$^3H_\Lambda$ lifetime: an open issue in hypernuclear physics

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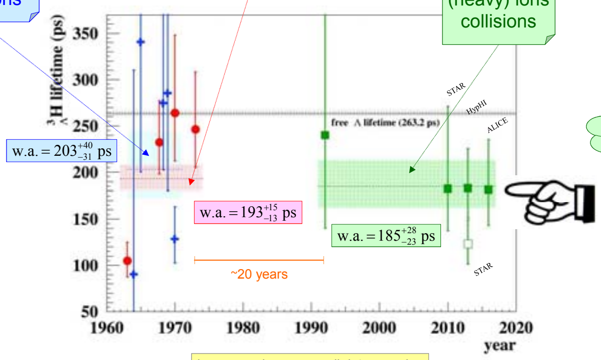
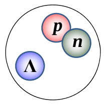
The physics case: which value for $^3H_\Lambda$ lifetime?



unexpected? surprising?

The naive expectation

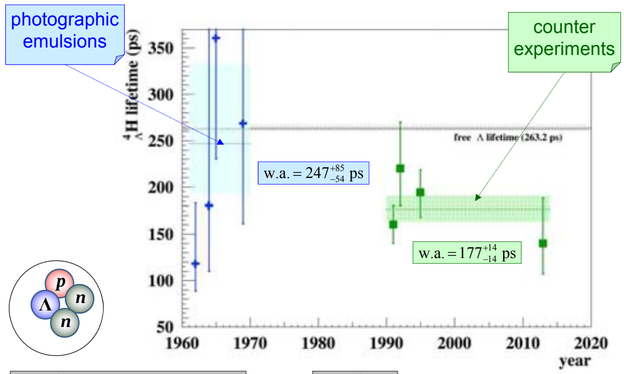


$B_\Lambda(^3_\Lambda\mathrm{H}) = 0.13 \pm 0.05$ MeV

$\tau(^3_\Lambda\mathrm{H}) \approx \tau(\Lambda_{free})$

supported by several theoretical predications, e.g.: M. Rayet, R.H. Dalitz, NCA 46 (1966) 786; H. Kamada *et al.*, PRC 57 (1998) 1595

The $^4H_\Lambda$ situation



$B_\Lambda(^4_\Lambda\mathrm{H}) = 2.12 \pm 0.01$ MeV >> $B_\Lambda(^3_\Lambda\mathrm{H})$

A new $\tau(^{3,4}H_\Lambda)$ measurement @ J-PARC

original idea: K^0 spectroscopy

$\pi^- + {}^{3,4}\mathrm{He} \rightarrow K^0 + {}^{3,4}_{\ \Lambda}\mathrm{H}$ @ $p_\pi \approx 1.0 \div 1.1$ GeV/c

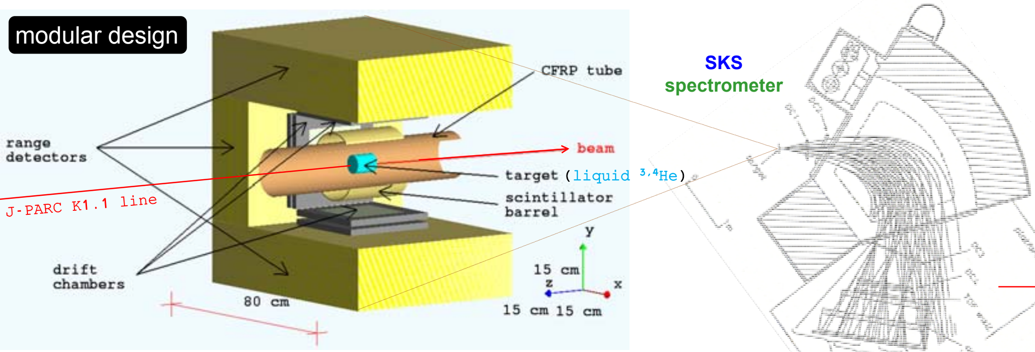
$\hookrightarrow \pi^+ + \pi^-$

asymmetric decay

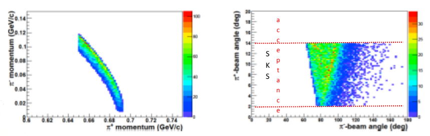
never exploited before!!!

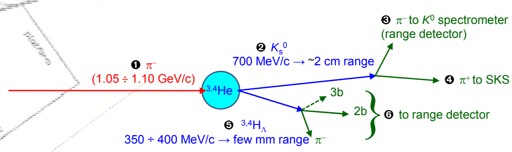
delayed time spectrum technique ⇒ $\tau(^A Z_\Lambda)$ ($t_{decay} - t_{production}$)

Experimental concept layout (not to scale)



Reaction kinematics:





Design performances:

- σ_{MM} ≤ 3 MeV (FWHM)
- σ_{time} ≤ 100 ps (FWHM)
- $\Delta\Omega$ ≈ 2 π sr
- $\sigma_{T(prongs)}$ ≤ 3 MeV
- σ_ϑ ≤ 100 mrad

Selection criteria:

❹ π⁺: p >650 MeV/c, 2° < ϑ < 14° ❸ π⁻: 10 < p < 120 MeV/c, 60° < ϑ < 100°
❻ π⁻: 0 < p < 133 MeV/c, 0° < ϑ < 180°

Expected rates

$$\mathrm{yield}(^4_\Lambda\mathrm{H}) = \mathrm{N_{beam}} \times \frac{\mathrm{N_{target}}}{4} \times N_A \times \frac{d\sigma}{d\Omega} \times \Omega_{sp} \times \varepsilon_{sp} \times \varepsilon_{an} \times \frac{time}{T_{cycle}}$$

$\mathrm{N_{beam}} = 10^9\ \pi/\mathrm{spill}$ $\mathrm{N_{target}} = 1\ \mathrm{g/cm^2}$

$\frac{d\sigma}{d\Omega} \approx 10\ \mu\mathrm{b/sr}$ $\Omega_{sp} = 0.02$ sr

$\varepsilon_{sp} = \mathrm{BR}(K^0 \rightarrow K^0_s \rightarrow \pi^+\pi^-) \times \varepsilon_{rc}(\pi^+\pi^-) = 0.03$

$\varepsilon_{an} = 0.5$ $\frac{time}{T_{cycle}} = 3.4$ s/spill

$$\mathrm{yield}(^4_\Lambda\mathrm{H}) \approx 1.14 \cdot 10^4 / \mathrm{d}$$

$$\mathrm{yield}(^4_\Lambda\mathrm{H} \rightarrow \pi^- + {}^4\mathrm{He}) = \mathrm{yield}(^4_\Lambda\mathrm{H}) \times \mathrm{BR} \times \Omega_\pi \times \varepsilon_\pi \times \varepsilon_{an} \approx \mathrm{yield}(^4_\Lambda\mathrm{H}) \times 0.2$$

H. Tamura *et al.*, PRC 40 (1989) 479 — 0.49 $\Omega_\pi \approx 0.5$ $\varepsilon_\pi \approx 1$ $\varepsilon_{an} = 0.8$

$$\mathrm{yield}(^3_\Lambda\mathrm{H}) = \mathrm{yield}(^4_\Lambda\mathrm{H}) \times \frac{4}{3} \times \frac{[d\sigma/d\Omega]_{^3_\Lambda\mathrm{H}}}{[d\sigma/d\Omega]_{^4_\Lambda\mathrm{H}}}$$

$$\frac{[d\sigma/d\Omega]_{^3_\Lambda\mathrm{H}}}{[d\sigma/d\Omega]_{^4_\Lambda\mathrm{H}}} = \ ?$$ educated guess $\approx (0.1 \div 1)$

$$\mathrm{yield}(^3_\Lambda\mathrm{H} \rightarrow \pi^- + p + d) = \mathrm{yield}(^3_\Lambda\mathrm{H}) \times \mathrm{BR} \times \Omega_\pi \times \varepsilon_\pi \times \varepsilon_{an} \approx \mathrm{yield}(^3_\Lambda\mathrm{H}) \times 0.1$$

H. Kamada *et al.*, PRC 57 (1998) 1595 — 0.40 $\Omega_\pi \approx 0.5$ $\varepsilon_\pi \approx 1$ $\varepsilon_{an} = 0.4$

$^4H_\Lambda$

π^- beam intensity	decay yield (/day)	beam time (days)	detected decays
10^9	~ 2 10^3	1-2	2-4 10^3
10^8	~ 2 10^2	5-10	1-2 10^3
10^7	~ 2 10^1	10-20	2-4 10^2

$\frac{[d\sigma/d\Omega]_{^3_\Lambda\mathrm{H}}}{[d\sigma/d\Omega]_{^4_\Lambda\mathrm{H}}}$ = 1 / = 0.1

$^3H_\Lambda$

π^- beam intensity	production yield (/day)	decay yield (/day)	beam time (days)	detected decays
10^9	1.14 10^4	~ 1000	1-2	1-2 10^3
	1.14 10^3	~ 100	5-10	0.5-1 10^3
10^8	1.14 10^3	~ 100	5-10	0.5-1 10^3
	1.14 10^2	~ 10	15-20	1.5-2 10^2
10^7	1.14 10^2	~ 10	15-20	1.5-2 10^2
	1.14 10^1	~ 1	20-30	20-30

educated guess on the beam intensity improvement

Further readings:
1) E. Botta *et al.*, RNC 38 (2015) 387
2) M. Agnello *et al.*, NPA 954 (2016) 176