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

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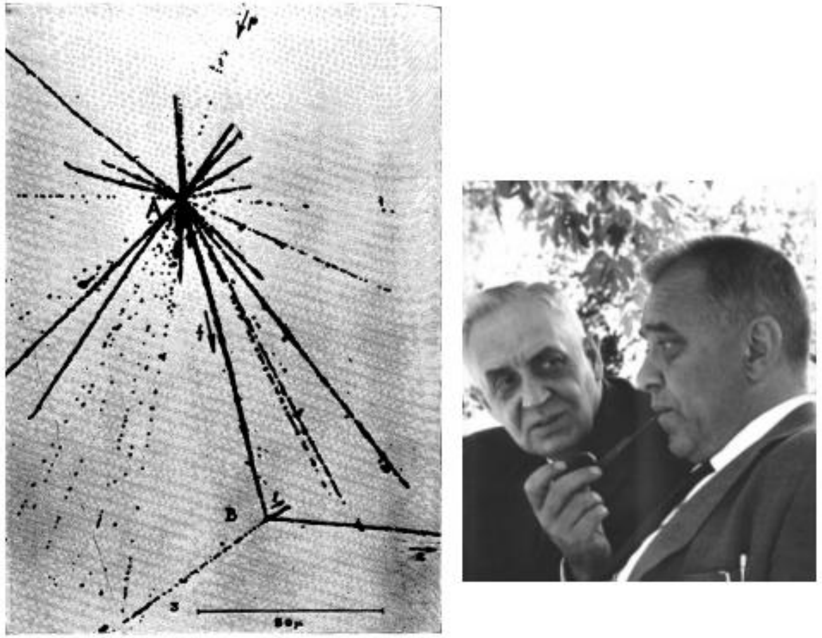
Introduction: hypernuclei

- 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

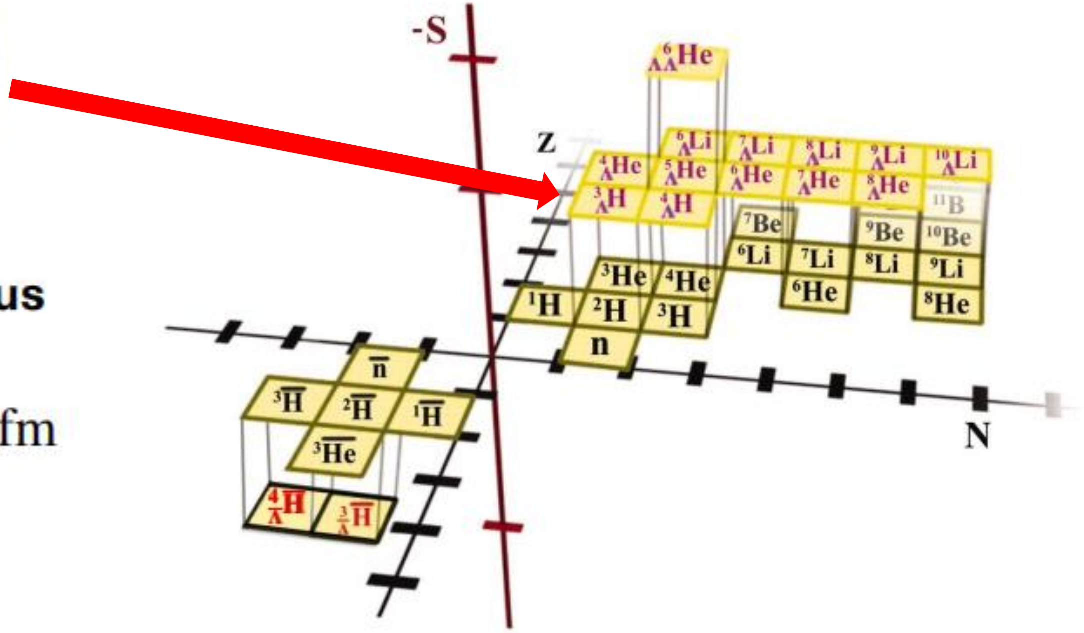
M. Danysz, J. Pniewski, Philos. Mag. 44 (1953) 348.

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

lightest hypernucleus

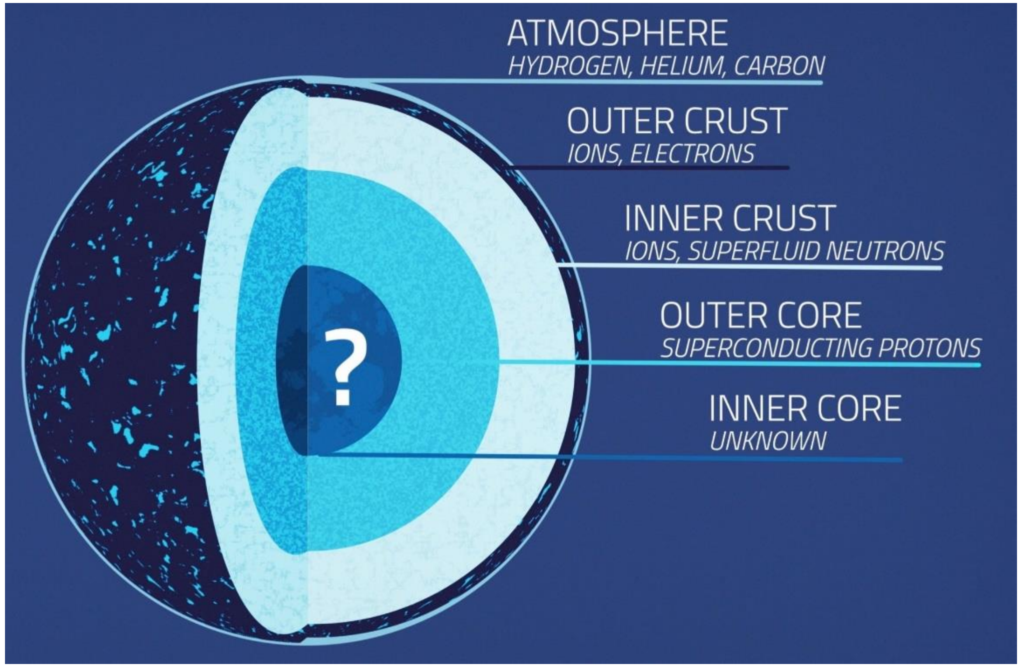
$B_\Lambda \sim 0.15$MeV

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)

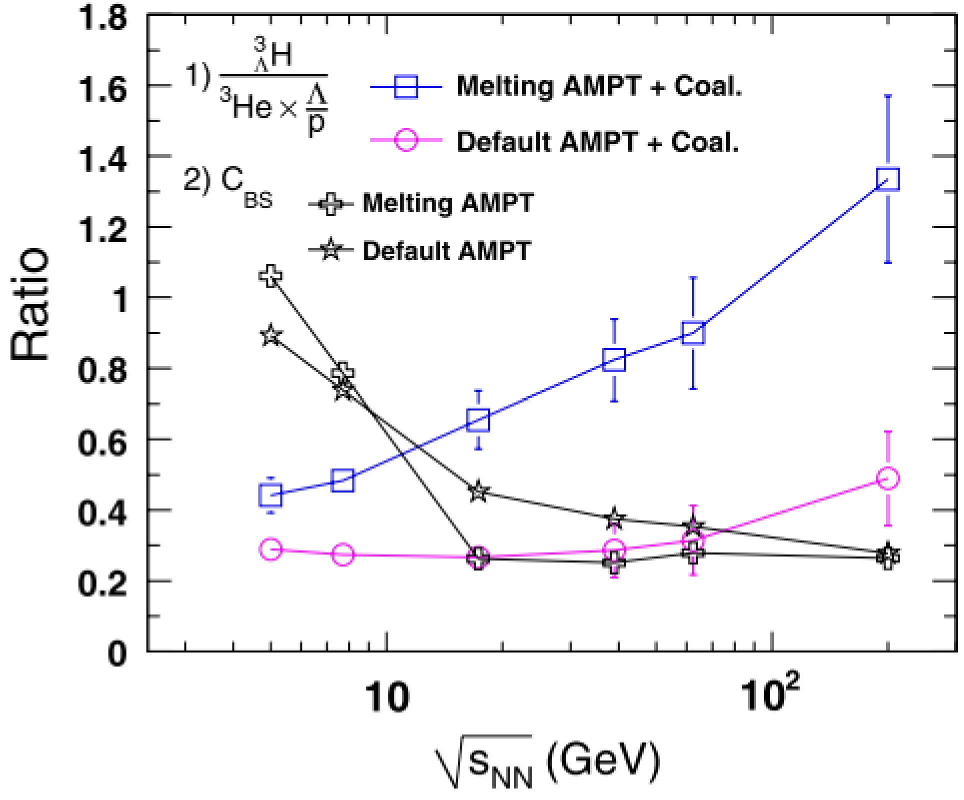
Introduction: the strangeness population factor S_3

- S_3 may be sensitive to the onset of deconfinen

$$S_3 = \frac{{}^{3}_{\Lambda}H}{{}^{3}_{2}He \times \frac{\Lambda}{P}}$$

  - 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})



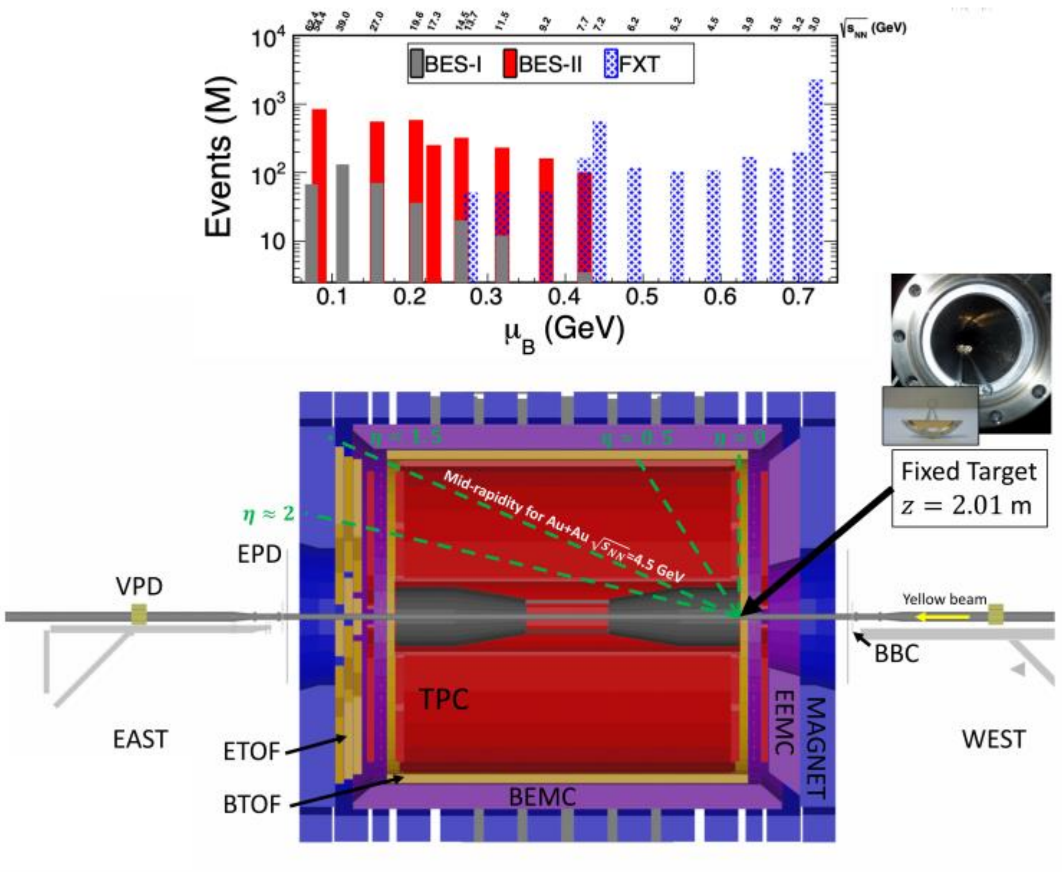
S. Zhang et al. PLB 684 (2010) 224–227

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

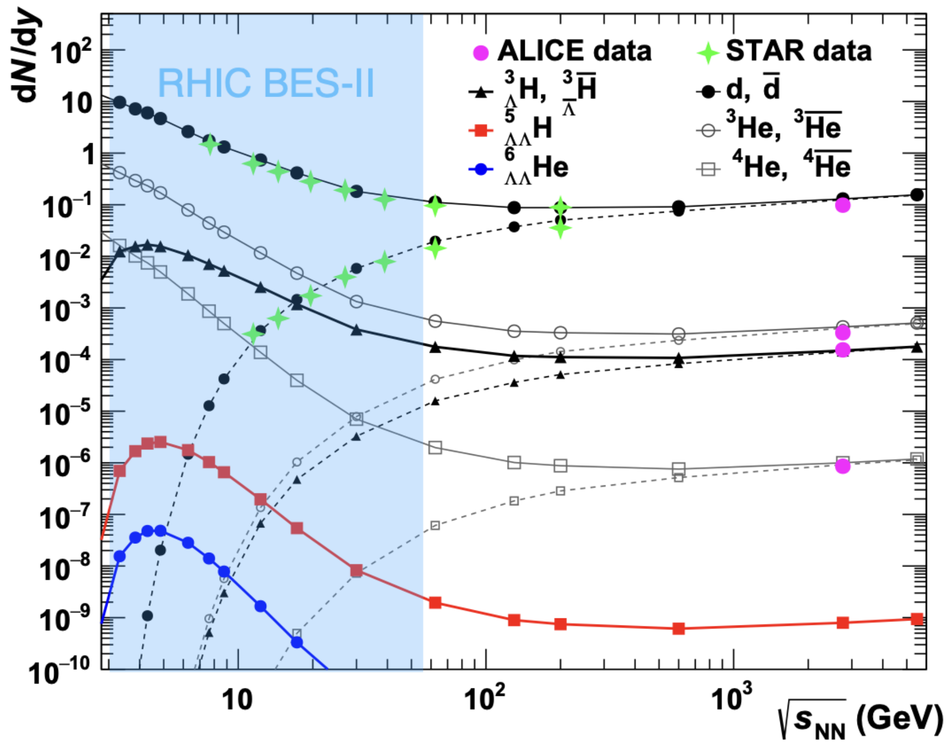
Production mechanism of hypernuclei is still not well understood.

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

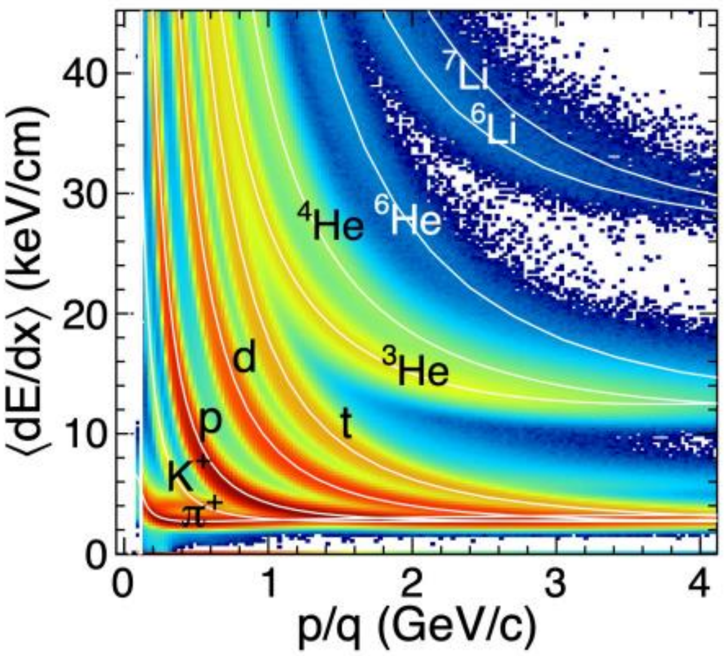
RHIC BES-II offers great opportunity for hypernuclei measurements.

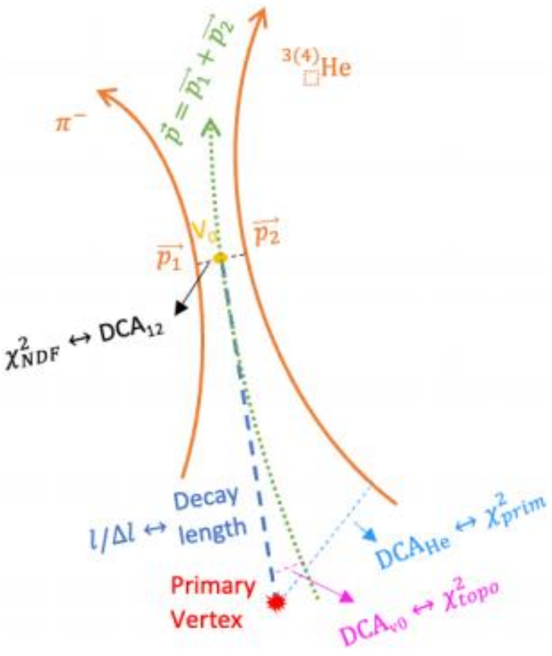


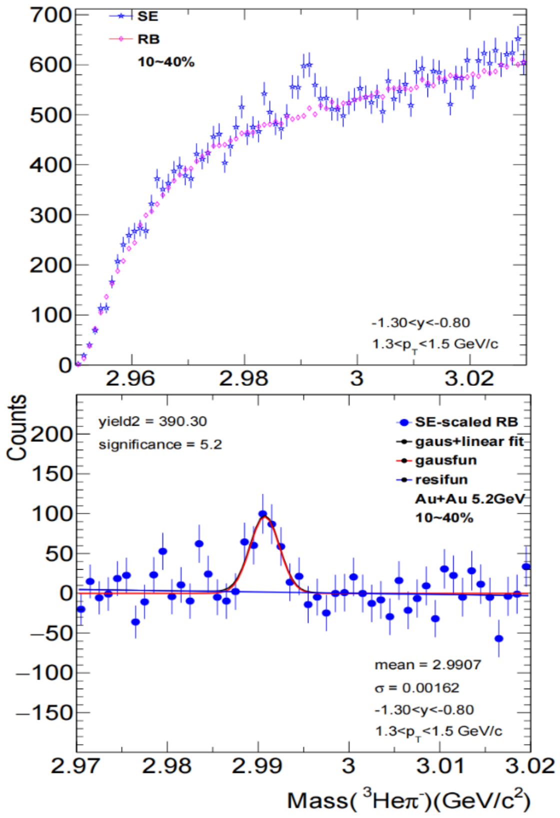
B. Dönigus, Eur. Phys. J. A (2020) 56:280
A. Andronic et al. PLB (2011) 697:203–207

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

$^{3}_{\Lambda}H -> ^{3}_{2}He + \pi^{-}$



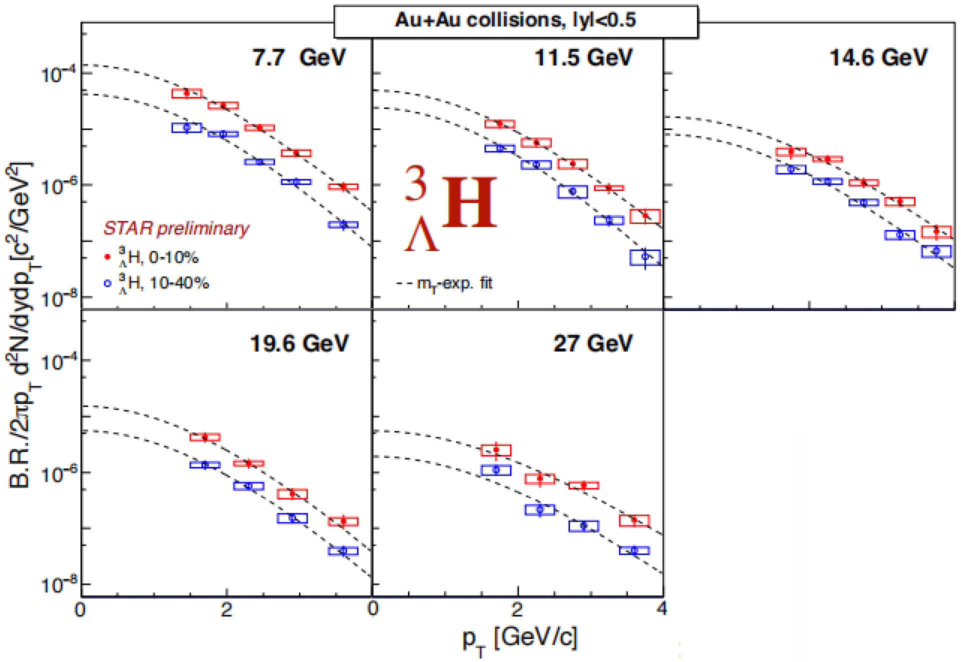




- Reconstruction channel: $^{3}_{\Lambda}H -> ^{3}_{2}He + \pi^{-}$
- Particle identification from energy loss measurement using TPC
- KF particle package is used for signal reconstruction

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

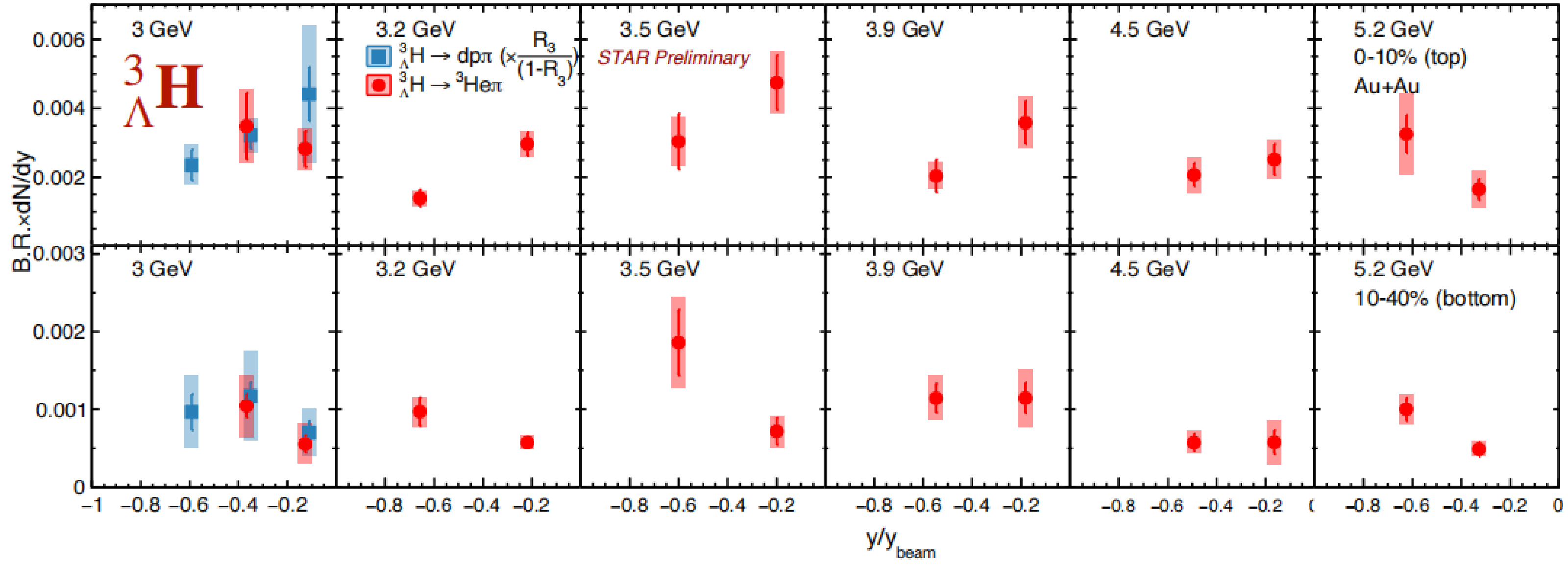
$^{3}_{\Lambda}H$ rapidity and p_T spectra



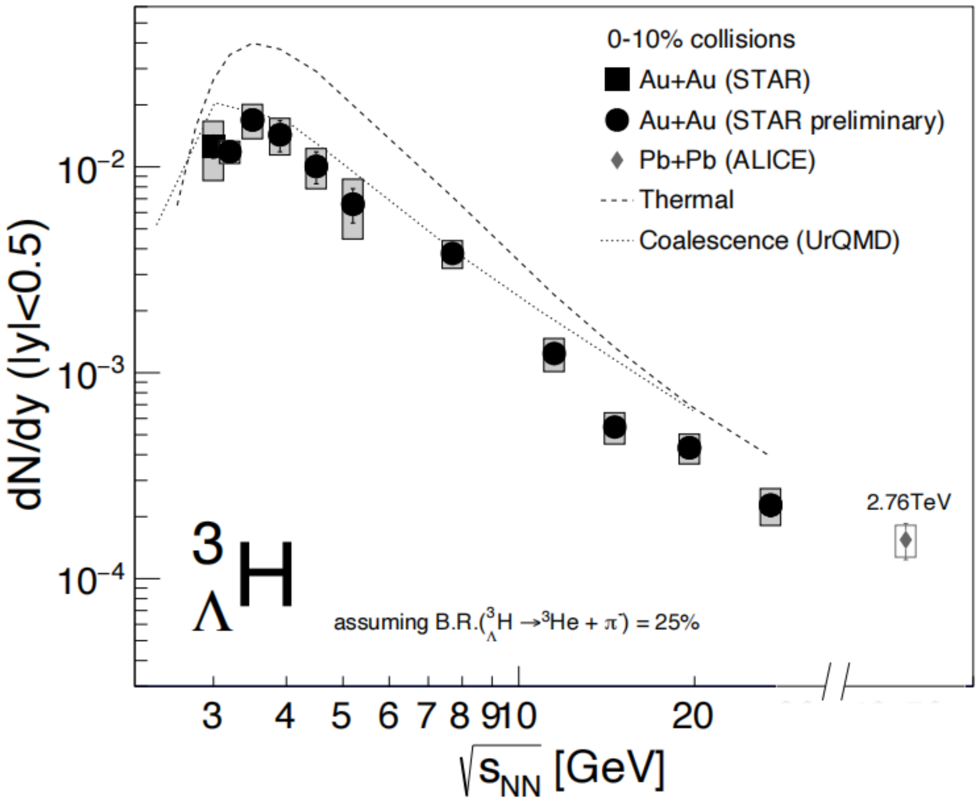
- Measurements cover 11 different energies

  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

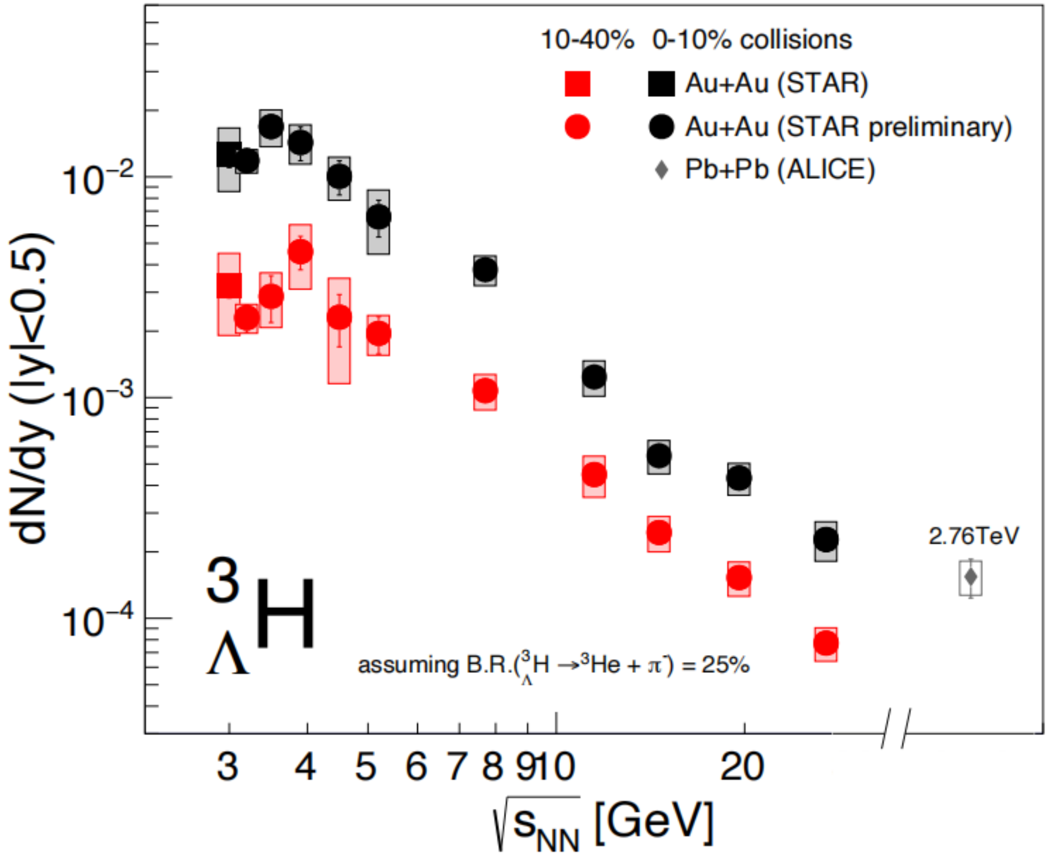


- Yields increase strongly from $\sqrt{S_{NN}} = 27$ GeV to ~4GeV
- Peak at 3-4 GeV
- Hadronic transport + coalescence models qualitatively describe the data
- Thermal model overestimates the data

First energy dependence of ${}^{3}_{\Lambda}H$ 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

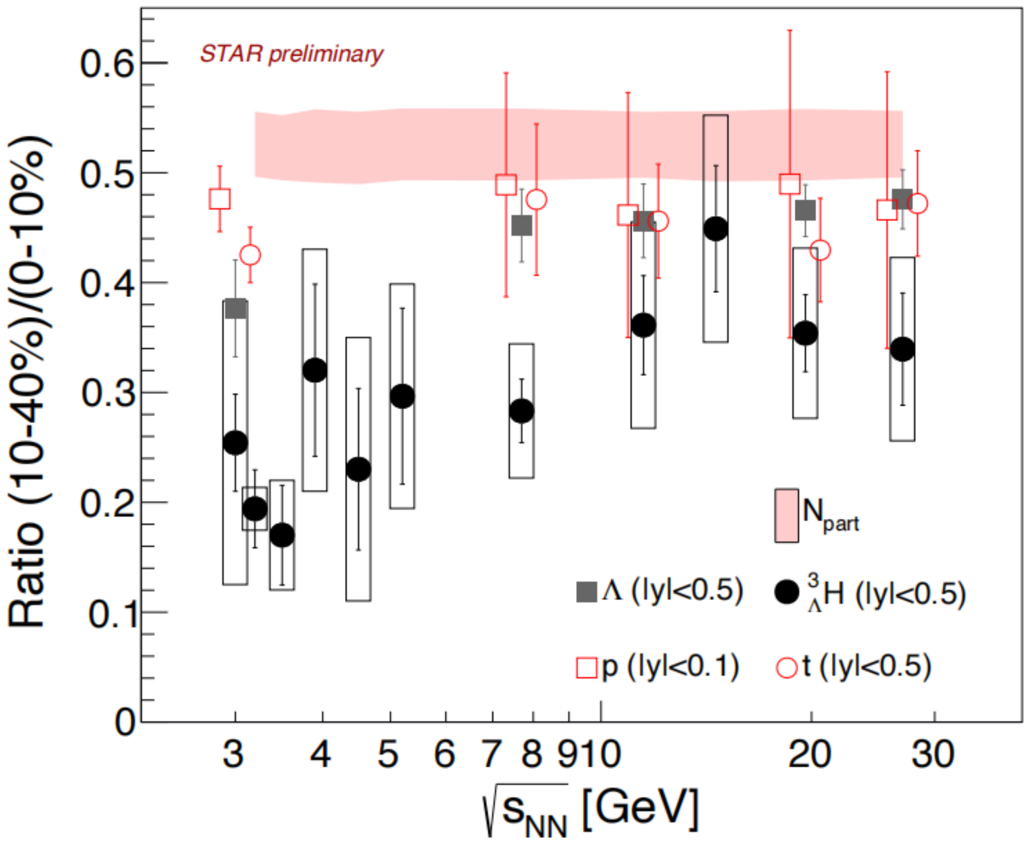
Centrality dependence of ${}^{3}_{\Lambda}H$ production



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

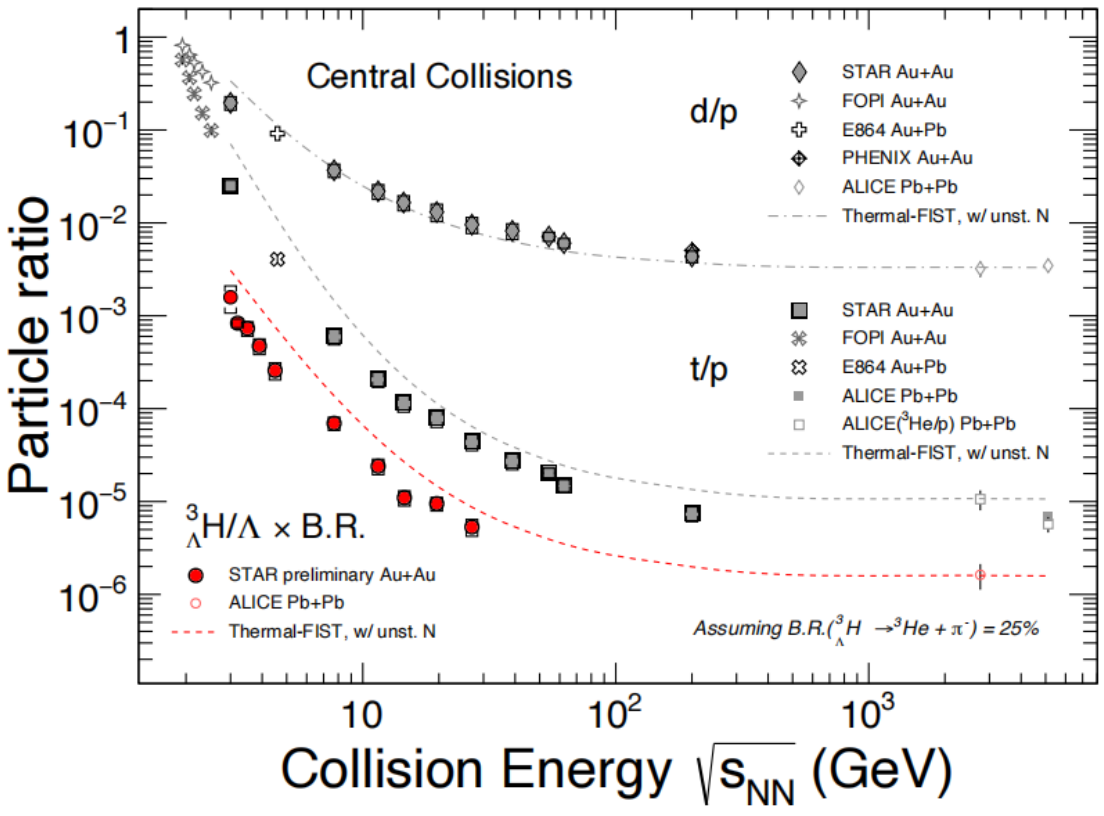


- Suppression of mid-central/central ${}^{3}_{\Lambda}H$ yield ratio seems more apparent below $\sqrt{S_{NN}} = 7.7$ GeV

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

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

Nuclei-to-Hadron ratios



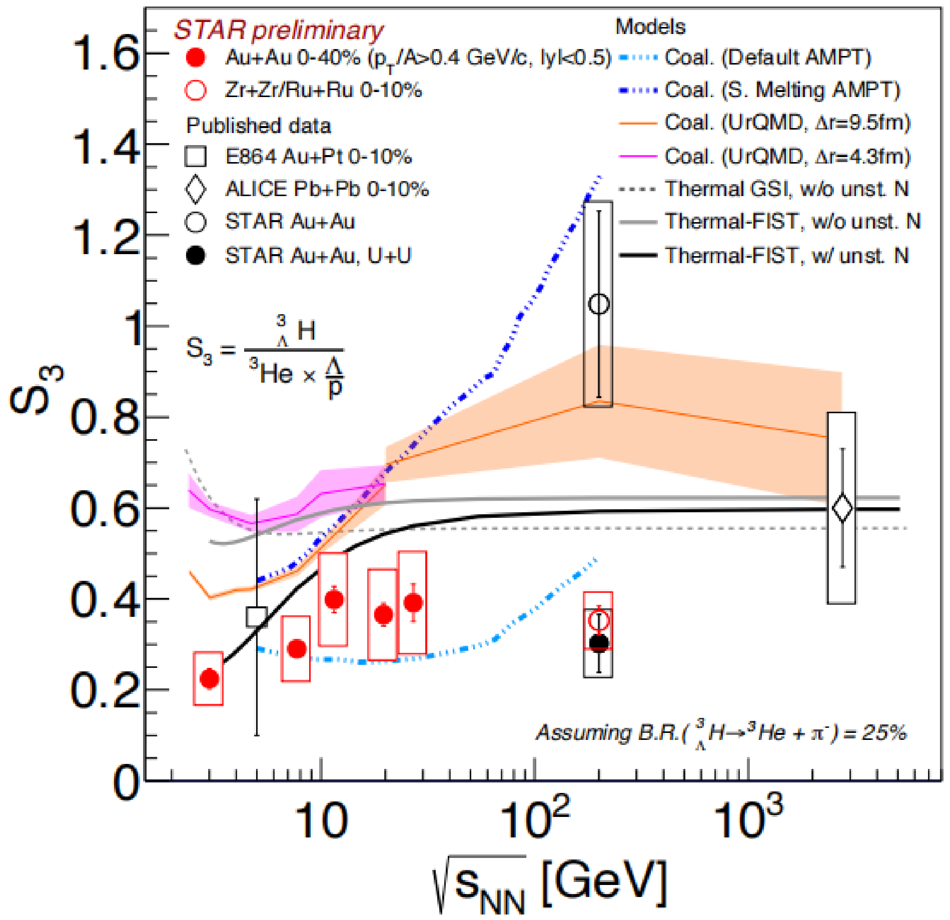
- Thermal model, assuming that chemical freeze-out of light/ hypernuclei happens at same time with hadrons, **overestimates** ${}^{3}_{\Lambda}H/\Lambda$ by a factor of ~2, as well as **t/p**

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

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

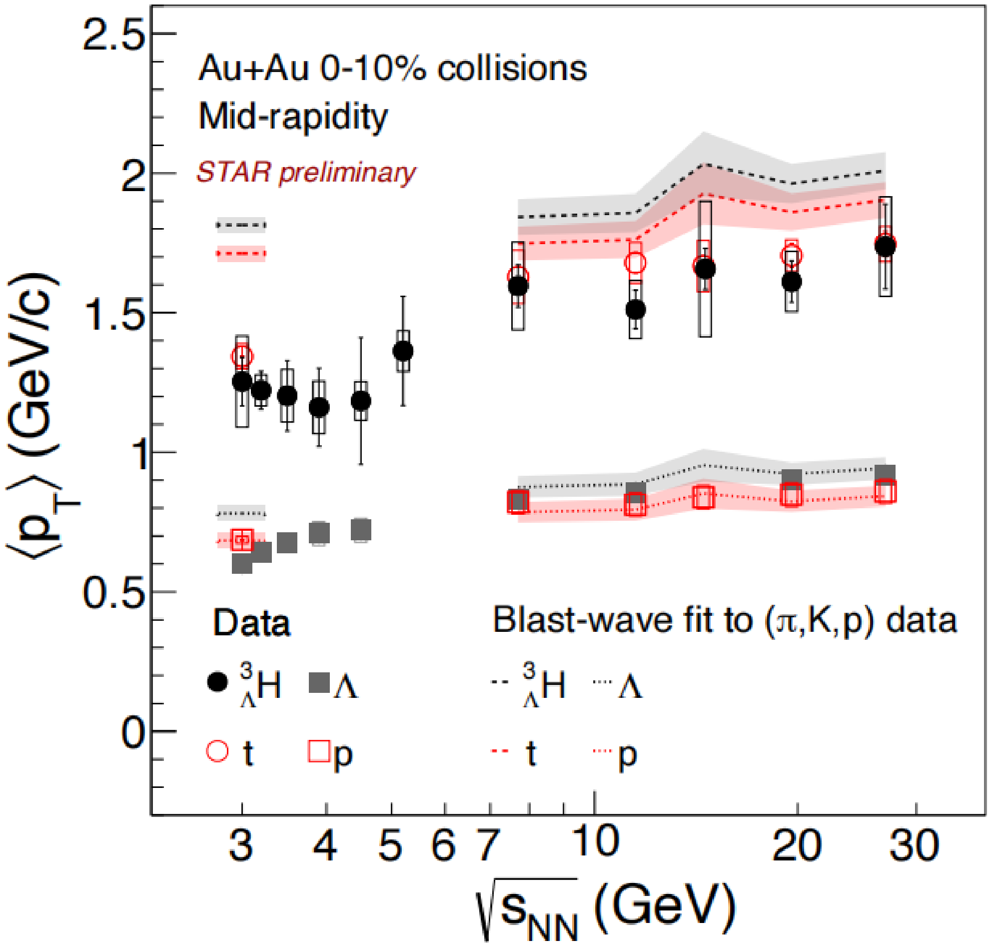


- A prominent enhancement of S_3 was proposed as a probe for deconfinement
- Data shows a mild increasing trend from $\sqrt{S_{NN}} = 3.0$ GeV to 2.76 TeV
- For coalescence(UrQMD) models, the energy dependence is sensitive to the **source radius** （ Δr ）
  - Due to the difficulty in forming ${}^{3}_{\Lambda}H$ of large radius in small systems
- Thermal-FIST, which includes **feed-down** from unstable nuclei to stable p, ${}^{3}_{2}He$， 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 ${}^{3}_{\Lambda}H$ and $\langle p_T \rangle$



- Similar $\langle p_T \rangle$ for ${}^{3}_{\Lambda}H$ and t

- Hint of ${}^{3}_{\Lambda}H$ and t $\langle p_T \rangle < \langle p_T \rangle^{BW}$ >7.7GeV
Blast-wave expectation calculated using measured kinetic freeze-out parameters from light hadrons (π, K, p)spectra.
${}^{3}_{\Lambda}H$ and t might do not follow same collective expansion as light hadrons. Can be interpreted as ${}^{3}_{\Lambda}H$ and t decoupling at different times compared to light hadrons

- Different trend for $\sqrt{S_{NN}} = 3.0 - 4.5$ GeV and $\sqrt{S_{NN}} = 7.7 - 27$ GeV

- Suggest different expansion dynamics?

Summary

- ${}^{3}_{\Lambda}H$ yields and ${}^{3}_{\Lambda}H/\Lambda$ 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 ~2

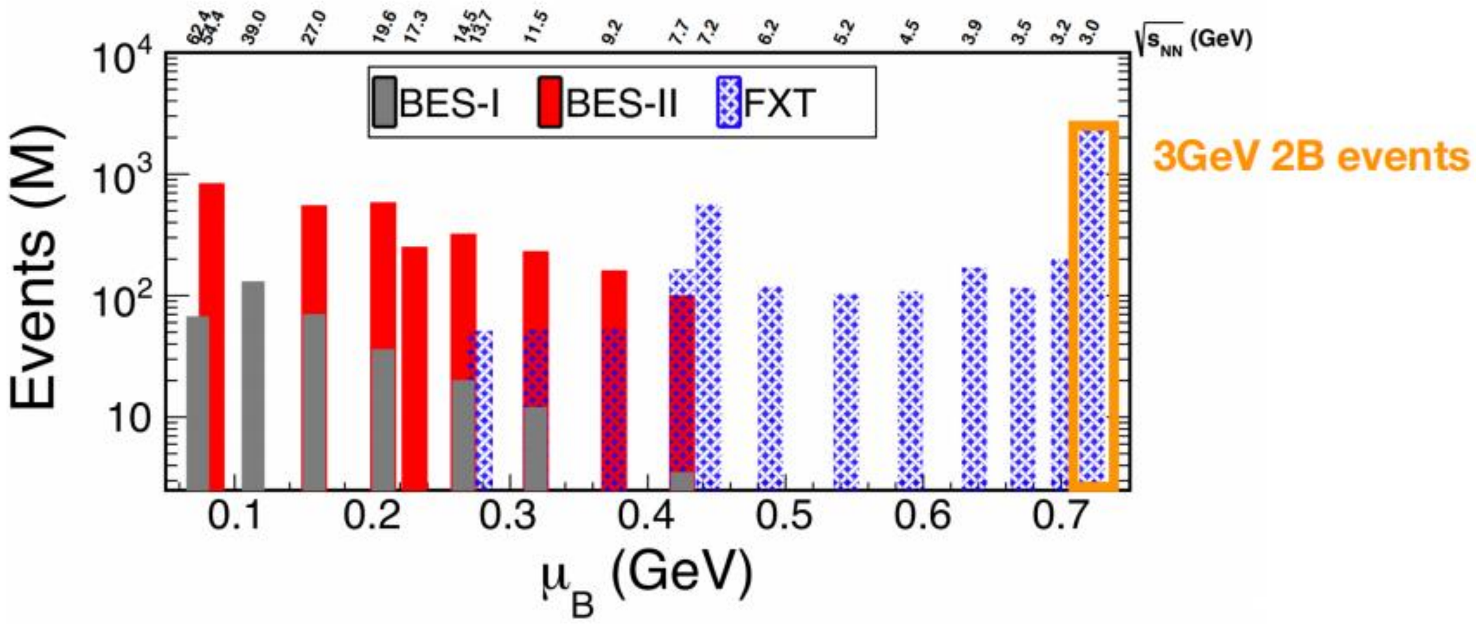
- ${}^{3}_{\Lambda}H$ $\langle p_T \rangle$ overestimated by Blast-wave fit parameterization from light hadrons

    - **${}^{3}_{\Lambda}H$ are likely formed at or decouples from the system at a different time compared to the light hadrons**

- Suppression of ${}^{3}_{\Lambda}H$ 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 hypernucleimeasurements
  - **Run 21, Au+Au 3 GeV, ~2 billion events**
  - Run 18, Isobar 200 GeV, ~6 billion events

- Opportunities for heavier hypernuclei: $\boldsymbol{{}^{4}_{\Lambda}H}$, $\boldsymbol{{}^{4}_{\Lambda}He}$, ${}^{5}_{\Lambda}He$, ${}^{6}_{\Lambda}H$, ${}^{A}_{\Lambda\Lambda}H$, ${}^{A}_{\Lambda\Lambda}He$

Back up

- Motivation
- The process of analysis
  - ⇨Dataset and event selections
  - ⇨PID recalibration
  - ⇨Signal reconstruction
  - ⇨Reconstuction efficiency
- Results
  - ⇨H3L p_T spectra and p_T-integrated yield
  - ⇨Systematic uncertainty
  - ⇨H3L yields and $< p_T >$ vs $\sqrt{s_{NN}}$
- Summary