中国物理学会高能物理分会

“晨光杯”论文答辩

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

Observation of the antimatter hypernucleus $^{4}_{\bar{\Lambda}}\overline{\mathrm{H}}$

Based on: *Nature volume 632, pages1026–1031 (2024)*

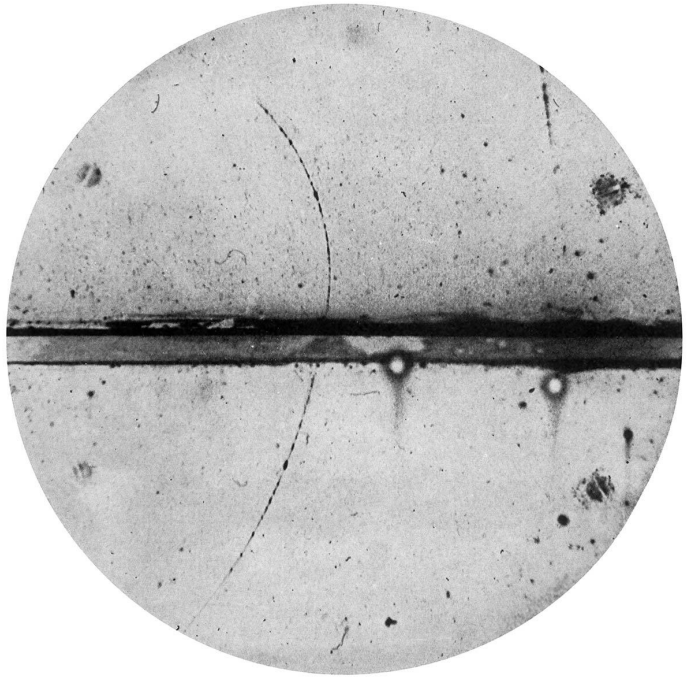
吴俊霖

中国科学院大学/核科学与技术学院

答辩时间：2026年7月15日

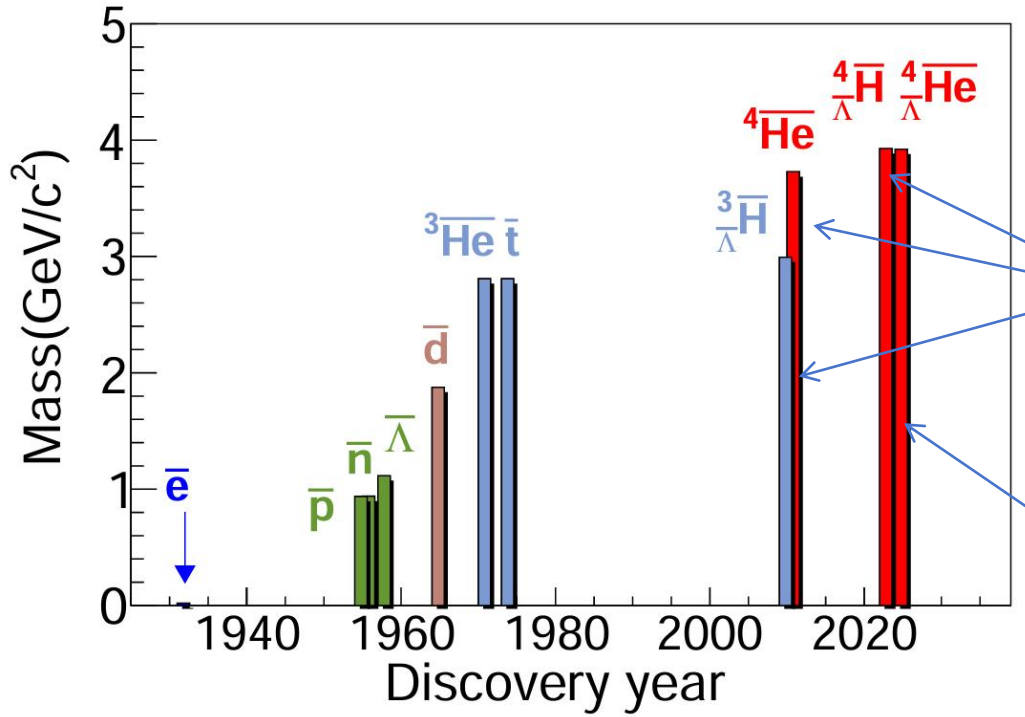
Introduction

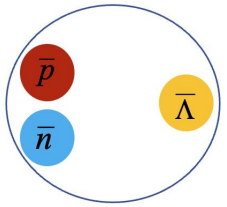
- P.A.M. Dirac, The Quantum Theory of the Electron. Proc. Roy. Soc. Lond. A 117, 610 (1928); 狄拉克方程。
- C. D. Anderson 在1932年使用云室在宇宙线中发现了反电子；

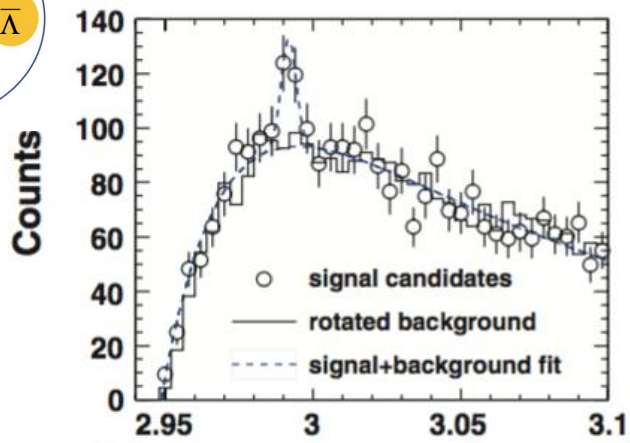


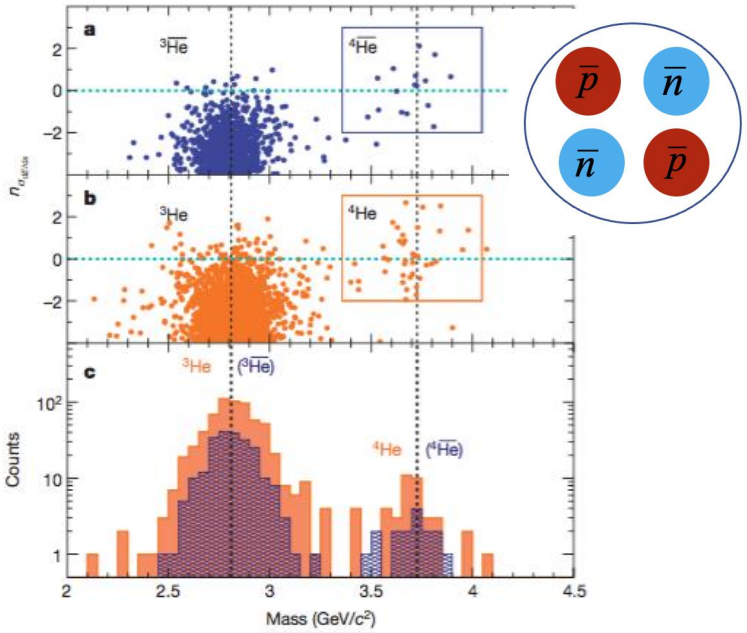
Anderson 拍摄的带有反电子径迹的云室照片。

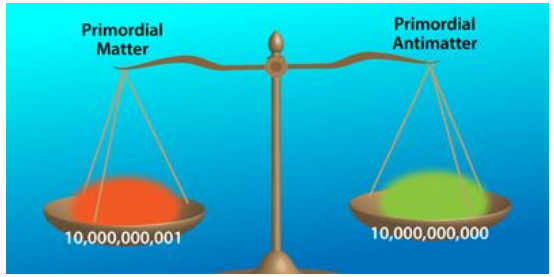
Introduction





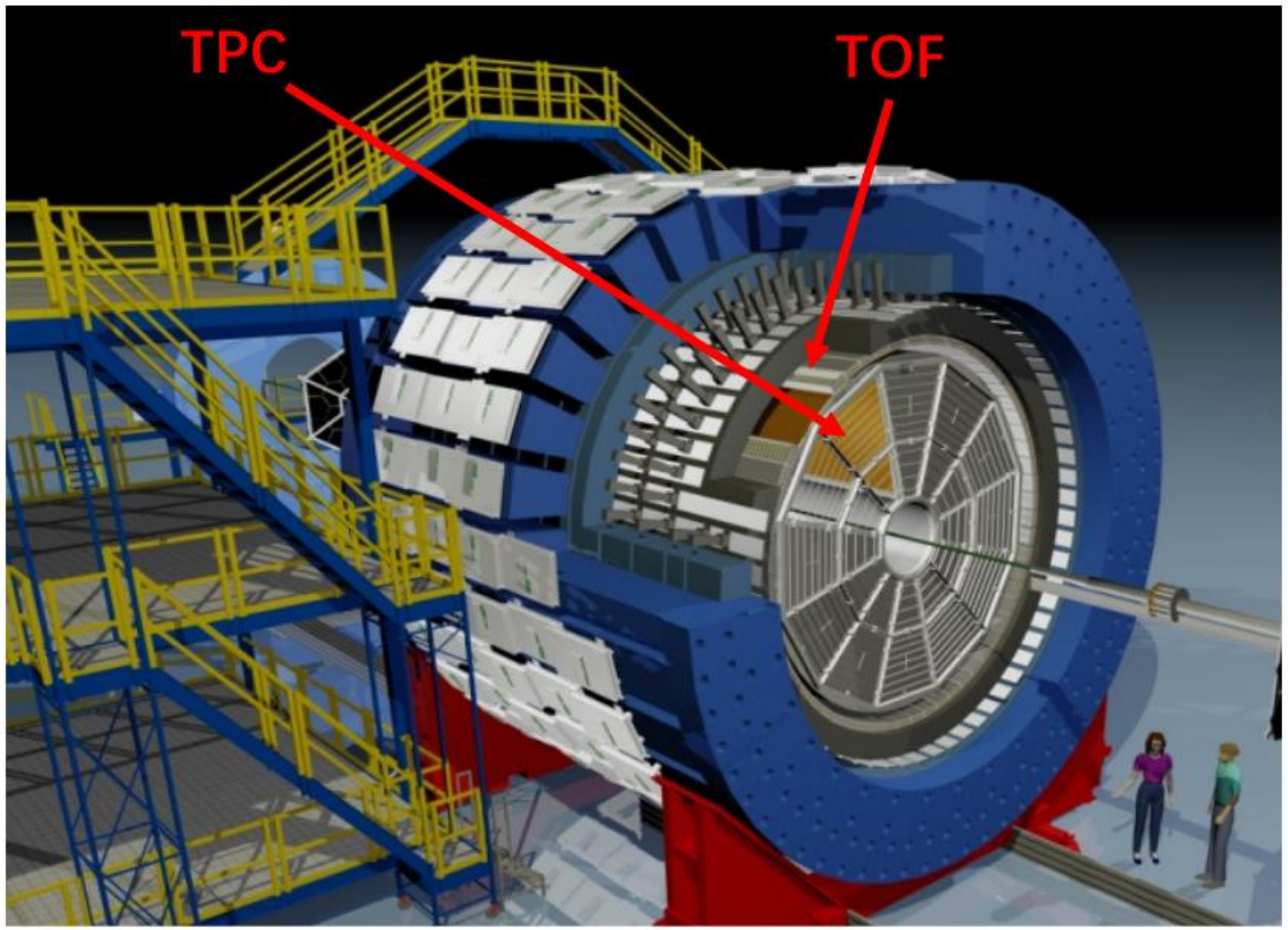






- 在宇宙大爆炸开始时：BSU (Baryon-Symmetric Universe) or BAU (Baryon-Asymmetric Universe)?
- 正物质主导的宇宙如何形成？
- 需要发现新的反物质核并研究其性质。

STAR Detector and Data Sets



Time Projection Chamber (时间投影室，TPC)

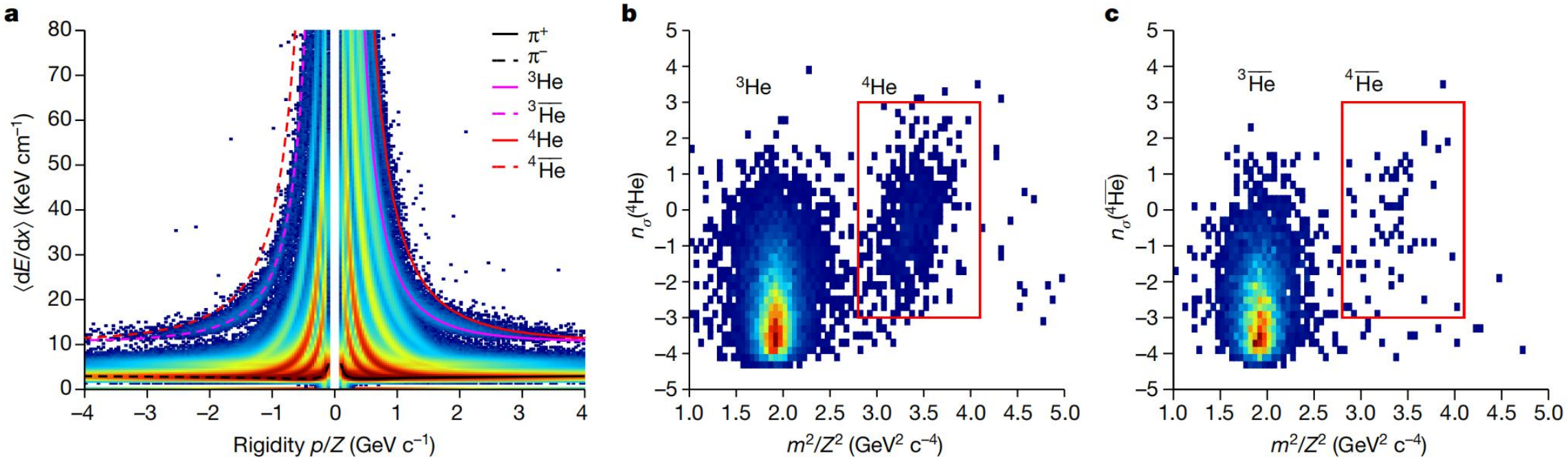
- 带电粒子径迹、动量重建；
- 由能量损失作粒子鉴别 (dE/dx vs. p/Q)

Time of Flight (飞行时间探测器，TOF)

- 由 M^2/Q^2 作粒子鉴别

data set	year	N events
AuAu@200 GeV	2010	~606 M
AuAu@200 GeV	2011	~626 M
UU@193GeV	2012	~512 M
ZrZr+RuRu(Isobar) @200GeV	2018	~4.7 B

Particle Identification and Reconstruction

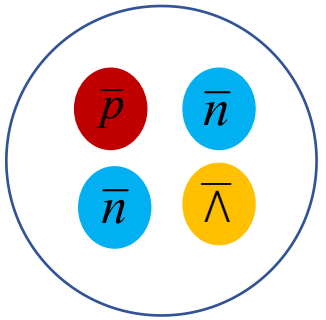


$$ {}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-} $$

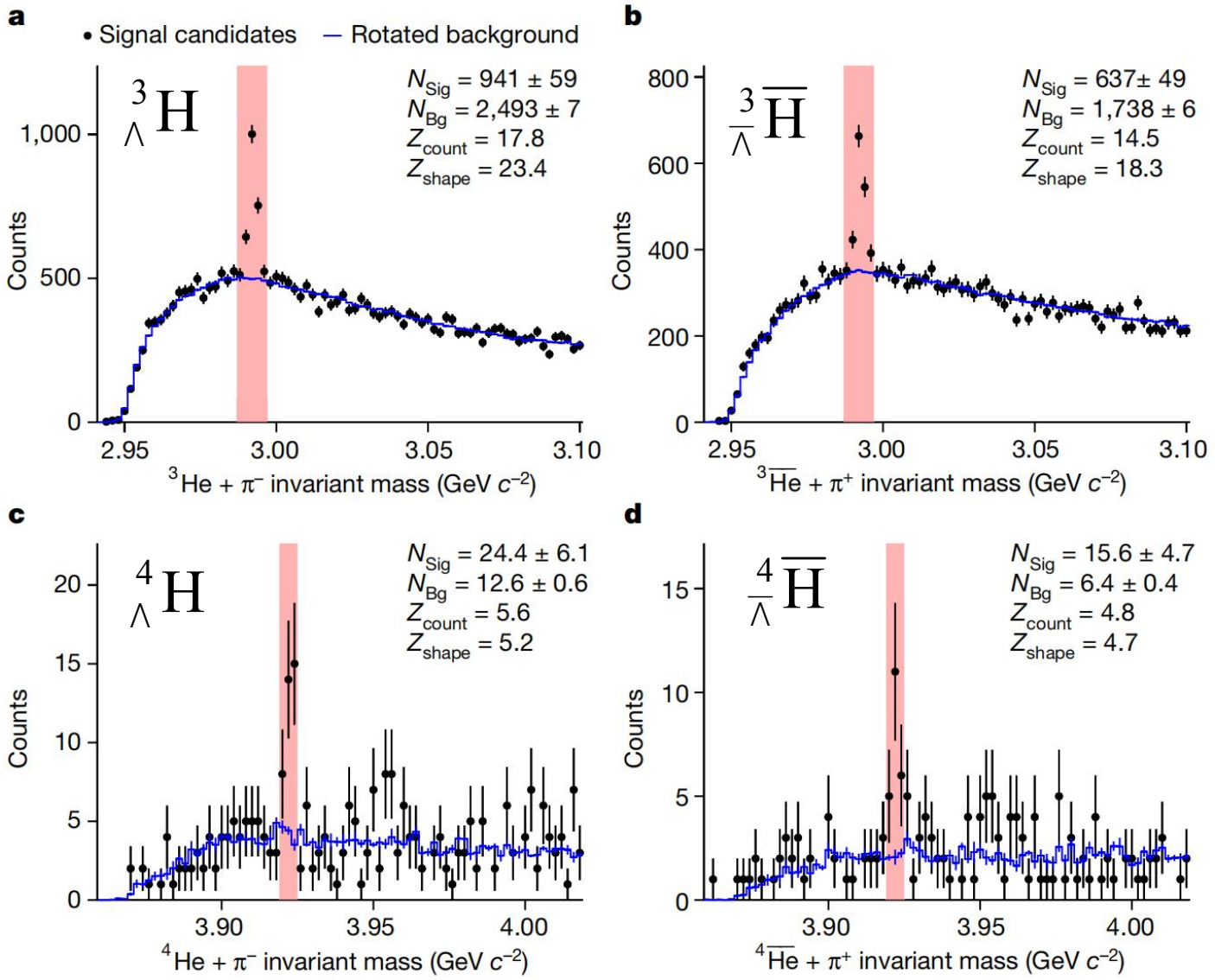
$$ {}^{3}_{\overline{\Lambda}}\overline{\mathrm{H}} \rightarrow {}^{3}\overline{\mathrm{He}} + \pi^{+} $$

$$ {}^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^{-} $$

$$ {}^{4}_{\overline{\Lambda}}\overline{\mathrm{H}} \rightarrow {}^{4}\overline{\mathrm{He}} + \pi^{+} $$



Particle Identification and Reconstruction

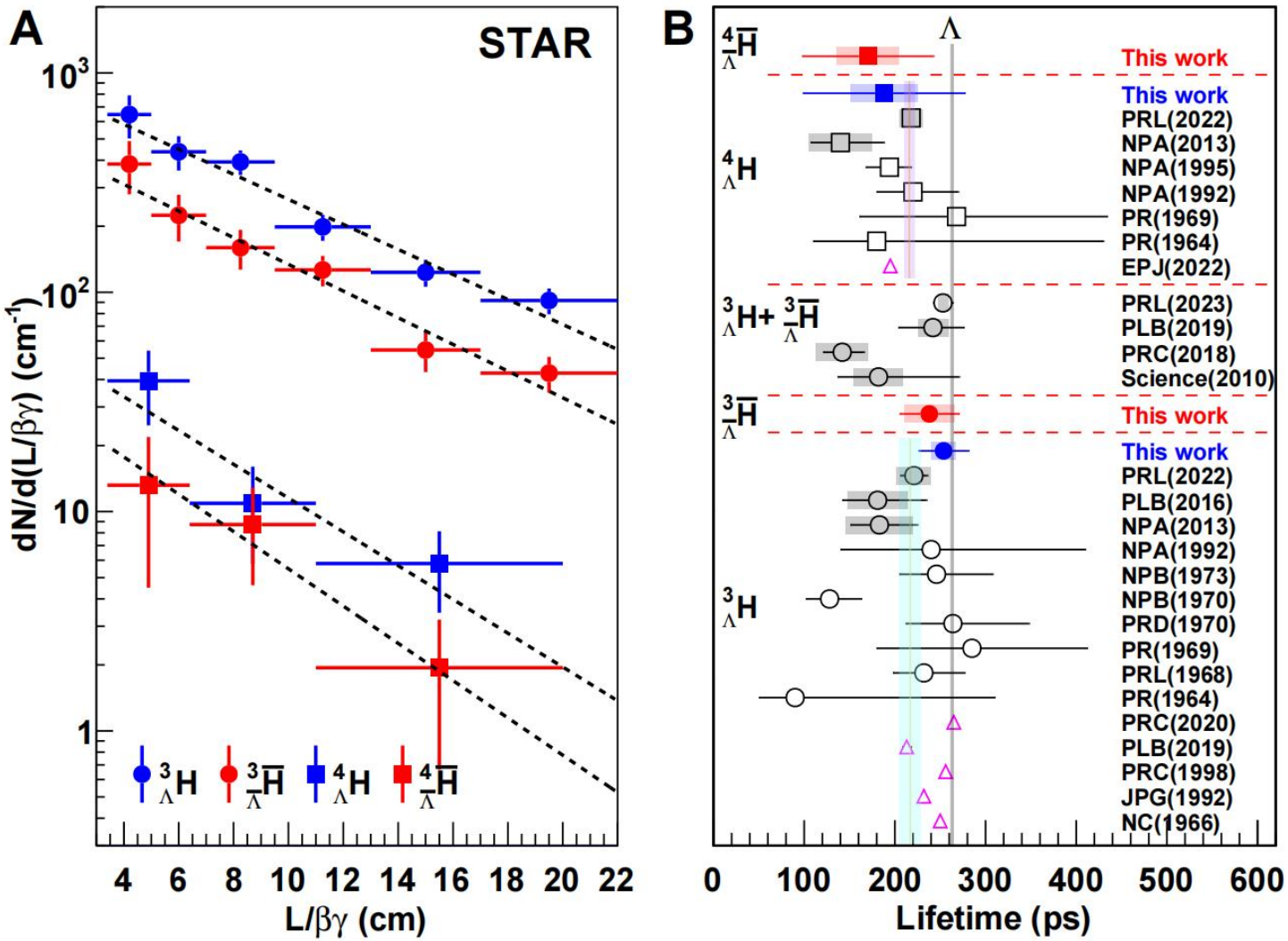


- Kalman Filter 算法；
- 旋转背景
- 显著度 Z_{shape}，Z_{count}计算基于假设检验渐进公式

$$Z_{count} = \sqrt{2\left[(N_{Sig}+N_{Bg})\ln\left(1+\frac{N_{Sig}}{N_{Bg}}\right)-N_{Sig}\right]}$$

- 得到15.6 个 $^{4}_{\overline{\Lambda}}\overline{\mathrm{H}}$ 候选者信号，其显著度Z_{count}为4.7，足以标志着新粒子的发现。
- **这是迄今为止，在实验室中发现的最重的反物质超核。**

Result: Lifetime and CPT Test

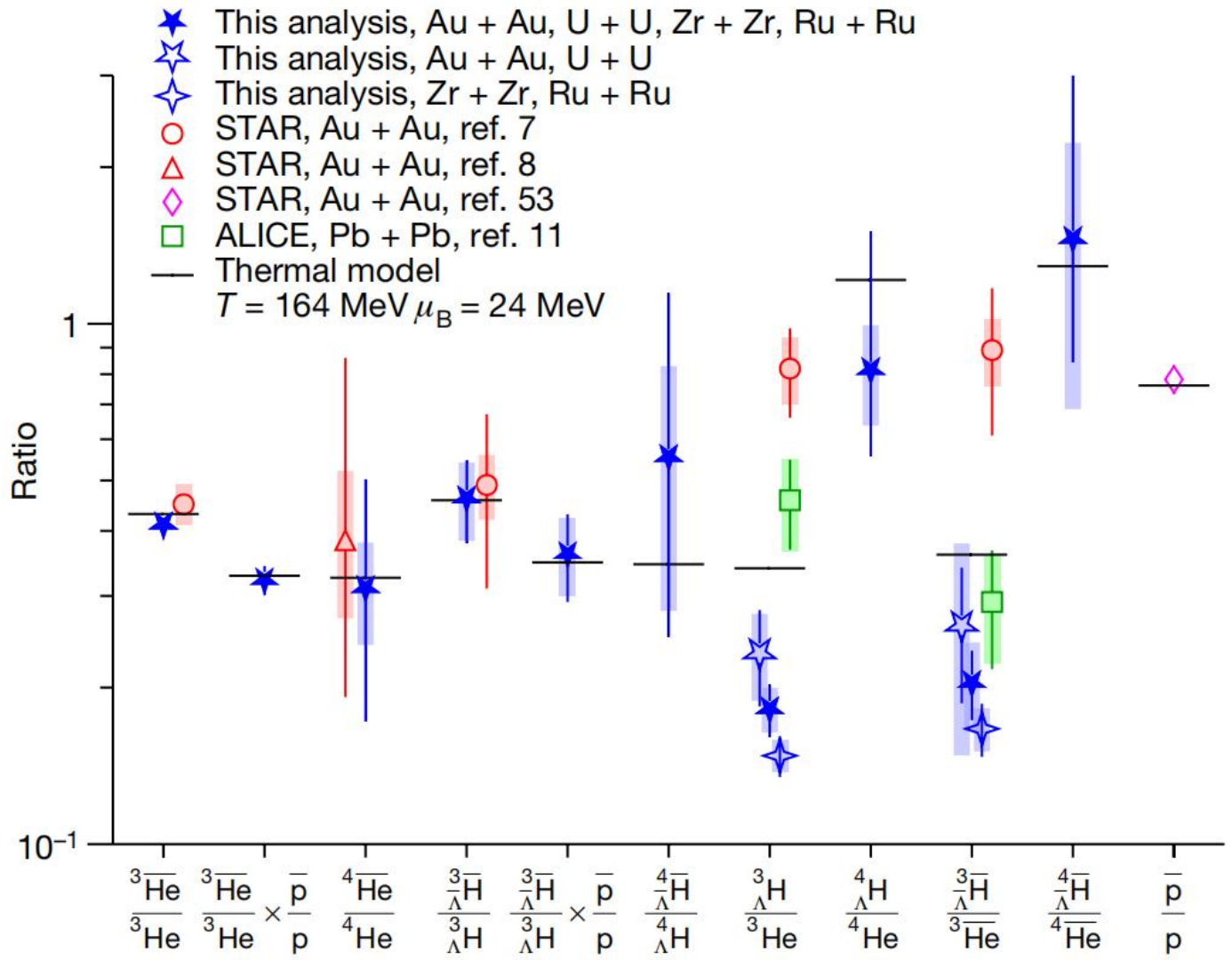


$$\tau_{{}^{3}_{\Lambda}\mathrm{H}} - \tau_{{}^{3}_{\Lambda}\overline{\mathrm{H}}} = 16 \pm 43(\mathrm{stat.}) \pm 20(\mathrm{sys.})\ \mathrm{ps}$$

$$\tau_{{}^{4}_{\Lambda}\mathrm{H}} - \tau_{{}^{4}_{\Lambda}\overline{\mathrm{H}}} = 18 \pm 115(\mathrm{stat.}) \pm 46(\mathrm{sys.})\ \mathrm{ps}$$

验证CPT对称性：超核与其对应的反物质超核寿命没有显著差异。

Result: Yield Ratio



- 粒子产额比值与 Thermal Model 计算一致。

- 符合聚合模型的物理图像

$$^{4}\overline{\mathrm{He}}/^{4}\mathrm{He} \sim {}^{3}\overline{\mathrm{He}}/^{3}\mathrm{He} \times \bar{\mathrm{p}}/\mathrm{p}$$

$$^{4}_{\bar{\Lambda}}\overline{\mathrm{H}}/^{4}_{\Lambda}\mathrm{H} \sim {}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}/^{3}_{\Lambda}\mathrm{H} \times \bar{\mathrm{p}}/\mathrm{p}$$

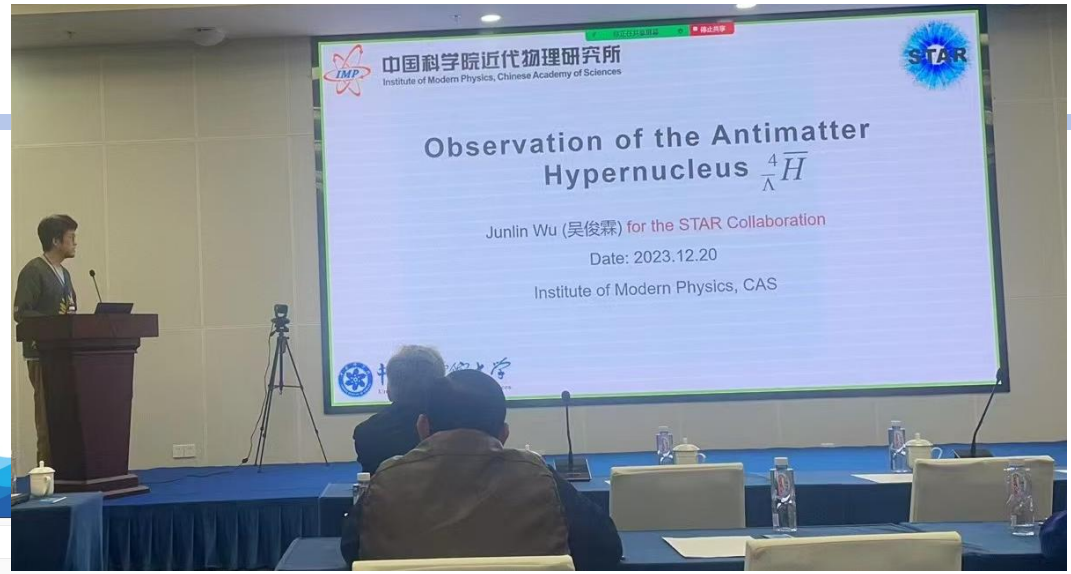
$$E_A\frac{d^3N_A}{d^3p_A} = B_A\left(E_p\frac{d^3N_p}{d^3p_p}\right)^Z\left(E_n\frac{d^3N_n}{d^3p_n}\right)^{A-Z} \approx B_A\left(E_p\frac{d^3N_p}{d^3p_p}\right)^A$$

- A=4超核可能存在J=1的激发态

$$^{4}_{\Lambda}\mathrm{H}/^{4}\mathrm{He} \sim 4 \times {}^{3}_{\Lambda}\mathrm{H}/^{3}\mathrm{He}$$

$$^{4}_{\bar{\Lambda}}\overline{\mathrm{H}}/^{4}\overline{\mathrm{He}} \sim 4 \times {}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}/^{3}\overline{\mathrm{He}}$$

PA Representative for STAR



RICE

Prof. Frank Geurts, Ph.D.
T.W. Bonner Nuclear Laboratory
Department of Physics & Astronomy

May 3, 2024

To Whom It May Concern:

This letter is to certify that Junlin Wu is one of the Principal Authors of the following pa
that is about to be accepted by the journal.

- "Observation of the Antimatter Hypernucleus $^4_\Lambda\overline{H}$," STAR Collaboration, submitt
  Nature, arXiv:2310.12674

Principle Authors, in a specific paper published by the STAR Collaboration, are those
collaborators who have made significant and immediately relevant contributions to the
idea, analyses, and paper process directly leading to the publication.

Do not hesitate to contact me if there is any question.

Sincerely,

Frank Geurts

Professor of Phys
Rice University, H
STAR Collaborati

SQM2022
The 20th International Conference on Strangeness in Quark Matter
13-17 June 2022 Busan, Republic of Korea

2022年6月13日至17日
Paradise Hotel Busan
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First observation of $^4_\Lambda\overline{H}$ in heavy-ion collisions at RHIC

2022年6月15日 11:50
20m
GBR2

Talk | Resonances and Hy... | PA-Resonances

报告人

Junlin Wu

说明

Matter-antimatter asymmetry is a precondition necessary to explain the existence of our world made predominately matter over antimatter. Antimatter is rare in the current universe making it difficult to study, but the Relativistic Heav Collider (RHIC) provides us a unique opportunity to study antimatter with high-energy nuclear-nuclear collisions.

In this talk, we will report the first observation of $^4_\Lambda\overline{H}$ with the STAR experiment at RHIC. $^4_\Lambda\overline{H}$ is the heaviest anti-hyp ever observed in experiments. Its observation will bring new opportunities for the study of matter-antimatter asymn will also report the various production yield ratios among (anti-)hypernuclei and (anti-)nuclei, as well as the lifetime measurements of $^3_\Lambda H$, $^3_\Lambda\overline{H}$, $^4_\Lambda H$, and $^4_\Lambda\overline{H}$.

arXiv

Nuclear Experiment

[Submitted on 19 Oct 2023 (v1), last revised 8 Jun 2024 (this version, v3)]

Observation of the Antimatter Hypernucleus $^4_\Lambda\overline{H}$

STAR Collaboration: M. I. Abdulhamid, B. E. Aboona, J. Adam, L. Adamczyk, Bielcikova, J. D. Brandenburg, C. Broodo, X. Z. Cai, H. Caines, M. Calderón d Crawford, M. Csanád, G. Dale-Gau, A. Das, I. M. Deppner, A. Dhamija, P. Dix Gagliardi, T. Galatyuk, T. Gao, F. Geurts, N. Ghimire, A. Gibson, K. Gopal, X. Huang, S. L. Huang, T. Huang, X. Huang, Y. Huang, Y. Huang, T. J. Humanic

At the origin of the Universe, asymmetry between the amount of created matter and anti with comparable amounts of matter and antimatter. Much of the created antimatter escap asymmetry between matter and antimatter. Here we report the first observation of the an Relativistic Heavy Ion Collider. In total, 15.6 candidate \hbox($^4_\Lambda\overline{H}$) antimatter hypernuclei are obtained with an estimated backg matter and antimatter. Various production yield ratios among (anti)hypernuclei and (anti)nuclei are also measured and compare

Comments: 28 pages, 5 figures in the main paper; 16 pages, 5 figures in the methods part
Subjects: **Nuclear Experiment (nucl-ex)**; High Energy Physics - Experiment (hep-ex)
Cite as: arXiv:2310.12674 **[nucl-ex]**
(or arXiv:2310.12674v3 **[nucl-ex]** for this version)
https://doi.org/10.48550/arXiv.2310.12674
Related DOI: https://doi.org/10.1038/s41586-024-07823-0

Submission history
From: Junlin Wu [view email]
[v1] Thu, 19 Oct 2023 12:06:47 UTC (839 KB)
[v2] Tue, 2 Apr 2024 10:58:50 UTC (761 KB)
[v3] Sat, 8 Jun 2024 11:36:25 UTC (776 KB)

Article

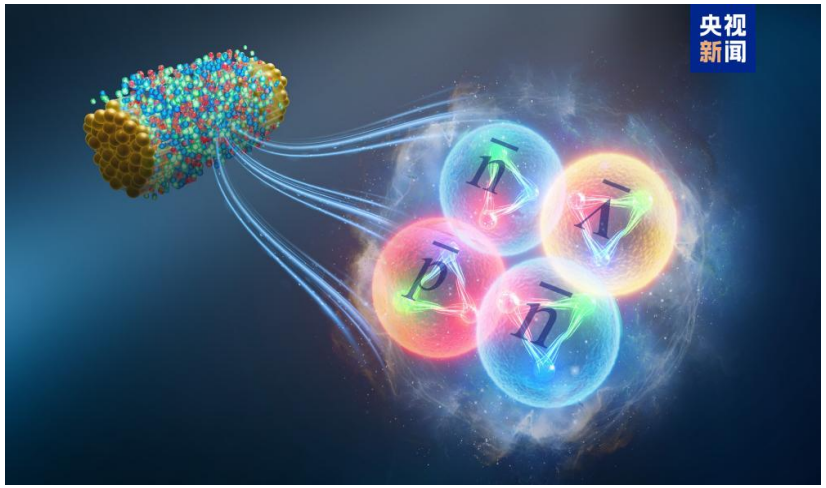
Observation of the antimatter hypernucleus $^4_\Lambda\overline{H}$

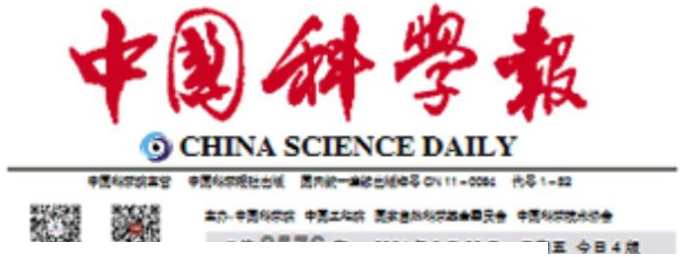
https://doi.org/10.1038/s41586-024-07823-0
Received: 20 October 2023
Accepted: 12 July 2024
Published online: 21 August 2024
Check for updates

STAR Collaboration*

At the origin of the Universe, an asymmetry between the amount of created matter and antimatter led to the matter-dominated Universe as we know it today. The origins of this asymmetry remain unknown so far. High-energy nuclear collisions create conditions similar to the Universe microseconds after the Big Bang, with comparable amounts of matter and antimatter[1–6]. Much of the created antimatter escapes the rapidly expanding fireball without annihilating, making such collisions an effective experimental tool to create heavy antimatter nuclear objects and to study their properties[7–14], hoping to shed some light on the existing questions on the asymmetry between matter and antimatter. Here we report the observation of the antimatter hypernucleus $^4_\Lambda\overline{H}$, composed of a $\overline{\Lambda}$, an antiproton and two antineutrons. The discovery was made through its two-body decay after production in ultrarelativistic heavy-ion collisions by the STAR experiment at the Relativistic Heavy Ion Collider[15,16]. In total, 15.6 candidate $^4_\Lambda\overline{H}$ antimatter hypernuclei are obtained with an estimated background count of 6.4. The lifetimes of the antihypernuclei $^3_\Lambda\overline{H}$ and $^4_\Lambda\overline{H}$ are measured and compared with the lifetimes of their corresponding hypernuclei, testing the symmetry between matter and antimatter. Various production yield ratios among (anti)hypernuclei (hypernuclei and/or antihypernuclei) and (anti)nuclei (nuclei and/or antinuclei) are also measured and compared with theoretical model predictions, shedding light on their production mechanisms.

Viewpoint





学校代码：10730　　密级：公开
分类号：O57

兰州大学

博 士 学 位 论 文

（ 学 术 学 位 ）

论文题目（中文）	相对论重离子碰撞中反物质超核反超氢-4 的发现与研究
论文题目（外文）	Discovery and Study on the Antimatter Hypernucleus $^{4}_{\Lambda}\overline{\mathrm{H}}$ in Relativistic Heavy-Ion Collisions
作 者 姓 名	吴俊霖
学 科 专 业	物理学・粒子物理与原子核物理
研 究 方 向	相对论性重离子碰撞
教 育 类 型	学历教育
指 导 教 师	许怒　研究员　　仇浩　研究员
合 作 导 师	龙文辉　教授
论文工作时间段	2020 年 5 月　至　2024 年 5 月
答 辩 日 期	2024 年 8 月 27 日

校址：甘肃省兰州市城关区天水南路 222 号

A New Milestone for Antimatter Hypernuclei in Relativistic Heavy-Ion Collisions

Jinhui Chen, Yu-Gang Ma, Hao Qiu, Junlin Wu & Zhangbu Xu

To cite this article: Jinhui Chen, Yu-Gang Ma, Hao Qiu, Junlin Wu & Zhangbu Xu (11 Mar 202
A New Milestone for Antimatter Hypernuclei in Relativistic Heavy-Ion Collisions, Nuclear Physics News, DOI: 10.1080/10619127.2025.2454220

To link to this article: https://doi.org/10.1080/10619127.2025.2454220

- 引起央视新闻、中国科学院新闻网、中国科学报（头版头条）等新闻媒体广泛报道。
- 申请人的博士学位论文
- 评论文章：“新的里程碑”

Summary

- 在RHIC-STAR探测器上，我们发现了迄今为止最重的反物质超核 ${}^{4}_{\bar{\Lambda}}\overline{\mathrm{H}}$；
- 测量超核以及对应反超核寿命，验证CPT对称性；
- 测量了一系列轻核、超核、及其反物质核的产额比值。

感谢各位老师和评委批评指正！