Weak decay measurement of light hypernuclei at J-PARC

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- – Weak decay of hypernuclei
- – n/p ratio, asymmetry parameter
- – Proposed experiment
- – Yield estimation
- – Summary

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Weak decay of Λ hypernuclei

- mesonic decay: $\Lambda \rightarrow N\pi$
- nonmesonic decay: $\Lambda N \rightarrow NN$

  main decay mode medium/heavy hypernuclei

  large momentum transfer (~400MeV/c)

  strangeness changing weak interaction

  YN weak → baryon-baryon weak interaction

  observables:

  $\Gamma n/\Gamma p = \Gamma(\Lambda n \rightarrow nn)/\Gamma(\Lambda p \rightarrow np)$: n/p ratio

  α: asymmetry parameter

n/p ratio

np(I=0,1), nn(I=1) ⇒ isospin structure

one pion exchange

- large $^3S_1 \rightarrow {}^3D_1$ amplitude(I=0) ⇒ n/p ratio ~ 0.1

- Meson exchange – Ramos, Parreno, …
- Quark model – Oka, Inoue, Sakaki, …
- $2\pi/\rho$, $2\pi/\sigma$ mechanism– Itonaga, …

⇒ np-ratio: 0.4 ~ 0.7

n/p ratio – exp.

${}^{5}_{\Lambda}He$

0.93 ± 0.55 (J. Szymanski et al., PRC 43(1991)849)

${}^{12}_{\Lambda}C$

$1.33\ ^{+1.12}/_{-0.81}$ (J. Szymanski et al., PRC 43(1991)849)

$1.87 \pm 0.59\ ^{+0.32}/_{-1.00}$ (H. Noumi et al., PRC52(1995)2936)

(derived from single proton/neutron spectrum)

E462/E508 exp. – exclusive measurement of weak decay of ${}^{5}_{\Lambda}He$, ${}^{12}_{\Lambda}C$

0.4 ~ 0.6 (almost final)

- Now the theories become compatible with experimental results.
- We have to measure the nonmesonic weak decay with coincidence of final two nucleon

Asymmetry parameter

E160 – asymmetric proton emission from polarized $^{12}_{\Lambda}C$/$^{11}_{\Lambda}B$

$^{12}_{\Lambda}C$: A=–0.01±0.11, P_{Λ}=0.06~0.09
$^{11}_{\Lambda}B$: A=–0.19±0.10, P_{Λ}=0.16~0.21 PL B282(1992)293

- asymmetry parameter: –1.3±0.4

E278 – $^{5}_{\Lambda}He$

- asymmetry parameter: +0.24 ± 0.22 PRL 84(2000)4052
- polarization was determined experimentally

E462/E508 – $^{5}_{\Lambda}He$, $^{12}_{\Lambda}C$/$^{11}_{\Lambda}B$

$^{5}_{\Lambda}He$: +0.07 ± 0.08(stat.) (preliminary)

We confirm E278 result, although the asymmetries are derived from single proton spectra.

Theory – Meson-ex/DQ-ex

- –0.7 for both s-/p-shell hypernuclei

Asymmetry parameter

- Recent experimental results suggest small asymmetry parameter, which contradicts theoretical prediction.
- BUT the theory explains branching ratio fairly well.

→ Initial $^1S_0$ contribution has to be important for asymmetry.

(decay rates are mainly determined by $^3S_1$ amplitudes)

$^1S_0$ / $^3S_1$ $\qquad$ $^3S_1$

$$\frac{2\sqrt{3}\,\mathrm{Re}\left[-ae^* + b\left(c-\sqrt{2}d\right)^* / \sqrt{3} - f\left(\sqrt{2}c+d\right)^*\right]}{a^2+b^2+3\left(c^2+d^2+e^2+f^2\right)}$$

We need …

- to measure $^1S_0$ amplitudes directly,
- to measure asymmetry parameter with back-to-back coincidence of final two nucleons.

Nonmesonic decay of A=4, 5 hypernuclei

Allowed initial states for A=4, 5 hypernuclei

hypernucleus	$\Lambda n \rightarrow nn$	$\Lambda p \rightarrow np$
${}^{4}_{\Lambda}H$	${}^{1}S_{0}$, ${}^{3}S_{1}$	${}^{1}S_{0}$
${}^{4}_{\Lambda}He$	${}^{1}S_{0}$	${}^{1}S_{0}$, ${}^{3}S_{1}$
${}^{5}_{\Lambda}He$	${}^{1}S_{0}$, ${}^{3}S_{1}$	${}^{1}S_{0}$, ${}^{3}S_{1}$

- $\Gamma p({}^{4}_{\Lambda}H)$, $\Gamma n({}^{4}_{\Lambda}He)$

$\Rightarrow$ we can measure ${}^{1}S_{0}$ amplitudes directly.

- If $\Delta I=1/2$ rule holds, $\Gamma n({}^{4}_{\Lambda}He)/\Gamma p({}^{4}_{\Lambda}H)=2$.

$\Rightarrow$ we can check the validity of the $\Delta I=1/2$ rule in B-B weak interaction.

<u>Existing experimental results</u>

$\Gamma n({}^{4}_{\Lambda}He)/\Gamma_{\Lambda}=0.01^{+0.04}/_{-0.01}$ (KEK), 0.04 ± 0.02(BNL)   NP A639(1998)261c

$\Gamma p({}^{4}_{\Lambda}He)/\Gamma_{\Lambda}= 0.16\pm0.02$(KEK), 0.16 ± 0.02(BNL)   NP A639(1998)251c

Proposed experiment

Subject	Reaction	Spectrometer
${}^{4}_{\Lambda}$H: $\Lambda p \rightarrow np$	^{4}He(K^{-},π^{0})	π^{0}-spectrometer ΔM_{hyp} ~ 2MeV
${}^{4}_{\Lambda}$He: $\Lambda n \rightarrow nn$	^{4}He(K^{-},π^{-})	mag. spectrometer ΔM_{hyp} ~ 2MeV
${}^{5}_{\Lambda}$He: asymmetry	^{6}Li(π^{+},K^{+}p)	mag. spectrometer ΔM_{hyp} ~ 2MeV large acceptrance

We need to develop:

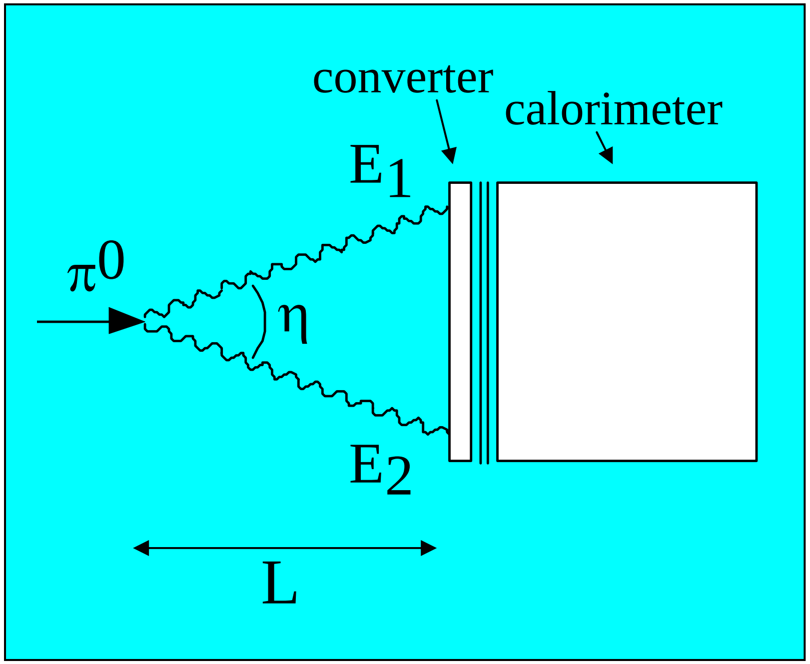
liq. He target, π^{0}-spectrometer, decay counter system

BNL E907/E931: measure the ^{4}He(stopped K^{-}, π^{0}) reaction

π^0 spectrometer

$$E_{\pi^0} = M_{\pi^0}\sqrt{\frac{2}{(1-\cos\eta)(1-X^2)}}$$

$$X = \frac{E_1 - E_2}{E_1 + E_2}$$



Energy resolution

$$\Delta E_{\pi^0} = \sqrt{\left(\frac{\partial E_{\pi 0}}{\partial E_\gamma}\Delta E_\gamma\right)^2 + \left(\frac{\partial E_{\pi 0}}{\partial \eta}\Delta \eta\right)^2}$$

at X ~ 0

$$\left(\Delta E_{\pi^0}\right)_{\Delta E_\gamma} \cong \frac{\sqrt{3}}{2}C^2, \quad \Delta E_\gamma = C\sqrt{E_\gamma}$$

CsI: C ~ 0.15 $\Rightarrow$ $\Delta E_{\pi 0}$ ~ 0.0022 MeV

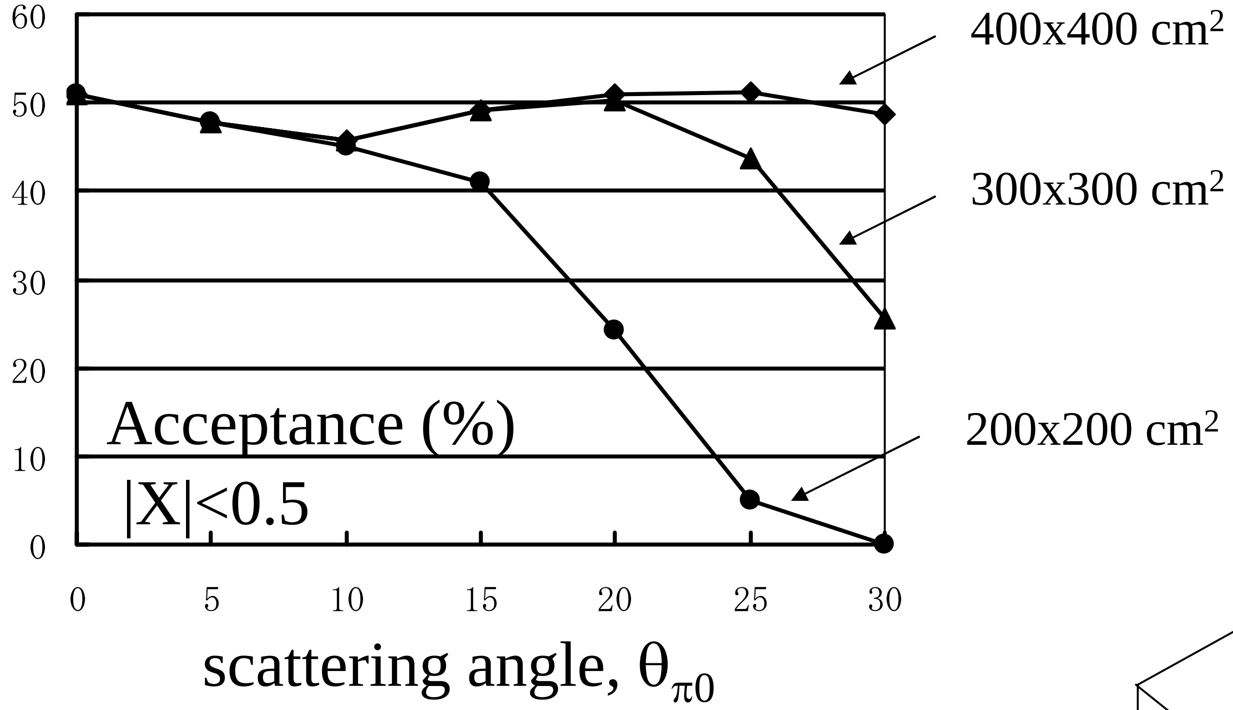
$$\left(\Delta E_{\pi^0}\right)_{\Delta \eta} \cong \frac{E^2\beta}{2M}\Delta\eta$$

700MeV/c π^0: <0.5 mrad for $\Delta E_{\pi 0}$(rms) < 1MeV

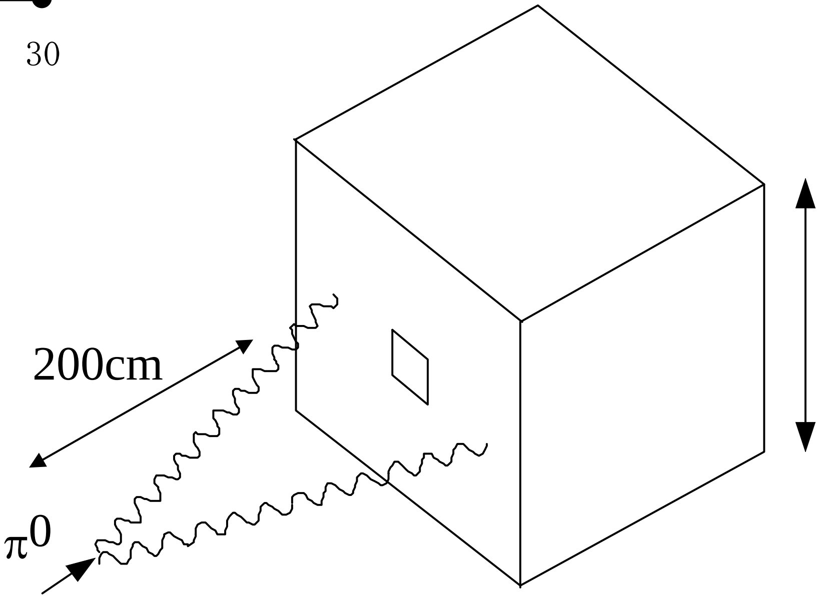
$\Rightarrow$ $\Delta L/L < 0.16$ %

1cm target thickness, if L=200cm

π^0 spectrometer – acceptance



acceptance ~ 100 msr
200x200cm2@200cm
including conversion efficiency: ~0.5



Yield estimation

	${}^{4}_{\Lambda}H$	${}^{4}_{\Lambda}He$	${}^{5}_{\Lambda}He$
beam intensity	5×10^{6} K^{-}/3.4 sec	5×10^{6} K^{-}	1×10^{7} π^{+}
target thickness	0.125 g/cm^2	1.25	4
cross section	0.2 mb/sr	0.5	0.005
spectrometer acceptance	0.10 sr	0.05	0.03
spectrometer efficiency	0.8	0.5	0.5×0.5
decay counter acceptance	0.5	0.5	0.5
efficiency for decay p	0.8	0.8	0.8
efficiency for decay n	0.2	0.2	0.2
branching ratio ($\Lambda n \rightarrow nn$)	0.1	0.01	-
branching ratio ($\Lambda p \rightarrow np$)	0.01	0.1	0.2
nn events/200 shifts	10000	5500	-
np events/200 shifts	4000	220000	4000
expected error level	1.6%	1.5%	4%

Summary

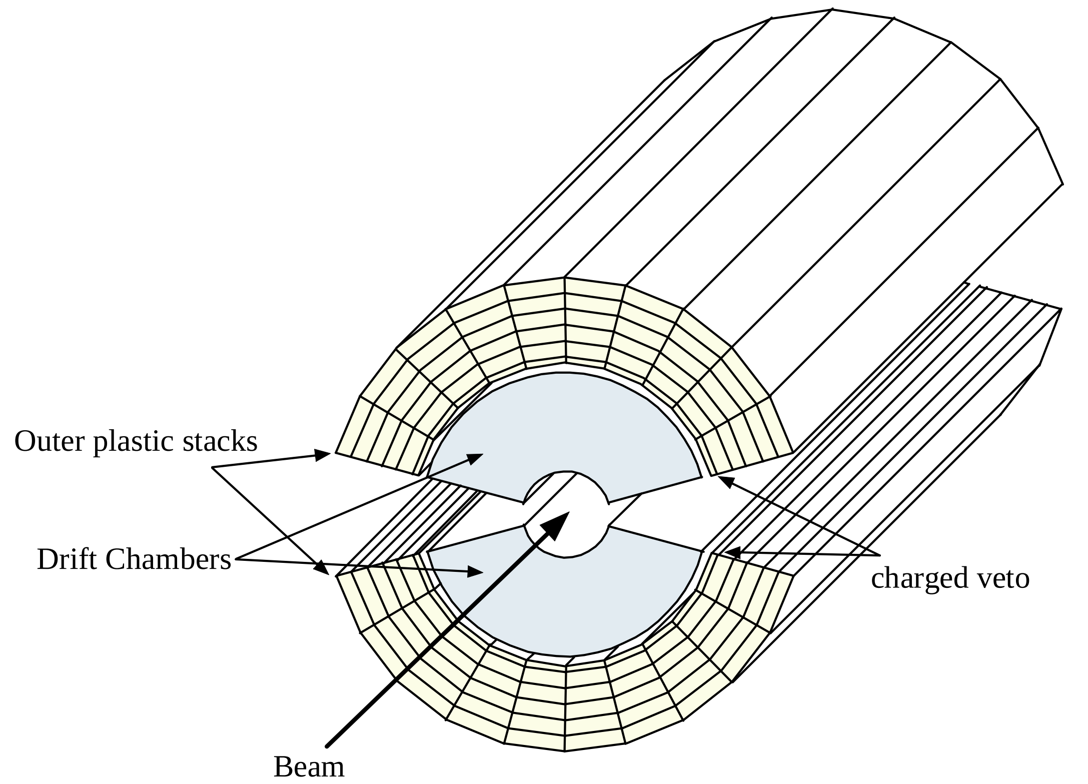
- We propose to measure the nonmesonic weak decay of A=4,5 hypernuclei with back-to-back coincidence of final nucleons.
- Key observables are:

  Decay rate of $\Lambda n \rightarrow nn$ of ${}^{4}_{\Lambda}He$

  Decay rate of $\Lambda p \rightarrow np$ of ${}^{4}_{\Lambda}H$

  Asymmetry parameter for $\Lambda p \rightarrow np$ of ${}^{5}_{\Lambda}He$
- Intense and pure secondary beam available at 50GeV-PS can give us a chance to derive conclusive experimental results for the nonmesonic weak decay of hypernuclei.

Conceptual design of decay counter system



- π/p separation

  ΔE – E

  ΔE – TOF

- thin plastic counter surrounding target(ΔE)

- outer plastic stack(E)

- tracking by DC

- neutron detection

- outer plastic stacks and charge veto

- γ/n separation and energy measurement can be done by TOF between beam hodoscope and outer plastic stacks

Nonmesonic decay

initial	final	amplitude	isospin	parity
$^1S_0$	$^1S_0$	a	1	no
	$^3P_0$	b	1	yes
$^3S_1$	$^1S_1$	c	0	no
	$^3D_1$	d	0	no
	$^1P_1$	e	0	yes
	$^3P_1$	f	1	yes

assuming initial S state

- n/p ratio: ratio of final isospin 1 to sum of 0 and 1

$$\frac{a_n{}^2 + b_n{}^2 + 3f_n{}^2}{a_p{}^2 + b_p{}^2 + 3(c_p{}^2 + d_p{}^2 + e_p{}^2 + f_p{}^2)}$$

- asymmetry parameter: interference between parity conserving and parity changing amplitudes

$$\frac{2\sqrt{3}\,\mathrm{Re}\left[-ae^* + b\left(c-\sqrt{2}d\right)^* / \sqrt{3} - f\left(\sqrt{2}c + d\right)^*\right]}{a^2 + b^2 + 3\left(c^2 + d^2 + e^2 + f^2\right)}$$

Nabetani et al.,

PRC 60(1999)017001