Observation of antihypertriton in Au+Au collisions at 200 GeV
-- the antinuclei journey with Prof. Keane

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STAR Col. Science **328**, 58 (2010)
STAR Col. Nat. Phys. **16**, 409 (2020)
J. Chen, D. Keane, Y.-G. Ma, A. Tang, Z. Xu, Phys. Rept. **760**, 1 (2018)
…

Outline

- First of all, Happy 70th Birthday!
- Introduction to the antinuclei study
- Focus on the antihypertriton
- Summary

Introduction

in 2009, we said:

- Hypernuclei: ideal lab for YN and YY interaction
  - Baryon-baryon interaction with strangeness sector
  - Input for theory describing the nature of neutron stars

- No anti-hypernuclei have ever been observed

- Coalescence mechanism for production: depends on overlapping wave functions of Y+N at final stage

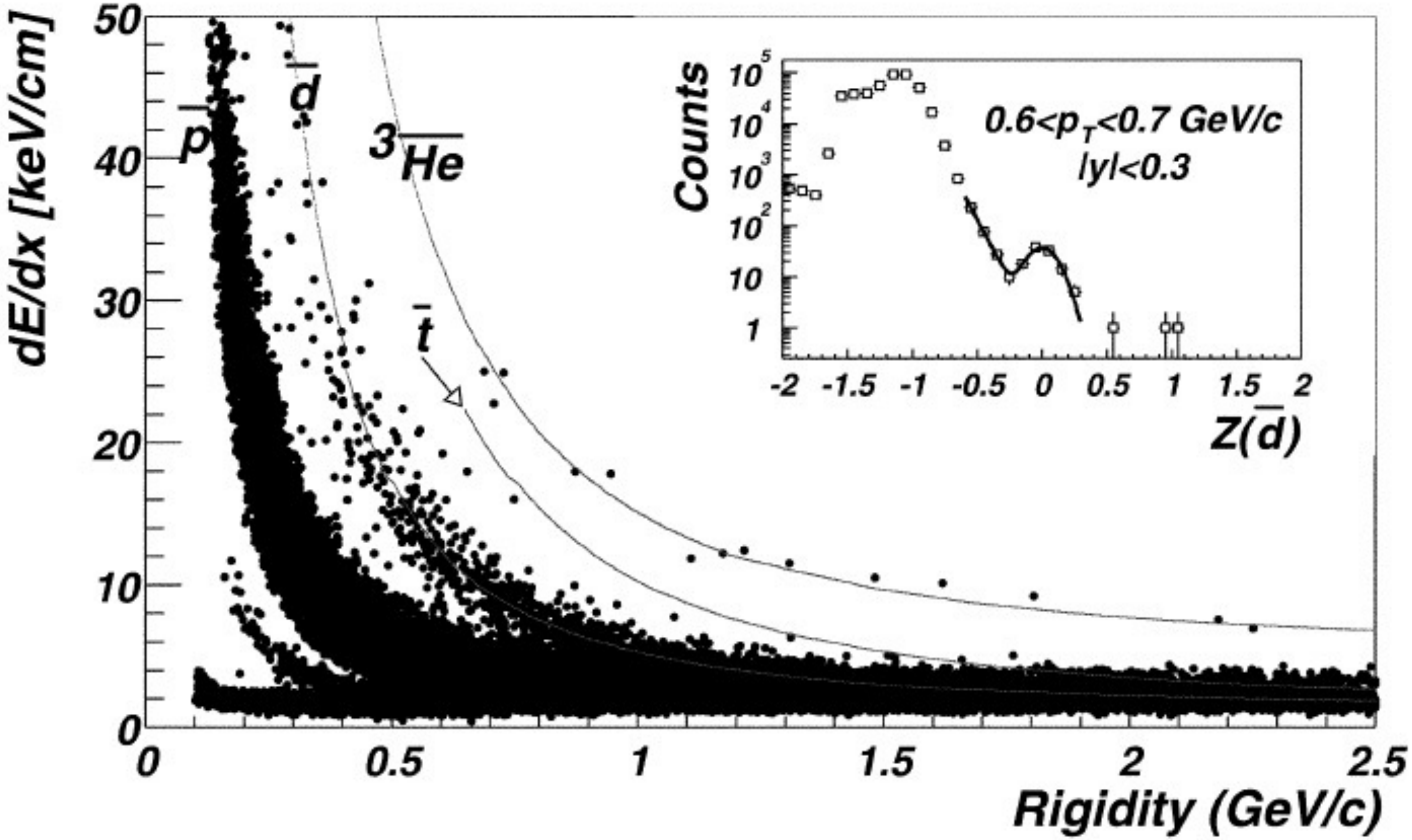
- Anti-hypernuclei and hypernuclei ratios: sensitive to anti-matter and matter profiles in HIC
  - Extension of the nuclear chart into anti-matter with S [1]

[1] W. Greiner, *Int. J. Mod. Phys. E 5 (1995) 1*

STAR has measured antinuclei in run1

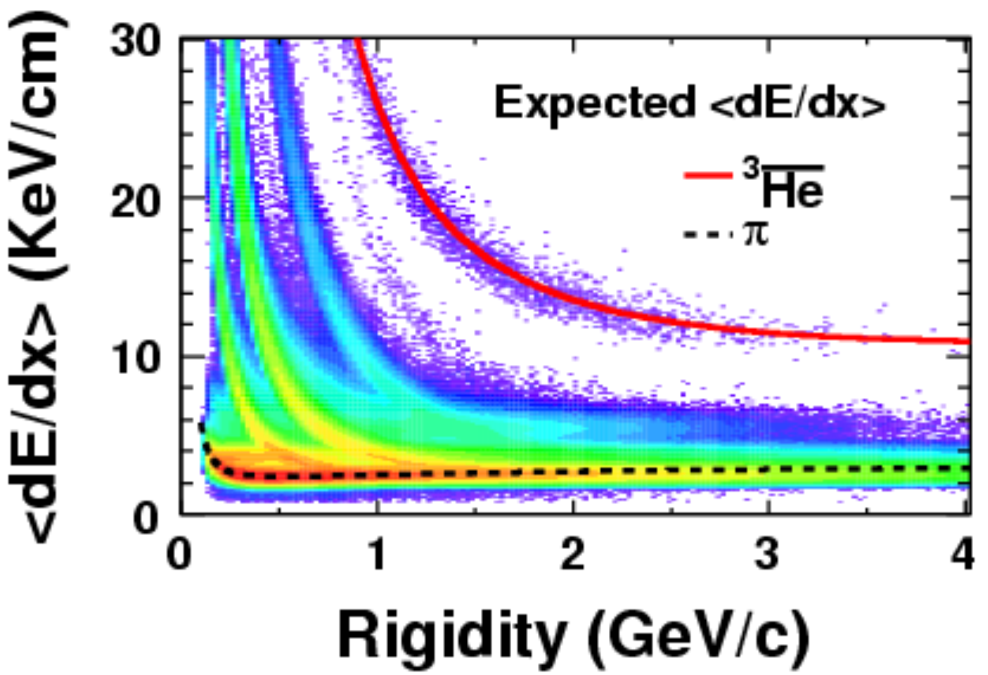
VOLUME 87, NUMBER 26 PHYSICAL REVIEW LETTERS 24 DECEMBER 2001

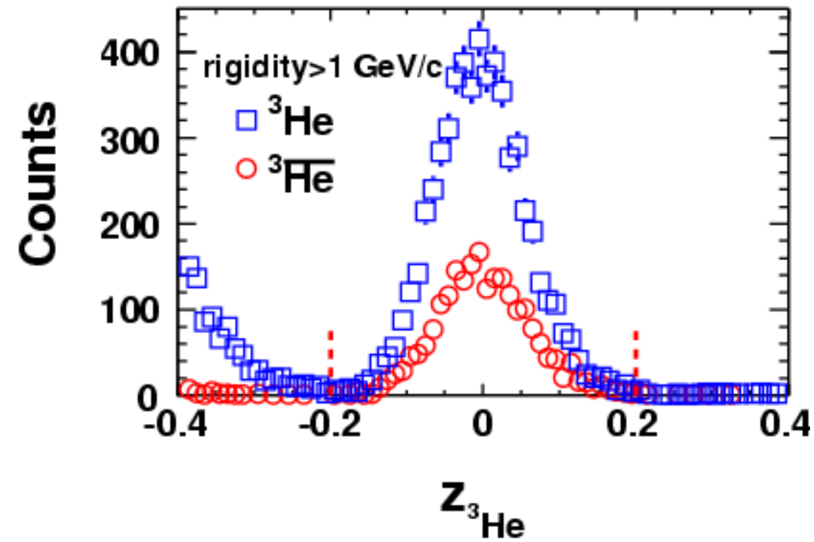
$\bar{d}$ and $^3\overline{\mathrm{He}}$ Production in $\sqrt{s_{NN}}$ = 130 GeV Au + Au Collisions



★ 14 anti-^{3}He based on 0.6M central Au+Au at 130 GeV

Collect giant data with run4 + run7





$$z = \ln\left(\frac{\langle dE/dx \rangle}{\langle dE/dx \rangle^{th}}\right)$$

Theory curve: *Phys. Lett. B 667 (2008) 1*

★ **Select pure ^{3}He sample:** **^{3}He: 5810 counts**

anti-^{3}He: 2168 counts

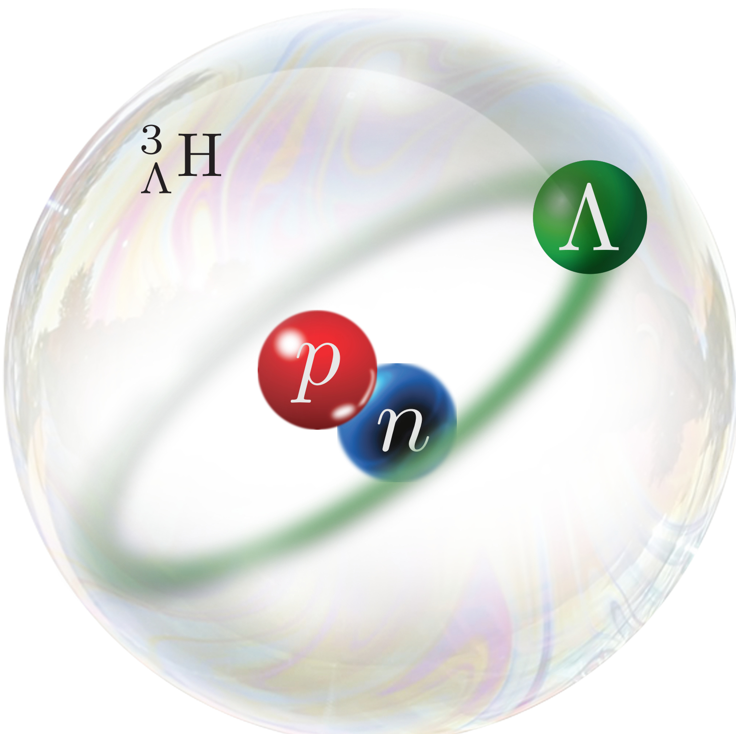
condition: -0.2<z<0.2 & dca<1.0cm & p>2 GeV/c…

Extend the antinuclei study with v0

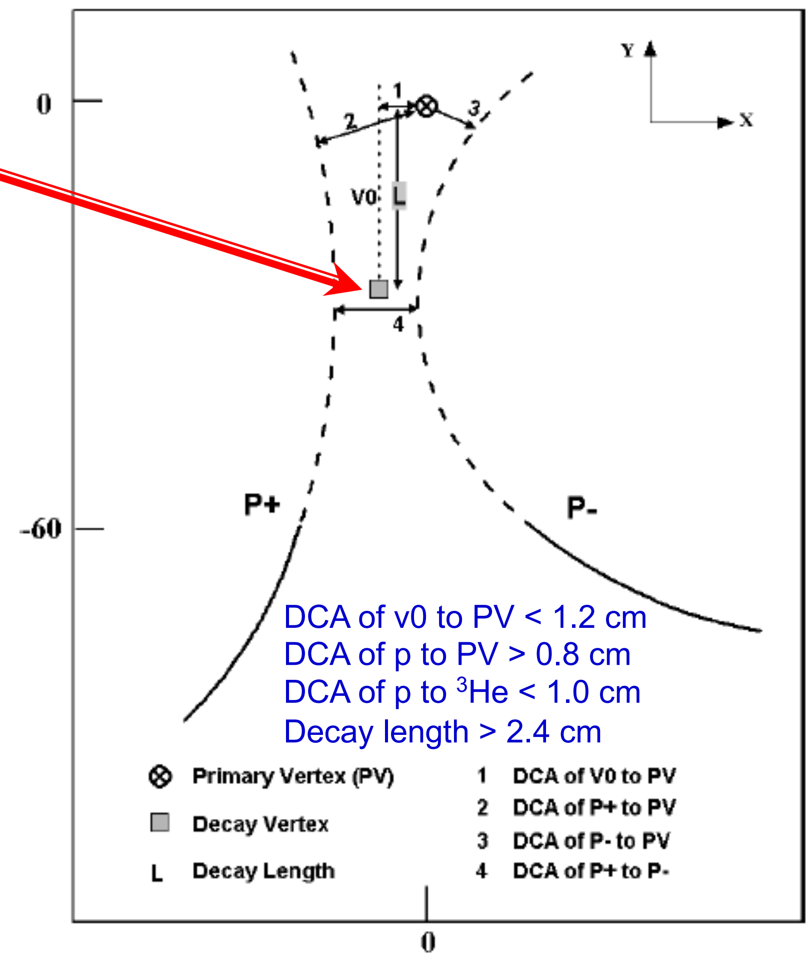
$^{3}_{\Lambda}$H mesonic decay, m=2.991 GeV, B.R. 0.25;

$$^{3}_{\bar{\Lambda}}\overline{H} \rightarrow {}^{3}\overline{He} + \pi^{+}$$

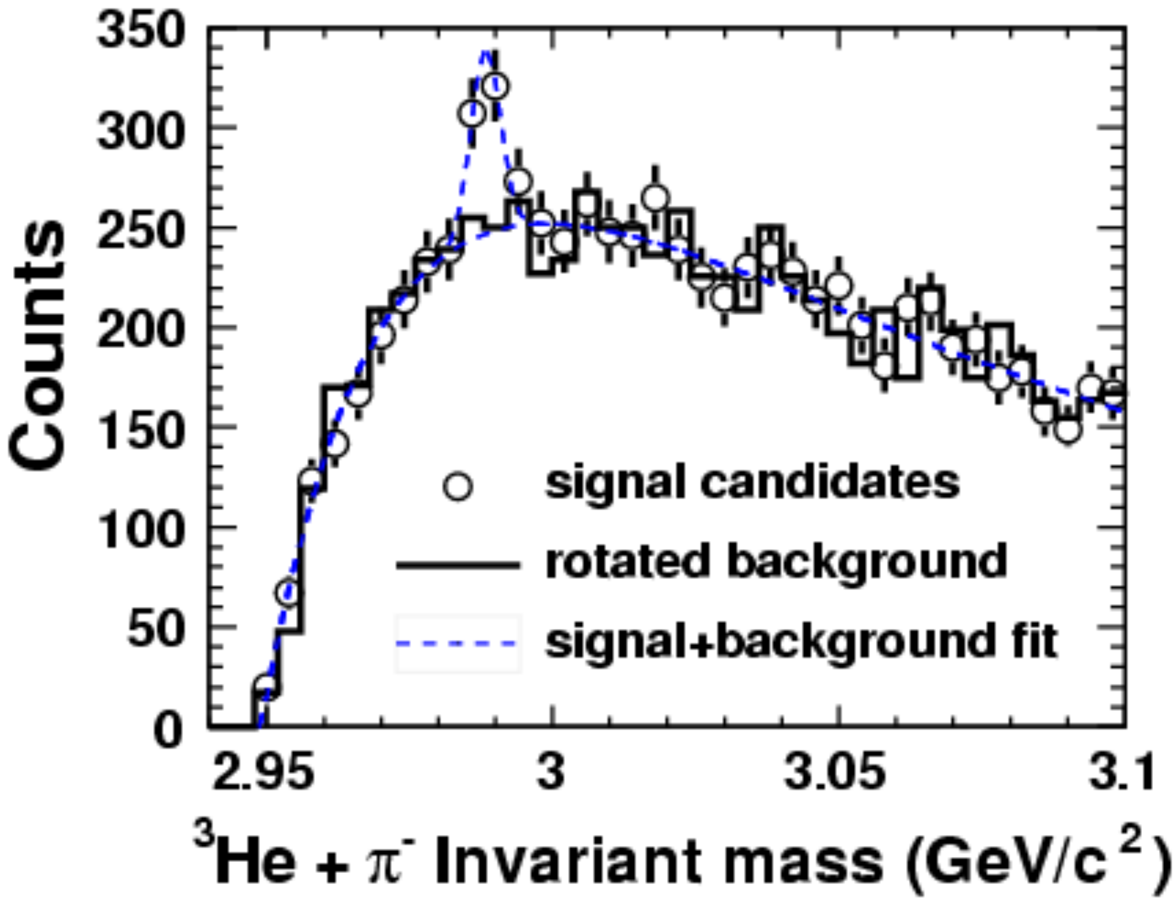
$$^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$$



Secondary vertex finding technique



${}^{3}_{\Lambda}\mathrm{H}$ signal from the data

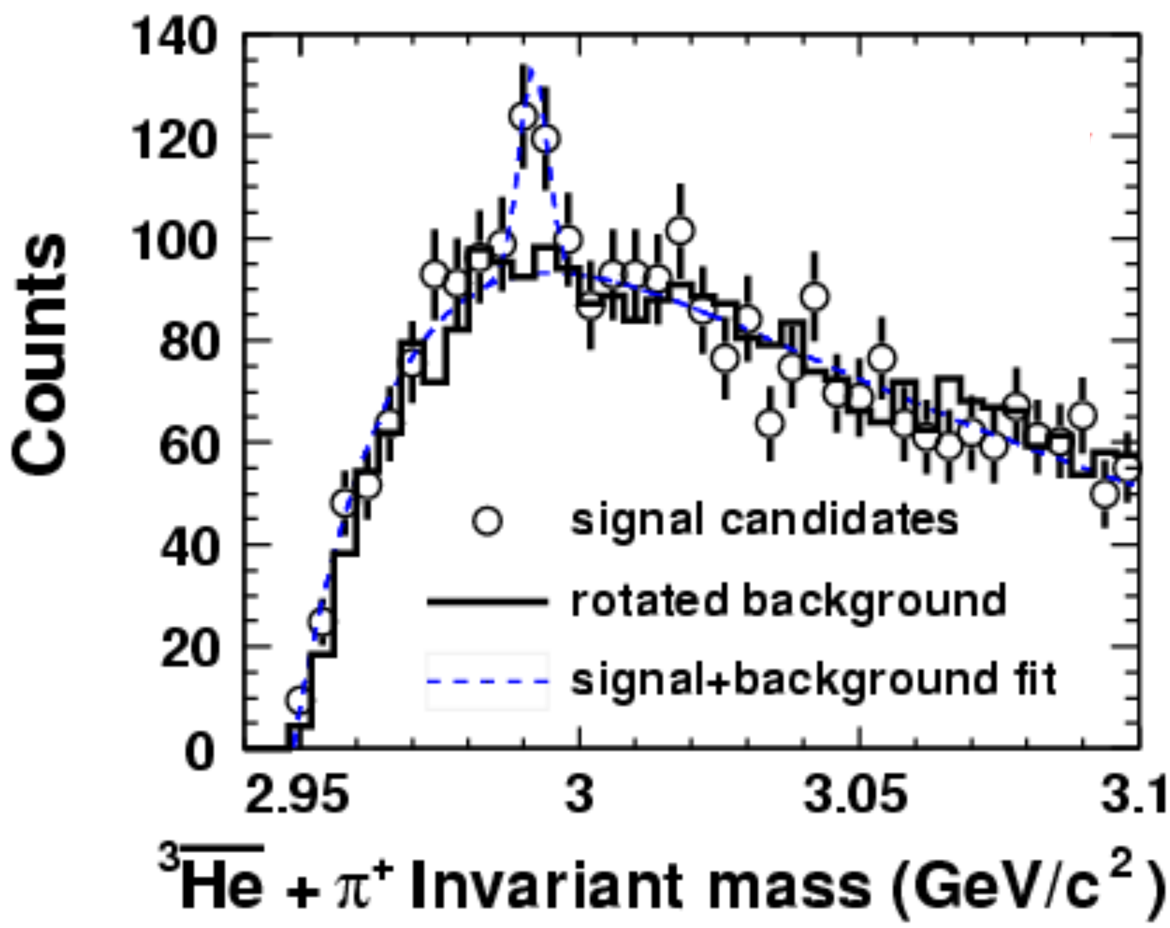


- Signal observed from the data (bin-by-bin counting): **157±30**;

  Mass: 2.989±0.001±0.002 GeV; Width (fixed): 0.0025 GeV.

- Projection on anti-hypertriton yield: ${}^{3}_{\Lambda}\overline{\mathrm{H}} = {}^{3}_{\Lambda}\mathrm{H} \times {}^{3}\overline{\mathrm{He}} / {}^{3}\mathrm{He}$ =157*2168/5810= **59±11**

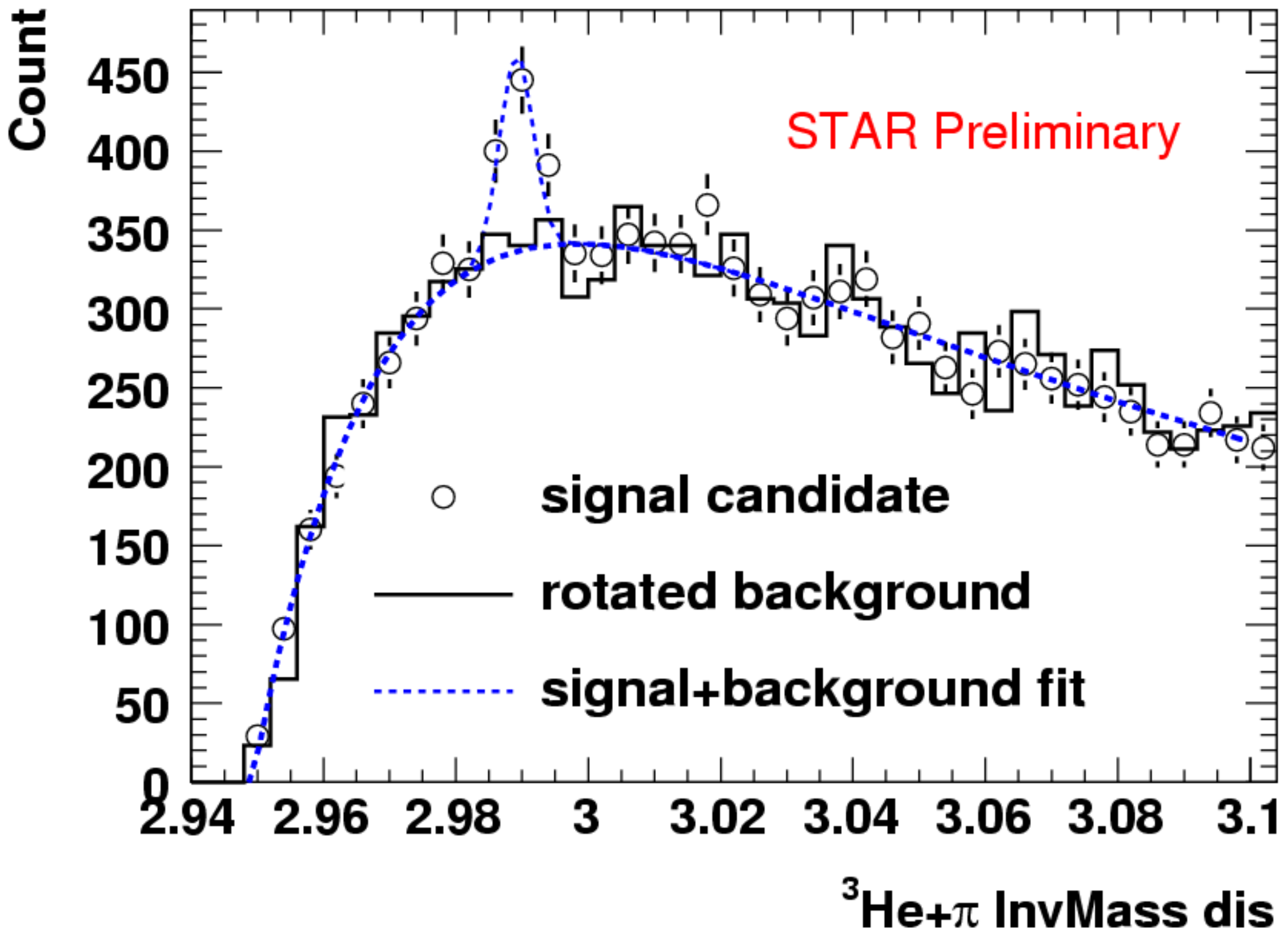
${}^{3}_{\bar{\Lambda}}\overline{H}$ signal from the data



★ Signal observed from the data (bin-by-bin counting): **70±17**;

Mass: 2.991±0.001±0.002 GeV; Width (fixed): 0.0025 GeV.

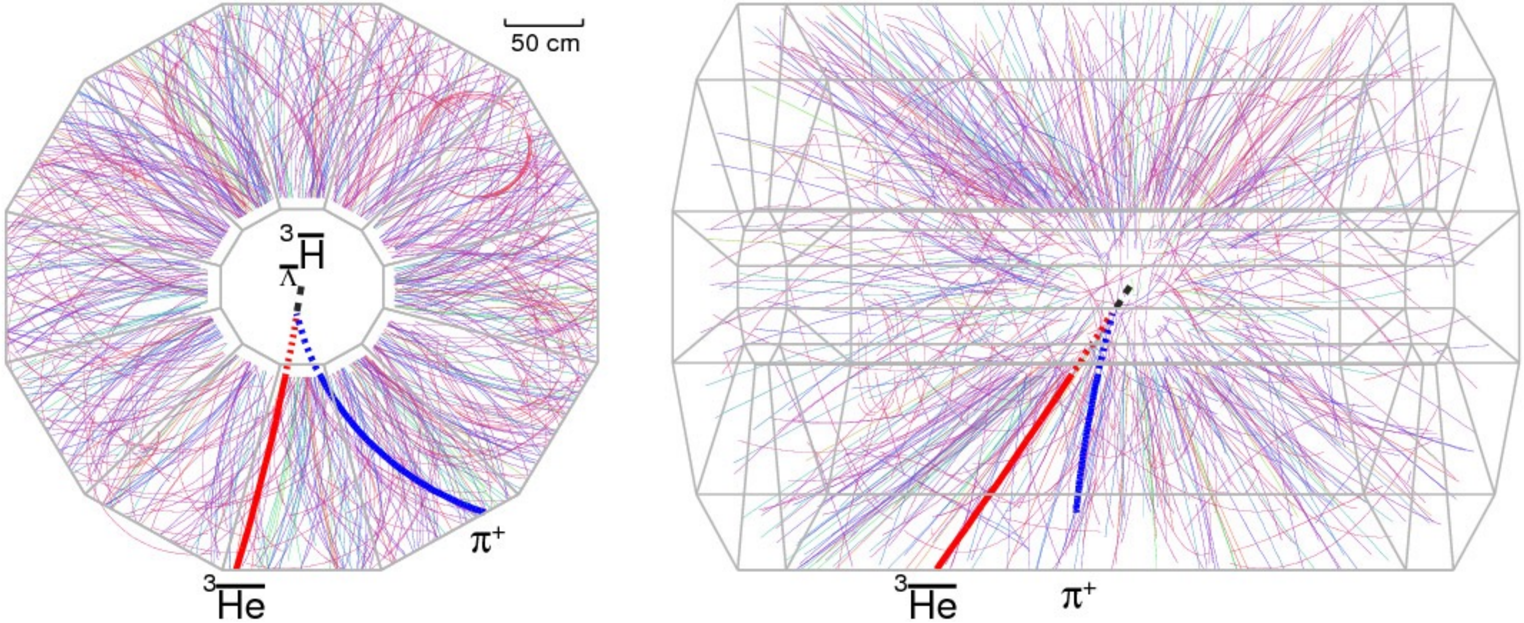
Combined the signal



★ Combined hyperT and anti-hyperT signal : **225±35**;

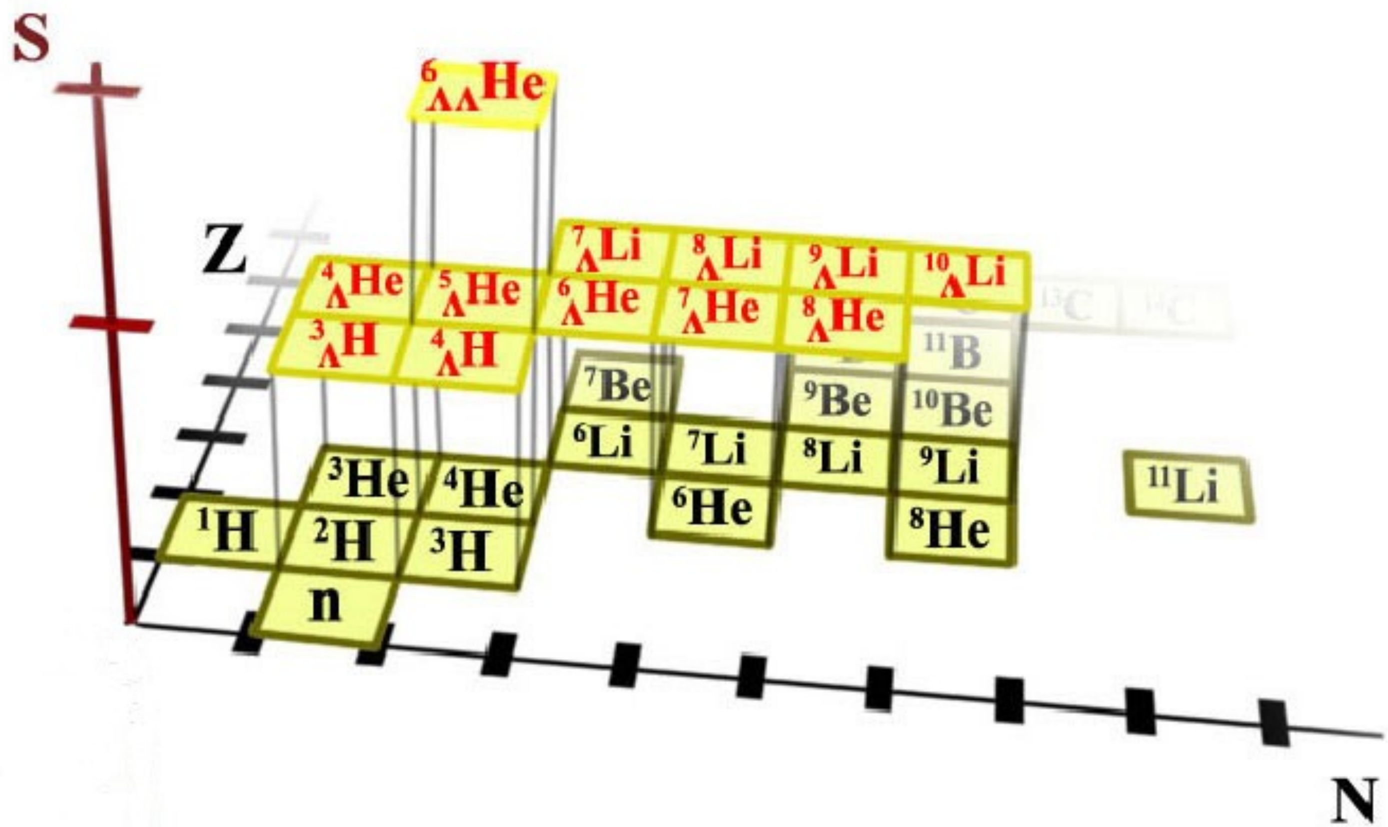
It provides a >6σ significance for discovery.

A beautiful event and the PR



- Anti-hyperT : anti-proton, anti-neutron & anti-Λ – the first antinucleus with strangeness, and the heaviest antinucleus until 2011.
- After searching >100 million AuAu collisions, found 70 anti-hyperT.
- Published in *Science* in March 2010; much favorable PR for STAR & RHIC. News stories in *Nature*, *Scientific American*, *National Geographic*, many news outlets worldwide.

3-D Chart of the Nuclides



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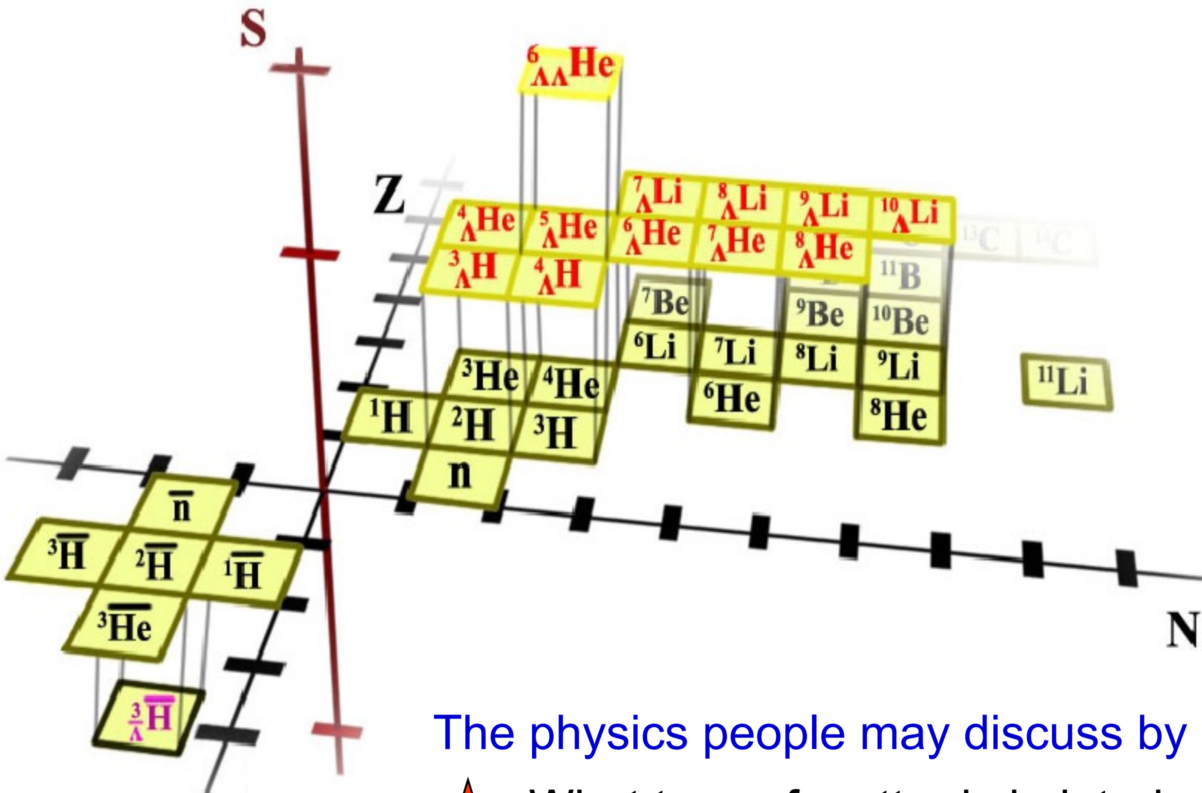
Extension of the Chart of the Nuclides into antimatter with Strangeness sector



Out of **>800** peer-reviewed papers from all Brookhaven programs in 2010, antimatter paper in *Science* was named by lab management in Jan 2011 as one of the **"top 5 for 2010"**

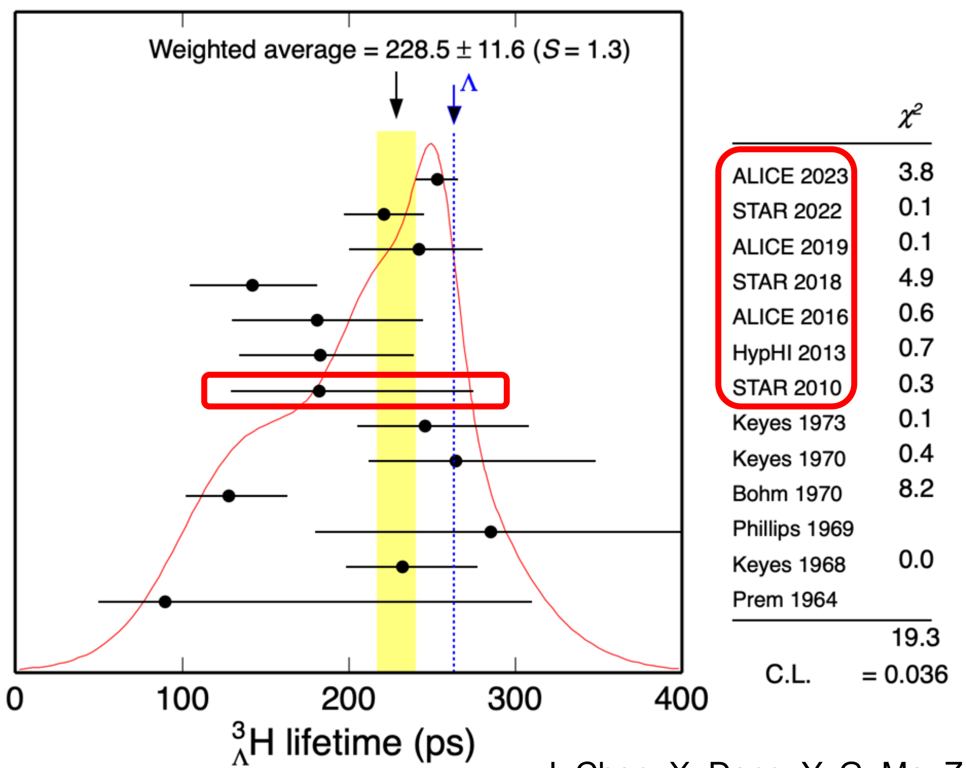
The physics people may discuss by measuring antinuclei:

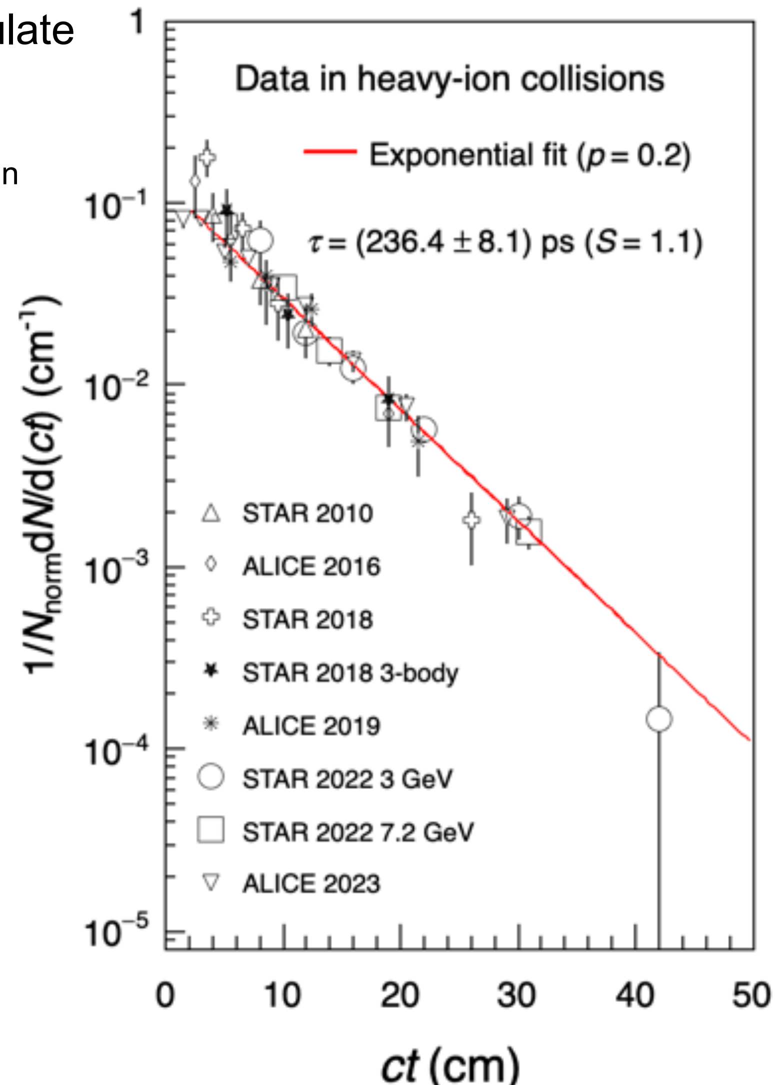
- ★ What type of matter is in interior of collapsed stars?
- ★ What happened to antimatter created in the Big Bang?
- ★ Implications for cosmic ray searches for new physics.

The lifetime quest

- First measurement of the lifetime in HIC and stimulate studies from other experiments.

"a measurement to a precision of a few percent will guide and constrain the theoretical input leading to a more precise determination of the YN interaction, eventually contributing to solving the hyperon puzzle"





J. Chen, X. Dong, Y.-G. Ma, Z. Xu, arXiv:2311.09877

From τ to Λ separation energy

Dalitz's comment on the lifetime "I feel that we are far from seeing the end of this road. A good deal of theoretical work on this 3-body system would still be well justified."

Nucl. Phys. A 754, 14 (2005)

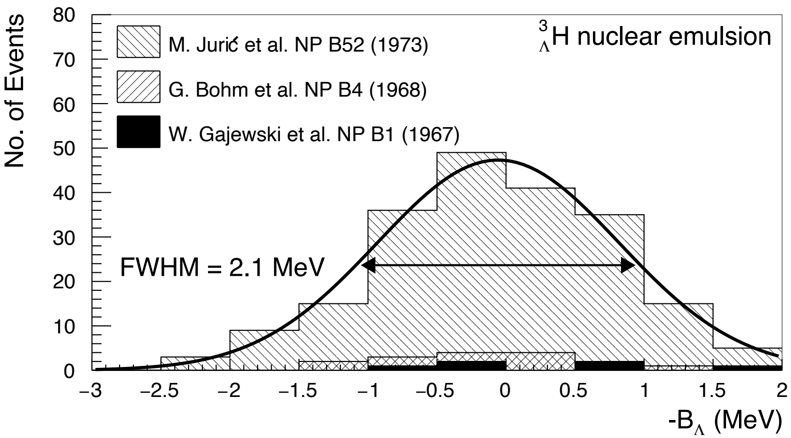
★ The early data suffers from large statistical uncertainty!

Hypernuclide	Decay mode	Number of events	$\bar{B}_\Lambda \pm \Delta\bar{B}_\Lambda$ (MeV) [a]
${}^{3}_{\Lambda}H$	$\pi^-\ {}^3He$ [b]	26	0.13 ± 0.15
	$\pi^-\ {}^1H\ {}^2H$	6	0.33 ± 0.21
	total	32	0.20 ± 0.12

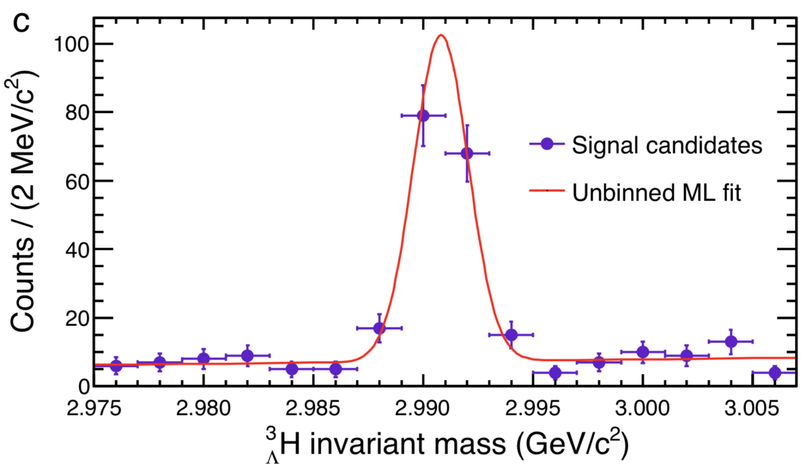
W. Gajewski et al., Nucl. Phys. B 1, 105 (1967)

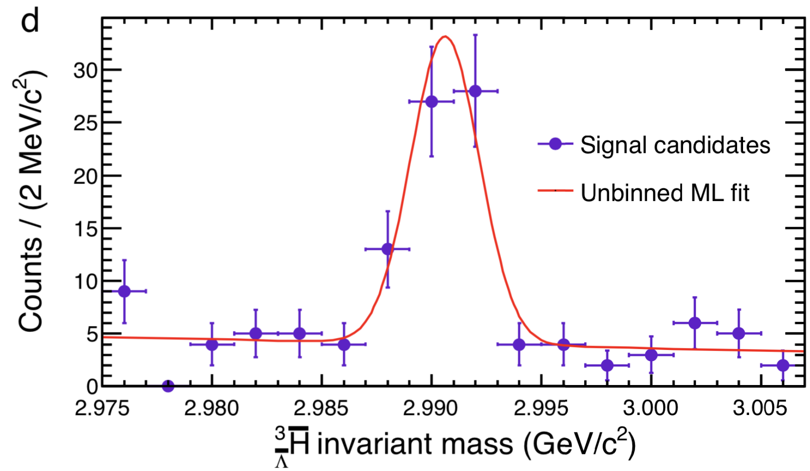
	$B_\Lambda \pm \Delta B_\Lambda$ (MeV)	
	Bohm et al.[a]	This work
${}^{3}_{\Lambda}H$	0.01 ± 0.07	0.15 ± 0.08

a) G. Bohm et al., Nucl. Phys. B4, 511 (1968)
b) This work : M. Juric, G. Bohm et al., Nucl. Phys. B52,1 (1973)

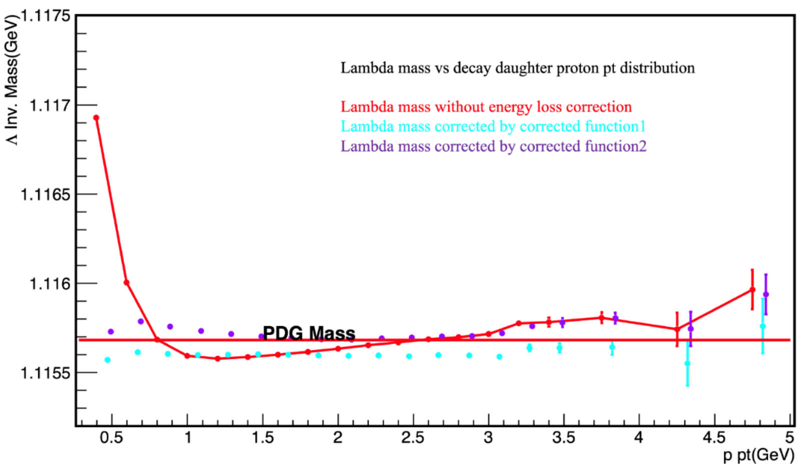


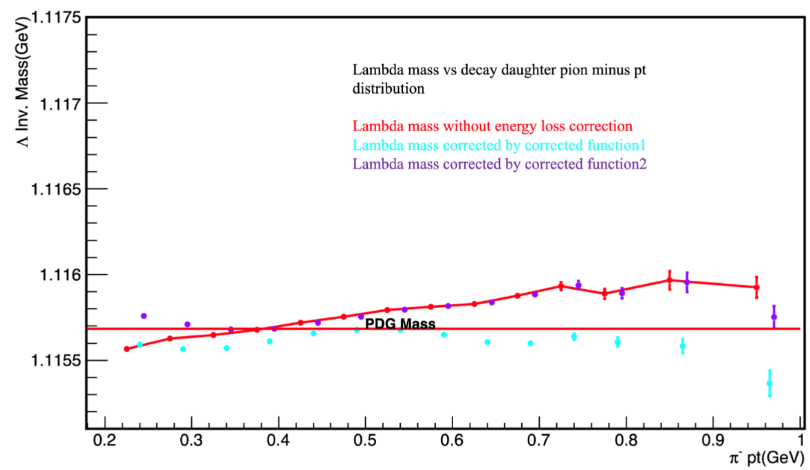
STAR measurements with detector upgrade





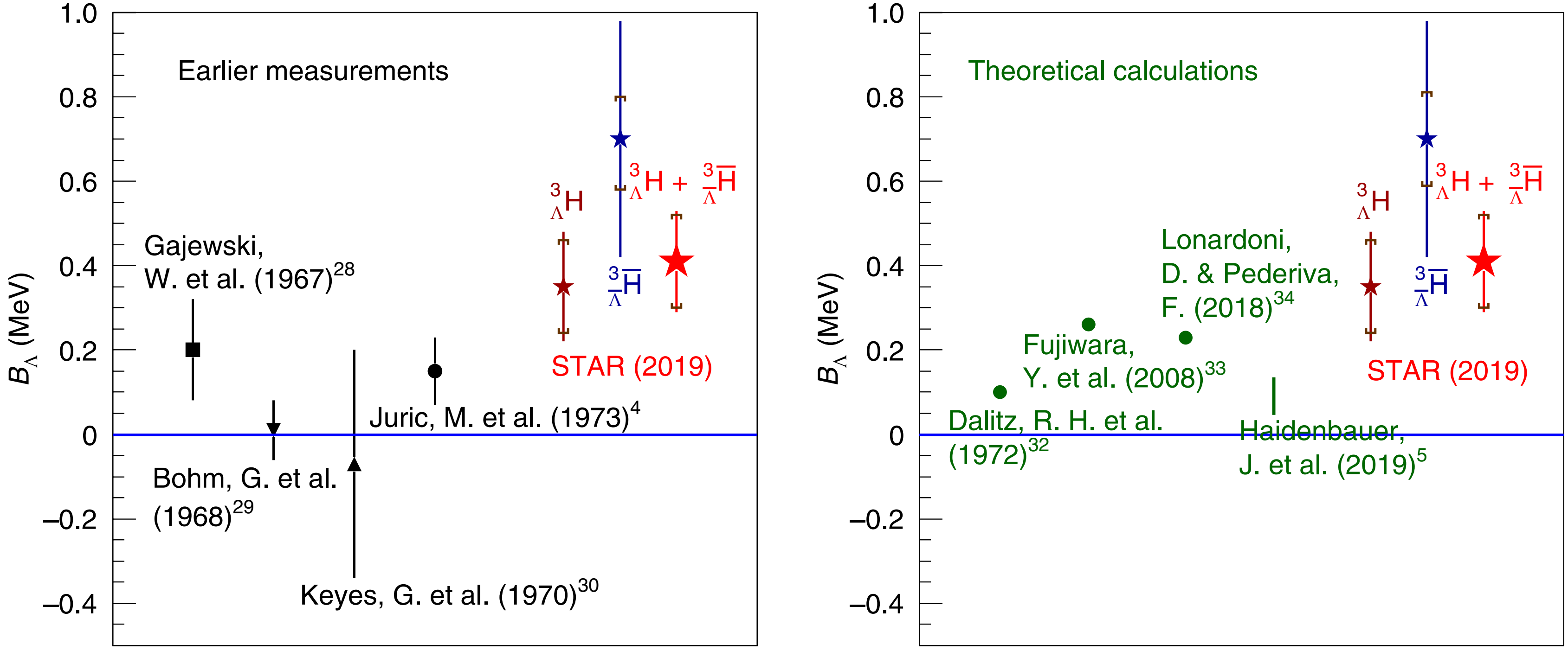
$m_{^3_\Lambda \mathrm{H}} = 2990.95 \pm 0.13(\mathrm{stat.}) \pm 0.11(\mathrm{syst.})\ \mathrm{MeV}/c^2$ $\quad$ $m_{^3_{\bar\Lambda} \overline{\mathrm{H}}} = 2990.60 \pm 0.28(\mathrm{stat.}) \pm 0.11(\mathrm{syst.})\ \mathrm{MeV}/c^2$





Λ serves as a calibrated probe to understand the momentum distortion

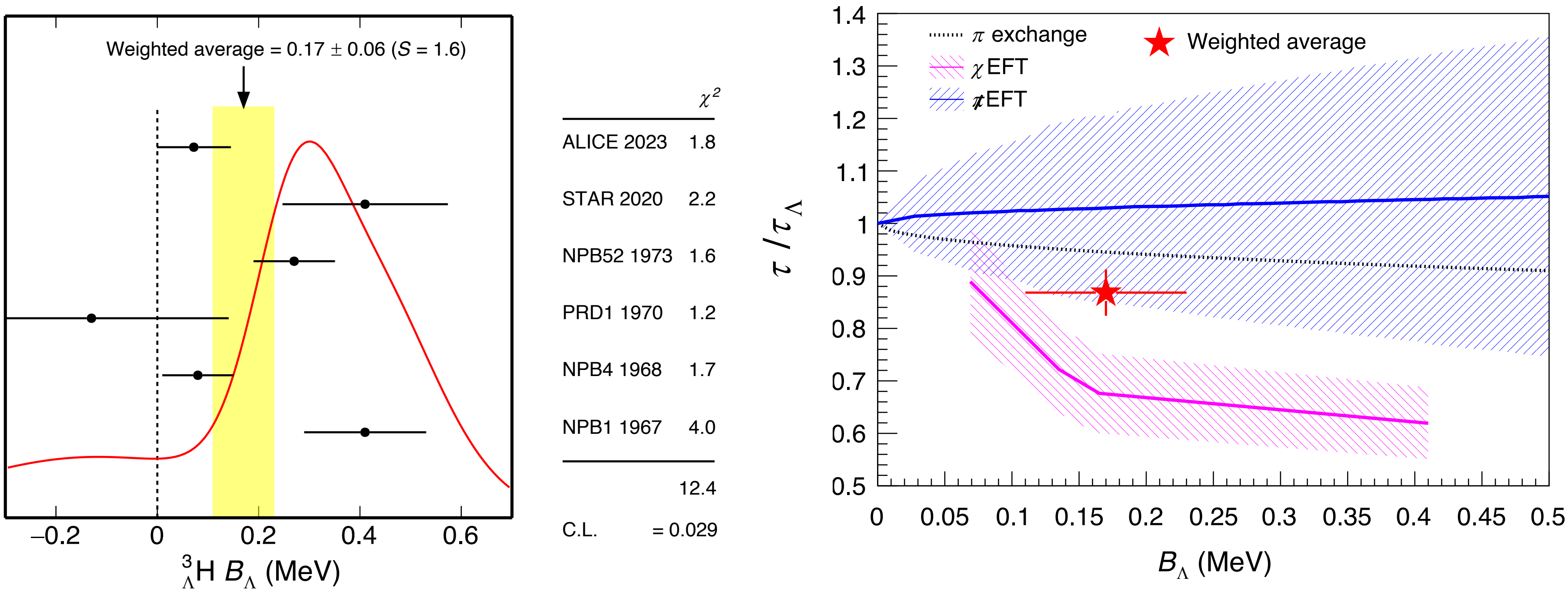
And the results



$$B_{\Lambda} = 0.41 \pm 0.12(\text{stat.}) \pm 0.11(\text{syst.})\ \text{MeV}$$

- STAR data differs from zero (3.4σ) and larger than the prior measurements from 1973
- Theoretical calculations span in a wide range

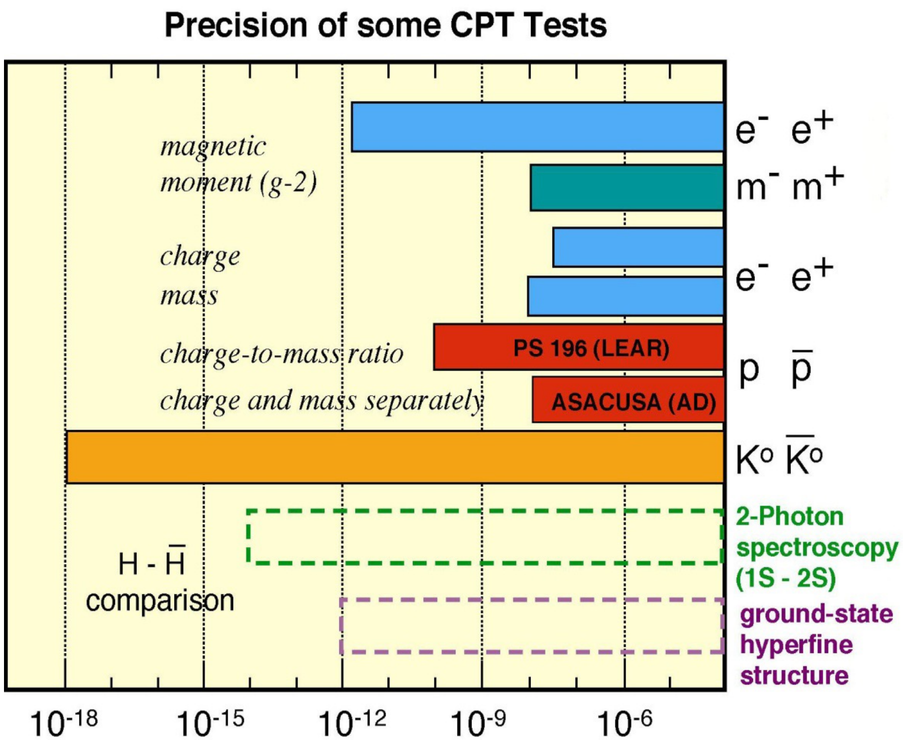
Correlated the τ and the B_Λ

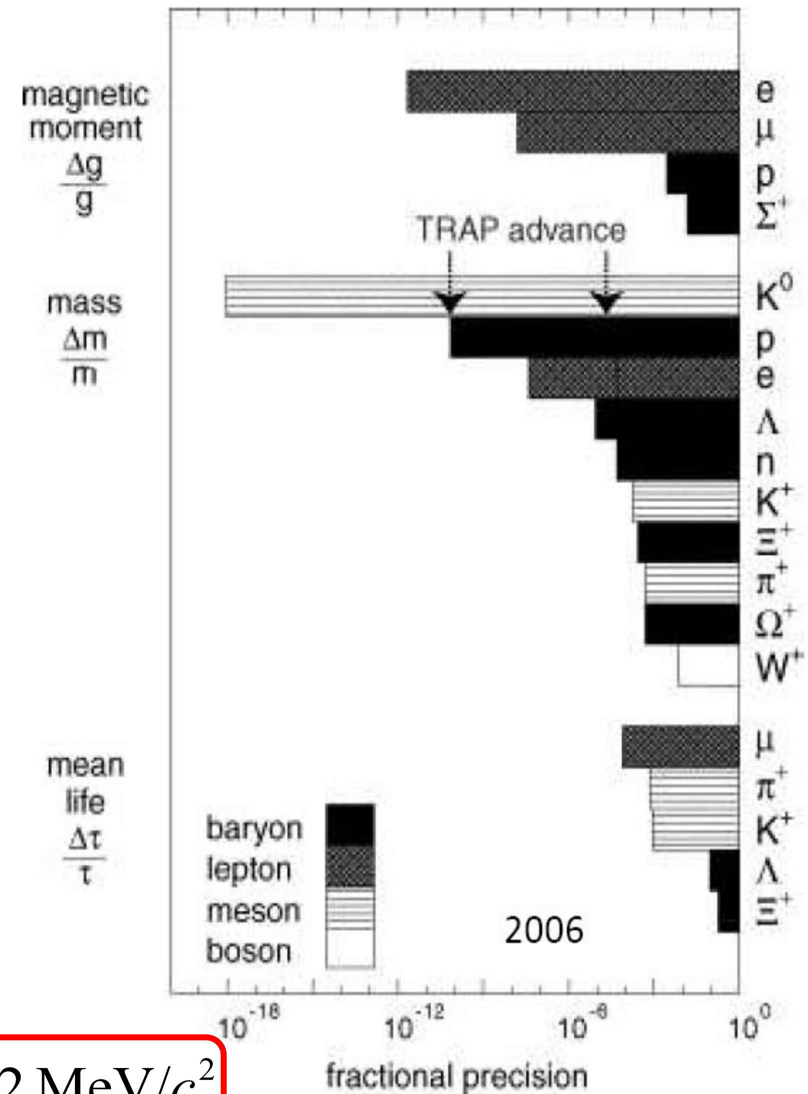


J. Chen, X. Dong, Y.-G. Ma, Z. Xu, arXiv:2311.09877

- The ideogram presentation of the data points shows a large spread of the values
- The weighted average value is consistent with predictions, considering the uncertainties associated in calculations

The CPT test

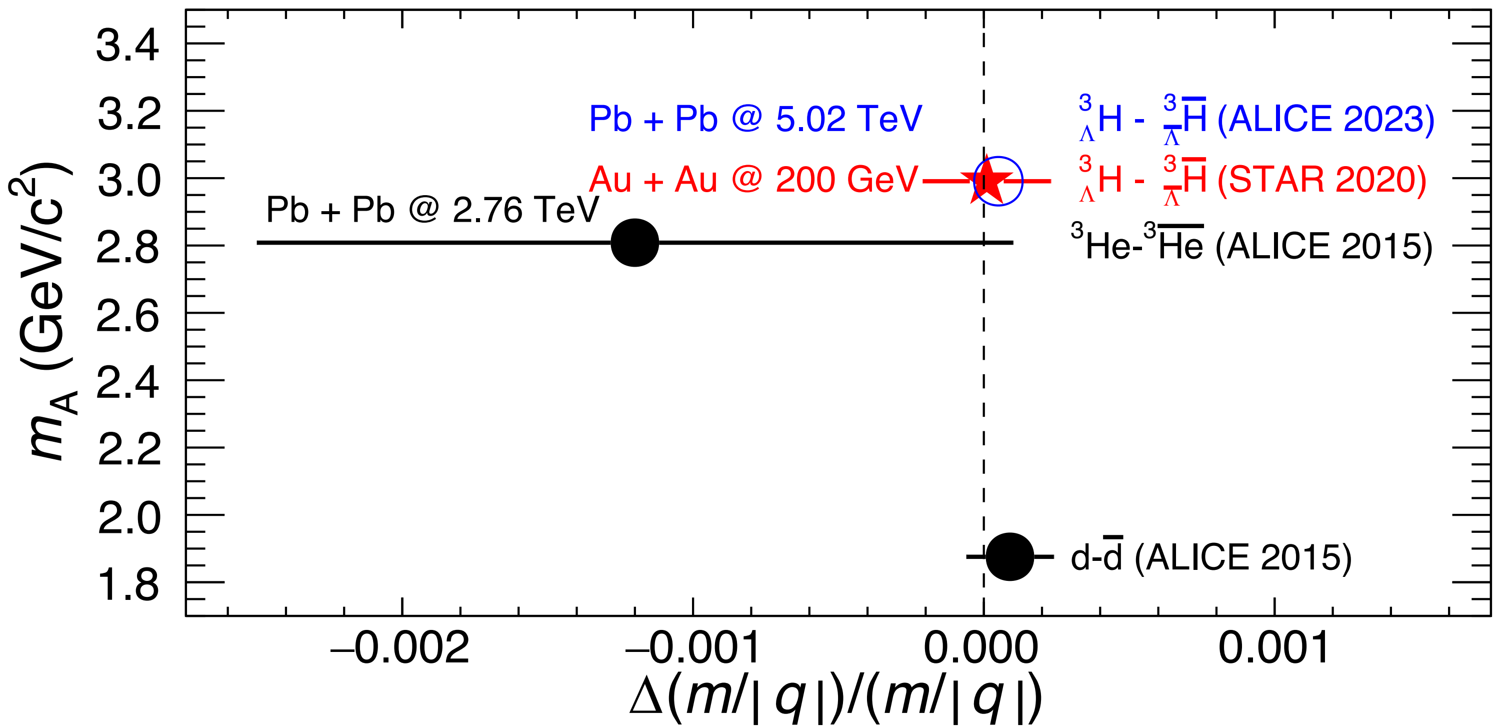




- antinuclei mass difference to probe any diff. in the interaction between nucleons and antinucleons encoded in the antinuclei masses, which can not be directly derived from QCD yet.

Declan in GHP 2011 $^{3}_{\Lambda}\overline{\mathrm{H}} - ^{3}_{\Lambda}\mathrm{H} \quad \Delta m = 0 \pm 1 \pm 2\ \mathrm{MeV}/c^2$

Improved precision on the test



★ From antihypertrion to anti^{3}He, two order of magnitude improved

$$\frac{\Delta\mu_{^3\text{He}^3\overline{\text{He}}}}{\mu_{^3\text{He}}} = (-1.2 \pm 0.9(\text{stat.}) \pm 1.0(\text{syst.})) \times 10^{-3}$$

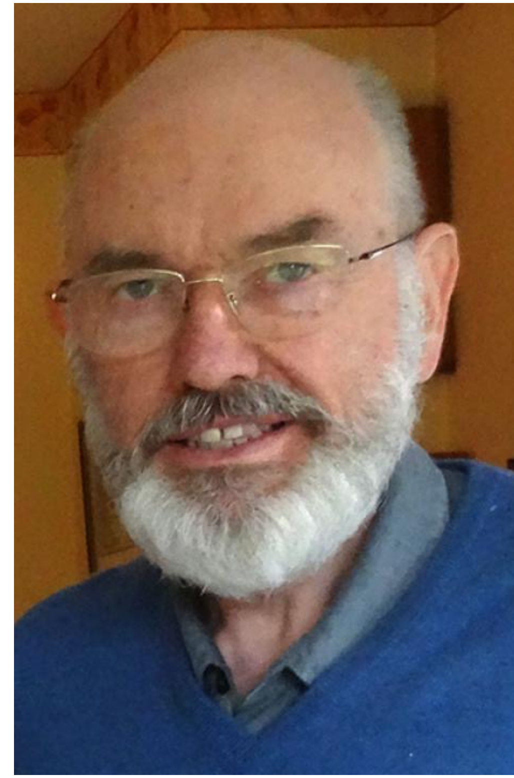
ALICE Col. Nat. Phys. 11 (2015) 811
STAR Col. Nat. Phys. 16 (2020) 409
ALICE Col. PRL 131 (2023) 102302

$$\frac{m_{^3_\Lambda\text{H}} - m_{^3_{\bar\Lambda}\overline{\text{H}}}}{m} = (\ 0.1 \pm 2.0(\text{stat.}) \pm 1.0(\text{syst.})) \times 10^{-4} \qquad \frac{m_{^3_\Lambda\text{H}} - m_{^3_{\bar\Lambda}\bar{\text{H}}}}{m_{^3_\Lambda\text{H}}} = [5 \pm 5(\text{stat}) \pm 3(\text{syst})] \times 10^{-5},$$

Summary

photo from web page of ~2009

Our captain of the antinuclei journey



- We have observed the 1st antihypernucleus, we have seen many interesting physics
- How does his mentorship shape my career?
  - the 2009 project guaranteed a professor position
  - the 2020 measurement won the competition of NSFC for Distinguished Young Scholars
- Wish you good health and looking forward to another 15-year journey