Lifetime measurements of light hypernuclei in Au+Au collisions from the STAR experiment

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Introduction

- Hypernuclei: bound nuclear systems of non-strange and strange baryons
  - Probe hyperon-nucleon (Y-N) interaction
  - Help understand inner structure of neutron stars
- $^3_\Lambda$H lifetime “puzzle”
  - Assuming $\Lambda$ and deuteron weakly bound in $^3_\Lambda$H
    → Indicate the lifetime of $^3_\Lambda$H will be close to that of $\Lambda$.
  - Large uncertainties in experimental measurements
    - Tension between STAR and ALICE
- Light hypernuclei abundantly produced at low collision energies due to the high baryon density.
  - Great opportunity to study hypernuclei production using STAR BES-II data.

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Particle reconstruction

- **Decay channels:**
  - $^3\Lambda H \rightarrow ^3\text{He} + \pi^-$, $^4\Lambda H \rightarrow ^4\text{He} + \pi^-$, $^4\Lambda \text{He} \rightarrow ^3\text{He} + p + \pi^-$

- **Background reconstruction:**
  - For $^3\Lambda H$ and $^4\Lambda H$, estimated by rotating the daughter particle $\pi^-$ in the transverse plane.
  - For $^4\Lambda \text{He}$, estimated by mixed-event method.
  - Mix $^3\text{He}$ and $p\pi^-$ pairs.
Lifetime of $^{3}_\Lambda H$, $^{4}_\Lambda H$ and $^{4}_\Lambda He$

- Extract lifetime $\tau$ from an exponential fit to the corrected signal counts $dN/d(L/\beta\gamma)$ vs. $L/\beta\gamma$
  - $N(t) = N_0 e^{-L/\beta\gamma c \tau}$, $L$: decay length
- $\Lambda$ lifetime crosscheck
  - $\tau^{3}_\Lambda = 267 \pm 4$ ps, consistent with PDG value (263±2 ps)
- $^{3}_\Lambda H$, $^{4}_\Lambda H$ lifetimes from 3.0 GeV consistent with 7.2 GeV results

$\tau^{3}_\Lambda H = 221 \pm 15\text{(stat.)} \pm 19\text{(syst.)}$ ps
$\tau^{4}_\Lambda H = 218 \pm 6\text{(stat.)} \pm 13\text{(syst.)}$ ps
$\tau^{4}_\Lambda He = 229 \pm 23\text{(stat.)} \pm 20\text{(syst.)}$ ps

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Summary

- $^3\Lambda H$ and $^4\Lambda H$ lifetimes with improved precision

- World average lifetimes of $^3\Lambda H$ and $^4\Lambda H$ are shorter than $\tau_\Lambda$ by $(24\pm5)\%$ and $(21\pm4)\%$

- $\tau_{^3\Lambda H}$ and $\tau_{^4\Lambda H}$ (STAR 2022) are shorter than $\tau_\Lambda$ with 1.8$\sigma$ and 3$\sigma$ respectively

- $\tau_{^3\Lambda H}$ and $\tau_{^4\Lambda H}$ (STAR 2022) are consistent with all former measurements within 2.5$\sigma$

- Compare the results with theoretical calculations.

- $\tau_{^3\Lambda H}$ result consistent with calculation including pion FSI (2019) and calculation under $\Lambda d$ 2-body picture (1992) within 1$\sigma$.

- $\frac{\tau_{^4\Lambda H}}{\tau_{^4\Lambda He}} = 0.85 \pm 0.07$, consistent with theoretical prediction applying the $\Delta I = \frac{1}{2}$ rule(2022): $0.74 \pm 0.04$

- Precision lifetime measurements provide constraints on theoretical models, which will lead to better determination of the Y-N interaction.

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