Possible measurement of the lifetime of Hydrogen hyperisotopes at J-PARC and JLab

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Outline

• starting point
• present experimental knowledge
• how to measure $\tau(3_\Lambda H, 4_\Lambda H)$
  – at J-PARC
  – at JLab
• evaluation: rates, beam times, statistics, .... apparatuses (feasibility, requirements)
Status and perspectives of experimental studies on hypernuclear weak decays

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Summary. — From the first beginning the weak decay of \( \Lambda \)-hypernuclei has been considered a very interesting physics case, since its study could shed light on several topics in nuclear and particle physics, among which the \( \Lambda N \rightarrow NN \) four-baryon weak interaction not otherwise accessible. However, only in the last decade a substantial series of reliable experimental data samples has been produced thanks to the synergic effort of dedicated facilities at some laboratories in the world. The existing pattern of data on lifetimes, partial decay widths for mesonic and non-mesonic decay (both one- and two-nucleon induced) and energy spectra and correlations of the emitted particles is reviewed and compared with existing theoretical predictions. Updated tables and plots summarizing the existing experimental information are presented. For each item a brief account of possible new experimental efforts, approved, planned or futuristic is given. From these analyses the full pattern of partial decay widths for \(^4\Lambda\text{He}, ^5\Lambda\text{He}, ^{11}\Lambda\text{B}, \) and \(^{12}\Lambda\text{C} \) is discussed. Rare decay channels and polarization studies are also briefly analyzed.

PACS 21.80.+a – 25.80.Pw.
• present experimental knowledge

<table>
<thead>
<tr>
<th>A</th>
<th>$B_{\Lambda}$ (MeV)</th>
<th>$\tau$ (ps)</th>
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<tr>
<td>$\Lambda$</td>
<td>--</td>
<td>$263.2\pm2.0$</td>
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<td>CPC 38(9) (2104) 090001</td>
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<tr>
<td>$^3\Lambda H$</td>
<td>$0.13\pm0.05\pm0.04$</td>
<td>$216^{+19}_{-16}$ RNC</td>
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<td></td>
<td>Juric NPB 52 (1973) 1</td>
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<tr>
<td>$^4\Lambda H$</td>
<td>$2.08\pm0.08$ Juric NPB 52 (1973) 1</td>
<td>$192^{+20}_{-18}$ RNC</td>
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<td></td>
<td>$2.04\pm0.04\pm0.04$ Davis, NPA 754 (2005) 1</td>
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<tr>
<td></td>
<td>$2.12\pm0.01\pm0.09$ Esser PRL 114 (2015) 232501</td>
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<tr>
<td>$^4\Lambda He$</td>
<td>$2.39\pm0.03\pm0.04$ Davis, NPA 754 (2005) 1</td>
<td>$250\pm18$ RNC</td>
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<tr>
<td></td>
<td>$\Delta B(1^+\rightarrow 0^+)=1.406\pm0.002\pm0.003$ (Yamamoto arXiv:a508.00376)</td>
<td></td>
</tr>
<tr>
<td>$^5\Lambda He$</td>
<td>$3.12\pm0.02$ Davis, NPA 754 (2005) 1</td>
<td>$273\pm10$ RNC</td>
</tr>
</tbody>
</table>

puzzling situation:
A=1, 3, 4, 5 lifetime
A=4 $I_3=-1/2$ vs $I_3=1/2$  \[ B_{\Lambda} \] && lifetime
\( ^3 \Lambda H \)

- ions & HI: precise, not completely consistent
- new precise dedicated counter experiments to find out eventual systematic effects due to measurement method

\( ^4 \Lambda H \)

- new precise dedicated counter experiments
  \( \rightarrow \) resolution below 10\% (3-5\%)
- UR-HI: statistics, schedule …?
• how to measure $\tau(^3\Lambda H, ^4\Lambda H)$

• counter experiments, MM spectra
• direct time delayed spectra technique ($t_{\text{decay}} - t_{\text{react}}$)

• production reaction detection to identify the hypernucleus (MM) and measure $t_{\text{react}}$ (HI/Ions) → trigger, apparatus ($\varepsilon$, $\Delta\Omega$)
• coincidence detection of MWD products (2b&3b) ($t_{\text{decay}}$) → coincidence apparatus ($\varepsilon'$, $\Delta\Omega'$)

• good MM spectroscopy resolution
• start and stop time counters with very good time resolution
• energy measurement for decay charged particles ($\pi$, $p$)
• background reactions ($\Lambda$ q.f. production and decay, ...) rejection
• prompt reaction for system time response function ($\sigma \sim 50$ ps)
• **how to measure** $\tau(\Lambda_{3}^4H, \Lambda_{4}^4H)$ at J-PARC

• $\pi$, K beams $\rightarrow 3\Lambda^4H, 4\Lambda^4H$ produced through associated production reaction:

$$\pi^- (1.05 \text{ GeV/c}) + 3.4^4\text{He} \rightarrow 3\Lambda^4H (~400 \text{ MeV/c}) + K^0 (~700 \text{ MeV/c}) \text{ forw. dir.}$$

• **E22 Proposal**: $\Lambda N$ weak interaction in $A=4$ $\Lambda$-hypernuclei ($\Gamma_n$, $\Gamma_p$, $\alpha^{NM}_p$, $\Delta l=1/2$) K1.8 beamline, 1.1 GeV/c, $^4\text{He}(\pi^+, K^+) 4\Lambda^4\text{He}$, beam & SKS spectrometer & decay arm (E15 CDC without magnet)

• **Day-2 experiment** to study NMWD of $\Lambda^4H$

  production reaction $^4\text{He}(\pi^-, K^0) 4\Lambda^4\text{He} \text{ isospin symmetric}$

  $K^0$ from $K_s$ decay ($\pi^+ \pi^-$: 68.95%) $\rightarrow$ small detection efficiency $\rightarrow$ HIHR (?)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Parameter in Eqs.(5)</th>
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<tbody>
<tr>
<td>$\pi^+$ beam momentum</td>
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<td>$N_{Beam}$</td>
</tr>
<tr>
<td>$\pi^+$ beam intensity</td>
<td>$1 \times 10^9$/spill</td>
<td>$T_{Cycle}$</td>
</tr>
<tr>
<td>PS acceleration cycle</td>
<td>3.4 sec/spill</td>
<td>$N_{Target}$</td>
</tr>
<tr>
<td>$^4\text{He}$ target thickness</td>
<td>$1 \text{ g/cm}^2$</td>
<td>$d\sigma/d\Omega$</td>
</tr>
<tr>
<td>Reaction cross section</td>
<td>$10 \text{ \mu b/sr}$</td>
<td>$\Omega_{SP}$</td>
</tr>
<tr>
<td>Spectrometer solid angle</td>
<td>0.02 sr</td>
<td>$\varepsilon_{SP}$</td>
</tr>
<tr>
<td>Spectrometer efficiency</td>
<td>0.03</td>
<td>$\varepsilon_{Anal}$</td>
</tr>
<tr>
<td>Analysis efficiency</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

*Experimentally obtained NMWD decay branching ratio, $BR(K^0 \rightarrow \pi^+ \pi^-)$.

*E22 Proposal: $\Lambda^4H$ hypernucleus, we need to use single charge-exchange reactions. Here we propose associated production reaction: $^4\text{He}(\pi^+, K^+) 4\Lambda^4\text{He}$ produced through associated production reaction: $^4\text{He}(\pi^-, K^0) 4\Lambda^4\text{He}$ at J-PARC. To override the di.

The most significant di.

A Measurement of NMWD of

priv. comm.
\[ \text{Yield}(^{4}_{\Lambda}H) = N_{\text{Beam}} \times \frac{N_{\text{Target}}}{4} \times N_A \times \frac{d\sigma}{d\Omega} \times \Omega_{SP} \times \varepsilon_{SP} \times \varepsilon_{\text{Anal}} \times \frac{\text{Time}}{T_{\text{Cycle}}} \]

\[ \sim 11.4k \text{ } ^{4}_{\Lambda}H/\text{day}. \]

\[ \pi^{-}_{\text{react}} + ^{3,4}_{\Lambda}\text{He} \rightarrow ^{3,4}_{\Lambda}H + K^0 \quad 3,4\text{ }_{\Lambda}H \rightarrow ^{4}\text{He} + \pi^{-}_{\text{decay}}/d+p+\pi^{-}_{\text{decay}} \]

**lifetime measurement:** \( t_{\text{decay}} - t_{\text{react}} = T1 - T0 = t_{\pi^{-}(\text{react})} + \tau + t_{\pi^{-}(\text{decay})} \)

**prompt reaction:** \( T1 - T0 = t_{\text{decay}} - t_{\text{react}} = t_{\pi^{-}(\text{react})} + t_{\pi^{-}(\text{decay})} \)

Yield(\( ^{4}_{\Lambda}H \rightarrow ^{4}\text{He} + \pi^{-} \)) = Yield(\( ^{4}_{\Lambda}H \)) \times \text{BR} \times \Omega_{\pi} \times \varepsilon_{\pi} \times \varepsilon_{\text{analysis}}

\[ = \text{Yield}(^{4}_{\Lambda}H) \times 0.49 \times 0.5 \times 1 \times 0.8 \sim \text{Yield}(^{4}_{\Lambda}H) \times 0.2 \]

Tamura PRC 40 (1989) R479

\[ \sim 2 \times 10^3/\text{day} \quad 10^9 \pi^{-}/\text{spill} \rightarrow 1-2 \text{ beam days (full HIHR)} \rightarrow 2-4 \times 10^3 \text{ entries} \]

\[ \sim 2 \times 10^2/\text{day} \quad 10^8 \pi^{-}/\text{spill} \rightarrow 5-10 \text{ beam days (10\% HIHR)} \rightarrow 1-2 \times 10^3 \text{ entries} \]

\[ \sim 2 \times 10^1/\text{day} \quad 10^7 \pi^{-}/\text{spill} \rightarrow 10-20 \text{ beam days (present beam)} \rightarrow 2-4 \times 10^2 \text{ entries} \]
Yield($^3_{\Lambda}H$) = Yield($^4_{\Lambda}H$) * 4/3 * $[d\sigma/d\Omega]_3/[d\sigma/d\Omega]_4$

= Yield($^4_{\Lambda}H$) * 1 → 11.4 10^3/day 10^9 $\pi^-$/spill
= Yield($^4_{\Lambda}H$) * 0.1 → 11.4 10^2/day 10^9 $\pi^-$/spill

Yield($^3_{\Lambda}H \rightarrow d + p + \pi^-$) = Yield($^3_{\Lambda}H$) * BR * $\Omega_\pi$ * $\varepsilon_\pi$ * $\varepsilon_{\text{analysis}}$

~ Yield($^3_{\Lambda}H$) * 0.4 * 0.5 * 1 * 0.4 ~ Yield($^3_{\Lambda}H$) * 0.08

Kamada PRC 57 (1998) 1595 & & $\Lambda$ BR

~ 1.0 10^3/day 10^9 $\pi^-$/spill & & 1→ 1-2 days → 1-2 10^3 entries
~ 1.0 10^2/day 10^8 $\pi^-$/spill & & 1→ 5-10 days → 0.5-1 10^3 entries
~ 1.0 10^1/day 10^7 $\pi^-$/spill & & 1→ 10-20 days → 1-2 10^2 entries

~ 1.0 10^2/day 10^9 $\pi^-$/spill & & 0.1→ 5-10 days → 0.5-1 10^3 entries
~ 1.0 10^1/day 10^8 $\pi^-$/spill & & 0.1→ 10-20 days → 1-2 10^2 entries
Apparatus hints/ideas
(high K1.8/HIHR momentum and MM resolution performances)

- LHe target, E15 He target cell, very thin material layers
  (threshold on $\pi^-$ momentum $\sim 70$ MeV/c)
  inserted inside the inner CDC wall

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“free space” between LHe target outer wall and CDC inner wall $\sim 0.4$ cm radius
```
- time counters: start (T0), small segmented scintillator system \((10^7/cm^2 \ s \ vs \ \pi^-/spill)\) stop (T1), scintillator barrel (12-15 slabs), 3 mm thick, 15 cm length, \(~80-100 \ \text{ps} \ \sigma \ \text{res.}, \) located between LHe target and CDC (r\(\sim\)7.8 cm)

- CDC used by E22 to reject n background due to MWD \(\pi^-\) absorption at rest
  \(\rightarrow\) track straight charged decay particles \(\rightarrow\) vertex and Pld
  \(\rightarrow\) use as tracker if magnet is present (E15) \(\rightarrow\) vertex, \(\pi^-\) momentum and Pld

- range counter: \(\pi^-\) energy measurement and Pld \((dE/dx \ vs \ E, R, \ \text{hit position})\)
  (10 layers, 5.5 cm tot)
  \(\rightarrow\) energy resolution < 4-5 MeV FWHM
  \(\rightarrow\) Pld contamination < 1%

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**Figure 9:** Simulation calculation of the excitation energy spectrum of the \(^4\text{He}(\pi^+,K^-)\) reaction. The energy resolution of 2 MeV (FWHM) and the quasi-free background of integrated yield \((E_X < 15\text{MeV})\) 10 times as much as that of the signal events were assumed.

**Figure 10:** A conceptual design of the decay arm detector system. Figure shows a side view.

**Figure 11:** Same as Fig.10. Figure shows a beam view.

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E22 proposal (modified)
- \( ^3\Lambda H \) not stopped before decay (~400 MeV/c, \( R\sim\beta c\tau, \geq 50\% \) (?), decay in flight in the target) \( \rightarrow \gamma \sim 1.005, 0.5\% \) max. syst.

- prompt reaction: \((\pi^-, \pi^+ \pi^-_{\text{prompt}})\), time thresholds/windows
  - \( \pi^- \) from production reaction: \( \pi^- + \:^3\:^4\text{He} \rightarrow ^3\:^4\Lambda H + K^0, K^0_S \rightarrow \pi^+ \pi^-\pi^+ \): 2\(^{\circ}\)-14\(^{\circ}\), \( p_\pi > 650 \) MeV/c \( \rightarrow \pi^-: 40^{\circ}-100^{\circ}, p_\pi < 100 \) MeV/c, \( \tau \) well known
  - \( \pi^-_{\text{prompt}} \) from \((\pi^-, \pi^+ \pi^-)\) inelastic scattering

- background: \( \Lambda_{\text{q.f.}} \)
  - “absent” for \( ^4\Lambda\text{He} \) (\( B_{\Lambda} \sim 2 \) MeV, MM resolution!
    \( p_\pi \approx 133 \) MeV/c)

- \( ^3\Lambda\text{H} \) (\( B_{\Lambda} \sim 0.13 \) MeV) \( \rightarrow 3\text{b MWD: }^3\Lambda\text{H} \rightarrow d + p + \pi^- \)
  - lower \( \pi^- \) momentum (70-100 MeV/c): range counters \( \rightarrow \) magnetic analysis
how to measure $\tau(3\Lambda H, 4\Lambda H)$ at JLab

- $e$ beams $\rightarrow$ produce $3\Lambda H, 4\Lambda H$ through electroproduction reaction:

$$e + 3,4\text{He} \rightarrow e' + 3,4\Lambda H + K^+$$

- $E_\gamma = E(e) - E(e')$
- $Q^2 = E_\gamma^2 - p_\gamma^2$
- $p_\gamma = p(K^+) + p(\Lambda)$
- $p(\Lambda) \sim 0.35$ GeV/c

$\frac{d\sigma}{d\Omega} \propto 1/Q^2 \rightarrow$ low $Q^2$

$\frac{d\sigma}{d\Omega} \rightarrow$ small $\theta_e$

$p(\Lambda)$ small $\rightarrow \theta_{\gamma K} \sim 0^\circ$

high $p(K^+)$ for surv. prob.

$$MM^2 = (q^\mu + P_{\text{miss tot}} - p_{\mu K})^2$$

$\sigma_{MM} \sim 500-600$ keV FWHM

MM calibration: $p(e, e' K+ )\Lambda$
3. Experimental Setup

3.1 Experimental configuration

The proposed experiment is to obtain high precision mass spectroscopy of hypernuclei produced by the (e, e′K+) reaction and will employ a configuration including a pair of room temperature Septum magnets, the high resolution HRS (Hall A) and the large solid angle HKS spectrometers, as schematically illustrated in Fig. 3-1.

This pair of Septum magnets will be used to separate the scattered electrons and produced kaons at small forward angles to sufficiently large spectrometer angles, while allowing the post-beam to be directly transported to the dump. It also minimizes the chance for the high rate backgrounds (electrons and positrons) at near zero degrees to enter either of the two spectrometers. The collaboration has demonstrated the technique successful in avoiding the background from e′ and K+ accidental coincidences by maintaining sufficiently low singles rates at each of the two spectrometers under high luminosity conditions.

![Experimental layout diagram](image)

**Table 3-I: Basic kinematics parameters of the Septum+HRS and Septum+HKS systems.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Beam energy (12 GeV mode, 2-passes, injector energy included)</td>
<td>4.5238 GeV</td>
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<tr>
<td>E' (HRS) central angle (horizontal and vertical bites)</td>
<td>7° (±1.5° and ±2.5°)</td>
</tr>
<tr>
<td>E' (HRS) central momentum (percentage bite)</td>
<td>3.0296 GeV/c (±4.0%)</td>
</tr>
<tr>
<td>Virtual photon central angle (φ=π)</td>
<td>14°</td>
</tr>
<tr>
<td>Virtual photon energy range</td>
<td>1.37 – 1.62 GeV</td>
</tr>
<tr>
<td>Virtual photon momentum range</td>
<td>1.42 – 1.70 GeV/c</td>
</tr>
<tr>
<td>Average Q²</td>
<td>-0.21 (GeV/c)²</td>
</tr>
<tr>
<td>K⁺ (HKS) central angle (horizontal and vertical bites)</td>
<td>14° (±4.5° and ±2.5°)</td>
</tr>
<tr>
<td>K⁺ (HKS) central momentum (percentage bite)</td>
<td>1.2 GeV/c (±12.5%)</td>
</tr>
</tbody>
</table>

- ΛN interaction & charge-zero exotic hyp. (nΛ, nnΛ)
- CSB A=4
- BΛ for heavier hypernuclei (A=40-50, 208)

cryogenic gaseous ³,⁴He target: thickness ~ 58 mg/cm² (200 psi, 20 cm length → ρ ~ 0.0029 g/cm³ ~ 20 * ρ_gas)
Hall A & C results

<table>
<thead>
<tr>
<th>Target and objective hypernucleus</th>
<th>Beam current (µA)</th>
<th>Target thickness (mg/cm²)</th>
<th>Assumed cross section (nb/sr)</th>
<th>Expected Yield (/hour)</th>
<th>Num. of events</th>
<th>Req. beamtime (hours)</th>
<th>B.G. Rate (/MeV/h)</th>
<th>S/N (±1σ)</th>
<th>Comments</th>
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<tr>
<td>(^3)He ((^3)_ΛH)</td>
<td>20</td>
<td>58</td>
<td>5</td>
<td>1.3</td>
<td>100</td>
<td>80</td>
<td>0.08</td>
<td>18</td>
<td>Gas, Reference</td>
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<tr>
<td>(^4)He ((^4)_ΛH)</td>
<td>20</td>
<td>58</td>
<td>20</td>
<td>3.8</td>
<td>1000</td>
<td>266</td>
<td>0.07</td>
<td>57</td>
<td>Gas</td>
</tr>
</tbody>
</table>

**Yield\(^4\)_ΛH, \(^3\)_ΛH) production**

very thin target → negligible energy loss, good momentum resolution → good S/N

\[
\text{Yield}(^4\Lambda \rightarrow ^4\text{He} + \pi^-) = \text{Yield}(^4\Lambda \rightarrow ^4\text{He}) \times BR \times \Omega_\pi \times \varepsilon_\pi \times \varepsilon_{\text{analysis}}
\]

\[
= \text{Yield}(^4\Lambda \rightarrow ^4\text{He}) \times 0.49 \times 0.5 \times 1 \times 0.8 \sim 18/\text{day}
\]

500-1000 entries: 30-60 days

\[
\text{Yield}(^3\Lambda \rightarrow ^3\text{He} + \pi^-) = \text{Yield}(^3\Lambda \rightarrow ^3\text{He}) \times BR \times \Omega_\pi \times \varepsilon_\pi \times \varepsilon_{\text{analysis}}
\]

\[
= \text{Yield}(^3\Lambda \rightarrow ^3\text{He}) \times 0.4 \times 0.5 \times 1 \times \mathbf{0.4} \sim 2.5/\text{day}
\]

100-500 entries: 40-200 days
more dense target: \( \rightarrow \rho_{\text{dense}} \)

Dohrmann, PRL 93, 242501

high density cryogenic targets \(^3\text{He}: 0.310 \text{ g/cm}^2 \rightarrow \rho_{\text{dense}} \sim 0.0775 \text{ g/cm}^3, \(^4\text{He}: 0.546 \text{ g/cm}^2 \rightarrow \rho_{\text{dense}} \sim 0.1365 \text{ g/cm}^3 \)

\[
\text{Yield}(^4\Lambda\text{H}, ^3\Lambda\text{H})_{\text{dense}} = \text{Yield}(^4\Lambda\text{H}, ^3\Lambda\text{H}) \times \frac{\rho_{\text{dense}}}{\rho}
\]

\(^3\Lambda\text{H}: 1.3/\text{hour} \rightarrow \sim 35/\text{hour} \sim 800/\text{day} \)

\(^4\Lambda\text{H}: 1.3/\text{hour} \rightarrow \sim 179/\text{hour} \sim 4300/\text{day} \)

\[
\text{Yield}(^4\Lambda\text{H}, ^3\Lambda\text{H \ decay})_{\text{dense}}:
\]

\(^3\Lambda\text{H}: \sim 60/\text{day} \quad 500-1000 \text{ entries: 8-15 days} \)

\(^4\Lambda\text{H}: \sim 800/\text{day} \quad 1000-2000 \text{ entries: 2-3 days} \)

Drawbacks:
- worse momentum resolution (\(e', K^+, \pi^-\)), worse spectroscopy S/N
- higher energy loss \(\rightarrow\) higher momentum threshold on MWD \(\pi^-\)
Apparatus hints/ideas

• cryogenic gaseous He target: **higher density needed**
  - common (gas/liquid/solid) target chamber, external diameter 60-90 cm ...??
  - define dimensions, smaller diameter or T1 inside the chamber

• T0: probably not a direct measurement (I=20 μA), $t_{\text{react}}$ calculated from time signals on the K+ trajectory or from beam clock signal (DC?)

• T1: scintillator barrel (12-15 slabs?), 20 cm length, 4-5 mm thick, radius ...

• hollow cylindrical drift chamber (inner radius depending on target dimensions, thickness ~ 30 cm)
  → track straight charged decay particles, vertex
  → use as tracker if a magnet can be added (difficult, background): vertex, $\pi^-$ momentum and PID

• range counter: $\pi^-$ energy measurement and PID (dE/dx vs E, R, hit position) w/out magnet (and drift chamber?)
  (8-10 layers, 5-10 cm tot, to be studied!)
  → energy resolution < 4-5 MeV FWHM
  → PID contamination < 1%: e ($\beta$~1), $\pi$ (~100 MeV/c), p (≤400 MeV/c)
3. Experimental Setup

3.1 Experimental configuration

The proposed experiment is to obtain high precision mass spectroscopy of hypernuclei produced by the $(e, e'K^+)_{\text{reaction}}$ and will employ a configuration including a pair of room temperature Septum magnets, the high resolution HRS (Hall A) and the large solid angle HKS spectrometers, as schematically illustrated in Fig. 3.1.

This pair of Septum magnets will be used to separate the scattered electrons and electroproduced kaons at small forward angles to sufficiently large spectrometer angles, while allowing the post-beam to be directly transported to the dump. It also minimizes the chance for the high rate backgrounds (electrons and positrons) at near zero degrees to enter either of the two spectrometers. The collaboration has demonstrated the technique successful in avoiding the background from $e'$ and $K^+$ accidental coincidences by maintaining sufficiently low singles rates at each of the two spectrometers under high luminosity conditions.

Figure 3.1: Schematic illustration of the experimental layout. A pair of Septum magnets will be used to separate the scattered electrons (analyzed by HRS) and the reaction kaons (analyzed by HKS). All particles at near zero degrees will be sent to the dump.

adapted from Proposal JLab
• total material thickness:
  
  - low density target: He completely negligible, only apparatus materials
  - high density target: similar to LHe in J-PARC

  in general, presumably comparable to the J-PARC situation
  \( \rightarrow \) momentum cut on MWD \( \pi^- \sim 70 \text{ MeV/c} \)

• \( ^3,^4 \Lambda \text{H not stopped in He before decay} \) (\( \sim 350 \text{ MeV/c}, \gamma \sim 1.004, 0.4\% \text{ syst.} \))
  - low density target: \( R \gg \beta c \tau \rightarrow \) mainly decay in flight, outside the target
  - high density target (\( \sim \text{LHe} \)): \( R \sim \beta c \tau, \geq 50\% \) decay in flight, inside the target

• prompt reaction: \( (e, e' K^+(e^+)) \pi^- \) inelastic scattering

• background:
  
  \( \Lambda \text{ q.f.} \)
  - “absent” for \( ^4 \Lambda \text{H} (B_\Lambda \sim 2 \text{ MeV}, \text{MM resolution} \sim 600 \text{ keV}) \)
  - \( ^3 \Lambda \text{H} (B_\Lambda \sim 0.13 \text{ MeV}) \rightarrow 3b \text{ MWD}, \)
    lower \( \pi^- \) momentum (70-100 MeV/c): range counters (\( \rightarrow \) magnetic analysis ..)

  accidental \( (e' K^+) \) reduced by large opening angles of HRS and HKS

\( \text{to be carefully evaluated}!! \)
J-PARC

✓ YES
• present beam for $^4_\Lambda^4\text{H}$
• present beam/HIHR for $^3_\Lambda^3\text{H}$ vs $d\sigma/d\Omega$
• careful study of T1 insertion
• prompt reaction ($K^0_s$ lifetime)
• parasitic measurement possible

JLab

✓ YES $^4_\Lambda^4\text{H}$, $^3_\Lambda^3\text{H}$
• dense target (rate, decay point)
• T0 not directly measured

✓ HOWEVER
• no tracking for MWD products
• range counter critical (Pid, E)
• prompt reaction
• background study

✓ NO
• parasitic measurement

MAMI ...?

THANK YOU !!!
Kamada PRC 57 (1998) 1595 & & $\Lambda$ BR

$^3\Lambda H \to d+p+\pi^-$ and $d+n+\pi^0$: $\Gamma/\Gamma_\Lambda = 0.619$
$\Gamma_{tot}/\Gamma_\Lambda = 1.03$

$\Lambda \to p + \pi^-$  BR: 0.639
$\quad \to n + \pi^0$  BR: 0.358

$^3\Lambda H \to d+p+\pi^-$  BR: $0.619 * 0.639 \sim 0.4$
**detailed situation analysis**  $^3\Lambda$H lifetime measurements

<table>
<thead>
<tr>
<th>year</th>
<th>ref.</th>
<th>method</th>
<th>lab./react</th>
<th>$\tau$ (ps)</th>
<th>events</th>
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<tbody>
<tr>
<td>1963</td>
<td>Block, St. Cergue p.63</td>
<td><strong>He BC</strong></td>
<td>K$^-$, LBL Bevatron</td>
<td>$105^{+20}_{-18}$</td>
<td>29f + 7r</td>
</tr>
<tr>
<td>1964</td>
<td>Prem, PR 136 B1803</td>
<td>emuls.</td>
<td>K$^-$, BNL AGS</td>
<td>$90^{+220}_{-40}$</td>
<td>3f+1r</td>
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<tr>
<td>1965</td>
<td>Kang, PR 139 B401</td>
<td>emuls.</td>
<td>K$^-$, BNL AGS</td>
<td>$340^{+820}_{-140}$</td>
<td>5f+18r</td>
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<tr>
<td>1968</td>
<td>Keyes, PRL 20 819</td>
<td><strong>He BC</strong></td>
<td>K$^-$, ANL ZGS</td>
<td>$232^{+45}_{-34}$</td>
<td>3f+1r</td>
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<tr>
<td>1968</td>
<td>Phillips PRL 20 1383</td>
<td>emuls.</td>
<td>K$^-$, BNL AGS</td>
<td>$274^{+110}_{-72}$</td>
<td>21f+32r</td>
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<tr>
<td>1969</td>
<td>Phillips PR 180 1307</td>
<td>emuls.</td>
<td>K$^-$, BNL AGS</td>
<td>$285^{+114}_{-75}$</td>
<td>3f+1r</td>
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<tr>
<td>1970</td>
<td>Bohm, NPB 16 46</td>
<td>emuls.</td>
<td>K$^-$, CERN PS</td>
<td>$128^{+35}_{-26}$</td>
<td>120f+34r</td>
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<tr>
<td>1970</td>
<td>Keyes, PRD 1 66</td>
<td><strong>He BC</strong></td>
<td>K$^-$, ANL ZGS</td>
<td>$264^{+84}_{-52}$</td>
<td>27f</td>
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<td>1973</td>
<td>Keyes, NPB 67 269</td>
<td><strong>He BC</strong></td>
<td>K$^-$, ANL ZGS</td>
<td>$246^{+62}_{-41}$</td>
<td>40f</td>
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<tr>
<td>1992 (A)</td>
<td>Avramenko, NPA 547 95c</td>
<td>ions</td>
<td>He, Li on C, Dubna</td>
<td>$240^{+170}_{-100}$</td>
<td>few events</td>
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<tr>
<td>2010</td>
<td>STAR, Science 328, 58</td>
<td>HI</td>
<td>Au, BNL RHIC</td>
<td>$182^{+89}_{-45} \pm 27$</td>
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<tr>
<td>2013 (B)</td>
<td>STAR, NPA 904, 551c</td>
<td>HI</td>
<td>Au, BNL RHIC</td>
<td>$123^{+26}_{-22} \pm 10$</td>
<td>&gt; stat. ?</td>
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<tr>
<td>2013</td>
<td>HypHI, NPA 913, 170</td>
<td>ions</td>
<td>Li on C, GSI SIS</td>
<td>$183^{+42}_{-32} \pm 37$</td>
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<tr>
<td>2014</td>
<td>Rappold et al., PLB 728, 543</td>
<td>analysis</td>
<td>no (A) and (B)</td>
<td>$216^{+19}_{-16}$</td>
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<tr>
<td>2015</td>
<td>ALICE, arXiv:1506.08453</td>
<td>HI</td>
<td>Pb CERN LHC</td>
<td>$181^{+54}_{-38} \pm 33$</td>
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## $^4\Lambda\ H$ lifetime measurements

<table>
<thead>
<tr>
<th>year</th>
<th>ref.</th>
<th>method</th>
<th>lab./react</th>
<th>$\tau$ (ps)</th>
<th>events</th>
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<tbody>
<tr>
<td>1962</td>
<td>Crayton, HEP CERN, p. 460</td>
<td>emuls.</td>
<td>K$, LBL Bevatron</td>
<td>&lt; 120 $^{+70}_{-30}$</td>
<td>52f</td>
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<tr>
<td>1964</td>
<td>Prem, PR 136 B1803</td>
<td>emuls.</td>
<td>K$, BNL AGS</td>
<td>180 $^{+250}_{-70}$</td>
<td>3f + 4r</td>
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<tr>
<td>1965</td>
<td>Kang, PR 139 B401</td>
<td>emuls.</td>
<td>K$, BNL AGS</td>
<td>240 $^{+600}_{-100}$</td>
<td>5f + 40r</td>
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<tr>
<td>1969</td>
<td>Phillips PR 180 1307</td>
<td>emuls.</td>
<td>K$, BNL AGS</td>
<td>268 $^{+166}_{-107}$</td>
<td>10f + 5r</td>
</tr>
<tr>
<td>1991 (C)</td>
<td>Szymanski PRC 43 849</td>
<td>counter</td>
<td>K$^-$ on $^6$Li, BNL AGS</td>
<td>160 ± 20</td>
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<tr>
<td>1992 ('89)</td>
<td>Avramenko, NPA 547 95c</td>
<td>ions</td>
<td>He, Li on C, Dubna</td>
<td>220 $^{+50}_{-40}$</td>
<td>22</td>
</tr>
<tr>
<td>1992</td>
<td>Outa, NPA 547 109c</td>
<td>counter</td>
<td>K$^{-\text{stop}}$ on $^4$He, KEK PS</td>
<td></td>
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</tr>
<tr>
<td>1995</td>
<td>Outa, NPA 585 109c</td>
<td>counter</td>
<td>K$^{-\text{stop}}$ on $^4$He, KEK PS</td>
<td>194 $^{+24}_{-26}$</td>
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<tr>
<td>1998</td>
<td>Outa, NPA 639 251c</td>
<td>counter</td>
<td>K$^{-\text{stop}}$ on $^4$He, KEK PS</td>
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<tr>
<td>2013</td>
<td>HypHI, NPA 913, 170</td>
<td>ions</td>
<td>Li on C, GSI SIS</td>
<td>140 $^{+48}_{-33}$ ±35</td>
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</tr>
<tr>
<td>2014</td>
<td>Rappold et al., PLB 728, 543</td>
<td>analysis</td>
<td>no (C)</td>
<td>192 $^{+20}_{-18}$</td>
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</tr>
</tbody>
</table>

w.a. = 173 ± 14 ps with (C) (weighted average)
w.a. = 183 ± 18 ps w/out (C)
Dohrmann, PRL 93, 242501