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

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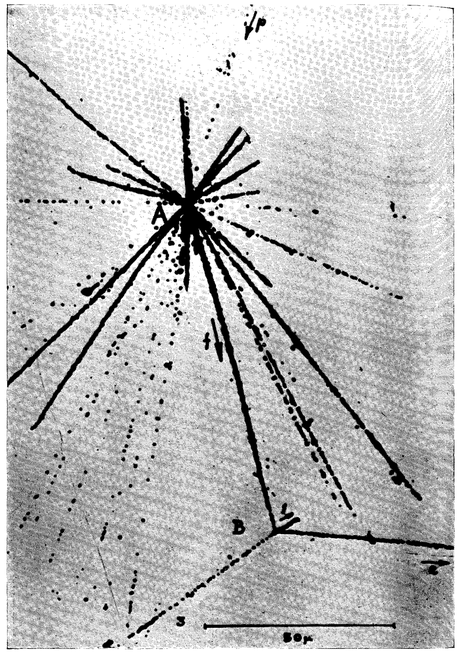
Introduction: hypernuclei

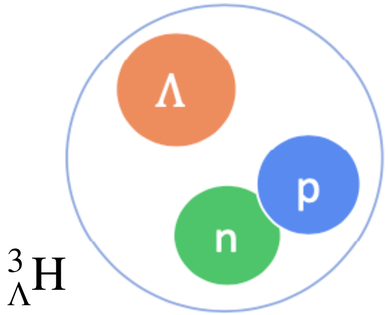
- Hypernuclei: bound nuclear systems of non-strange and strange baryons

  —**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.

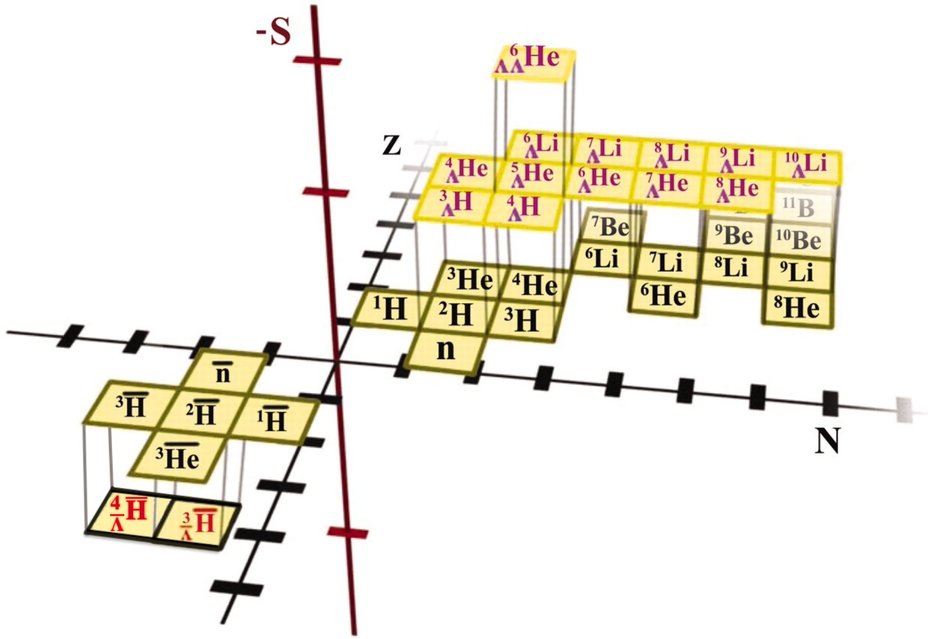


$^{3}_{\Lambda}\mathrm{H}$

lightest hypernucleus

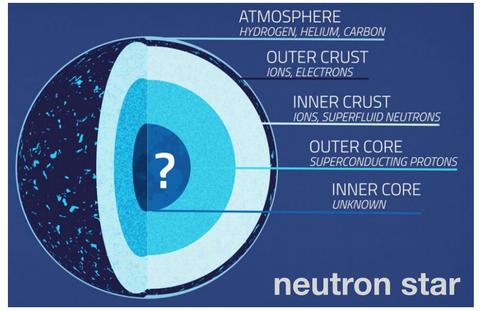
$B_\Lambda \sim 0.15\mathrm{MeV}$

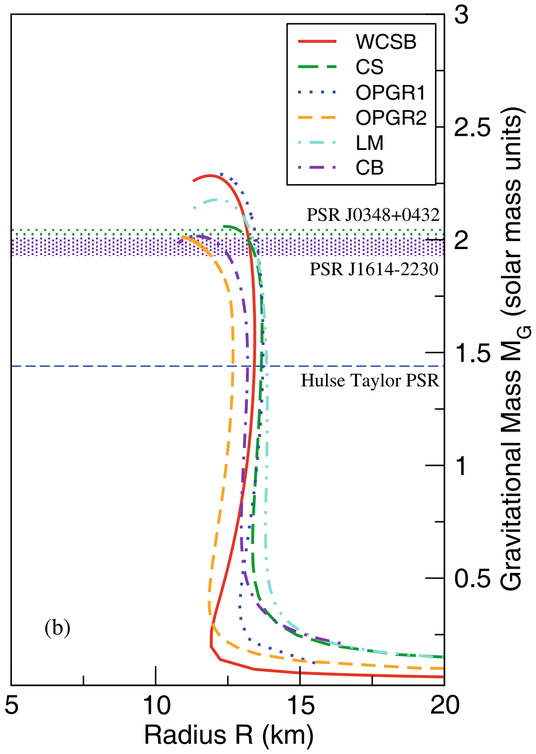
RMS radius $5 \sim 10$ fm



Introduction: YN interaction in dense matter

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





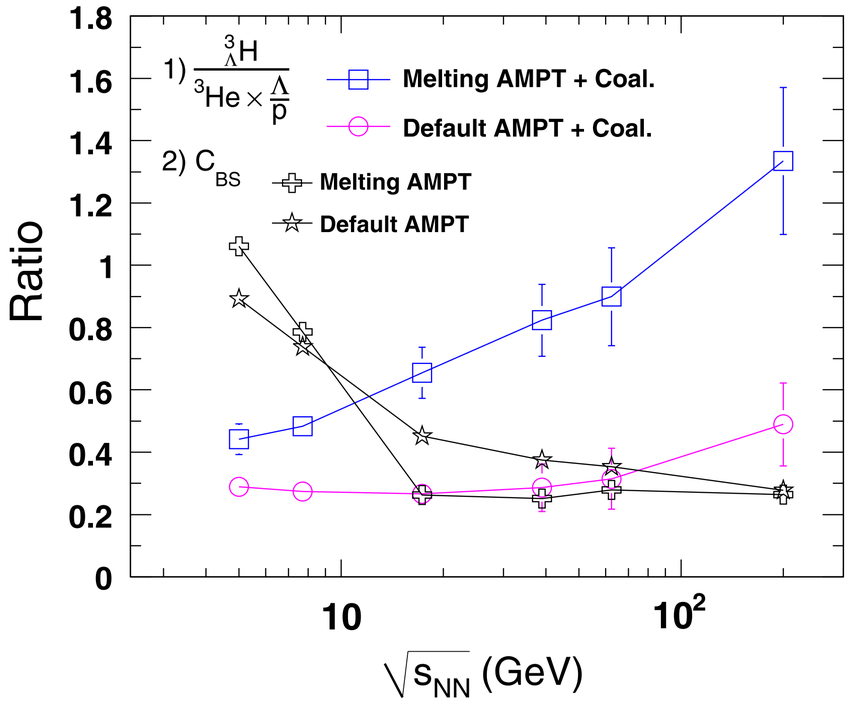
D. Chatterjee, Eur. Phys. J. A 52 (2016) 29

Introduction: the strangeness population factor S_3

- S_3 may be sensitive to the onset of deconfinement

S. Zhang et al. PLB 684 (2010) 224–227

$$S_3 = \frac{{}^{3}_{\Lambda}\mathrm{H}}{{}^{3}\mathrm{He} \times \frac{\Lambda}{\mathrm{p}}}$$

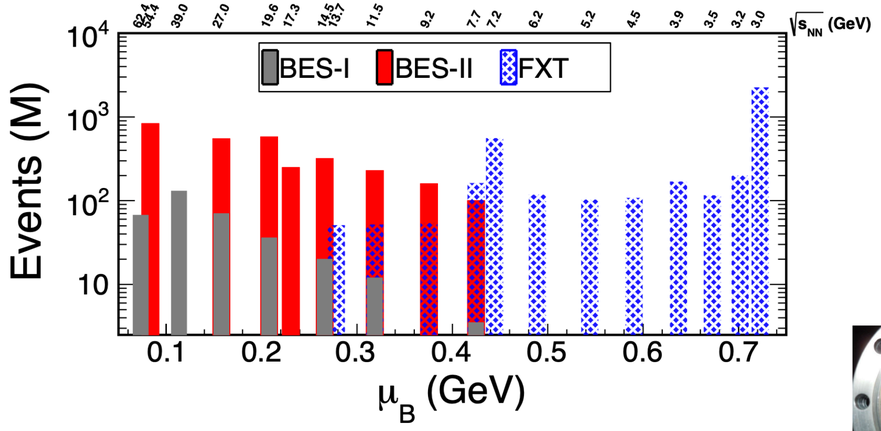


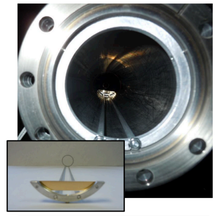
- S_3 maybe enhanced in a system involving partonic interactions
- Models suggest S_3 is more sensitive to the local baryon-strangeness correlation than the global baryon-strangeness correlation coefficient (C_{BS})

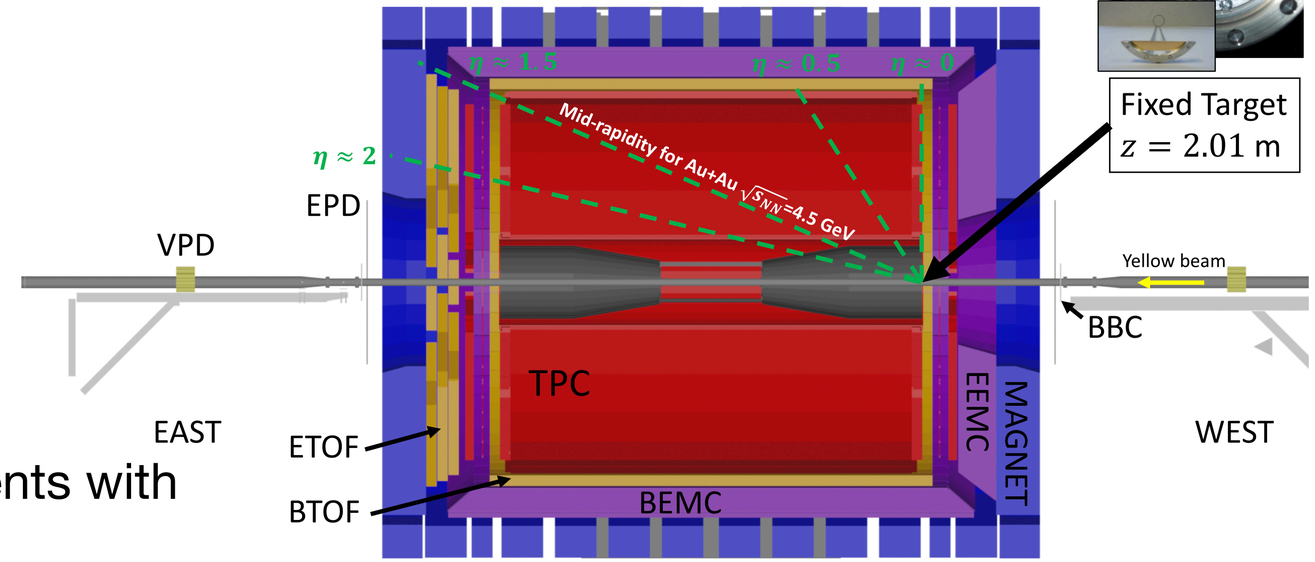
Introduction: RHIC BES-II

- 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





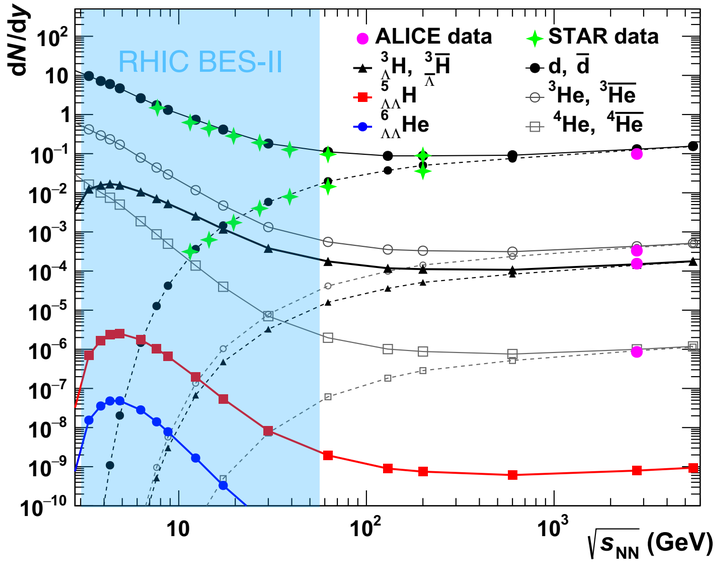


Introduction: hypernuclei in HI collisions

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.**

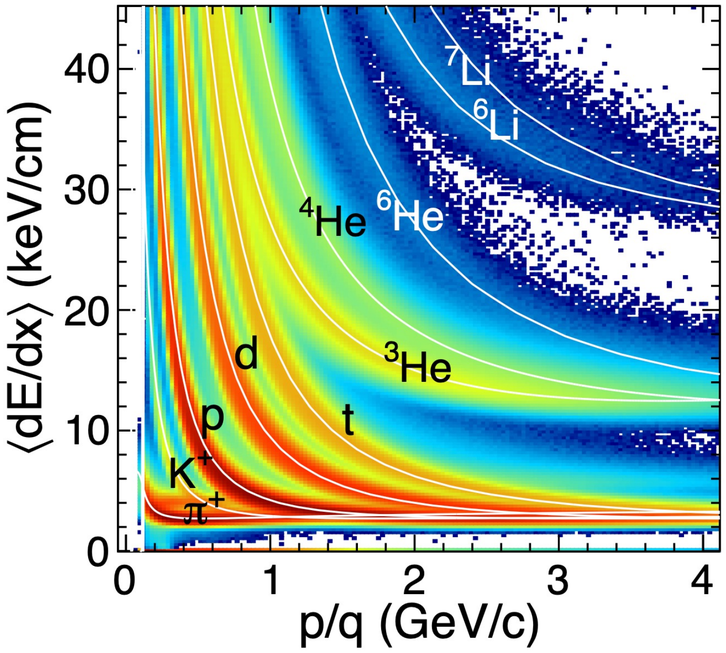


- Hypernuclei measurements are scarce in HI collision experiments
- At **low beam energies**, hypernuclei production is expected to be **enhanced** due to high baryon density

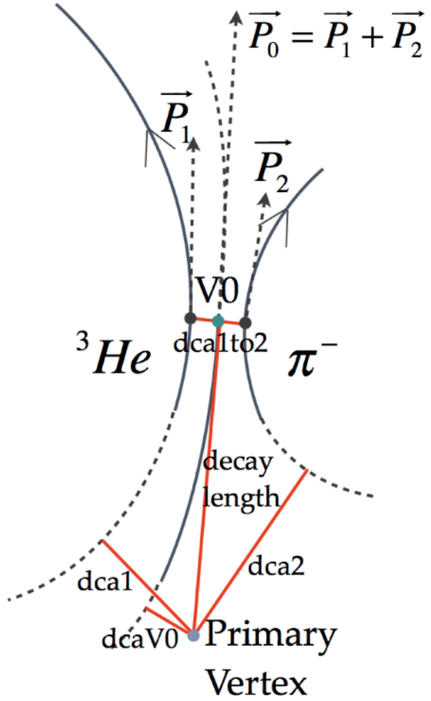
RHIC BES-II offers great opportunity for hypernuclei measurements.

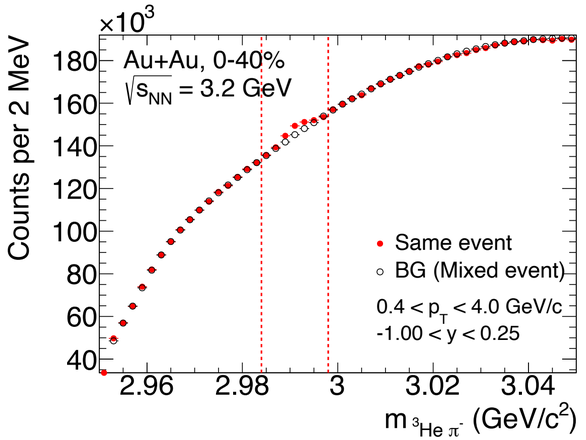
B. Dönigus, Eur. Phys. J. A (2020) 56:280
A. Andronic et al. PLB (2011) 697:203–207

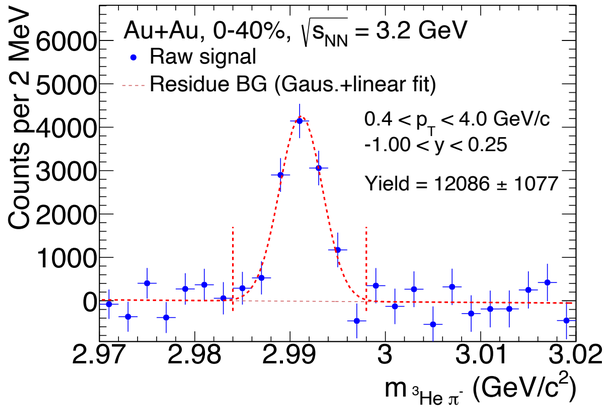
${}^{3}_{\Lambda}\mathrm{H}$ reconstruction



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



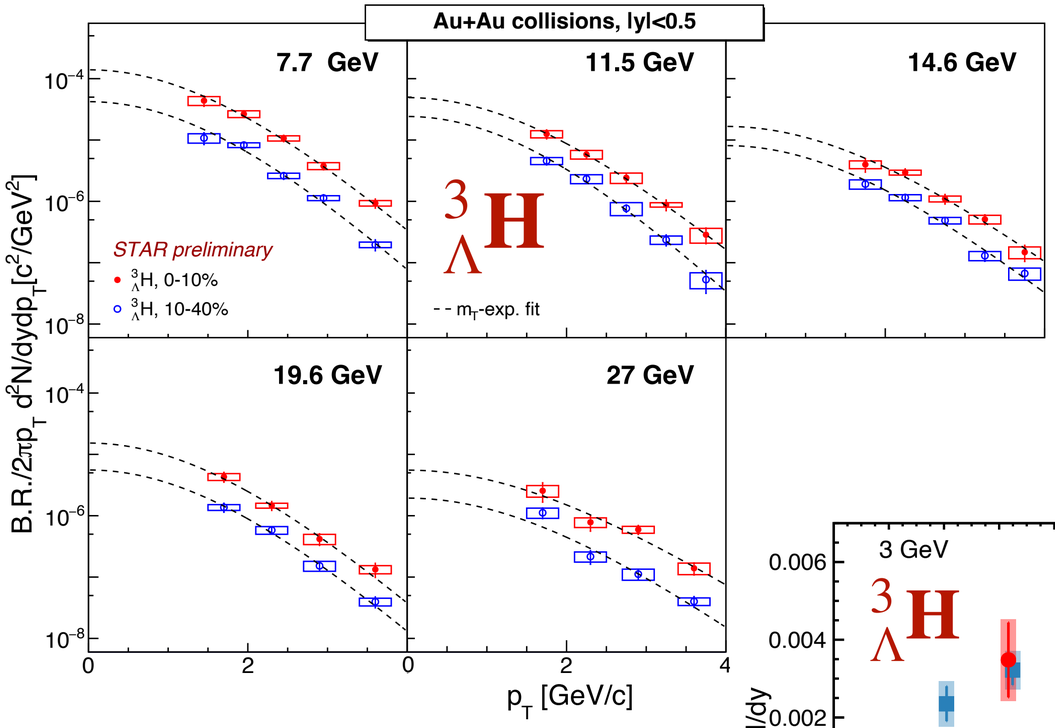




- Reconstruction channel: ${}^{3}_{\Lambda}\mathrm{H}\rightarrow{}^{3}\mathrm{He}+\pi^{-}$
- Particle identification from energy loss measurement using TPC
- KF particle package is used for signal reconstruction

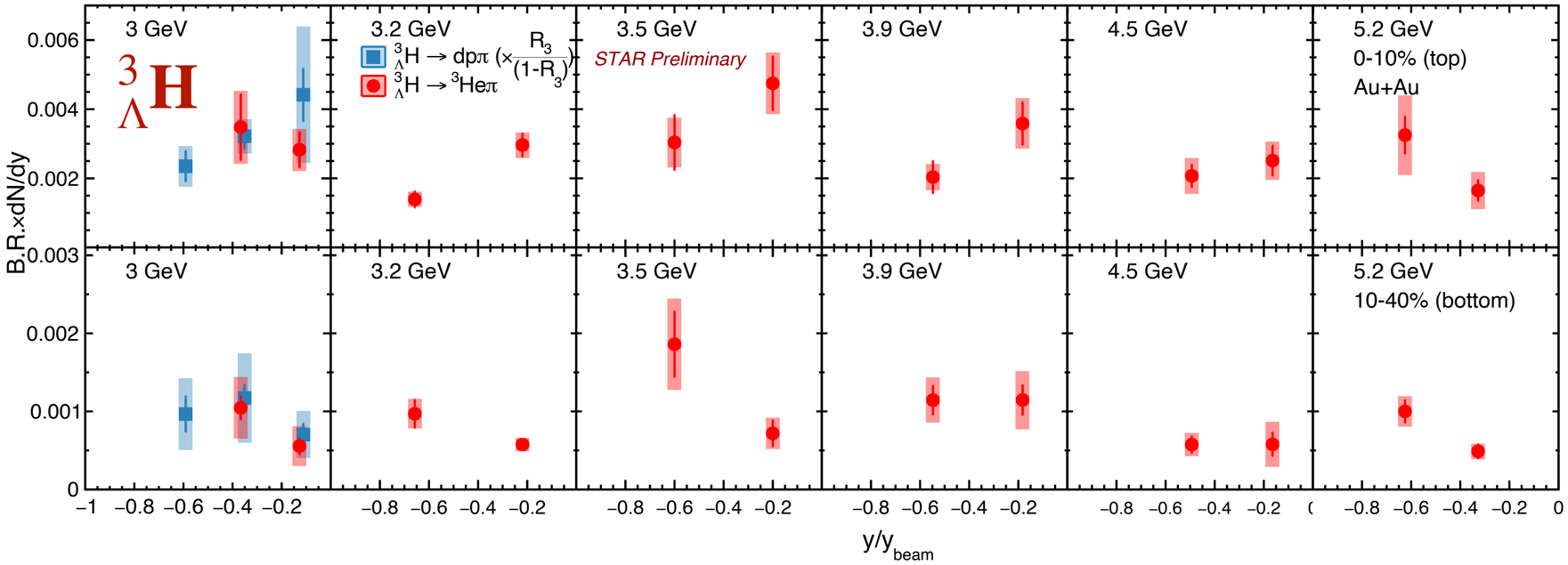
XY. Ju et al. Nucl.Sci.Tech. 34 (2023) 10, 158

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

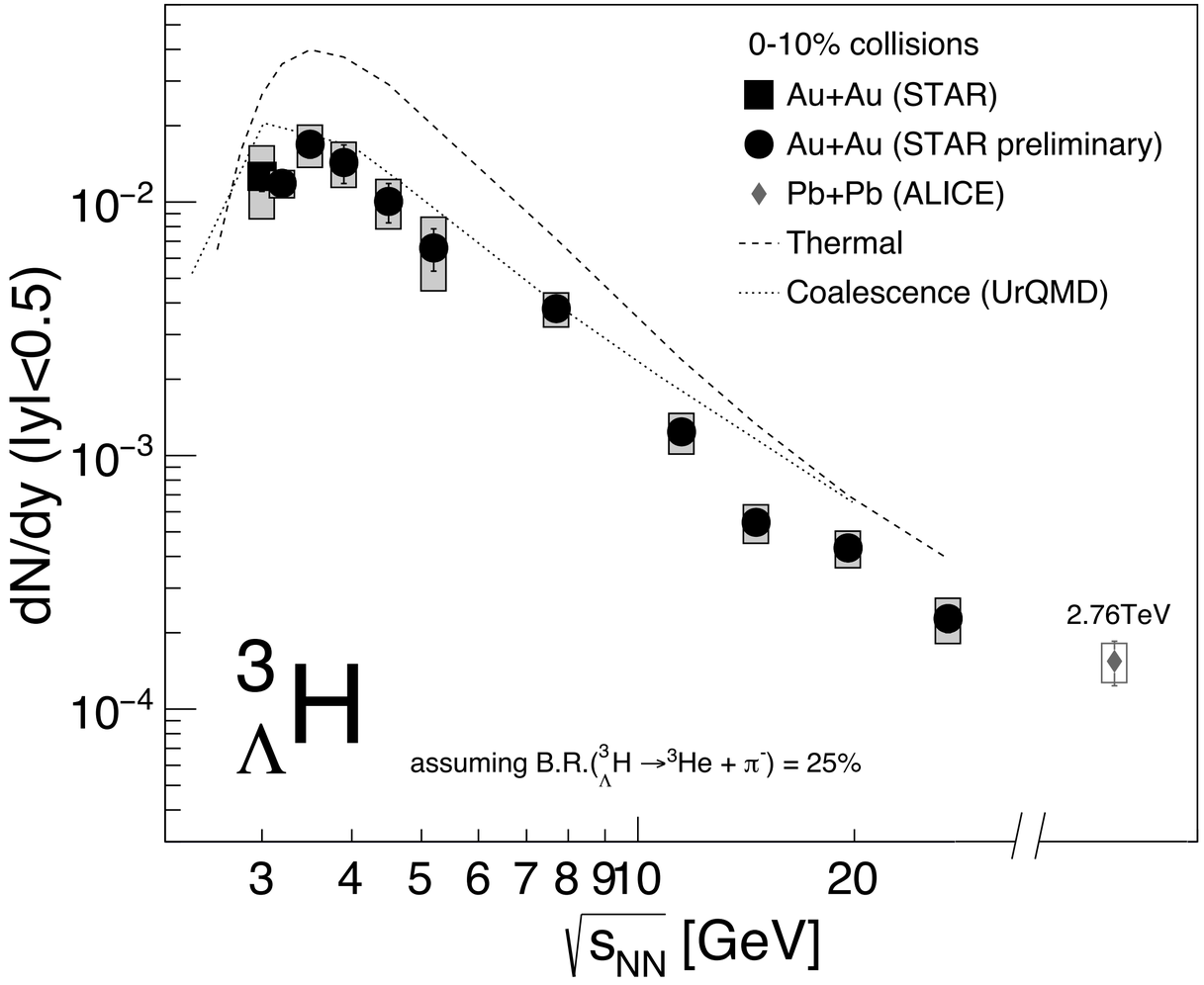


- Measurements cover 11 different energies

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

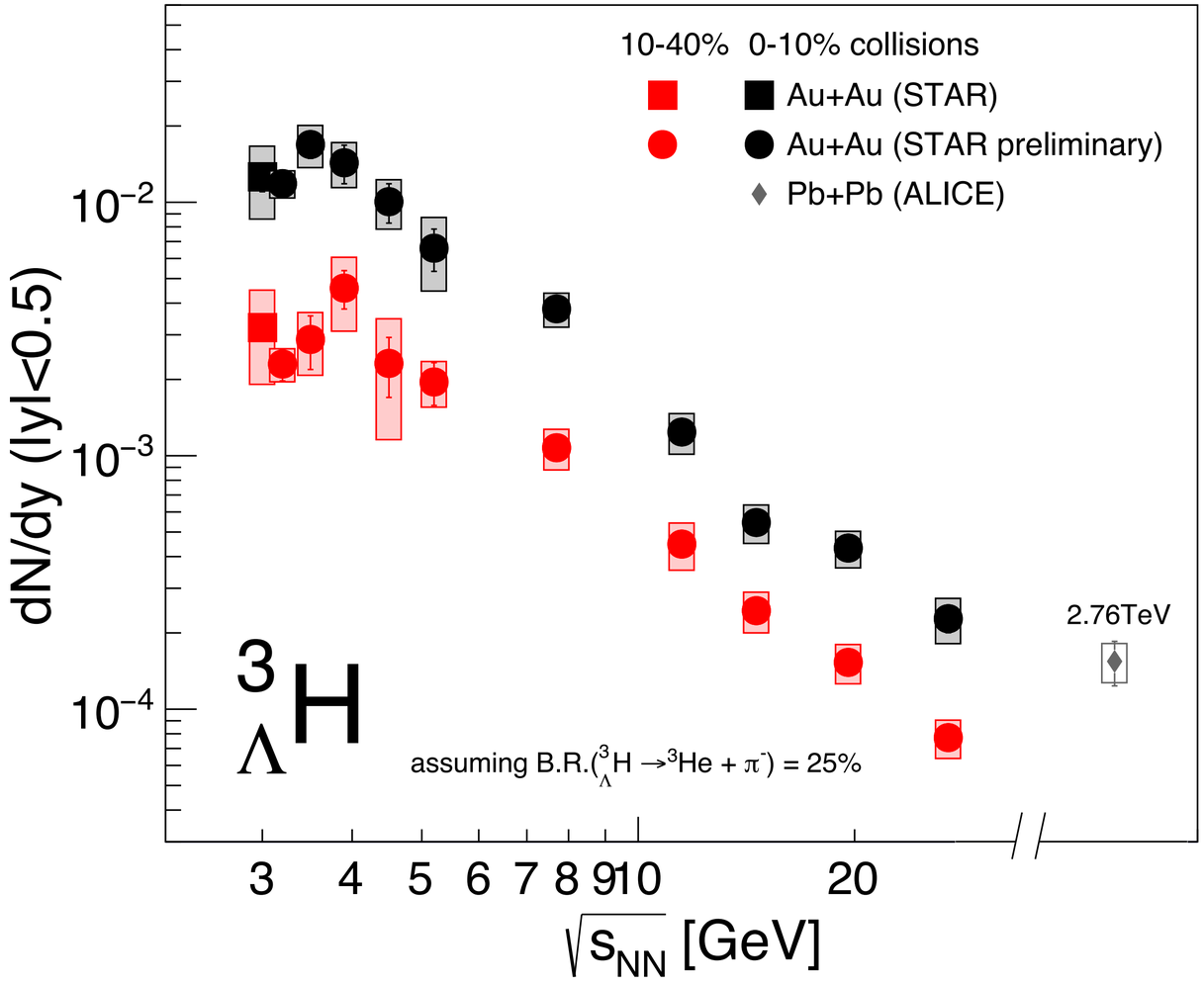


- Yields increase strongly from $\sqrt{s_{NN}}$ = 27 GeV to ~4 GeV
- Peak at 3-4 GeV
- Hadronic transport + coalescence models qualitatively describe the data
- Thermal model overestimates the data

First energy dependence of $^{3}_{\Lambda}\mathrm{H}$ production yields in the high-baryon-density region

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

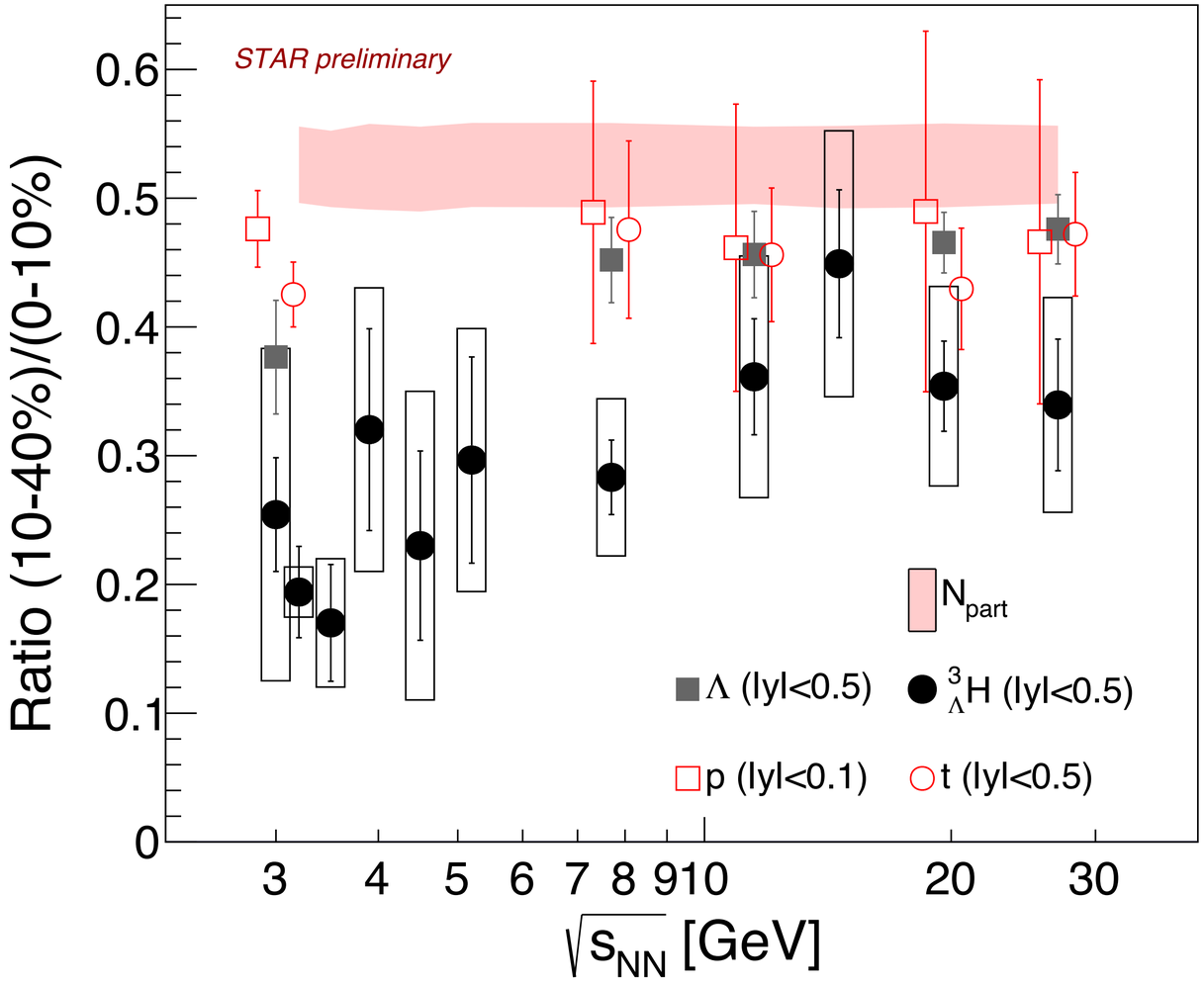
Centrality dependence of ${}^{3}_{\Lambda}\mathrm{H}$ production



- 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

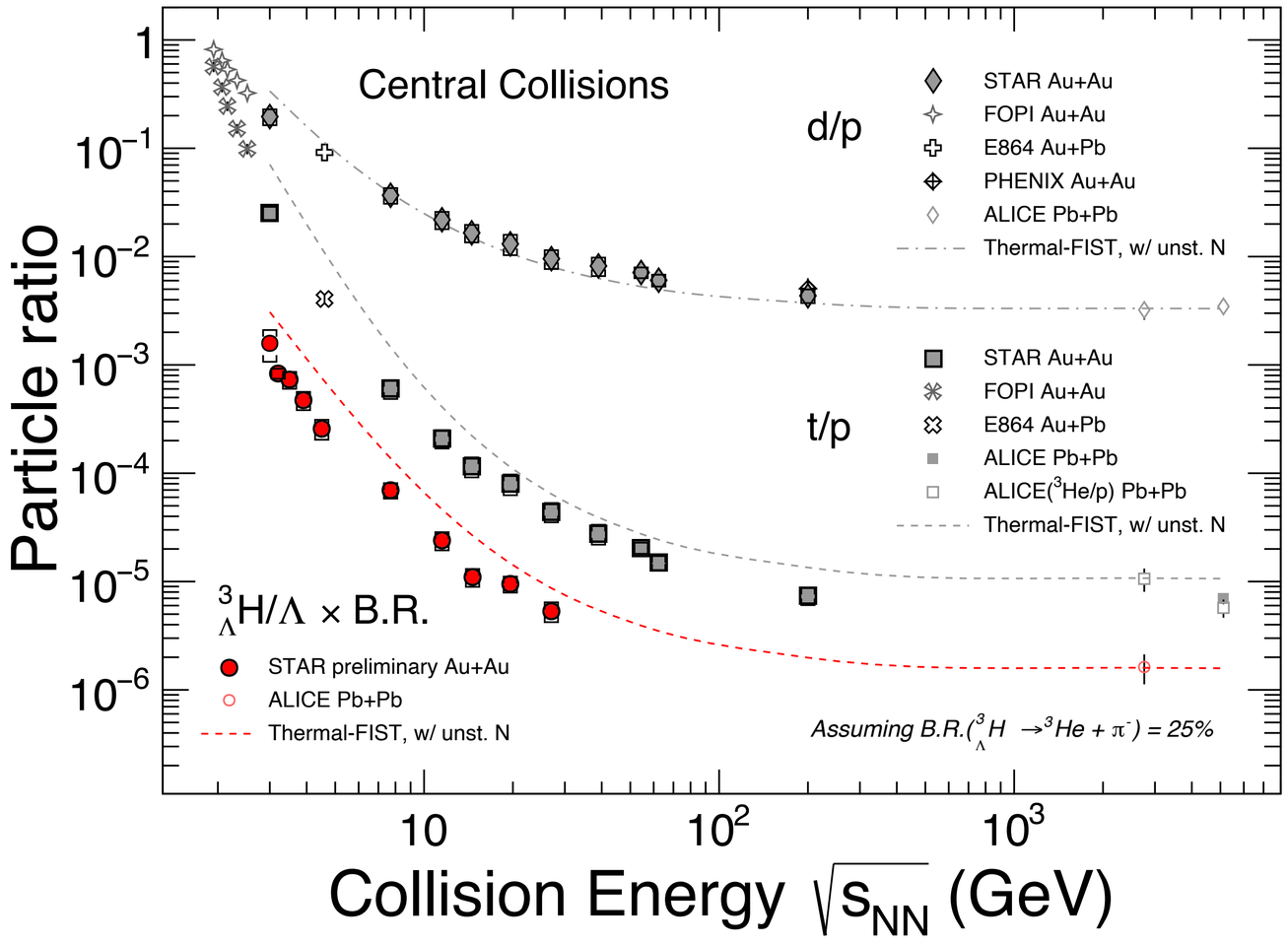


- Suppression of mid-central/central $^{3}_{\Lambda}\mathrm{H}$ yield ratio w.r.t N_{part}, seems more apparent below $\sqrt{s_{NN}}$ = 7.7 GeV

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

Suppression of $^{3}_{\Lambda}\mathrm{H}$ production in mid-central collisions at low energies compared to central collisions

Nuclei-to-Hadron ratios



- Thermal model, assuming that chemical freeze-out of light/ hypernuclei happens at same time with hadrons, **overestimates** $^{3}_{\Lambda}\mathrm{H}/\Lambda$ by a factor of ~2, as well as **t/p**

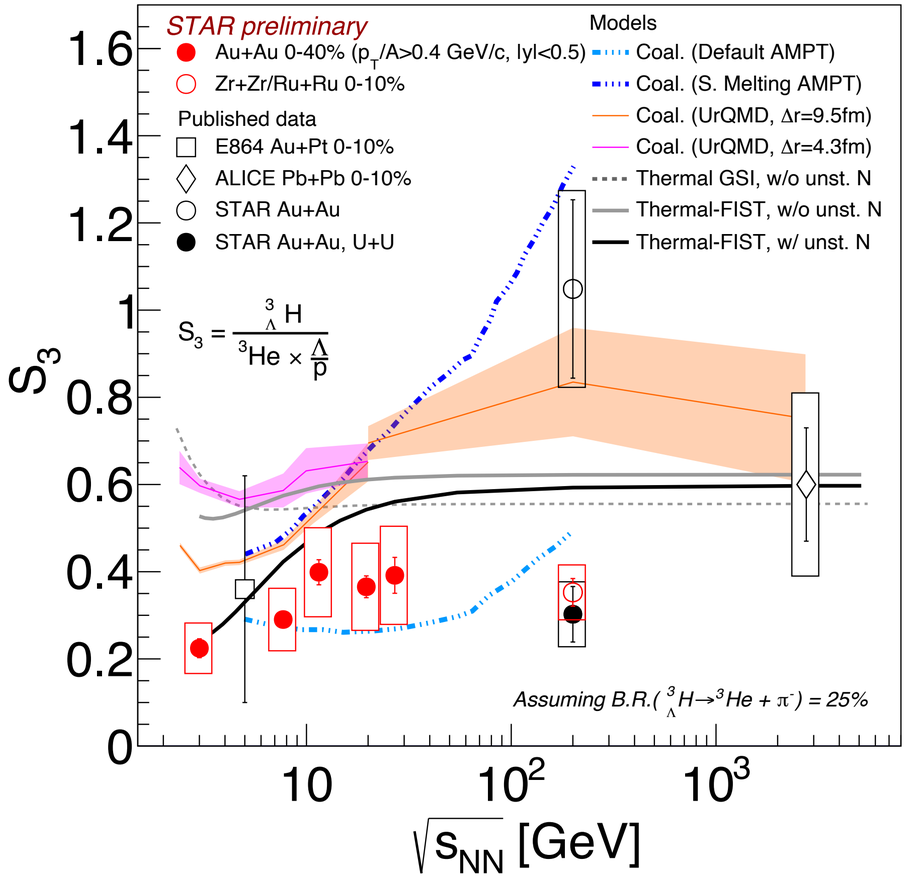
- In thermal model, particle yield ratio is independent of volume. $^{3}_{\Lambda}\mathrm{H}/\Lambda$ yield ratio is dependent of strangeness correlation length

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

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

Energy dependence of S_3

Multiplicity dependence discussed in talk by Dongsheng Li (6/5, T3)

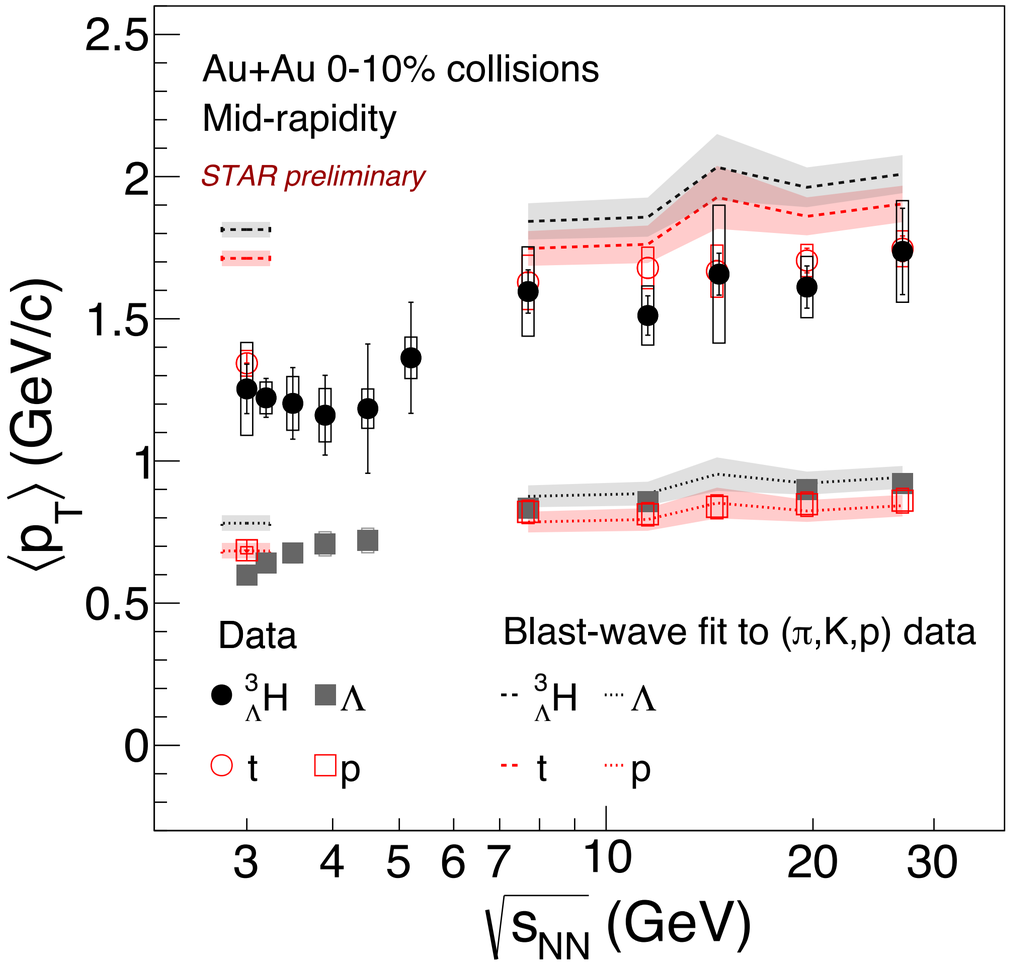


- A prominent enhancement of S_3 was proposed as a probe for deconfinement
- Data shows a mild increasing trend from $\sqrt{s_{NN}}$ = 3.0 GeV to 2.76 TeV
- For coalescence(UrQMD) models, the energy dependence is sensitive to the **source radius (Δr)**
  - Due to the difficulty in forming $^3_\Lambda H$ 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
- Blast-wave fit using measured kinetic freeze-out parameters from light hadrons (π, K, p) **overestimates both ${}^{3}_{\Lambda}\mathrm{H}$ and t**

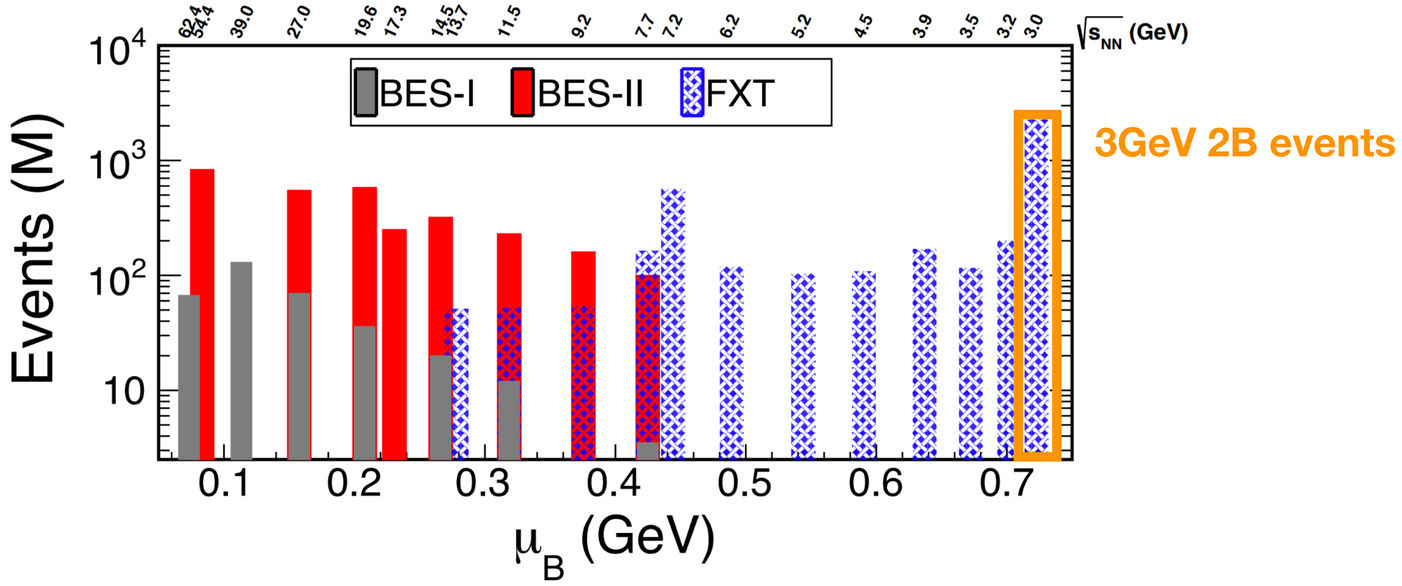
${}^{3}_{\Lambda}\mathrm{H}$ and t do not follow same collective expansion as light hadrons. Can be interpreted as ${}^{3}_{\Lambda}\mathrm{H}$ and t decoupling at different times compared to light hadrons

- 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
- ${}^{3}_{\Lambda}\mathrm{H}$ $\langle p_{\mathrm{T}} \rangle$ 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

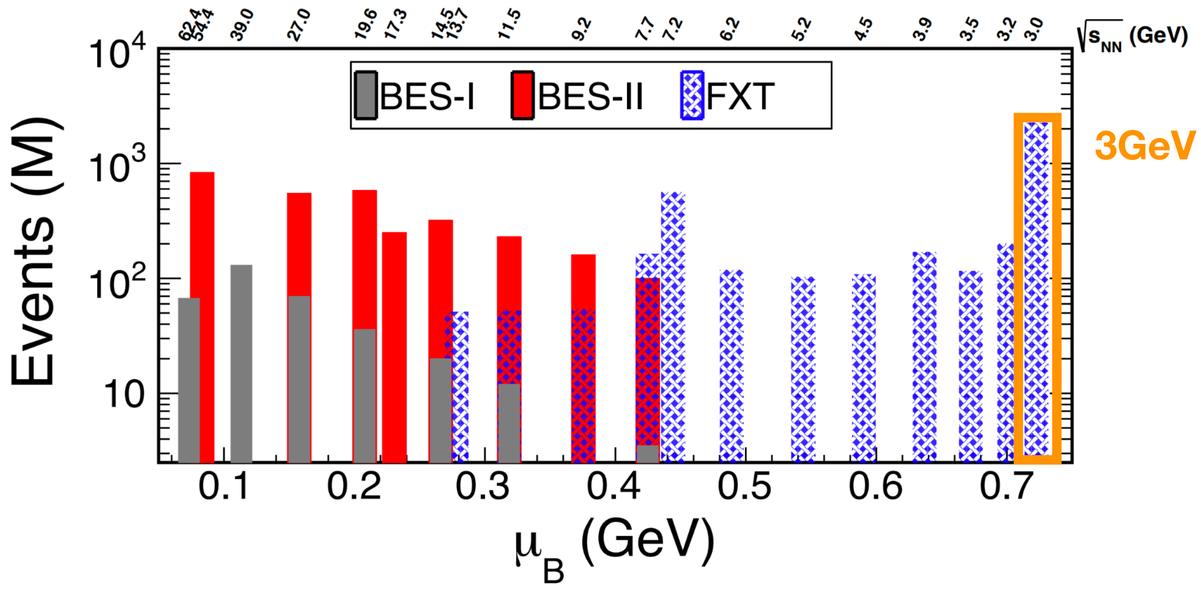


3GeV 2B events

- Huge datasets enable precision hypernuclei measurements
  - Run 21, Au+Au 3 GeV, ~2 billion events
  - **Run 18, Isobar 200 GeV, ~6 billion events** See talk by Dongsheng Li, 05/06/24, 11:40AM
  - Run 23-25, Au+Au 200 GeV, ~18 billion events
- Opportunities for heavier hypernuclei: ${}^{4}_{\Lambda}\mathbf{H}$, ${}^{4}_{\Lambda}\mathbf{He}$, ${}^{5}_{\Lambda}\mathrm{He}$, ${}^{6}_{\Lambda}\mathrm{H}$, ${}^{A}_{\Lambda\Lambda}\mathrm{H}$, ${}^{A}_{\Lambda\Lambda}\mathrm{He}$

See talks by Junyi Han, 04/06/24, 2:40PM
Chenlu Hu, 05/06/24, 9:10AM
Yuanjing Ji, 06/06/24, 11:00AM

Outlook



3GeV 2B events

Thank you!

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