NP04, Aug. 4, 2004

Hypernuclear γ spectroscopy at J-PARC

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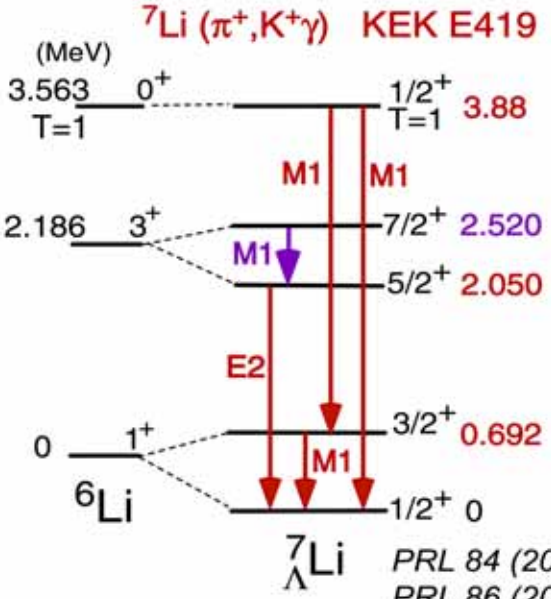
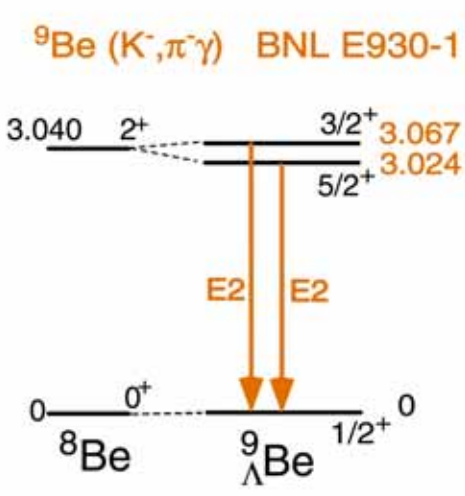
Tohoku Univ.

1. Present Status
2. Proposed Experiments
3. Hyperball-J and R&D

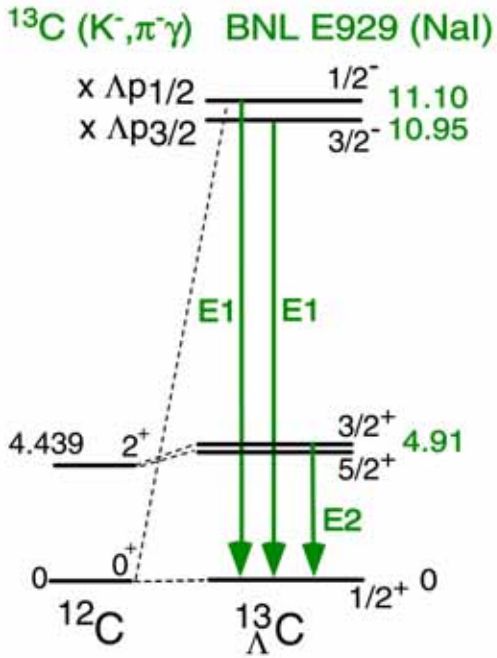
1. Present status



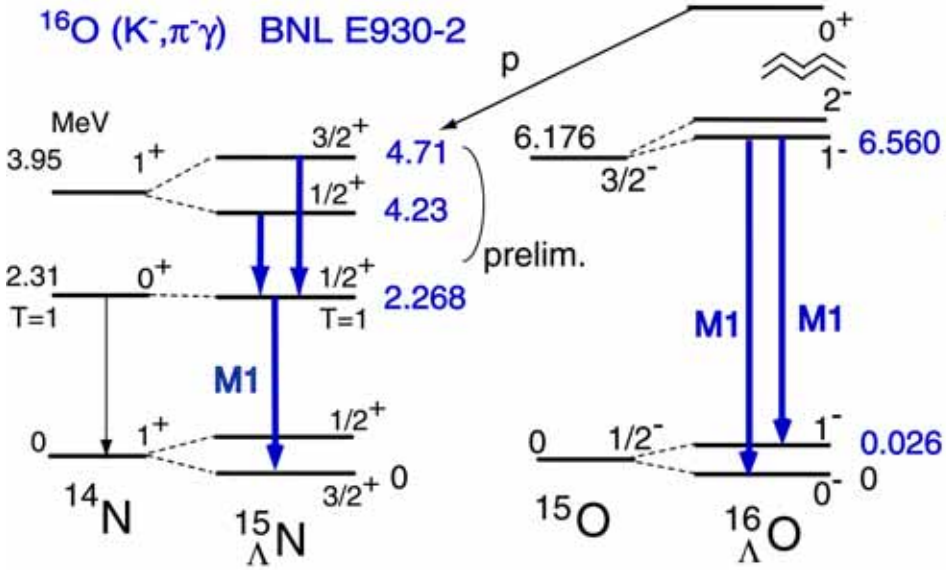
PRL 84 (2000) 5963
PRL 86 (2001) 1982
PLB 579 (2004) 258

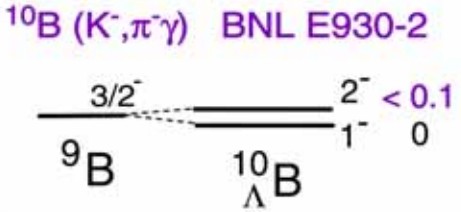


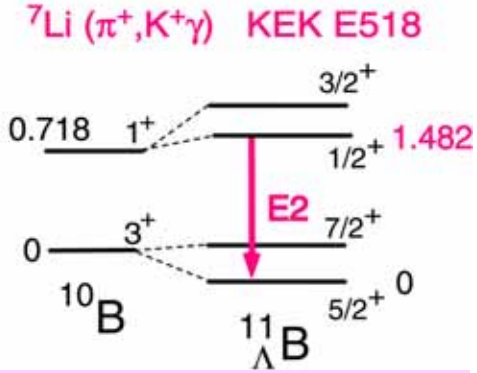
PRL 88 (2002) 082501



PRL 86 (2001) 4255







-> “Table of hyper-isotopes”

Motivation of Hypernuclear γ Spectroscopy

High-precision (ΔE∼a few keV) spectroscopy with Ge detectors

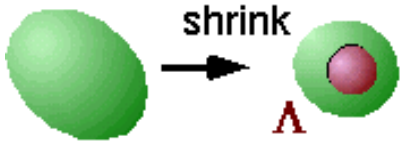
1. YN, YY interactions

-> Unified picture of B-B interactions,
Understand short-range nuclear forces
ΛN spin-dependent forces, ΛΛ force, …

2. Impurity effects in nuclear structure

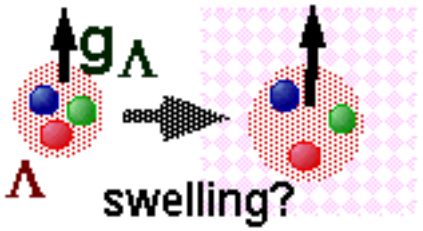
Changes of size/shape, symmetry, cluster/shell structure,..

B(E2) -> shrinking effect



3. Medium effects of baryons probed by hyperons

B(M1) -> μ_Λ in nucleus



Present Status and Future

1. ΛN interaction :

LS splitting $^{13}_{\Lambda}$C: Λ(p1/2,p3/2)

- Spin-spin (Δ), spin-orbit (S_Λ, S_N), tensor (T) strengths determined from $^{7}_{\Lambda}$Li (3/2$^+$,1/2$^+$), $^{9}_{\Lambda}$Be (3/2$^+$,5/2$^+$), $^{7}_{\Lambda}$Li (5/2$^+$,1/2$^+$), $^{16}_{\Lambda}$O (1$^-$,0$^-$)
- Cross check successful for $^{7}_{\Lambda}$Li (7/2$^+$,5/2$^+$), $^{15}_{\Lambda}$N (1/2$^+$,3/2$^+$), etc.
- Inconsistent data $^{10}_{\Lambda}$B (2$^-$,1$^-$), $^{11}_{\Lambda}$B (1/2$^+$,5/2$^+$)

➡ Future: ΣN-ΛN coupling; charge symmetry breaking; p-wave force; ΛΛ, ΞN, ΛΛ-ΞN forces

2. Shrinking effect from B(E2) : $^{7}_{\Lambda}$Li (5/2$^+$,1/2$^+$)

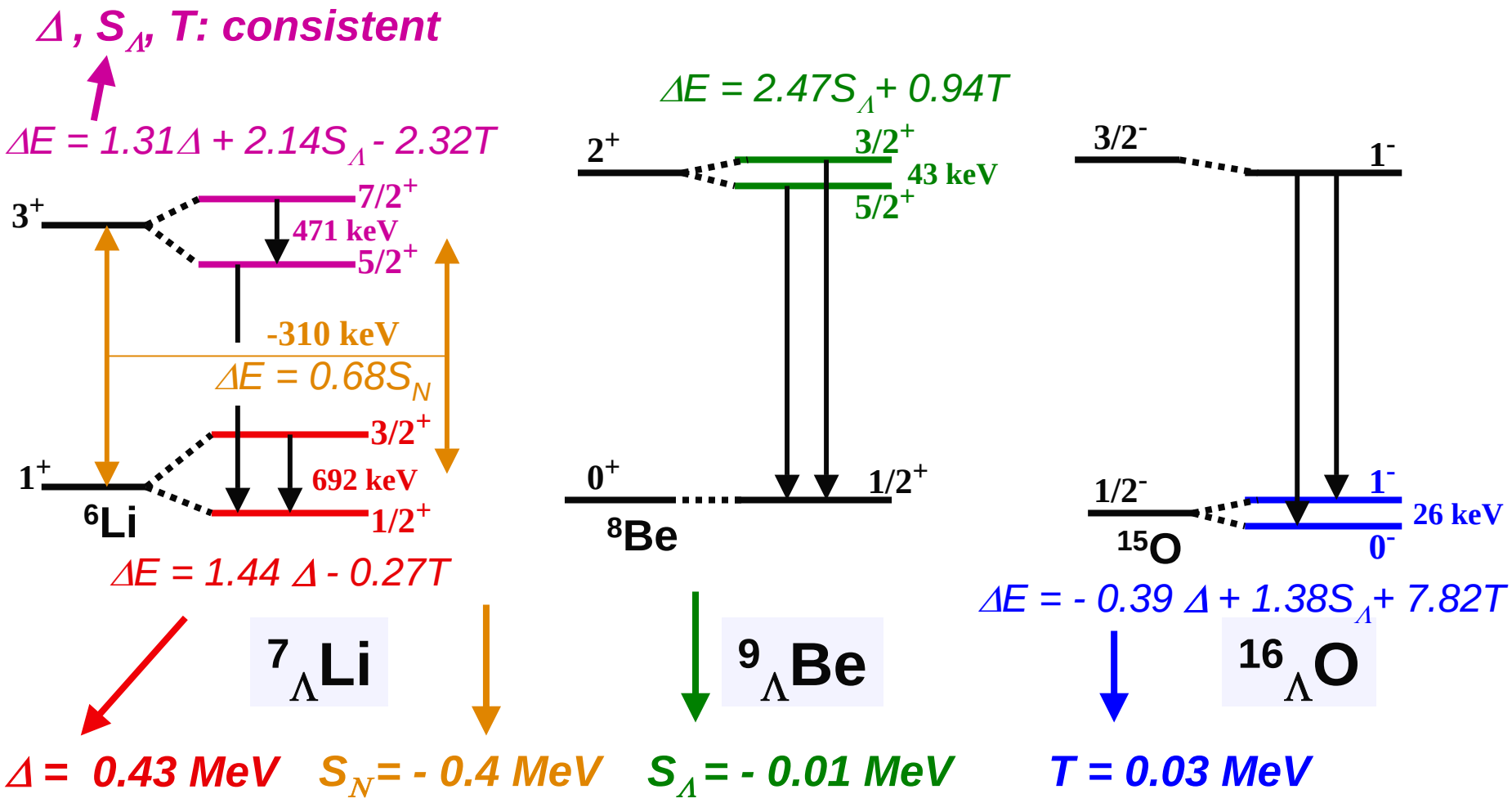
➡ Future: parity inversion, shrinkage/disappearance of n-halo, ρ-dep. of shrinkage, change of collective motions?

3. g_Λ from Spin-flip B(M1) : in progress for $^{11}_{\Lambda}$B

➡ Future: ρ-dependence, T-dependence

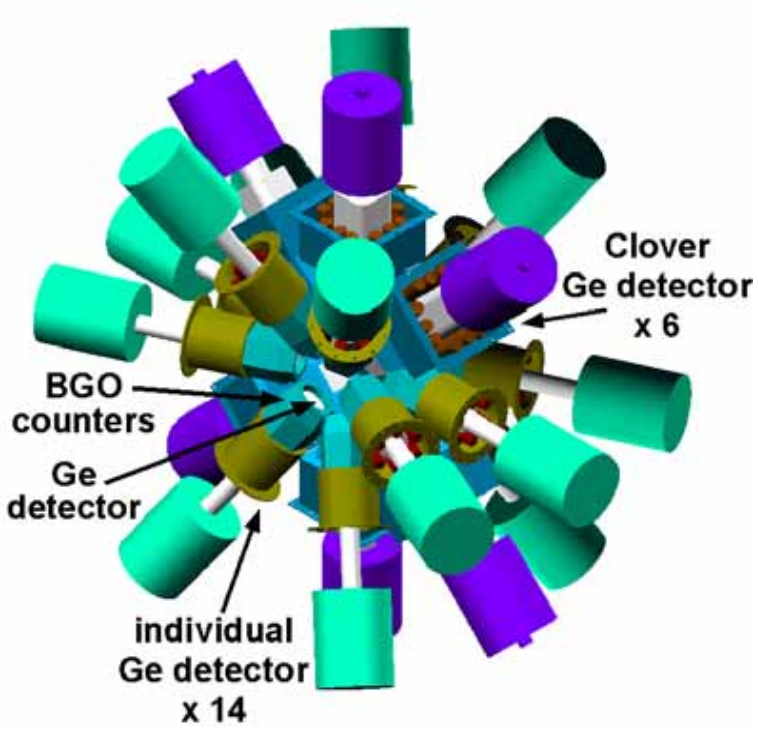
Λ swelling?

Determination of the spin-dependent force parameters



All the spin-dependent force parameters determined !

Hyperball Plans before J-PARC



- Hyperball2 (x2 of Hyperball)
  ready in fall, 2004

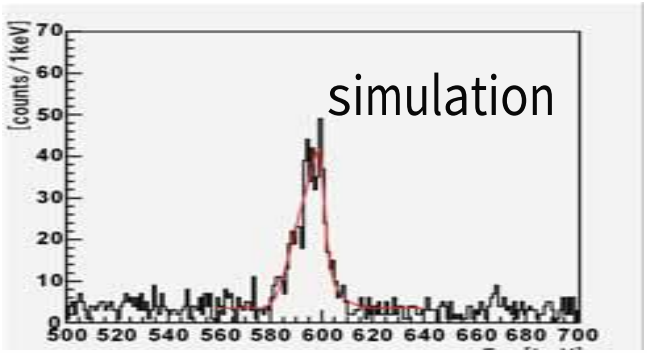
- KEK-PS at K6
  to be proposed in the next PAC [2005, summer?]

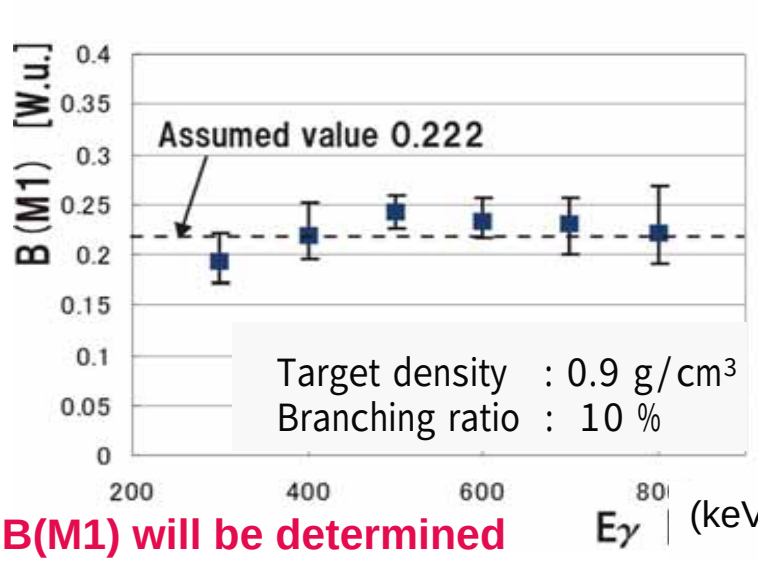
  $^{12}_{\Lambda}$C / $^{11}_{\Lambda}$B : B(M1), $\Sigma\Lambda$ coupling force, cross check

- BNL E964 (Ξ-atom X rays) [after 2005??]

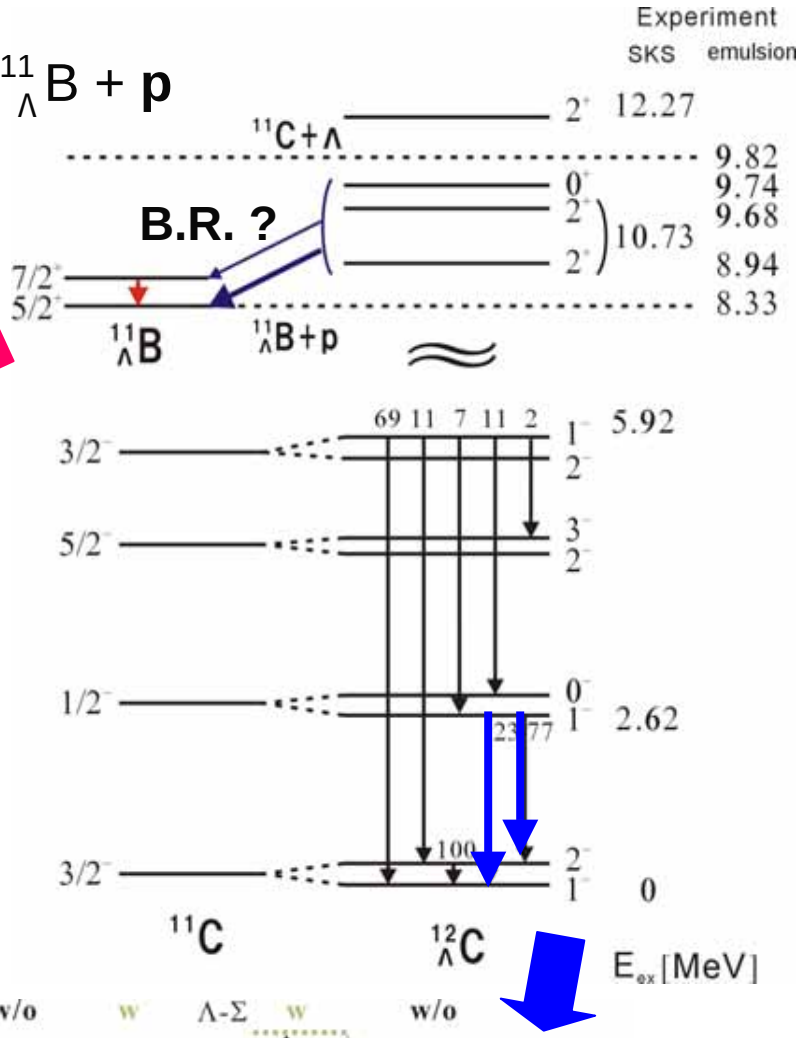
- BNL E930-3 (470 hours left)
  ^{10}B, ^{12}C or ^{14}N target [after 2005??]

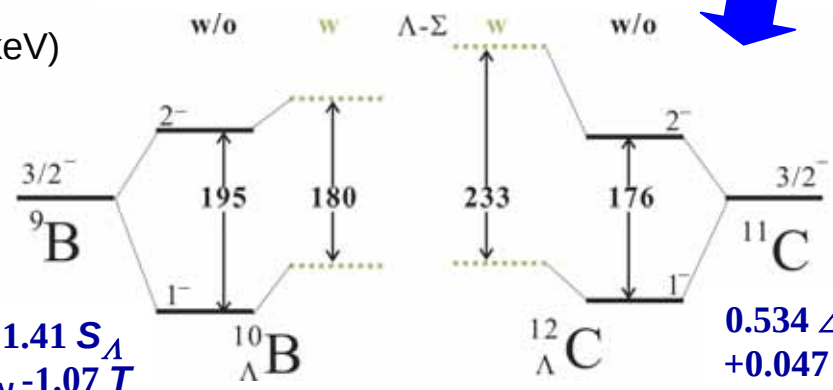
Proposed Exp. $^{12}C\,(\pi^+, K^+)\,^{12}_{\Lambda}C \rightarrow {}^{11}_{\Lambda}B + p$





B(M1) will be determined within 10 % error (B.R. 10%)





Similar structure but for ΣΛ effect -> solve the $^{10}_{\Lambda}B$ puzzle

$0.578\,\Delta + 1.41\,S_\Lambda + 0.014\,S_N - 1.07\,T$

$0.534\,\Delta + 1.44\,S_\Lambda + 0.047\,S_N - 1.72\,T$

Exp. <100 keV ?? keV

2. J-PARC Experiments

LOI 06 "Day1" → Full proposal

Low intensity beam usable, minimum setup

(1) Complete study of light (A<30) hypernuclei

(2) Systematic study of medium and heavy hypernuclei

($K^-,\pi^-\gamma$) *spin-flip/ no-flip productions*

ΛN interaction (ΛN–ΣN, p-wave, ..)

Shrinkage, collective motion, ...

(3) n-rich/ p-rich/ mirror hypernuclei

(K^-, $\gamma\gamma$) *hyperfragments*

(K^-, $\pi^0\gamma$) *mirror hypernuclei*

ΛN interaction (ΛN–ΣN, Charge Sym. Br.)

Shrinkage of n-halo, ..

(4) Spin-flip *B(M1)*

($K^-,\pi^-\gamma$), ($\pi^+,K^+\gamma$) *Doppler shift atten.*

($K^-,\pi^-\gamma$ *p*) *γ-weak coincidence*

μ_Λ in nuclei (ρ,T- dependence)

(5) Double strangenss (Ξ⁻ atom X rays and ΛΛ-hypernuclei)

(K^-, $K^+\gamma$)

ΞN, ΛΛ, ΞN-ΛΛ interactions

Proposal for DAY1
Hypernuclear γ Spectroscopy by (K^-,$\pi^-\gamma$)

K1.1+ SPESII
p_K= 1.1 and 0.8 GeV/c

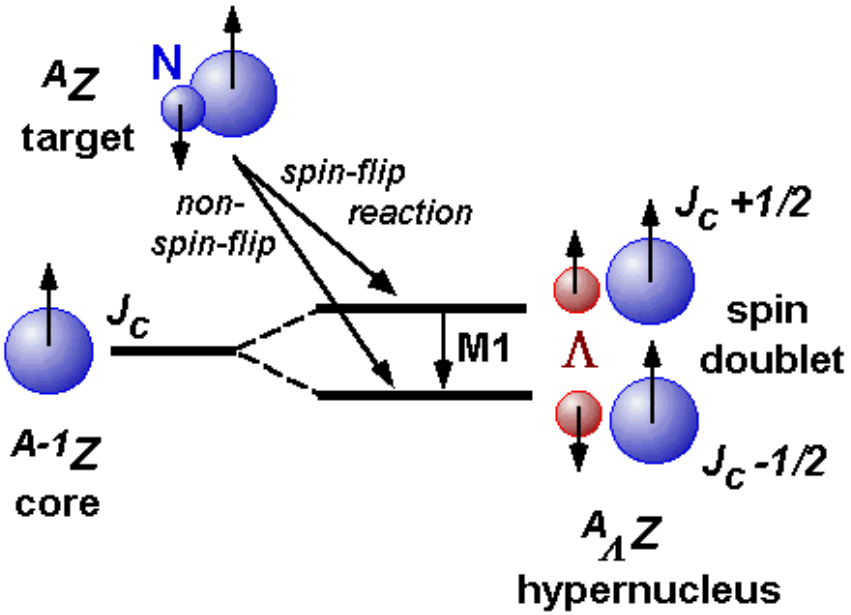
or

K1.8 + SKS
p_K= 1.8 and 1.1 (or 1.5) GeV/c

- **Light** (survey study)
  - A=4ー~30 all possible targets **$^{4}_{\Lambda}$He, $^{13}_{\Lambda}$C/ $^{14}_{\Lambda}$N, $^{20}_{\Lambda}$Ne, $^{23}_{\Lambda}$Na, $^{27}_{\Lambda}$Al / $^{28}_{\Lambda}$Si, …**
    (-> Table of hyper-isotopes, ΛN interaction, ...)
- **Light** (detailed study for some important hypernuclei)
  - $\gamma\gamma$ coin, $\theta\gamma\pi$/ $\theta\gamma\gamma$, polarization -> level scheme, spin-parity
  - DSAM -> B(E2), B(M1) **$^{12}_{\Lambda}$C (parity mixing states), $^{20}_{\Lambda}$Ne (parity inversion),..**
    $^{9}_{\Lambda}$Be (B(E2)),$^{11}_{\Lambda}$B (B(M1)), …
- **Hyperfragments** (K^-, $\gamma\gamma$ (π^-)), 0.8 GeV/c
  - Light targets (^{9}Be,^{10}B, ^{11}B, ^{12}C) **$^{7}_{\Lambda}$He, $^{8}_{\Lambda}$Li, $^{8}_{\Lambda}$Be, $^{9}_{\Lambda}$Li, $^{9}_{\Lambda}$B,... ($\Lambda\Sigma$, CSB,..)**
- **Medium and heavy** p=0.8--1.8, large θ -> large q
  - E1(p_Λ->s_Λ) ~4 MeV **$^{89}_{\Lambda}$Y, $^{139}_{\Lambda}$La, $^{208}_{\Lambda}$Pb (p-wave ΛN int.,..)**

Total beam time to be estimated.

K^- Beam momentum

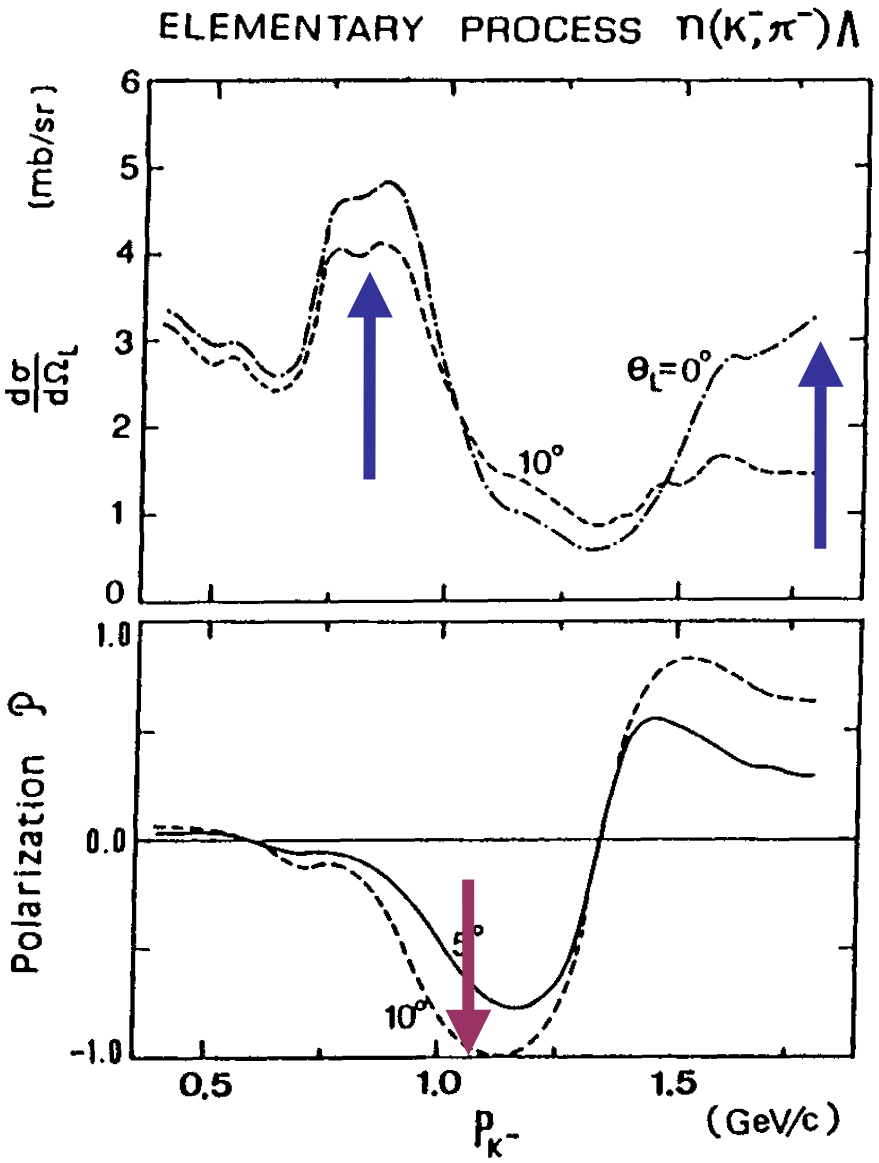


0.8, 1.8 GeV/c (K^-,π^-)
= large σ and non-spin-flip

+

1.1 GeV/c (K^-,π^-)
= spin-flip

- **Reveal all the levels**
- **Level assignment**
- **Spin-flip B(M1) -> μ_Λ**



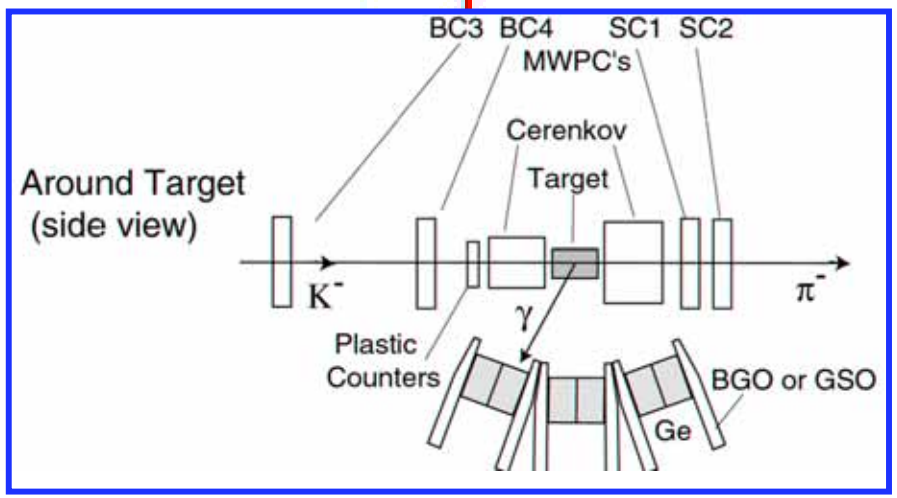
Beam and Setup

K^- 1.1
+ 0.8 GeV/c

- **Beamline: K1.1**
  1.2×10^7 K^-/spill at 1.1 GeV/c
  $K/\pi > 1$

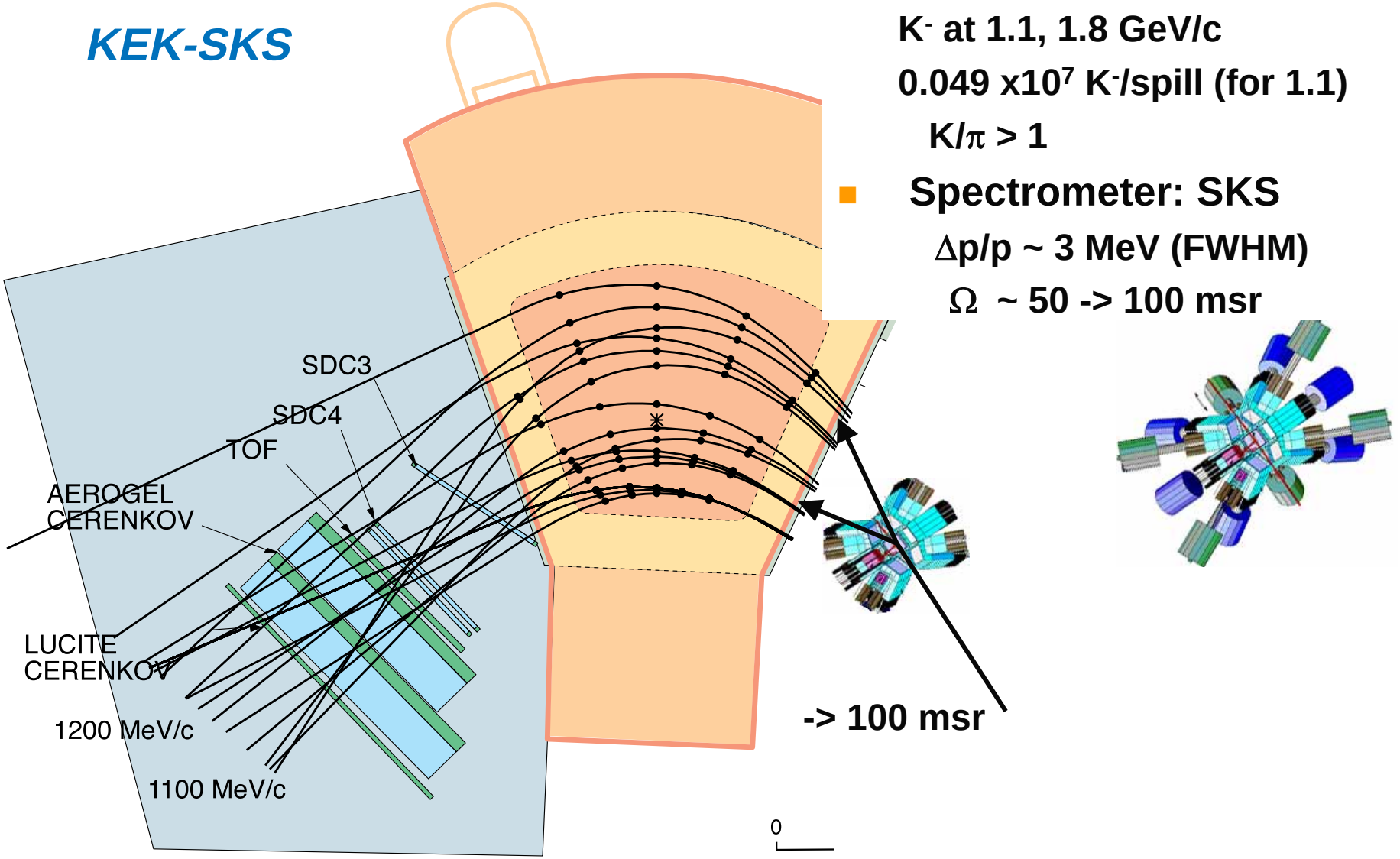
- **Spectrometer: SPESII**
  $\Delta p/p < 2$ MeV (FWHM)
  Ω ~ 20 msr

- **Hyperball-J**
  ε ~ 10% at 1 MeV



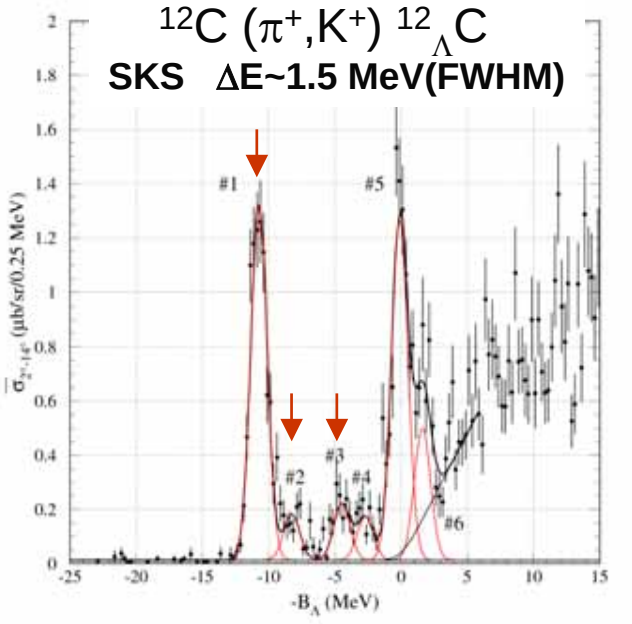
Option for K1.8 + SKS

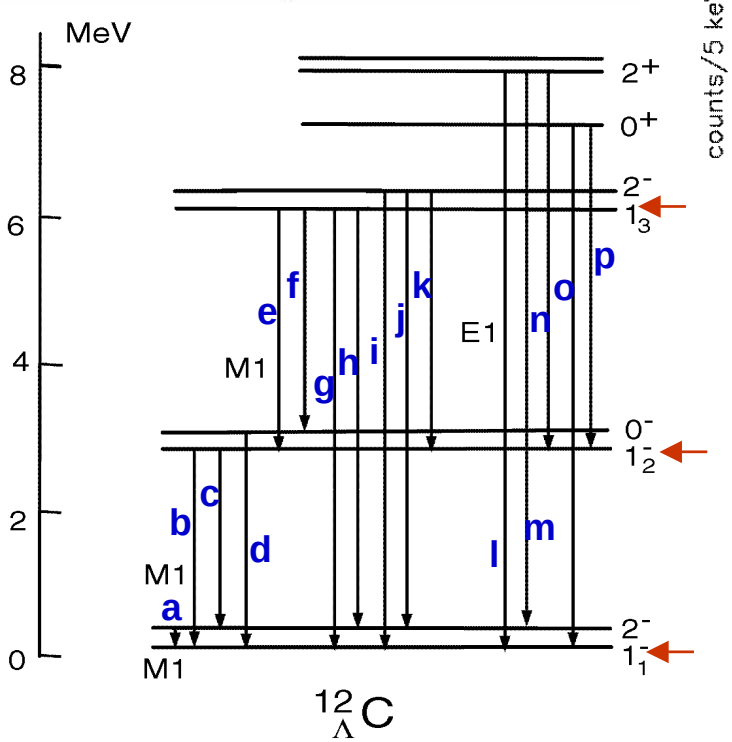
- **Beamline: K1.8**
  K^- at 1.1, 1.8 GeV/c
  0.049 x10^7 K^-/spill (for 1.1)
  K/π > 1
- **Spectrometer: SKS**
  Δp/p ~ 3 MeV (FWHM)
  Ω ~ 50 -> 100 msr

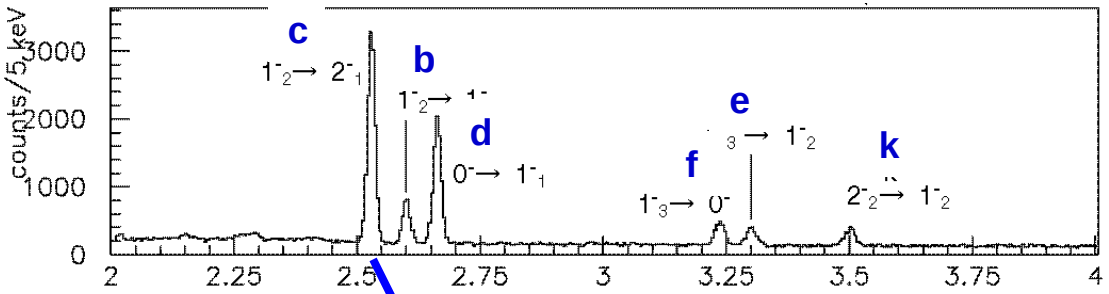


Light hypernuclei --- example of $^{12}_{\Lambda}$C

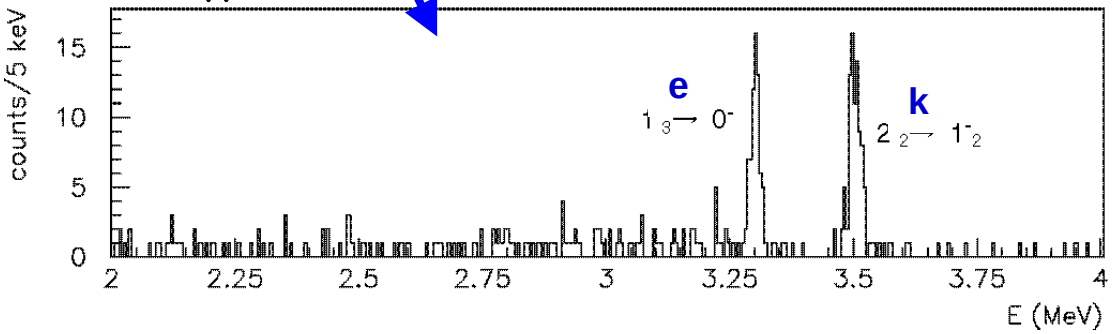
Simulation: K1.1, 10g/cm^2, 120 hours

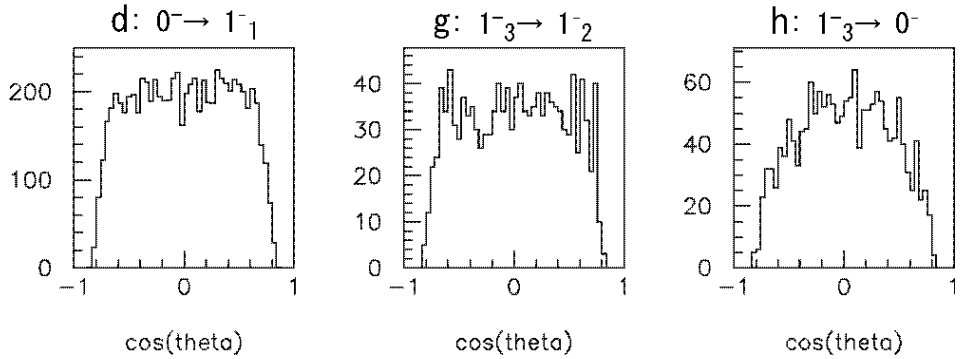






γγ coincidence with c -> level scheme

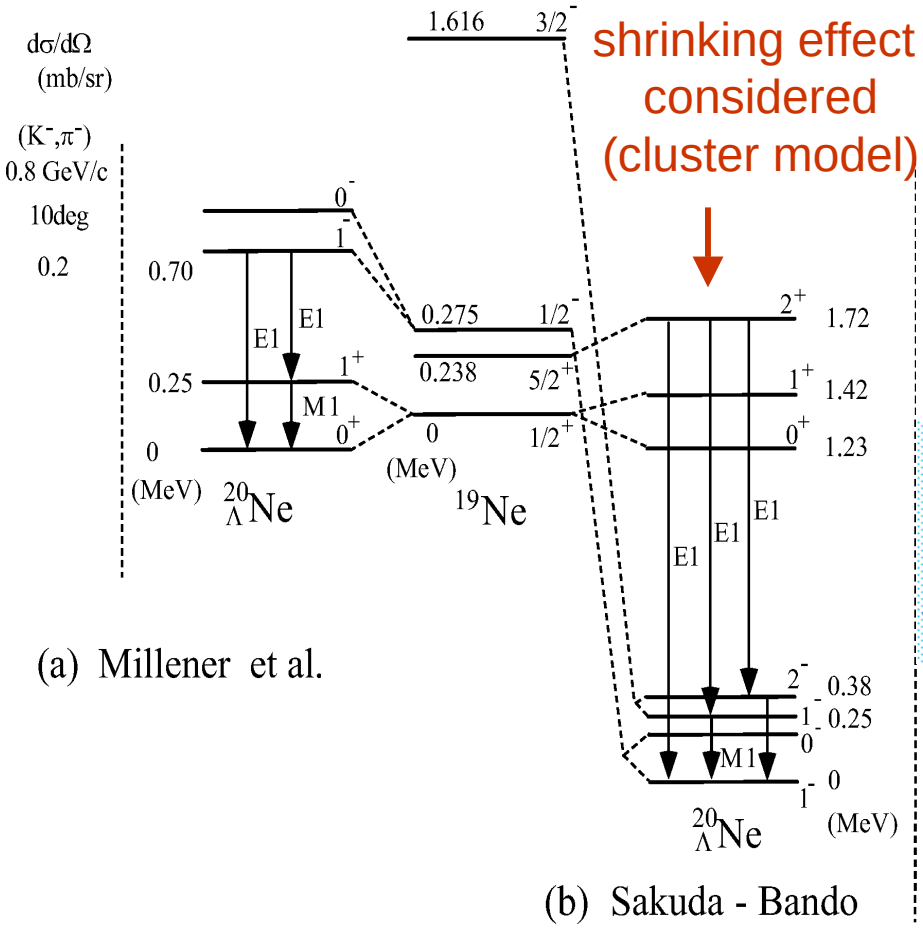




$\theta_{\pi\gamma}$ angular correlation -> spin assignment

Light hypernuclei: Impurity effect

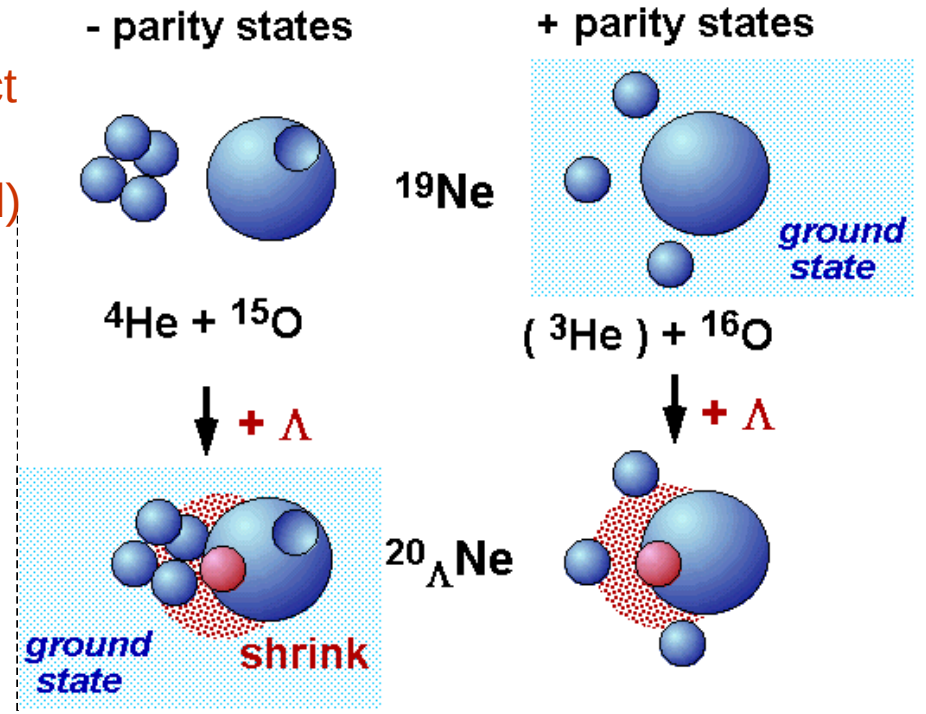
example of $^{20}_{\Lambda}$Ne --- parity inversion due to shrinkage



shrinking effect considered (cluster model)

(a) Millener et al.

(b) Sakuda - Bando



different shrinkage for clusterized/ spherical nucleus

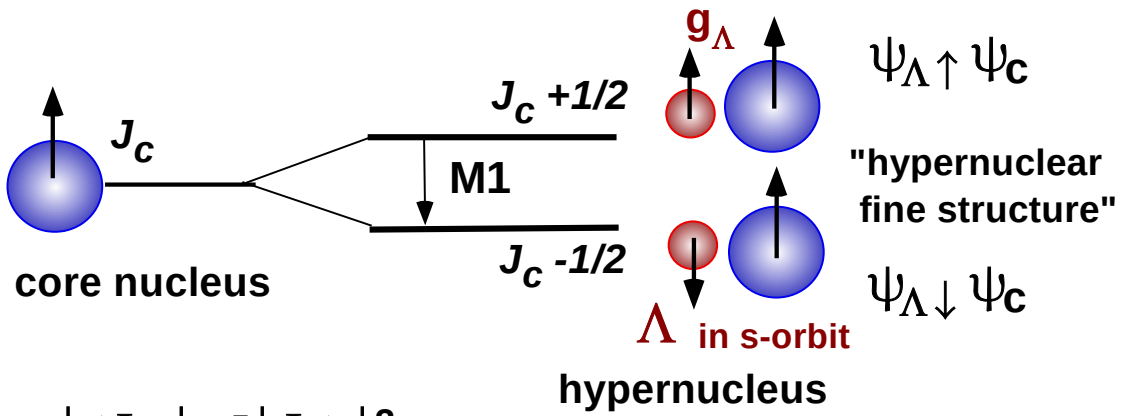
(c) M

0.20 0.1

Determination of Parity
-> measure γ polarization with 4 Ge crystals of "Clover"

B(M1) measurements

μ_Λ in nucleus -> medium effect of baryons



$$B(M1) \propto |\langle\Phi_f|\mu^z|\Phi_i\rangle|^2$$

$$= |\langle\psi_\Lambda\uparrow\psi_c|\ g_c J_c^z + g_\Lambda J_\Lambda^z\ |\psi_\Lambda\downarrow\psi_c\rangle|^2$$

$$\propto (g_c - g_\Lambda)^2$$

Accuracy Δg_Λ < 5% achievable

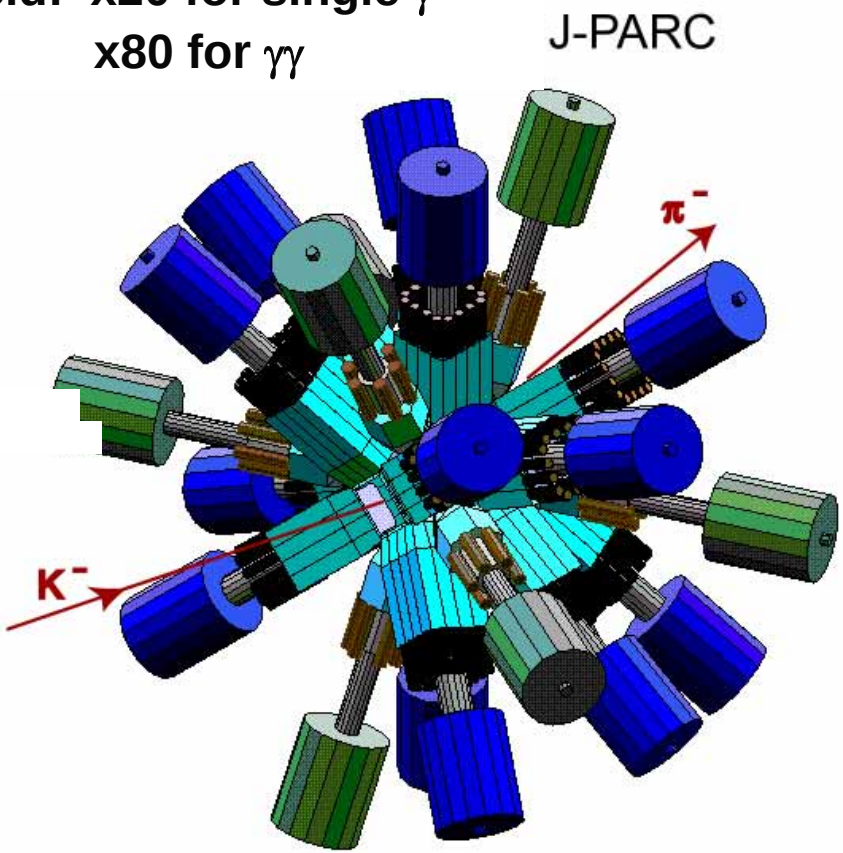
- **Doppler shift attenuation method** *[same as B(E2), established]*
  for light hypernuclei; Weak K^- or π^+ beam usable
- **γ-weak coincidence method** *[new, only possible at J-PARC]*
  for heavy hypernuclei; Intense K^- beam necessary

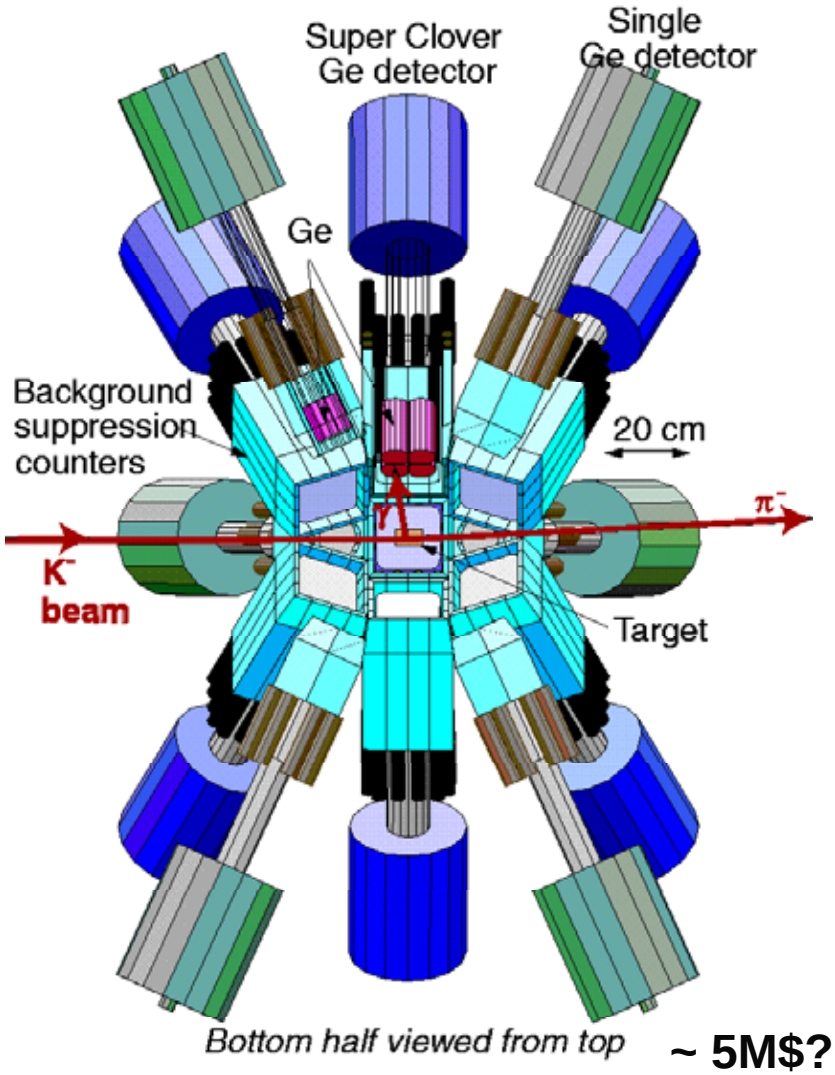
T-dependence -> $\Sigma\Lambda$ coupling effect; ρ-dependence -> medium effect

3. Hyperball-J

- ε > 10% at 1 MeV
  (x4 of Hyperball)
- Rate limit
  ~2x10^7 particles /s (x5)
- Yield: x20 for single γ
  x80 for γγ

- (Segmented) Super Clover (350%) x 14
  (or normal x 32?) + old normal (60%) x8
- Waveform readout
- Fast suppression counters (BGO=>PWO?)



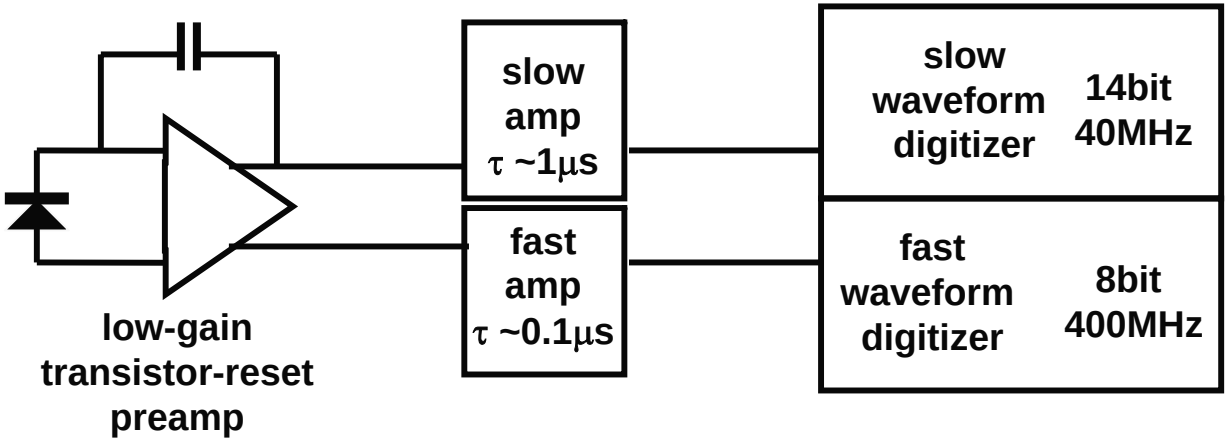


~ 5M$?

R&D's for Hyperball-J

- **Waveform readout method**

  pileup decomposition, baseline correction by software
  (single rate:100->500kHz, energy rate 0.5->2.5TeV/s)
  beam limit: K6: 3×10^6/sec -> K1.1: 1.5×10^7/sec



- **LN2-free cooling**
- **Radiation damage** -- most serious

  New detector annealable at higher temperature
- **Faster background suppression counters**

  BGO -> PWO, BSO, ...

Faster suppressor

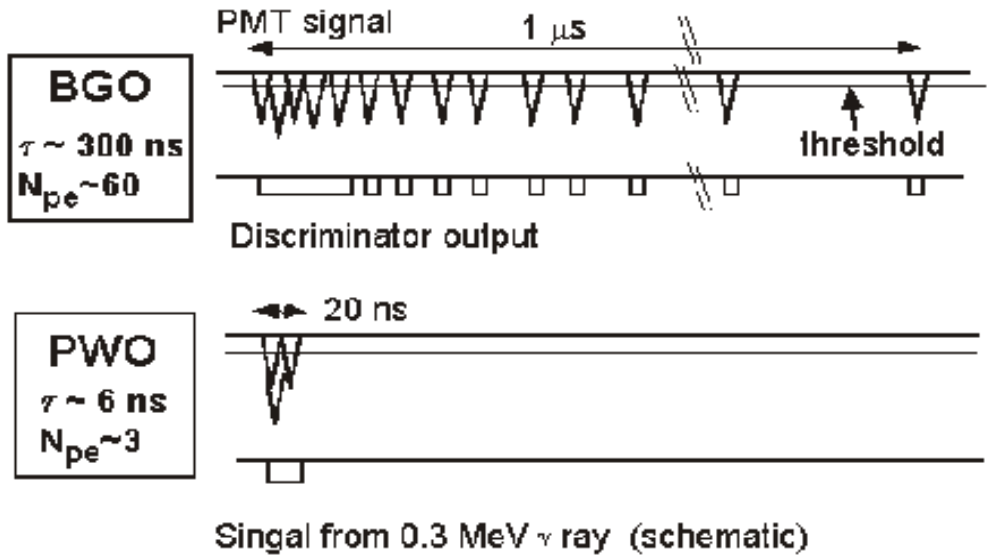
BGO: rate limit (overkill ~5-10%)

-> faster scintillator
PWO, LSO, BSO, LaBr ...

PWO
- Good Y_{light}/τ
- Cheap (30% of BGO)
- Small light yield
  (< 1 p.e./0.1 MeV)
  --> low eff. for low-energy γ

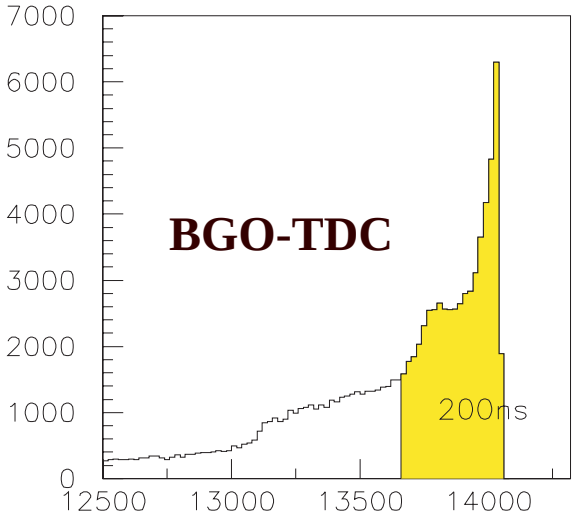
Limited performance
for Compton suppression
->to be tested
Good for high energy γ
(main BG for hypernuclei)
-> tested. OK

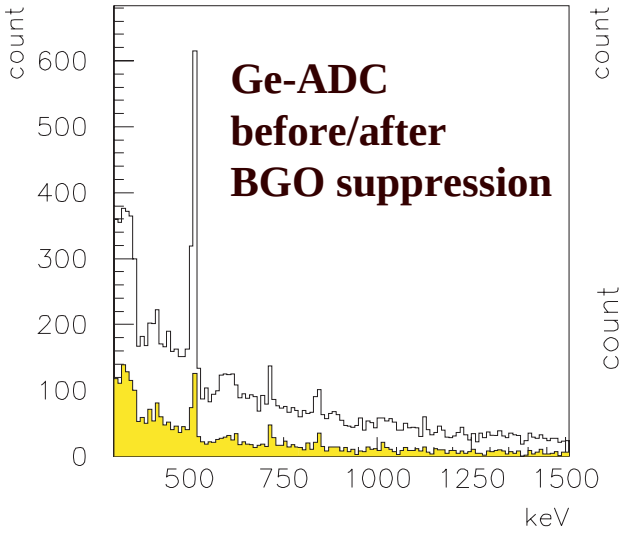
	density [g/cm3]	L_R [cm]	τ [ns]	Y_{light} [% NaI]	Y_{light}/τ
PWO	8.28	0.89	~6	1	~0.2
BGO	7.23	1.12	300	15	~0.05
NaI(Tl)	3.67	2.59	250	100	
CsI(Tl)	4.53	1.85	565	40	

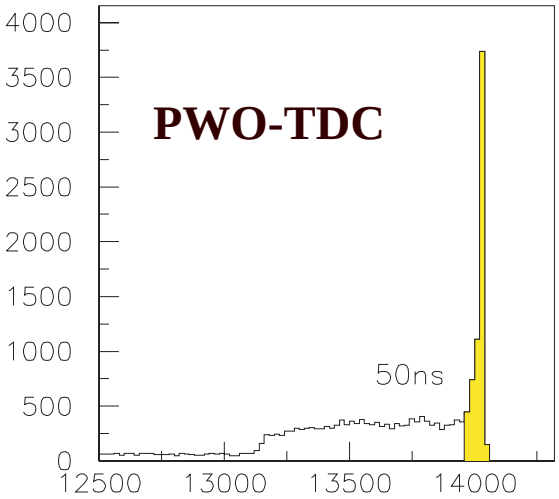


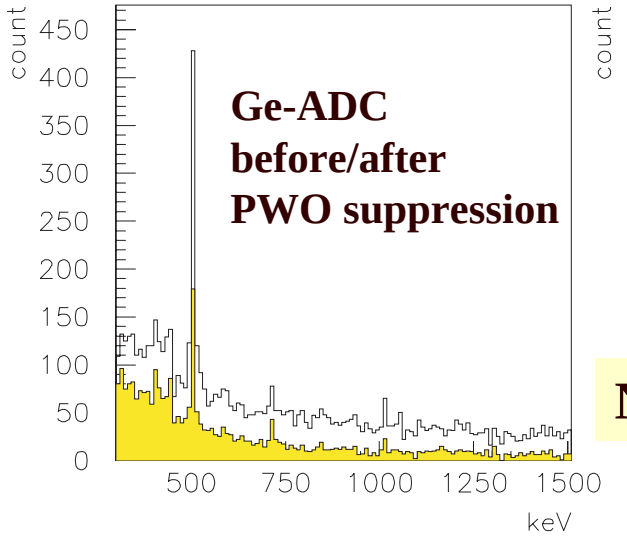
Beam test of PWO counters

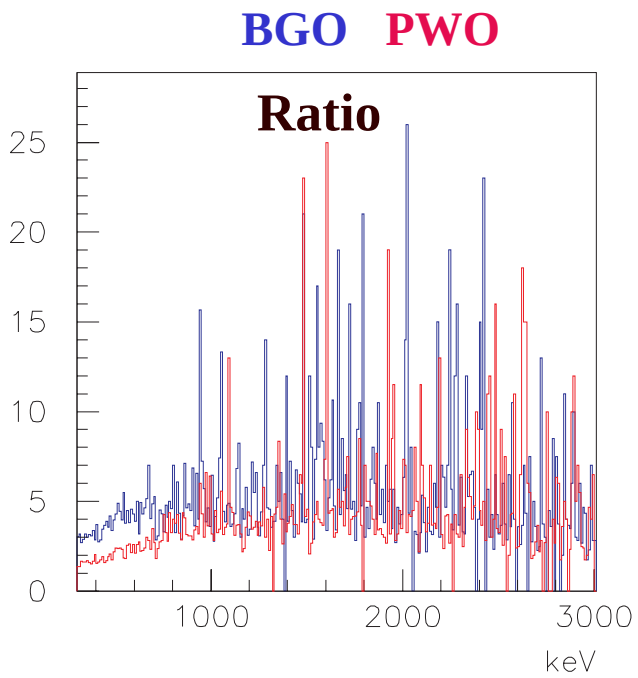
K6 line, π^+ on ^{10}B











No difference for E>1 MeV

Summary

- **Motivations of γ spectroscopy at J-PARC:**
  - **further ΛN interaction, $\Lambda\Lambda$/ΞN interaction**
  - **impurity effect (B(E2))** **medium effect (B(M1))**
- **Proposal of the DAY-1 experiment planned:**

  -- Light to heavy hypernuclei by (K^-,$\pi^-\gamma$) reaction at 1.1 and 0.8 GeV/c--
- **Hyperball-J to be designed, R&D's for strong beams started.**
- **Request K1.1+SPESII (but K1.8+SKS usable).**

-- Please join the discussion on the proposal.