Revised Run Plan of E13
“Gamma spectroscopy of light Λ hypernuclei”

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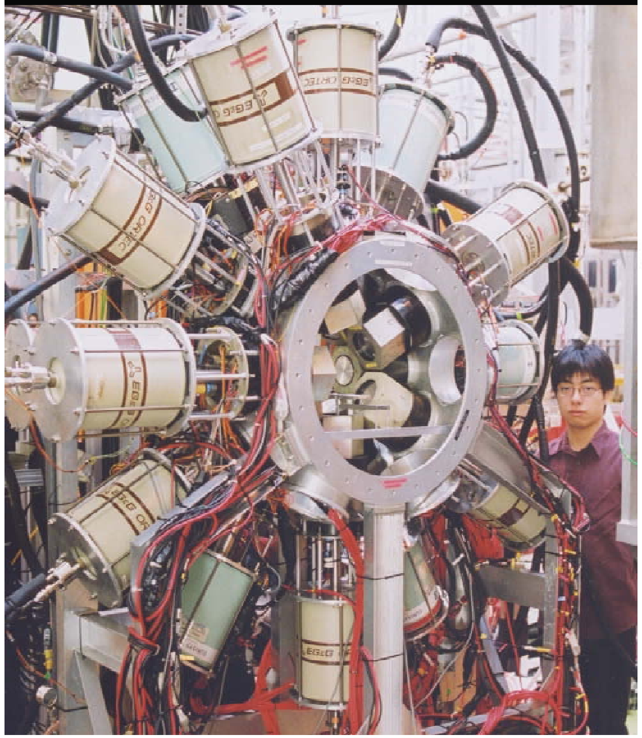
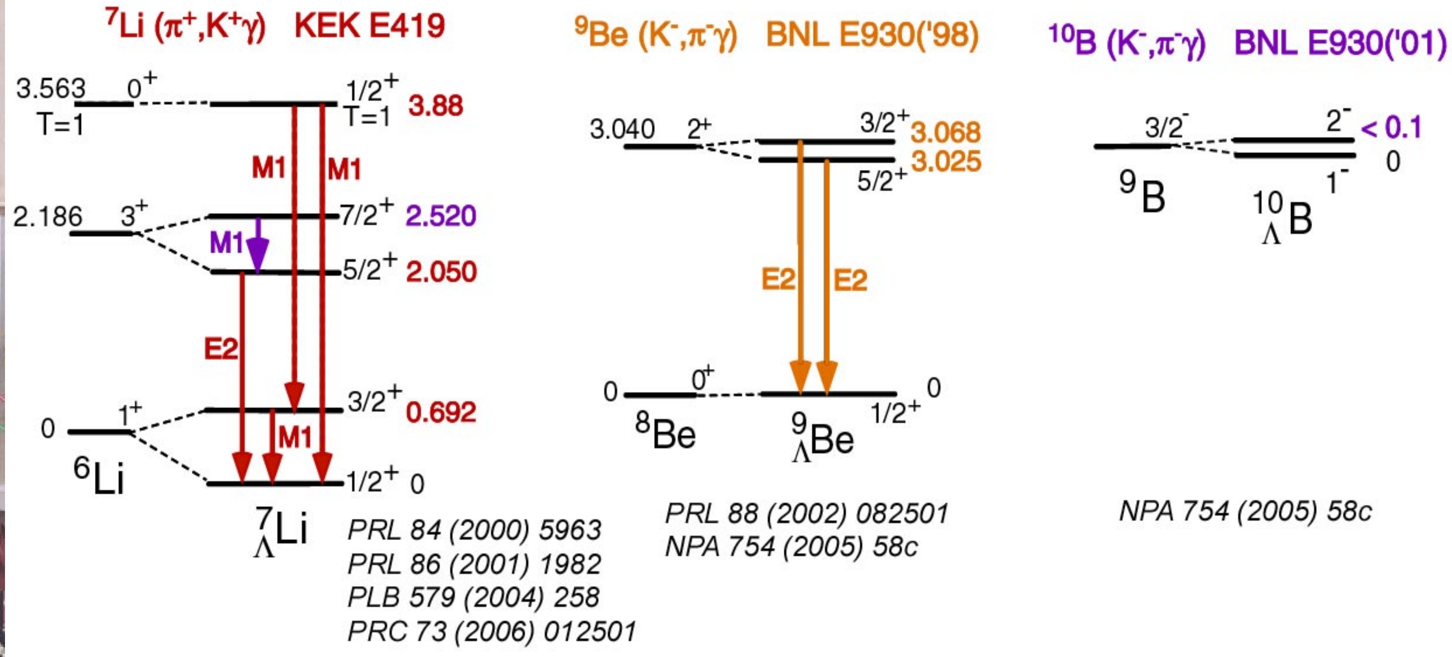
for the E13 Collaboration

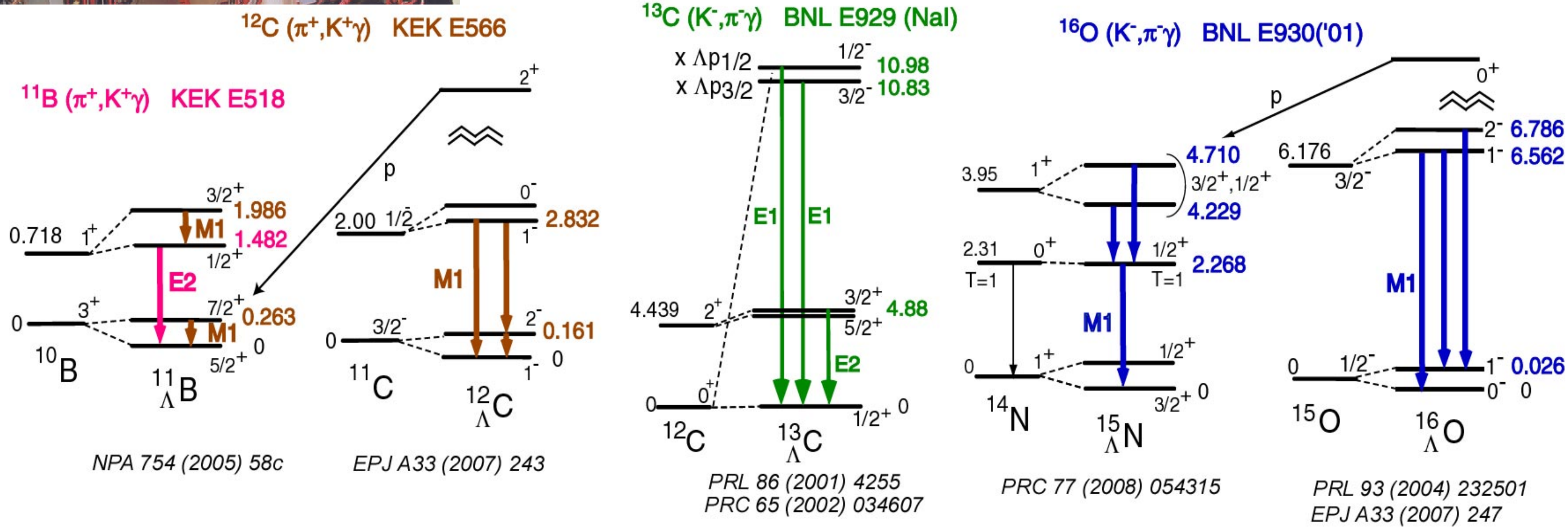
1. Introduciton

Hyperball



Hypernuclear γ-ray data





Motivation of Hypernuclear γ Spectroscopy

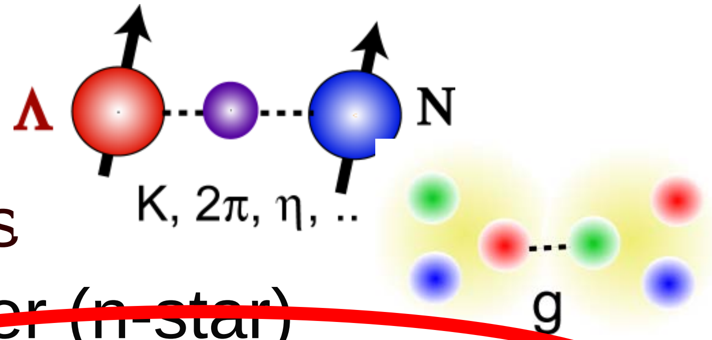
High-precision (ΔE$\sim$a few keV) spectroscopy with Ge detectors

1. YN, YY interactions

Unified picture of B-B interactions

Understand short-range nuclear forces

Understand high density nuclear matter (n-star)



Level energies -> ΛN spin-dependent forces, ΣN-ΛN force, CSB,…

E13

2. Impurity effects in nuclear structure

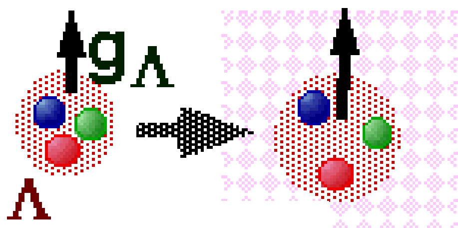
Changes of size/shape, symmetry, cluster/shell structure,..

B(E2), E(2$^+$) -> shrinking effect, deformation change

3. Medium effects of baryons probed by hyperons

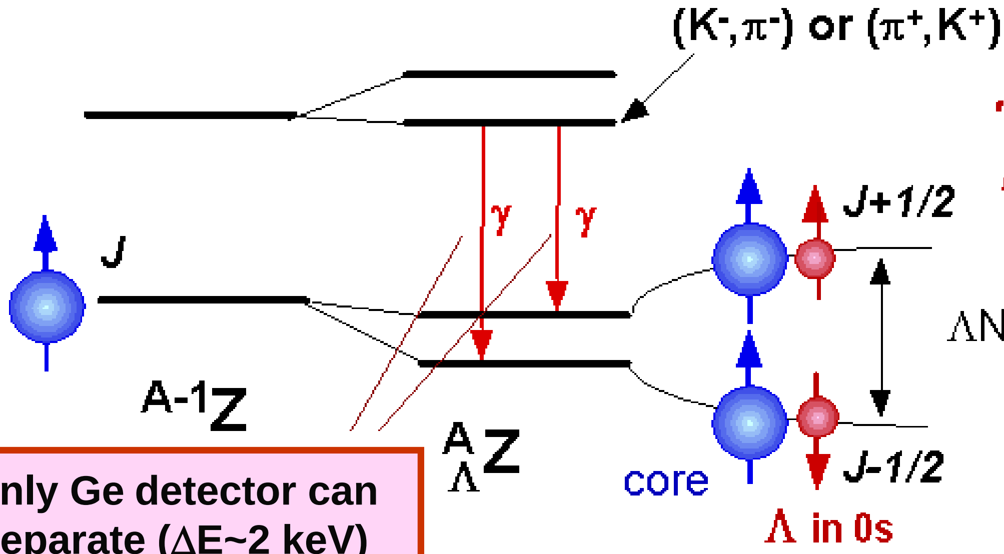
B(M1) -> μ_Λ in nucleus

E13



ΛN spin-dependent interactions

- **Low-lying levels of Λ hypernuclei**



"Hypernuclear Fine Structure"

split by
ΛN spin-dependent
interactions
$\lesssim$ 0.1 MeV

Level spacing: Linear combination of Δ, S_Λ, S_N, T

Only Ge detector can separate (ΔE~2 keV)

- **Two-body ΛN effective interaction**

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

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

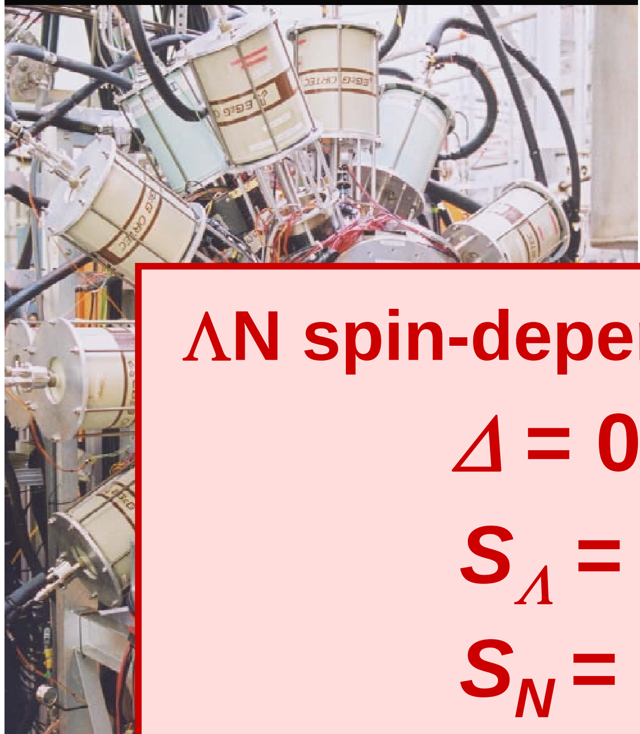
$\bar{V}$ | Δ | S_Λ | S_N | T

Well know from U_Λ = - 30 MeV

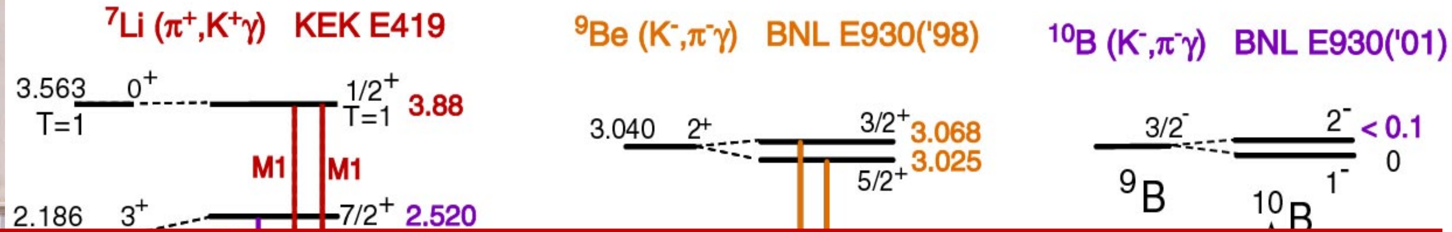
p-shell: 5 radial integrals for $s_\Lambda p_N$ w.f.

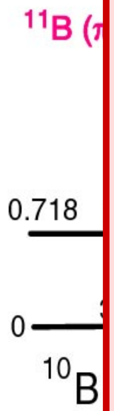
$$\Delta = \int V_\sigma(r)\,|u(r)|^2 r^2 dr, \quad \mathbf{r} = \mathbf{r}_{s_\Lambda} - \mathbf{r}_{p_N}$$

Hyperball



Hypernuclear γ-ray data





ΛN spin-dependent interaction strengths determined:

Δ = 0.33 MeV (A>10), 0.42 MeV (A<10)

S_Λ = -0.01 MeV
S_N = -0.4 MeV
} *Agree with quark model prediction*

T = 0.03 MeV → *Agree with meson exchange model prediction*

- **Almost all these p-shell levels are reproduced by this parameter set. (D.J. Millener)**
- **Feedback to BB interaction models toward unified understanding of BB interactions**

PRL 86 (2001) 4255
PRC 65 (2002) 034607

PRC 77 (2008) 054315

PRL 93 (2004) 232501
EPJ A33 (2007) 247

2. Purpose of E13

Purpose of E13 experiment

Approved as DAY1, Second priority

ΛN interaction

Using (K^-,π^-) reaction at p_K= 1.5 (or 1.1) GeV/c

(1) Charge symmetry breaking in ΛN interaction and spin-flip property in hypernuclear production

$^{4}_{\Lambda}$He : Largest CSB is suggested but previous data is suspicious.
Easiest (100 hrs)

(2) Radial dependence of ΛN interaction from sd-shell hypernuclei

$^{19}_{\Lambda}$F : The first sd-shell hypernuclei (100 hrs)

(3) Study ΛN–ΣN coupling force

$^{10}_{\Lambda}$B and $^{11}_{\Lambda}$B: (100+200 hrs)

Inconsistency exist but previous data not enough.
Few-body approach as well as shell model possible.

g-factor of Λ in nucleus

(4) Spin-flip B(M1) measurement and g_Λ in a nucleus

$^{7}_{\Lambda}$Li : Least ambiguities exist and most reliable. (500 hrs)

Purpose of E13 experiment

Approved as DAY1, Second priority

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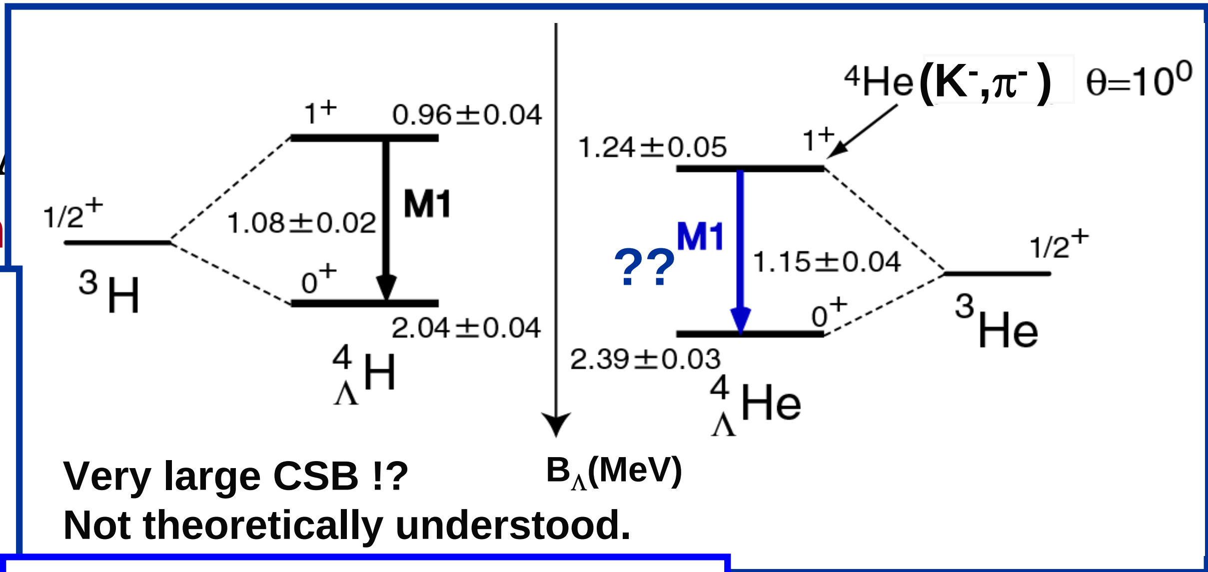
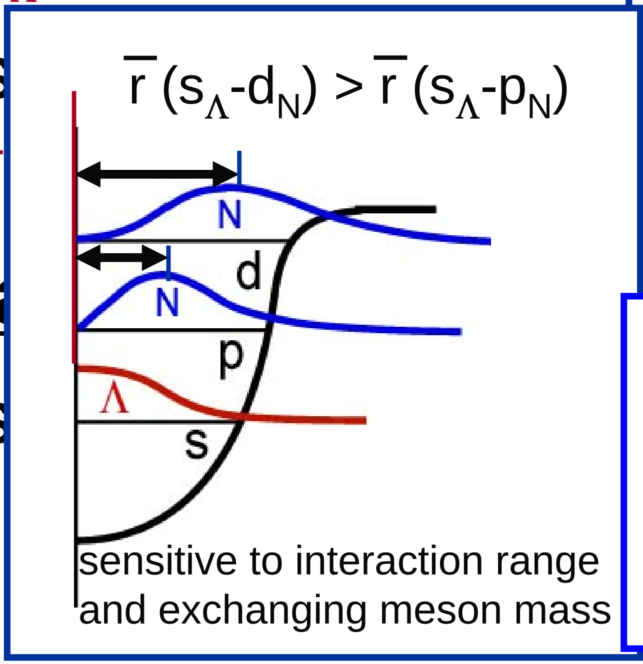


(2) Radial dependence of ...

$^{19}_\Lambda$F : The first sd-shell h...



(3) S...

1...

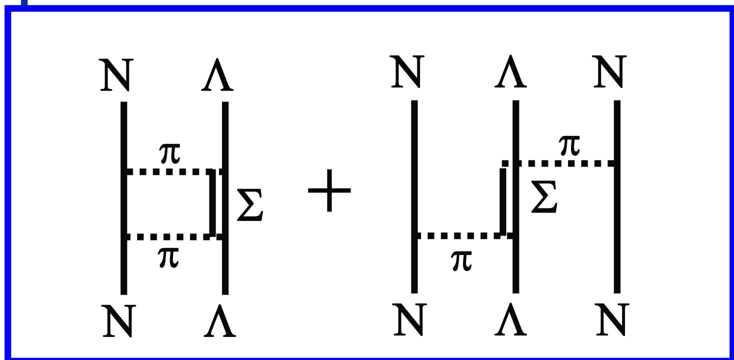
...gh.

...sible.

g-fa...

(4) S...

...) hrs)



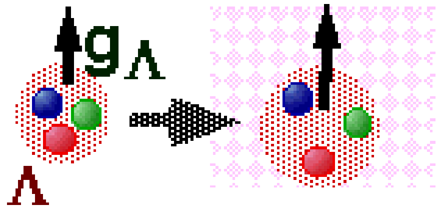
Magnetic moment of a Λ in a nucleus

Baryon magnetic moment in nucleus:
affected by partial restoration of chiral symmetry?
→ Origin of baryon spin and mass
Λ free from Pauli effect is a good probe.

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

m_q : Constituent quark mass

decrease m_q → increase μ_q?



- **Direct measurement is difficult (τ ~ 0.1-- 0.2 ns)**

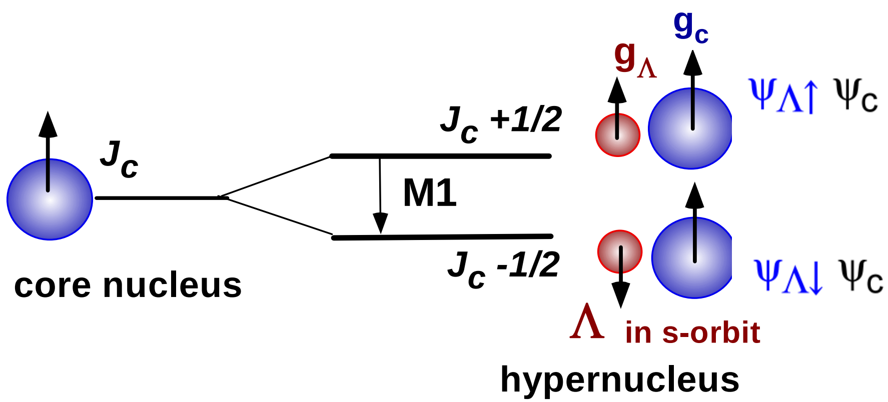
- **Λ-spin-flip M1 transition: B(M1) -> g_Λ**

$$B(M1) = (2J_{up}+1)^{-1} \left|\langle \Psi_{low} \| \mu \| \Psi_{up} \rangle\right|^2$$

$$= (2J_{up}+1)^{-1} \left|\langle \psi_{\Lambda\downarrow}\, \psi_c \| \mu \| \psi_{\Lambda\uparrow}\, \psi_c \rangle\right|^2$$

$$\mu = g_c J_c + g_\Lambda J_\Lambda = g_c J + (g_\Lambda - g_c) J_\Lambda$$

$$= \frac{3}{8\pi} \frac{2J_{low}+1}{2J_c+1} (g_\Lambda - g_c)^2 \quad [\mu_N^2]$$

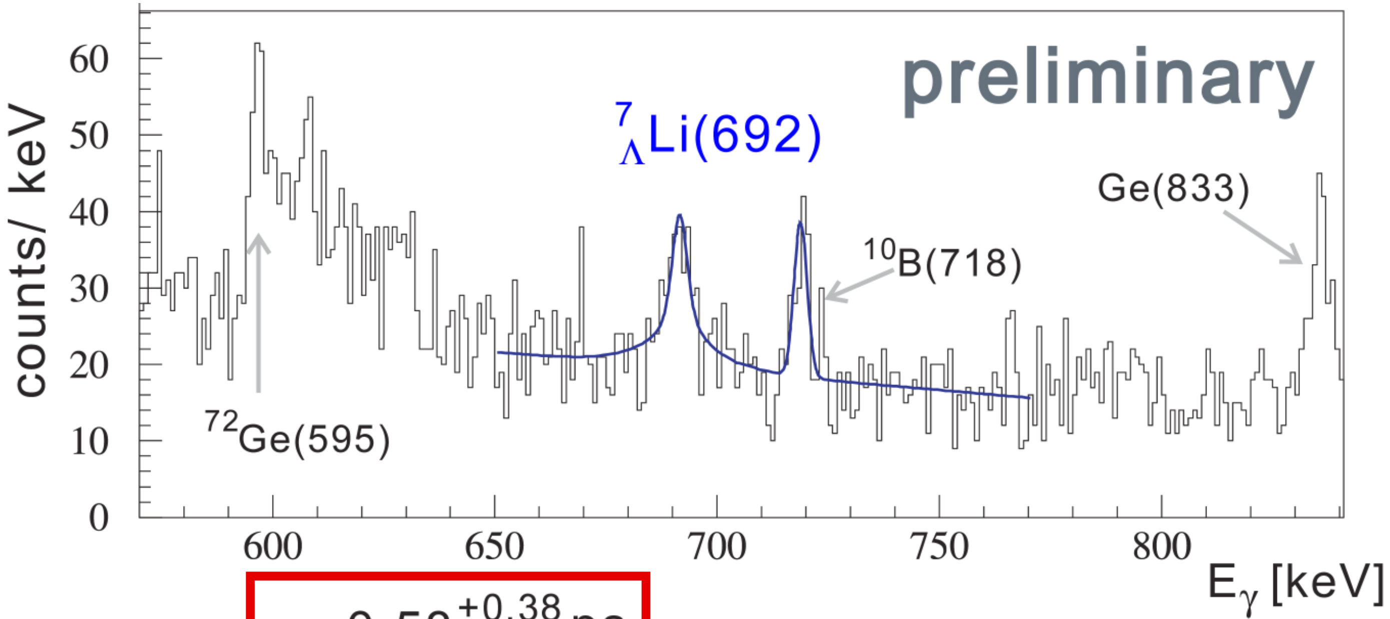


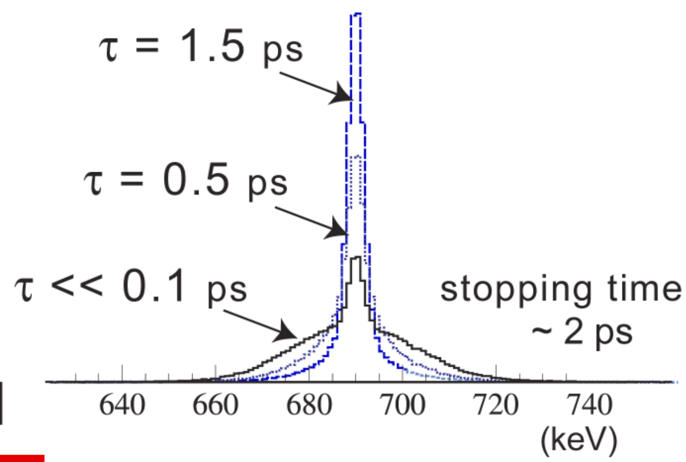
~100% **Doppler Shift Attenuation Method**

$$\Gamma = BR / \tau = \frac{16\pi}{9} E_\gamma^3\, B(M1)$$

Preliminary data on B(M1) in $^{7}_{\Lambda}$Li (BNL E930)

^{10}B (K$^-$, π^-) $^{10}_{\Lambda}$B*, $^{10}_{\Lambda}$B*(3$^+$) -> $^{7}_{\Lambda}$Li*(3/2$^+$) + ^{3}He indirect population

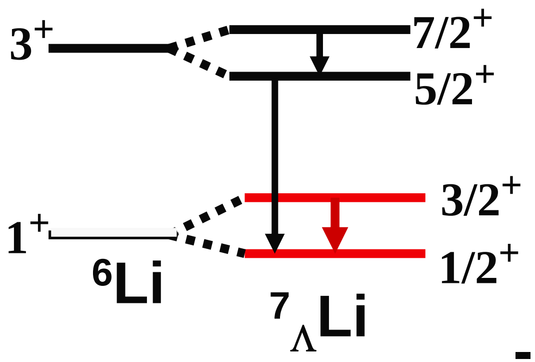




$\tau = 0.58^{+0.38}_{-0.20}$ ps

BR(M1)=100%

$B(M1) = 0.30^{+0.12}_{-0.16}$ [μ_N^2]



$- g_\Lambda = 1.1^{+0.4}_{-0.6}$ μ_N

preliminary
(statistical error only)

$- g_\Lambda$(free) = 1.226 μ_N

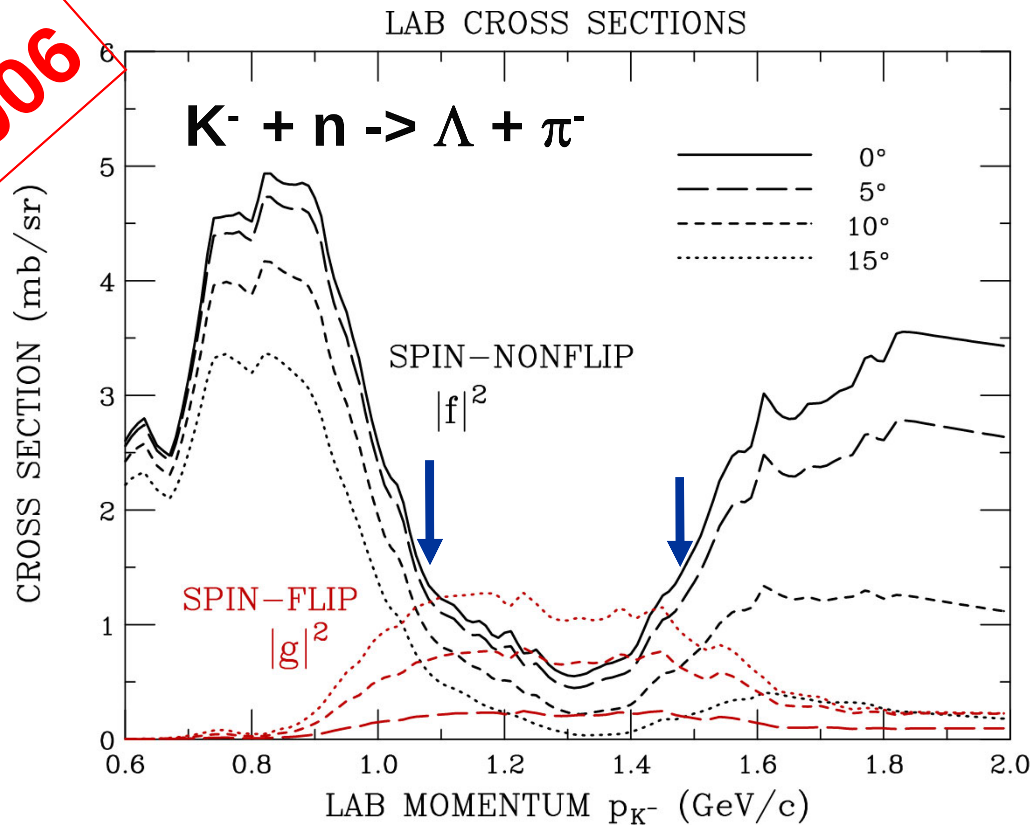
First data of g_Λ in nucleus

-> Precise(~5%) B(M1) measurement of $^{7}_{\Lambda}$Li at J-PARC E13

3. Revised Run Plan

Best K$^-$ beam momentum

A slide I used in the PAC in 2006



Both spin-flip and nonflip states should be produced.

-> p_K = 1.1 or 1.5 GeV/c

p_K = 1.1 GeV/c : K1.1 + "SKS" (ideal)
p_K = 1.5 GeV/c : K1.8 + SKS (realistic)

High K/π ratio to minimize radiation damage to Ge detectors
-> Double-stage separation. K1.8BR is not good.

E13 Run Plan

Target	original plan: beam line spectr. p power	original plan: p_K (GeV/c)	original plan: beam time (hrs.)	revised plan: beam line spectr. p power	revised plan: p_K (GeV/c)	revised plan: beam time (hrs.)	
tuning	K1.8 + SKS 270 kW (Ni)		300	K1.8 + SKS 10 kW (Pt)		120	1st Part Oct. 2012 ~ Jul. 2013
$^{4}_{\Lambda}$He		1.1, 1.3, 1.5, 1.8	100		1.5	240	
$^{19}_{\Lambda}$F		1.5 CF_2 target	100		1.8	480 HF target	
tuning				K1.1 + SKS 50 kW (Pt)		300	2nd Part after Jan. 2014
$^{10}_{\Lambda}$B		1.5	100		1.1	100	
$^{11}_{\Lambda}$B		1.5	200		1.1	200	
$^{7}_{\Lambda}$Li B(M1)		1.5	500		1.1	720	

very difficult

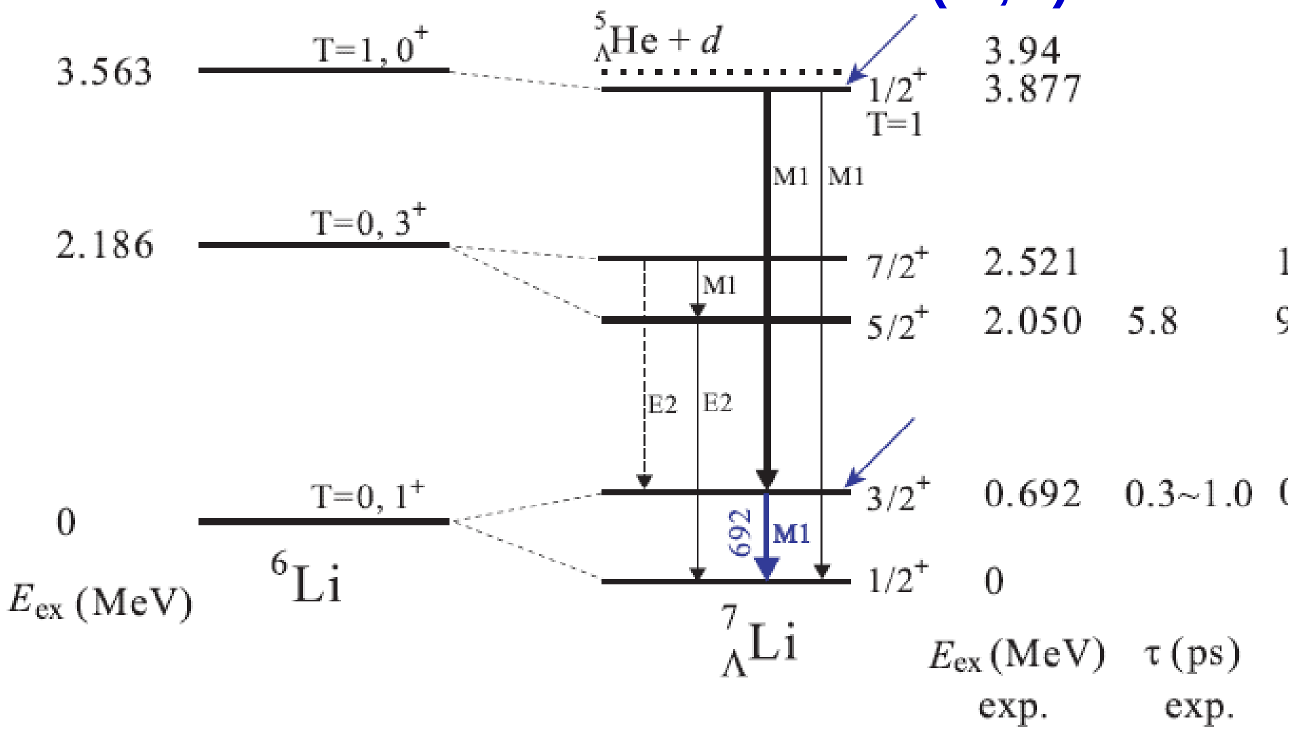
Using K1.1, we can run simultaneously with other exp'ts at K1.8/K1.8BR lines.

Proposed B(M1) measurement

To avoid ambiguities, we use the best-known hypernucleus, $^{7}_{\Lambda}$Li.

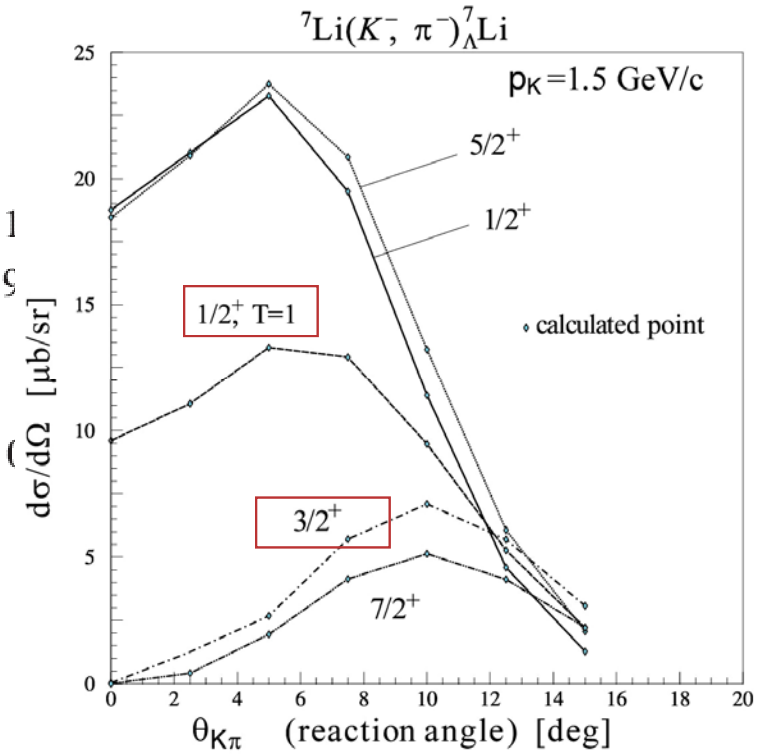
- **Energies of all the bound states and γ-ray background were measured.**
- **Cross sections are reliably calculated.**
- **τ = 0.5ps, t_{stop} ~2.7 ps for 1.5 GeV/c (K^-,π^-) and Li_2O target**
  ~ 2.2 ps for 1.1 GeV/c

(Doppler Shift Attenuation Method works only when τ < t_{stop})



Tamura et al., PRL 84 (2000) 5963
Ukai et al., PRC 73 (2006) 012501

Calc. by Motoba

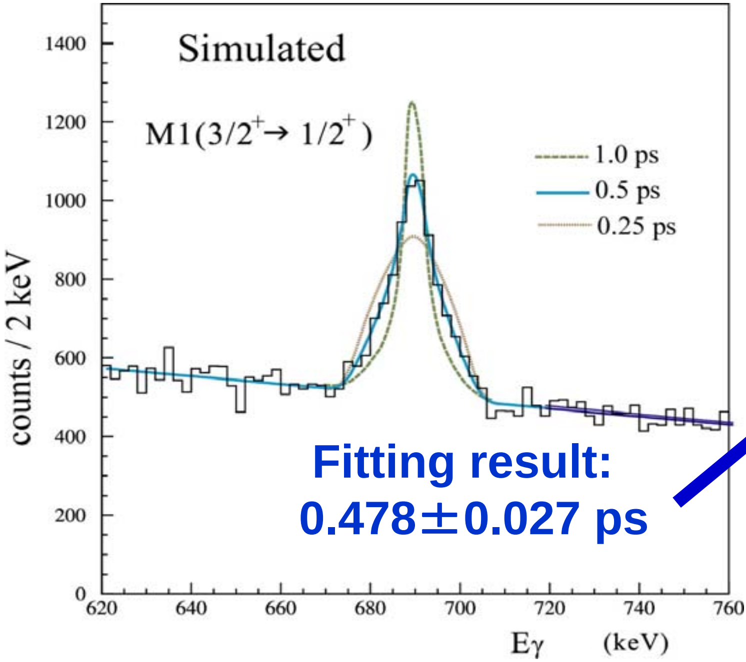


Expected yield and sensitivity

Original run plan

p_K = 1.5 GeV/c
at K1.8+SKS
500 hours
270 kW (Ni)

Original proposal



■Stat. error $\Delta\tau/\tau = 5.4\%$

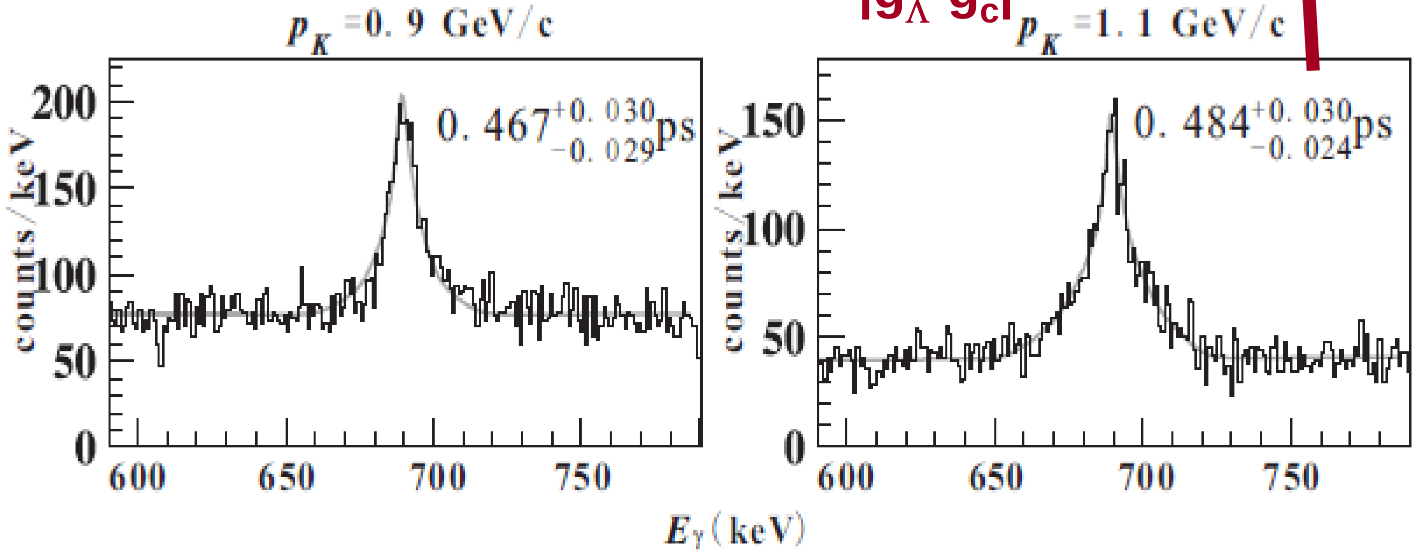
$$=> \frac{\Delta|g_\Lambda - g_c|}{|g_\Lambda - g_c|} \sim 3\%$$

■Syst. error < 5%
mainly from stopping time

Revised run plan

p_K = 1.1 GeV/c
at K1.1+SKS
4 weeks (672 hours)
50 kW (Pt)

Revised estimate

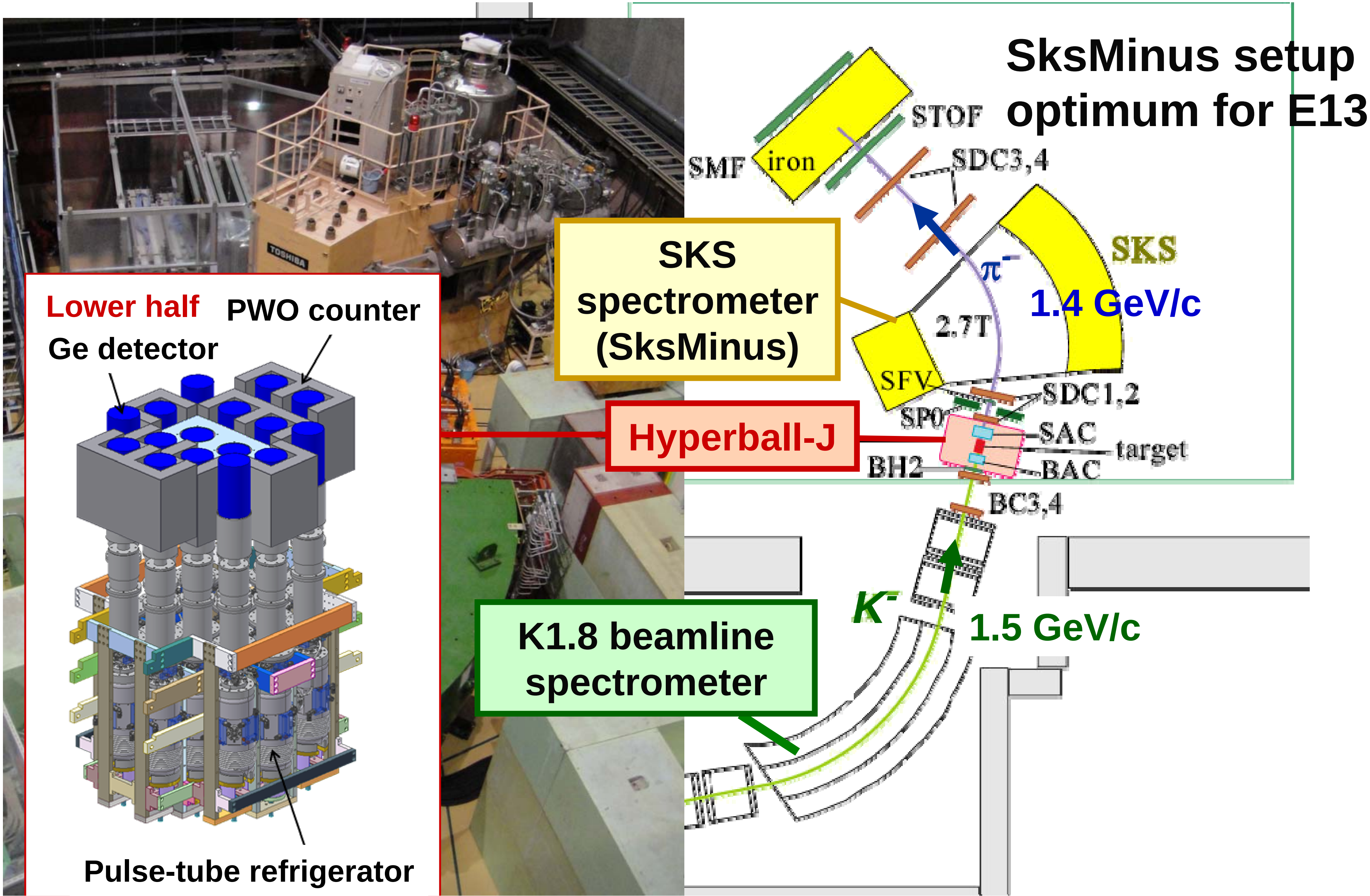


■Stat. error $\Delta\tau/\tau = 5.6\%$

$$=> \frac{\Delta|g_\Lambda - g_c|}{|g_\Lambda - g_c|} \sim 3\%$$

4. Preparation Status

Setup at K1.8 (for E13 1st Part)



Hyperball-J

J-PARC conditions

- Higher counting and energy deposit rate (2 MHz π^+ -> 10 MHz K^- beam)
- Severe radiation damage

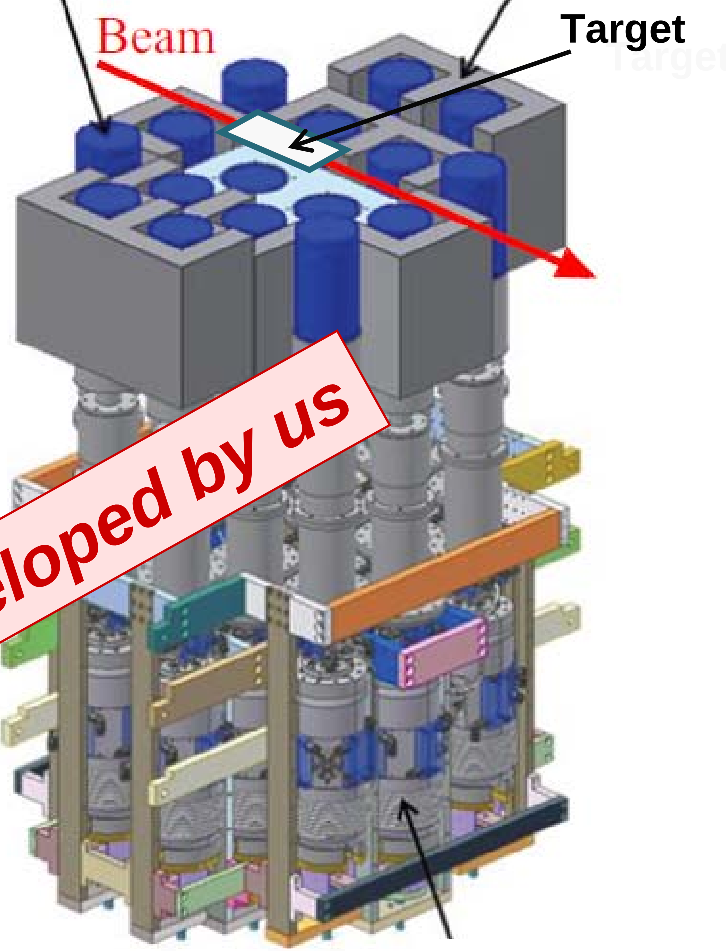
Features

- **Large photo-peak efficiency**
  - $\varepsilon \sim 6\%$ @1 MeV with 32 Ge's (60%)
  - high $\gamma\gamma$ coincidence efficiency
- **Radiation-hard Ge detector**
  - Mechanically-cooled low temp. detector
- **Fast background suppressor**
  - PWO counters
- **Digital readout and Pulse shape analysis**
  - Pile-up decomposition
- **Adjustable detector geometry**

Newly developed by us

Mechanically -cooled low temp. **Ge detector**

PWO background suppression counter



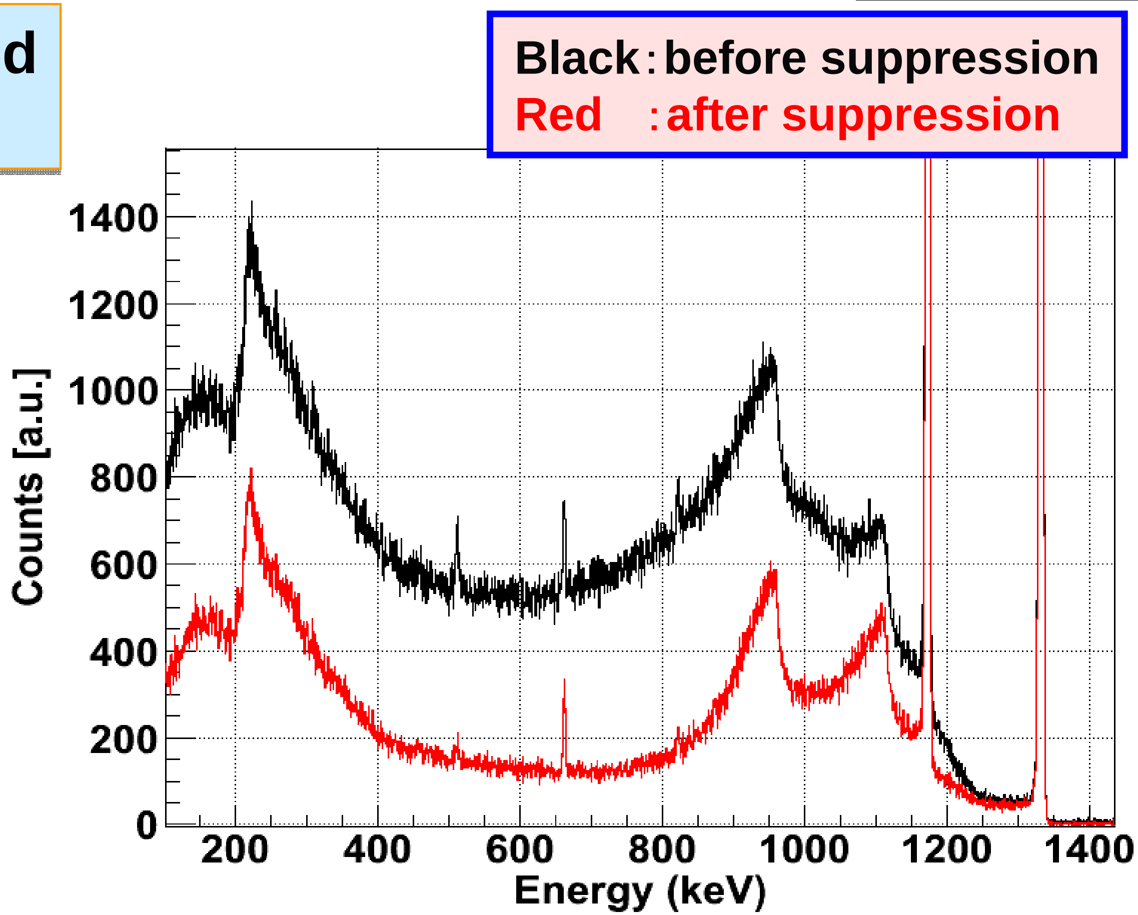
Pulse-tube cooler

Lower half of Hyperball-J

Hyperball-J under assembly at Tohoku Univ.

Test of the Hyperball-J system

Test with detector unit mounted to frame @ELPH, Tohoku



Ge energy resolution : 3.5 keV @1.33MeV

-> under noise reduction

Peak/Total after PWO suppression : 0.33

(0.19 before suppression)

-> as good as expected

Preparation Status for Part 1

- **SksMinus Spectrometer**

  Ready. Performance to be checked next month.

- **Hyperball-J**
  - **Ge detectors**

    All (28) purchased, but 4 damaged on 3.11. To be repaired by June

    Performance with mechanical cooler almost OK.

    (Under noise reduction)
  - **PWO counters**

    All purchased, Under assembly,

    Cooling system ready, performance OK
  - **Support frame -- Ready, Tested at Tohoku Univ.**

- **Targets**

  He cryo-target: Fabrication almost finished. To be tested soon.

  HF target: Designed. No security problem.

We can start running after October, 2012

6. Summary

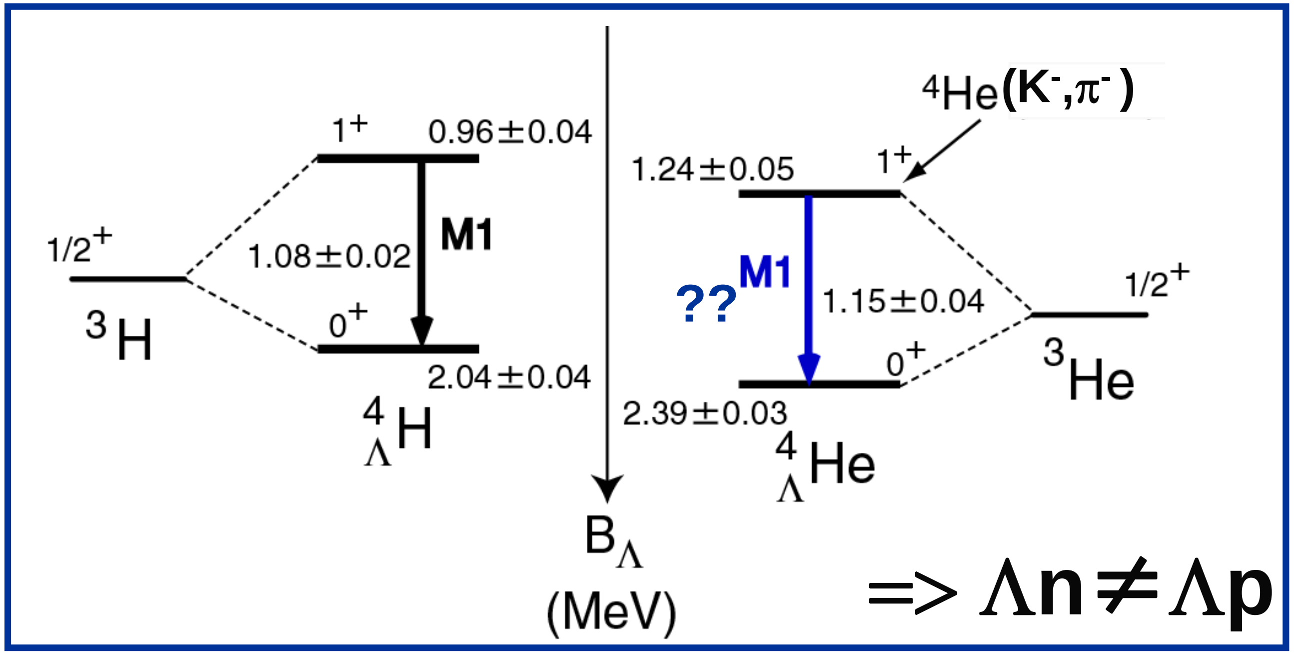
- E13 aims at studies of ΛN interaction from $^{4}_{\Lambda}$He, $^{10}_{\Lambda}$B, $^{11}_{\Lambda}$B and $^{19}_{\Lambda}$F, and measurement of Λ's g-factor in nucleus from $^{7}_{\Lambda}$Li.
- Finishing all the E13 menu requires 270 kW x 1000(+30) hrs, which seems unrealistic now.
- We decided to split the beam time into two parts:

  1st Part for $^{4}_{\Lambda}$He,$^{19}_{\Lambda}$F: K1.8 and SKS, 10 kW power x 720(+120) hrs.

  2nd Part for $^{7}_{\Lambda}$Li, $^{10}_{\Lambda}$B, $^{11}_{\Lambda}$B: K1.1 and SKS, 50 kW power x 1020(+300) hrs.
- Almost the same results as in the original proposal are expected to be obtained in a reasonable beam time.
- Preparation for Hyperball-J and SksMinus is going well. We can start running the 1st Part after October 2012.
- We request installation of SKS at K1.1 beam line after the 1st Part.

Backup

Charge Symmetry Breaking in ΛN int.



B_Λ should be measured in ~30 keV accuracy by different methods.

$^4_\Lambda$H: (e,e'K$^+$)

and/or $^4_\Lambda$H-> ^{4}He + π^-

$^4_\Lambda$He: very difficult

Measure the γ rays

in a few keV accuracy

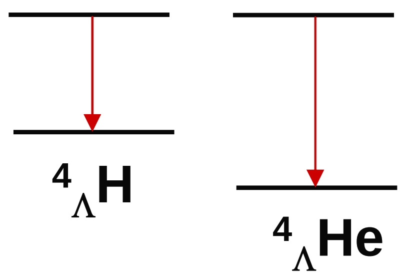
J-PARC E13 (+ more)

- **^{4}He(K$^-$,$\pi^-\gamma$) $^4_\Lambda$He(1$^+$->0$^+$)**
- **^{4}He (K$^-$,$\pi^0\gamma$) $^4_\Lambda$H(1$^+$->0$^+$)** *later*

-> confirmation of CSB

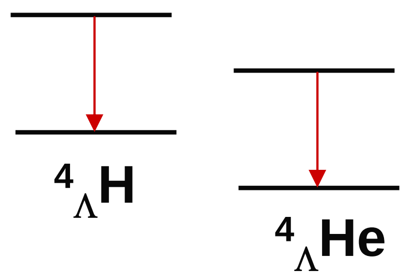
mechanism of CSB from spin dependence

The same B_Λ(1$^+$)



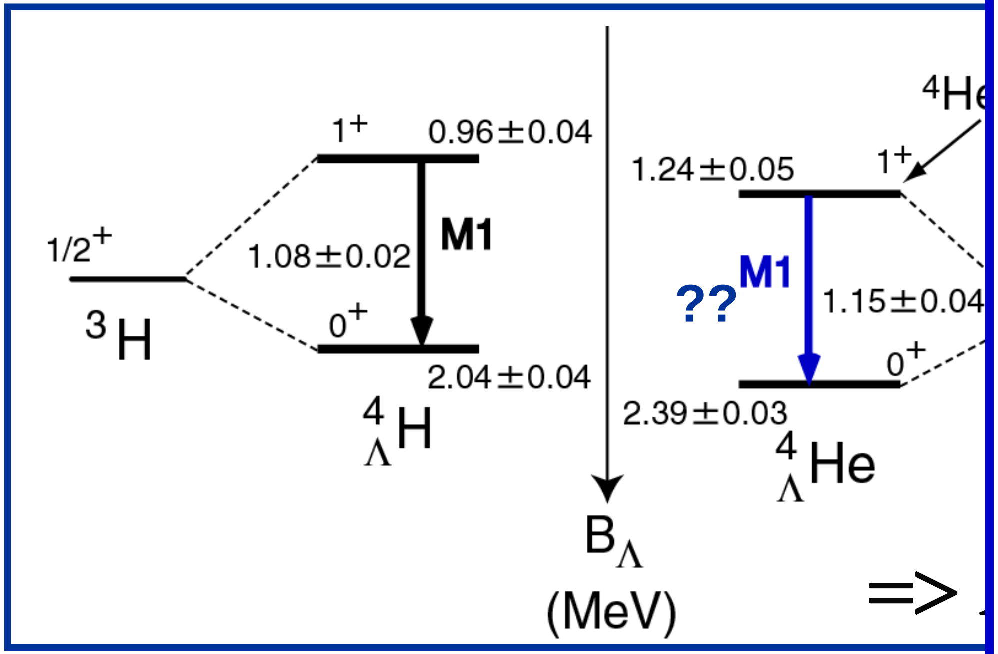
Large effect of $\Sigma^+/\Sigma^0/\Sigma^-$ because 1$^+$ has less Σ mixing than 0$^+$

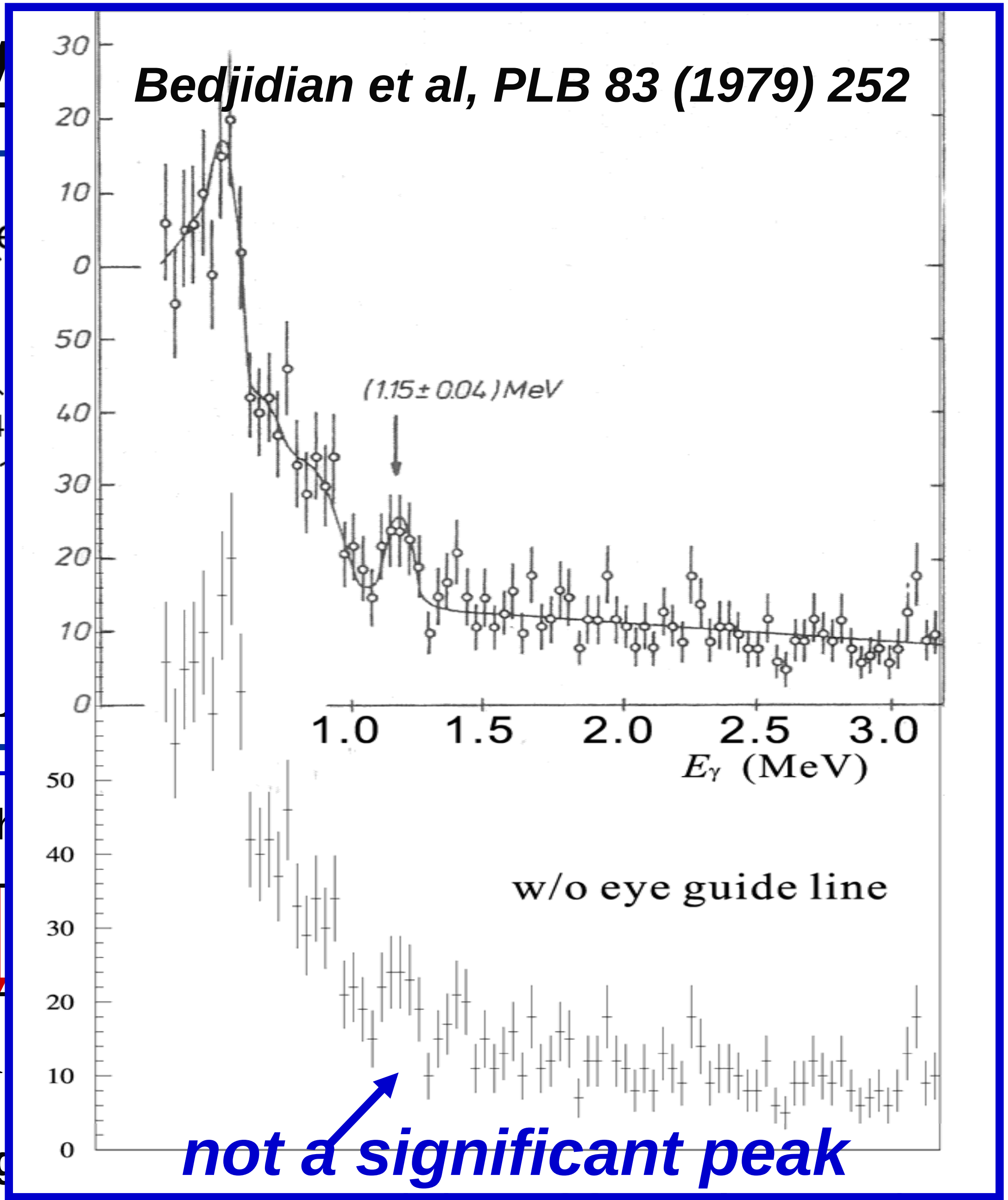
The same ΔE(1$^+$-0$^+$)



Strongly suggests no CSB and B_Λ(0$^+$) in incorrect

Charge Symmetry





Th

Larg
because 1$^+$ has less
Σ mixing than 0$^+$

no CSB and
B$_\Lambda$(0$^+$) in incorrect

Measure the γ rays
in a few keV accuracy

J-PARC E13 (+ more)

- ^{4}He(K$^-$,π$^-$γ) $^4_\Lambda$He(1$^+$->0$^+$)
- ^{4}He (K$^-$,π^{0}γ) $^4_\Lambda$H(1$^+$->0$^+$) *later*

-> confirmation of CSB
mechanism of CSB from spin dependence