Lifetime measurements of ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$ in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.2GeV from STAR experiment

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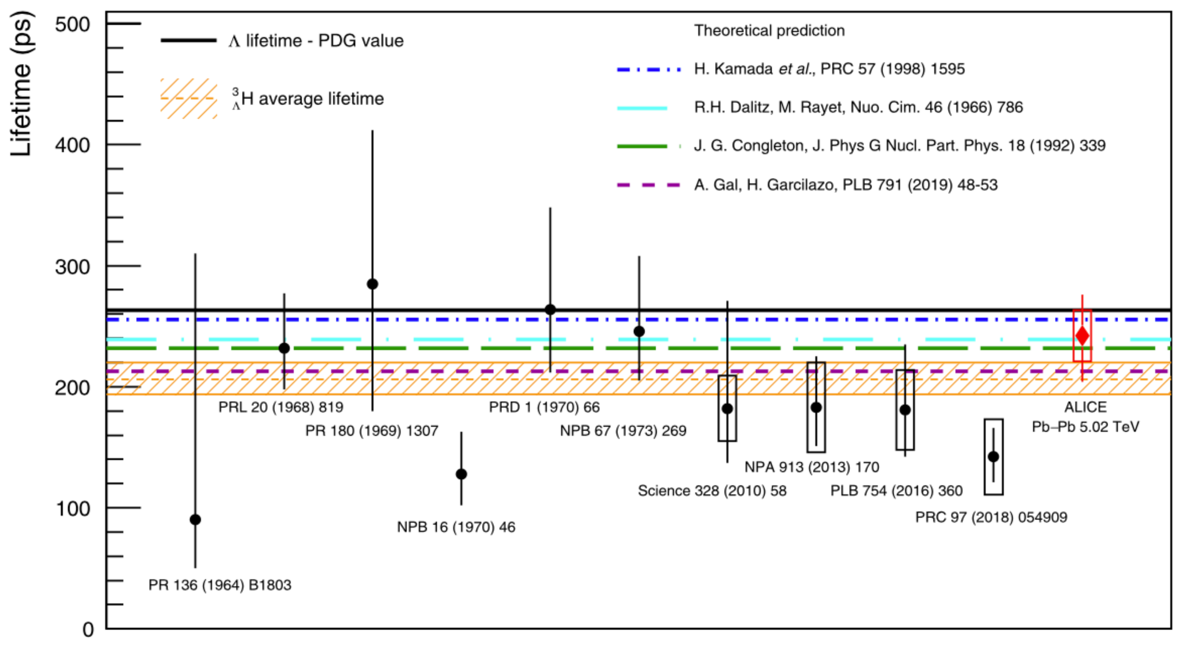
Abstract

Hypernuclei are bound nuclear systems of non-strange and strange baryons. They are natural hyperon-baryon correlation systems and provide direct access to the hyperon—nucleon (YN) interaction. The knowledge of this interaction has become more relevant in recent years due to its connection to the modeling of astrophysical objects like neutron stars. The lifetime of a hypernucleus depends on the strength of the Y-N interaction, and therefore a precise determination of the lifetime of hypernuclei provides information on the Y-N interaction strength.

Thanks to the large data sample recorded by STAR in 2018 and the low collision energy of it, we are able to perform more precise measurements of the lifetime of ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$. In this poster, we will present the lifetime measurements of ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$ in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.2 GeV from the STAR experiments with the fixed-target mode.

Motivation

- Lifetime of hypernuclei – probe to the Y-N interaction
- Y-N interaction – probing the inner core of neutron stars
  - "Hyperon puzzle" : do hyperons exist in the core?
- ${}^{3}_{\Lambda}H$ lifetime puzzle
  - The world-average value of the experimental measurements of ${}^{3}_{\Lambda}H$ lifetime is shorter than the lifetime of free Λ (263.2±2.0 ps) by ~ 20%.
- Large data sample and high hypernuclei production
  - 2018 $\sqrt{s_{NN}}$ = 7.2 GeV dataset: ~ 150 M events
  - Lower collision energy → higher baryon density → abundantly produced hypernuclei

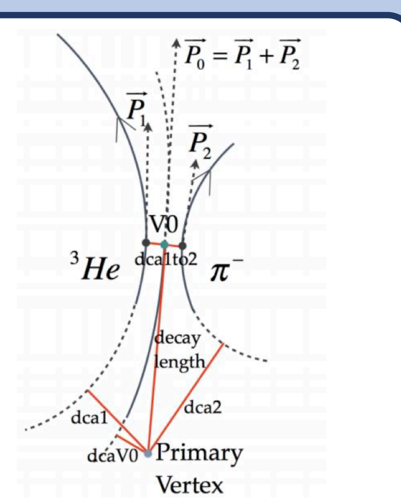


ALICE, PLB 797, 134905 (2019)

${}^{3}_{\Lambda}H$, ${}^{4}_{\Lambda}H$ reconstruction

- ${}^{3}_{\Lambda}H$, ${}^{4}_{\Lambda}H$ reconstructed through their 2-body decay channe.

	Decay Channel
${}^{3}_{\Lambda}H$	$\pi^- + {}^{3}_{\Lambda}He$
${}^{4}_{\Lambda}H$	$\pi^- + {}^{4}_{\Lambda}He$



Particle reconstruction: KFparticle method

- Kalman Filter based reconstruction method, developer based on CBM, ALICE experiments[1].
- All particles (mother and daughter) described by state vectors and covariance matrices.
- The reconstruction takes parameters and the respective errors into account.
- Analysis cuts in KFParticle:
  - Normalized by respective errors; represented
  - e.g. :
    - l/dl is the normalized decay length;
    - $\chi^2_{prim,He}$ is the DCA of daughter particle Helium to primary vertex in χ^2;
    - χ^2_{ndf} is χ^2 of Helium- π^- fit;
    - χ^2_{topo} is the DCA of ${}^{3}_{\Lambda}H/{}^{4}_{\Lambda}H$ in χ^2.

$$\mathbf{r} = \{ x, y, z, p_x, p_y, p_z, E \}$$

State vector

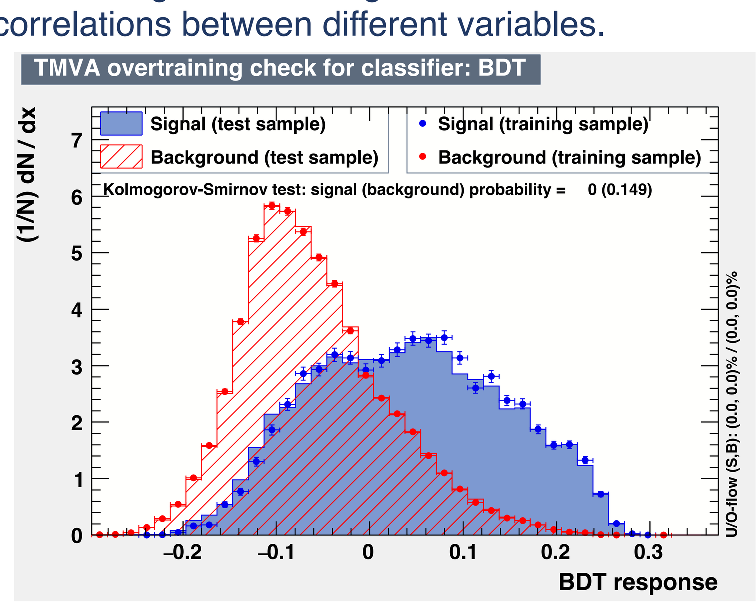
$$\mathbf{C} = \langle \mathbf{r}\mathbf{r}^T \rangle = \begin{bmatrix} \sigma_x^2 & C_{xy} & C_{xz} & C_{xp_x} & C_{xp_y} & C_{xp_z} & C_{xE} \\ C_{xy} & \sigma_y^2 & C_{yz} & C_{yp_x} & C_{yp_y} & C_{yp_z} & C_{yE} \\ C_{xz} & C_{yz} & \sigma_z^2 & C_{zp_x} & C_{zp_y} & C_{zp_z} & C_{zE} \\ C_{xp_x} & C_{yp_x} & C_{zp_x} & \sigma_{p_x}^2 & C_{p_xp_y} & C_{p_xp_z} & C_{p_xE} \\ C_{xp_y} & C_{yp_y} & C_{zp_y} & C_{p_xp_y} & \sigma_{p_y}^2 & C_{p_yp_z} & C_{p_yE} \\ C_{xp_z} & C_{yp_z} & C_{zp_z} & C_{p_xp_z} & C_{p_yp_z} & \sigma_{p_z}^2 & C_{p_yE} \\ C_{xE} & C_{yE} & C_{zE} & C_{p_xE} & C_{p_yE} & C_{p_zE} & \sigma_E^2 \end{bmatrix}$$

Covariance matrix

${}^{3}_{\Lambda}H$ cut optimization: TMVA

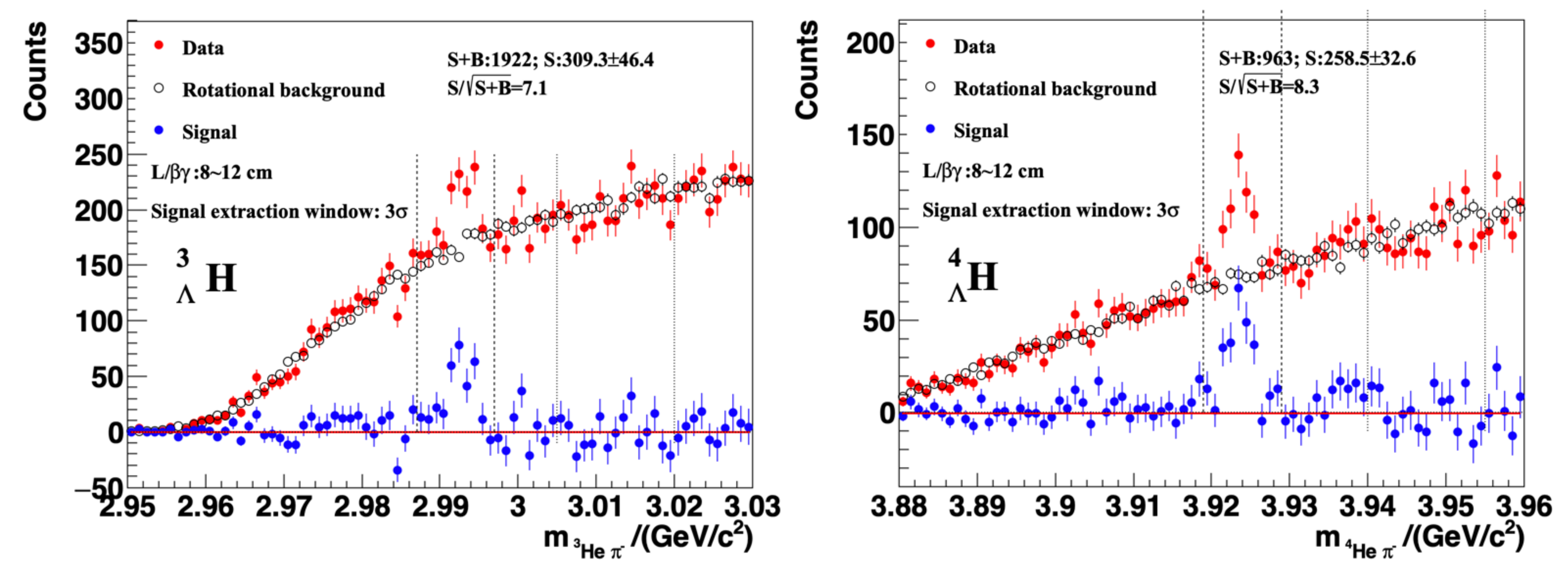
- TMVA (Toolkit for Multivariable Data Analysis)[2]: A family of supervised learning algorithms.
  - Make use of training events, typically events labelled "signal" or "background".
  - Multivariable analysis that takes into account correlations between different variables.
- Training on multiple variables(χ^2_{topo}, χ^2_{ndf}, decay length, etc.) based on the BDT (Boosted decision tree) method.
  - All variables simplified to a single axis (BDT response)
  - Scan BDT response cut value to optimize signal significance

Signal: embedding simulation
Background: rotational background from real data



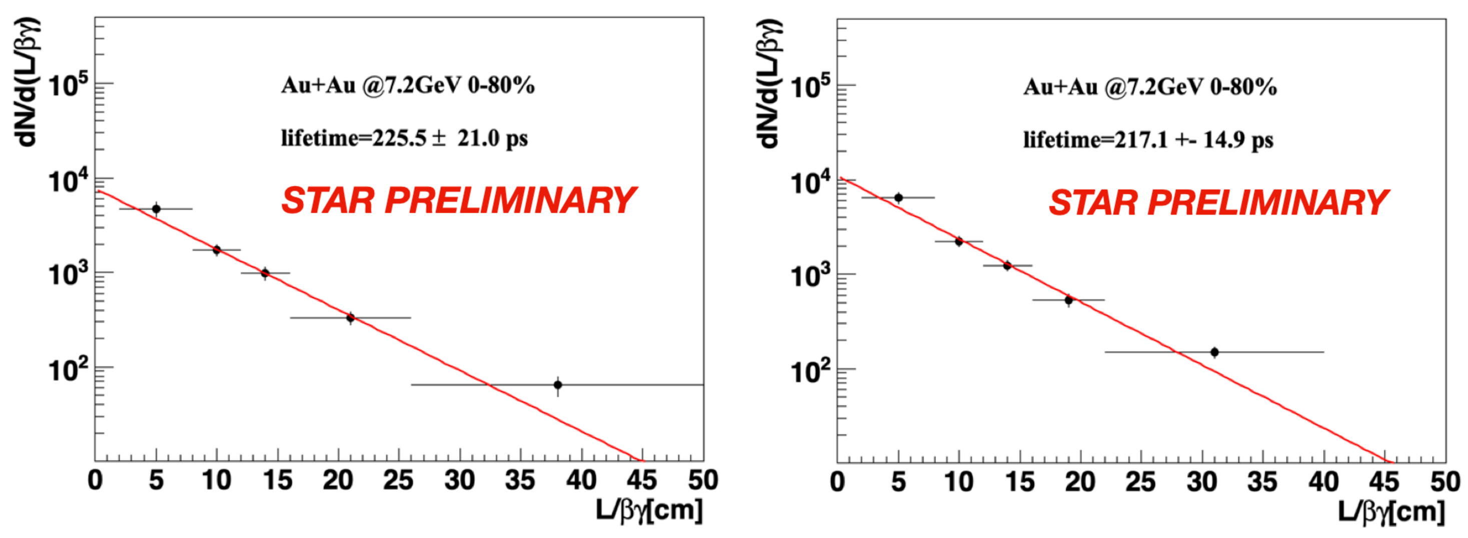
Signal extraction

- Raw counts are calculated within a 3σ mass range from gaussian fit with the bin counting methods in each $L/\beta\gamma$ bin.
- Background is estimated by rotating the daughter particle π^- in the transverse plane by 45°, 90°, 135°, 180°, 225, 270°, 315°.



Lifetime results

- After raw counts are corrected by efficiency in each $L/\beta\gamma$ bin, we fit the counts with an exponential function to extracted the lifetime τ.
  - $N(t) = N_0 e^{-t/\tau} = N_0 e^{-L/\beta\gamma c\tau}$, L: decay length, t: proper time



- Hypernuclei lifetime from STAR FXT $\sqrt{s_{NN}}$ = 7.2 GeV are:

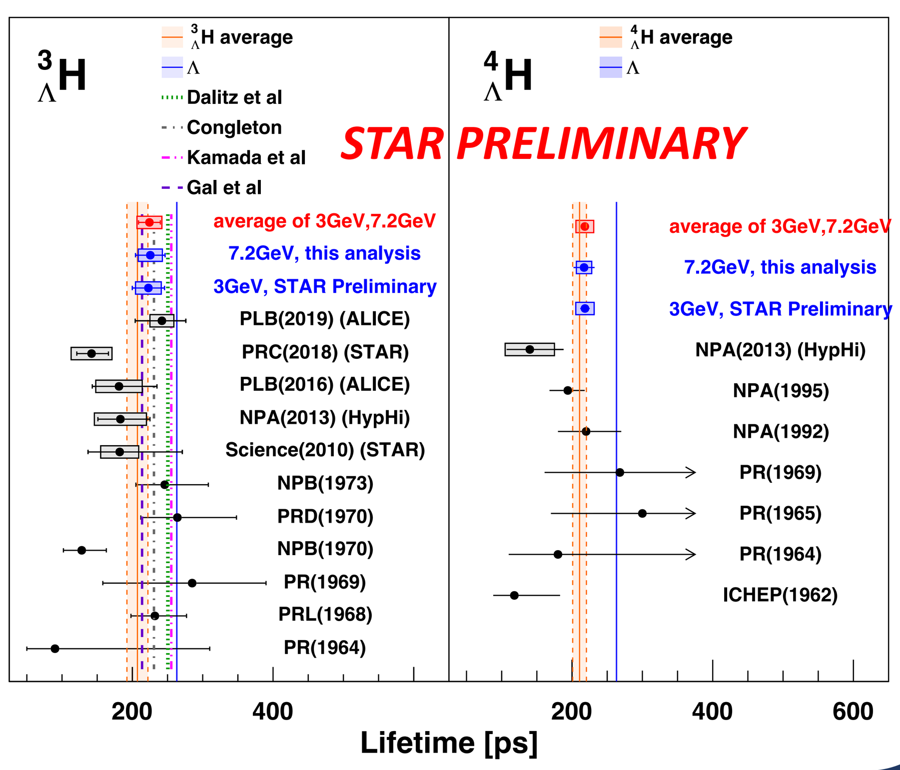
$\tau_{{}^{3}_{\Lambda}H} = 225.5 \pm 21.0(stat.) \pm 17.1(sys.)[ps]$

$\tau_{{}^{4}_{\Lambda}H} = 217.1 \pm 14.9(stat.) \pm 10.9(sys.)[ps]$

- Averaged results from STAR Au+Au $\sqrt{s_{NN}}$ = 3 GeV and 7.2 GeV:

$\bar{\tau}_{{}^{3}_{\Lambda}H} = 224.3 \pm 15.5(stat.) \pm 17.6(sys.)[ps]$

$\bar{\tau}_{{}^{4}_{\Lambda}H} = 218.2 \pm 6.2(stat.) \pm 12.6(sys.)[ps]$



Summary

- We present the first lifetime measurement of ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$ in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.2 GeV from the STAR experiments with the fixed-target mode. The results are consistent with STAR 3 GeV results and most of the previous measurements, and shorter than the free Λ lifetime.
- We present the averaged ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$ lifetimes from STAR 3GeV and 7.2 GeV measurements, which give the most precise measurements to date.

References

[1] Zyzak M. Online selection of short-lived particles on many-core computer architectures in the CBM experiment at FAIR. 2016

[2] Hoecker A , et al. TMVA - Toolkit for Multivariate Data Analysis[J]. Arxiv, 2007.

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The STAR Collaboration
drupal.star.bnl.gov/STAR/presentations