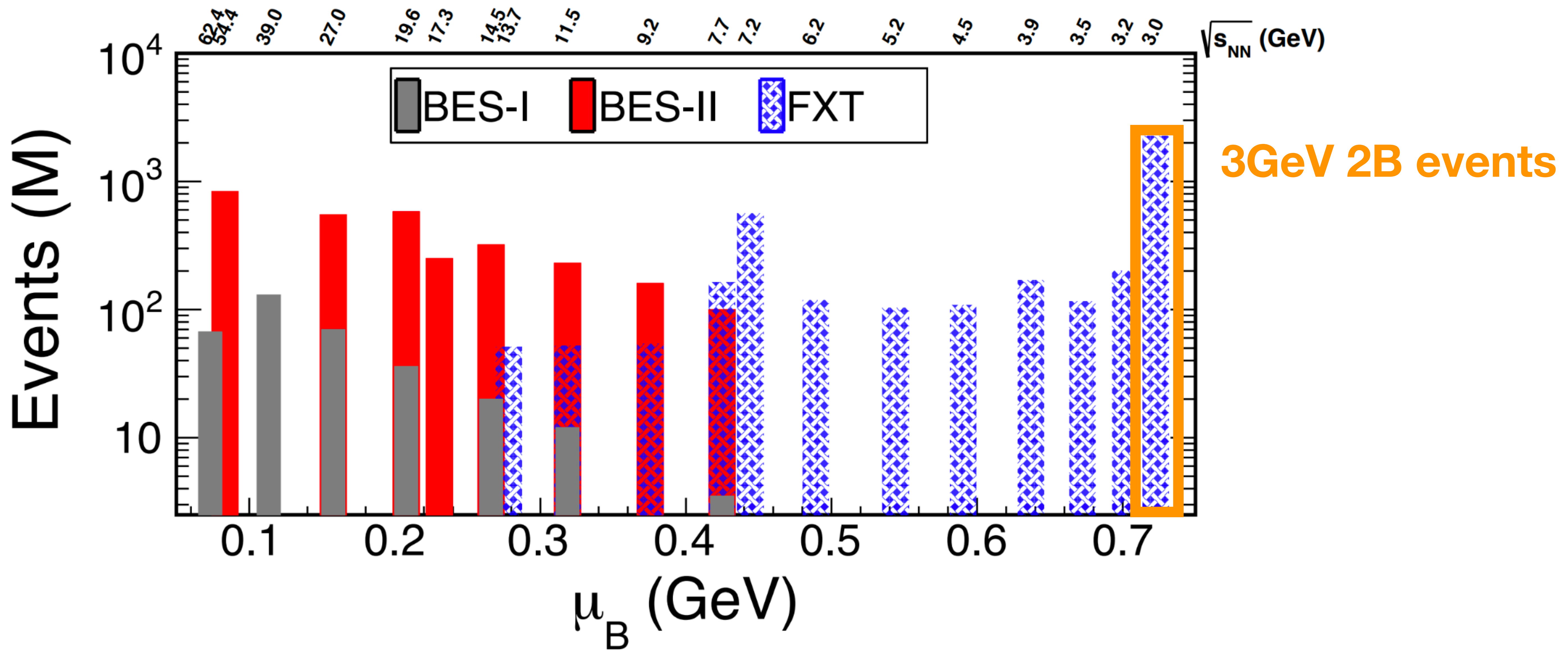
${}^{3}_{\Lambda}\mathrm{H}$ and t might do not follow same collective expansion as light hadrons. Can be interpreted as ${}^{3}_{\Lambda}\mathrm{H}$ and t decoupling at different times compared to light hadrons

- Different trend for $\sqrt{s_{NN}}$ = 3-4.5 GeV and $\sqrt{s_{NN}}$ = 7.7-27 GeV
  - Suggest different expansion dynamics?

Summary

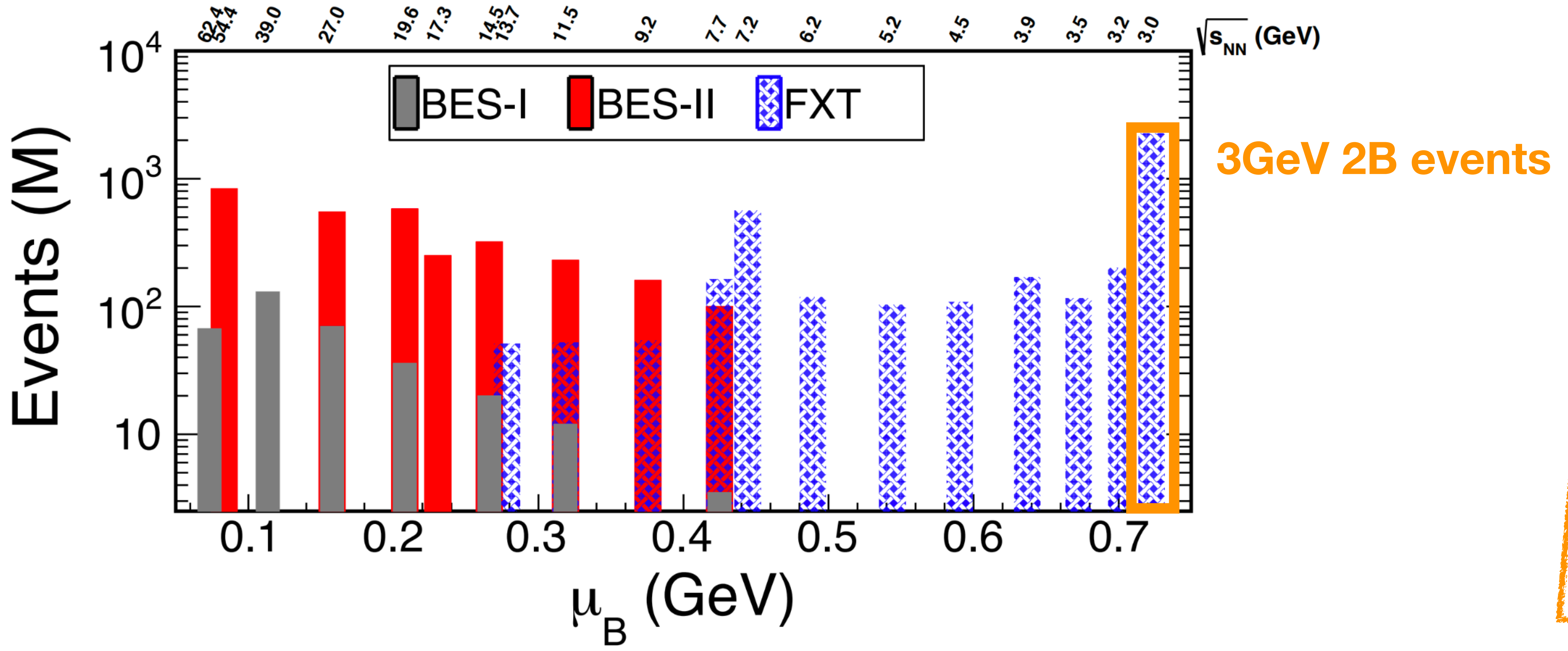
- ${}^{3}_{\Lambda}\mathrm{H}$ yields and ${}^{3}_{\Lambda}\mathrm{H}/\Lambda$ ratio in 0-10% collisions overestimated by thermal model, assuming chemical freeze-out of light/hypernuclei happens at same time with hadrons, by a factor of $\sim$2
- ${}^{3}_{\Lambda}\mathrm{H}$ $\langle \mathrm{p_T} \rangle$ overestimated by Blast-wave fit parameterization from light hadrons
  - **${}^{3}_{\Lambda}\mathrm{H}$ are likely formed at or decouples from the system at a different time compared to the light hadrons**
- Suppression of ${}^{3}_{\Lambda}\mathrm{H}$ in 10-40% collisions at low collisions energies observed
- Energy dependence of S_3 suggests feed-down from unstable nuclei

Outlook



- Huge datasets enable precision hypernuclei measurements
  - Run 21, Au+Au 3 GeV, ~2 billion events
  - **Run 18, Isobar 200 GeV, ~6 billion events**
  - Run 23-25, Au+Au 200 GeV, ~18 billion events
- Opportunities for heavier hypernuclei: $^{4}_{\Lambda}\mathbf{H}$, $^{4}_{\Lambda}\mathbf{He}$, $^{5}_{\Lambda}\mathbf{He}$, $^{6}_{\Lambda}\mathrm{H}$, $^{A}_{\Lambda\Lambda}\mathrm{H}$, $^{A}_{\Lambda\Lambda}\mathrm{He}$

Outlook



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