

# OBSERVATION OF AN ANTIMATTER HYPERNUCLEUS $\frac{4}{\Lambda}\bar{H}$

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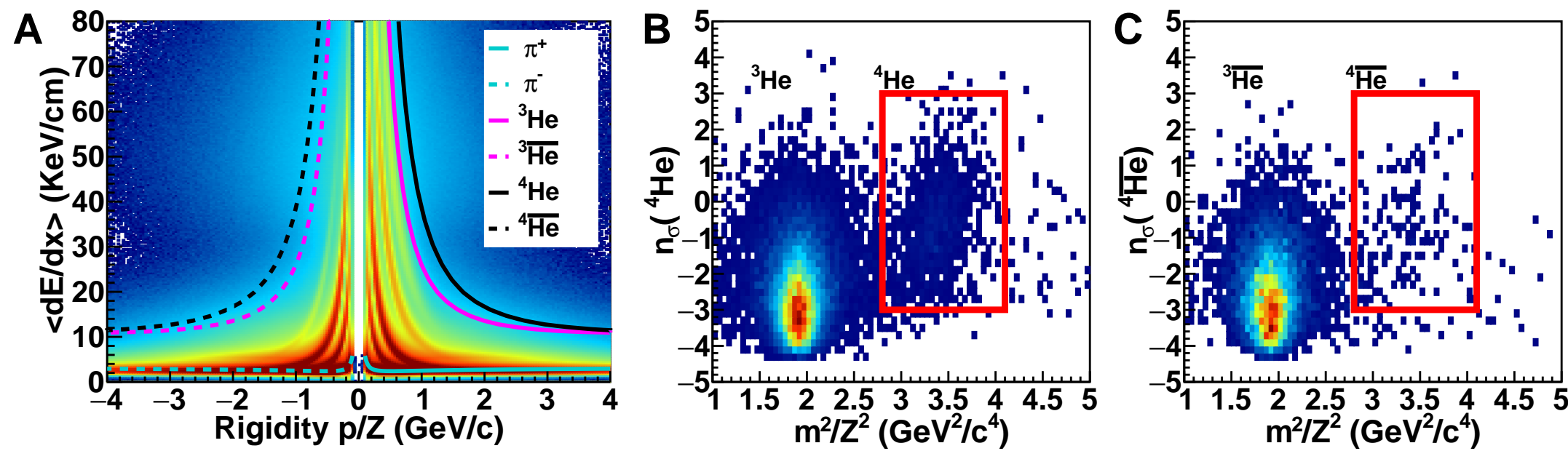
## Abstract

Matter-antimatter asymmetry is a research topic of fundamental interest, as it is the basis for the existence of the matter world, which survived annihilation with antimatter in the early Universe. High energy nuclear collisions create conditions similar to the Universe microseconds after the Big Bang, with comparable amounts of matter and antimatter. Much of the antimatter created escapes the rapidly expanding fireball without annihilation, making such collisions an effective experimental tool to create heavy antimatter nuclear objects and study their properties. In this poster, we report the discovery of the heaviest antimatter particle ( $\frac{4}{\Lambda}\bar{H}$ ) ever seen on Earth, composed of an anti-Lambda ( $\bar{\Lambda}$ ), an antiproton and two antineutrons.  $\frac{4}{\Lambda}\bar{H}$  is reconstructed through its two-body decay in ultrarelativistic heavy ion collisions at the STAR experiment at the Relativistic Heavy Ion Collider. The measurement of antihypernuclei  $\frac{4}{\Lambda}\bar{H}$  lifetime is achieved for the first time and compared with lifetime of their corresponding hypernuclei  $\frac{4}{\Lambda}H$ , which allows for further tests of the CPT symmetry. Production yield ratios among (anti)hypernuclei and (anti)nuclei are also measured and compared with theoretical model predictions, shedding light on their production mechanism. (arXiv:2310.12674)

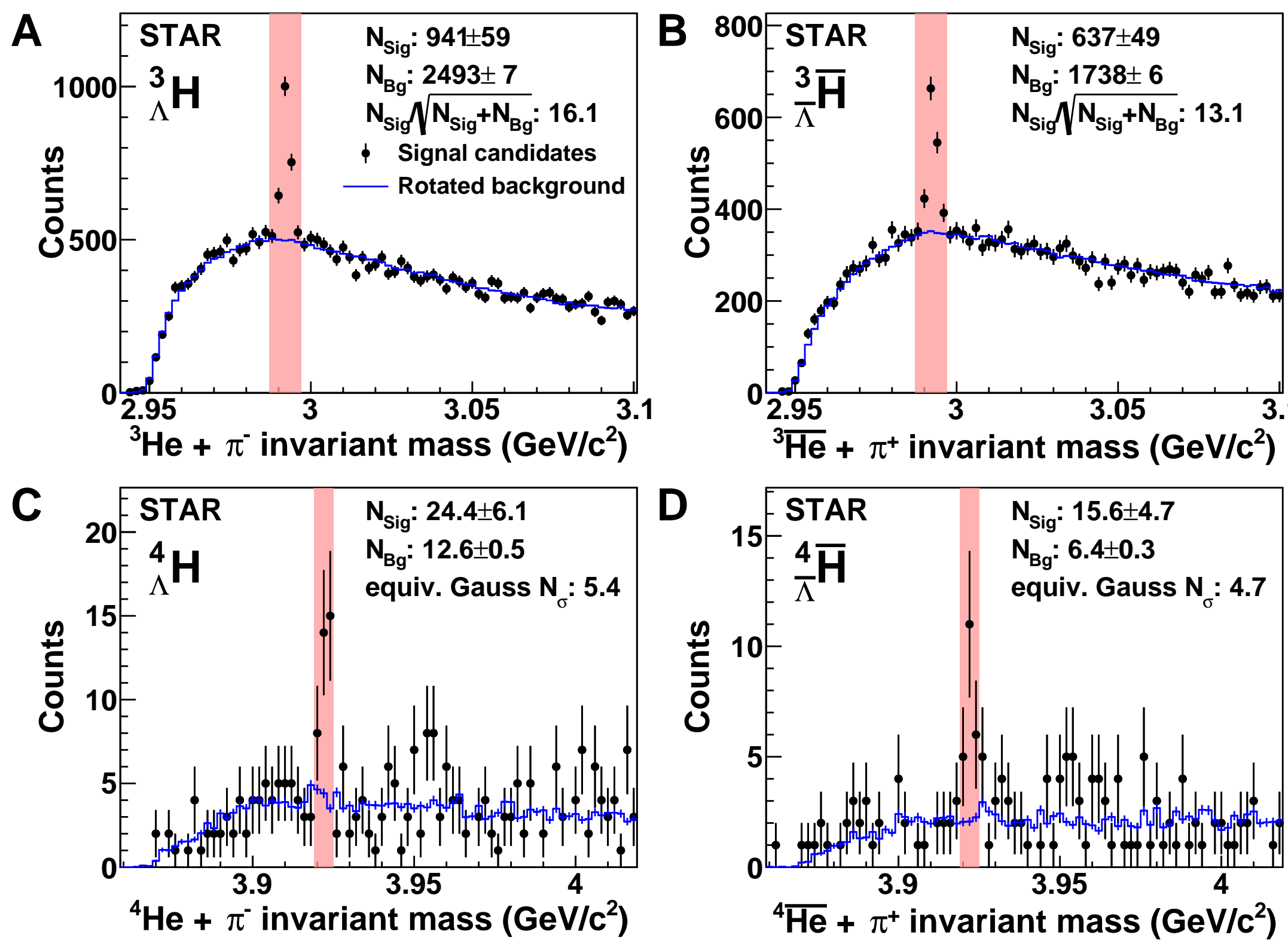
## Signal Reconstruction

These analyses used 606 million and 624 million  $\sqrt{s_{NN}} = 200$  GeV Au+Au collision events obtained in years 2010 and 2011, 512 million  $\sqrt{s_{NN}} = 193$  GeV U+U collision events from year 2012, and 4.7 billion  $\sqrt{s_{NN}} = 200$  GeV Ru+Ru and Zr+Zr collision events from year 2018.

- Particle Identification  
1 Time Projection Chamber (TPC).  
2 Time of Flight detector (TOF).



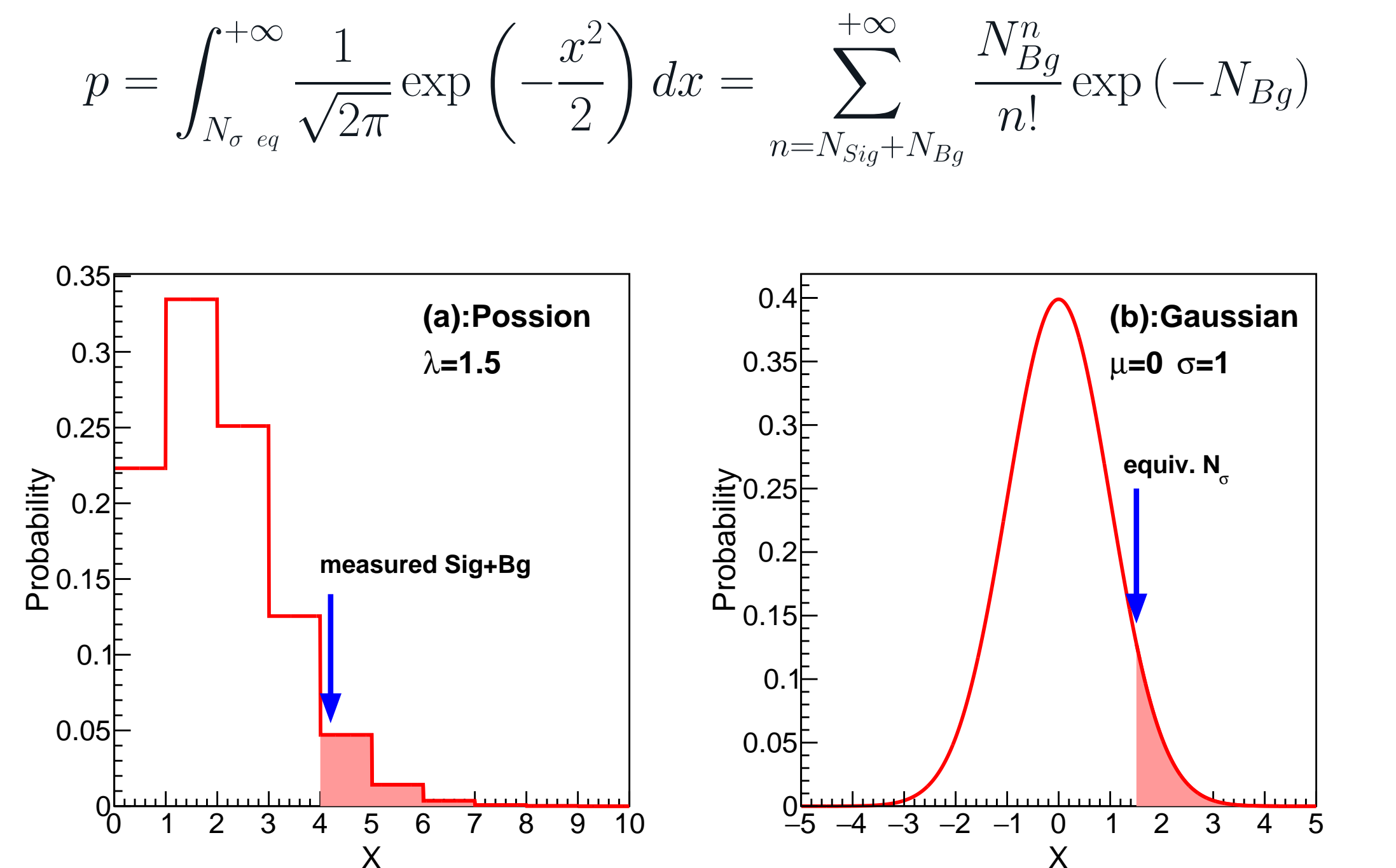
(Anti)hypernuclei  $\frac{3}{\Lambda}H$ ,  $\frac{3}{\Lambda}\bar{H}$ ,  $\frac{4}{\Lambda}H$  and  $\frac{4}{\Lambda}\bar{H}$  are reconstructed through their two-body decay channels:  $\frac{3}{\Lambda}H \rightarrow \frac{3}{\Lambda}\bar{H} + \pi^-$ ,  $\frac{3}{\Lambda}\bar{H} \rightarrow \frac{3}{\Lambda}H + \pi^+$ ,  $\frac{4}{\Lambda}H \rightarrow \frac{4}{\Lambda}\bar{H} + \pi^-$ , and  $\frac{4}{\Lambda}\bar{H} \rightarrow \frac{4}{\Lambda}H + \pi^+$ .



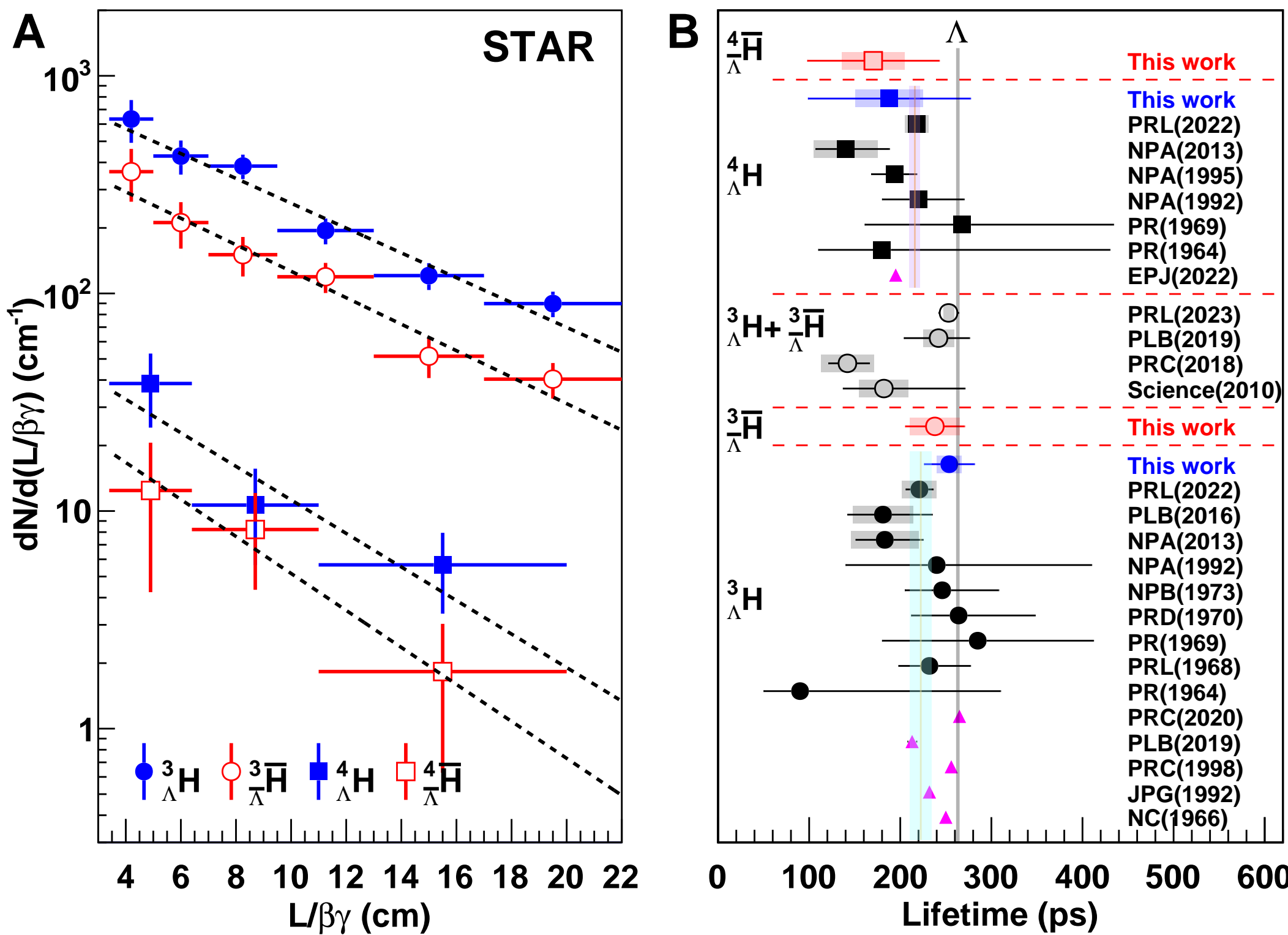
- 1 Kalman-Filter Particle Finder package.  
2 The selection cuts on the topological variables are optimized for the best  $\frac{4}{\Lambda}\bar{H}$  signal, instead of  $\frac{4}{\Lambda}H$  signal.  
3 Combinatorial backgrounds in the invariant mass distributions are reproduced with a rotation method.

In total,  $941 \pm 59$   $\frac{3}{\Lambda}H$ ,  $637 \pm 49$   $\frac{3}{\Lambda}\bar{H}$ ,  $24.4 \pm 6.1$   $\frac{4}{\Lambda}H$  and  $15.6 \pm 4.7$   $\frac{4}{\Lambda}\bar{H}$  signal candidates are observed.

For  $\frac{4}{\Lambda}H$  and  $\frac{4}{\Lambda}\bar{H}$ , due to a very low background count, the proper distribution to describe the measured background is a Poisson distribution, rather than a Gaussian. Thus an equivalent Gaussian significance is introduced, in order to describe the probability that the background with an expected value of  $N_{Bg}$  fluctuates to the measured total candidate count  $N_{Sig} + N_{Bg}$ .



## Lifetime Difference



Efficiency-corrected yields of  $\frac{3}{\Lambda}H$ ,  $\frac{3}{\Lambda}\bar{H}$ ,  $\frac{4}{\Lambda}H$  and  $\frac{4}{\Lambda}\bar{H}$  as a function of  $L/\beta\gamma$ . The lifetimes  $\tau$  can be extracted with the expression  $N(t) = N_0 \exp(-t/\tau) = N_0 \exp(-(L/\beta\gamma)/c\tau)$ .

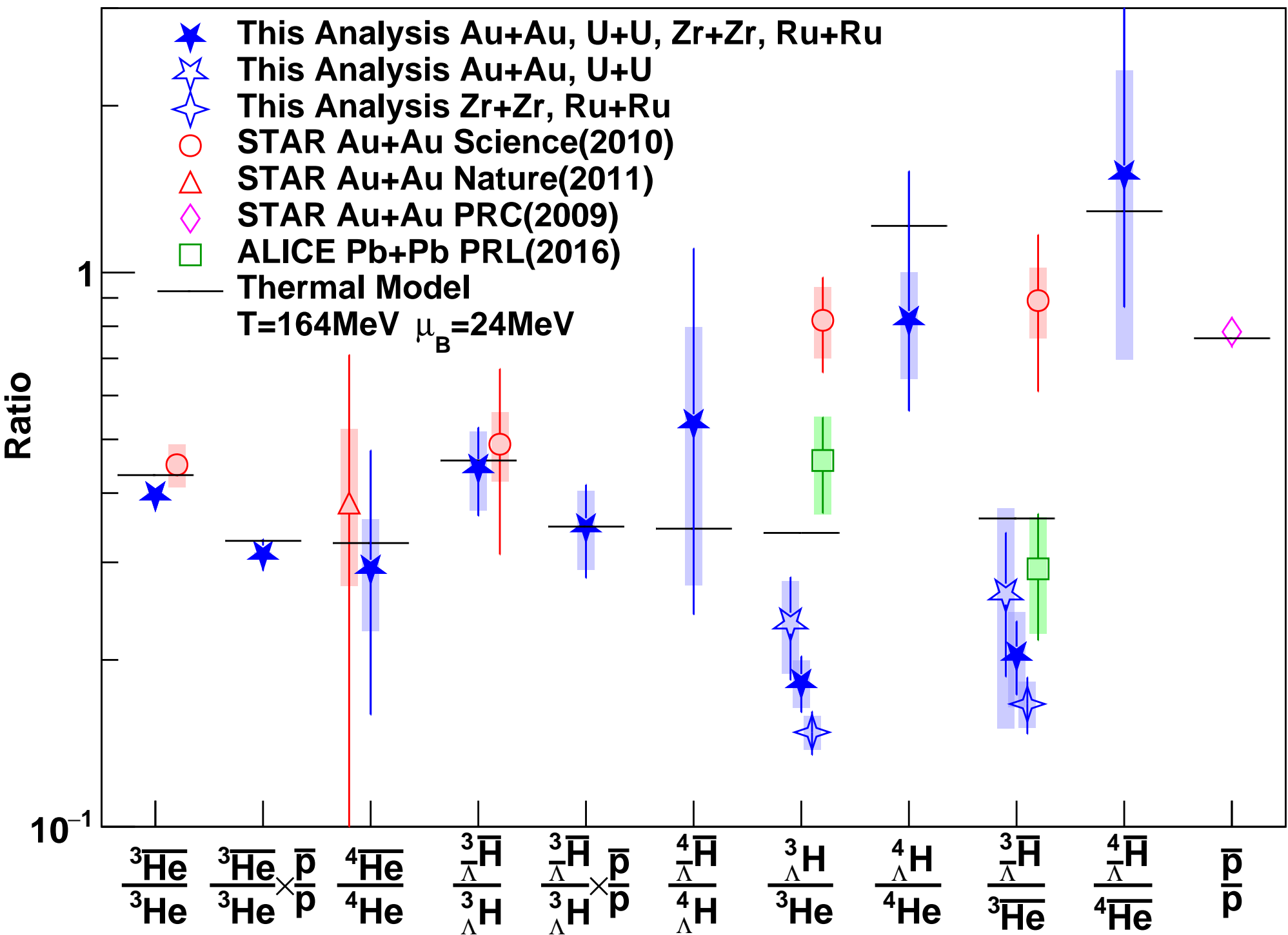
The extracted lifetimes are

$$\begin{aligned}\tau_{\frac{3}{\Lambda}H} &= 254 \pm 28(stat.) \pm 14(sys.) \text{ ps} \\ \tau_{\frac{3}{\Lambda}\bar{H}} &= 238 \pm 33(stat.) \pm 28(sys.) \text{ ps} \\ \tau_{\frac{4}{\Lambda}H} &= 188 \pm 89(stat.) \pm 37(sys.) \text{ ps} \\ \tau_{\frac{4}{\Lambda}\bar{H}} &= 170 \pm 72(stat.) \pm 34(sys.) \text{ ps}\end{aligned}$$

The lifetime differences between hypernuclei and their corresponding antihypernuclei are  $\tau_{\frac{3}{\Lambda}H} - \tau_{\frac{3}{\Lambda}\bar{H}} = 16 \pm 43(stat.) \pm 20(sys.)$  ps and  $\tau_{\frac{4}{\Lambda}H} - \tau_{\frac{4}{\Lambda}\bar{H}} = 18 \pm 115(stat.) \pm 46(sys.)$  ps. Both are consistent with zero within uncertainties. A test of CPT symmetry with the heaviest matter-antimatter.

## Yield Ratio

- 1 A combination of data from U+U, Au+Au, Ru+Ru, and Zr+Zr collisions. We therefore measure various yield ratios between particles with the same baryon number instead of absolute yields of each particle. The effect due to different collision system sizes will largely cancel out.  
2 Yield ratio measurements with only minimum bias triggered events, in order to avoid possible bias by trigger selection.  
3 The phase space region of rapidity  $|y| < 0.7$  and  $0.7c < p_T/m < 1.5c$ .  
4 Acceptance and efficiency are corrected for using the above-mentioned Monte Carlo simulation.  
5 The branching fractions of the (anti)hypernuclei two-body decay channels are assumed to be 0.25 for  $\frac{3}{\Lambda}H$  and  $\frac{3}{\Lambda}\bar{H}$  and 0.5 for  $\frac{4}{\Lambda}H$  and  $\frac{4}{\Lambda}\bar{H}$  following previous measurements.  
6  $\frac{3}{\Lambda}He$ ,  $\frac{3}{\Lambda}\bar{He}$ ,  $\frac{4}{\Lambda}He$ , and  $\frac{4}{\Lambda}\bar{He}$  yields are also corrected for contributions from  $\frac{3}{\Lambda}H$ ,  $\frac{3}{\Lambda}\bar{H}$ ,  $\frac{4}{\Lambda}H$ , and  $\frac{4}{\Lambda}\bar{H}$  decays when calculating the ratios.



- 1 The  $\frac{3}{\Lambda}\bar{He}/\frac{3}{\Lambda}He$ ,  $\frac{4}{\Lambda}\bar{He}/\frac{4}{\Lambda}He$  and  $\frac{3}{\Lambda}\bar{H}/\frac{3}{\Lambda}H$  ratios are in good agreement with the previous STAR measurements.  
2 The measured  $\frac{3}{\Lambda}H/\frac{3}{\Lambda}He$  and  $\frac{3}{\Lambda}\bar{H}/\frac{3}{\Lambda}\bar{He}$  ratios in U+U and Au+Au collisions are lower than previous STAR results by 2.8 and 1.9  $\sigma$ , respectively.  
3 The measured  $\frac{4}{\Lambda}\bar{He}/\frac{4}{\Lambda}He$  and  $\frac{4}{\Lambda}\bar{H}/\frac{4}{\Lambda}H$  ratios are consistent with the combined ratios of  $\frac{3}{\Lambda}\bar{He}/\frac{3}{\Lambda}He \times \bar{p}/p$  and  $\frac{3}{\Lambda}\bar{H}/\frac{3}{\Lambda}H \times \bar{p}/p$ , respectively.  
4 The enhancement of the total measured  $\frac{4}{\Lambda}H$  and  $\frac{4}{\Lambda}\bar{H}$  production yield by a factor of 4, compared to  $\frac{4}{\Lambda}He$  and  $\frac{4}{\Lambda}\bar{He}$  which have only a spin 0 state. Thus according to the coalescence model,  $\frac{4}{\Lambda}H/\frac{4}{\Lambda}He$  and  $\frac{4}{\Lambda}\bar{H}/\frac{4}{\Lambda}\bar{He}$  are expected to be about 4 times higher than  $\frac{3}{\Lambda}H/\frac{3}{\Lambda}He$  and  $\frac{3}{\Lambda}\bar{H}/\frac{3}{\Lambda}\bar{He}$ , respectively.  
5 A good agreement with the Thermal Model[1].

## References

[1] A Andronic et al. "Production of Light Nuclei, Hypernuclei and Their Antiparticles in Relativistic Nuclear Collisions". In: *Phys. Lett. B* 697.3 (2011), pp. 203–207.

## Conclusions

- 1  $\frac{4}{\Lambda}\bar{H}$  was observed for the first time in the experiment.  
2 No lifetime difference is observed between hypernuclei and antihypernuclei  
3 Various particle production yield ratios are measured, matched the coalescence picture.