The Detection of Anti-matter in STAR

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Contents

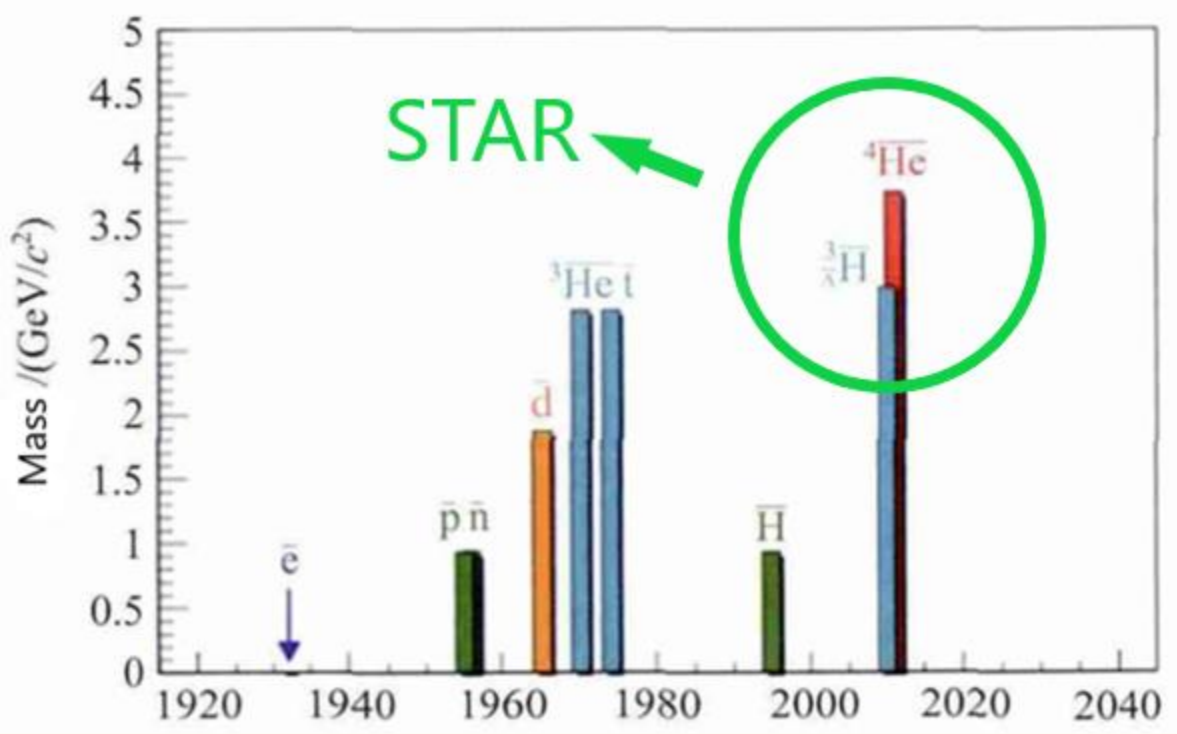
Introduction

- Big bang theory
  anti-matter=matter ?

- CPT theorem

- Positron anti-proton anti-neutron anti-deuteron anti-helium3 anti-tritium anti-hydrogen

- **Anti-hypertriton**(the first discovered antimatter hypernucleus)
  anti-proton anti-neutron anti-lambda hyperon
- **Anti-helium4**(the heaviest anti-nuclei observed so far)
  2 anti-proton 2 anti-neutron

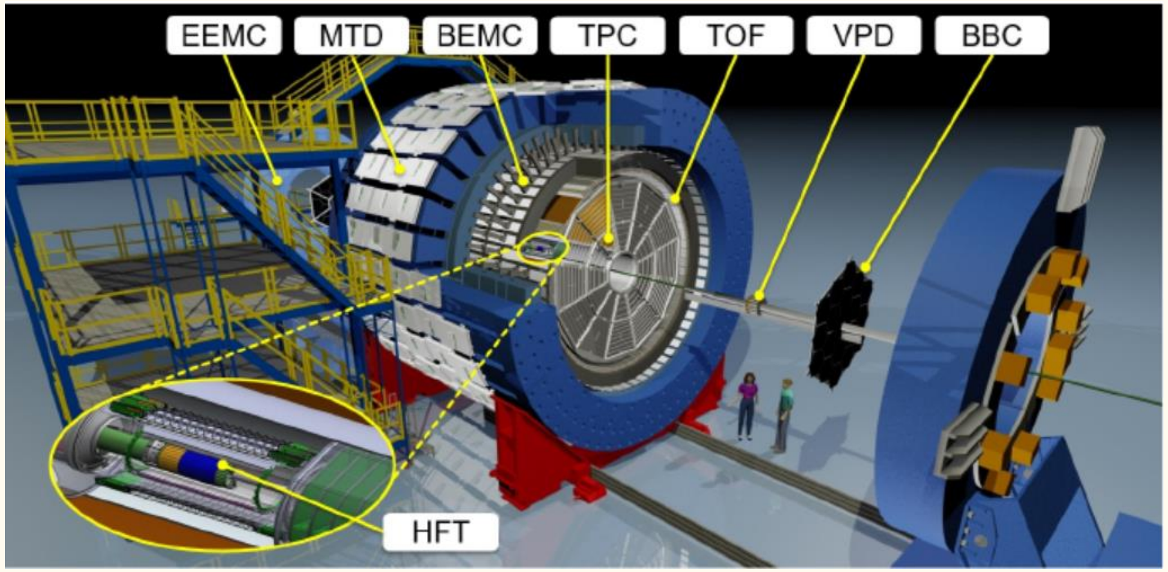


The discovery of different anti-matter in history [1]

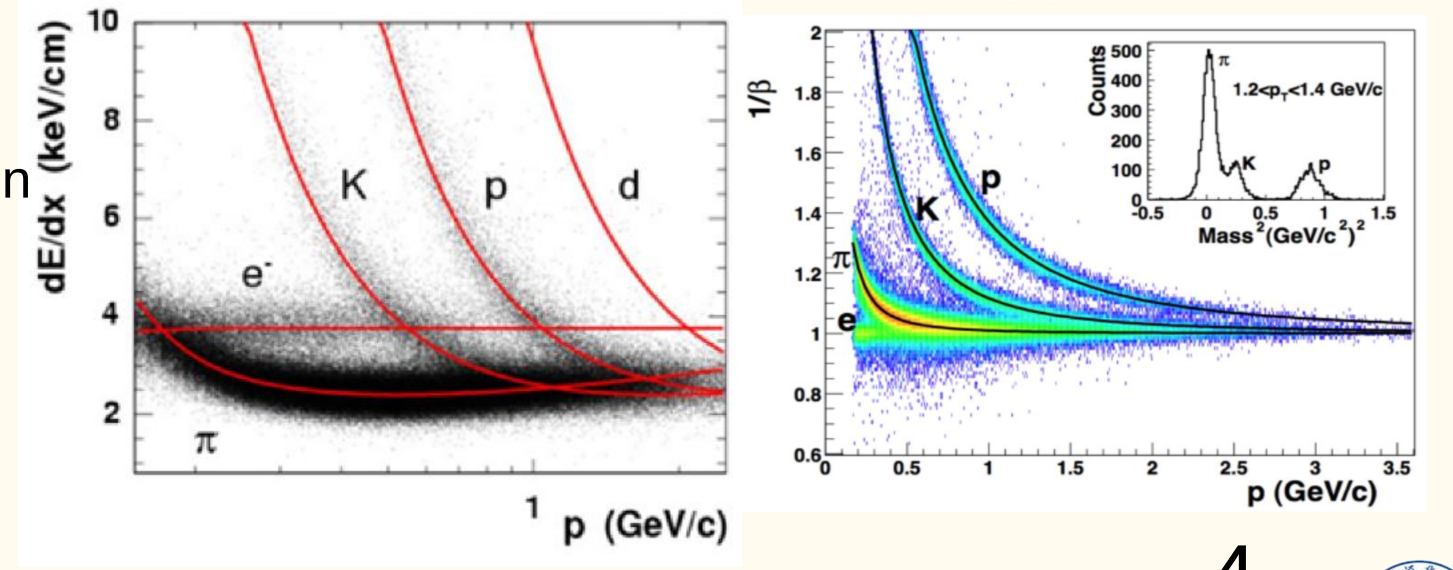
Experiments

STAR experiment

- Use Au+Au collision to create anti-matter
- The detector
  heavy flavor tracker
  time projection chamber
  time of flight
  zero degree calorimeter
- **TPC**
  central detector
  used for 3D imaging of the ionization trail left along the path of charged particles → momentum
- **TOF**
  about 4000 MRPC modules
  time of flight → mass
  excellent particle identification ability

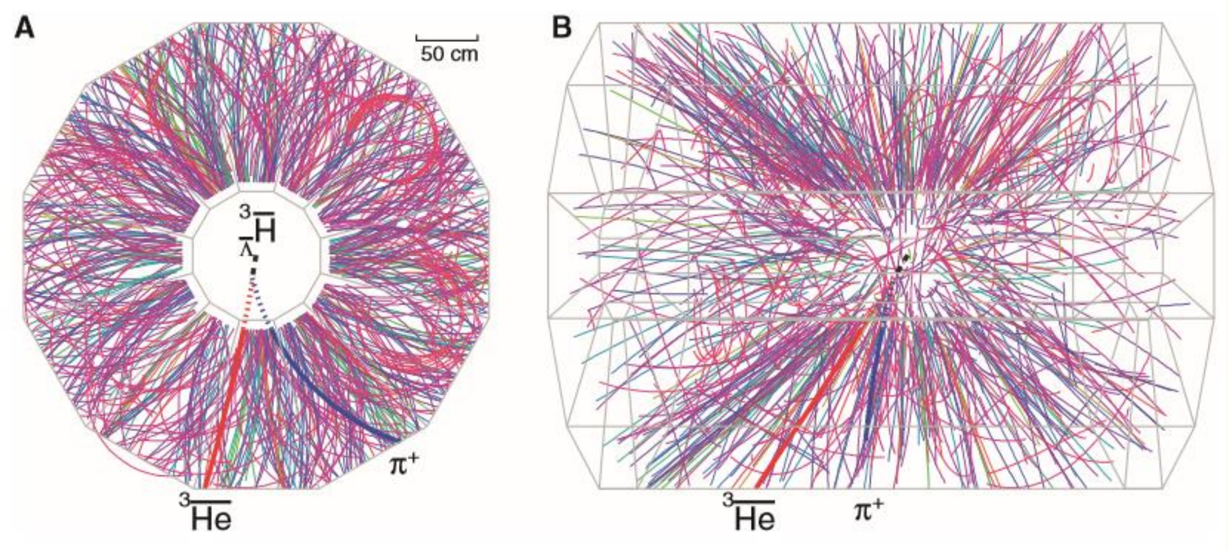


STAR detector [2]



Particle identification [3]

Anti-hypertriton ${}^{3}_{\Lambda}\overline{H}$



production and decay of a ${}^{3}_{\Lambda}\overline{H}$ [4]

Anti-hypertriton

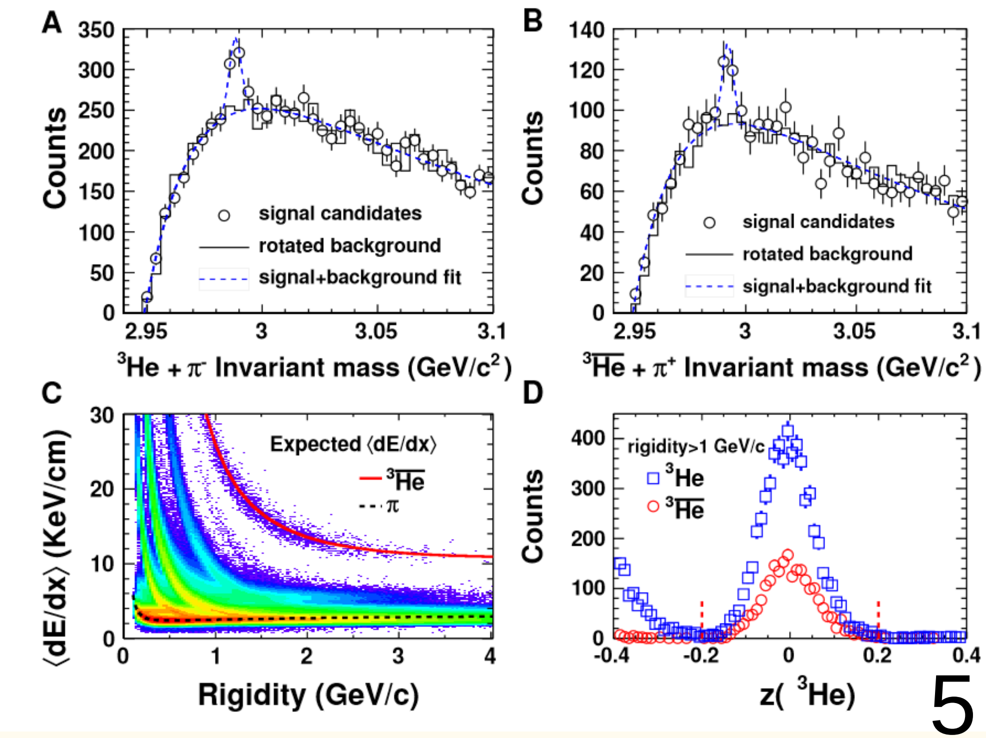
- Reconstructe the secondary vertex via the **decay channel** of

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

- **Particle identification**

  correlate their ionization energy loss $\langle dE/dx \rangle$
  in TPC with their magnetic rigidity
  $\langle dE/dx \rangle$ for negative tracks versus the magnetic rigidity
  different bands stand for different kinds of particles
  the distribution of a new variable z

$$z = Ln(\langle dE/dx \rangle / \langle dE/dx \rangle_B)$$



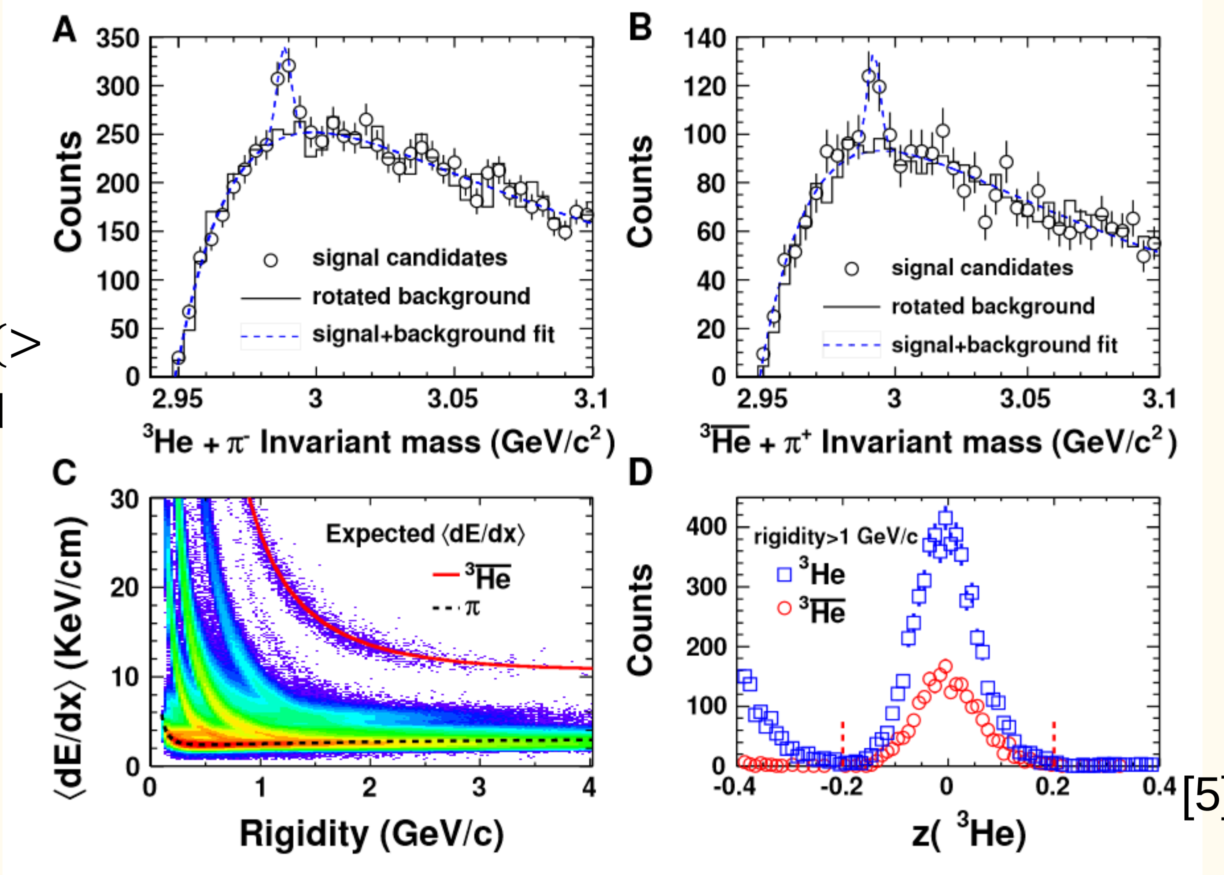
[5]

Anti-hypertriton $^{3}_{\bar{\Lambda}}\bar{H}$

- **Topological reconstruction**
- Topological cuts including the distance between two daughter tracks $^{3}\mathrm{He}$ and $\pi^{+}(< 1\mathrm{cm})$ distance of closest approach (DCA) between $^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}$ and primary vertex $(< 1\mathrm{cm})$, decay length of $^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}(> 2.4\mathrm{cm})$, and the DCA of $(> 0.8\mathrm{cm})$, are employed to enhance the signal to background ratio
- The invariant mass of $^{3}_{\Lambda}\mathrm{H}$and $^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}$ are calculated based on the conservation of momentum and energy in the decay process
- The successfully reproduced combinatorial background with a rotation strategy can be described by double exponential function

$$f(x) \propto \exp\left[-(x/p_1)\right] - \exp\left[-(x/p_2)\right]$$

- signals are counted by subtracting the double exponential background



[5]

Anti-helium4 $^4\overline{He}$

Anti-helium4

- 10 billion gold-gold collisions

→ 500 billion charged particles

→ 18 anti-helium4 (2 found in 2007’s data and 16 in 2010’s data)

- TPC

→ rigidity → momentum

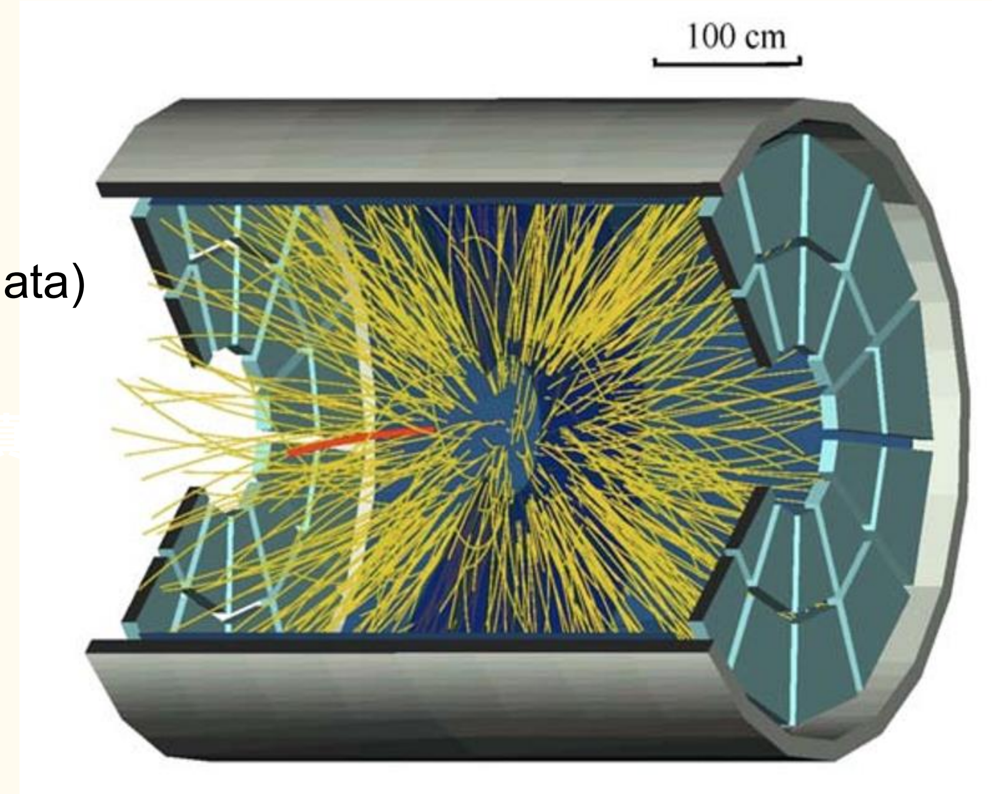
- TOF

→ time of flight → mass

$$m^2 = p^2(t^2/L^2 - 1)$$

- HLT(high level trigger)

→ select collisions which contains Ze=±2e



[6]

tracks from an event which contains a $^4\overline{\mathrm{He}}$

Anti-helium4 $^{4}\overline{He}$

- Colored bands: the helium sample collected by HLF
  Grey bands: $\langle dE/dx \rangle$ from minimum bias events at 200GeV

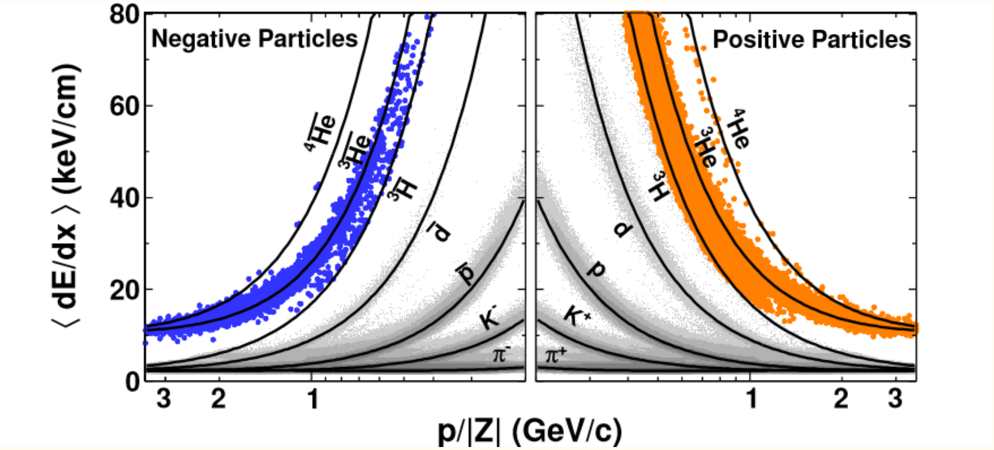
- a couple of $^{4}\overline{\mathrm{He}}$ candidates are identified and well separated from $^{3}\overline{\mathrm{He}}$ at the low momentum region

- Define

$$n_{\sigma_{dE/dx}} = \frac{1}{R} \ln(\langle dE/dx \rangle / \langle dE/dx \rangle^{B})$$

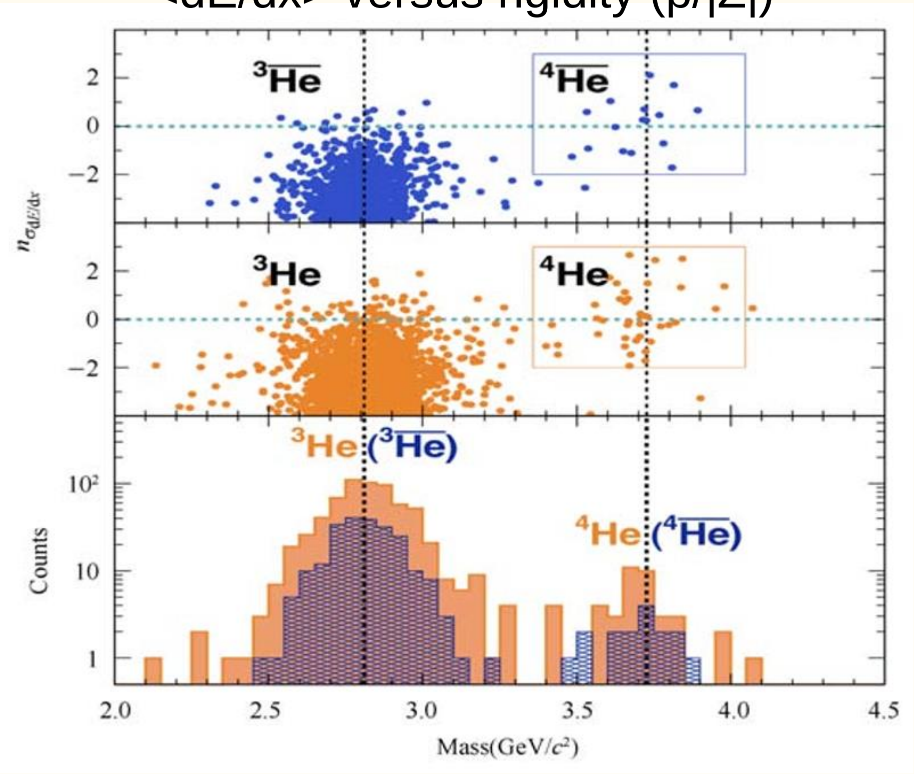
- A cluster of $^{4}\overline{\mathrm{He}}$ located at $n_{\sigma_{dE/dx}} = 0$, $\mathrm{mass}^2/Z^2 = 3.48(\mathrm{GeV/c^2})^2$ can be clearly separated from $^{3}\overline{\mathrm{He}}$

- $18\,^{4}\overline{\mathrm{He}}$ candidates are observed by the STAR experiment



[7]

<dE/dx> versus rigidity (p/|Z|)



[8]

the combined particle identification with $n_{\sigma_{dE/dx}}$ and mass^2/Z^2 value distribution

Production Mechanisms

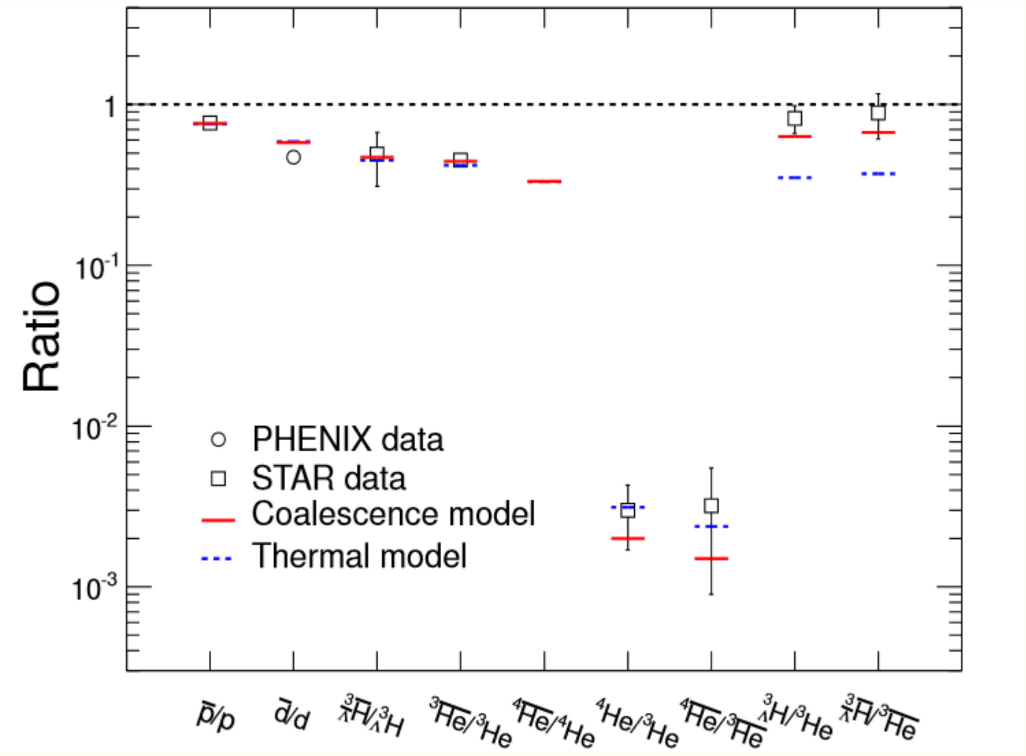
- produced by nucleon-nucleon reactions production rate can be described by both thermodynamic model

$$E_A \frac{d^3 N_A}{d^3 P_A} = \frac{gV}{(2\pi)^3} E_A e^{-m_p A/T}$$

and coalescence model

$$E_A \frac{d^3 N_A}{d^3 P_A} = B_A (E_p \frac{d^3 N_p}{d^3 P_p})^Z (E_n \frac{d^3 N_n}{d^3 P_n})^{A-Z}$$

- both thermal model and coalescence model can fit the antinucleus to nucleus ratios at RHIC energy. While the coalescence model has a better description for $\mathrm{H}/^{3}\mathrm{He}$and $^{3}_{\Lambda}\overline{\mathrm{H}}/^{3}\overline{\mathrm{He}}$ than thermal model



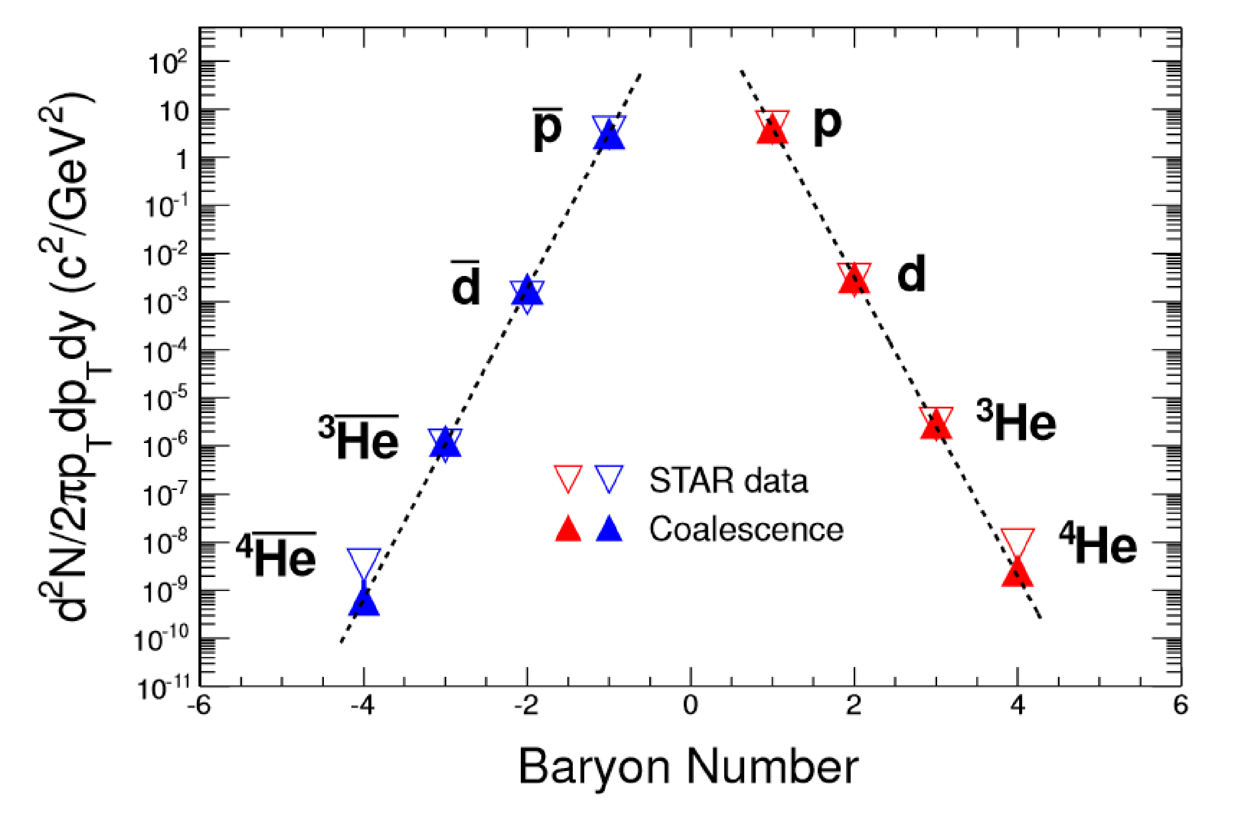
[9]

The comparison of particle ratios between data and model calculations

Production Mechanisms

- In a microscopic picture, both coalescence and thermal production of (anti)nucleus predict an exponential trend for the production rate as a function of baryon number.

- Next stable antinucleus: anti-lithium6
reduce by a factor of 2.6×10^6
impossible to be produced within current accelerator technology



[10]

Conclusion

- The detection of anti-helium4 (the heaviest antimatter nucleus observed so far)
  and anti-hypertriton (the first antimatter hyper nucleus)
- The exponential behavior of the differential invariant yields versus baryon number distribution
  the production rate of anti-lithium6 is about 10^{-16}, which can't be observed with the current accelerator technology
- The current STAR results and model calculations provide a good background estimation for the future observation of $^{4}\overline{\mathrm{He}}$ and even heavier antinuclei in Universe.

References

[1] Yu-Gang Ma 10.7693/wl20150504

[2] [3] Yi Wang Yuan-jing Li10.13405/j.cnki.xdwz.2012.06.003

[4] [5] The STAR Collaboration 10.1126/science.1183980

[6] – [10] Yu-Gang Ma 2013 J. Phys.: Conf. Ser. 420 012036