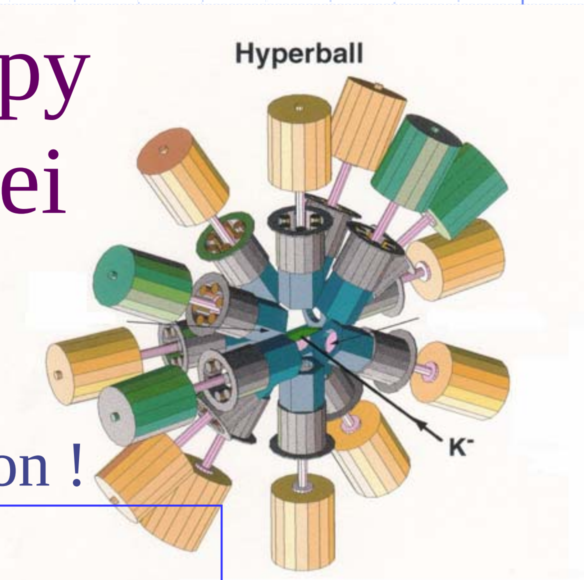
High-resolution γ-ray spectroscopy of hyperfragments produced by stopped K^- method

K.Miwa[a], H.Akikawa[a], Y.Fukao[a], H.Hotchi[d], K.Imai[a], Y.Miura[c], K.Mizunuma[c], S.N.Nakamura[c], M.Niiyama[a], S.Ota[a], P.K.Saha[e], H.Takahashi[a], T.Takahashi[c], H.Tamura[c], K.Tanida[b], S.Terashima[a], M.Togawa[a], and M.Ukai[c]

[a] Department of Physics, Kyoto University
[b] RIKEN(The Institute of Physical and Chemical Research)
[c] Department of Physics, Tohoku University
[d] Brookhaven National Laboratory
[e] Laboratory of Physics, Osaka Electro-communication University

The purpose of γ-ray spectroscopy of hypernuclei



The Hyperball project has revealed the structure on light hypernuclei with a few keV energy resolution !

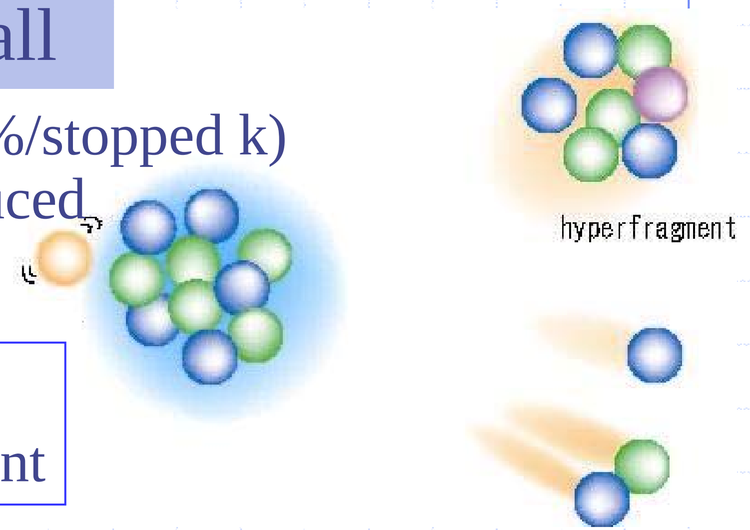
- Precise measurement of the level structure
  ➡ information of spin-dependent ΛN interaction
- Impurity nuclear physics induced by Λ
  ➡ shrinkage of nuclei
- Medium effect of baryons

But, in these experiment where (π^+, K^+),(K^-, π^-) reaction were used, a beam time of more than one month is necessary for each target. The systematic study of hypernuclei is difficult within a reasonable beam time.

For the systematic study of hypernuclei

stopped K^- method and Hyperball

- hypernuclei are produced abundantly(8%/stopped k)
- various species of hypernuclei are produced
- neutron (proton) rich hypernuclei



There is a chance to observe many γ rays
from various hypernuclei in one experiment

Some difficulties

Many background ⇒ good energy resolution of germanium detecto
Identify of γ ray ⇒ γ–γ coincidence method

We want to show this method is suitable for γ-ray spectroscopy,
and make great progress to the γ-ray spectroscopy of hypernuclei

E509 Experiment

KEK 12GeV PS

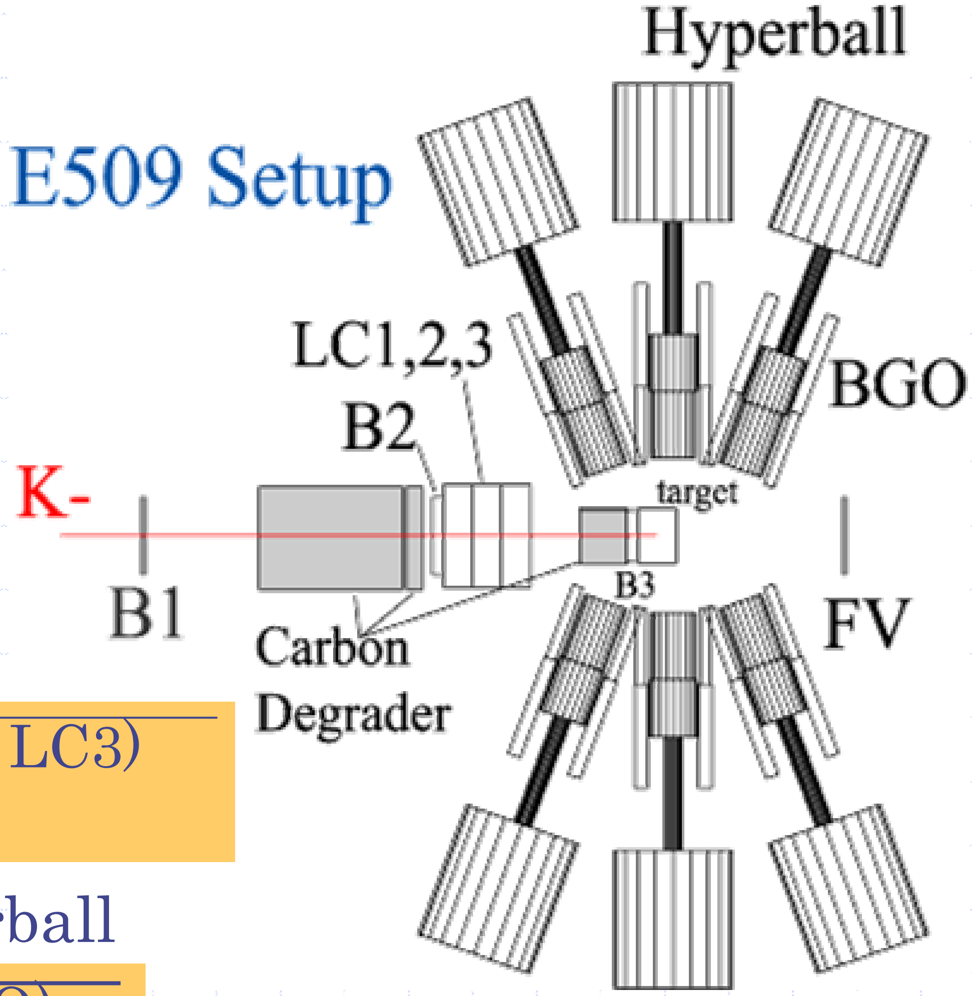
K5 beam line

650MeV/c K^- beam

K^- ・・・14k/spill

π/K ・・・ 160

E509 Setup



$K\ beam = B1 \times B2 \times B3 \times \overline{(LC2 + LC3)}$

$Stop\ K = K\ beam \times \overline{FV}$

γ–detector ・・・ Hyperball

$trigger = stop\ K \times \Sigma(Ge \times \overline{BGO})$

Target

^{7}Li, ^{9}Be, ^{10}B, ^{11}B, ^{12}C

To see the target dependence of γ–ray yield

Target dependence ? ⇒ γ ray from others

⇓ Yes

γ ray from target

From normal nuclei ($A \leq 12$) ?

⇓ No

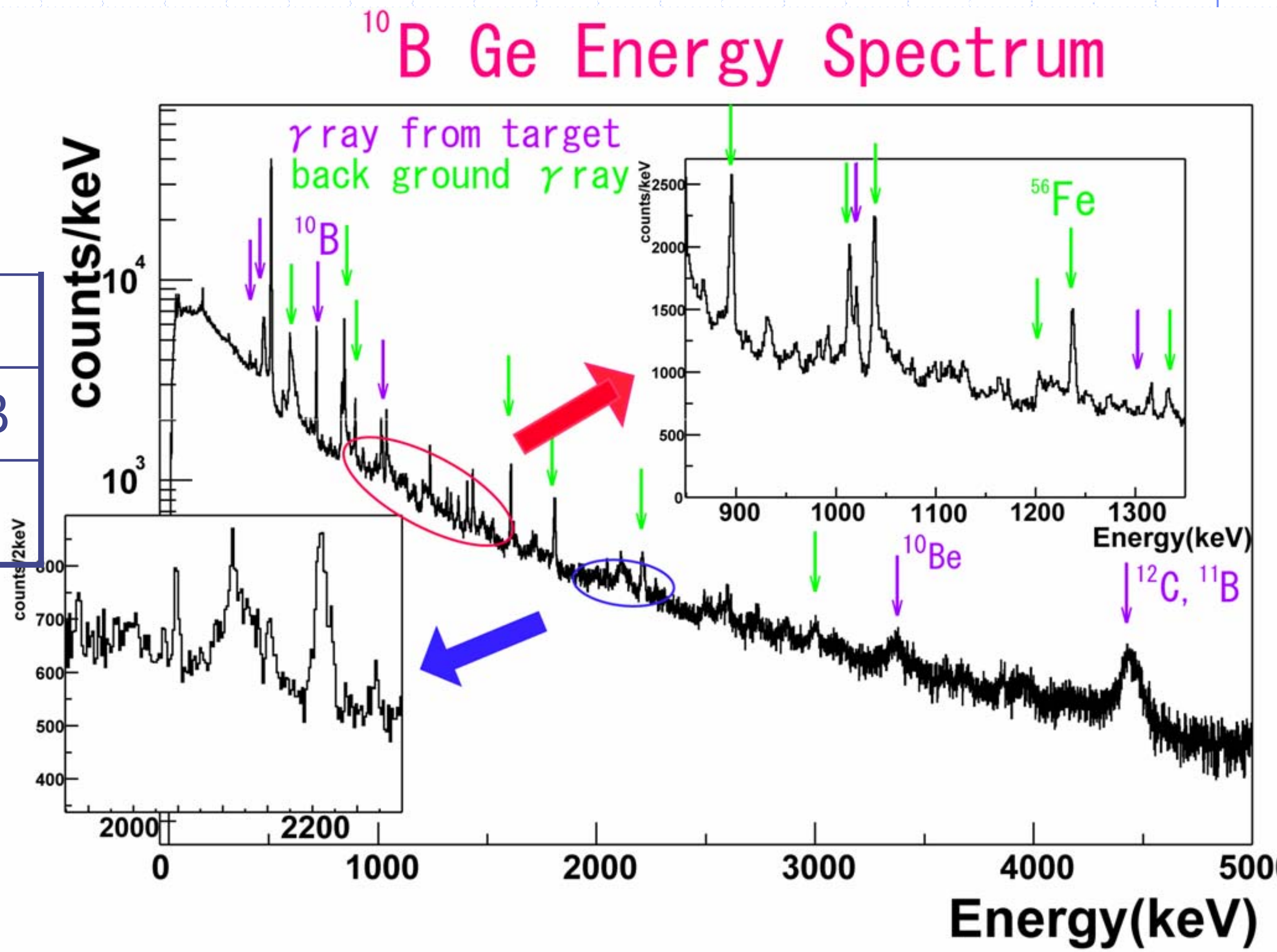
Candidate of hypernuclei

γ-ray spectrum

Many γ rays were observed

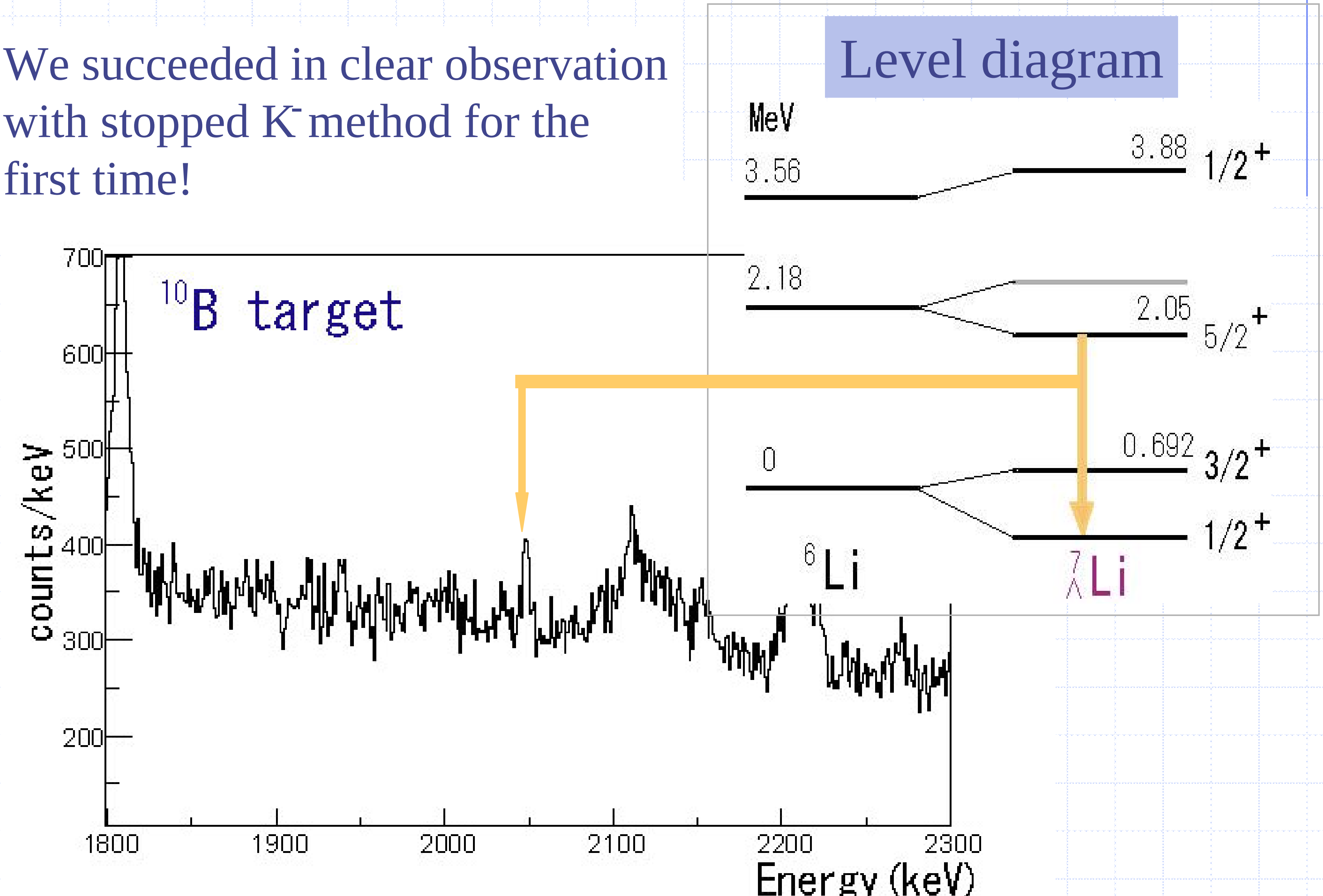
List of γ rays
(target dependent,
not normal nuclei)

Eγ(keV)	target
1302	^{9}Be ^{10}B ^{11}B
2049	^{10}B ^{11}B ^{12}C



${}^{7}_{\Lambda}$Li(5/2$^+$→1/2$^+$)E2 transition

- We succeeded in clear observation with stopped K$^-$ method for the first time!



${}^{7}_{\Lambda}$Li(5/2^{+}→1/2 $^{+}$)E2 transition

$$E_{\gamma} = 2049.4 \pm 0.3 \pm 0.5 \text{ keV}$$

$$\text{Peak Count} = 516 \pm 74(^{10}\text{B})$$

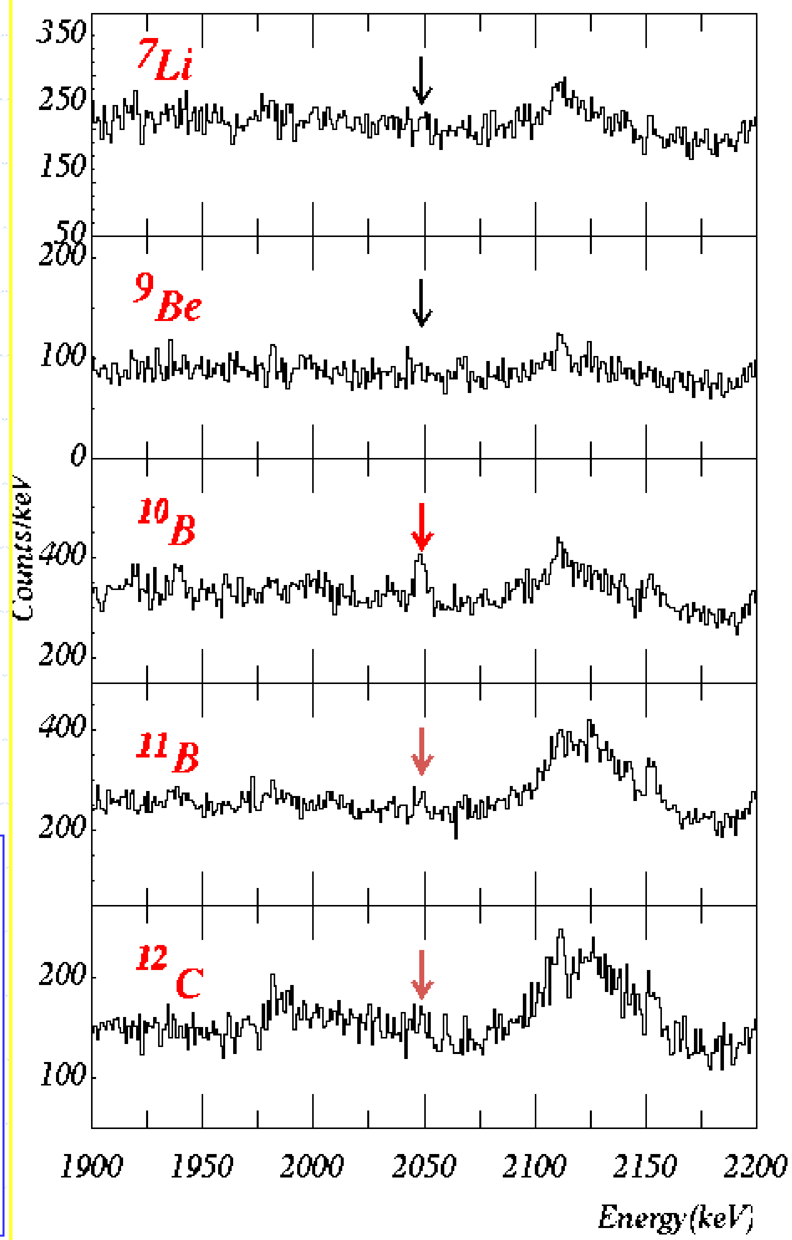
E419 (In-flight reaction)
PeakCount=197
beam time=1 month

2.5 times more statistics
within 3.5 days beam time

γ-ray intensity of ${}^{7}_{\Lambda}$Li
E2($5/2^{+} \rightarrow 1/2^{+}$) transition

$$0.075 \pm 0.016\% \text{ / stopped } K^{-} \ (^{10}\text{B})$$

production mechanism of hyperfragment

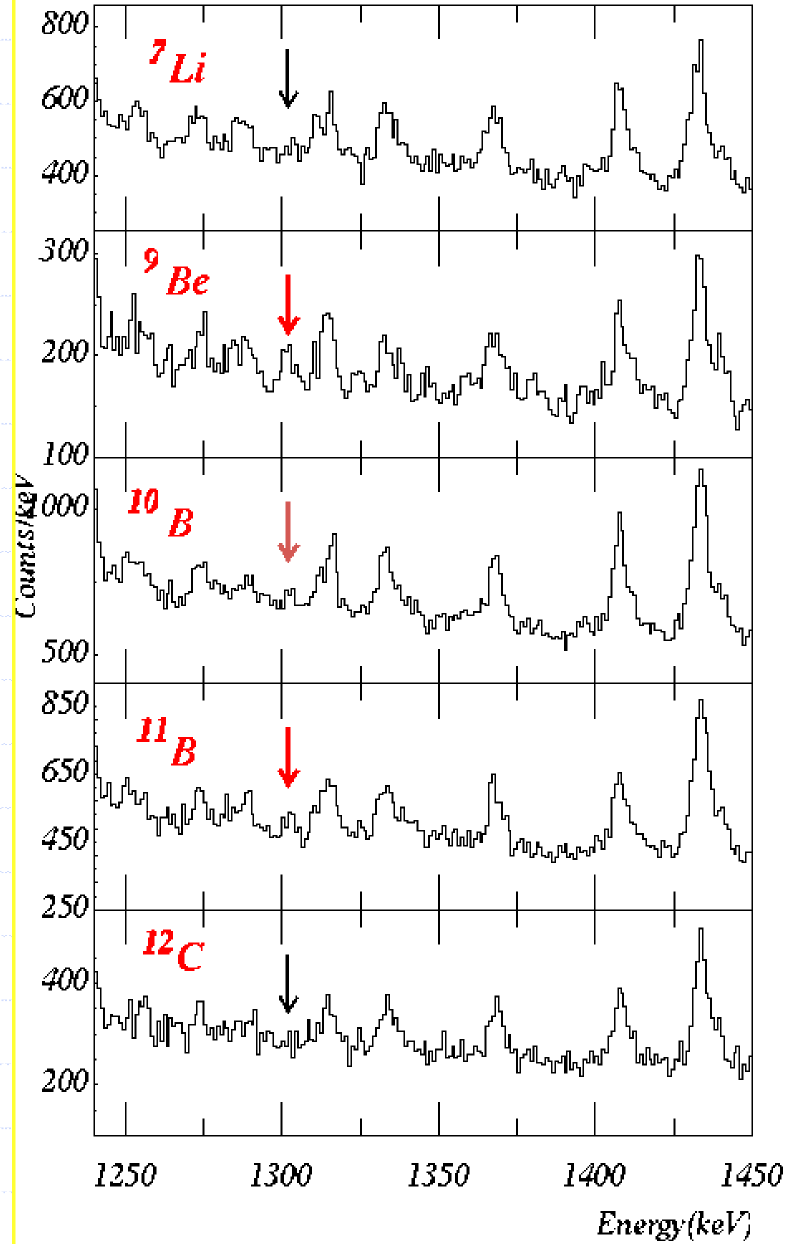


Another candidate

We observed an unknown γ ray in ^{9}Be, ^{10}B, ^{11}B target.

E_γ=1302.9 ±0.6 keV

→ $^{8}_{\Lambda}$Li or $^{9}_{\Lambda}$Li ??

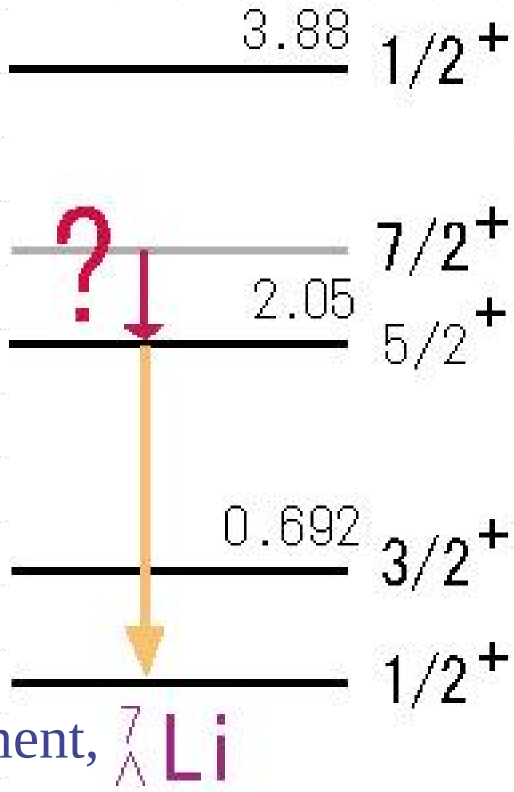


Possibility of γ–γ coincidence

Cascade of ${}^{7}_{\Lambda}$Li($7/2^+ \rightarrow 5/2^+ \rightarrow 1/2^+$)

- This experiment

  It was impossible because of
  low efficiency of germanium detector
  caused by BGO pile-up trouble.



From the background level measured in this experiment,
we conclude that γ–γ coincidence becomes possible
by improving the photo-peak efficiency.
This improvement can be realized by adjusting beam condition.
Furthermore the upgraded Hyperball having large photo peak
efficiency is now under development.

Summary

- We performed an experiment to measure γ ray from hyperfragment produced by stopped K^- method at the KEK K5 beam line. We employed Hyperball as γ-ray detector.
- We clearly observed $^{7}_{\Lambda}$Li E2($5/2^+ \rightarrow 1/2^+$) transition by stopped K^- method for the first time, and obtained that the γ–ray intensity is 0.075 ± 0.016 % per stopped K^-.
- From the result of this pioneering experiment, we conclude γ–γ coincidence become possible by improving photo-peak efficiency.
- This method is promising for the systematic study of γ-ray spectroscopy of hypernuclei.

ΛN interaction

Effective potential of ΛN interaction

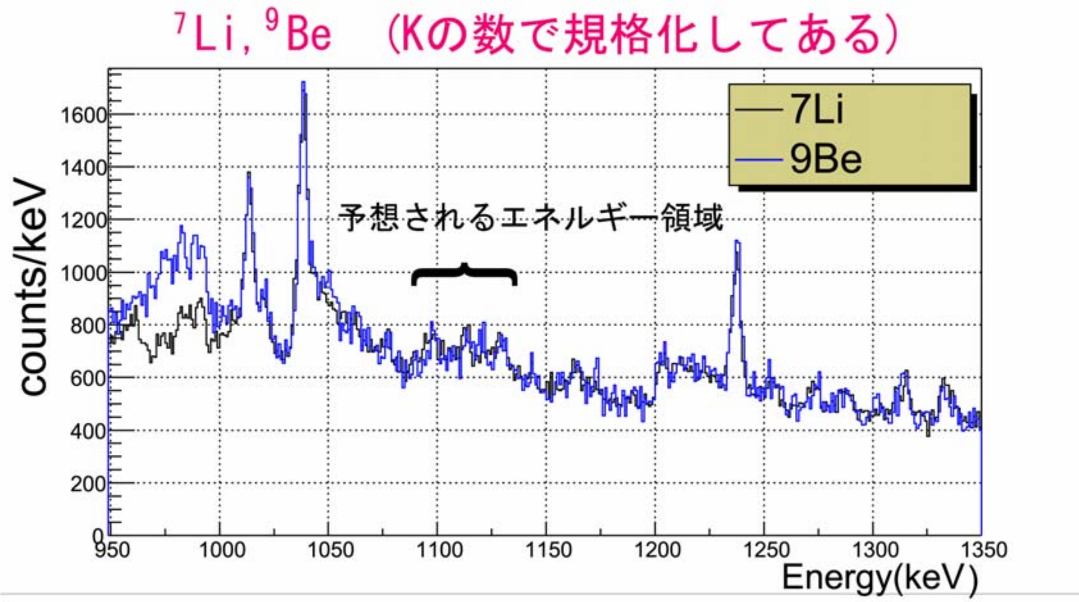
Term	Interaction	Our experiment
$V_{\Lambda N} = V_0 + V_s(r)\vec{s}_\Lambda \cdot \vec{s}_N$	spin spin interaction	E419 ($^{7}_{\Lambda}$Li)
$+V_\Lambda(r)\vec{L}\cdot\vec{s}_\Lambda$	spin(Λ) orbit force	E930 ($^{9}_{\Lambda}$Be)
$+V_N(r)\vec{L}\cdot\vec{s}_N$	spin(N) orbit force	
$+V_T\left(\frac{3(\vec{s}_\Lambda\cdot\vec{r})(\vec{s}_N\cdot\vec{r})}{r^2} - \vec{s}_\Lambda\cdot\vec{s}_N\right)$	tensor force	E930 ($^{16}_{\Lambda}$O)

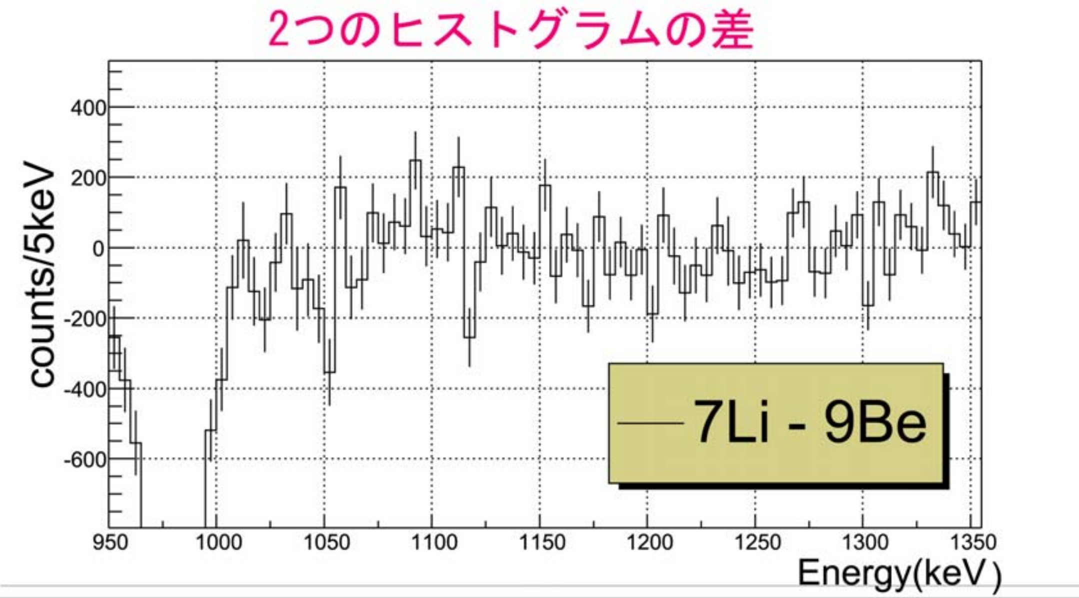
valuable information

But, in these experiment where (π^+,K^+),(K^-,π^-) reaction were used, a beam time of more than one month is necessary for each target. The systematic study of hypernuclei is difficult within a reasonable beam time.

About $^{4}_{\Lambda}H$

There is a broad peak in the expected energy Region (~ 1100 keV), we cannot recognize the target dependence.





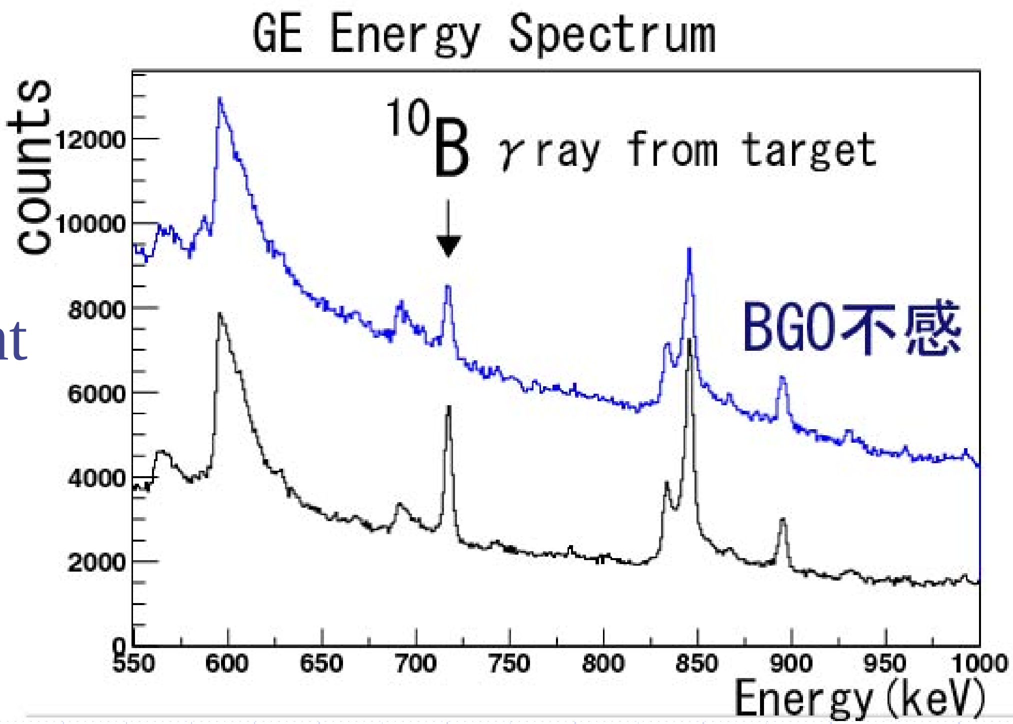
Analysis of BGO

BGO occurred pile-up due to high intensity of beam, almost attributed π^-

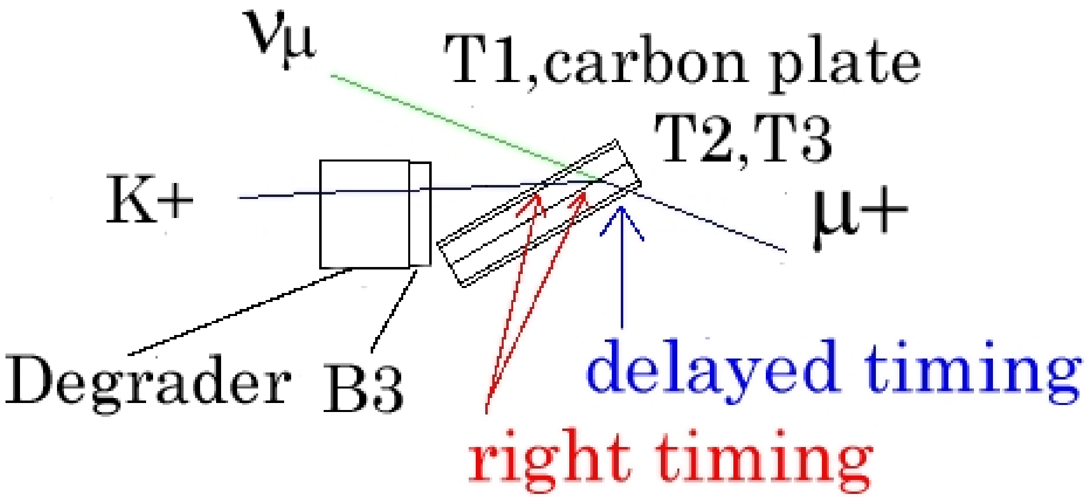
The points to be improved

We can reject such event by offline analysis.

BGO	
Single rate	700kHz
Width	650nsec



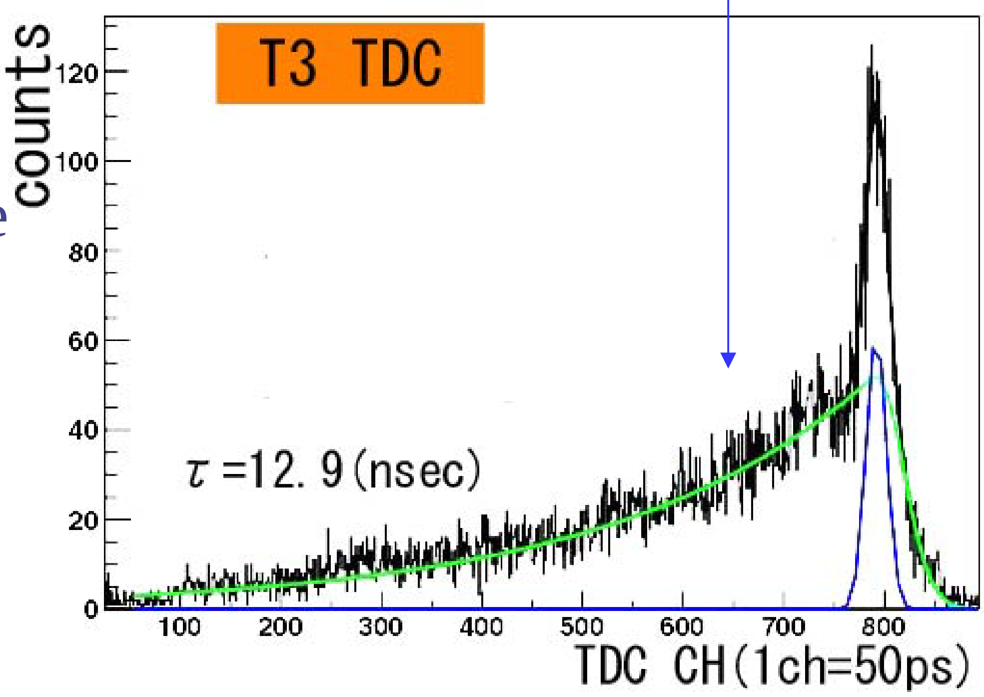
Estimation of stopped K^+ event



Decay after the life time

By detecting the charged particle after the decay of K^+

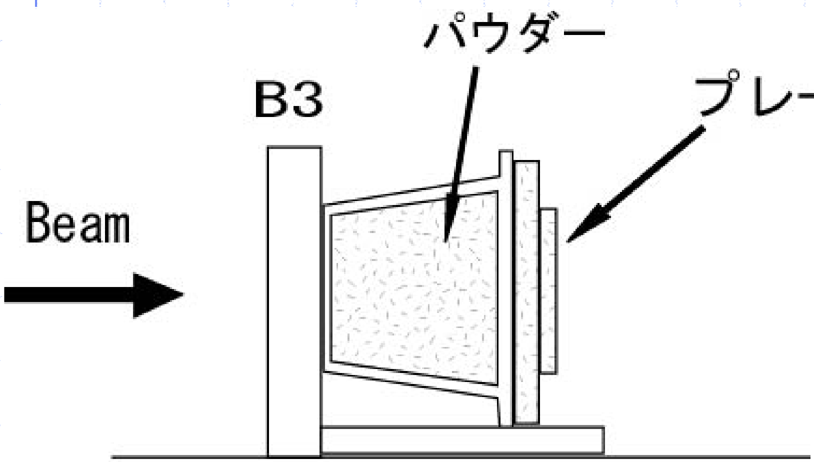
About 63 % of K^+ stopped in T1,carbon, and T2.



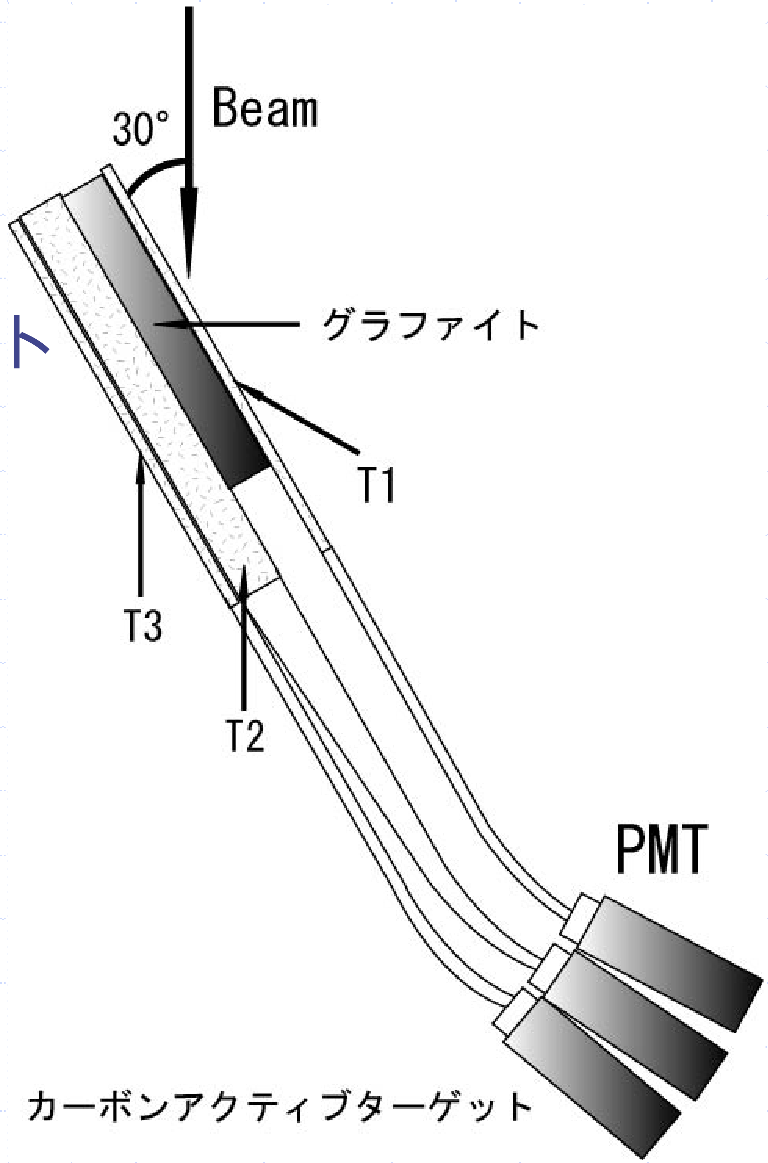
Target

^{7}Li, ^{9}Be, ^{10}B, ^{11}B, ^{12}C

生成されるハイパーフラグメントのターゲット依存性を考慮

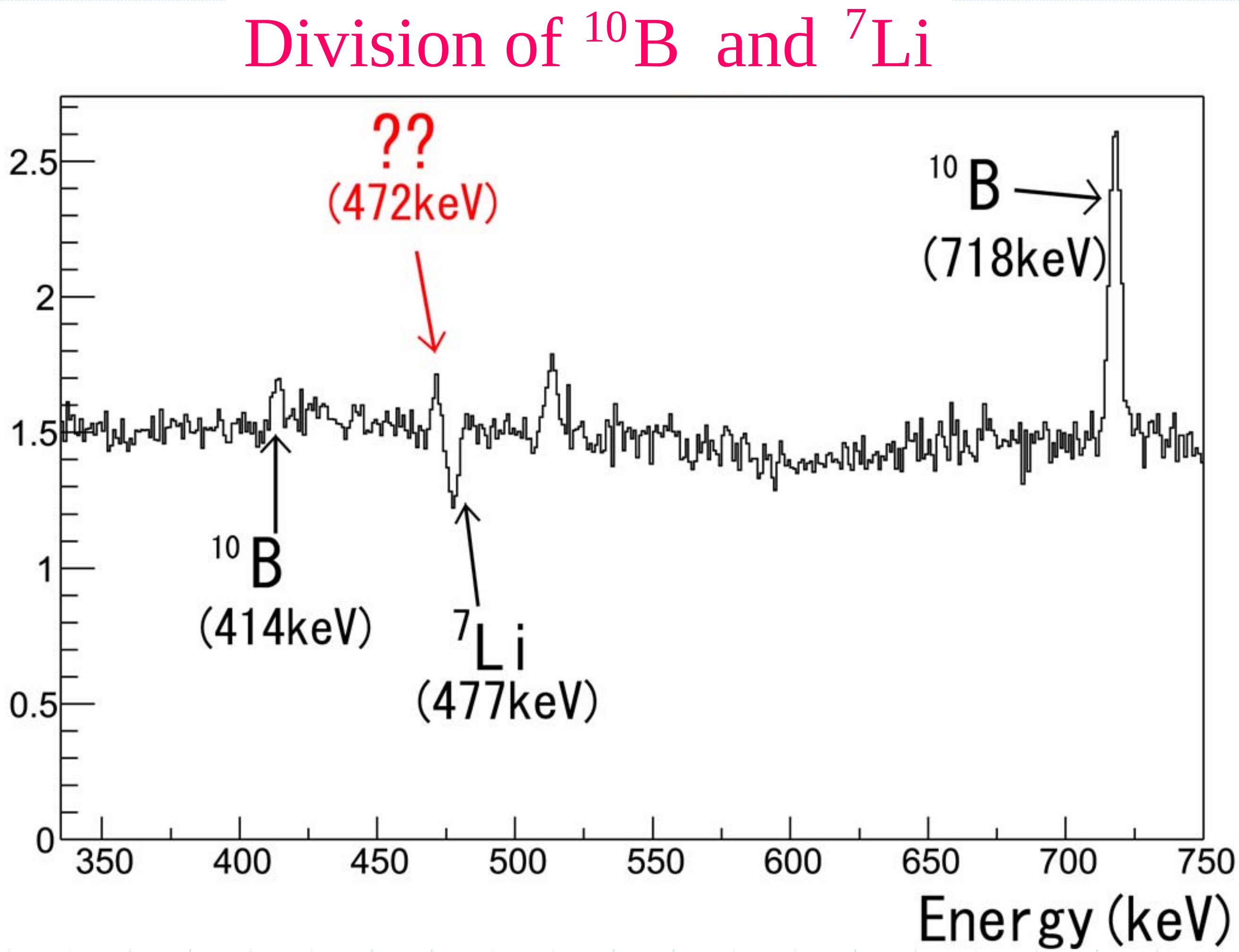


^{10}B, ^{11}B ターゲット



カーボンアクティブターゲット

Comparison of ^{10}B and ^{7}Li

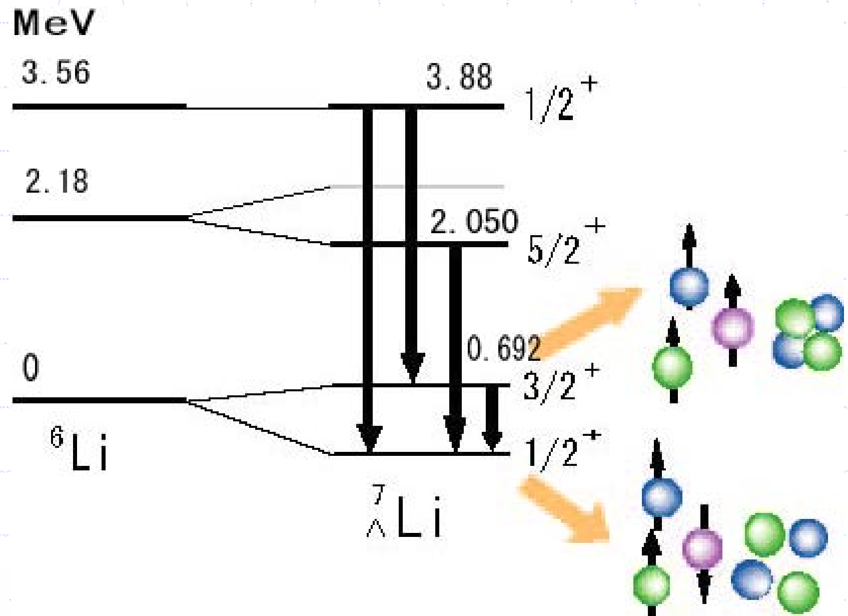


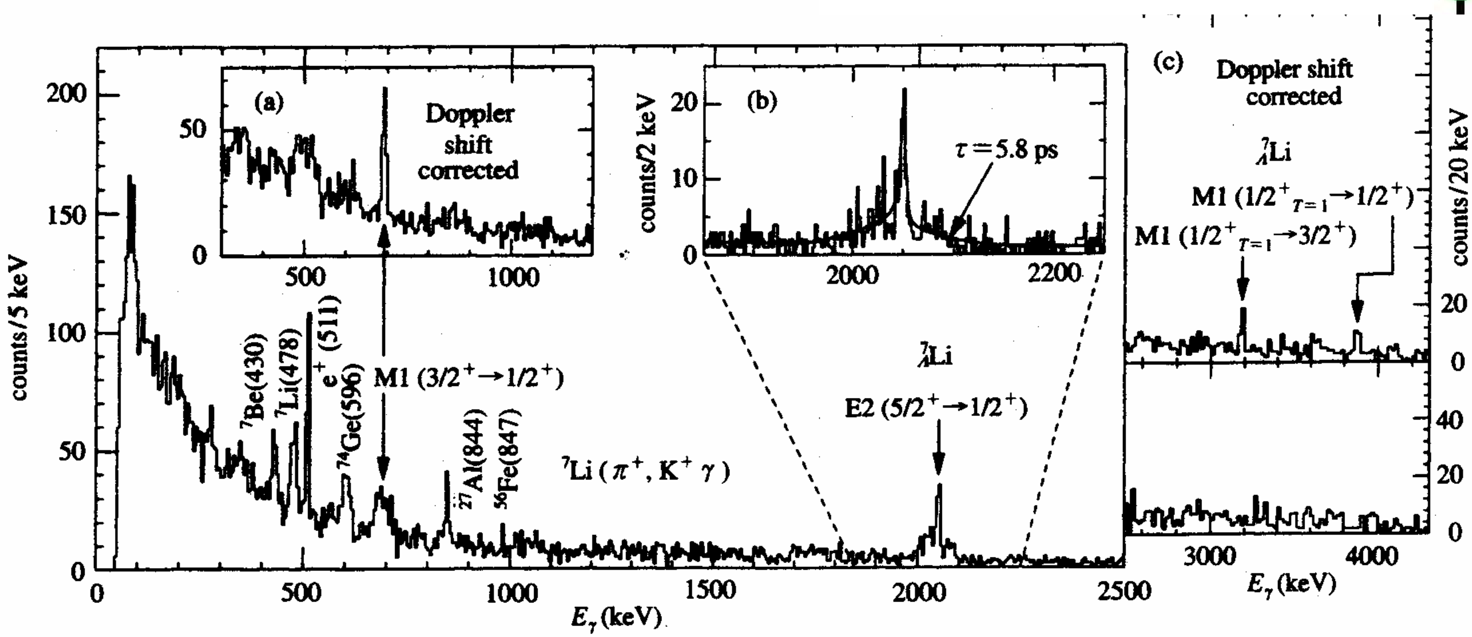
γ-ray spectroscopy of $^7_\Lambda$Li

Hyperball初めての実験

基底状態の2重項の間隔

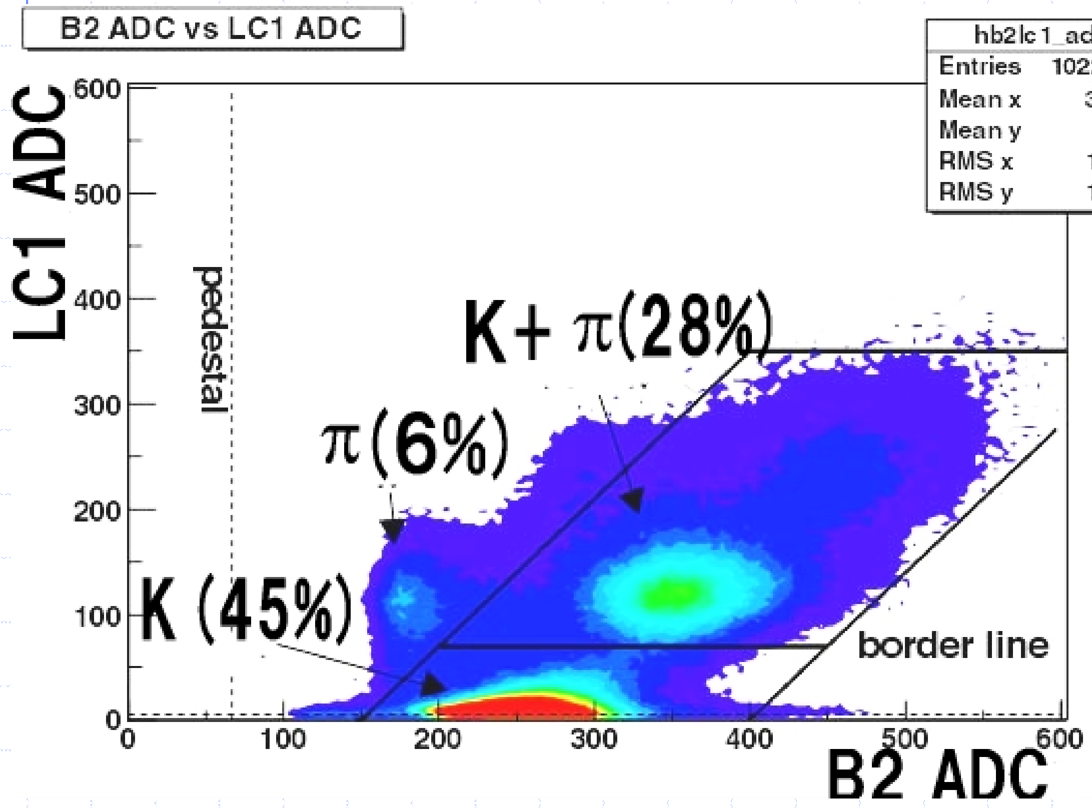
⇒ ΛNのスピン・スピン力





Identification of K$^-$

used B2 ADC and LC1 ADC



There were many pile-up event of K$^-$ and π^-

We used only K$^-$event (not pile-up) for analysis

Hyperball

14 set of germanium detector

- Large solid angle (15%)
- 3% photopeak efficiency for 1MeV γ ray
- 4.2keV(FWHM) @ 717keV

BGO counter

- Suppress of background from Compton scattering and π^0

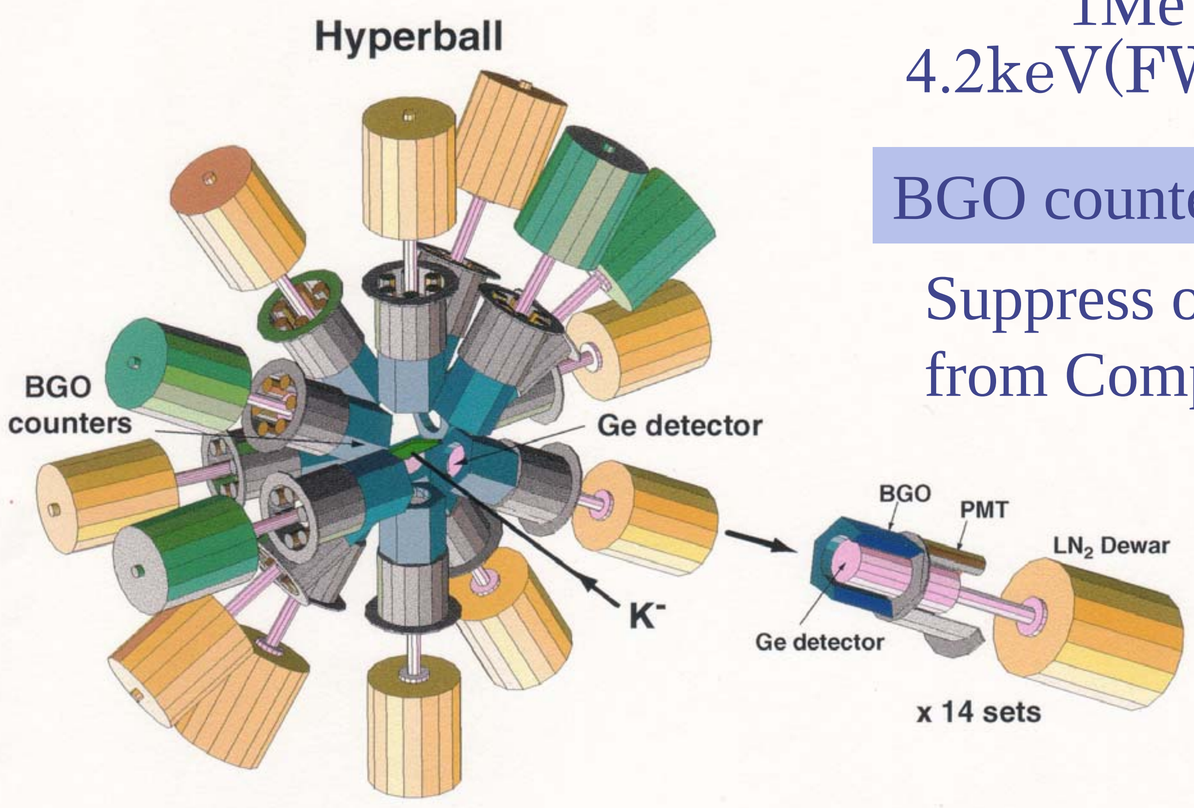


Figure 4: *Schematic drawings of Hyperball.*