Nonmesonic decays of light Λ and double-Λ hypernuclear systems

Kenji Sasaki

Institute for Particle and Nuclear Study, KEK

Weak Decay of Λ Hyperon in Nucleus

▷ Nonmesonic decay

◇ elementary process

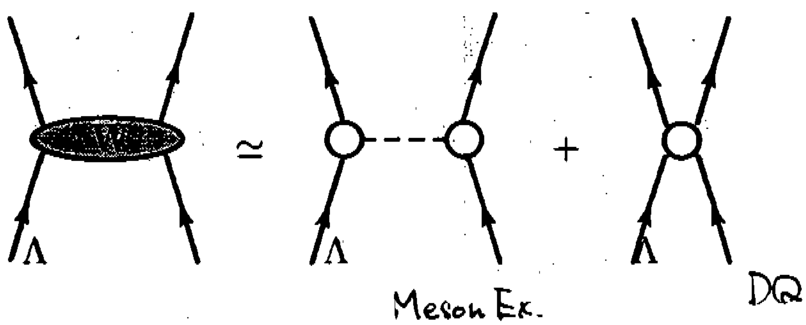
$$\Lambda + N \to N + N \quad p_N \simeq 400[\mathrm{MeV/c}]$$

⋆ proton induced decay : Γ_{pn} : $\Lambda + p \to p + n$

⋆ neutron induced decay : Γ_{nn} : $\Lambda + n \to n + n$

$$\boxed{\Gamma_{nm} = \Gamma_{pn} + \Gamma_{nn}}$$

▷ We assume both the meson and quark exchange diagrams.



▷ Topics

□ $\left(\frac{\Gamma_{nn}}{\Gamma_{pn}}\right)_{EXP} \gg \left(\frac{\Gamma_{nn}}{\Gamma_{pn}}\right)_{OPE}$

□ $J = 1$ dominance

□ breaking of $\Delta I = 1/2$ rule ?

□ puzzle of proton asymmetry

—Decay Rates

▷ In the finite nucleus
Here we consider only s-shell hypernuclei. ($^{5}_{\Lambda}$He, $^{4}_{\Lambda}$He, and $^{4}_{\Lambda}$H.)

$$\Gamma_{\rm NM} = \int \frac{d^3k_1}{(2\pi)^3} \int \frac{d^3k_2}{(2\pi)^3} (2\pi)\delta(E.C) \sum_{res} \mid \langle k_1, k_2, \Psi_{res} \mid \underline{V} \mid \Psi_i \rangle \mid^2$$

▷ Wave function

- Initial state
  - ⋆ Λ single particle wave function ← realistic Λ-nucleus potential
  - ⋆ Gaussian b parameters

b = 1.358[fm] for A = 5, b = 1.650[fm] for A = 4

$$\phi_Y(\vec{r}_Y)\phi_N(\vec{r}_N)\left\{\left(1 - e^{r^2/a^2}\right)^n - br^2e^{r^2/c^2}\right\}$$

a= 0.5, b=0.25, c=1.28, n=2

- Final state

$$e^{i\vec{K}\cdot\vec{R}'}e^{i\vec{k}\cdot\vec{r}}\left\{1 - j_0(q_c r)\right\} \quad q_c = 3.93\ [\mathrm{fm}^{-1}]$$

Comb. $^{2S+1}L_J$	Final Isospin I^f	Amplitudes $I^f_z = 0$	$I^f_z = -1$
$^1S_0 \to {}^1S_0$	$I^f = 1$	a_{pn}	a_{nn}
$\to {}^3P_0$	$I^f = 1$	b_{pn}	b_{nn}
$^3S_1 \to {}^3S_1$	$I^f = 0$	c_{pn}	—
$\to {}^3D_1$	$I^f = 0$	d_{pn}	—
$\to {}^1P_1$	$I^f = 0$	e_{pn}	—
$\to {}^3P_1$	$I^f = 1$	f_{pn}	f_{nn}

Structure of the weak interaction

M.M.Block, R.H.Dalitz
PRL11(1963)96

Initial	Final	Isospin	Amplitude		Parity
$^1S_0$	$^1S_0$	1	a_{pn}	a_{nn}	PC
	$^3P_0$	1	b_{pn}	b_{nn}	PV
$^3S_1$	$^1S_1$	0	c_{pn}		PC
	$^3D_1$	0	d_{pn}		PC
	$^1P_1$	0	e_{pn}		PV
	$^3P_1$	1	f_{pn}	f_{nn}	PV

$\Delta I=1/2$ rule

$a_{nn}=\sqrt{2}a_{pn},\ b_{pn}=\sqrt{2}b_{pn},\ f_{nn}=\sqrt{2}f_{pn}$

${}^4_\Lambda He : (p\Lambda)^{J=0}(n\Lambda)^{J=0}$

No f_{nn} amplitude

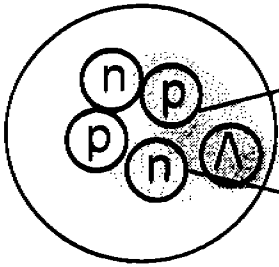
${}^4_\Lambda H : (p\Lambda)^{J=0}(nn)^{J=0}$

No d_{pn} amplitude

$\Delta I=1/2$ rule →

$$K=\frac{\Gamma_{nn}({}^4_\Lambda He)}{\Gamma_{pn}({}^4_\Lambda H)}=2$$

Nonmesonic decay of Λ hypernuclei



$\Lambda + p \rightarrow n + p : \Gamma_{pn}$

$\Lambda + n \rightarrow n + n : \Gamma_{nn}$

- n/p puzzle
- Asymmetry puzzle

${}^{5}_{\Lambda}He$	Total	Γ_{pn}	Γ_{nn}	n/p	α
π	0.372	0.328	0.044	0.133	-0.441
π +K	0.304	0.207	0.097	0.446	-0.362
π +K+DQ	0.523	0.304	0.219	0.720	-0.678
EXP	0.41 ± 0.14	0.21 ± 0.07	0.20 ± 0.11	0.93 ± 0.55	——
EXP	0.50 ± 0.07	0.17 ± 0.04	0.33 ± 0.04	1.97 ± 0.67	——
EXP	——	——	——	0.50 ± 0.10	0.09 ± 0.08

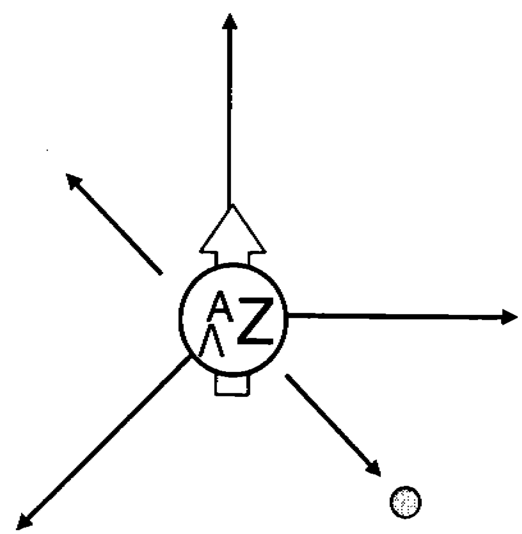
Proton Asymmetry

Explicit form of asymmetry parameter

$$\alpha \equiv \frac{2(\sqrt{3}[ae]-[bc]+\sqrt{2}[bd]+\sqrt{6}[cf]+\sqrt{3}[df])}{a^2+b^2+3(c^2+d^2+e^2+f^2)}$$

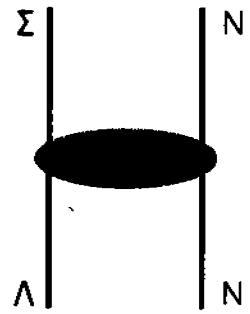
H.Nabetani, T.Ogaito, T.Sato, T.Kishimoto PRC60(1999)17001

Interference between J=0 and J=1 amplitudes



Σ-mixing contribution

H.Bando, Y.Shono, H.Takaki: IJMP.A3(1988)1581
K.Sasaki, T.Inoue, M.Oka: NPA707(2002)477

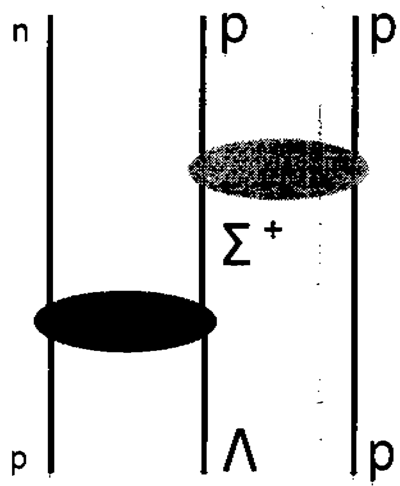


Virtual Σ N state is excited through Λ N→NN transition

Σ mixing nuclear state

$$\left|{}^{4}_{\Lambda}Z\right\rangle = \sqrt{1-\beta^2}\,\left|\Lambda\times[3N]\right\rangle + \beta\left|\Sigma\times[3N]\right\rangle$$

Physical hypernuclear state



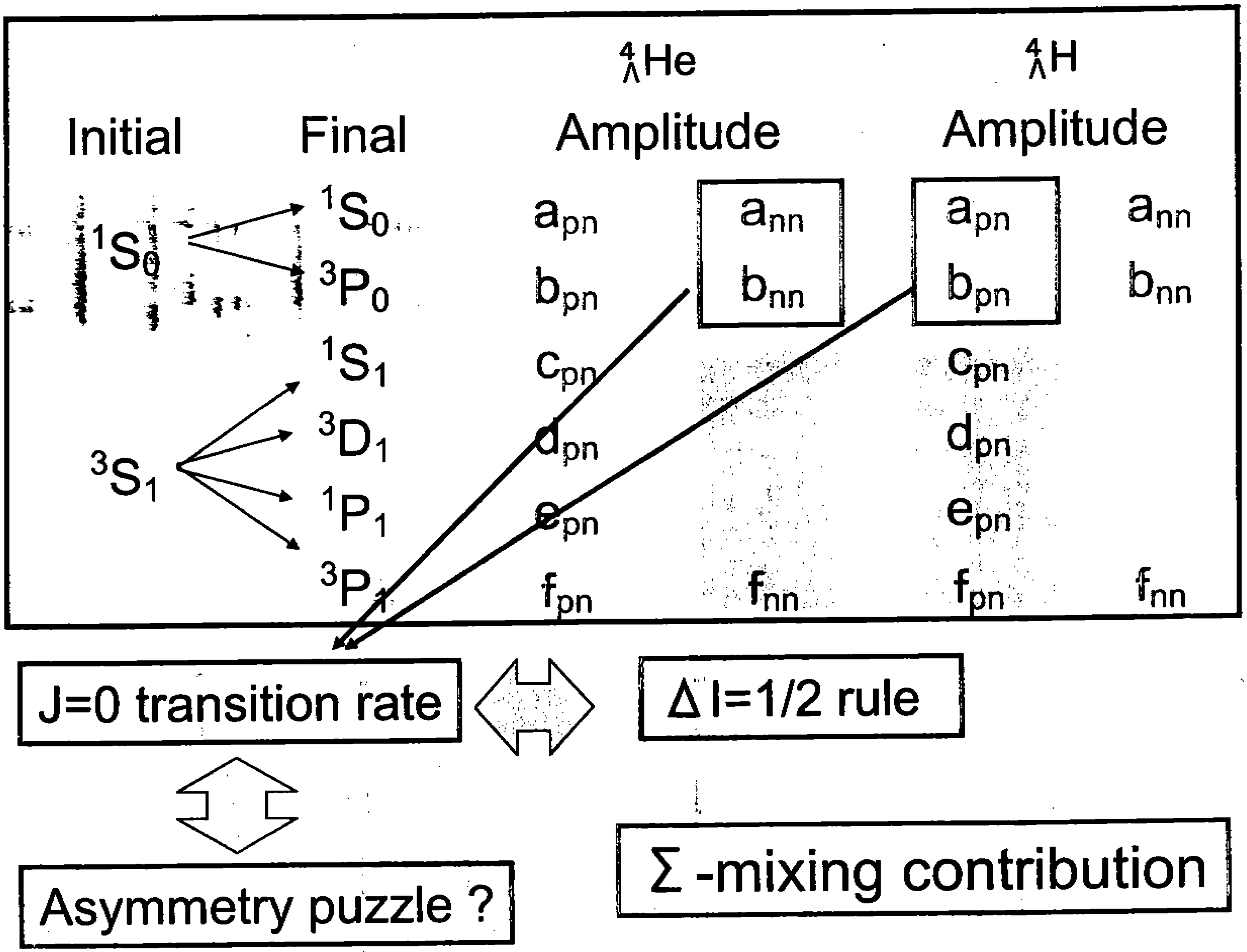
${}^{4}_{\Lambda}$He case

Weak decay from | Σ N;I=3/2> state

$\Sigma^{+}p \rightarrow pp$ transition is allowed

⇒ Signal of virtual Σ N state !

Four-body systems:



Breaking of $\Delta I=1/2$ rule in NM decay

${}^4_\Lambda He$	Total	Γ_{pn}	Γ_{nn}	n/p
π+K+DQ	0.218	0.214	0.004	0.019
$\beta=-0.1$	0.168	0.165	0.003	0.017
EXP	0.20 ± 0.03	0.16 ± 0.02	0.04 ± 0.02	0.25
EXP	0.17 ± 0.05	0.16 ± 0.02	0.01	0.06

${}^4_\Lambda H$	Total	Γ_{pn}	Γ_{nn}	n/p
π+K+DQ	0.187	0.030	0.157	5.318
$\beta=-0.1$	0.168	0.034	0.134	3.938
EXP	0.17 ± 0.11			

$\kappa(\pi+K+DQ)=0.13$

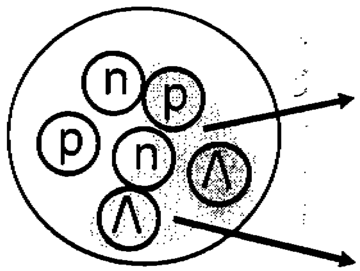
$\kappa^{\Sigma}(\pi+K+DQ)=0.09$

→ $\Delta I=1/2$ dominance is violated in our model

1. V.J.Zeps et al, NPA639(1998)261c
2. H.Outa et al, NPA639(1998)251c

We need the accurate data for ${}^4_\Lambda H$!

Nonmesonic decay of double-Λ hypernuclei



ΛN→NN transition
Dominant decay mode

ΛΛ→YN transition
Novel decay mode of double-Λ hypernuclei

ΛΛ pair is restricted to J=0

ΔI=1/2 rule
$2\Gamma_{\Sigma^- p} \fallingdotseq \Gamma_{\Sigma^0 n}$

${}^{6}_{\Lambda\Lambda}$He	Λn	$\Sigma^- p$	$\Sigma^0 n$
π	———	0.0070	0.0035
π+K	0.0003	0.0050	0.0100
π+K+DQ	0.0024	0.0085	0.0065

Summary and conclusion

Total decay rate and n/p ratio

J=1 transition rate → Property of J=1 amplitudes

J=1 transition rate → J=1 amplitude is hindered

Asymmetry puzzle

J=0 transition amplitude

J=1 transition amplitude

Both amplitudes are important !!

Four-body system

Σ -mixing contribution

$\Lambda\Lambda \to YN$ transition

$\Lambda\Lambda \to YN$ transition ↔ Decay rate is tiny

We need the data for $\Lambda\Lambda \to YN$ transition