γ spectroscopy of $^{11}_{\Lambda}$B

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for KEK-PS E518 collaborat

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3. Structure of $^{11}_{\Lambda}$B
4. Observed γ-rays from $^{11}_{\Lambda}$B
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6. Summary

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Purpose

- Spin dependent force of ΛN effective interaction

$\Delta =$ 0.5 MeV from $^{7}_{\Lambda}\mathrm{Li}\ (3/2^{+} \leftrightarrow 1/2^{+})$

$S_N =$ − 0.4 MeV from $^{7}_{\Lambda}\mathrm{Li}\ (5/2^{+} \leftrightarrow 1/2^{+})$

$S_\Lambda =$ −0.01 MeV from $^{9}_{\Lambda}\mathrm{Be}\ (5/2^{+} \leftrightarrow 3/2^{+})$

$T =$ 0.03 MeV from $^{16}_{\Lambda}\mathrm{O}\ (1^{-} \leftrightarrow 0^{-})$

Cross check with other hypernuclei is necessary

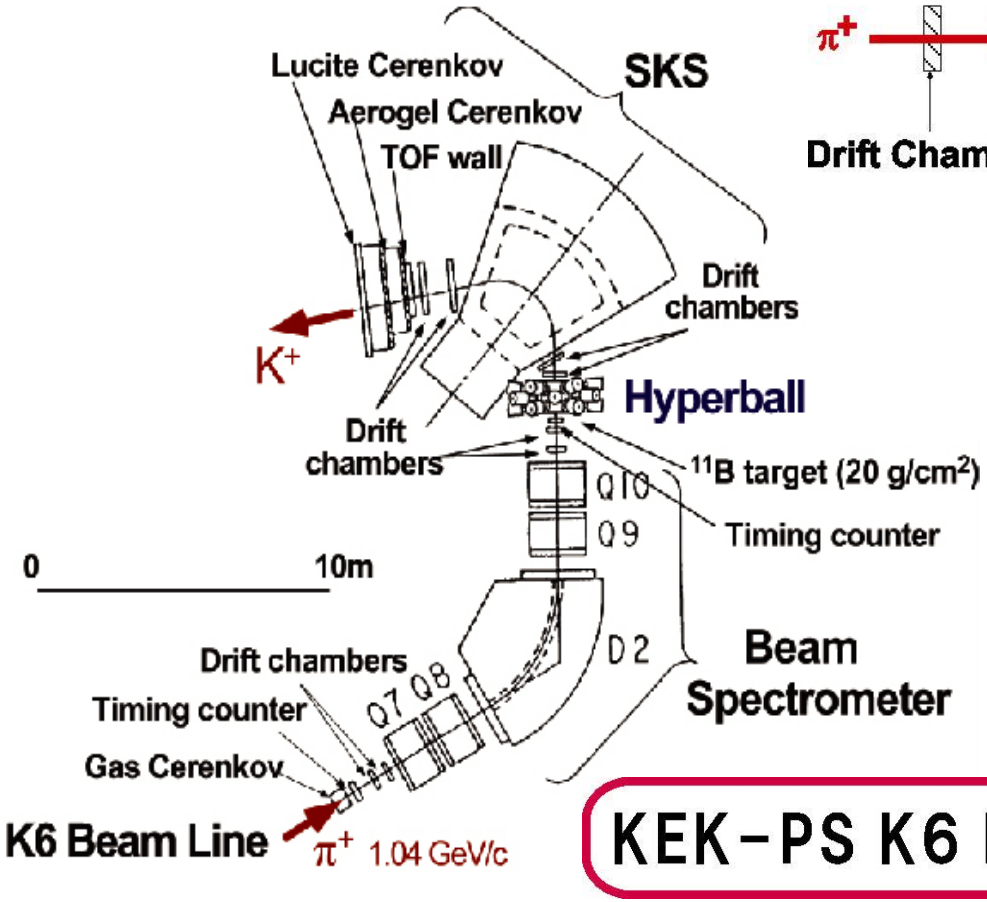
- Magnetic moment of Λ in the nucleus

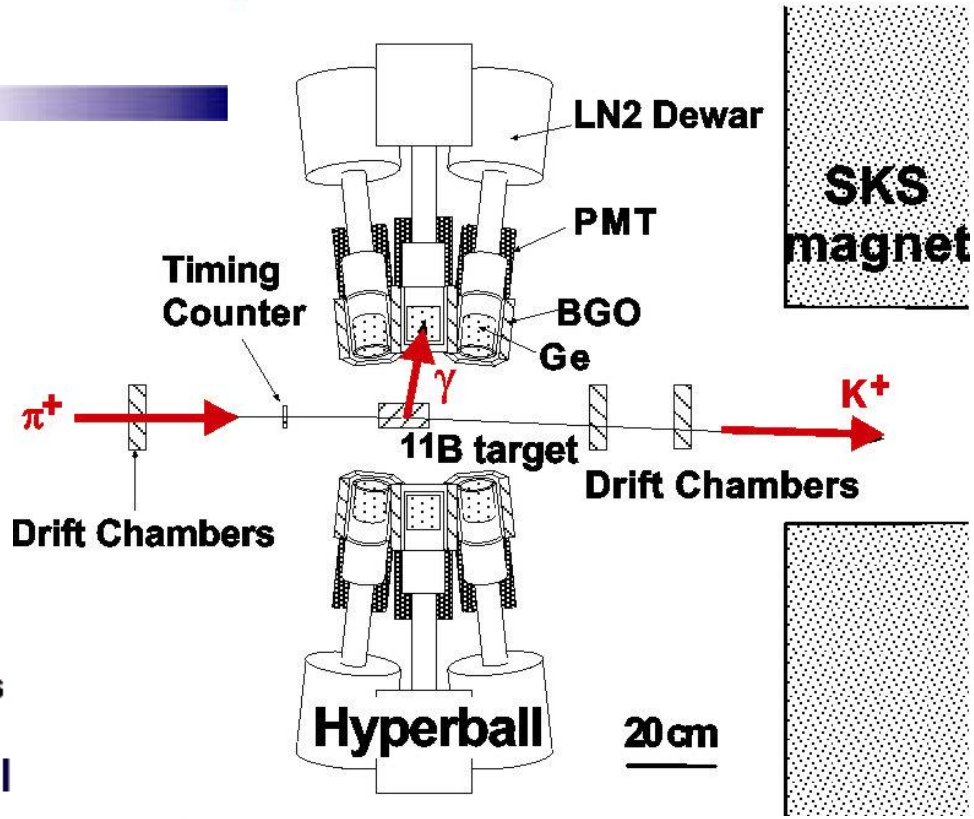
B(M1) of Λ spin-flip M1 transition

$$B(M1) \propto |\langle \phi_f | \mu^z | \phi_i \rangle|^2$$
$$\propto |\langle \phi_\Lambda \phi_{core} | g_{core} j_{core} + g_\Lambda j_\Lambda | \phi_\Lambda \phi_{core} \rangle|^2$$
$$\propto (g_\Lambda - g_{core})^2$$

Experimental Setup

$^{11}B(\pi^+, K^+\gamma)^{11}_{\Lambda}B$





Tag bound states of $^{11}_{\Lambda}B$

↓

Observe γ-ray

KEK-PS K6 beamline

Structure of $^{11}_{\Lambda}$B

Many bound states exist

- Nine γ transitions were expected to be observed in KEK-PS E518

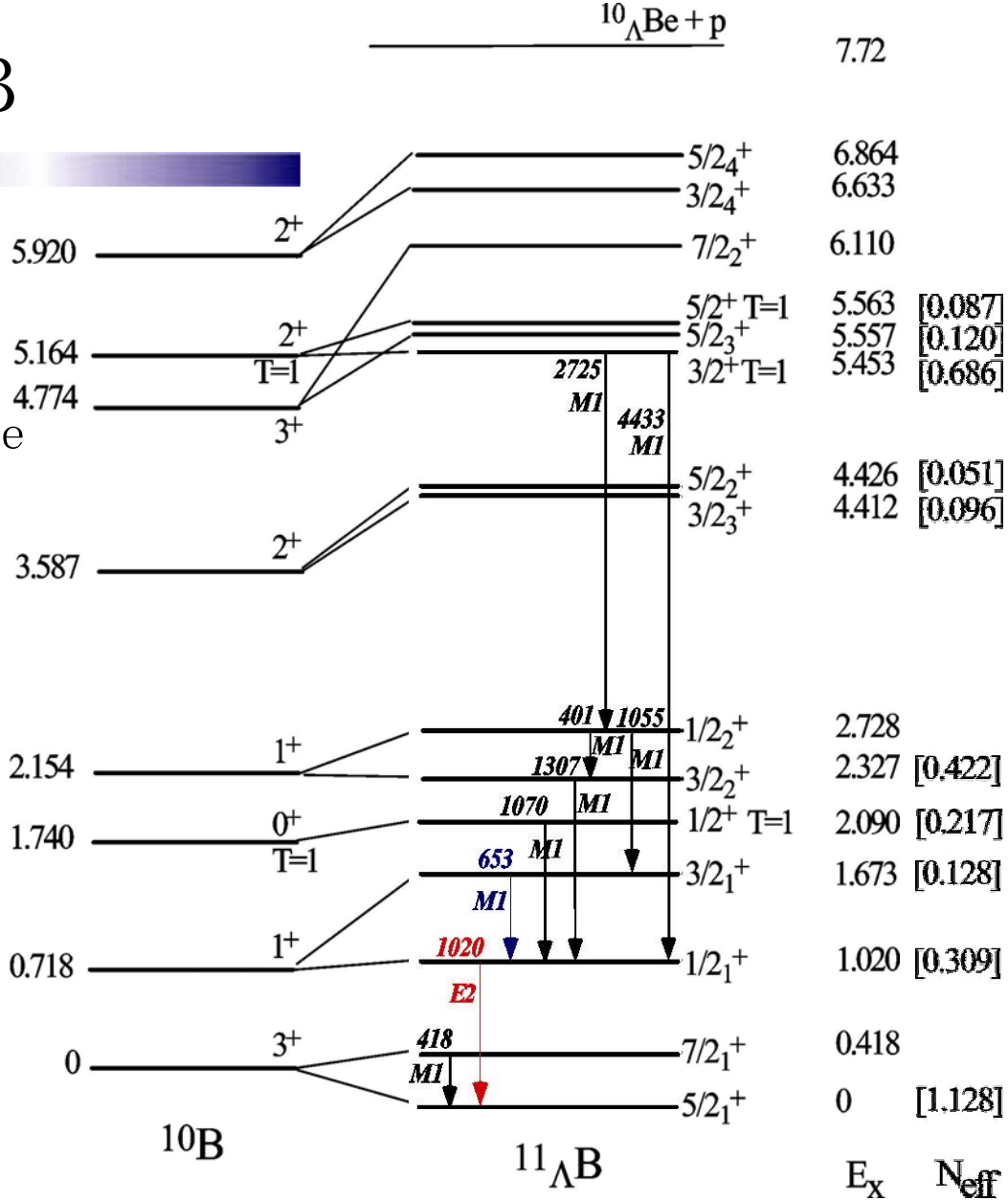
- $^{11}_{\Lambda}B(1/2^+ \rightarrow 5/2^+)$

  Largest yield

  direct + cascade

- $^{11}_{\Lambda}B(3/2^+ \rightarrow 1/2^+)$

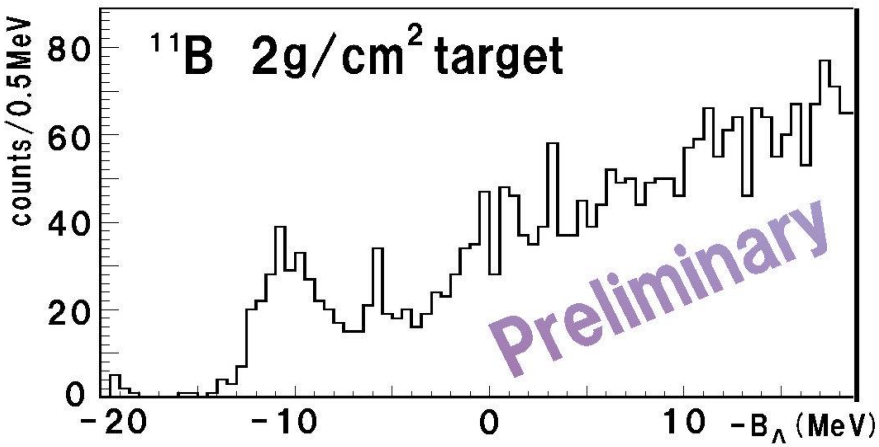
  B(M1) can be measured

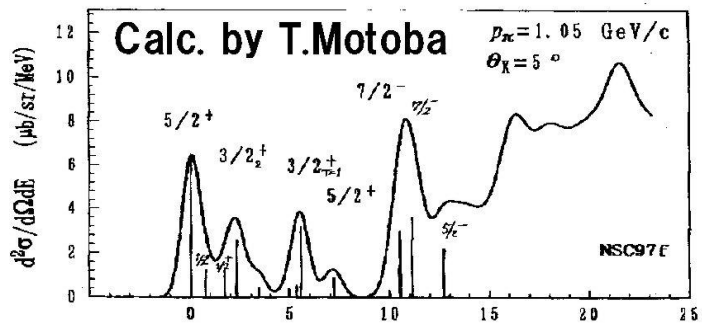


Millener's prediction

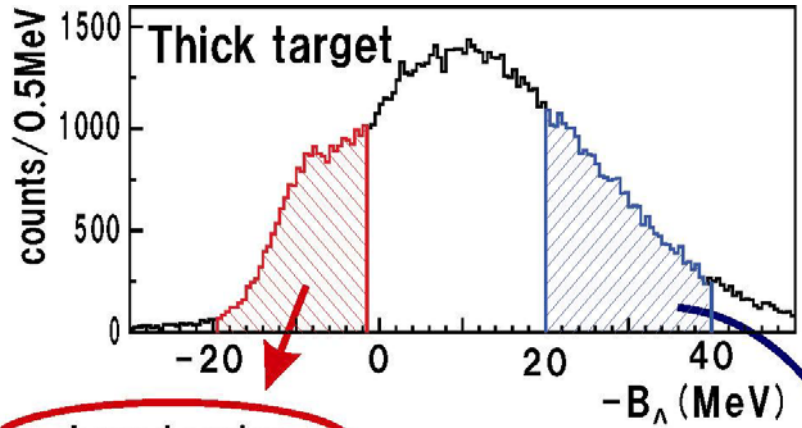
with experimentally determined parameters

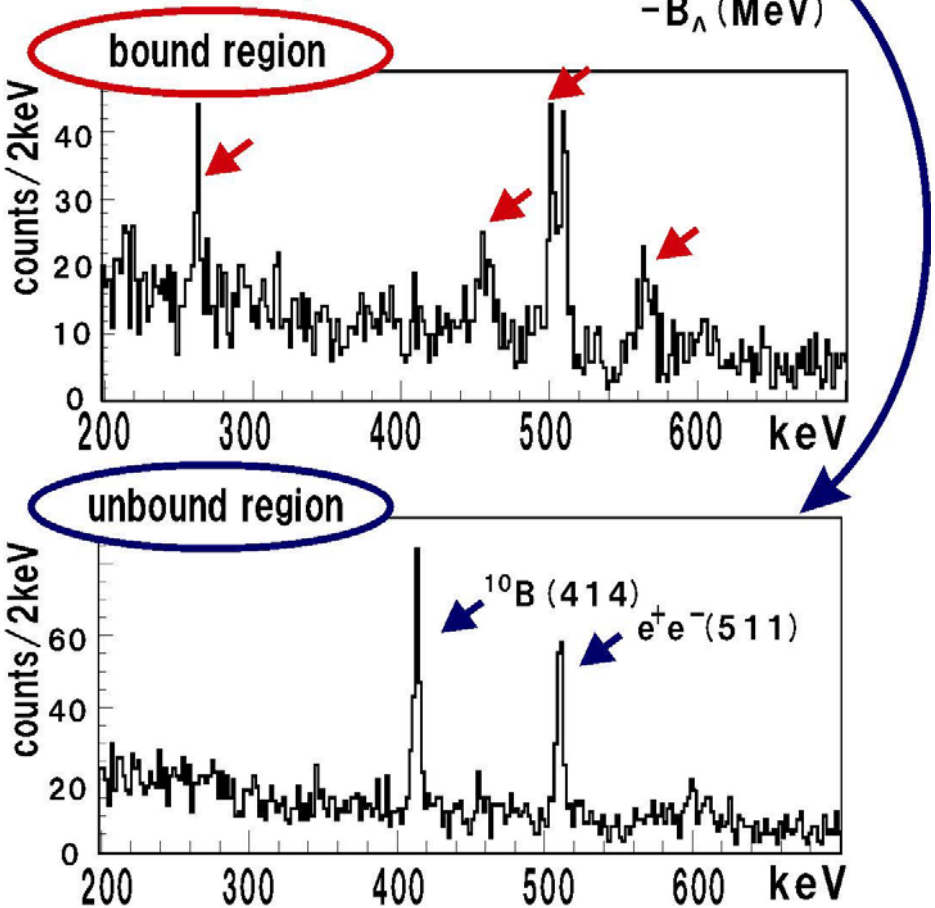
Analysis



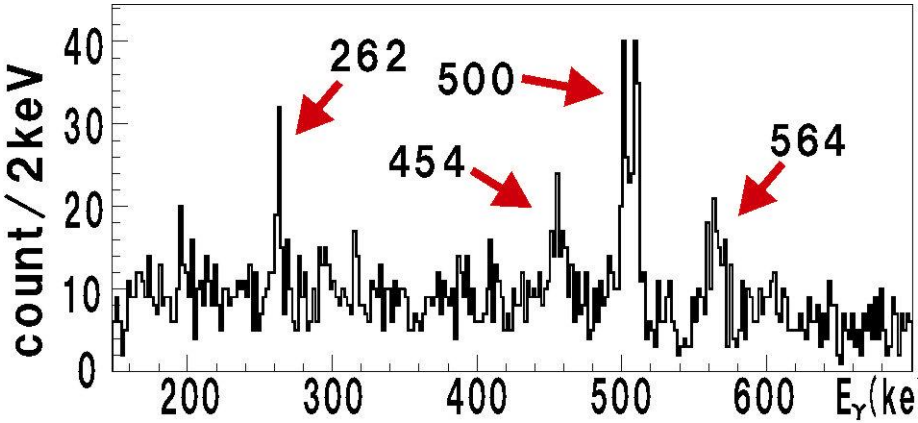


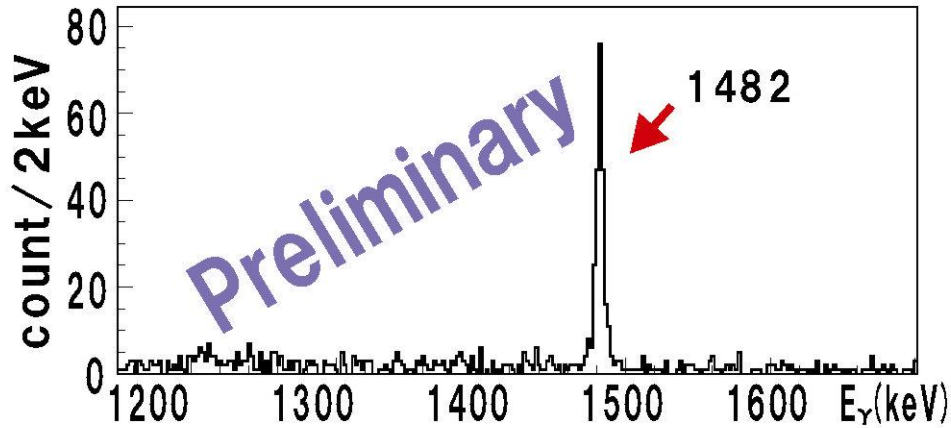
Total amount of irradiation
(one month)
Thick target : $1.6\times10^{12}\ \pi^+$





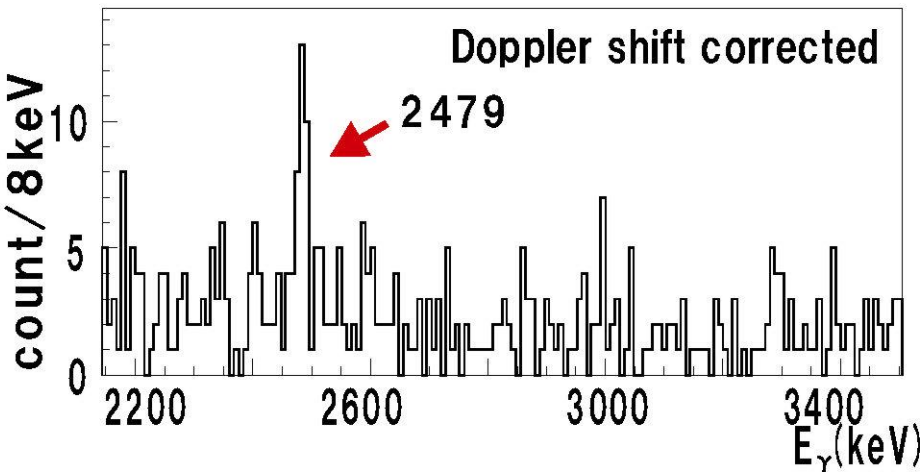
Observed γ-rays from $^{11}_{\Lambda}$B





E_γ(keV)	relative intensity
262	0.09
454	0.10
500	0.16
564	0.17
1482	1.00
2479	0.13

$$\text{relative intensity} = \frac{[\#\text{event}]}{225} \cdot \frac{[\text{efficiency@1482keV}]}{[\text{efficiency of Ge}]}$$

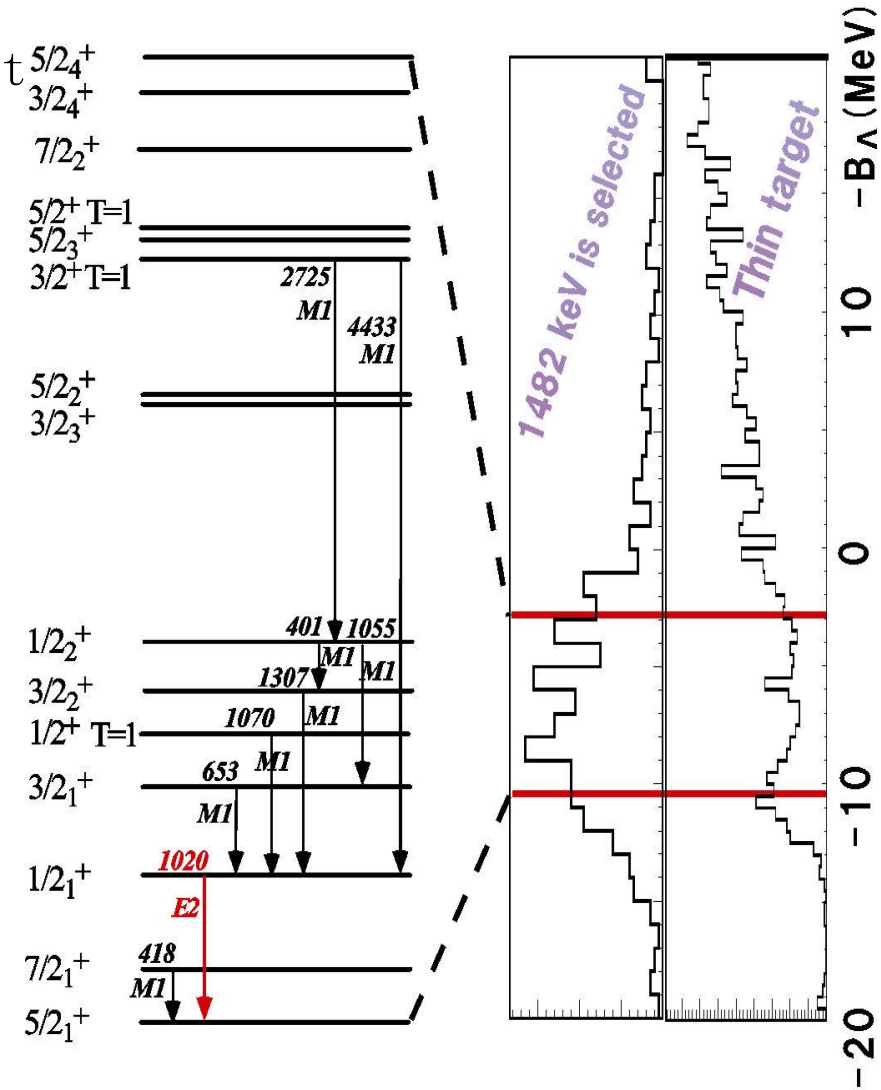


Identification of 1482 keV γ-ray

- Not broadened by Doppler effect
  - Peak width → $\tau > 10$[psec]
  - $B(M1) < 10^{-3}$ [W.u] → E2 is favored
- Largest yield
- Emitted from near ground state
  - Direct + Cascade

$^{11}_{\Lambda}B\,(E2;1/2^{+}\rightarrow 5/2^{+})$ is most likely

To identify other transitions,
$\gamma\,\gamma$ coincidence is necessary



Comparison with Millener's prediction

Expected energy spacing from ΛN interaction

$\Delta = 0.5$ MeV , $S_N = -0.4$ MeV , $S_\Lambda = -0.01$ MeV , $T = 0.03$ MeV

$$\Delta E\left(1/2^+_1 \rightarrow 5/2^+_1\right) = \Delta E_{core} - 0.243\Delta + 1.234 S_\Lambda - 1.090 S_N - 1.627 T + \Lambda\Sigma = 1020 \text{ keV}$$

transition	measured	expected	
${}^{7}_{\Lambda}\mathrm{Li}\left(3/2^+ \rightarrow 1/2^+_1\right)$	691.7 keV		Δ
${}^{7}_{\Lambda}\mathrm{Li}\left(5/2^+ \rightarrow 1/2^+_1\right)$	2050.1 keV		S_N
${}^{9}_{\Lambda}\mathrm{Be}\left(3/2^+ \leftrightarrow 5/2^+\right)$	46 keV		S_Λ
${}^{7}_{\Lambda}\mathrm{Li}\left(1/2^+_2 \rightarrow 1/2^+_1\right)$	3877 keV	3779 keV	S_N
${}^{13}_{\Lambda}\mathrm{C}\left(3/2^+ \rightarrow 1/2^+\right)$	4880 keV	4831 keV	S_N
${}^{16}_{\Lambda}\mathrm{O}\left(1^-_2 \rightarrow 1^-_1\right)$	6534 keV	6435 keV	S_N
${}^{11}_{\Lambda}\mathrm{B}\left(1/2^+_1 \rightarrow 5/2^+_1\right)$	1482 keV	1020 keV	S_N

$S_N = -0.9$ MeV from ${}^{11}_{\Lambda}$B

$S_N = -0.4$ MeV from ${}^{7}_{\Lambda}$Li

${}^{11}_{\Lambda}$B seems inconsistent with other experiments

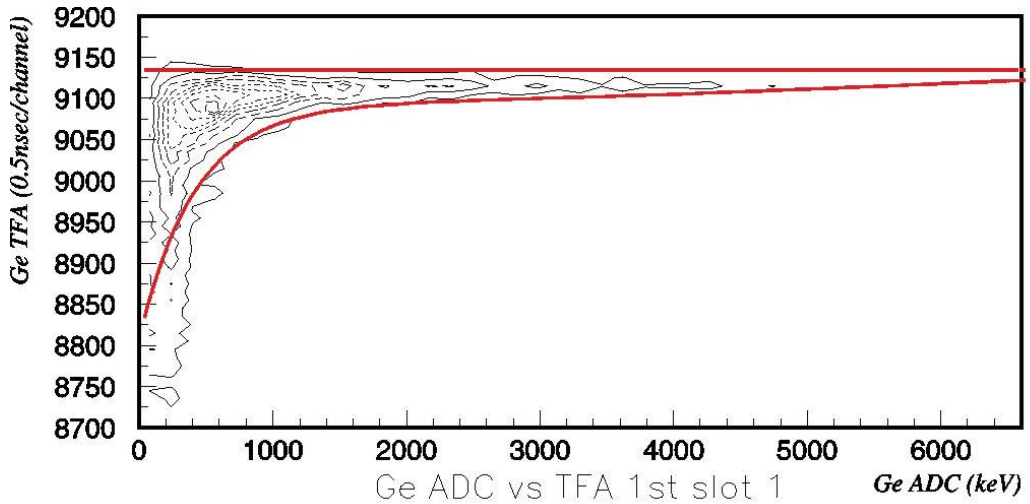
We need more experimental data to confirm ΛN interaction

Summary

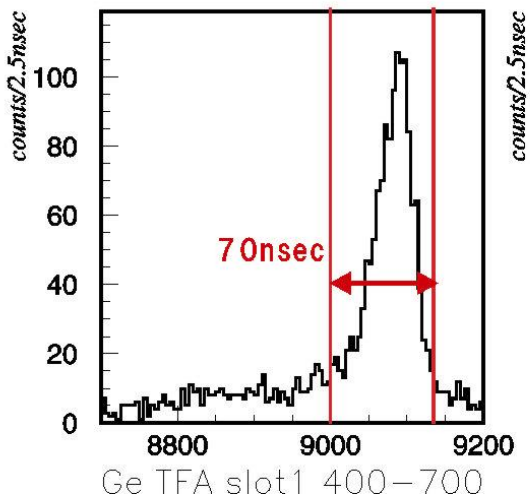
- Purpose of γ spectroscopy of $^{11}_{\Lambda}$B is to confirm ΛN effective interaction parameters and to measure magnetic moment of Λ in the nucleus.
- Using (π^+, K^+) reactions, six γ trasitions from $^{11}_{\Lambda}$B are obse
- The 1482 keV γ ray seems to be identified as $^{11}_{\Lambda}$B($E2; 1/2^+ \rightarrow 5/2^+$) but its energy is different from theoretical prediction.
- In order to identify other transitions, $\gamma\gamma$ coincidence is neces We need more beamtime.
- To confirm ΛN interaction, we have to investigate several hype

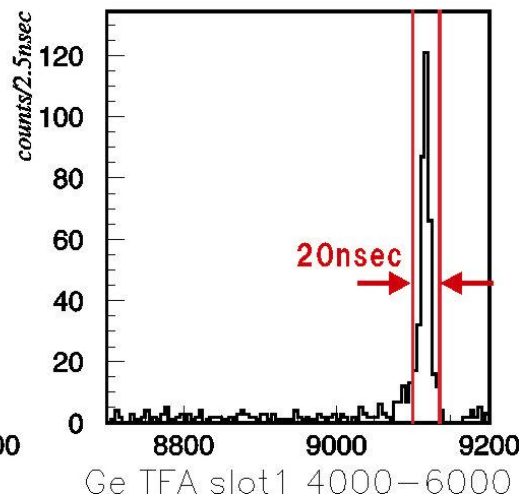
Analysis for Ge detectors

- Ge timing cut



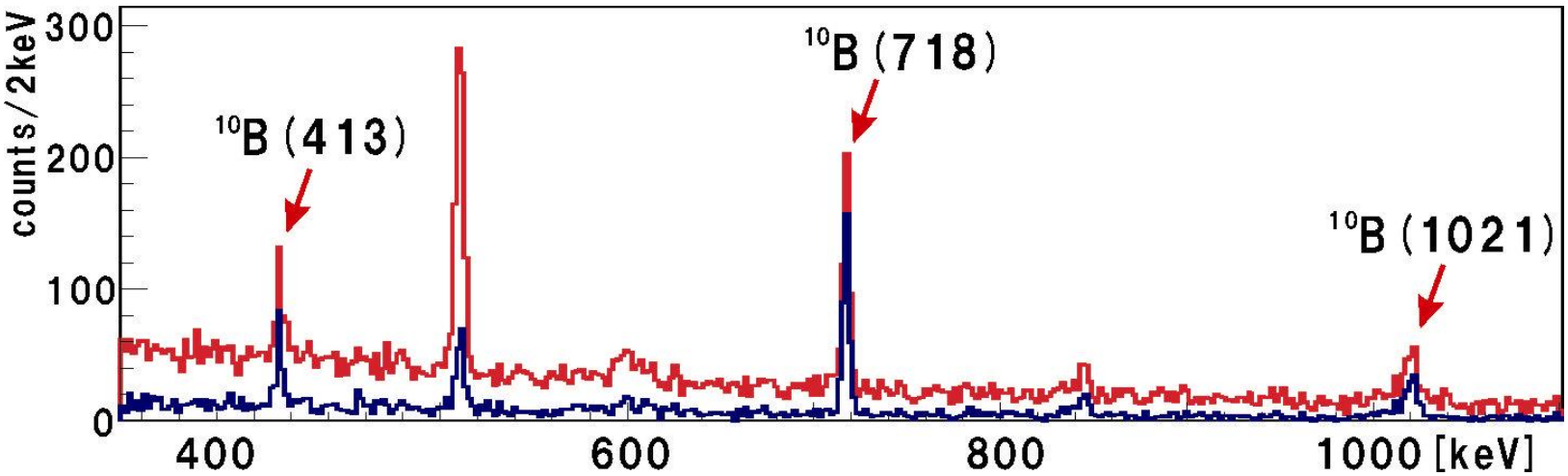
- Pile up rejection
  - → 2 hits within 3μsec
- Reset rejection





Analysis for Ge detectors

BGO suppression



γ-rays from ^{10}B is not reduced

Energy calibration

^{152}Eu source is used for calibration

No significant gain shift during beamtime

ΛN effective interaction

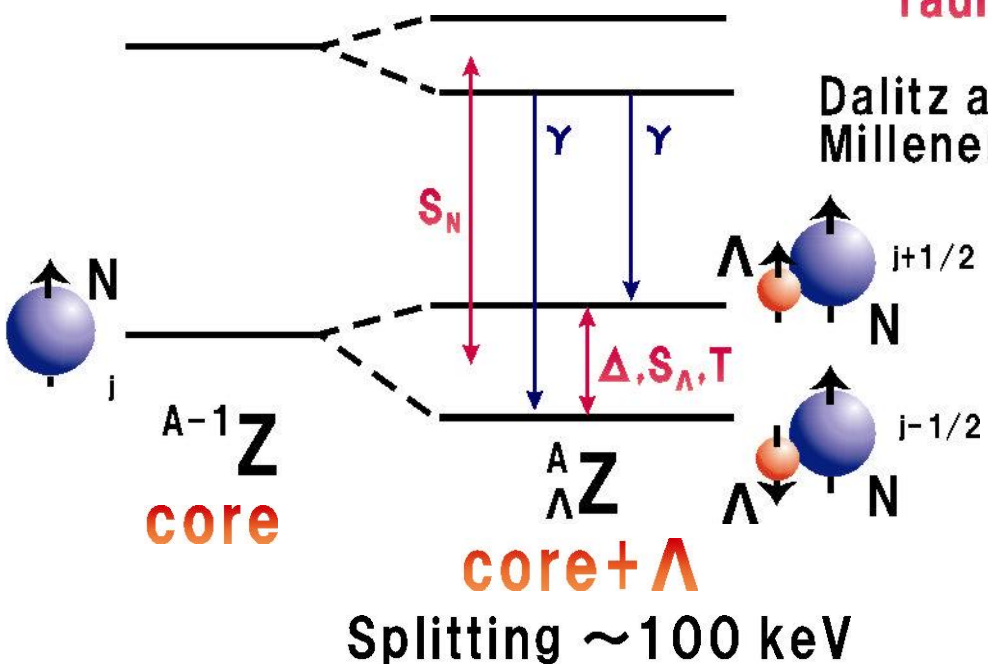
Spin-dependent forces of p-shell hypernuclei

$$V(r) = V_0(r) + \underline{V_\sigma(r)\,\vec{s}_N\cdot\vec{s}_\Lambda} + \underline{V_N(r)\,\vec{l}_{N\Lambda}\cdot\vec{s}_N} + \underline{V_\Lambda(r)\,\vec{l}_{N\Lambda}\cdot\vec{s}_\Lambda} + \underline{V_T(r)\,S_{12}}$$

Δ S_N S_Λ T

radial integral for p_N s_Λ wave function

Dalitz and Gal, Ann. Phys. 116 (1978) 167
Millener et al., Phys. Rev. C31 (1985) 499



Splitting ~100 keV

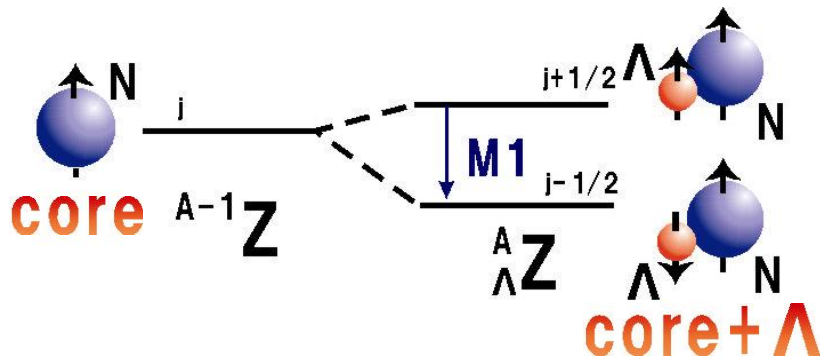
Only Ge can separate this fine structure

Medium effects of baryons

Magnetic moment of Λ in a nucleus

→ direct measurement is difficult

B(M1) of Λspin-flip M1 transition
+
Magnetic moment of core nucleus



$$B(M1) \propto |\langle \phi_f | \mu^z | \phi_i \rangle|^2$$
$$\propto |\langle \phi_\Lambda \phi_{core} | g_{core} j_{core} + g_\Lambda j_\Lambda | \phi_\Lambda \phi_{core} \rangle|^2$$
$$\propto (g_\Lambda - g_{core})^2$$

※ weak coupling limit

B(M1) → measure with DSAM