Recent Results of J-PARC E13

26th, October, 2016

黎明 Workshop at Inha University

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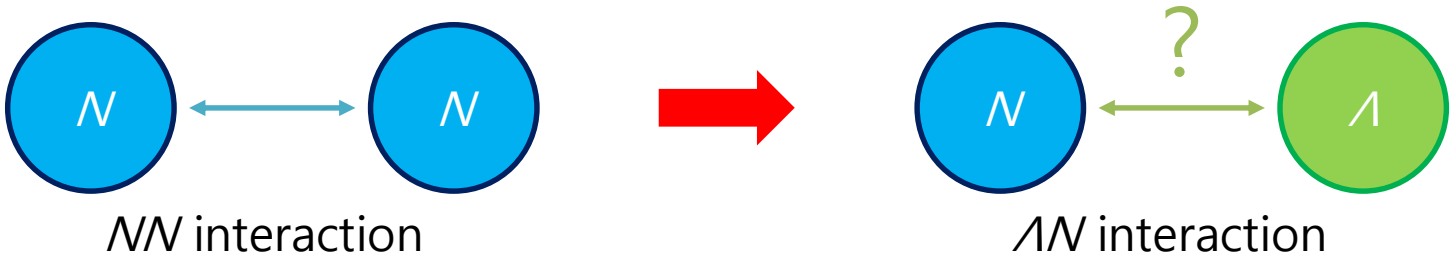
1. Gamma-Ray Spectroscopy of Λ Hypernuclei

ΛN Interaction and *Λ* Hypernucleus

■ *ΛN* interaction

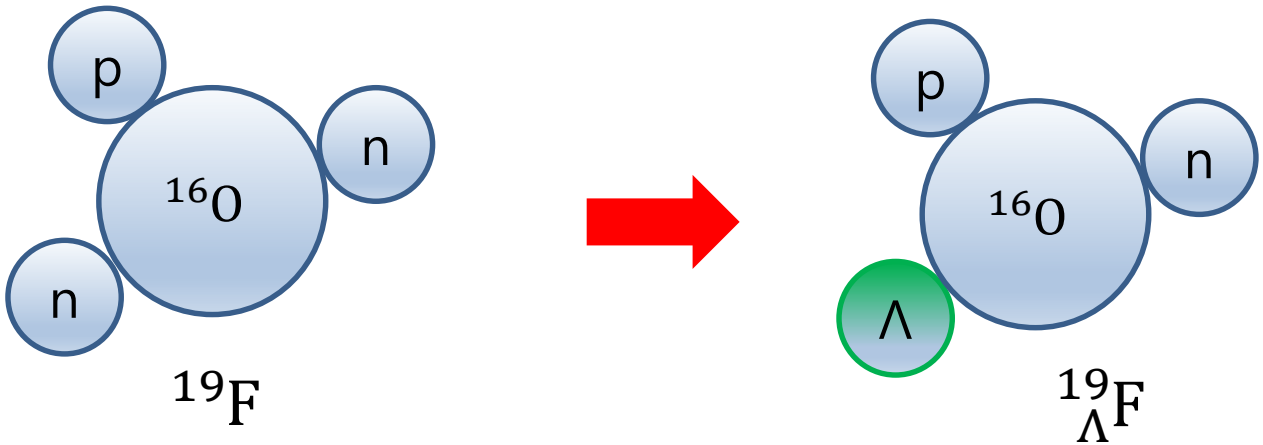
It is the first step to understand the general baryon-baryon interaction.



NN interaction　　*ΛN* interaction

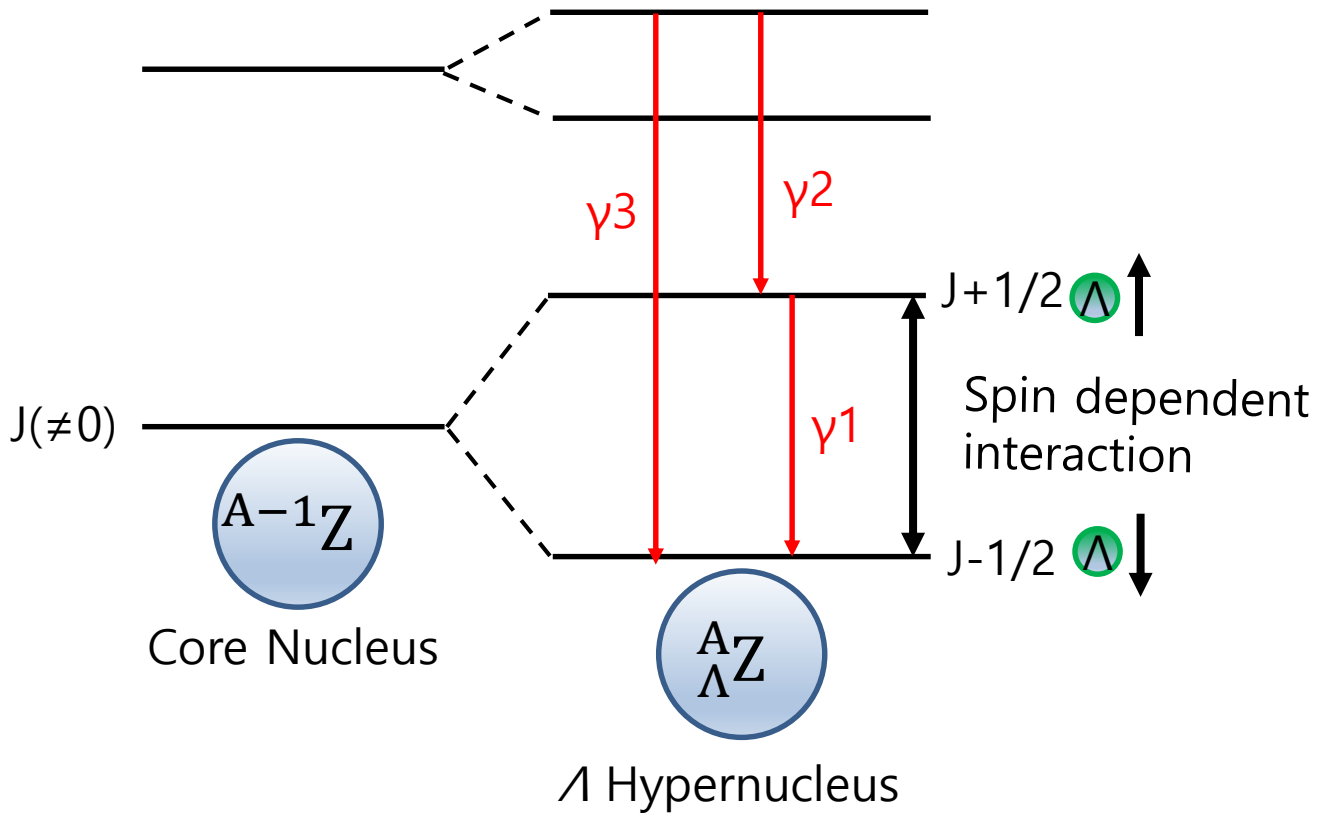
■ *Λ* hypernucleus

Due to the short life time of *Λ*, a scattering experiment is impossible for the *ΛN* interaction. In this case, a spectroscopy of *Λ* hypernucleus is the most powerful tool.



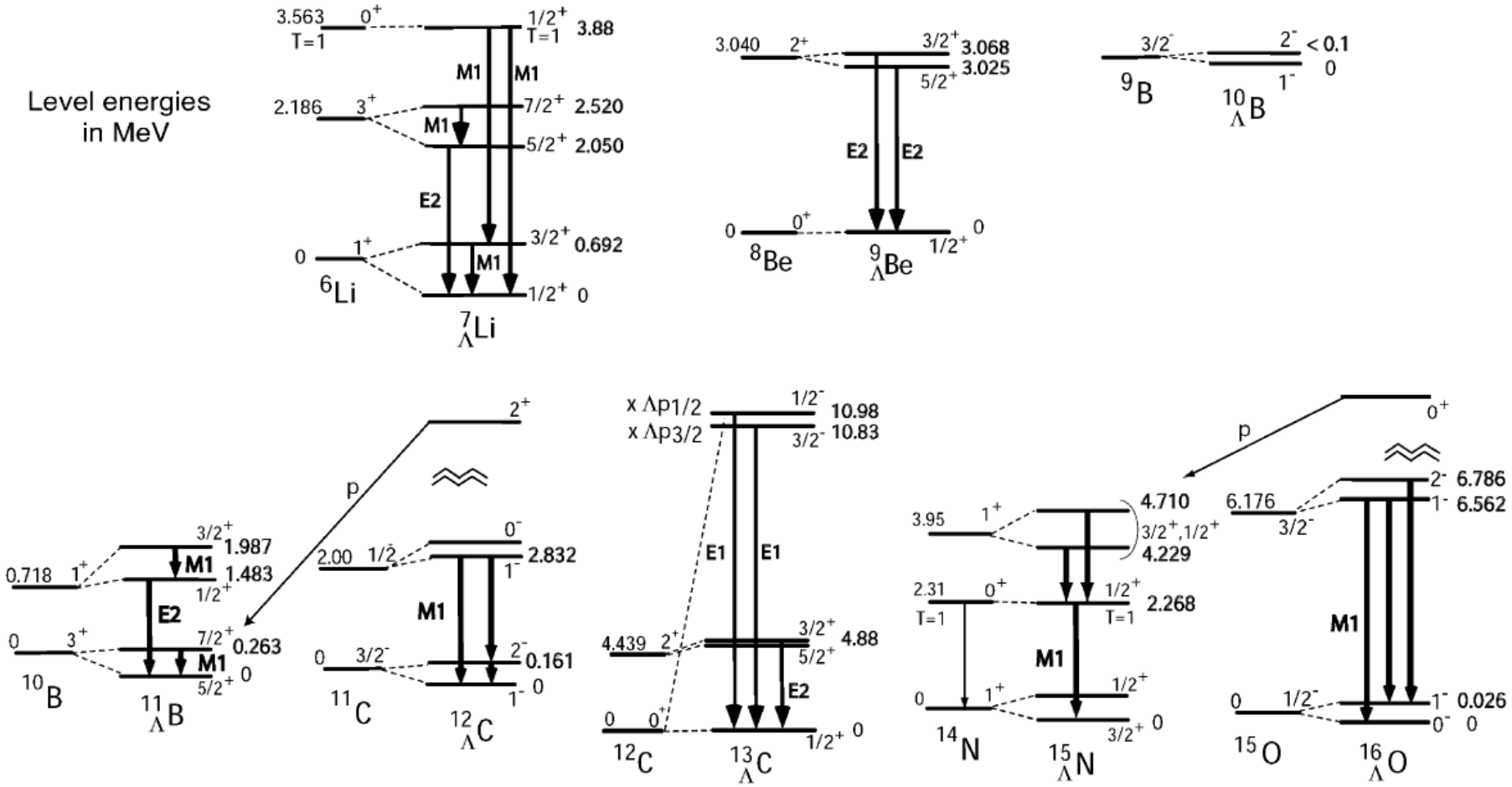
Gamma-Ray Spectroscopy of Λ Hypernuclei

■ Gamma-ray spectroscopy of Λ hypernuclei



→ By measuring energies of the γ rays, the split energy spacing is precisely estimated and we can know a fine structure of the hypernucleus.

■ Previous γ-ray spectroscopies: Hyperball project since 1998



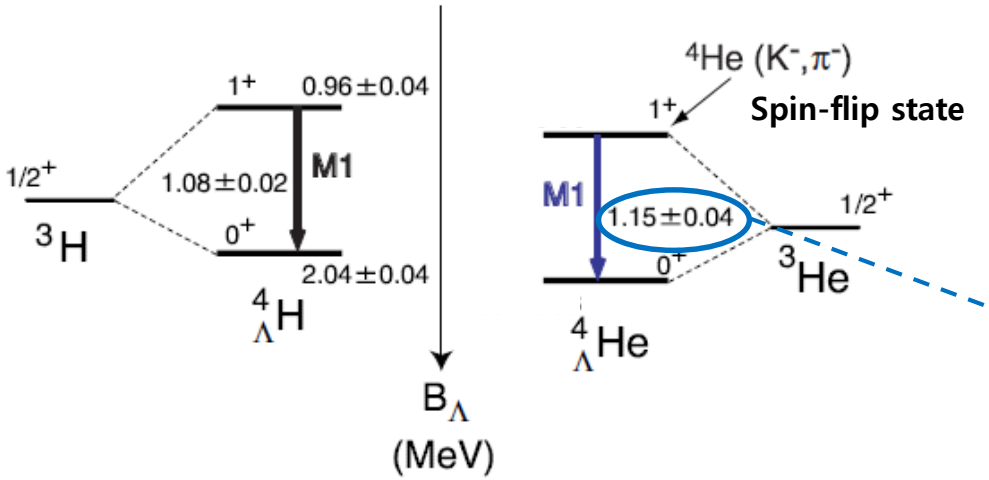
@NPA, 835, 3 (2010)

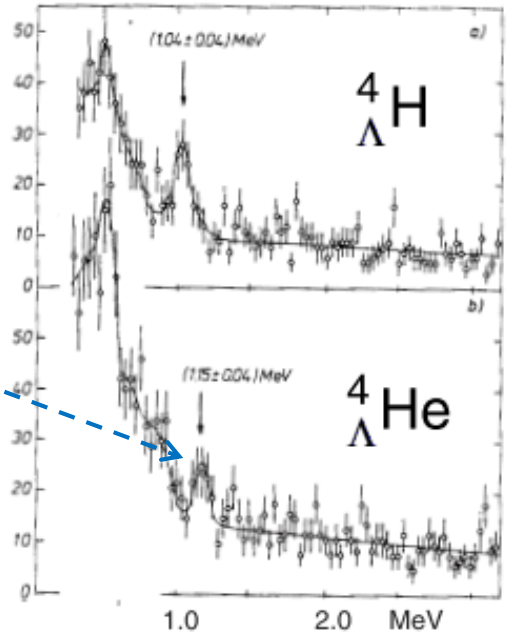
The experiment is continuing at J-PARC

2. J-PARC E13 1st Phase

Gamma-ray Spectroscopy of $^{4}_{\Lambda}$He

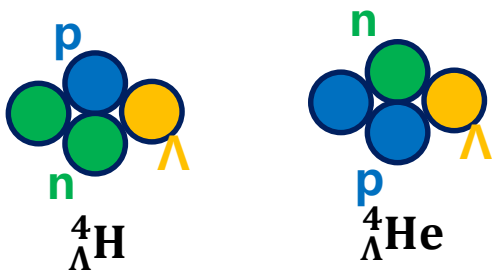
■ Charge symmetry breaking (CSB) in the ΛN Interaction





The difference between $^{4}_{\Lambda}$H and $^{4}_{\Lambda}$He was measured. But, poor statistical quality for $^{4}_{\Lambda}$He

* M. Bedjidian et al., Phys. Lett. 83B(1979) 252



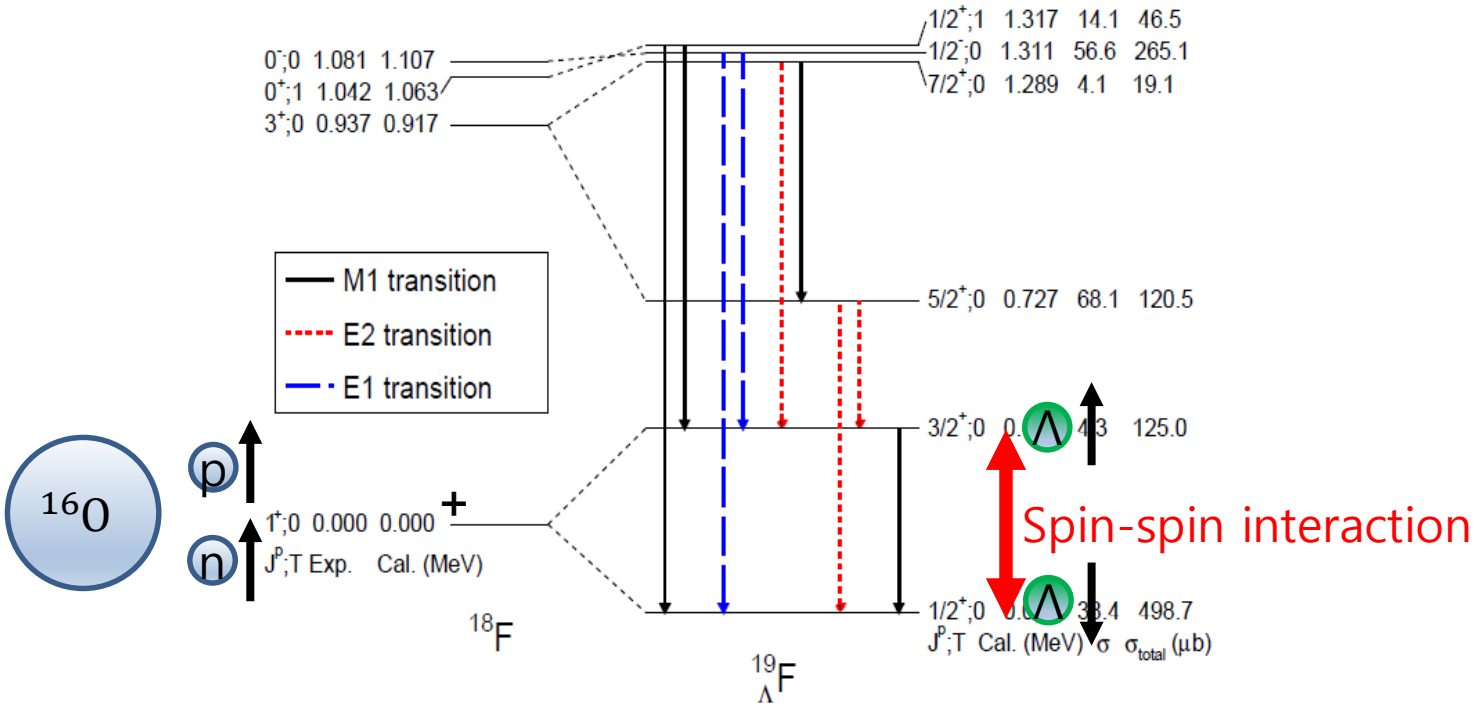
Λp ≠ Λn (?)

Gamma-ray Spectroscopy of $^{19}_{\Lambda}$F

- It is the first γ-ray spectroscopy for *sd*-shell hypernuclei.
- Energy spacing of ground state doublet ($1/2^+$, $3/2^+$)

→ Radial dependency of the *ΛN* spin-spin interaction?

→ *ΛN* spin-dependent interaction with different wave-function?



low-lying energy levels of $^{19}_{\Lambda}$F

**A. Umeya et. al, NPA in press*

Experimental Setup of J-PARC E13

■ Reaction: ${}^{A}\mathrm{Z}(K^-,\ \pi^-){}^{A}_{\Lambda}\mathrm{Z}$

■ K1.8 Beamline : High intensity and high purity K^- beam

→ Intensity of K^- beam: ~350 k/spill

→ K^-/π^- = ~2.5

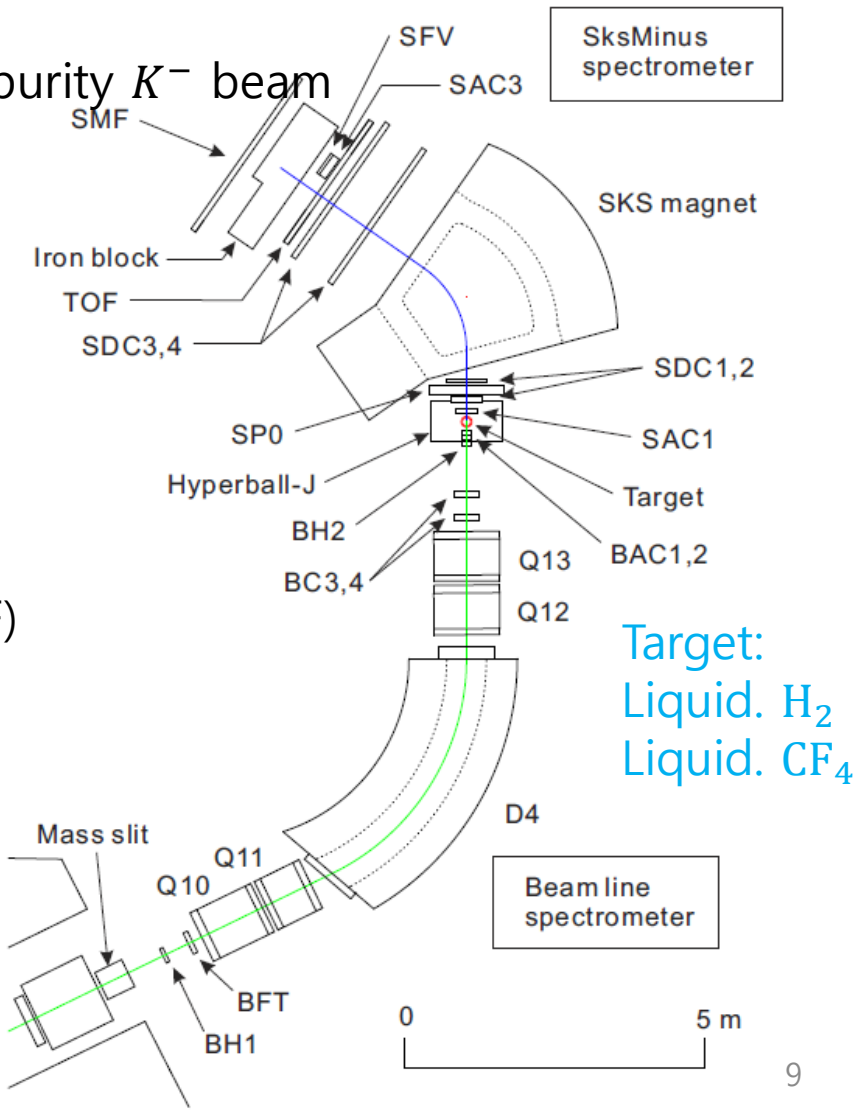
→ 1.5 GeV/c for ${}^{4}_{\Lambda}\mathrm{He}$ and 1.8 GeV/c for ${}^{19}_{\Lambda}\mathrm{F}$

■ SKS & K1.8 Beamline Spectrometers

→ High resolution of missing mass

→ Large acceptance for $(K^-,\ \pi^-)$

→ good beam decay suppressor (SP0, SMF)



■ Hyperball-J

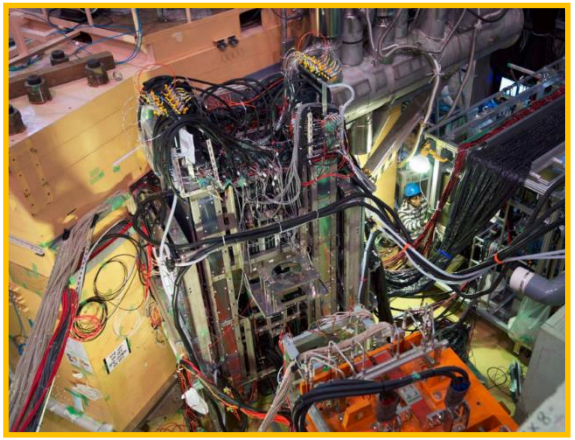
→ ${}^{A}\mathrm{Z}(K^-,\ \pi^-){}^{\mathrm{A}}_{\Lambda}\mathrm{Z}^*,\ {}^{\mathrm{A}}_{\Lambda}\mathrm{Z}^* \rightarrow \gamma + {}^{\mathrm{A}}_{\Lambda}\mathrm{Z}$

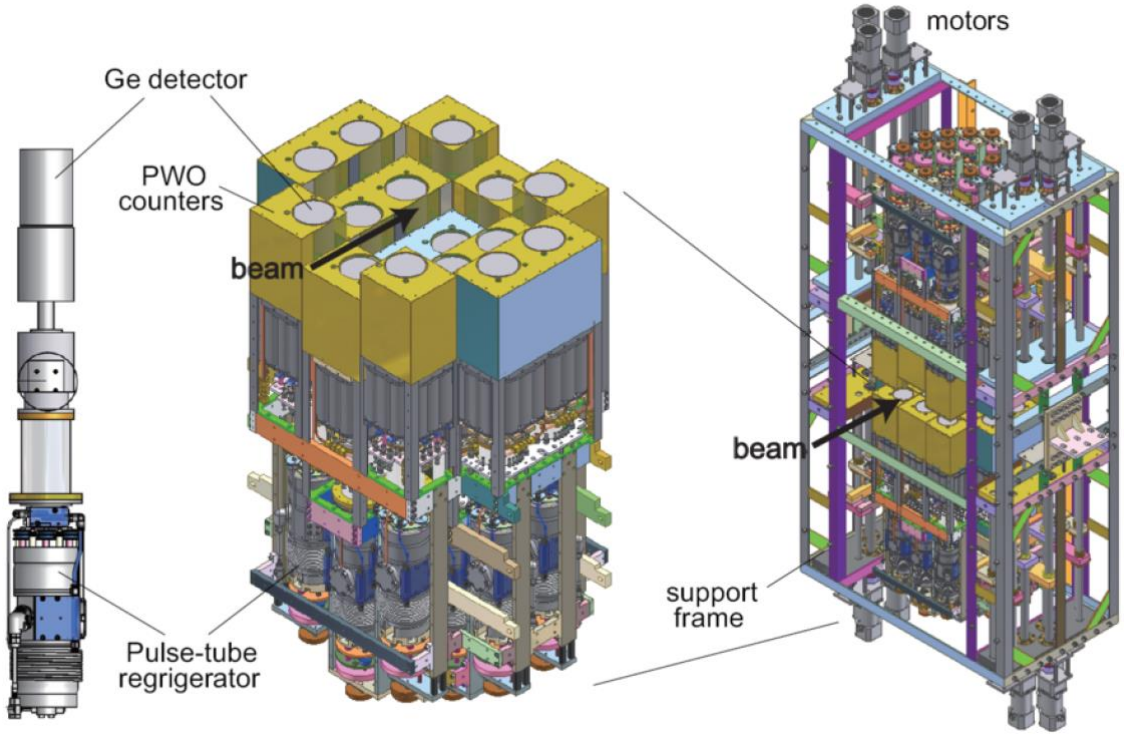
→ ~25 HPGe detectors - ΔE ~4.5 keV @ 1MeV

→ PWO counters - Fast background suppression

Mechanical cooling system
Crystal temp. ~70 K

*a view of K1.8 experimental hall



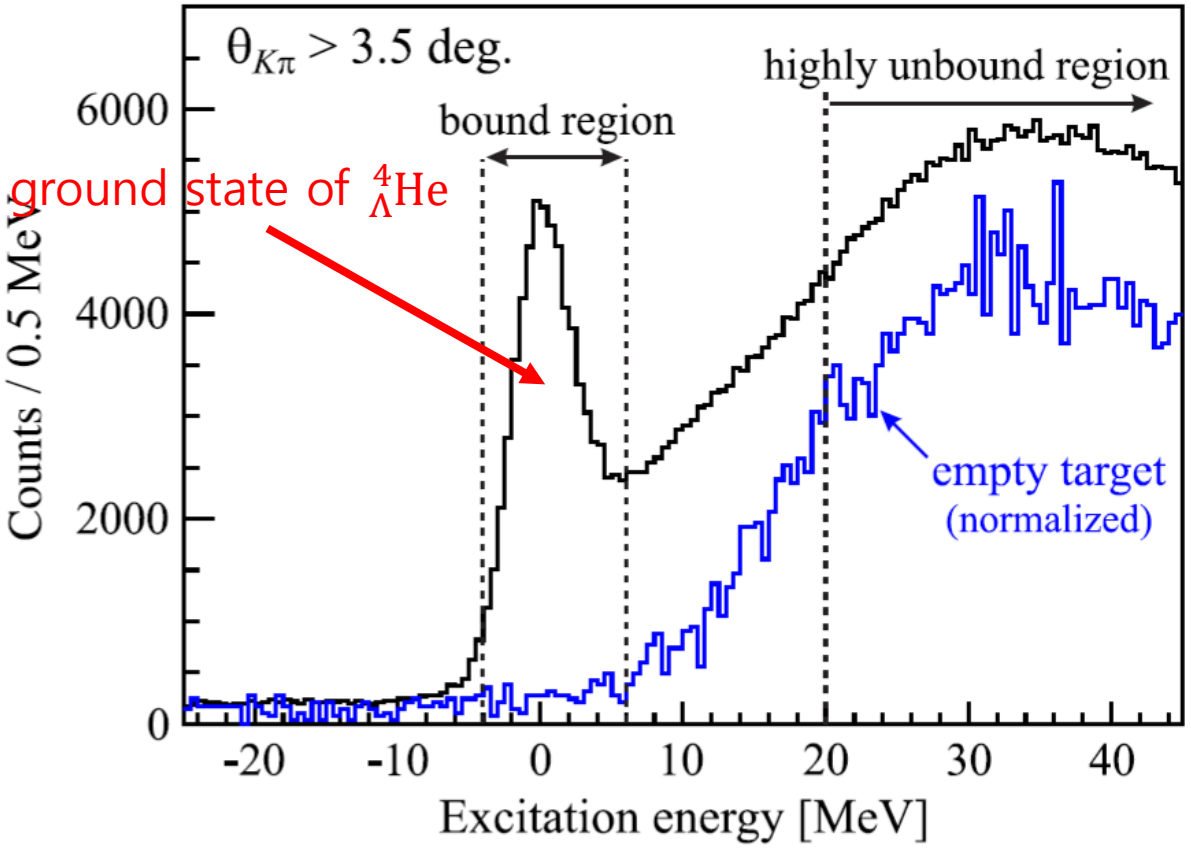


@NPA, 835, 3 (2012)

3. Results of ${}^{4}_{\Lambda}\mathrm{He}$

Excitation Energy Distribution of $^{4}_{\Lambda}$He

■ -2 MeV<Ex.<6 MeV is selected to observe the γ rays from $(1^{+} \rightarrow 0^{+})$ transition.

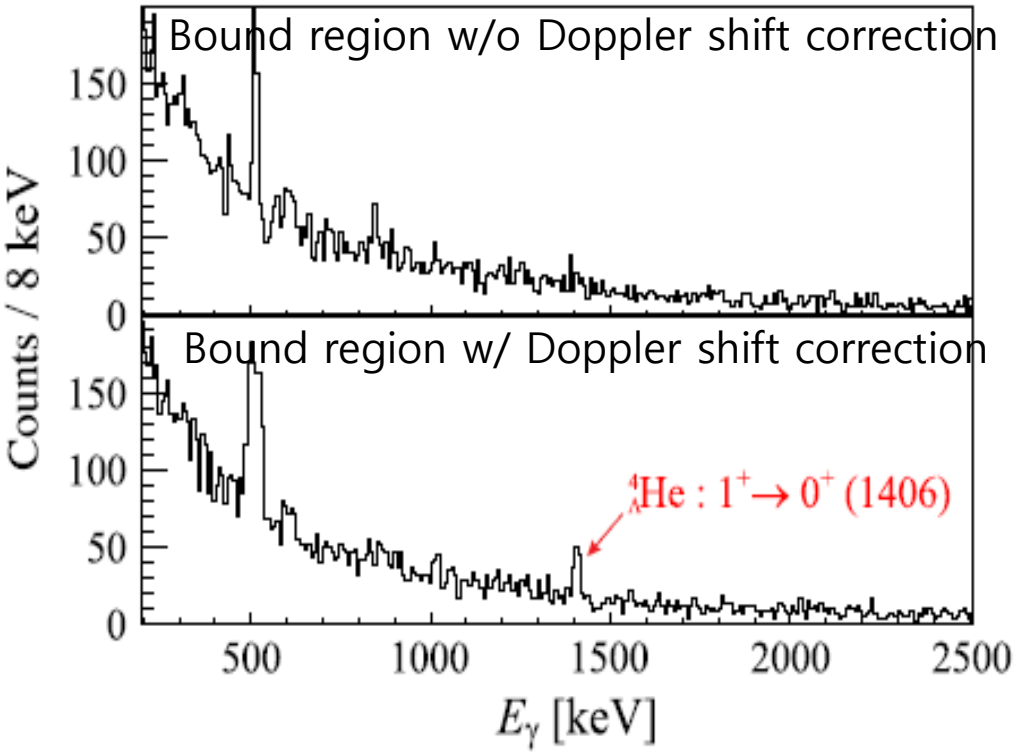


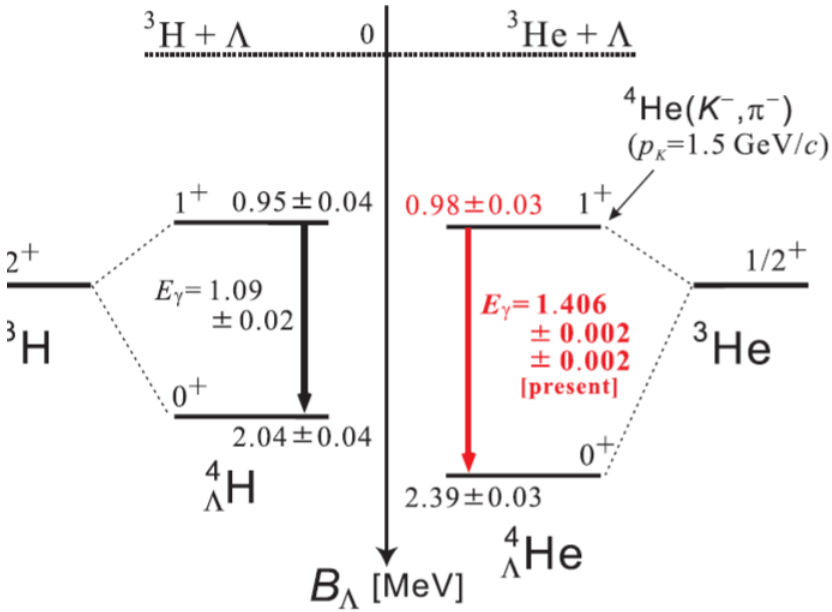
*@T.O. Yamamoto et. al., PRL **115**, 222501 (2015)*

Gamma-ray Spectra of $^{4}_{\Lambda}$He

■ We observed a γ ray at 1.406 MeV which emitted from $(1^+ \rightarrow 0^+)$ transition of $^{4}_{\Lambda}$He.

→ Compared with $^{4}_{\Lambda}$H result (1.09 MeV), we found a large charge symmetric breaking effect in *ΛN* interaction.



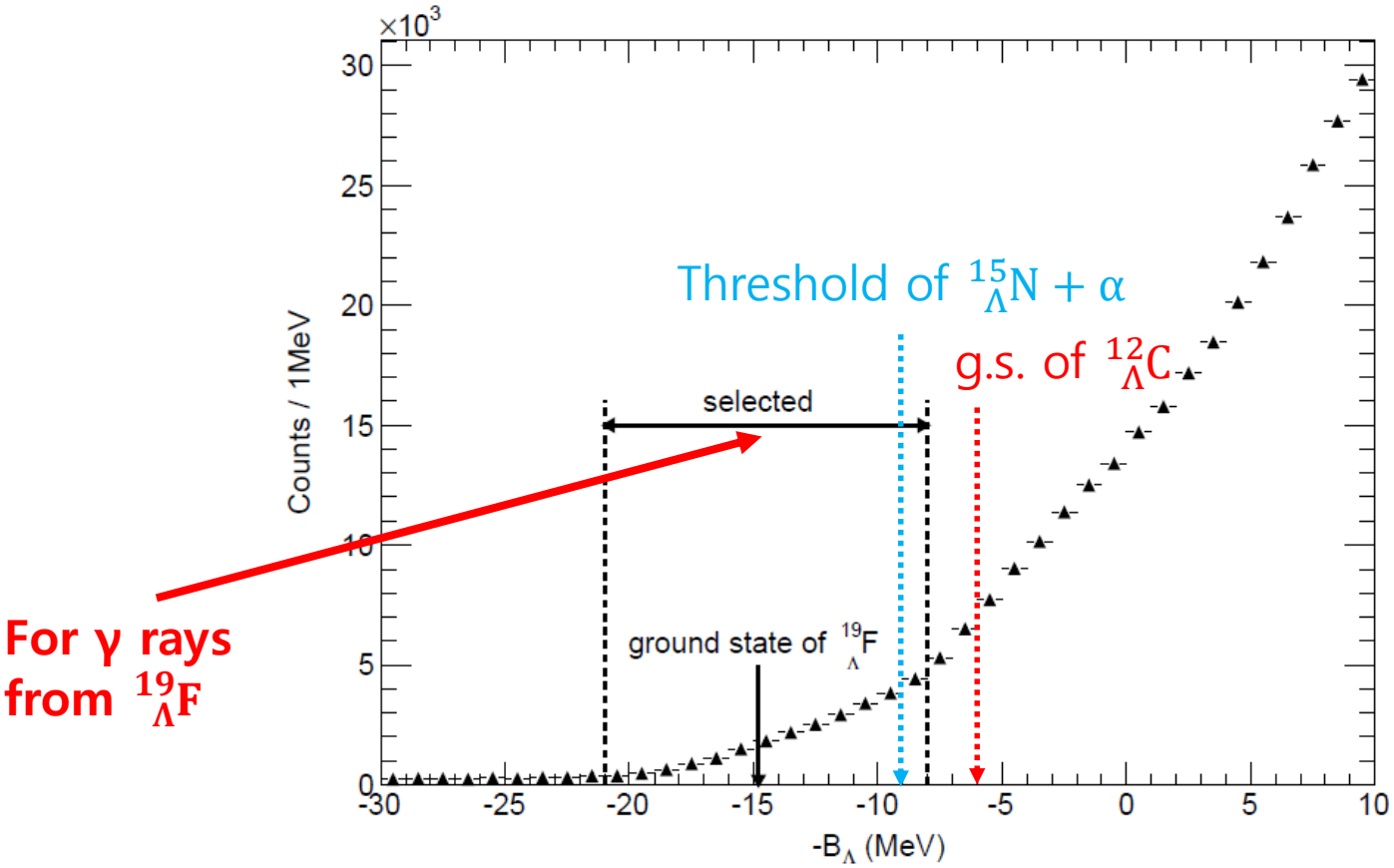


*@T.O. Yamamoto et. al., PRL **115**, 222501 (2015)*

4. Results of ${}^{19}_{\Lambda}\mathrm{F}$

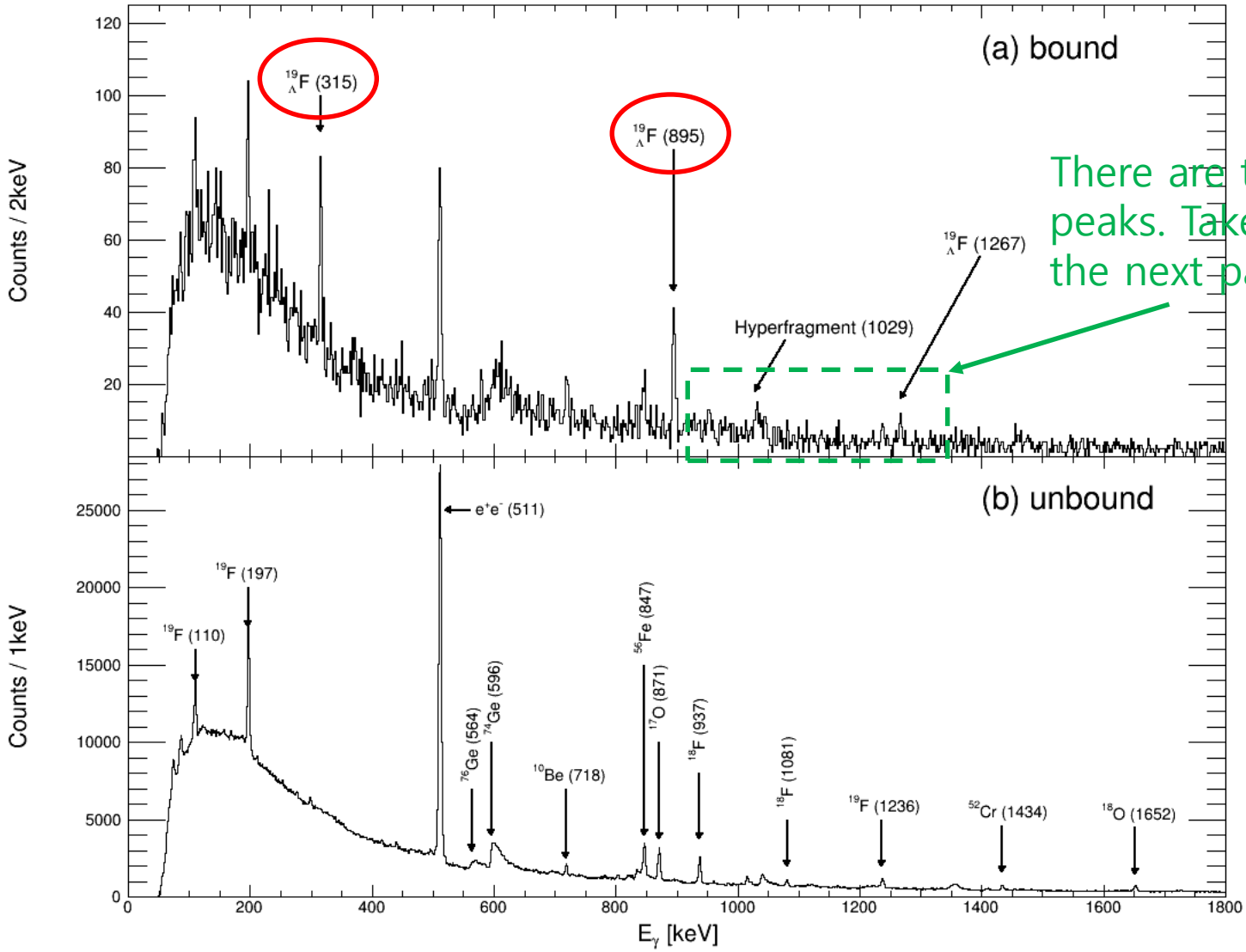
-B_Λ Distribution of $^{19}_{\Lambda}$F

■ -21 MeV<-B_Λ<-8 MeV is selected to observe the γ rays from low lying energy states.



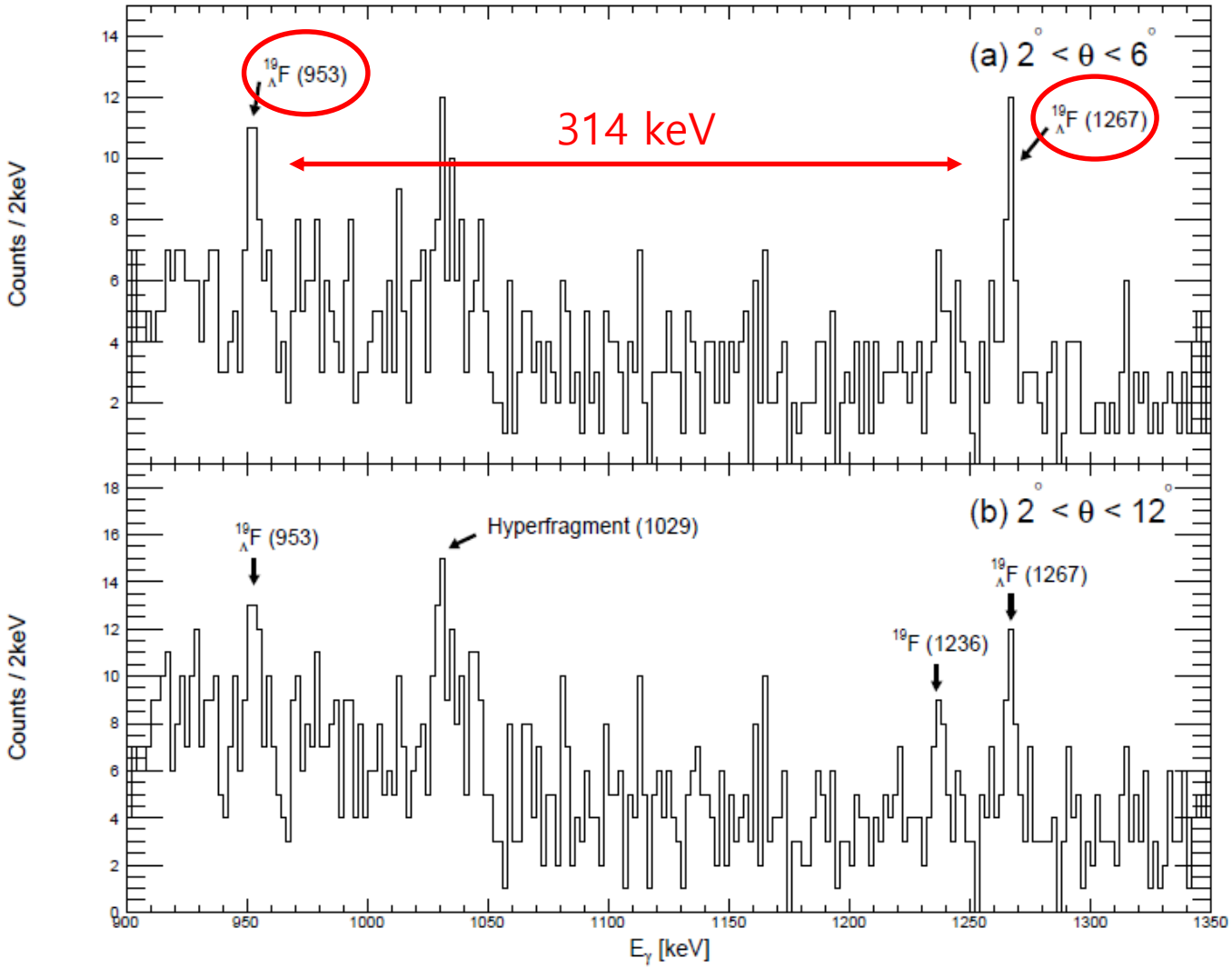
γ-ray spectra

■ γ-ray spectra: energy range: 0~1800 keV and without Doppler shift correction.



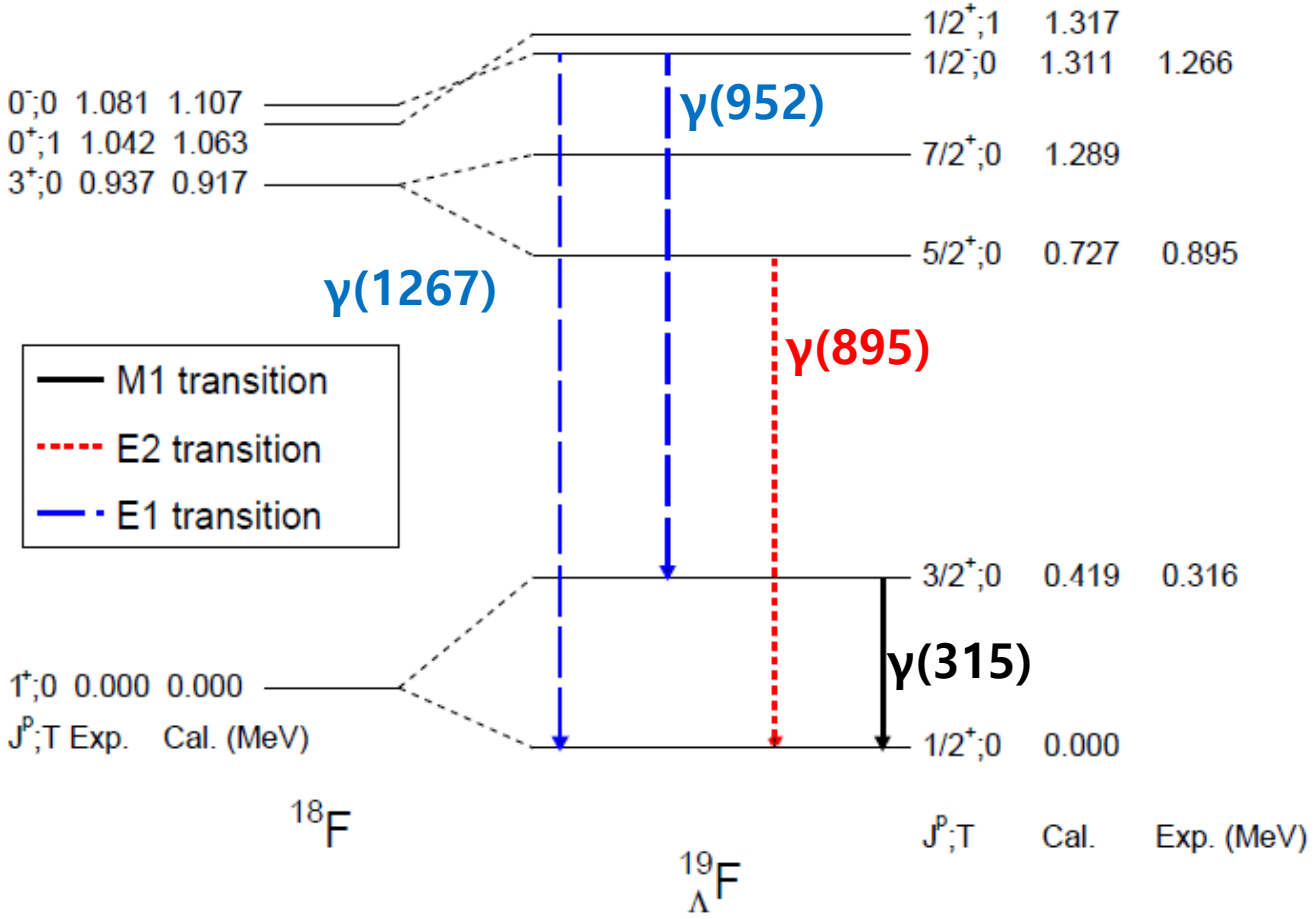
There are two more peaks. Take a look at the next page.

■ At the forward reaction angle, we found two more gamma-ray peaks at 953 keV and 1267 keV.



Transition Assignments

■ Based on theoretical calculations, the gamma rays are assigned to their gamma transitions.



Spin-Spin Interaction in *sd*-shell Hypernuclei

Theoretical Calculation	Experiment	Shell-model with NSC97f model by Umeya	Shell-model with *ΛN* spin-dependent interaction at *p*-shell hypernuclei by Millener
$\Delta E(3/2^+, 1/2^+)$ [keV]	$315.5 \pm 0.4^{+0.3}_{-0.2}$	419	305

→ The measured energy spacing is well represented by the spin-dependent interaction in *p*-shell hypernuclei. It also indicates the *ΛΣ* coupling effect is negligible for the energy spacing.

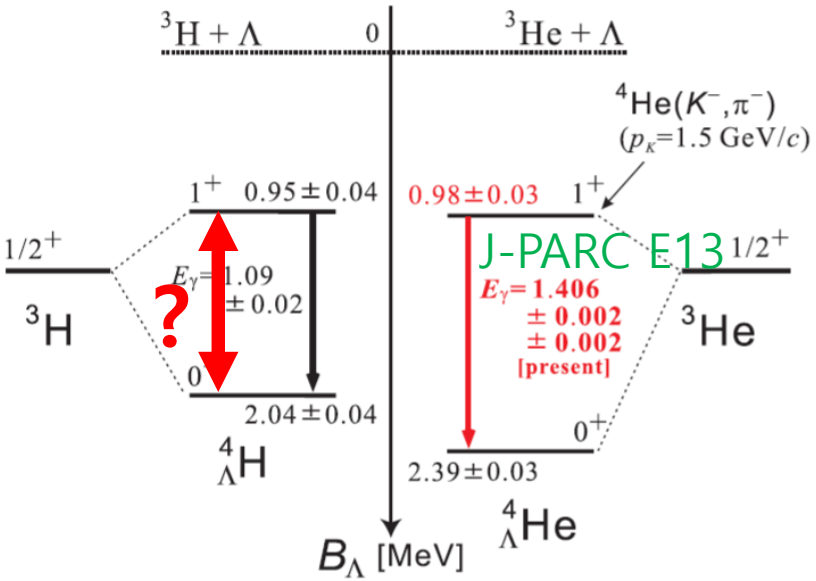
→ The results will be soon published in a major physics journal.

5. Next Plan (J-PARC E63)

J-PARC E63

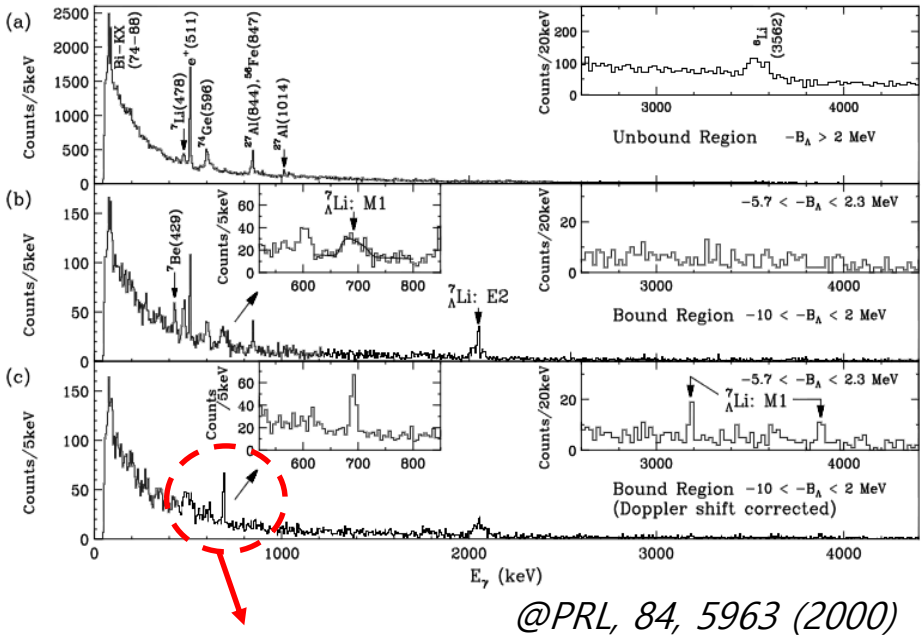
- The J-PARC E63 ($^{4}_{\Lambda}$H and $^{7}_{\Lambda}$Li) is a next step of the J-PARC E13 1st phase.
- A new beam line (K1.1 beam line) will be constructed at J-PARC hadron facility.

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



→ Charge symmetric breacking

$^{7}_{\Lambda}$Li



@PRL, 84, 5963 (2000)

From $M1(3/2^+ \rightarrow 1/2^+)$ transition.

→ First $B(M1)$ measurement

6. Summary

Summary

■ The J-PARC E13 1st phase for ${}^{4}_{\Lambda}\mathrm{He}$ and ${}^{19}_{\Lambda}\mathrm{F}$ was successfully performed in May and June, 2015.

■ ${}^{4}_{\Lambda}\mathrm{He}$: the energy spacing between 0^+ and 1^+ is determined to be 1.4 MeV.
→ a large charge symmetric breaking effect in the *ΛN* Interaction.

■ ${}^{19}_{\Lambda}\mathrm{F}$: the energy spacing between the ground state doublet is determined to be 315 keV.
→ It is well represented by the spin-dependent *ΛN* Interaction in *p*-shell hypernuclei.

■ The experiment will be continued at the new constructed beam line (K1.1 beam line).
→The next targets are ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{7}_{\Lambda}\mathrm{Li}$.

*Back Up

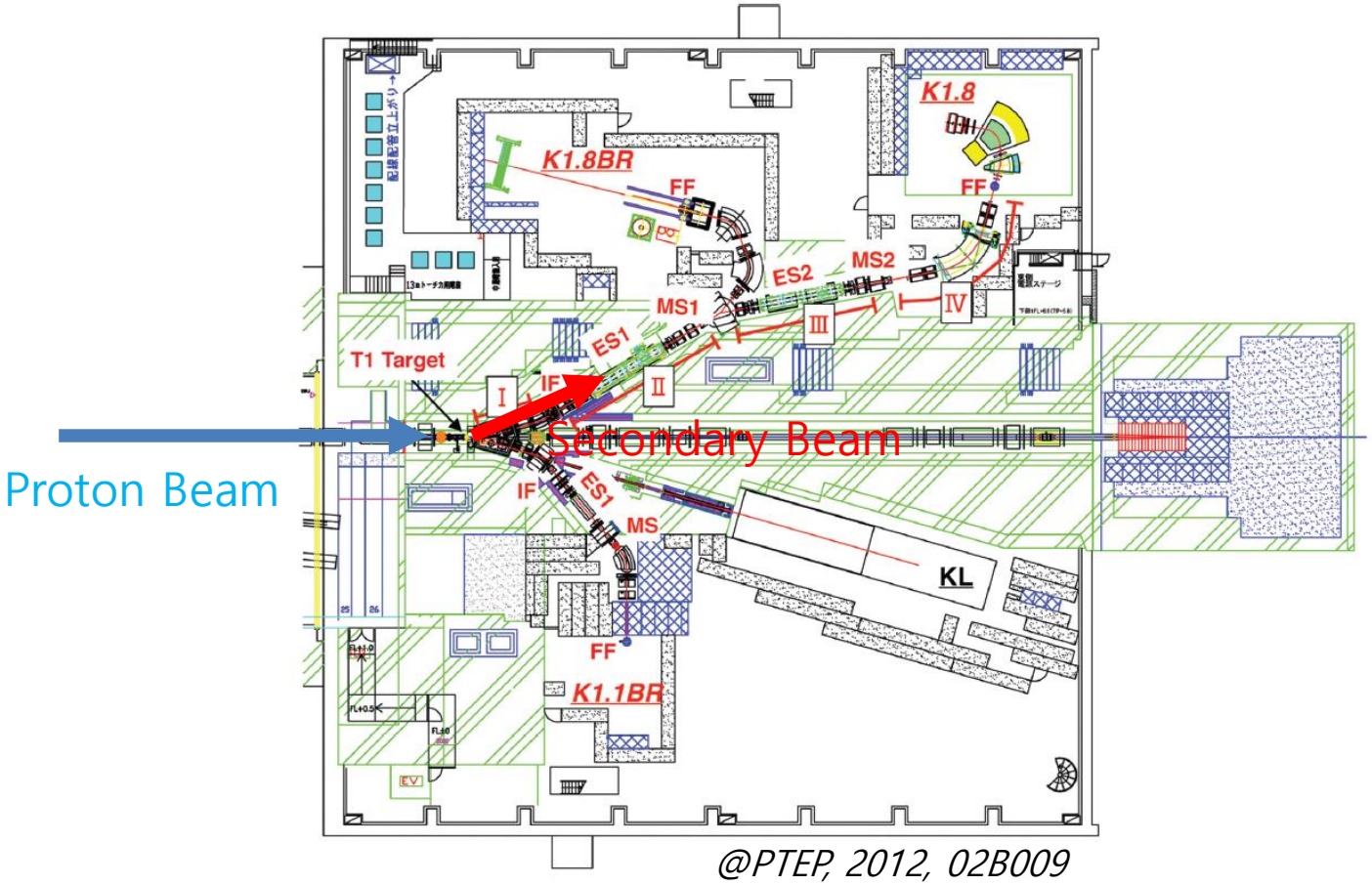
K1.8 Beamline

■ K1.8 Beamline : High intensity and high purity K^- beam

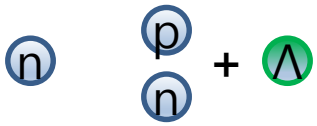
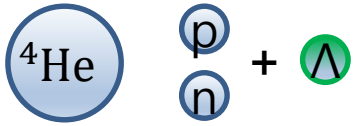
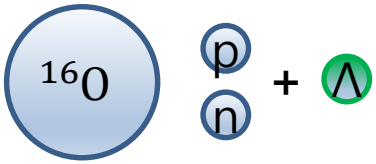
→ Intensity of K^- beam: ~350 k/spill

→ $K^-/\pi^- = \sim 2.5$

*J-PARC Hadron facility

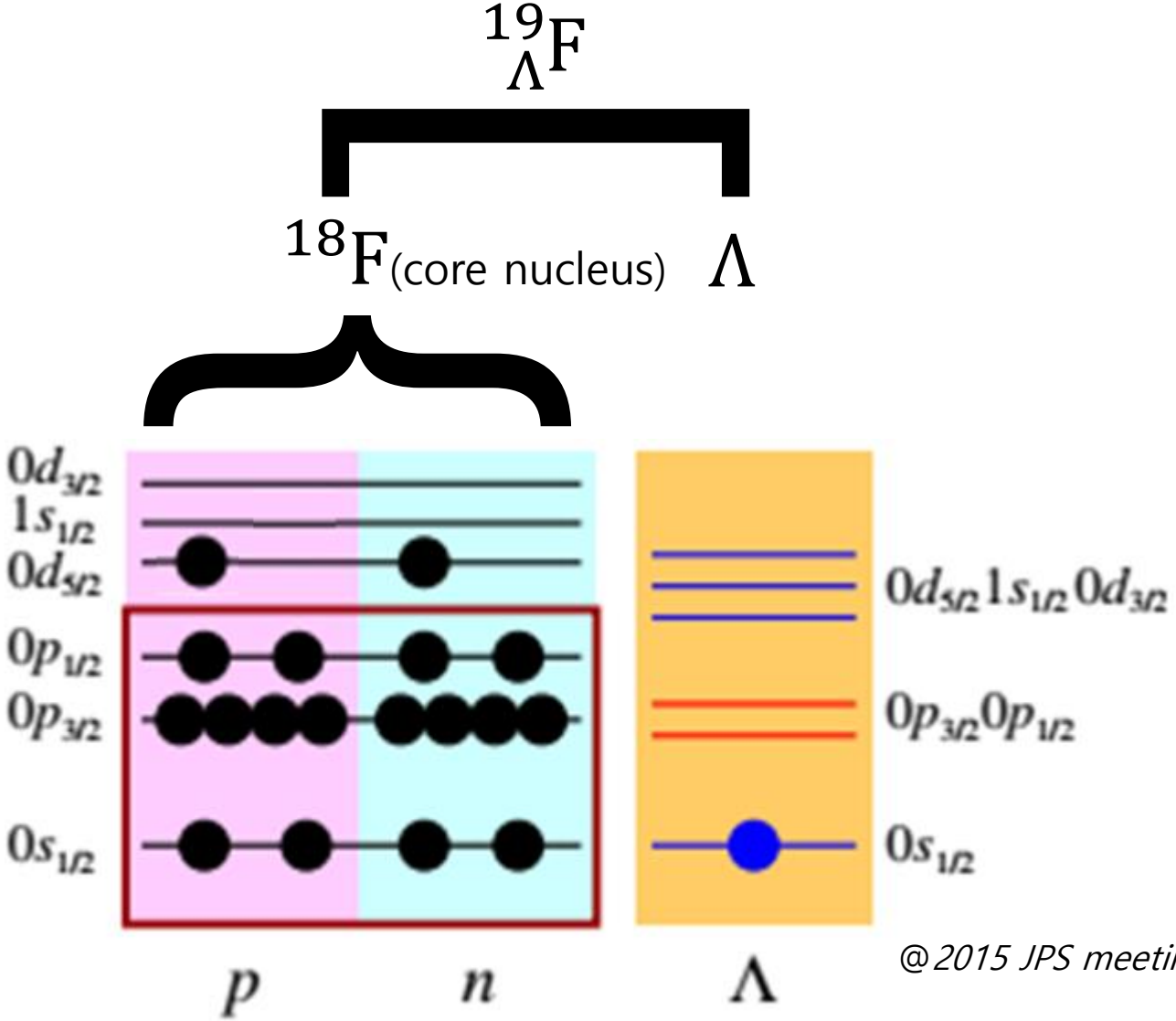


@PTEP, 2012, 02B009

	${}^{4}_{\Lambda}\mathrm{H}$	${}^{7}_{\Lambda}\mathrm{Li}$	${}^{19}_{\Lambda}\mathrm{F}$
Four-body Cluster model			
Wave-function	$s_N s_\Lambda$	$p_N s_\Lambda$	$(sd)_N s_\Lambda$
N, RMS radius [fm] *@by Millener, private communication*	2.5 $(0s)$	3.0 $(0p_{1/2})$ 2.9 $(0p_{3/2})$	3.4 $(1s_{1/2})$ 3.5 $(0p_{1/2})$ 3.3 $(0d_{5/2})$
Λ, RMS radius [fm] *@by Millener, private communication*	3.5 $(0s)$	2.6 $(0s)$	2.3 $(0s)$
ΔE_x (ground state doublet)	1.1 MeV	0.695 MeV ($\Delta_{p_N s_\Lambda}$=0.43 MeV)	?

■ Hypernucleus in the shell model,

Ex) ground state of ${}^{19}_{\Lambda}\mathrm{F}$ in the shell model,



@2015 JPS meeting, Motoba