



中国科学院大学  
University of Chinese Academy of Sciences

# Study of Hypernuclei in Heavy-ion Collisions

Chenlu Hu (胡晨露)

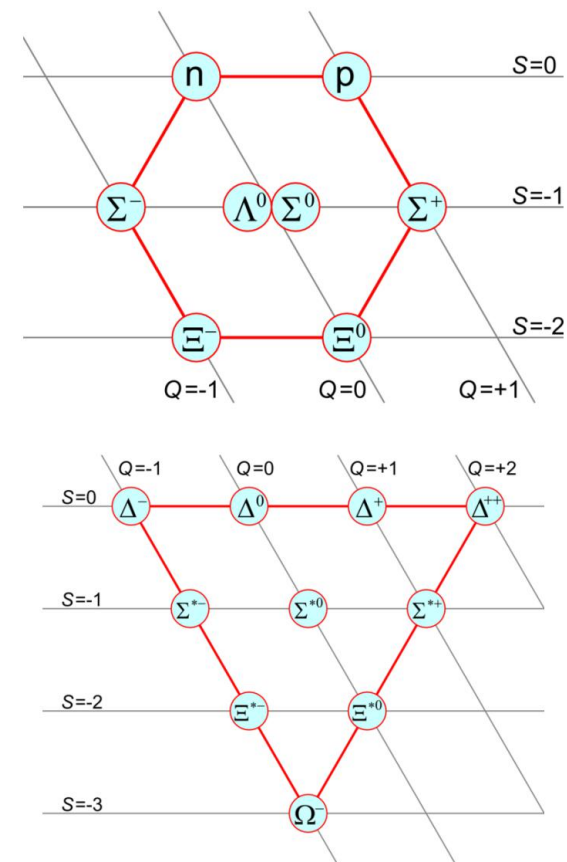
University of Chinese Academy of Science (UCAS)

2026-03-05

# Hyperon

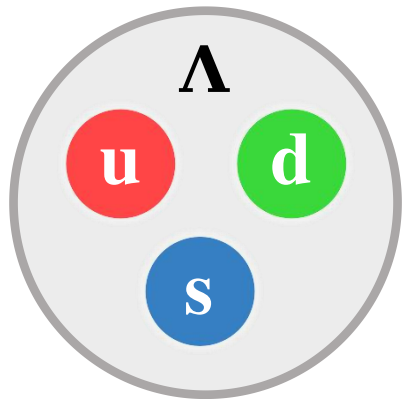
- Hyperon: A baryon made of  $\geq 1$  strange quark (e.g.  $\Lambda$ ,  $\Xi$ ,  $\Omega$  etc)

| Hyperon    | Quarks | I(J <sup>P</sup> )     | Mass (MeV) |
|------------|--------|------------------------|------------|
| $\Lambda$  | uds    | 0(1/2 <sup>+</sup> )   | 1115       |
| $\Sigma^+$ | uus    | 1(1/2 <sup>+</sup> )   | 1189       |
| $\Sigma^0$ | uds    | 1(1/2 <sup>+</sup> )   | 1193       |
| $\Sigma^-$ | dds    | 1(1/2 <sup>+</sup> )   | 1197       |
| $\Xi^0$    | uss    | 1/2(1/2 <sup>+</sup> ) | 1315       |
| $\Xi^-$    | dss    | 1/2(1/2 <sup>+</sup> ) | 1321       |
| $\Omega^-$ | sss    | 0(3/2 <sup>+</sup> )   | 1672       |



# $\Lambda$ Hyperon

The  $\Lambda$  hyperon is the lightest strange baryon and was first detected in 1947 in cosmic-ray experiments

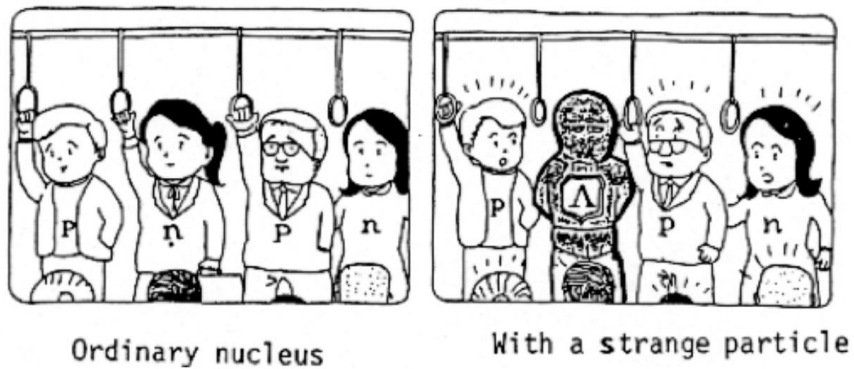
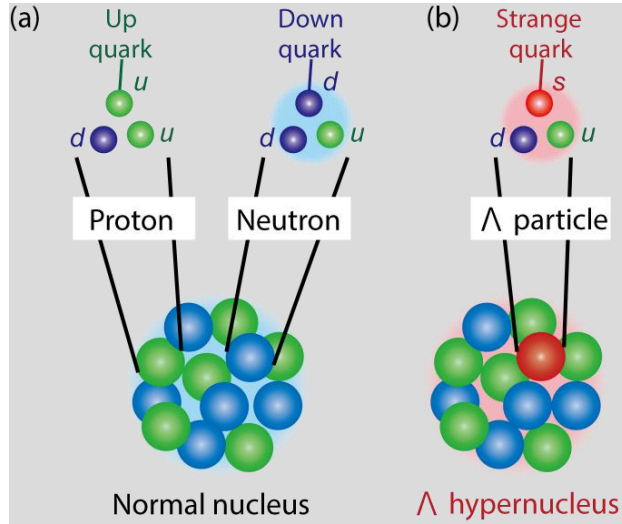


- Lifetime  $\tau$ :  $\sim 10^{-10}$  s instead of the expected  $\sim 10^{-23}$  s (typical timescales of strong interactions), this unexpected behavior led to the concept of "strangeness";
- Mass  $\approx 1.1156$  GeV/c<sup>2</sup>, charge = 0, spin = 1/2;
- Hyperons are produced through strong interactions (strangeness conserved), but decay through weak interactions (strangeness not conserved);

Their long lifetime allows them to be bound inside nuclei and form hypernuclei;

# Hypernuclei

- Hypernuclei: bound system of nucleons with one or more strange baryons (e.g.  $\Lambda$ ,  $\Xi$  etc)



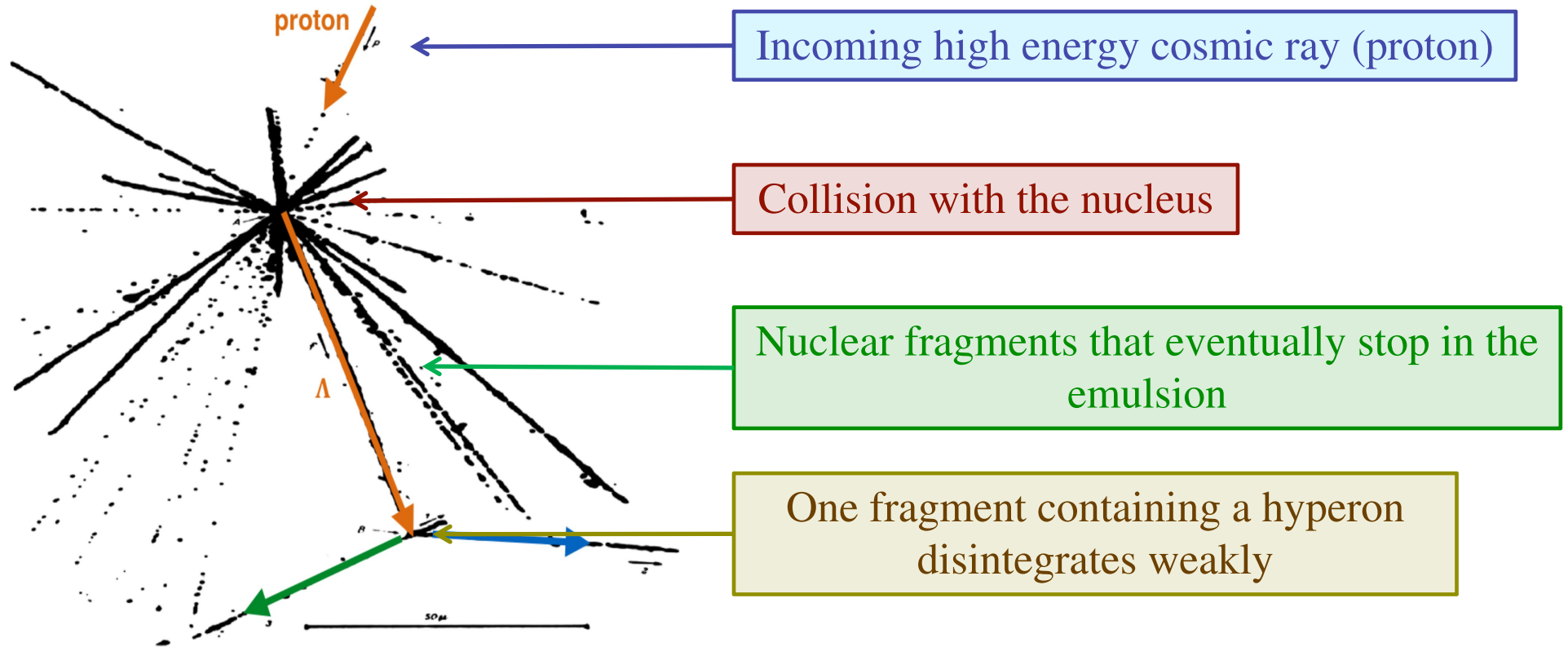
H. Bando, PARITY 1, 54 (1986)

- Strong interaction binds  $\Lambda$ :
  - Attractive  $\Lambda$ -N interaction;
  - Effective  $\Lambda$  potential  $\approx -30$  MeV;
  - Many bound hypernuclei have been observed;
- Weak decay  $\rightarrow$  long lifetime:
  - $\tau_{\Lambda} \approx 10^{-10}$  s;
- No Pauli blocking:
  - $\Lambda$  is distinguishable from nucleons;
  - Can occupy new quantum states;
  - Can penetrate deep into nuclei;

A hypernucleus is a “laboratory” to study hyperon-nucleon (YN) and hyperon-hyperon (YY) interactions;

# Discovery of Hypernuclei

- First hypernuclear event observed in a nuclear emulsion by Marian Danysz and Jerzy Pniewski in 1952



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

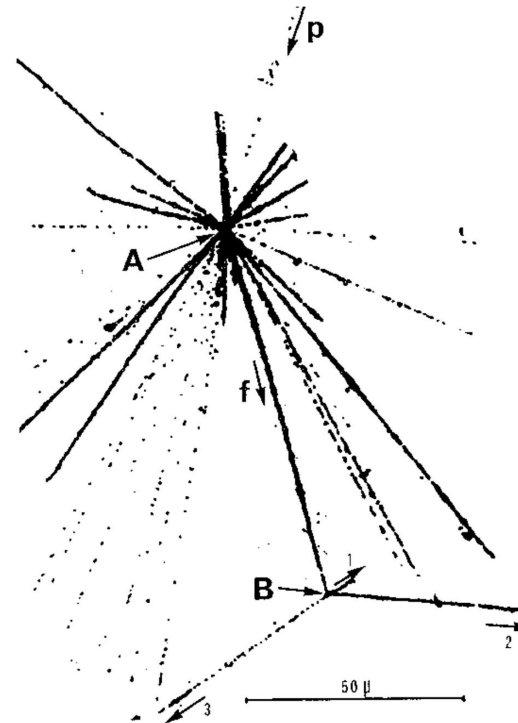
# History of Hypernuclei

In 1989, the postmark designed on the basis of the first hypernucleus observation was used for the 20th International Physics Olympiad at the Warsaw post office number 64

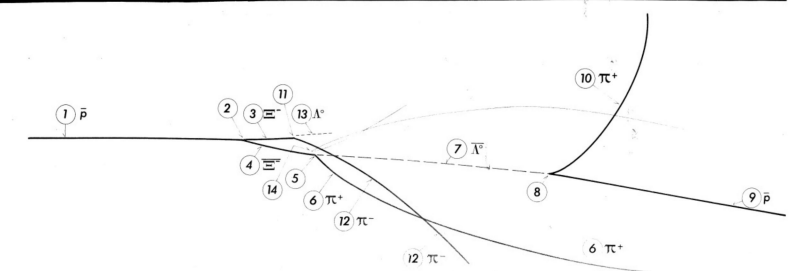
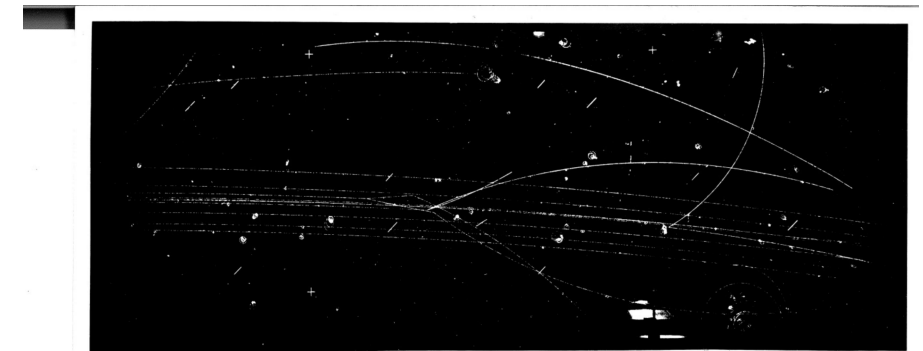


1953 -> 1970

- Hypernuclear identification with visualizing techniques emulsions, bubble chambers



nuclear emulsions



First discovery of the negative xi anti-particle (antixi) in the liquid hydrogen bubble chamber

# History of Hypernuclei

In 1989, the postmark designed on the basis of the first hypernucleus observation was used for the 20th International Physics Olympiad at the Warsaw post office number 64

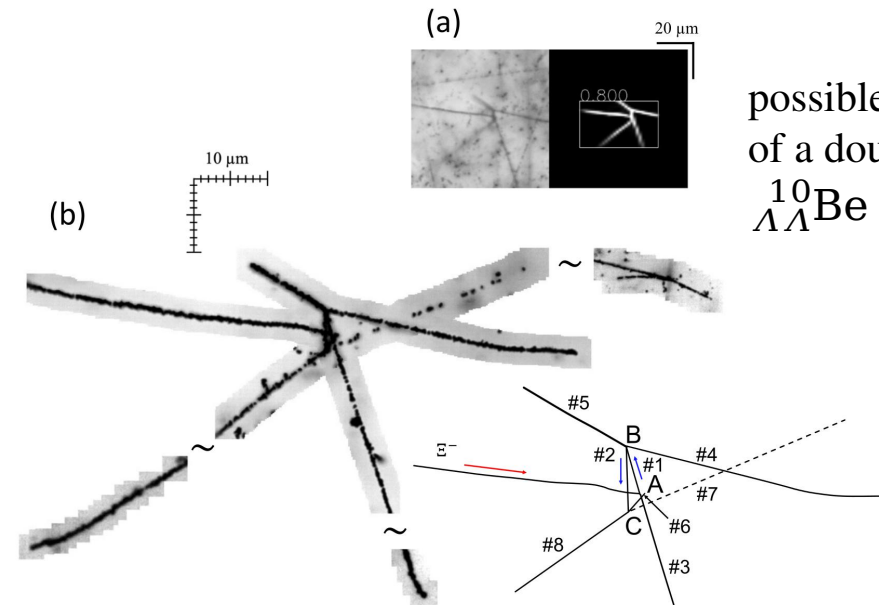


1953 -> 1970

- Hypernuclear identification with visualizing techniques emulsions, bubble chambers

1962

- First **double  $\Lambda$  hypernucleus** discovered in a nuclear emulsion irradiated by a beam of  $K^-$  mesons at CERN (YY interaction)



possible mesonic cascade decay of a double- $\Lambda$  hypernucleus of  ${}^{10}_{\Lambda\Lambda}\text{Be}$  or  ${}^{11}_{\Lambda\Lambda}\text{Be}$

Danysz et al., CERN nuclear emulsion experiment (1963)

# History of Hypernuclei

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1953 -> 1970

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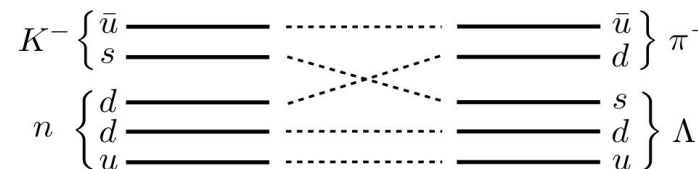
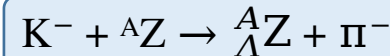
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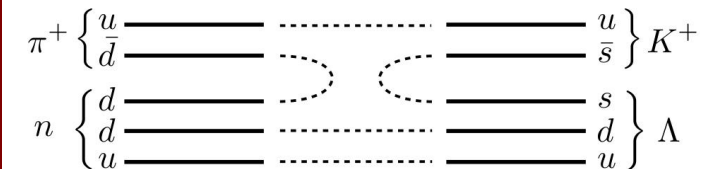
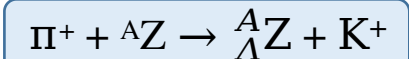
1970 -> now

- Spectrometers at accelerators (CERN, BNL, KEK ...): ( $K^-$ ,  $\pi^-$ ) and ( $\pi^+$ ,  $K^+$ ) production methods

Strangeness exchange: (BNL, KEK, J-PARC)  
(replace a u or d quark with a s quark)



Strangeness exchange: (BNL, KEK, J-PARC)  
(produce a  $S\bar{S}$  pair)



# History of Hypernuclei

In 1989, the postmark designed on the basis of the first hypernucleus observation was used for the 20th International Physics Olympiad at the Warsaw post office number 64



1953 -> 1970

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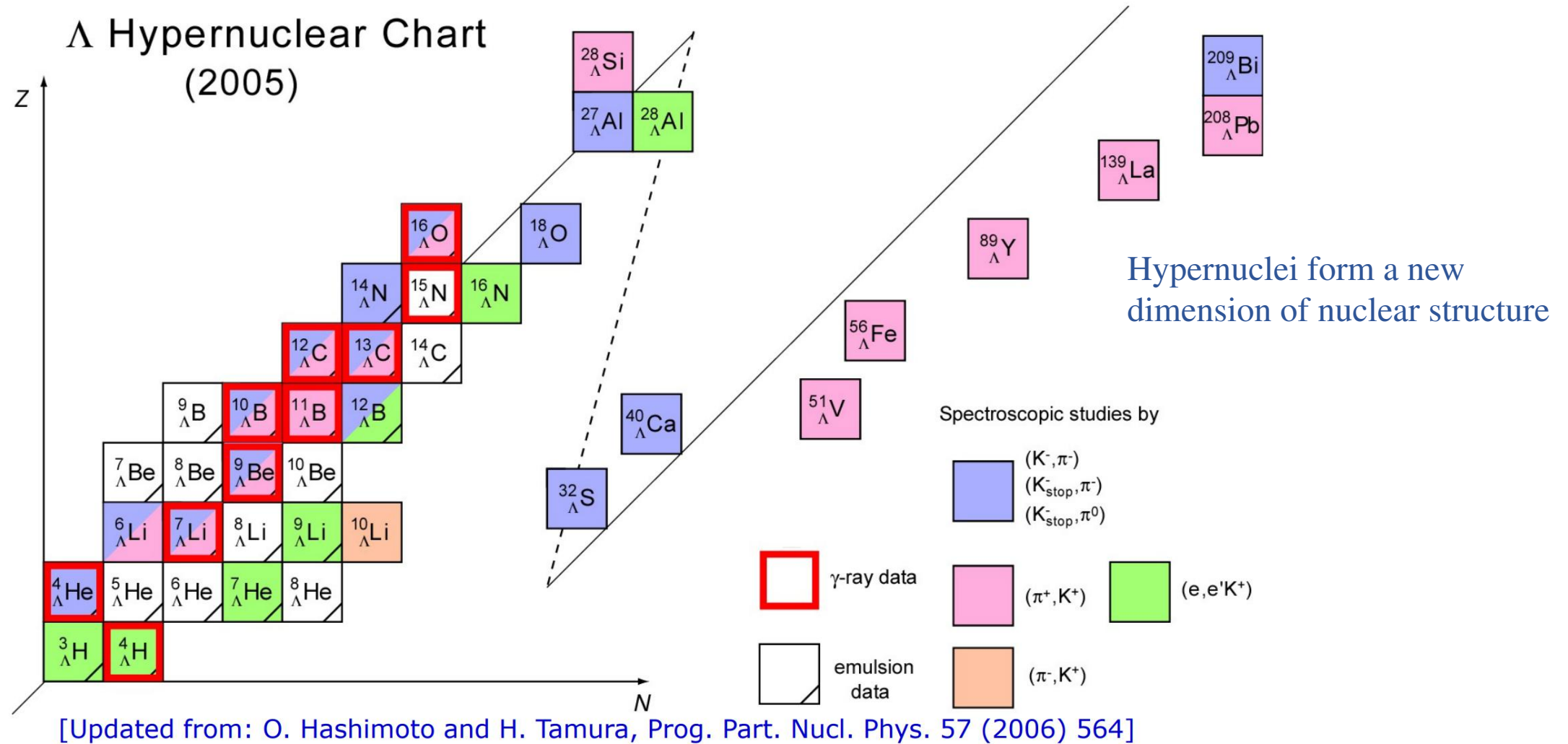
1970 -> now

- Spectrometers at accelerators (CERN, BNL, KEK ...): ( $K^-$ ,  $\pi^-$ ) and ( $\pi^+$ ,  $K^+$ ) production methods

After 2000

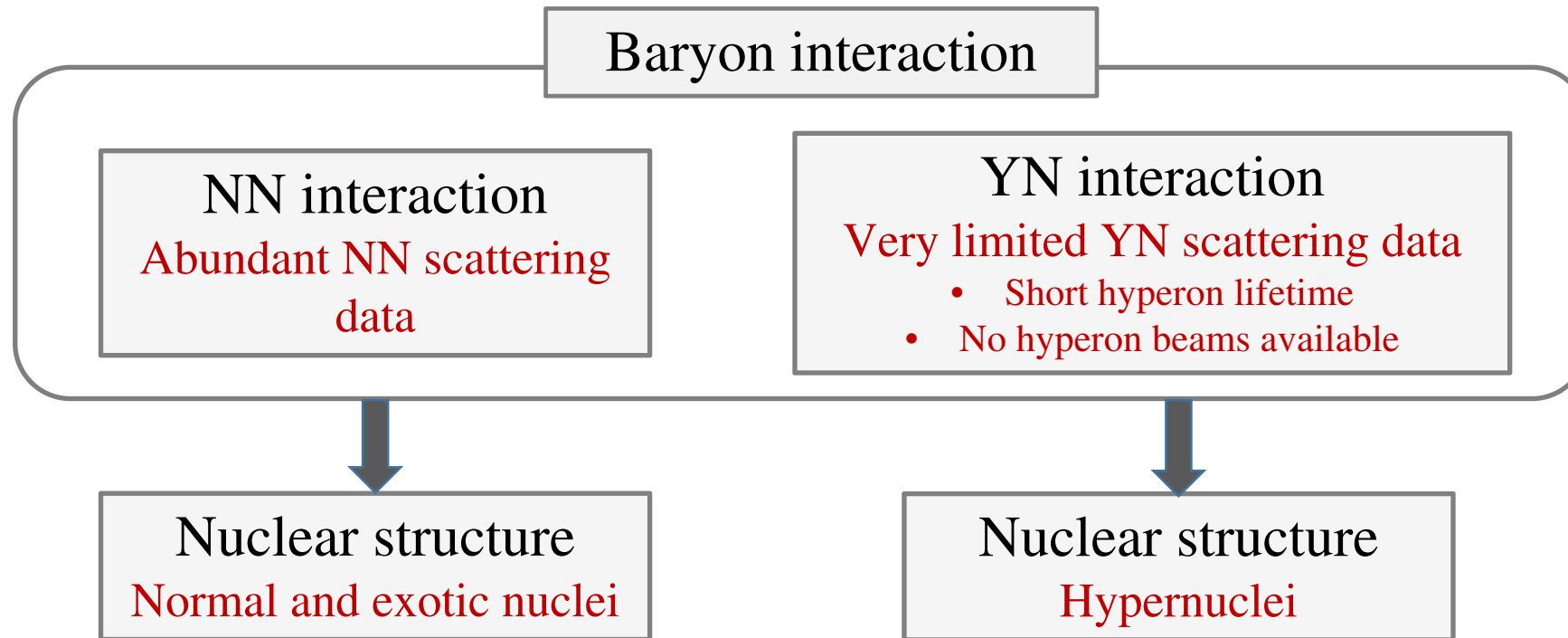
- Stopped kaons at DAΦNE (FINUDA): ( $K^-$ ,  $\pi^-$ )
- New electromagnetic way: electron beam ( $e$ ,  $e'K^+$ ) at JLAB & MAMI-C
- **Heavy-ion Collisions**

# Present status of $\Lambda$ Hypernuclear Spectroscopy



- Techniques such as emulsion,  $\gamma$  ray or strangeness exchange reactions used to study properties of hypernuclei

# Why Study Hypernuclei



- Nucleon–nucleon interactions are well constrained by abundant scattering data, while hyperon–nucleon (YN) interactions are poorly known due to limited experimental data.
- Hypernuclei provide a unique laboratory to study hyperon–nucleon (YN) interactions (eg. binding energies and energy level structures);

# From Hypernuclei to Neutron Stars

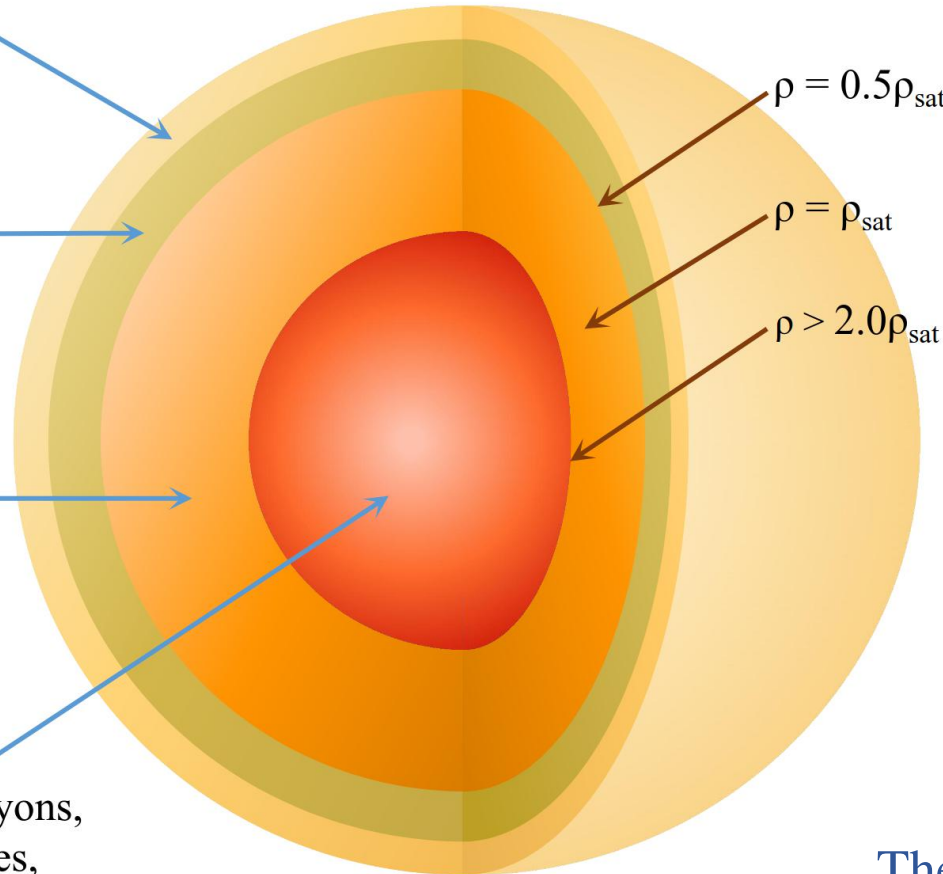
Hypernuclei  $\rightarrow$  YN interaction  $\rightarrow$  Dense matter EoS  $\rightarrow$  Neutron stars

**Outer crust**  $r < 13$  km  
Relativistic electrons, nuclei

**Inner crust**  $r < 12$  km  
Neutron-rich nuclei, pasta phase,  
unbound neutrons, electrons

**Outer core**  $r < 10$  km  
Neutrons, protons, electrons  
and muons

**Inner core**  $r < 6$  km  
Full baryon octet of spin-1/2 baryons,  
non-strange spin-3/2  $\Delta$ -resonances,  
mesonic Bose condensates, color superconducting phase of quark matter



- Neutron stars are one of the densest massive objects in the universe;
- Mass  $\sim 1\text{-}2 M_{\odot}$ ;
- Radius  $\sim 10\text{-}12$  km;
- Density at inner core can reach several times the nuclear matter saturation density ( $\rho_{\text{sat}} \sim 0.16 \text{ fm}^{-3}$ );

The properties of nuclear matter are determined by the equation of state (EoS)

A. Sedrakian, et al., PPNP 131, 104041 (2023)

# Equation of State (EoS) and Neutron Stars

The structure of neutron stars is determined by the equation of state (EoS), which describes the relation between pressure and density;

- Tolman–Oppenheimer–Volkoff (TOV) equation is the general-relativistic version of hydrostatic equilibrium, to determine neutron star structure, the TOV equation requires the EoS as input;

$$\frac{dP(r)}{dr} = - \frac{G \left( \rho(r) + \frac{P(r)}{c^2} \right) \left( m(r) + 4\pi r^3 \frac{P(r)}{c^2} \right)}{r^2 \left( 1 - \frac{2Gm(r)}{rc^2} \right)}$$

- The equation-of-state (EoS), which relates pressure to density  $P = P(\rho)$  is needed to solve the equation, TOV + EOS  $\rightarrow$  M-R relation
- EOS depends on microscopic interactions:
  - NN interaction (well known);
  - YN interaction (poorly known);
  - YNN interaction;

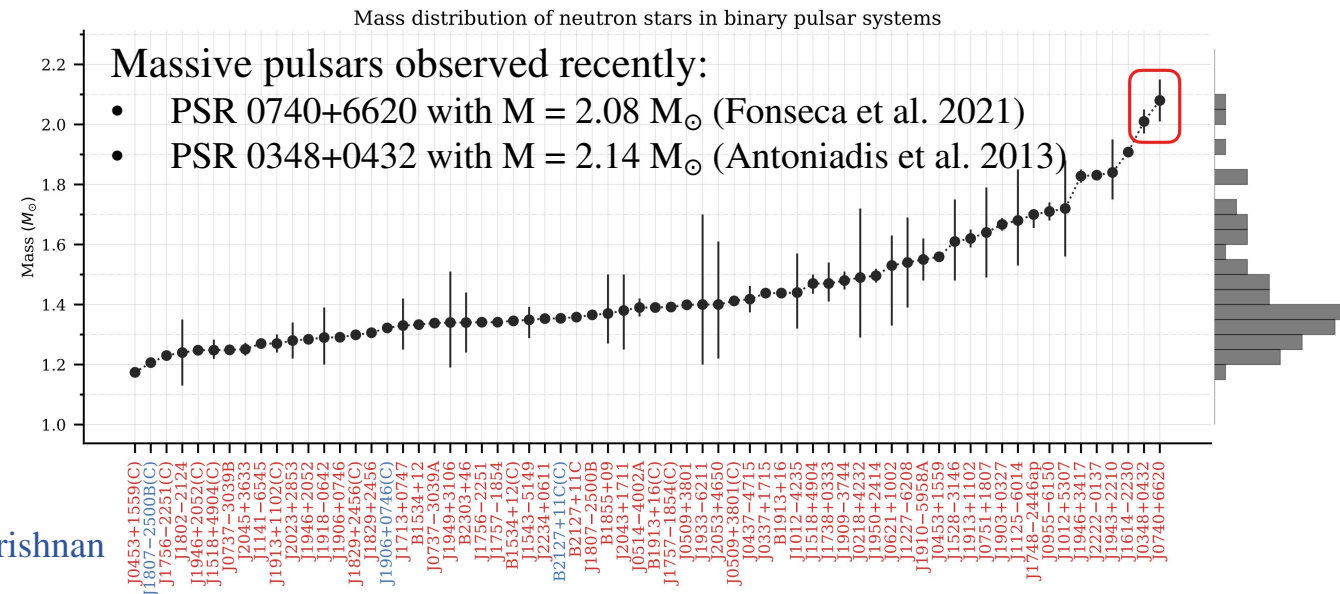


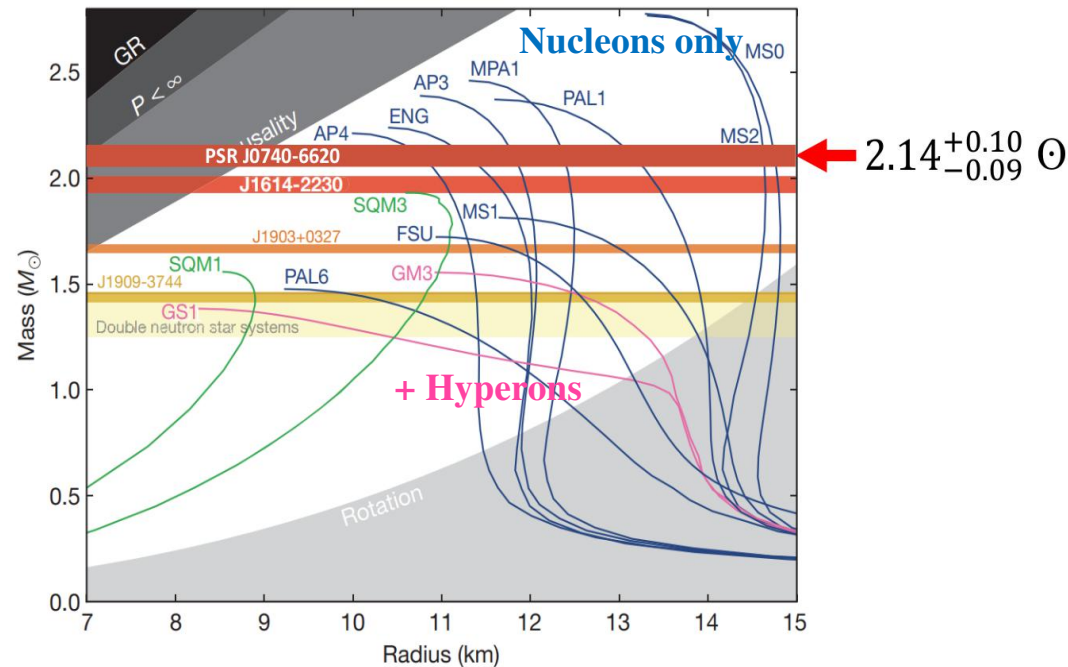
figure from Vivek V. Krishnan

# The Hyperon Puzzle

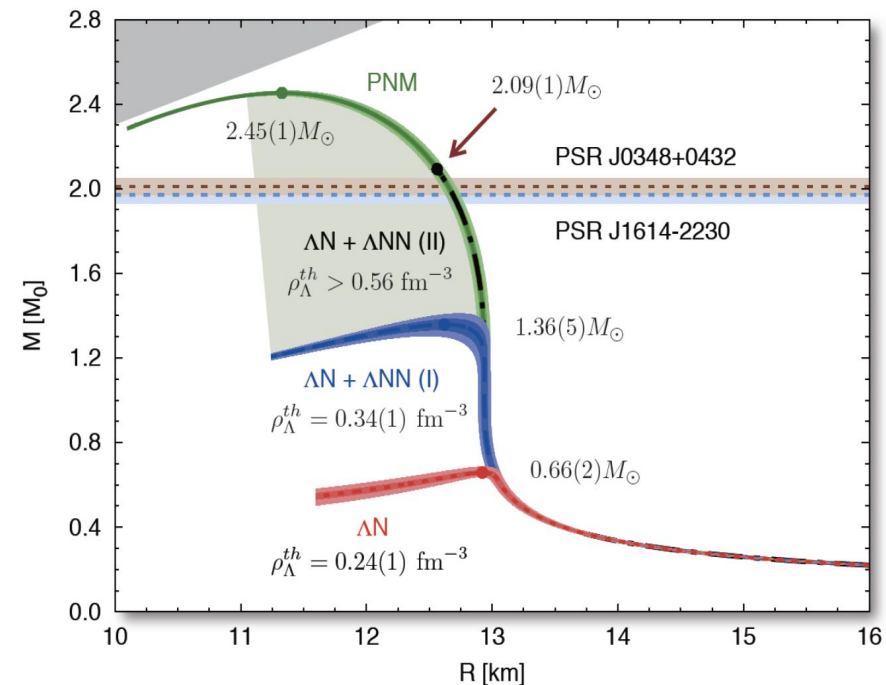
**Hyperon puzzle:** hyperons are expected to appear in the core of neutron stars, EoS's with hyperons are too soft to support massive neutron stars of  $> 1.5 M_{\odot}$ ;

P. Demorest et al., Nature 467 (2010) 1081

NANOGrav Collaboration, Nature Astron. 4 (2019) 1, 72



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



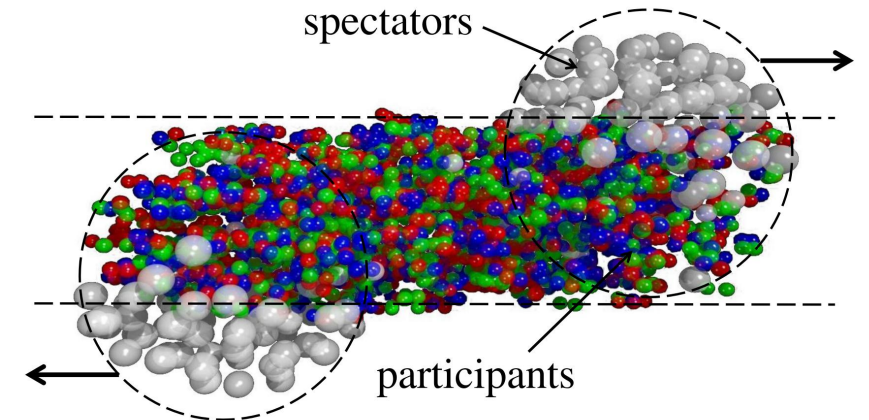
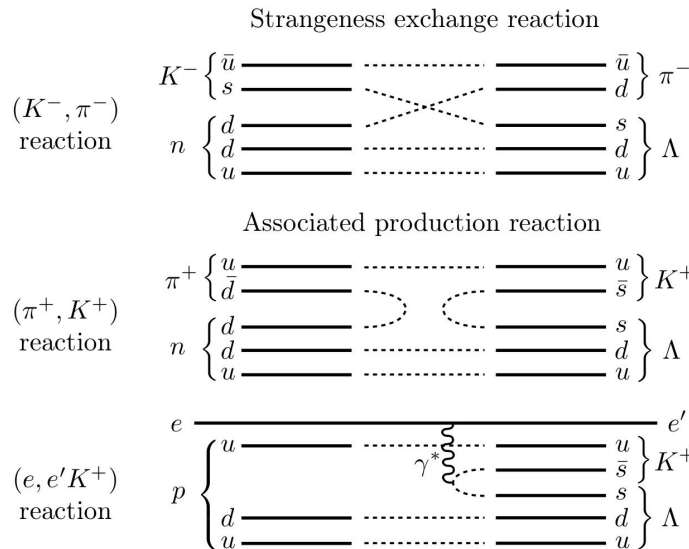
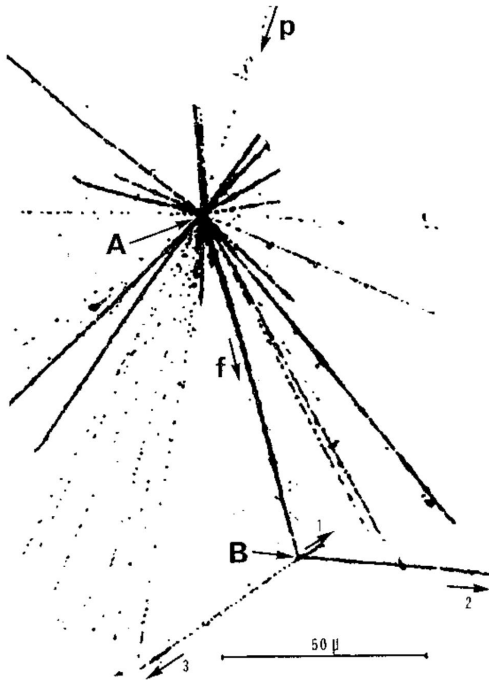
- Density dependent YN, YNN and YYN are essential inputs for solving the hyperon puzzle and constraining theoretical models of the dense matter equation of state (EoS);
- Therefore hypernuclear experiments provide essential constraints on YN interactions and the neutron-star EOS;

# How to Produce Hypernuclei?

- Emulsion experiments
  - First discoveries
  - Cosmic-ray events
  - Very limited statistics

- Accelerator reactions
  - Precision spectroscopy
  - $\gamma$ -ray measurements
  - Limited statistics

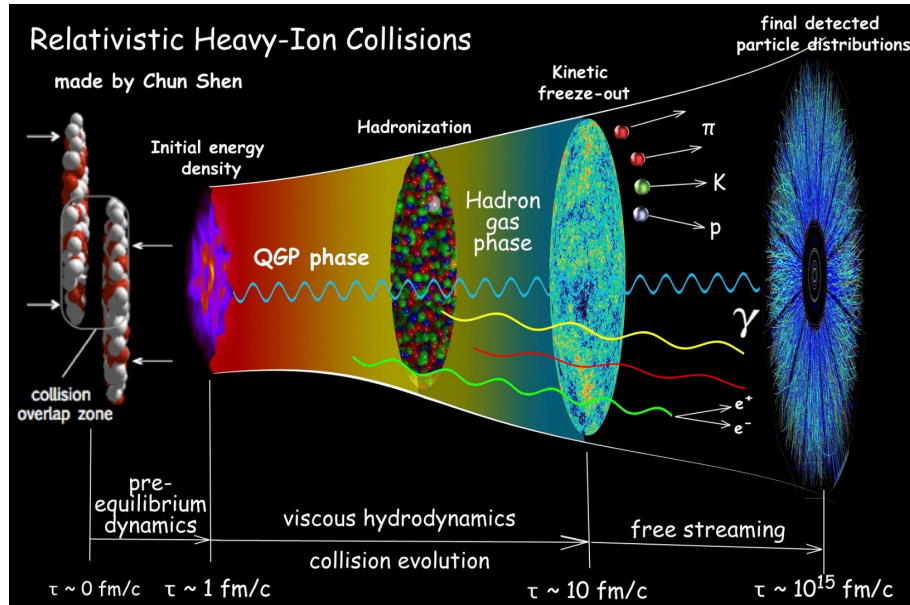
- **Heavy-ion collisions**
  - High baryon density
  - Large hyperon production
  - Many hypernuclei species



**Heavy-ion collisions** provide a unique environment for systematic and high-statistics studies of hypernuclei.

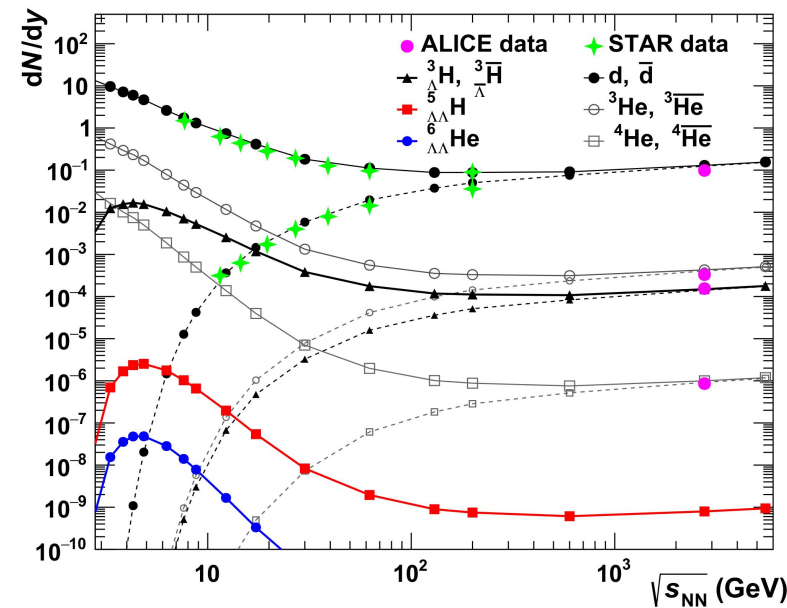
# Hypernuclei Production in Heavy-Ion Collisions

## Time evolution of HICs

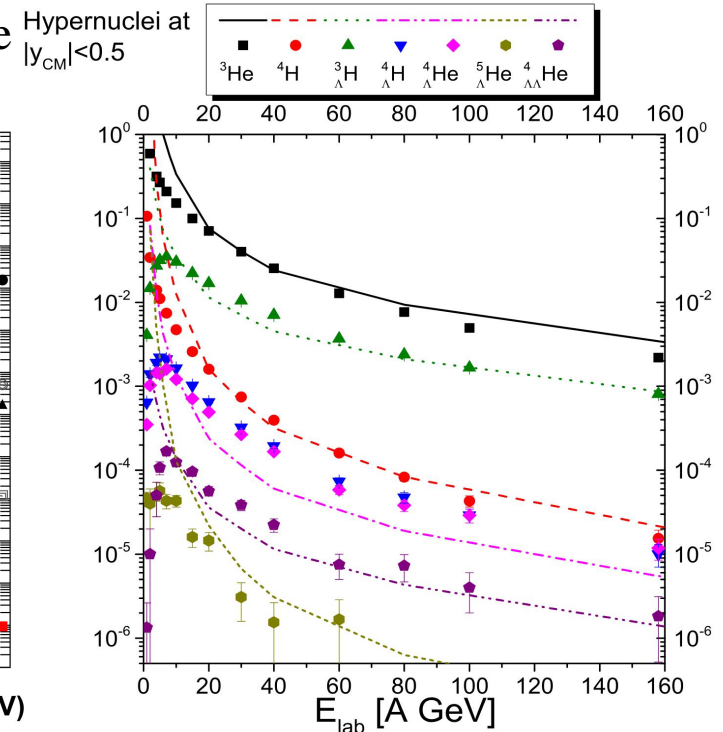


C. Shen, Ph.D. thesis, The Ohio State University (2014)

## Predictions from thermal and coalescence approaches

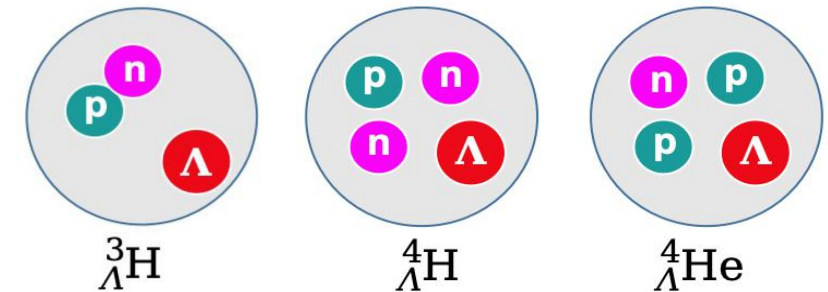


B. Dönigus, Eur. Phys. J. A (2020) 56:280  
A. Andronic et al, PLB 697 (2011)203



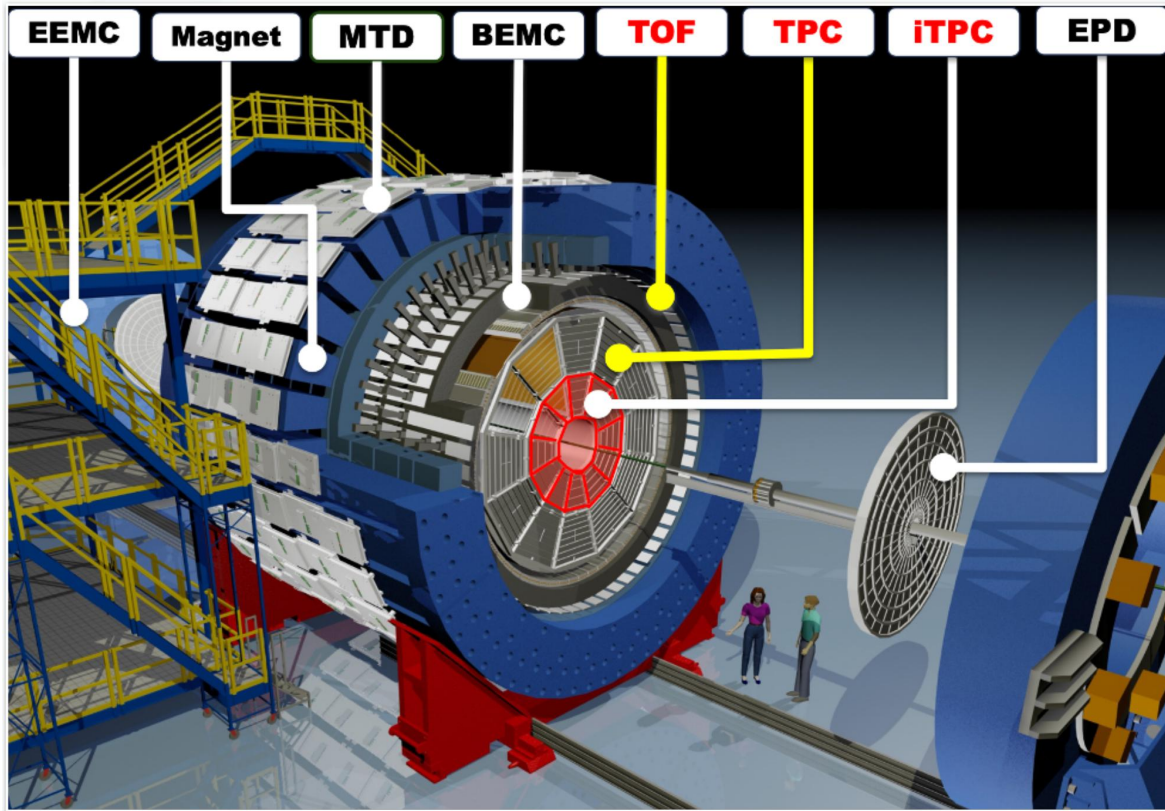
J. Steinheimer et al, PLB714(2012),85

- Heavy-ion collisions create hot and dense baryonic matter
- Abundant production of hyperons and nucleons favors hypernuclei formation
- Hypernuclei intrinsic properties (lifetime,  $\Lambda$  binding energy, branching ratio ...)
- Hypernuclei production (spectra, yields, collectivity ...):
  - Statistical thermal models
  - Coalescence models

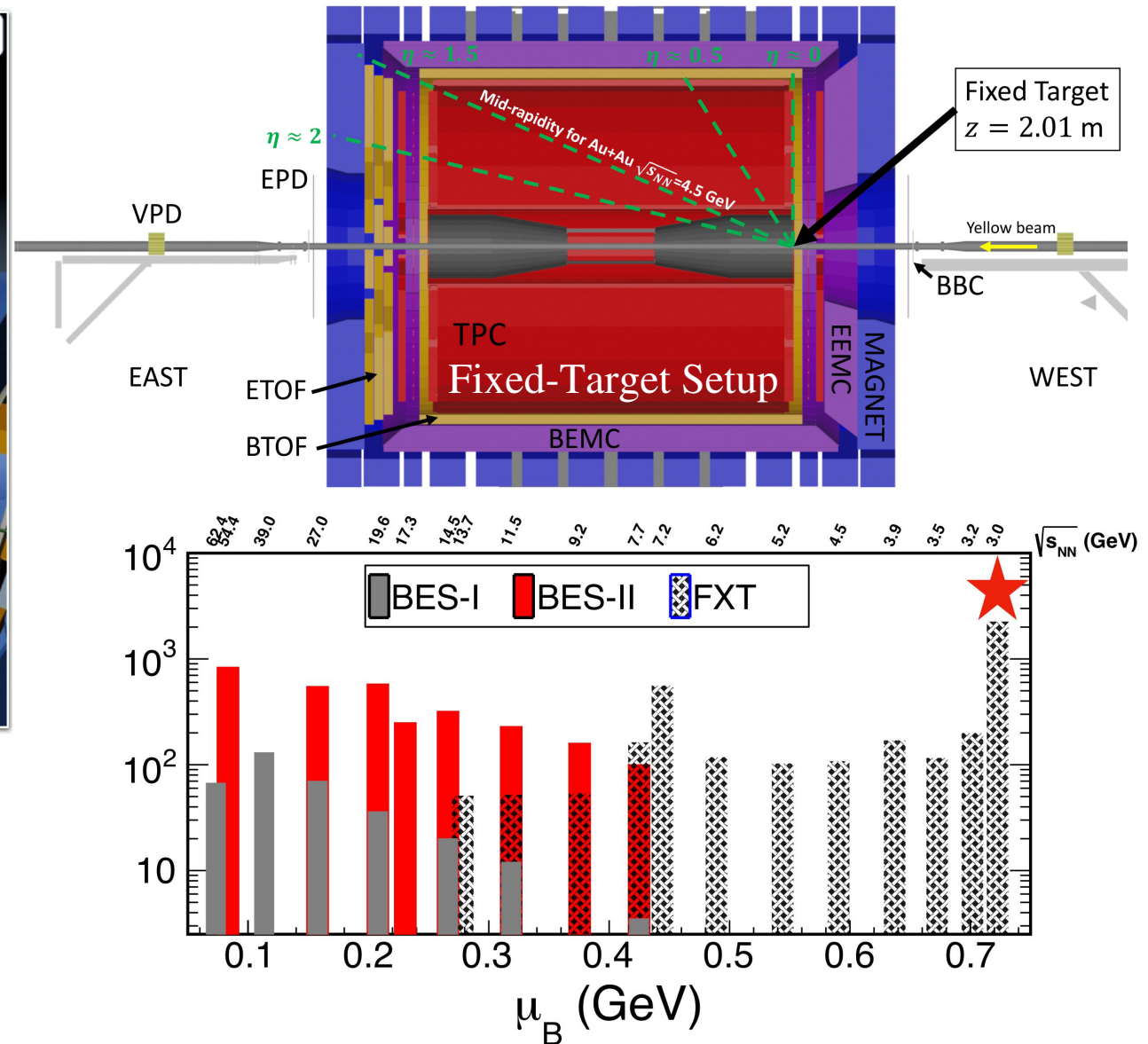


In this work we use the STAR experiment at RHIC

# The STAR (Solenoidal Tracker At RHIC) Detector

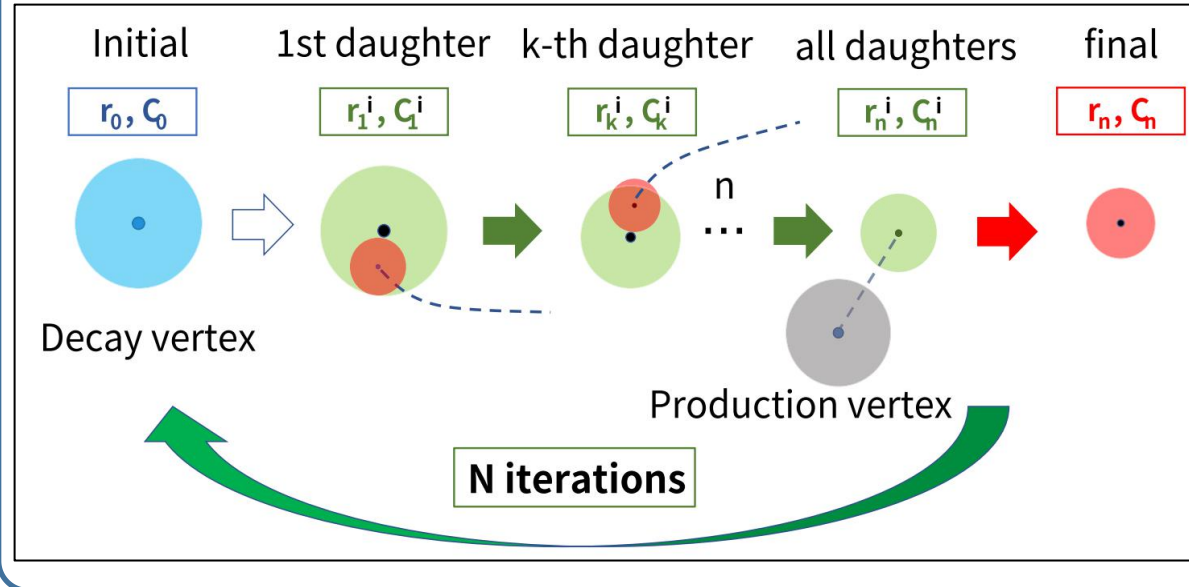


- Excellent particle identification
- Large, uniform acceptance at mid-rapidity

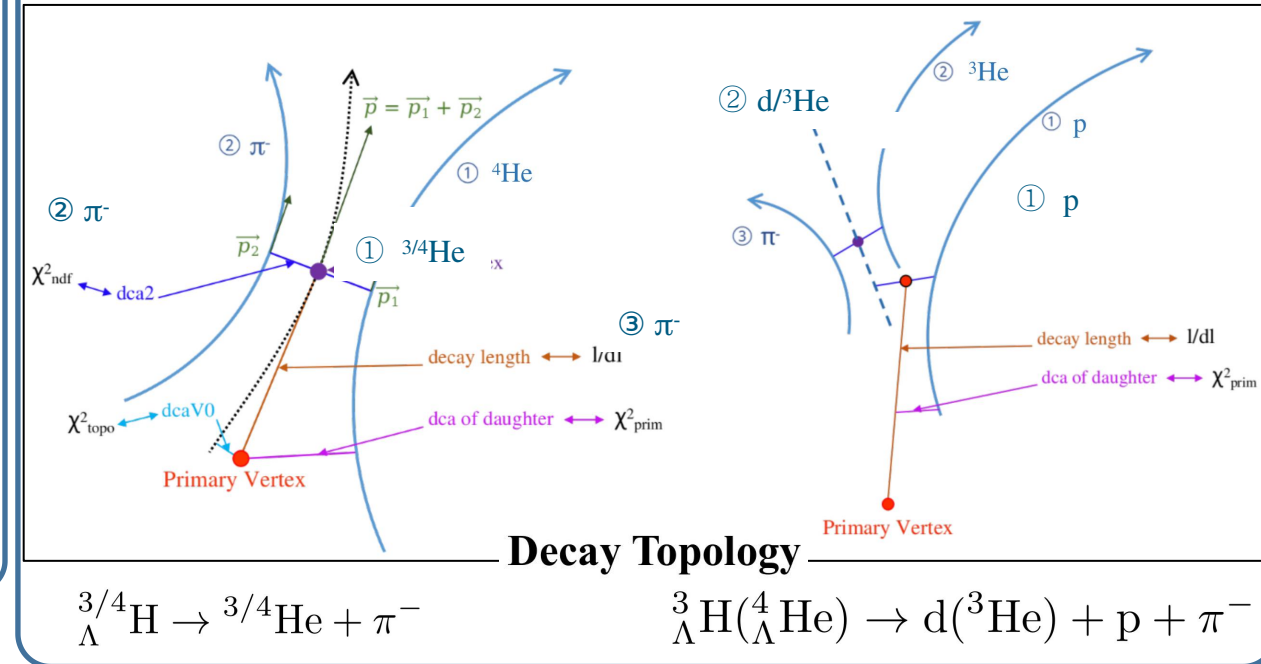


# Hypernuclei Reconstruction in STAR

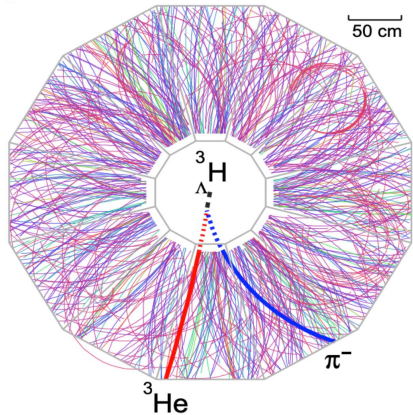
## Reconstruction schematic with the KF Particle package



## Hypernuclei reconstructed via weak decay (2-body and 3-body)

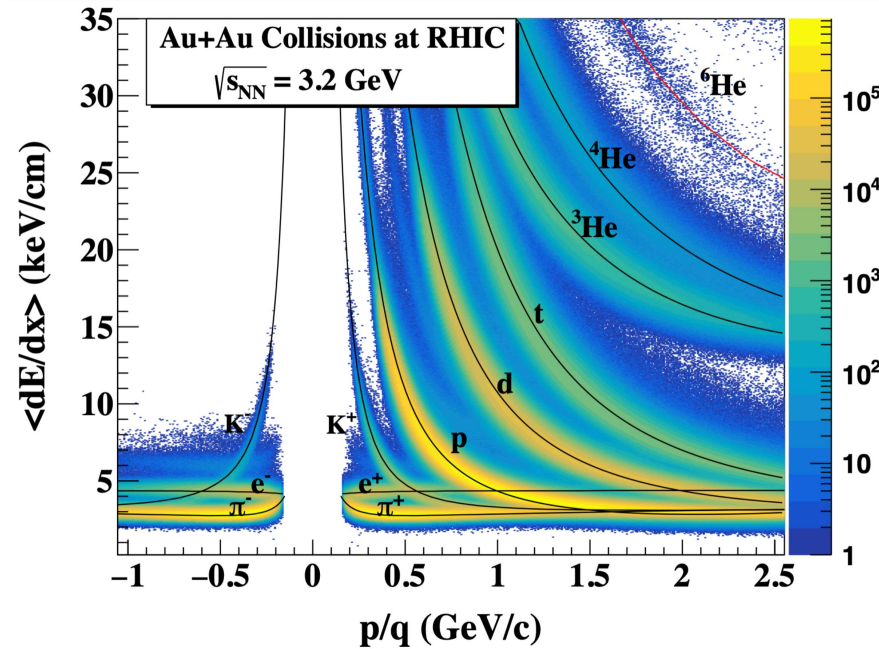


Nucl.Sci.Tech. 34 (2023) 10, 158

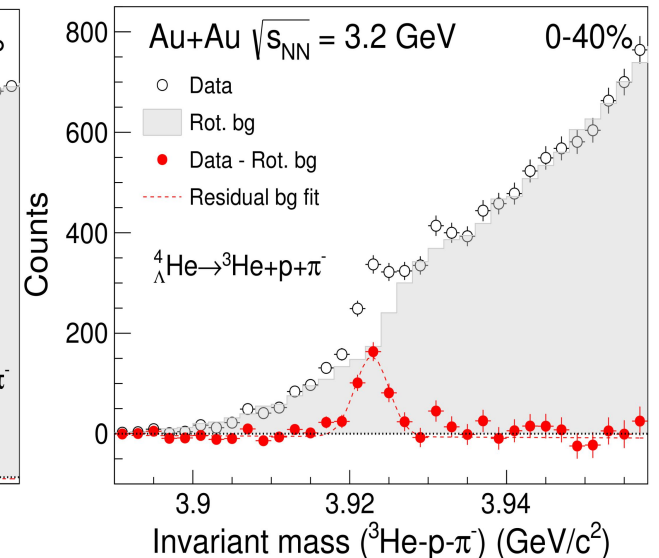
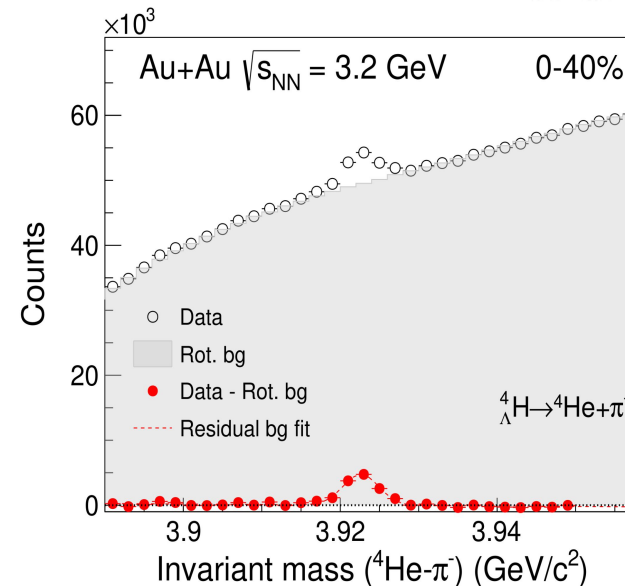
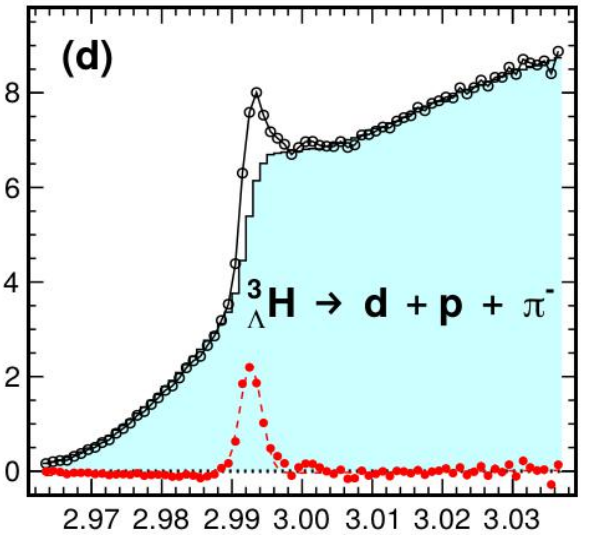
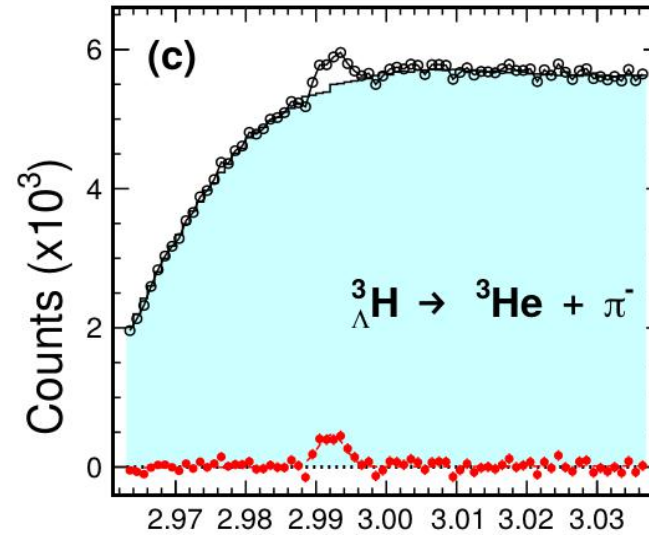


- **KF Particle package** shows a high quality of the reconstructed particles, high efficiencies, and high signal to background ratios
  - a Kalman Filter package for secondary vertex finding and fitting

# Hypernuclei Reconstruction in STAR

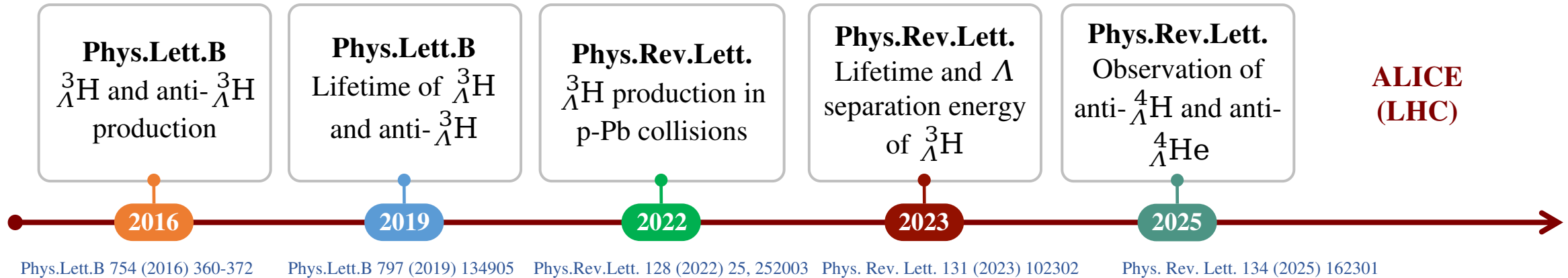
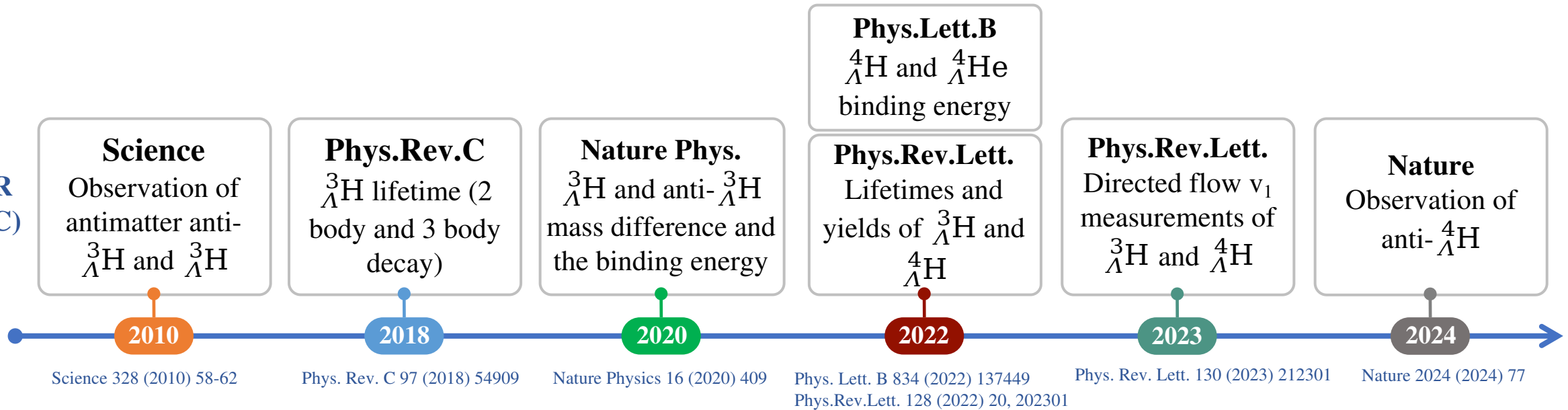


- TPC ionization energy loss used for PID of daughter tracks
- Hypernuclei reconstructed via weak decay channels
- Combinatorial background estimated via track rotation method



# Hypernuclei Measurements at STAR

STAR  
(RHIC)



ALICE  
(LHC)

# Observation of hypernuclei and anti-hypernuclei

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HOME > SCIENCE > VOL. 328, NO. 5974 > OBSERVATION OF AN ANTIMATTER HYPERNUCLEUS

RESEARCH ARTICLE

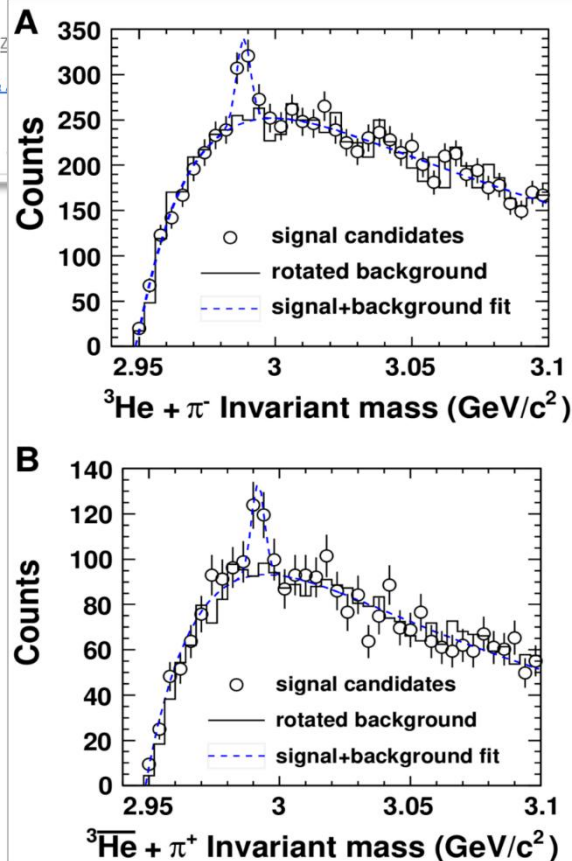
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## Observation of an Antimatter Hypernucleus

THE STAR COLLABORATION, B. I. ABELEV, M. M. AGGARWAL, Z.

Y. ZOULKARNEEVA +382 authors [Authors Info &](#)

SCIENCE • 4 Mar 2010 • Vol 328, Issue 5974 • pp. 58-62



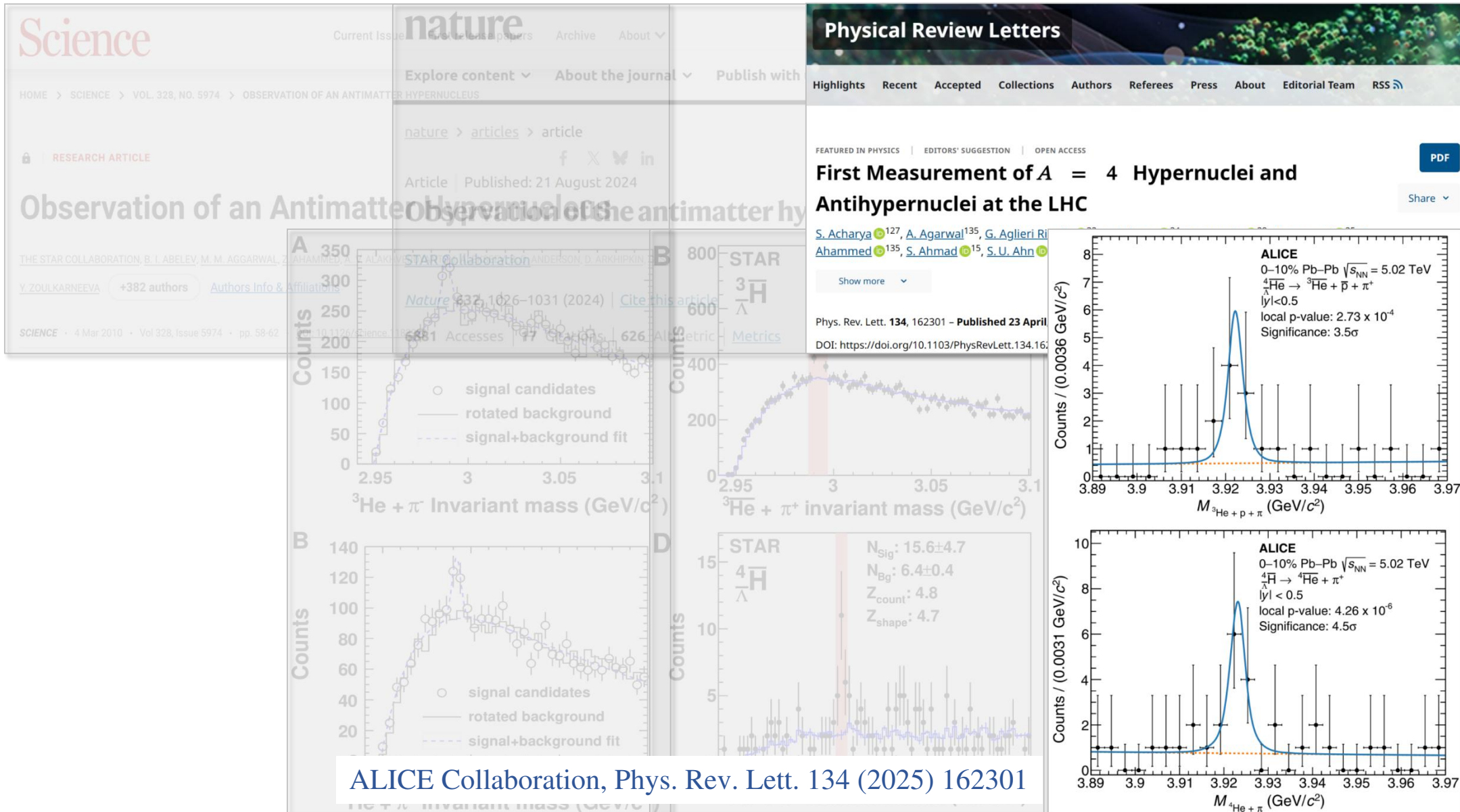
First observation of an antimatter hypernucleus at STAR

STAR Collaboration, Science 328 (2010) 58-62

[illegible]

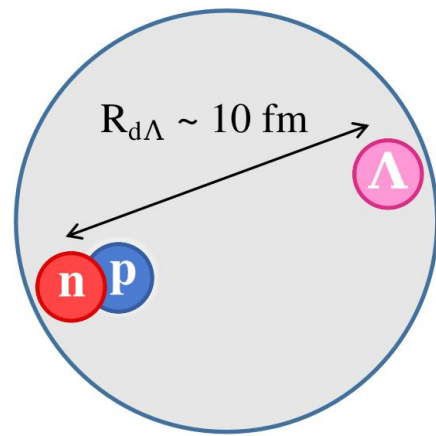
STAR Collaboration, Nature 2024 (2024) 77

# Observation of hypernuclei and anti-hypernuclei

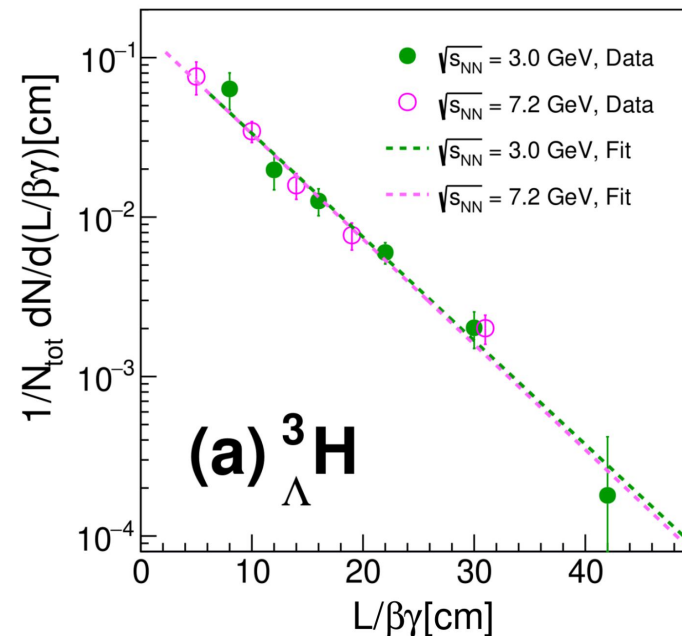


# Lifetime of hypertriton

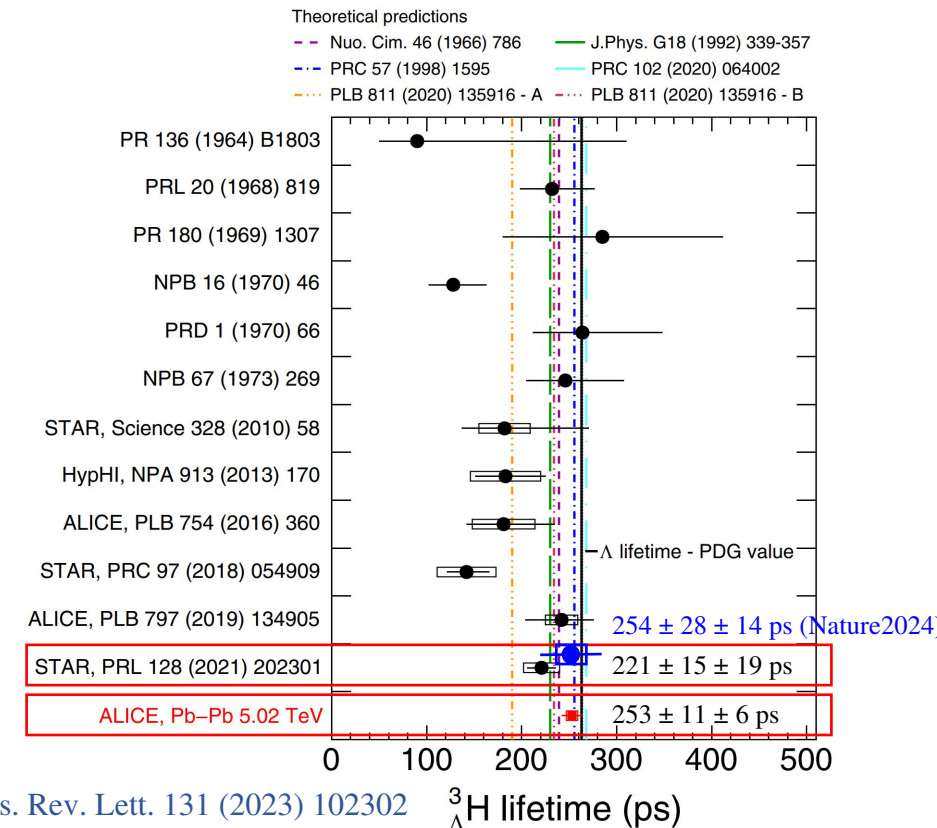
- Lifetime extracted by measuring the yields as a function of the proper decay length:  $N(t) = N_0 e^{-L/\beta\gamma c\tau}$ ;
- ${}^3_\Lambda\text{H}$  is loosely bound ( $B_\Lambda \sim 0.1$  MeV);
- Theory expects lifetime of hypertriton close to the lambda lifetime ( $> 90\%$   $\tau_\Lambda$ ,  $\tau_\Lambda = 263$  ps);
- Currently STAR, ALICE and HypHI reported lifetimes 30-40% shorter than  $\tau_\Lambda$ , albeit with large unc. → **Hypertriton lifetime puzzle**



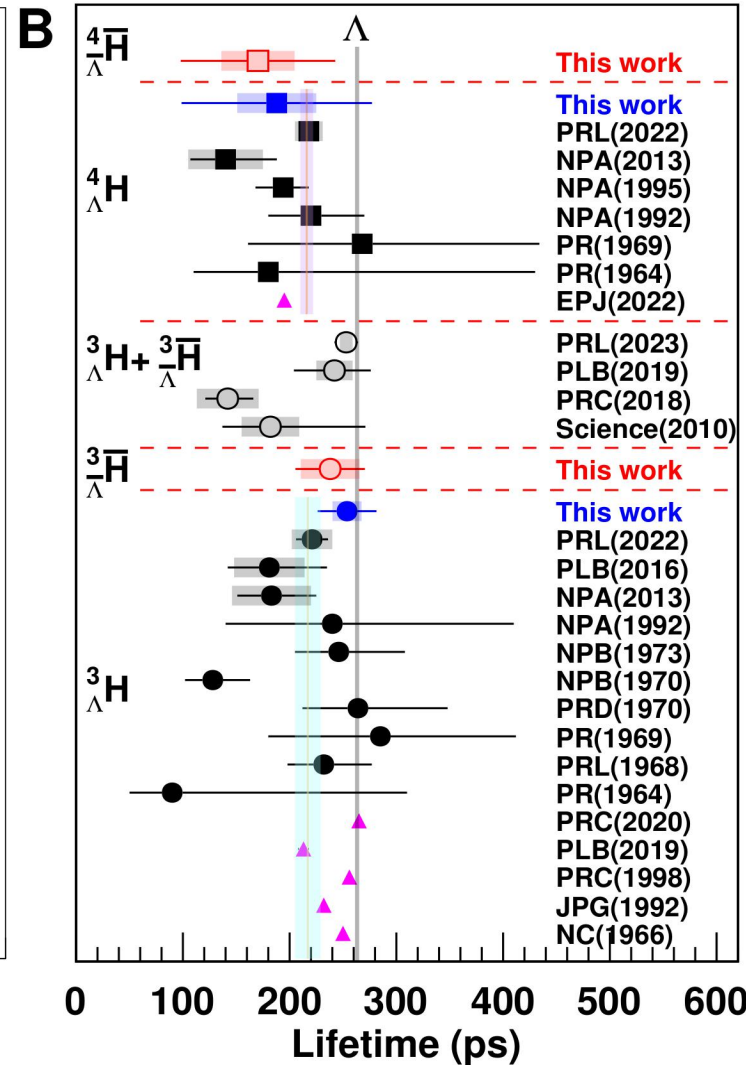
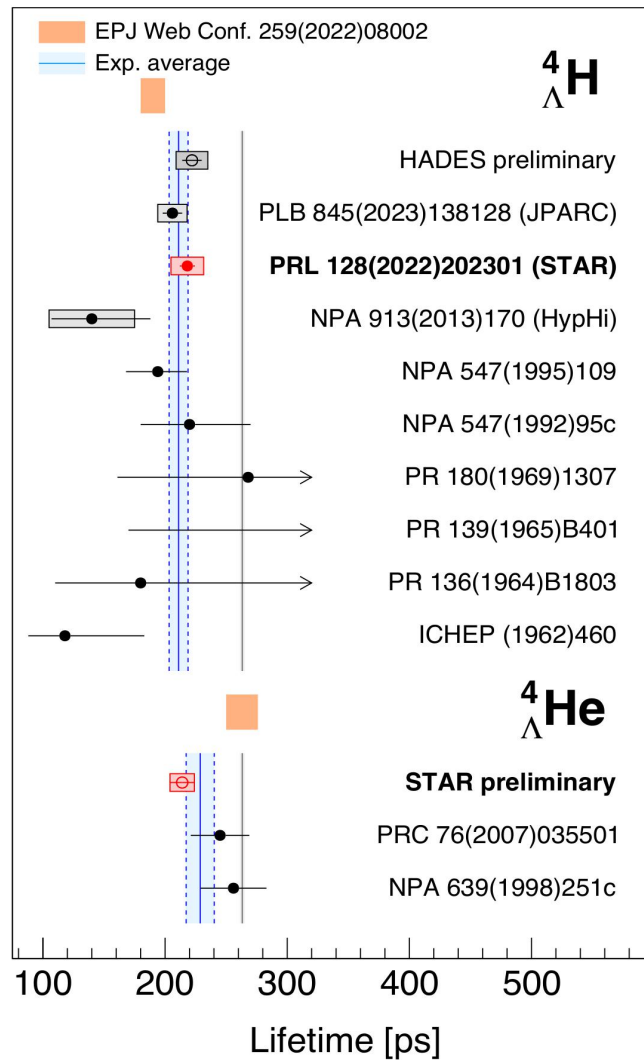
F. Hildenbrand, H.-W. Hammer,  
Phys. Rev. C 100 (2020), 034002



| Year | Technology            | Lifetime            |
|------|-----------------------|---------------------|
| 1964 | emulsion              | $90^{+220}_{-40}$   |
| 1968 | helium bubble chamber | $232^{+45}_{-32}$   |
| 1969 | emulsion              | $285^{+127}_{-105}$ |
| 1970 | emulsion              | $128^{+35}_{-26}$   |
| 1970 | helium bubble chamber | $264^{+84}_{-52}$   |
| 1973 | emulsion              | $246^{+62}_{-41}$   |



# Lifetime of hypernuclei and anti-hypernuclei

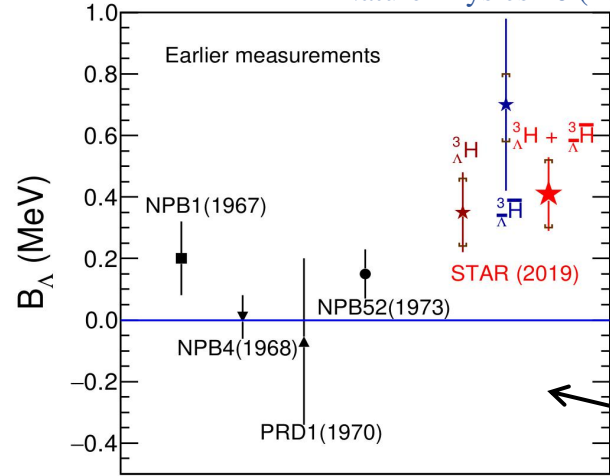


- New measure  $A = 4$  hypernuclei:  
 $\tau({}^4_{\Lambda}\text{H})/\tau({}^4_{\Lambda}\text{He}) = 0.92 \pm 0.06$ , consistent with theoretical estimation value within  $2.5\sigma$ ;
  - Isospin rule predicts:  $\tau({}^4_{\Lambda}\text{H})/\tau({}^4_{\Lambda}\text{He}) = 0.74 \pm 0.04$ ;
- Lifetimes of the anti-hypernucleus and the hypernucleus are consistent within uncertainties;
  - $\tau({}^3_{\Lambda}\text{H}) - \tau(\text{anti-}{}^3_{\Lambda}\text{H}) = 16 \pm 43 \pm 20$  ps;
  - $\tau({}^4_{\Lambda}\text{H}) - \tau(\text{anti-}{}^4_{\Lambda}\text{H}) = 18 \pm 115 \pm 46$  ps;
- No significant difference observed between hypernuclei and anti-hypernuclei  $\rightarrow$  consistent with CPT symmetry;

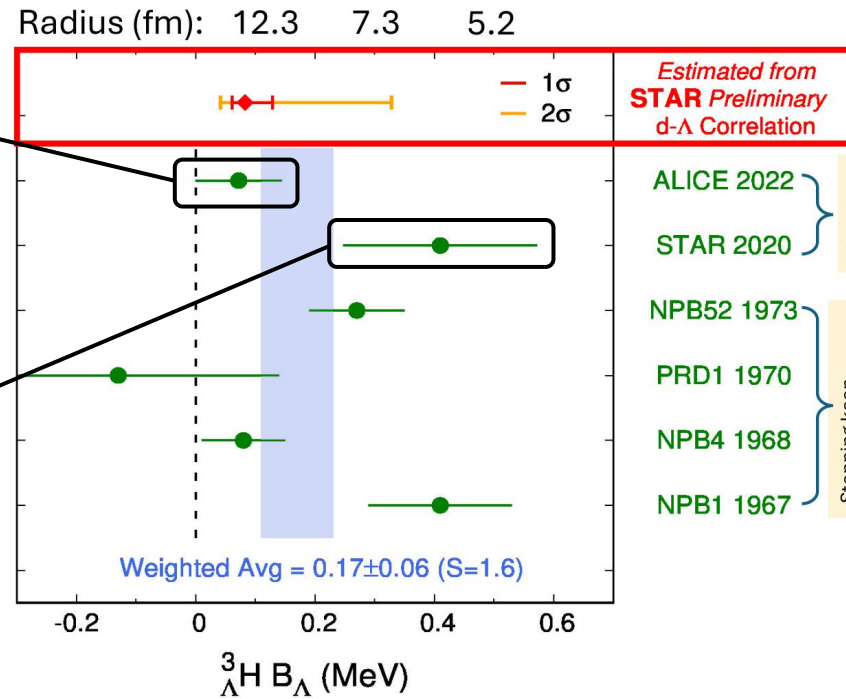
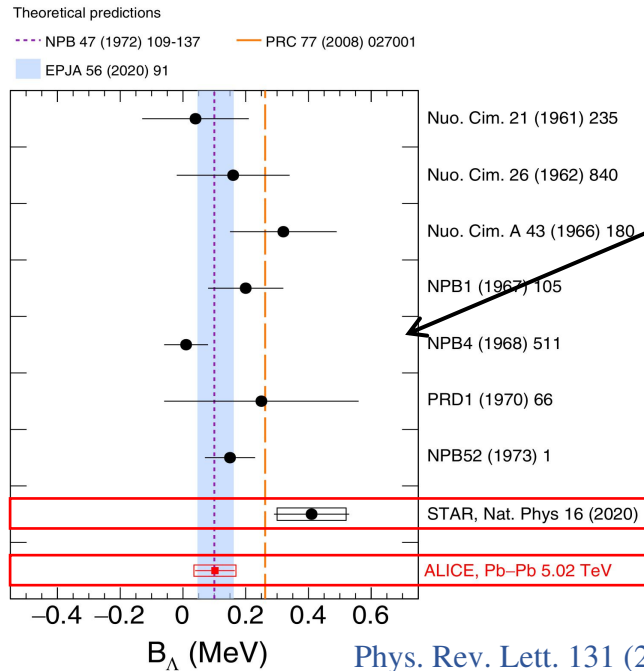
Provides a unique CPT test in multi-baryon systems

# $\Lambda$ separation energy: $B_\Lambda$

Nature Physics 16 (2020) 409

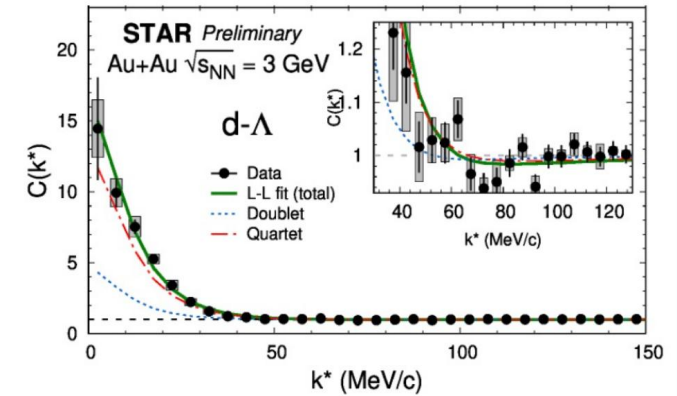


- $B_\Lambda$  provides a direct measure of the strength of the  $\Lambda$ -N interaction
- $B_\Lambda$ :  $\Lambda$  separation energy;
- ${}^3_\Lambda\text{H } B_\Lambda = M(d) + M(\Lambda) - M({}^3_\Lambda\text{H})$ ;



- Invariant mass method
- Femtoscopy method

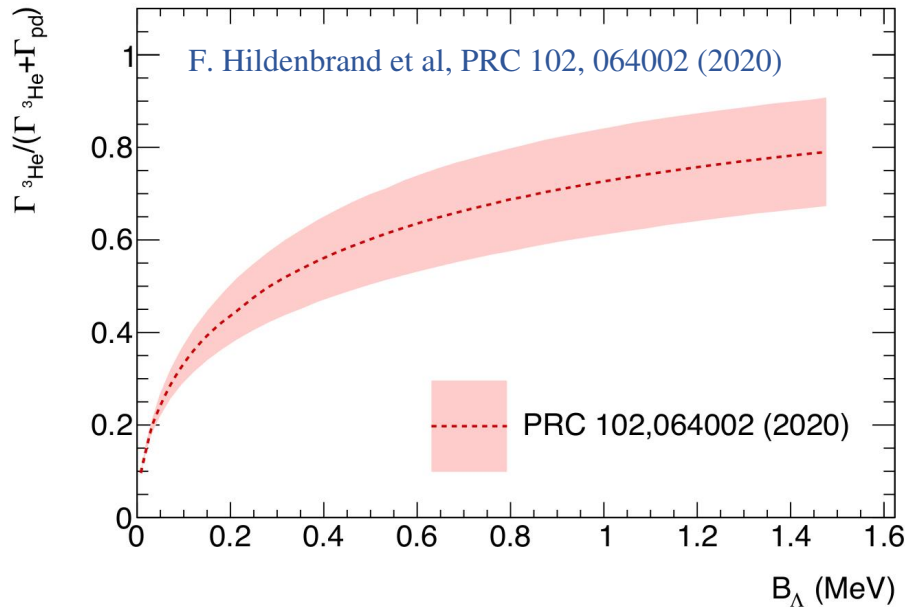
$$\frac{1}{-f_0} = \gamma - \frac{1}{2} d_0 \gamma^2, B_\Lambda = \frac{\gamma^2}{2\mu_{d\Lambda}}$$



- ${}^3_\Lambda\text{H}$  is a very loosely bound state

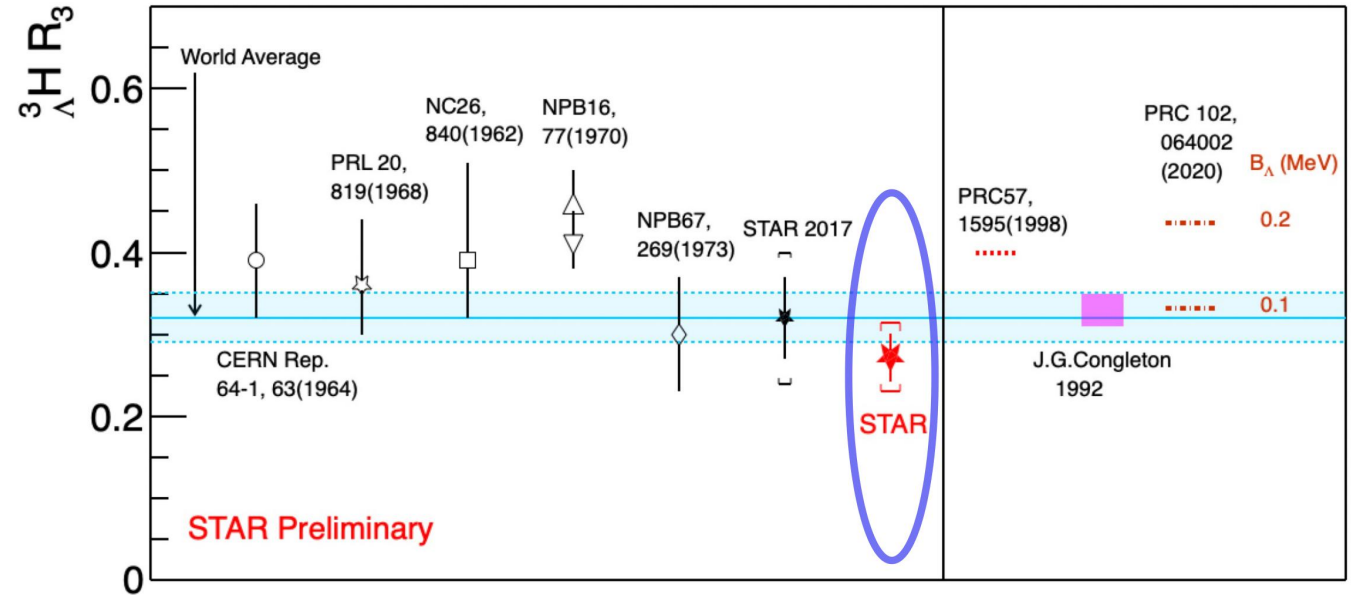
# Branching ratio of hypernuclei

- Calculations propose that  ${}^3_{\Lambda}\text{H}$  may be sensitive to  $B_{\Lambda}$ 
  - $B_{\Lambda}$ :  $\Lambda$  separation energy;
  - ${}^3_{\Lambda}\text{H } B_{\Lambda} = M(d) + M(\Lambda) - M({}^3_{\Lambda}\text{H})$ ;



$$R_3 = \frac{\text{B. R. } ({}^3_{\Lambda}\text{H} \rightarrow {}^3\text{He}\pi^-)}{\text{B. R. } ({}^3_{\Lambda}\text{H} \rightarrow p d \pi^-) + \text{B. R. } ({}^3_{\Lambda}\text{H} \rightarrow {}^3\text{He}\pi^-)}$$

$$\text{STAR: } R_3 = 0.272 \pm 0.030 \pm 0.042$$



- STAR new  $R_3$  data favors small binding energy of hypertriton

# Production of hypernuclei

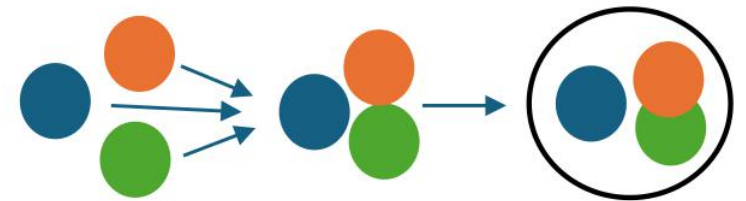
## Hypernuclei Production Models in Heavy-Ion Collisions:

### Thermal:

- Particle yields predicted with thermal equilibrium assumptions
  - Chemical freeze-out temperature  $T_{\text{ch}}$
  - Baryon-chemical potential  $\mu_B$
  - Volume  $V$
  - Strangeness correlation length  $r_C$

### Coalescence:

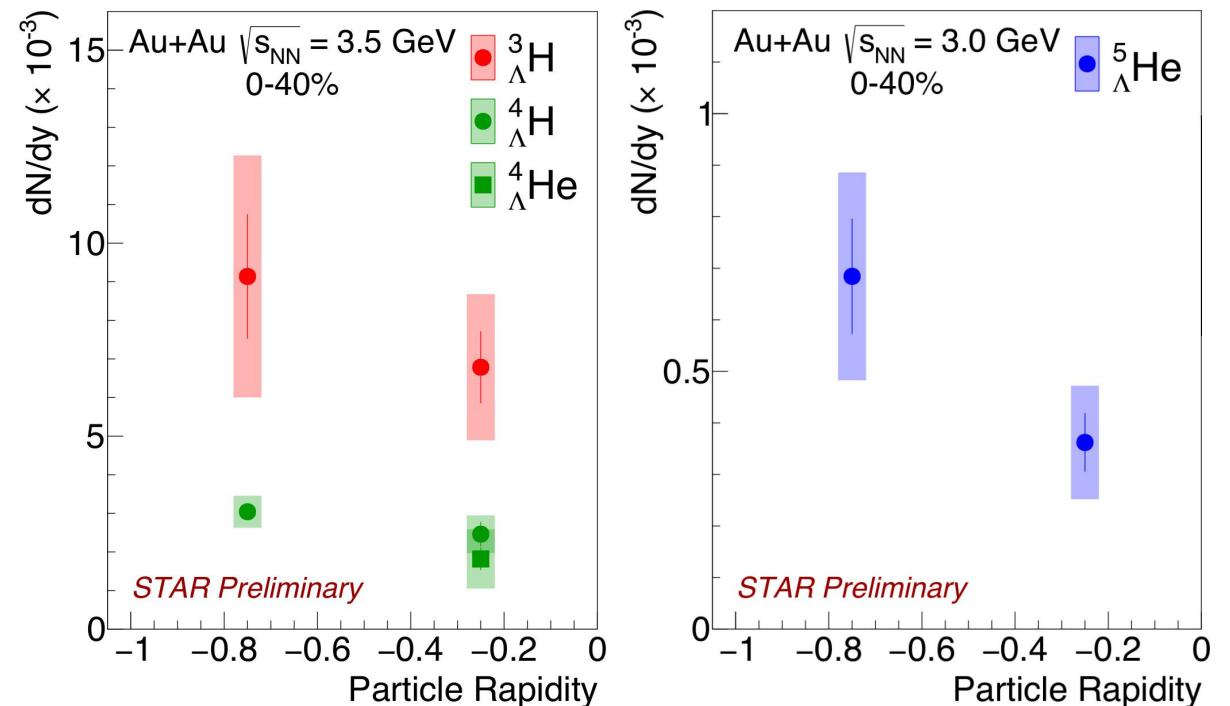
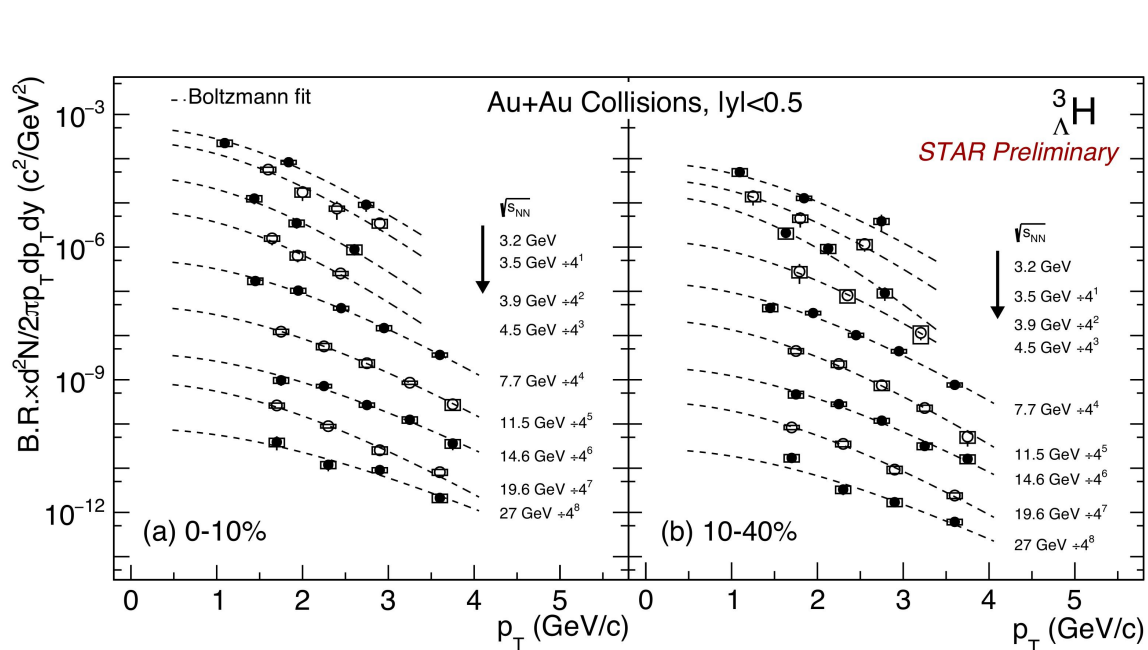
- Formed by nucleons (and hyperons) which are nearby in phase space after kinetic freeze-out;
- Formation probability given by overlap b/w:
  - Nucleon distributions at freeze-out
  - Nuclear wave function



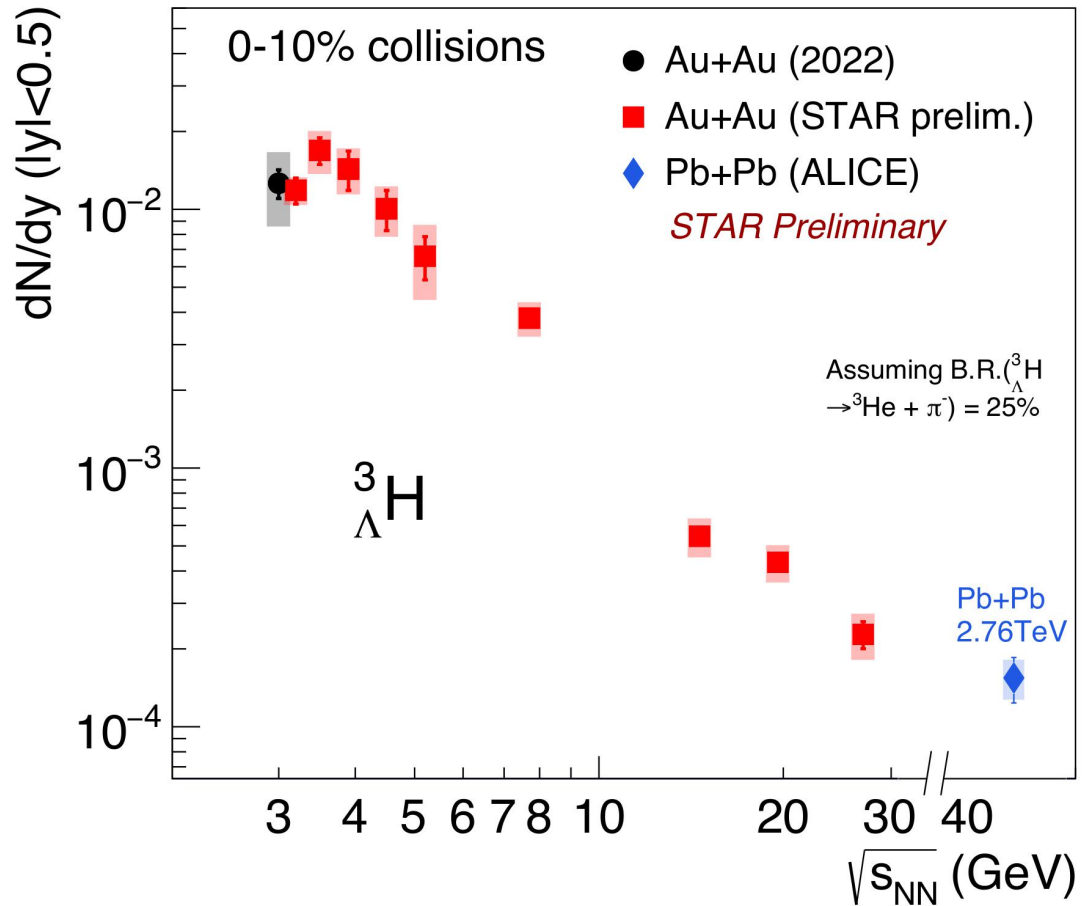
# Production of hypernuclei

Measurements cover different energies, different system size:

- ${}^3_{\Lambda}\text{H}$  in Au+Au collisions at  $\sqrt{s_{\text{NN}}} = 3\text{-}27$  GeV, Au+Au, Zr, Zr, Ru+Ru collisions at 200 GeV;
- ${}^4_{\Lambda}\text{H}$  and  ${}^4_{\Lambda}\text{He}$  in Au+Au collisions at 3-3.5 GeV;
- ${}^5_{\Lambda}\text{He}$  in Au+Au collisions at 3 GeV;



# Production of hypernuclei



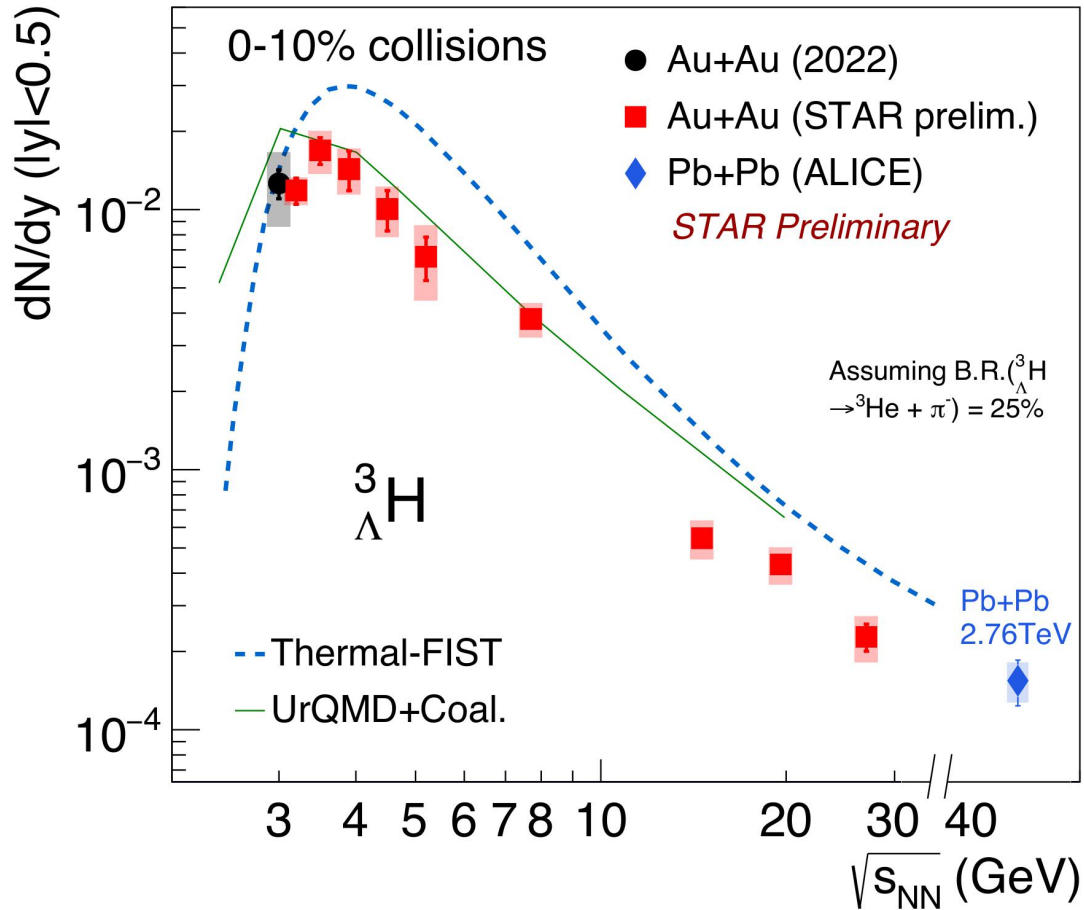
- ${}^3_{\Lambda}\text{H}$  production steep increase from 27 to 3 GeV
- Reach peak at around 3-4 GeV;
- Interplay between increasing baryon production and stronger strangeness canonical suppression towards low energies;
  - $\sqrt{s_{\text{NN}}} \downarrow$ , **baryon density**  $\uparrow$ , yields  $\uparrow$ ;
  - $\sqrt{s_{\text{NN}}} \downarrow$ , **strangeness canonical suppression**  $\uparrow$ , yields  $\downarrow$ ;

Thermal-FIST, Coal.+UrQMD: T. Reichert et al, PRC 107, 014912 (2023)

Pb+Pb: ALICE, PLB 754, 360 (2016)

Au+Au: STAR, PRL 128, 202301 (2022)

# Production of hypernuclei



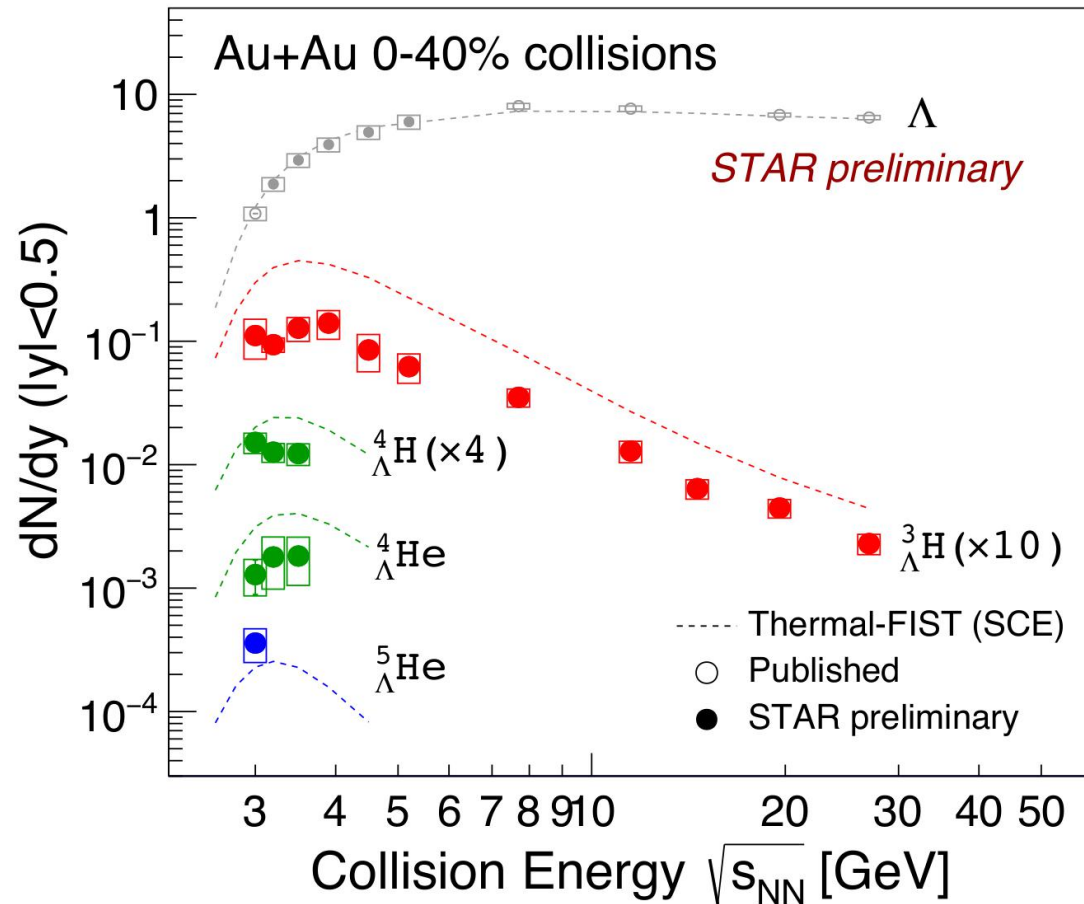
Thermal-FIST, Coal.+UrQMD: T. Reichert et al, PRC 107, 014912 (2023)

Pb+Pb: ALICE, PLB 754, 360 (2016)

Au+Au: STAR, PRL 128, 202301 (2022)

- Thermal-FIST model
  - Hadron chemical freeze-out  $T$  and  $\mu_B$ ;
  - Strangeness canonical ensemble in low energies;
  - $\sim 2$  times larger than the data;
- UrQMD + Instant coal.
  - Describe data from 3-10 GeV;
  - Instant coalescence after hadron kinetic freeze-out;
  - Coalescence condition:
    - $|\vec{p}_1 - \vec{p}_2| < \Delta P, |\vec{r}_1 - \vec{r}_2| < \Delta R$

# Production of hypernuclei



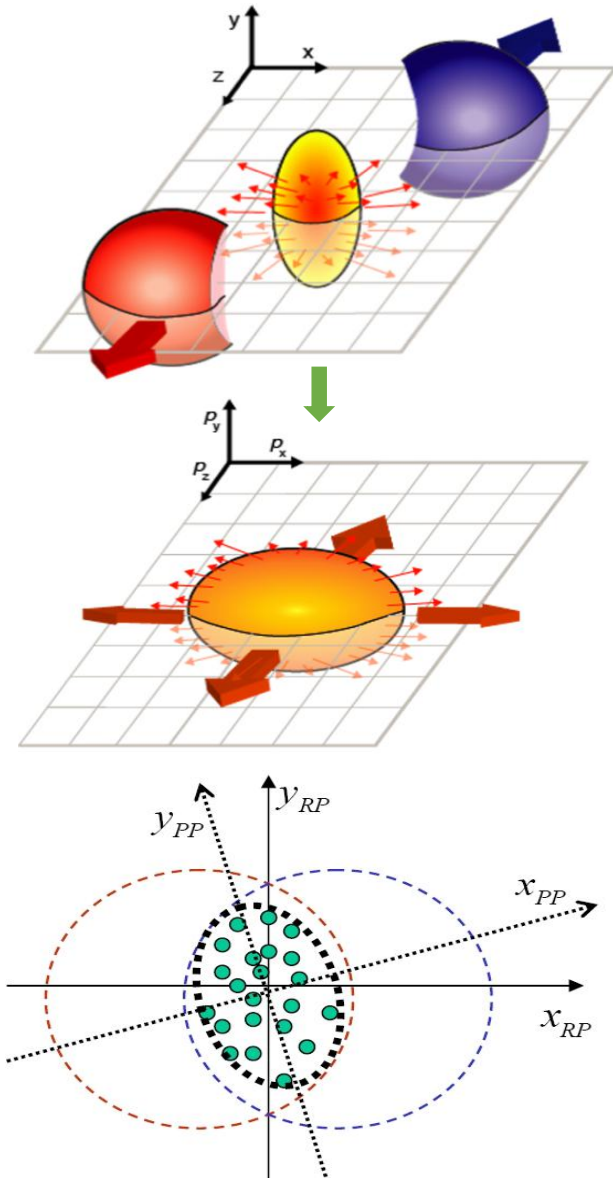
- Add  $A \geq 4$  hypernuclei energy dependence of yields;
- $A=3$  hypernuclei strongly overpredicted by thermal model;
- The discrepancy decreases for heavier hypernuclei ( $A \geq 4$ );

Driven by hypernuclei sizes?

Hypernuclei yields cannot be described by thermal production alone

STAR collaboration, PRL 128(2022)202301  
STAR collaboration, PRC 102 (2020) 34909  
STAR collaboration, JHEP 2024 (2024) 139

# Collectivity Flow

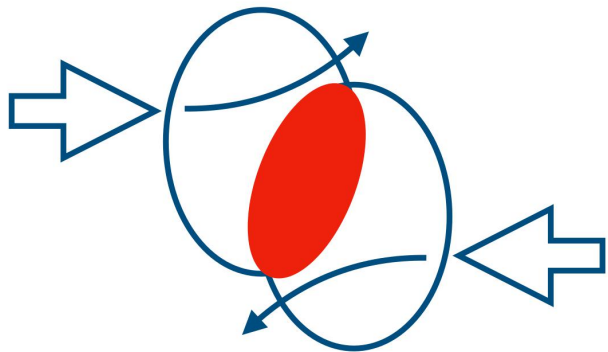


- Partial overlap  $\Rightarrow$  Spatial anisotropy  $\Rightarrow$  Different pressure gradients  $\Rightarrow$  Momentum anisotropy = “collective flow”
- Fourier series decomposition of azimuthal distribution of emitted particles:
  - $$\frac{d^2N}{p_T dp_T d\varphi} = \frac{1}{2\pi} \frac{dN}{p_T dp_T} \left\{ 1 + \sum_{n=1}^{\infty} 2v_n \cos[n(\varphi - \Psi_R)] \right\}$$
  - **Directed flow:**  $v_1 = \left\langle \frac{p_x}{p_T} \right\rangle$
  - Elliptic flow:  $v_2 = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle$
- Azimuthal anisotropy parameters ( $v_1, v_2$ ) are sensitive to the early stage of the system evolution and Equation-of-State (EoS) of medium

# Collectivity Flow of hypernuclei

First observation of hypernuclei flow in heavy-ion collisions

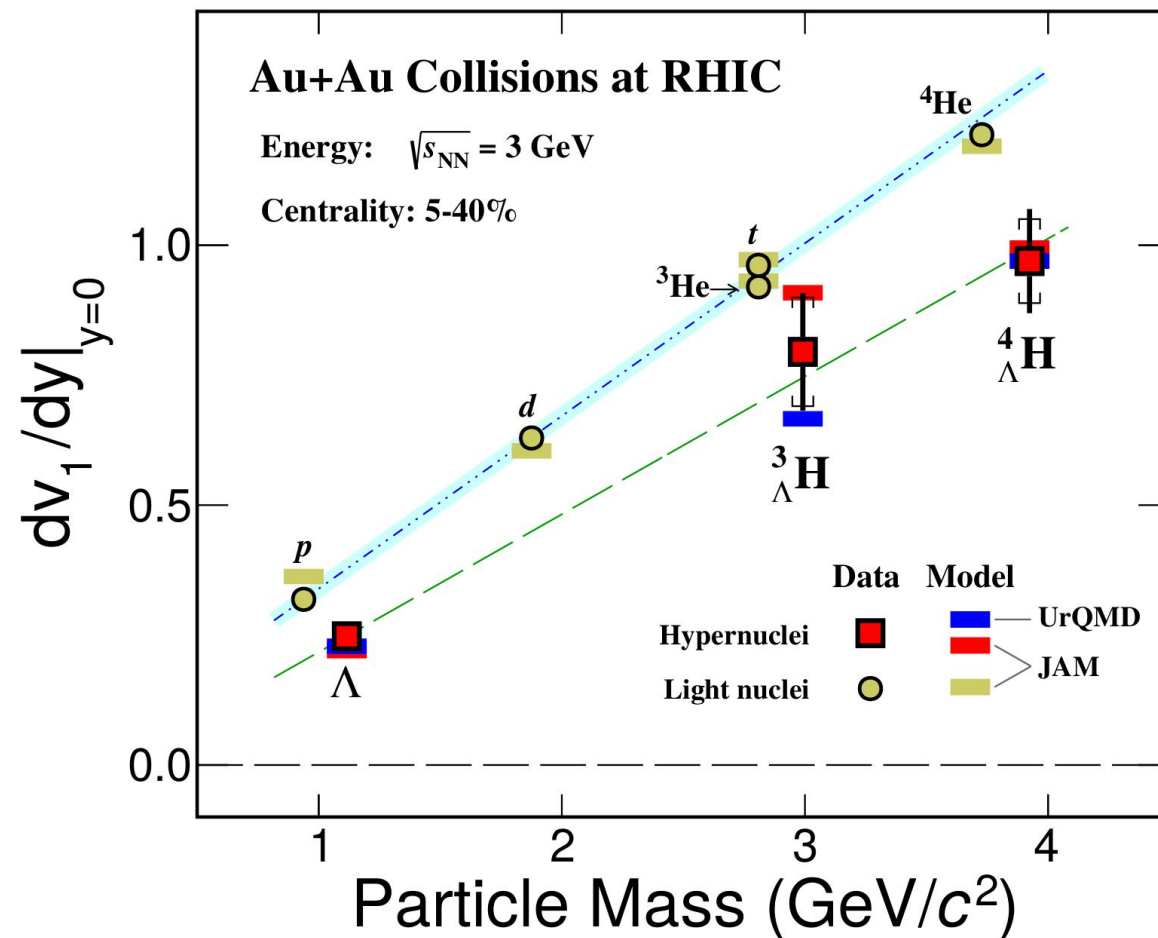
- Directed flow:  $v_1 = \langle \cos(\phi - \Psi_{EP}) \rangle$



- Nuclei and hypernuclei flow follows mass number scaling

Supports the coalescence picture

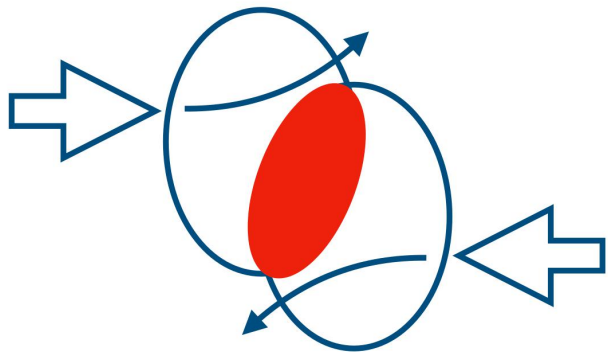
STAR collaboration, PRL130(2023)212301



# Collectivity Flow of hypernuclei

## First observation of hypernuclei flow in heavy-ion collisions

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

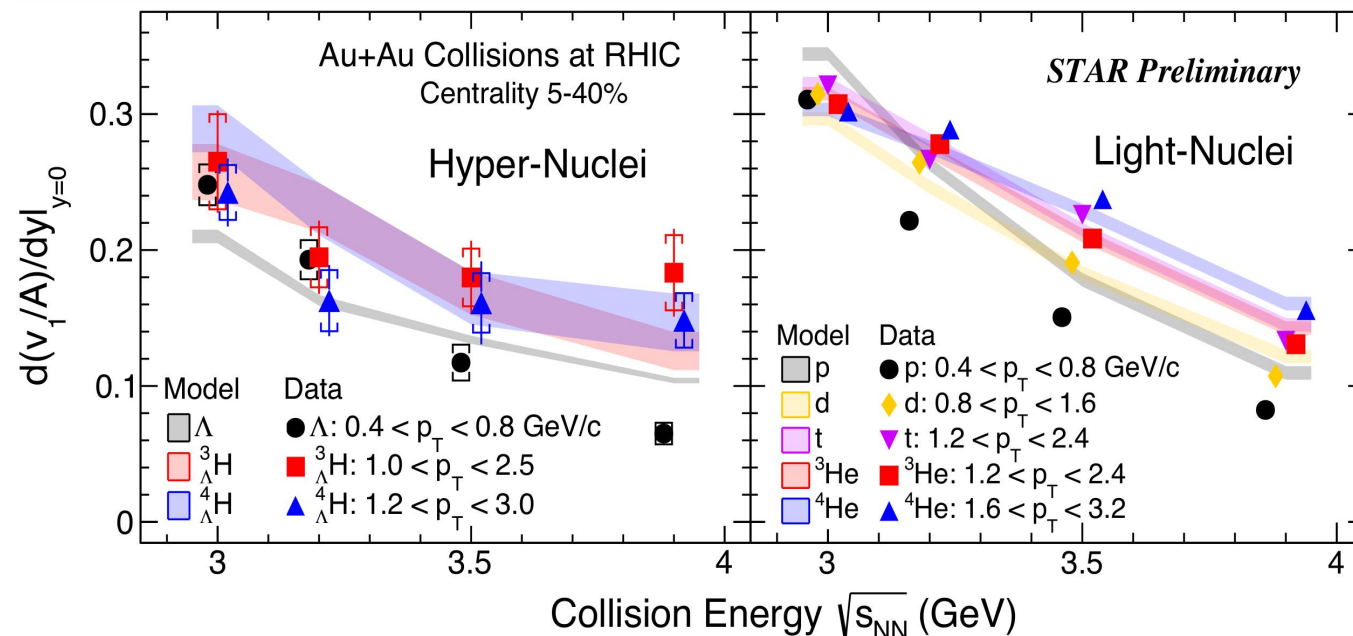


- Nuclei and hypernuclei flow follows mass number scaling

Supports the coalescence picture

Energy dependence

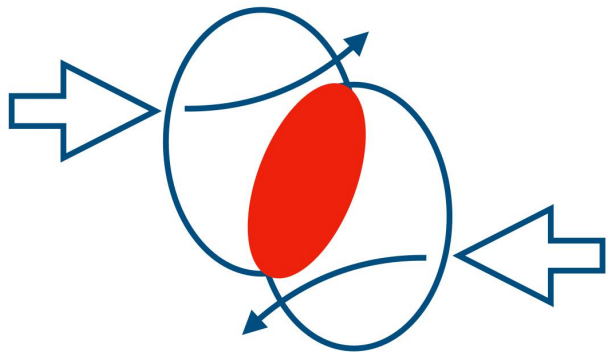
QM2023



# Collectivity Flow of hypernuclei

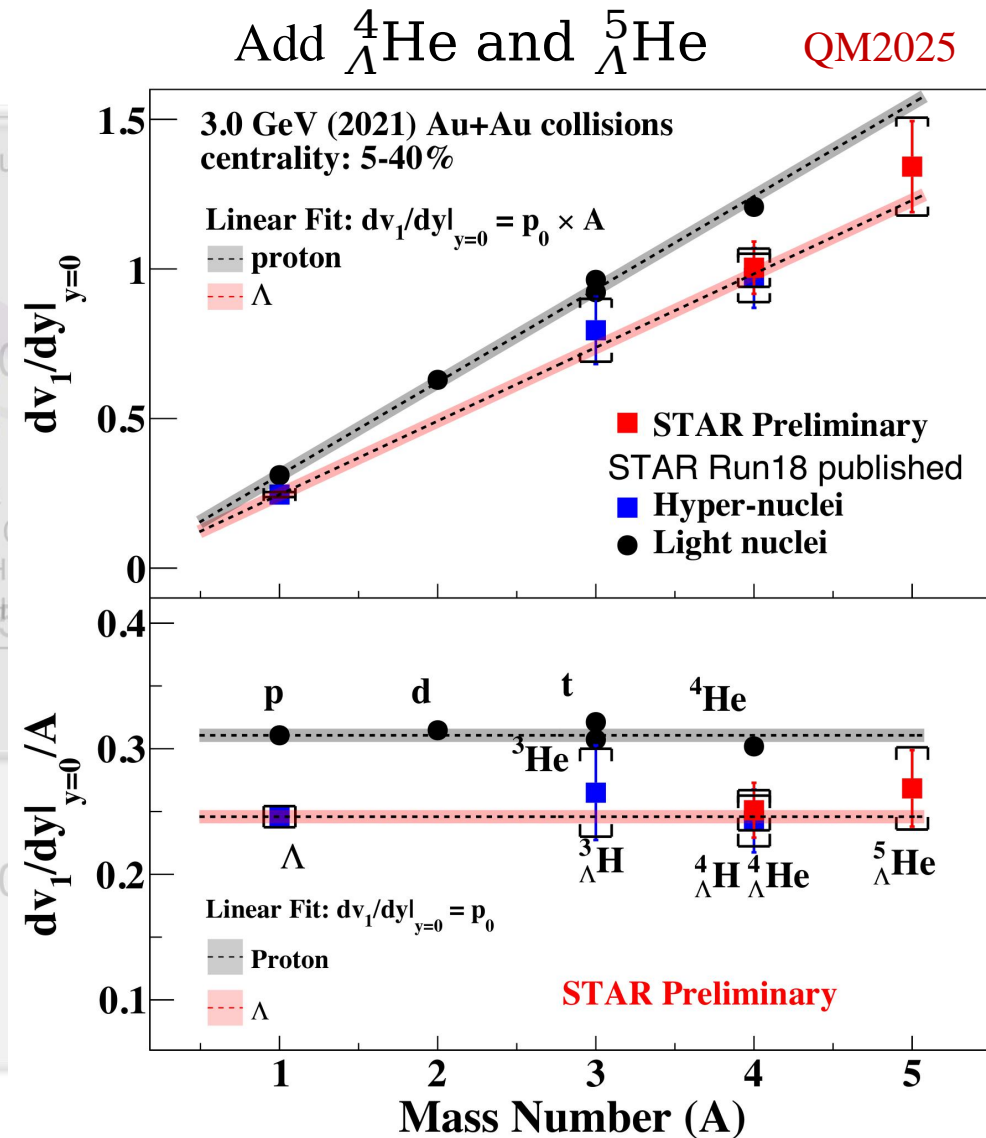
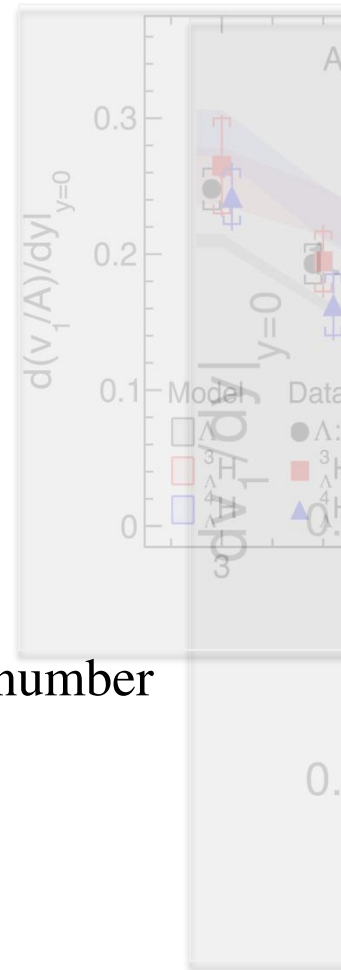
First observation of hypernuclei flow in heavy-ion collisions

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



- Nuclei and hypernuclei flow follows mass number scaling

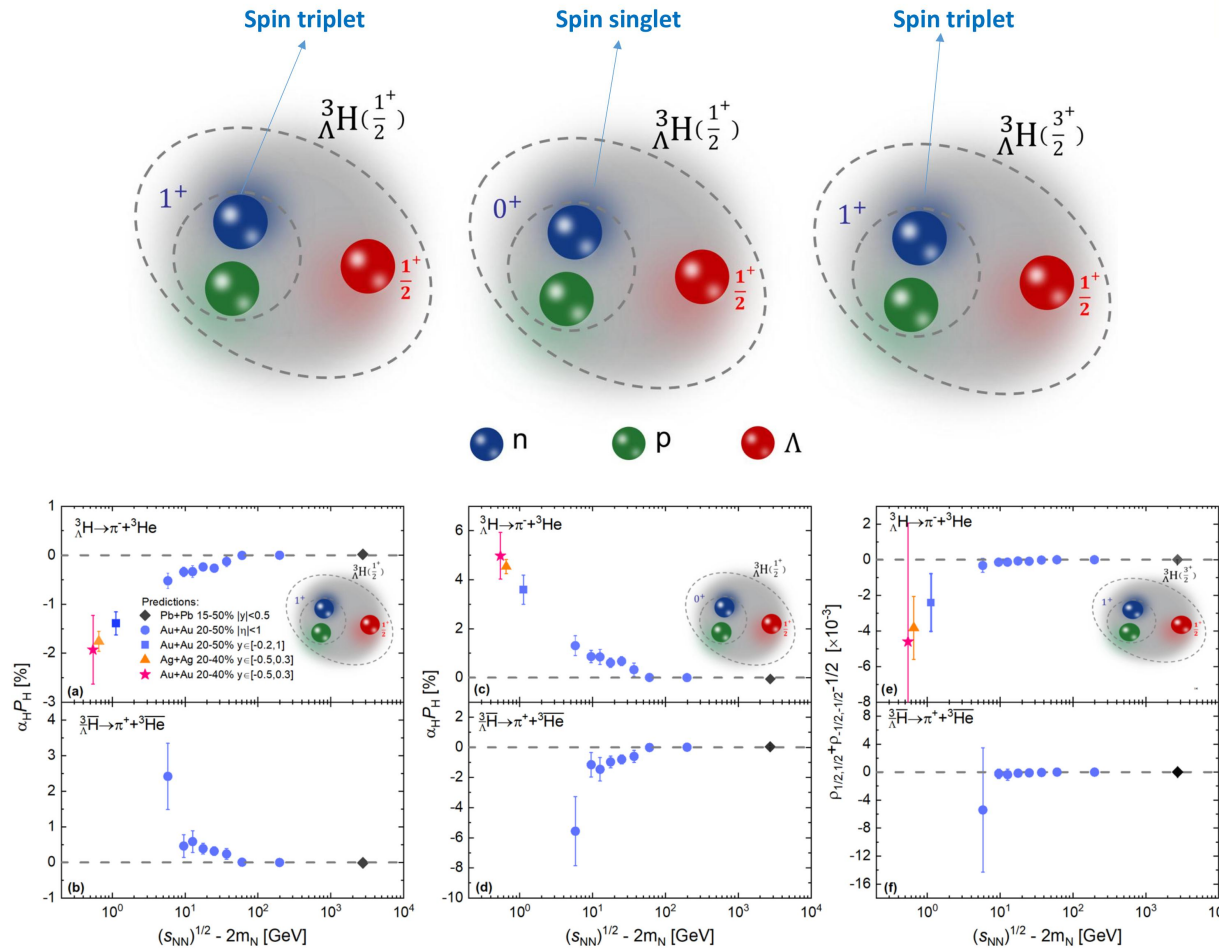
Supports the coalescence picture



# Global spin polarization of hypernuclei

Spin of hypertiron?

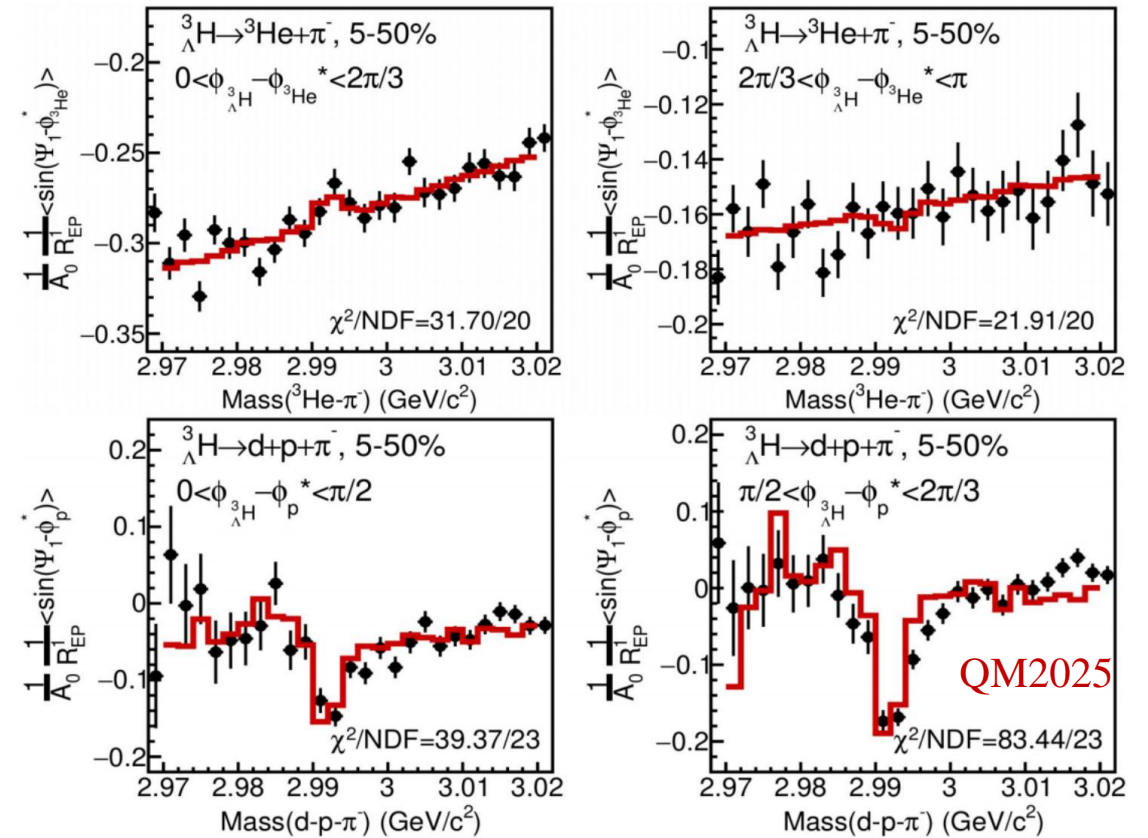
Phys.Rev.Lett. 134 (2025) 2, 022301



## First Measurements of Hyper-Nucleus ${}^3_\Lambda\text{H}$ Global Polarization in Au+Au Collisions at STAR

Chenlu Hu (huchenlu@ucas.ac.cn), for the STAR Collaboration

$$\frac{8}{\pi \alpha_H R_{EP}} \langle \sin(\Psi_1 - \phi_{\text{decay}}^*) \rangle_{\text{observe}} = P_H^{\text{real}} + c \cdot \sin(\phi_{\Lambda\text{H}} - \phi_{\text{decay}}^*)$$



# Summary

- From hyperon to hypernuclei;
- Measurements of hypernuclei in heavy-ion collisions;
  - Intrinsic Properties:
    - Lifetime,  $\Lambda$  separation energy, branching ratio, spin structure;
  - Production mechanism:
    - Spectra, yields, collectivity;

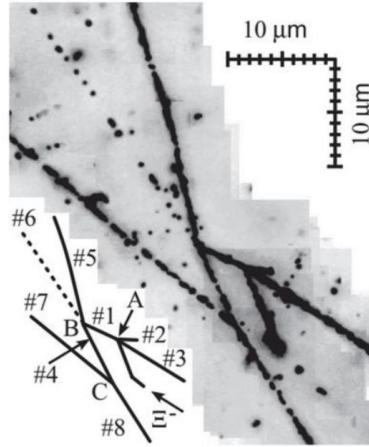
# Outlook

## $\Lambda\Lambda$ hypernuclei

- 1 confirmed  $\Lambda\Lambda$  hypernucleus:  ${}^6_{\Lambda\Lambda}\text{He}$

E373 (KEK-PS) Collaboration,  
PRC 88(2013)014003

- Constrain  $\Lambda\Lambda$  interactions

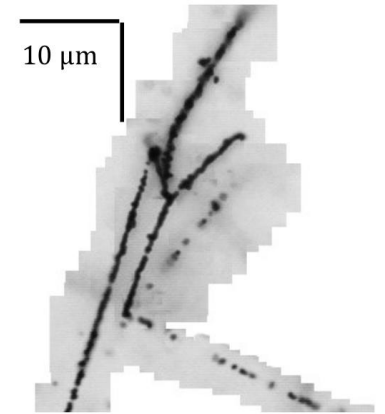


## $\Xi$ hypernuclei

- 1 confirmed  $\Xi$  hypernucleus:  ${}^{15}_{\Xi}\text{C}$

J-PARC E07 Collaboration,  
PRL 126(2021)062501

- Constrain  $N\Xi$  interactions



## $\Sigma$ hypernuclei

- 0 confirmed  $\Sigma$  hypernuclei
- Predicted to exist, e.g.:  ${}^4_{\Sigma}\text{He}$

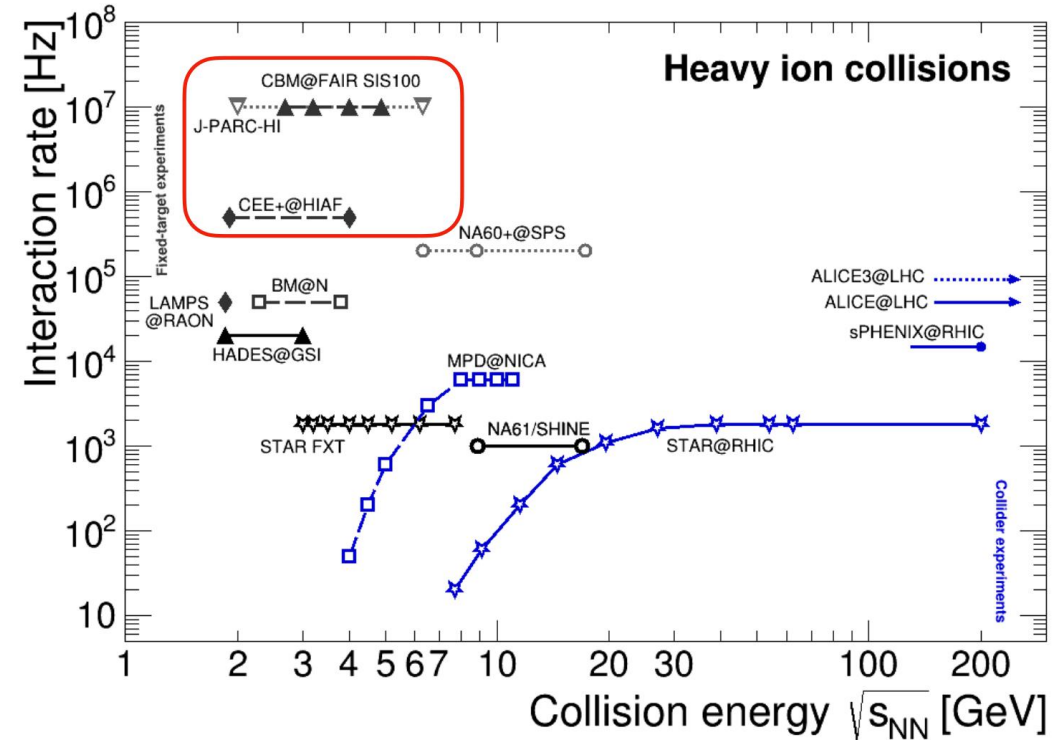
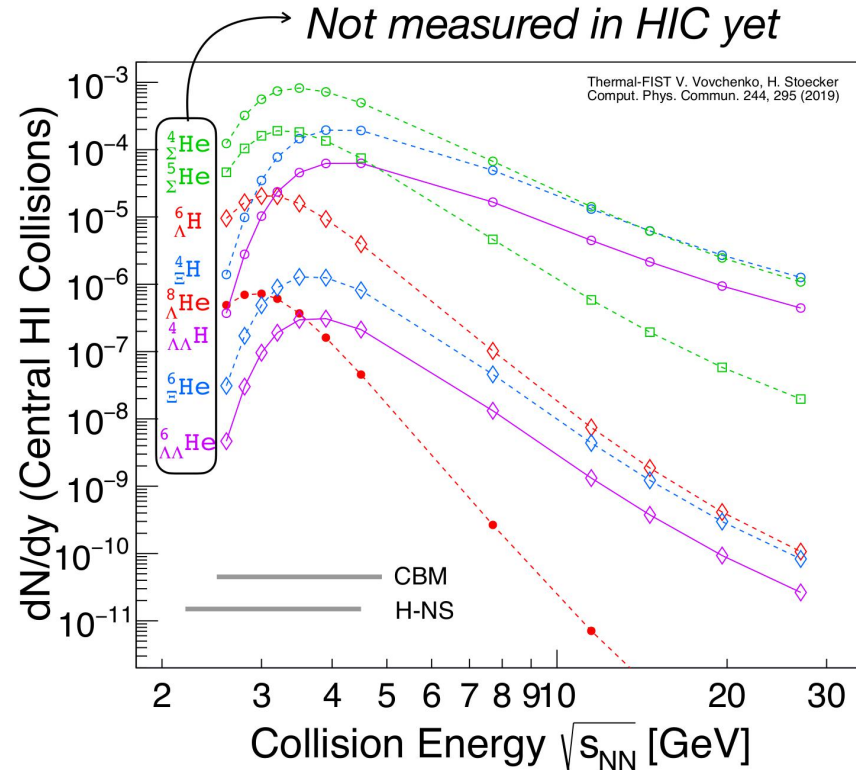
J. Johnstone and A W Thomas, Journal of Physics G 8(1982)105

- Constrain  $N\Sigma$  interactions

## Neutron-rich hypernuclei

- $\Lambda$  potential in isospin symmetric matter and neutron matter is not the same
- ${}^6_{\Lambda}\text{H}$ ,  ${}^8_{\Lambda}\text{He}$ , etc. have been predicted to exist, but not yet observed
- Probe  $\Lambda n$  in a neutron-rich environment

# Outlook



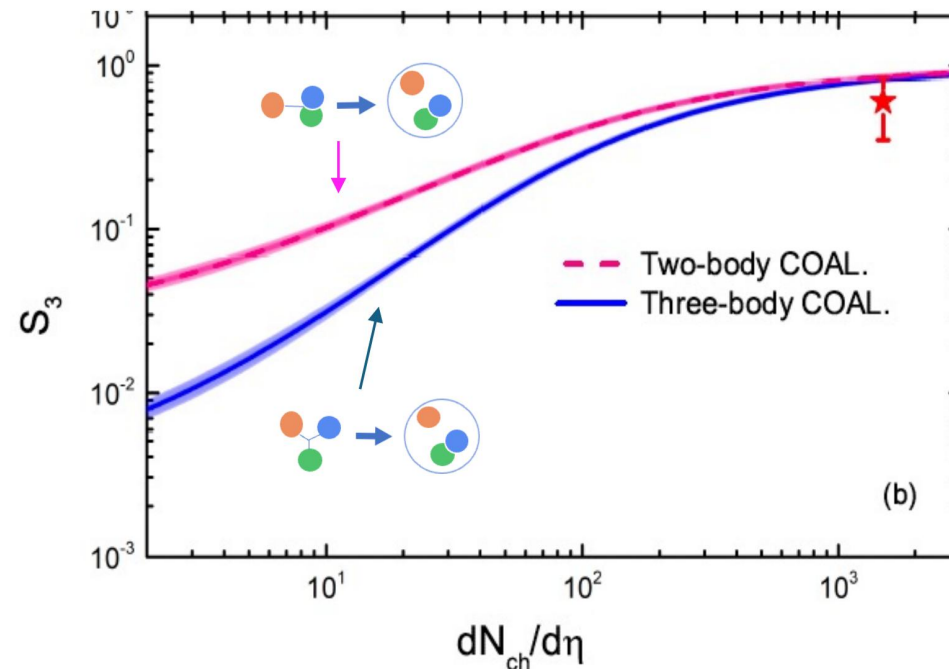
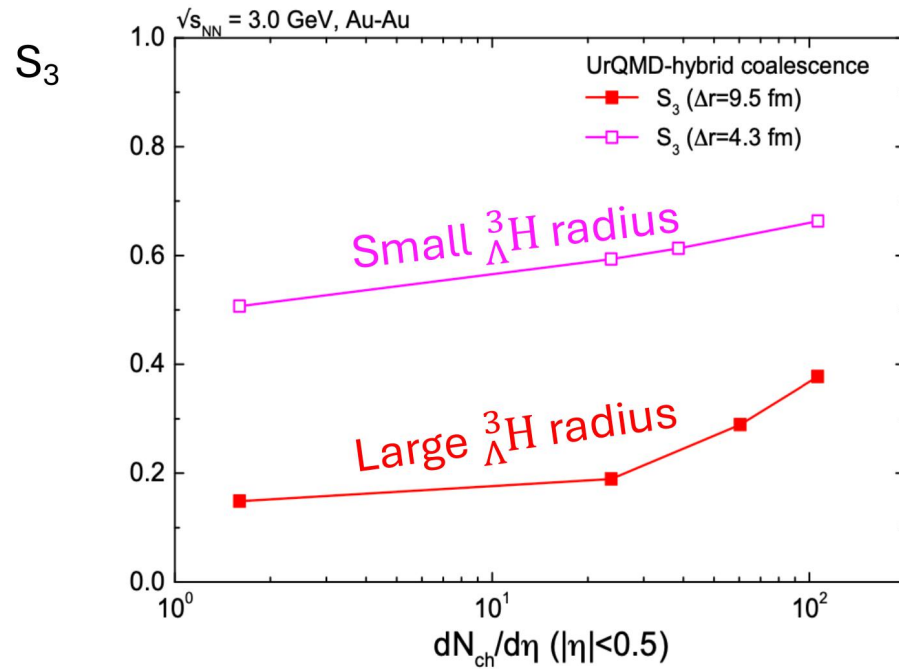
- Great potential for discovering unobserved hypernuclei in heavy ion collisions
  - $A \geq 5$ ,  $\Sigma$  and  $\Xi$  hypernuclei, may be accessible;
  - Anti-hypernuclei;
  - Exotic strangeness states and double  $\Lambda$  hypernuclei, etc

**Thank you very much for your  
attention!**

# Strangeness Population Factor $S_3$

$$S_A = \frac{{}^A_\Lambda\text{H}(A \times p_T)}{{}^A\text{He}(A \times p_T) \times \frac{\Lambda}{n}(p_T)} = \frac{B_A({}^A_\Lambda\text{H})(p_T)}{B_A({}^A\text{He})(p_T)} \quad E_A \frac{d^3 N_A}{dp_A^3} = B_A \left( E_{p,n} \frac{d^3 N_{p,n}}{dp_{p,n}^3} \right)^A \bigg|_{\vec{p}_p = \vec{p}_n = \frac{\vec{p}_A}{A}}$$

- Direct connection to coalescence parameters  $B_3$
- $S_3$  vs.  $dN_{\text{ch}}/d\eta$ : Possible insights to nuclei radius and coalescence mechanism;



# Strangeness Population Factor $S_3$

STAR, Nature 2024(2024)77

ALICE, PRL 128(2022)252003, PLB 754(2016)360

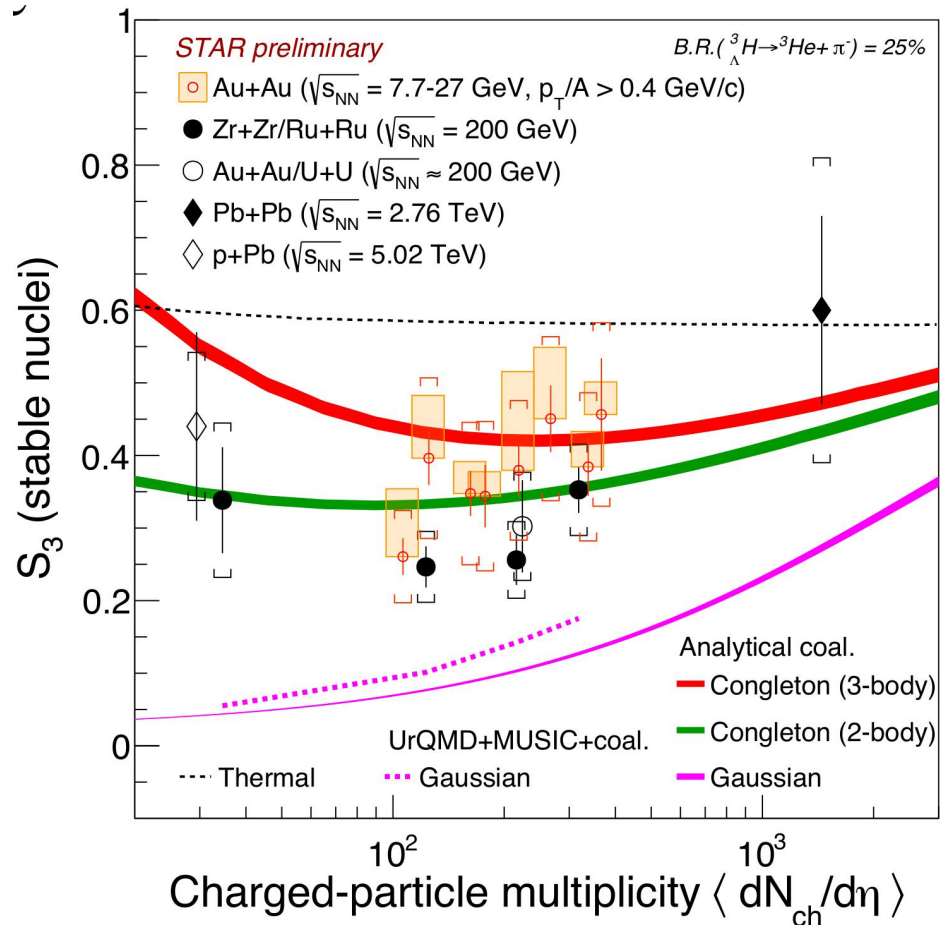
Thermal: V. Vovchenko et al., CPC 244(2019)295

UrQMD+MUSIC coal.: K. Sun et al., PLB 820(2021)136571

ana. coal.: F. Bellini et al, PRC 103(2021)014907

YHL et al, arXiv:2510.06758

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



- Compares  ${}^3_{\Lambda}\text{H}$  production to  ${}^3\text{He}$ ;
- Thermal model overestimates the data;
- Coalescence calculations using Congleton wave function describe the data well, more precise data needed

Suppression of  ${}^3_{\Lambda}\text{H}$  due to coalescence mechanism confirmed by data