Status of Hyperball-J (E13) and γ-ray spectroscopy of the sd-shell hypernuclei

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Hyperball-J collaboration

23 institutes

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  - γγ coincidence at J-PARC
- Hypernuclei of interests in E13
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- Hypernuclei in the sd-shell
  - Possible hypernuclei investigated with γγ coincidence
  - Mid shell region: nuclear deformation
- Status of Hyperball-J (E13) preparation
- Summary

Hypernuclear γ-ray spectroscopy

- Precise study of bound states of hypernuclei
  - Excitation energies →ΛN interaction (central, spin-spin, spin-orbit, and tensor)
  - Life times of γ transitions →Λ-core coupling
    - B(E2): nuclear size, deformation, collectivity
    - B(M1): property of Λ in hypernucleus
  - Linear polarization ・Angular dist./correlation →multipolarity of γ–ray transition (theory independent)
- γ-ray tagging of hypernuclear mesonic weak decay
  - much less affected by target thickness

γγ-coincidence technique at J-PARC

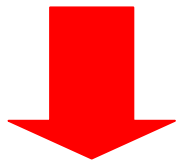
- **Resolving complex energy levels**
  - odd-odd core Λ hypernuclei (e.g. $^{11}_{\Lambda}$B)
- **Separation of produced hypernuclei**

  Use of natural (non-enriched) targets

  →investigation of hypernuclear isotopic chain

  Hyperfragments (together with gate on missing mass spectrum)
  - neutron channel never identified

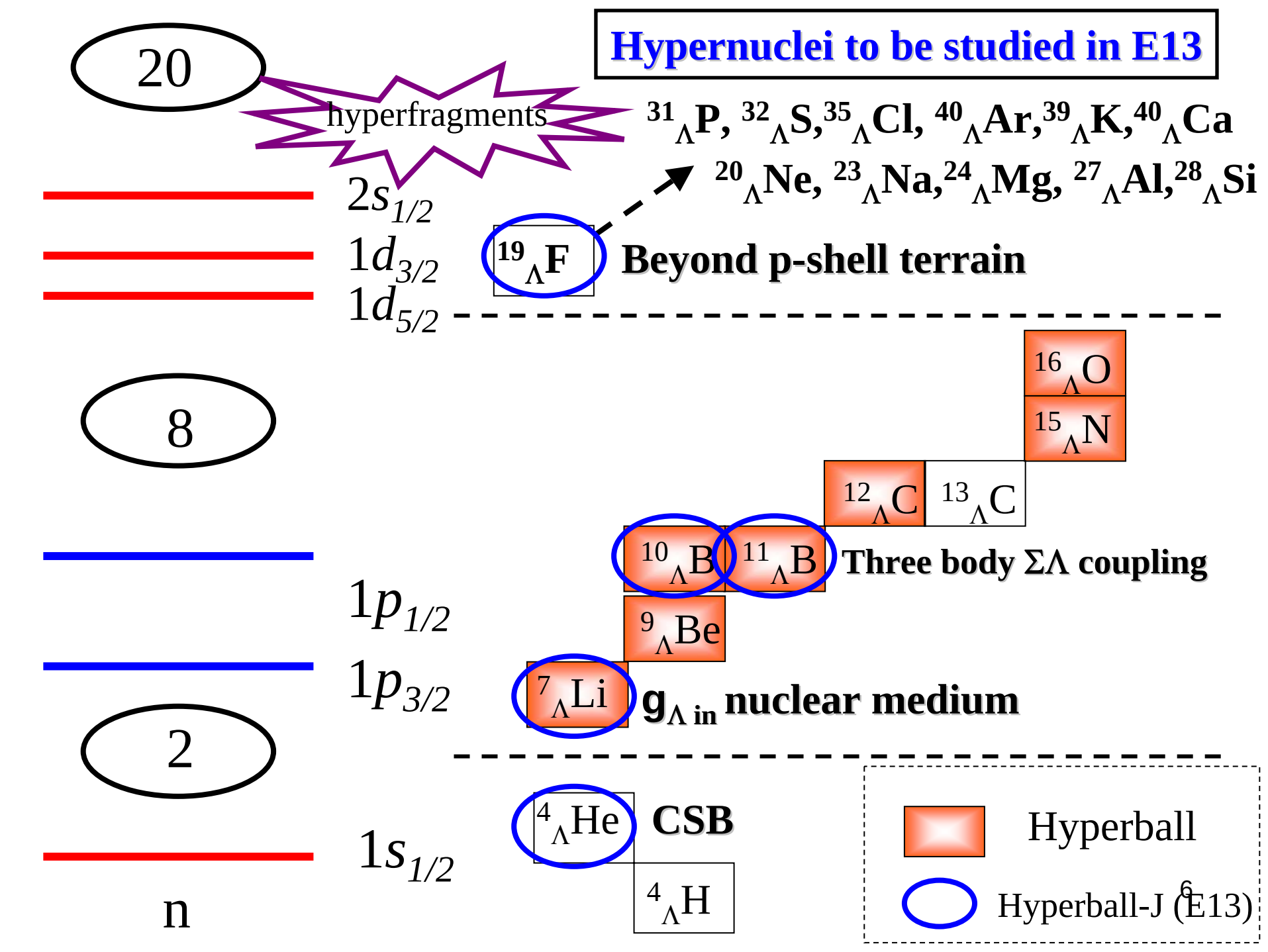
  →studies of mirror hypernuclei (proton and neutron channel)
- **First γγ coincidence observation in hypernucleus:** $^{7}_{\Lambda}$Li
  - M. Ukai *et. al*., Phys. Rev. C **73** 012501(R)



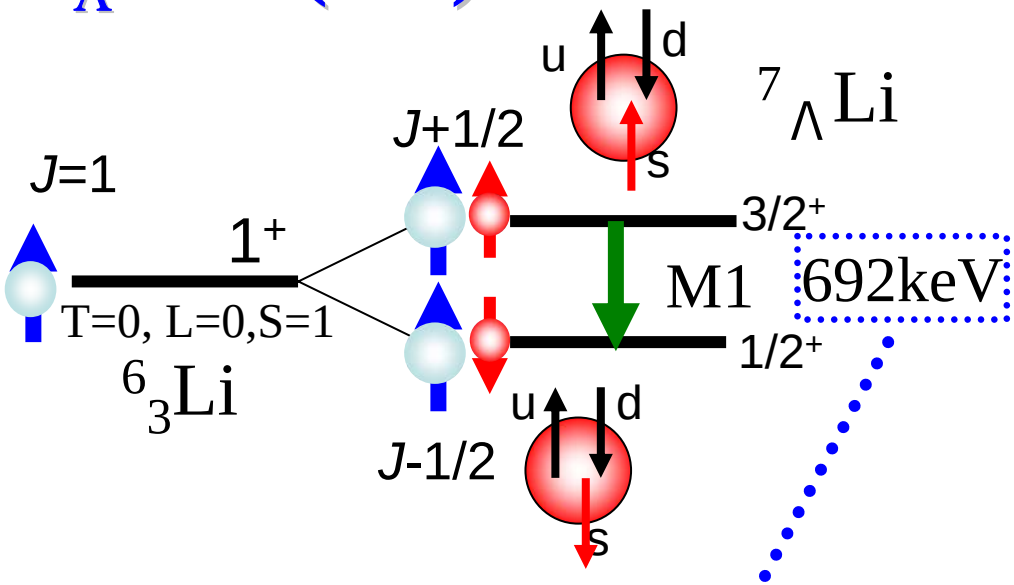
ε^2

High intensity beam →**J-PARC**

High γ ray detection efficiency→**Hyperball-J**


Hypernuclei to be studied in E13
20
hyperfragments
$^{31}_{\Lambda}$P, $^{32}_{\Lambda}$S,$^{35}_{\Lambda}$Cl, $^{40}_{\Lambda}$Ar,$^{39}_{\Lambda}$K,$^{40}_{\Lambda}$Ca
$^{20}_{\Lambda}$Ne, $^{23}_{\Lambda}$Na,$^{24}_{\Lambda}$Mg, $^{27}_{\Lambda}$Al,$^{28}_{\Lambda}$Si
$2s_{1/2}$
$1d_{3/2}$
$^{19}_{\Lambda}$F
Beyond p-shell terrain
$1d_{5/2}$
8
$^{16}_{\Lambda}$O
$^{15}_{\Lambda}$N
$^{12}_{\Lambda}$C
$^{13}_{\Lambda}$C
$^{10}_{\Lambda}$B
$^{11}_{\Lambda}$B
Three body ΣΛ coupling
$1p_{1/2}$
$^{9}_{\Lambda}$Be
$1p_{3/2}$
$^{7}_{\Lambda}$Li
$g_{\Lambda\ in}$ nuclear medium
2
$^{4}_{\Lambda}$He
CSB
$1s_{1/2}$
$^{4}_{\Lambda}$H
n
Hyperball
Hyperball-J (E13)

${}^{7}_{\Lambda}$Li: B(M1) measurement and a Λ in nucleus



Doppler **S**hift
Attenuation
Method

$$\Gamma = \frac{1}{\tau} \propto E_\gamma^3 B(M1)$$

Nuclear medium effect

- No Pauli blocking
  → Λ in 0s orbit
- Partial restoration of chiral symmetry?

$$\mu_q = \frac{e\hbar}{2m_q c}$$

reduction of constituent quark mass
→ change of μ_Λ

In the weak coupling limit between Λ and the core nucleus

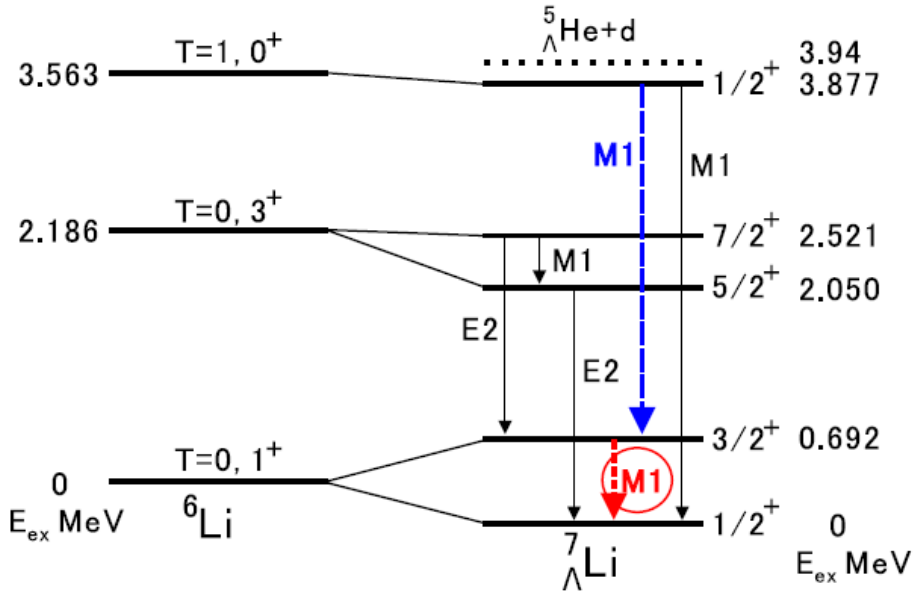
$$B(M1)\left[\mu_N^2\right] \propto \left\langle J = 3/2 \left\| \mu \right\| J = 1/2 \right\rangle^2 \propto (g_\Lambda - g_C)^2$$

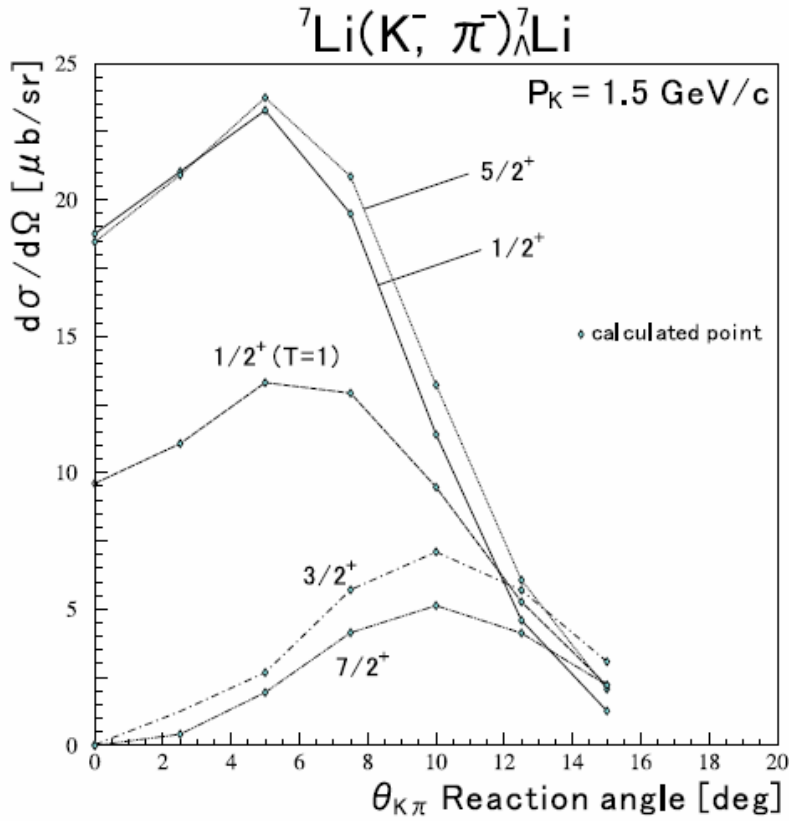
$$\mu = g_\Lambda J_\Lambda + g_C J_C$$

g_Λ,g_c: **Effective** g factor of Λ and core nucleus, respectively
J_Λ, J_c: Total spin of Λ and core nucleus, respectively

Population of spin-flip state

J-PARC K1.8 beam line
Reaction: ^{7}Li(K^{-},π^{-})$^{7}_{\Lambda}$Li
Beam momentum: P_K=1.5GeV/C
Target: Li_2O(2.01g/cm^2)

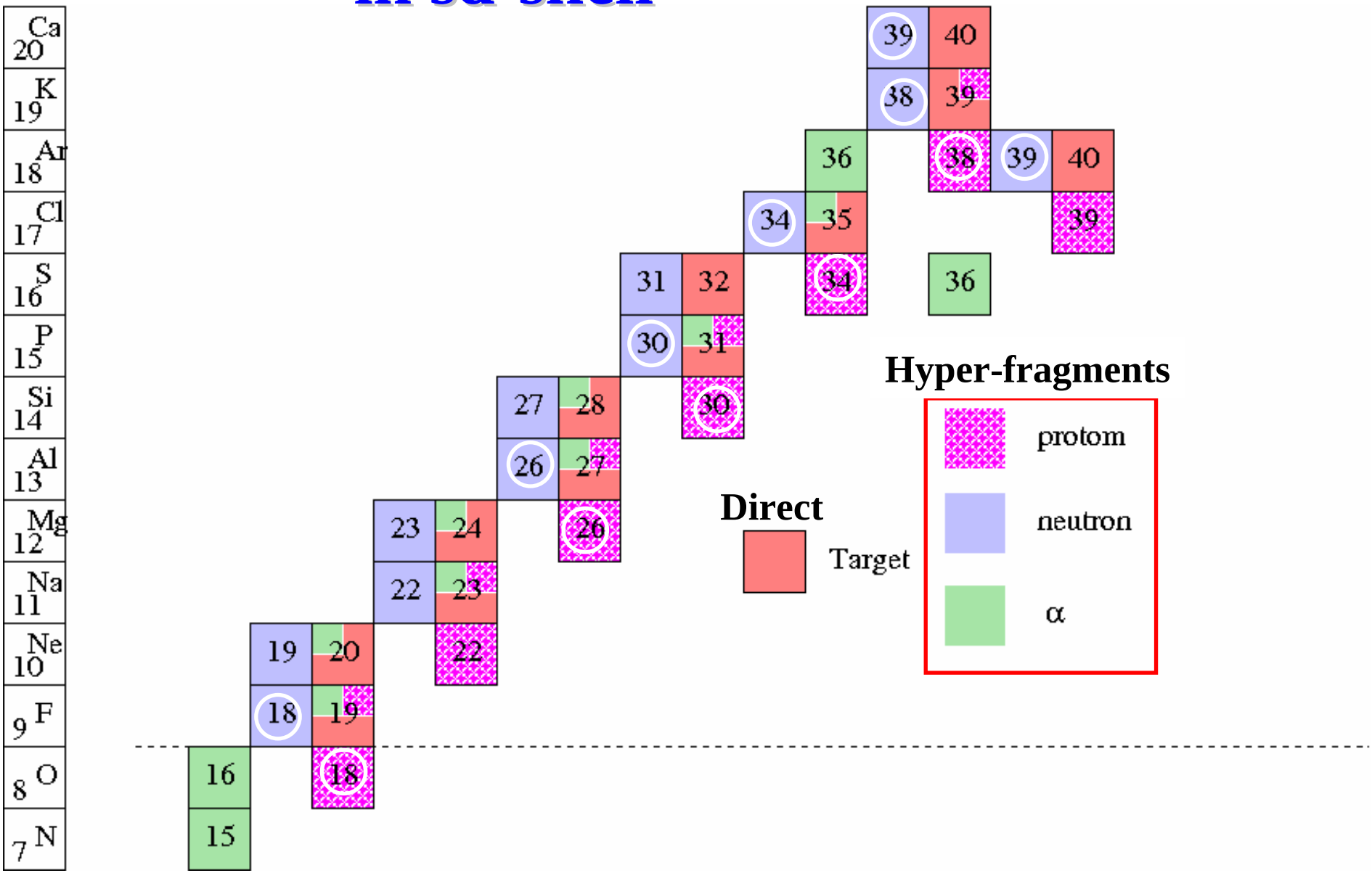




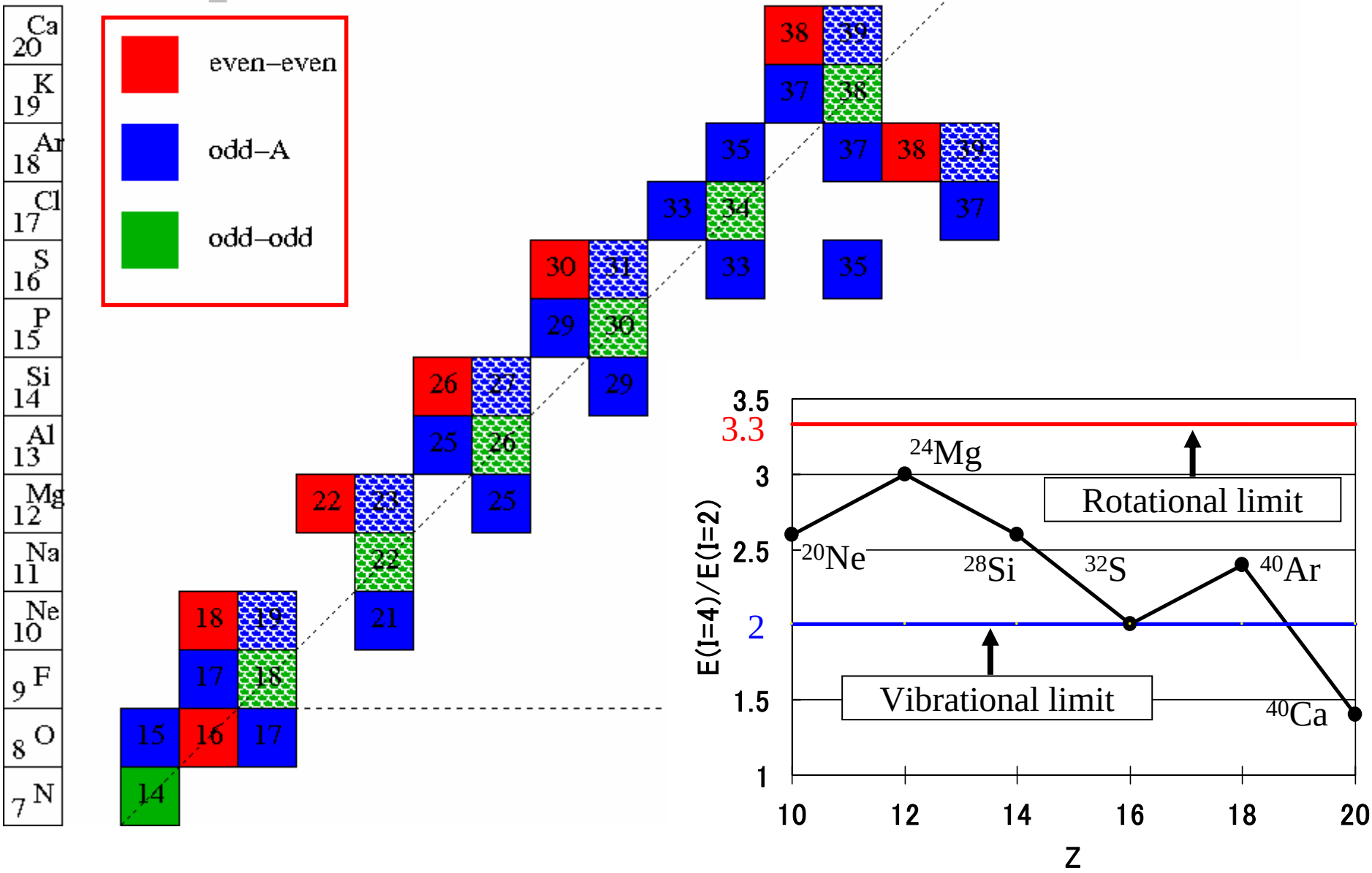
Calculated by T. Motoba

K. Shirotori, Master thesis, 2006

Possible hypernuclei produced in sd-shell



Cores of possible hypernuclei produced in sd-shell



Effect of Λ on nuclear deformation in the sd-shell hypernulei

Midshell core nuclei well deformed at g.s.(vacuum)

– ^{22}Na: β_2=0.36(2), ^{23}Mg: β_2=0.45(4), ^{13}Al: β_2=0.29(5),

Nuclear deformation

– spontaneous breaking of rotational invariance

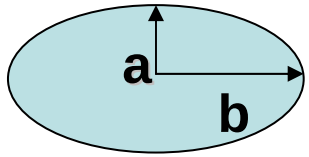
– emergence of collective mode

→ rotational band (energy spectrum)

– property of nuclear vacuum

– change in deformation

→ change in vacuum property



Deformation parameter: β

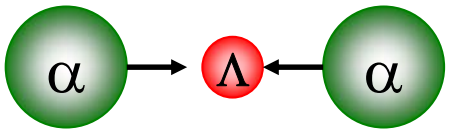
To what extent does a Λ as an impurity change nuclear vacuum?

$^{24,25,26}_{\Lambda}$Mg isotopic chain

- Use of natural Mg target
  - Isotopic abundance:
    - ^{24}Mg (78%), ^{25}Mg (10%), ^{26}Mg (11%)
- Core deformation
  - ^{23}Mg (β_2=0.45(4)), ^{24}Mg (β_2=0.61(1)), ^{25}Mg(β_2=0.38(2))
- $\gamma\gamma$ coincidence to separate three isotopes
- Shell model, few-body, cluster model in p-shell

→mean field and collective model (e.g. particle rotor) in the sd-shell

$^{9}_{\Lambda}$Be

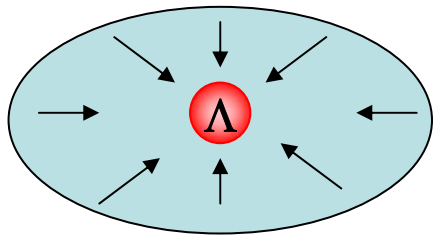


Change in nuclear size & deformation

$^{24,25,26}_{\Lambda}$Mg

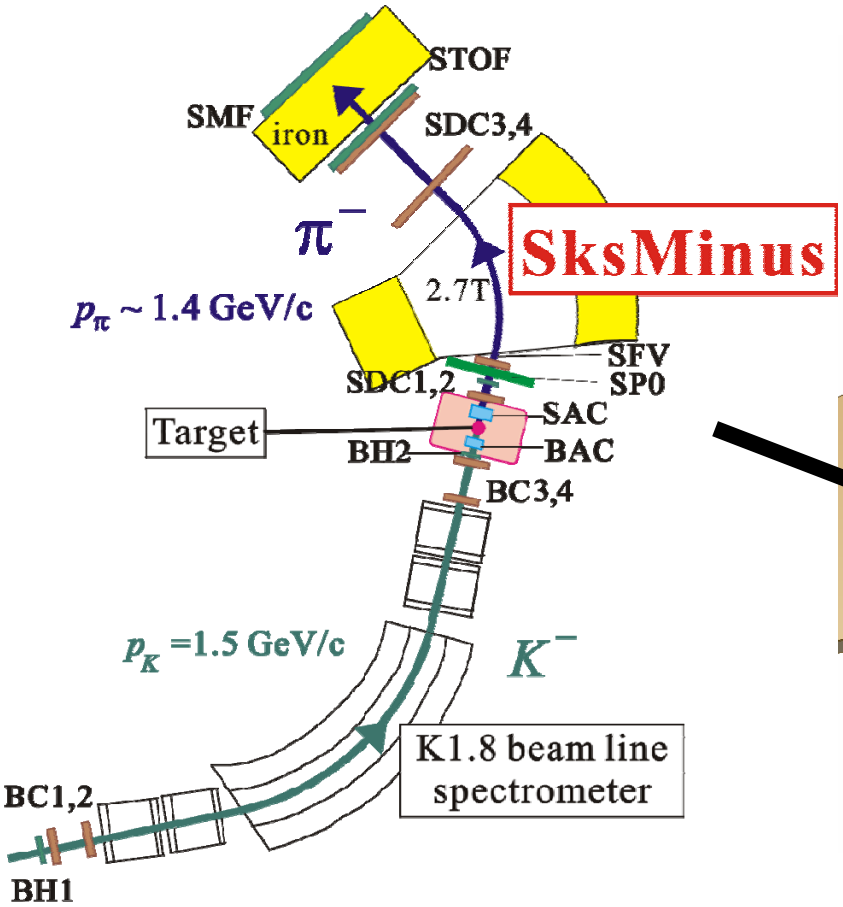
Change in nuclear size, but not much deformation

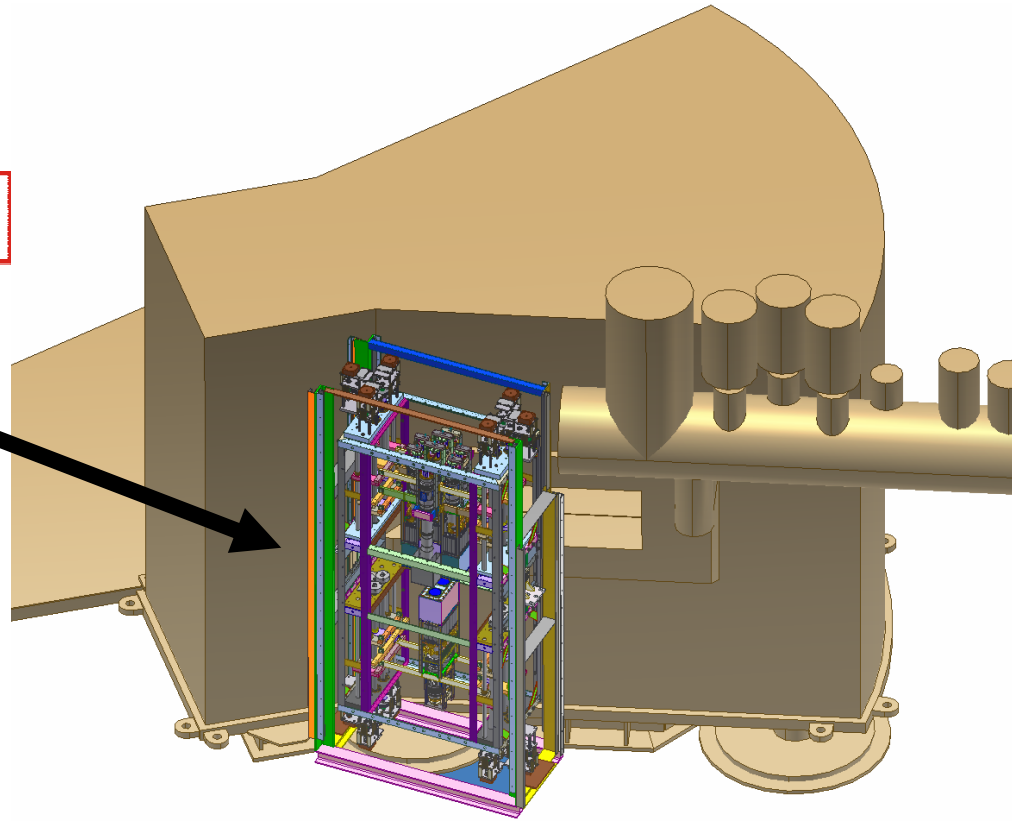
?



Status of Hyperball-J

(K^-, π^-) reaction @ p_K = 1.5 GeV/c

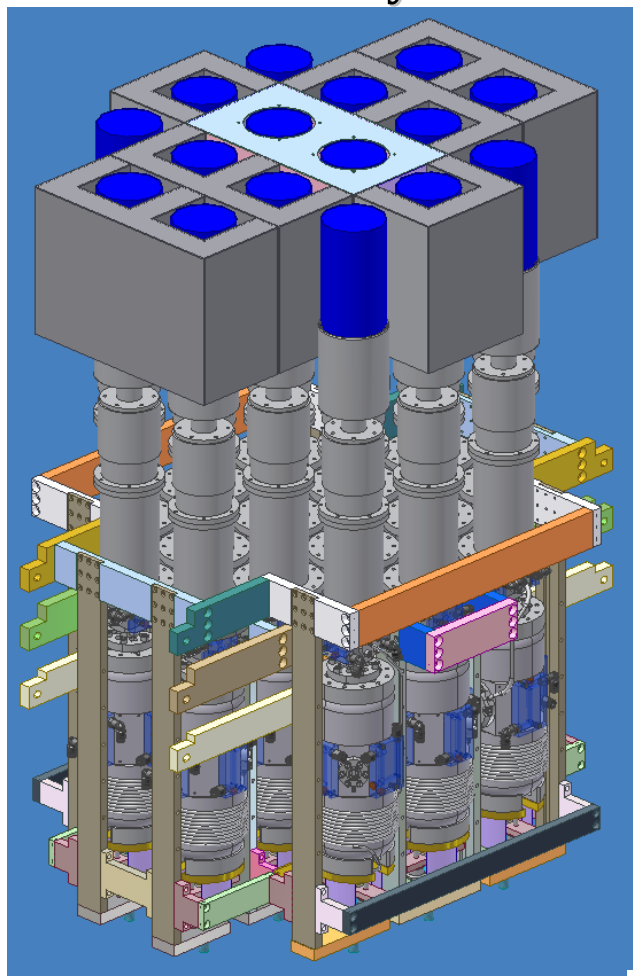




Hyperball-J Ge array at J-PARC

- Planar arrangement
- Ge detector **X32**
  - 60% relative eff., N-type, Transistor reset type (150MeV/reset)
- Total photo peak eff. ~6% for 1-MeV γ ray
- High modularity
- Adjustable geometry
  - E13 & E03,07 (Ξ x-ray)

Half the array shown



Planar arrangement

R&D

Radiation hardness:

- Mechanical cooling of Ge detector

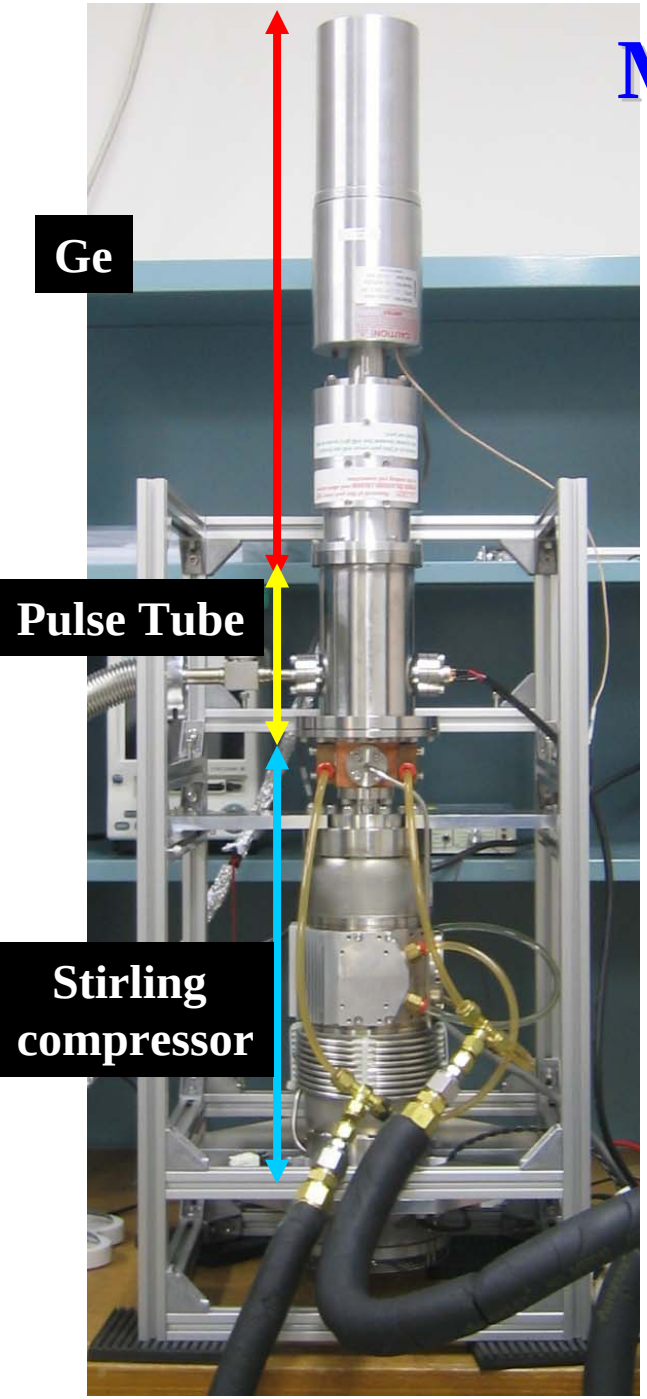
High background:

- PWO background suppressor

High energy deposit and counting rate:

- Baseline restoration and pile up separation via waveform analysis

Mechanical cooling of Ge detectors

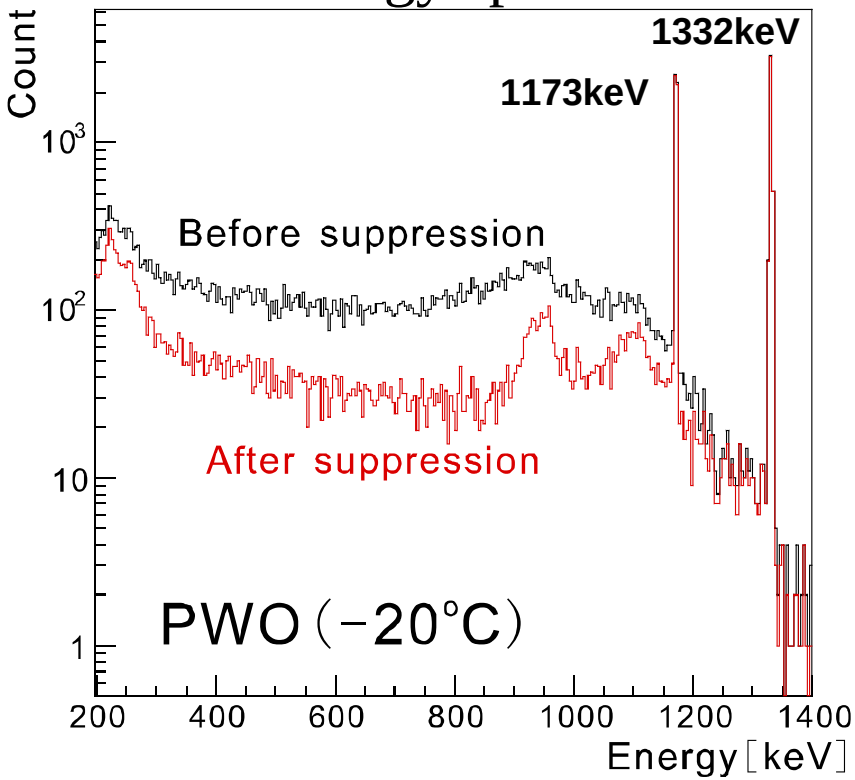


- **Ge det. Design and R&D (Apr. 2005 ~ Sept. 2007)**
- **First Ge detector delivered**
- **Pulse tube refrigerator mounted**
- **Cooling test**
  - **Input power: 160 W**
  - **Water cooling + Fan**
  - **C/H: 57 K**
  - **Ge crystal: 71 K (Bias off 69 K)**
  - **Holding time: 15 minutes (<85K)**
- **Resolution**
  - **ORTEC UHA973u (3μs)**
  - **Pulse Tube ON: 3.5 keV**
  - **Pulse Tube OFF: 3.5 keV**

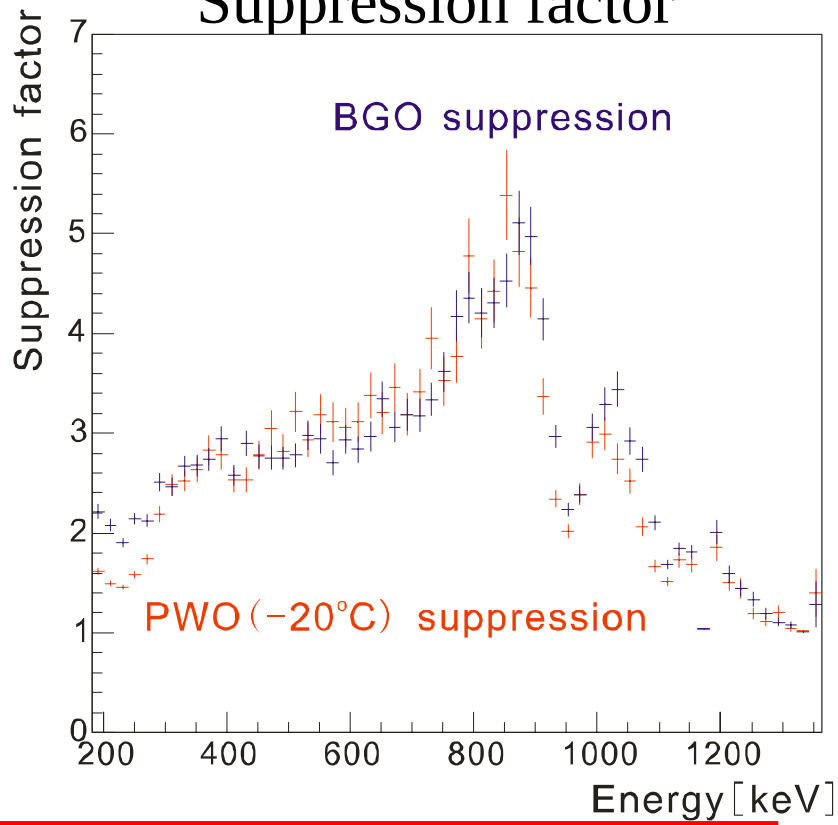
Test results of prototype PWO counter

(M. Mimori, Master thesis)

Energy spectra



Suppression factor



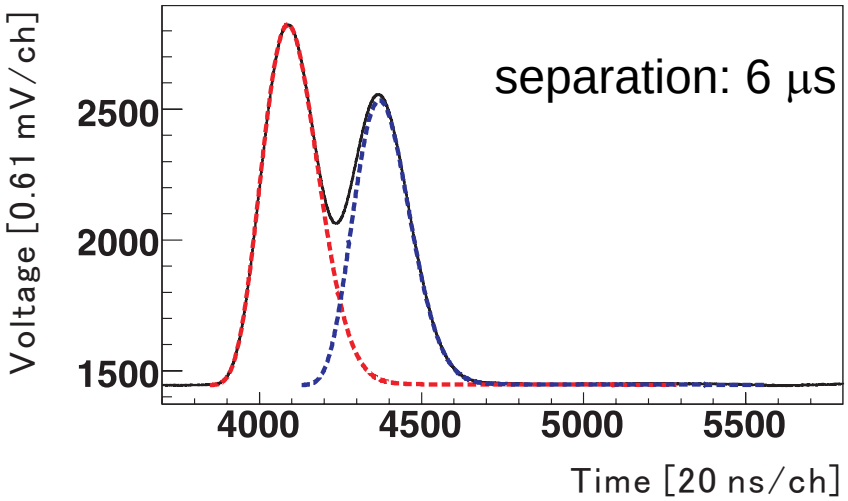
Doping and cooling of PWO crystals at-20℃

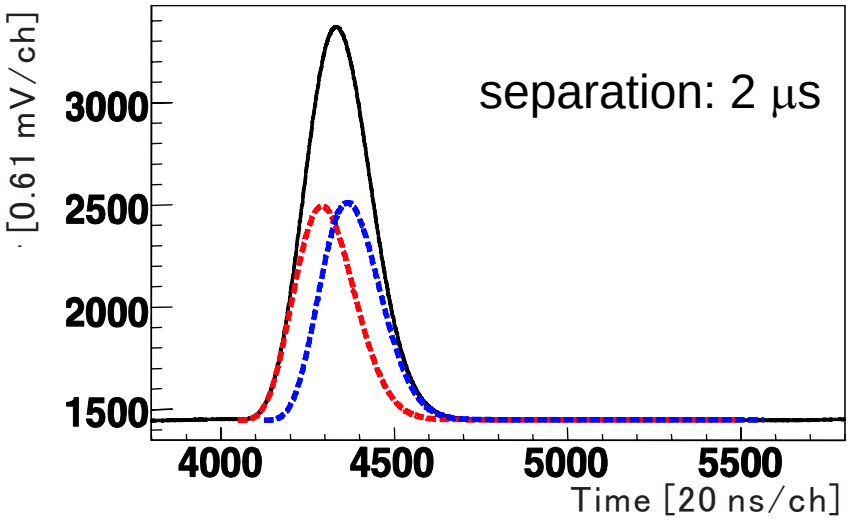
- comparable suppression performance to BGO
- 5 times faster than the BGO counter

Waveform analysis

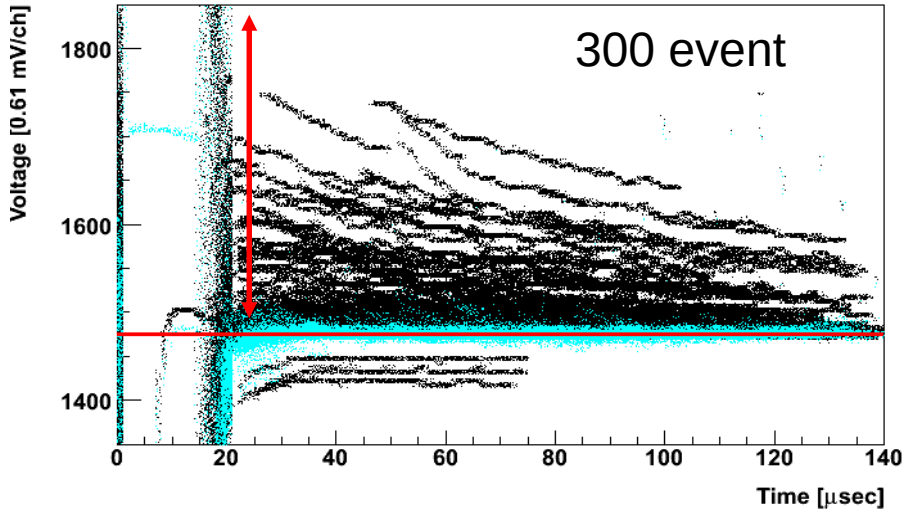
(K. Hosomi, Master thesis)

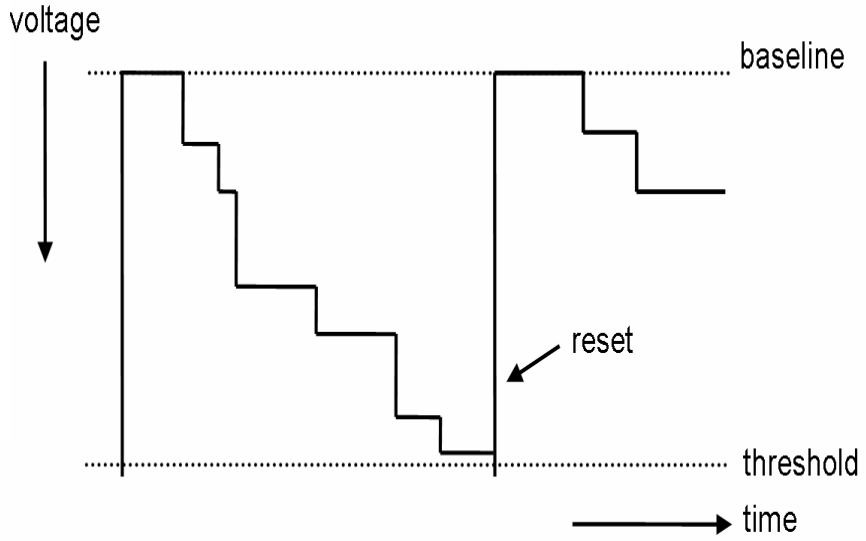
Pile up separation





Base line correction





Summary

- Intense K beam and Hyperball-J with a high detection efficiency at J-PARC
- B(M1) measurement of L spin doublet states in ${}^{7}_{\Lambda}\mathrm{Li}$ in E13 experiment
- Power of $\gamma\gamma$ coincidence
- Systematic investigation of the sd-shell nuclei and deformation in hypernuclei (K1.8 and K1.1)
- Major Hyperball-J R&D finished and its construction has begun to be completed by the summer of 2009.