Development of a triple coincidence method of reaction, gamma-ray, and weak decay in the hypernuclear gamma-ray spectroscopy at J-PARC

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for the J-PARC E63 collaborations

TOHOKU UNIVERSITY

JAEA

KEK
Unravelling the mysteries of matter, life and the universe.

Motivation
Charge Symmetry Breaking b/w ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{He}$

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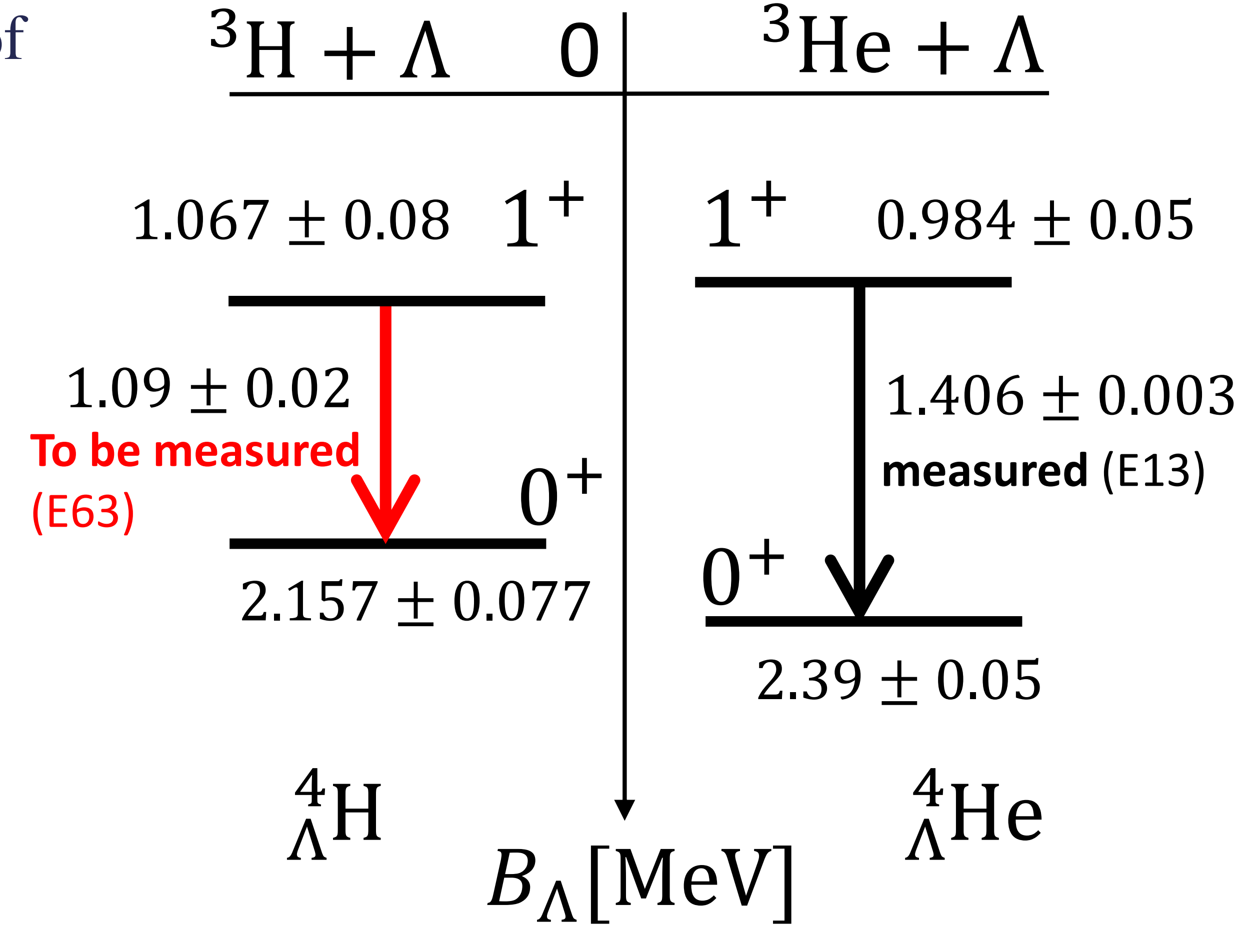
- ✦ The mechanism of the sizable CSB is still unclear.
- ✦ Study of the CSB, for deeper understanding of baryon-baryon interaction.

- ✦ ${}^{4}_{\Lambda}\mathrm{H}$ gamma-ray data: Less reliable than ${}^{4}_{\Lambda}\mathrm{He}$
  - ${}^{4}_{\Lambda}\mathrm{H}$: Low statistics, worse resolution (NaI)
  - ${}^{4}_{\Lambda}\mathrm{He}$: High statistics, good resolution (Ge)

- ✦ We plan to precisely measure the energy of ${}^{4}_{\Lambda}\mathrm{H}(1^{+} \rightarrow 0^{+})$ gamma-ray.
- ✦ Using a high-resolution Ge detector array (Hyperball-J) at J-PARC (E63 experiment)



Motivation
Hyperon-nucleons three-body interaction

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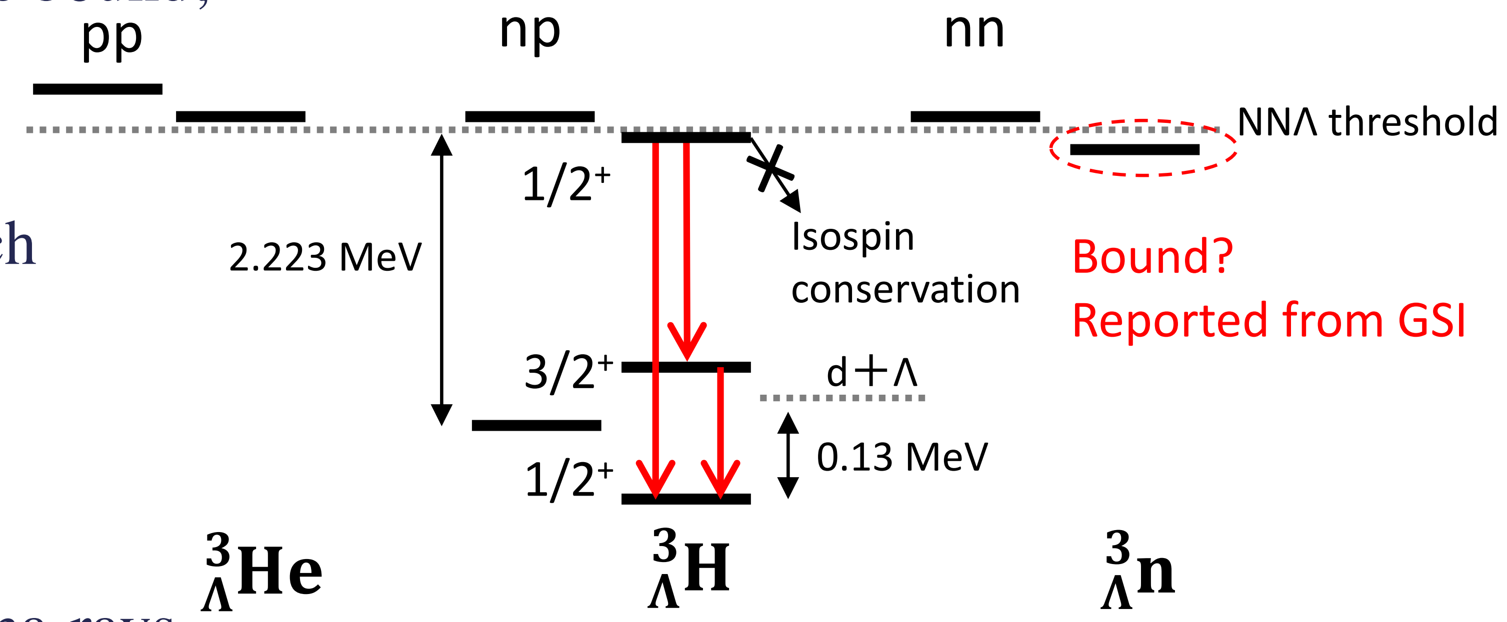
- ✦ T=1 excited-state of ${}^{3}_{\Lambda}$H is unbound, but it perhaps emits a gamma-ray.
- ✦ If T=0 excited state (3/2+) of ${}^{3}_{\Lambda}$H is bound, it emits a gamma-ray.
- ✦ From their energy, we can approach
  1. nnΛ is bound or not?
  2. hypertriton puzzle
- ✦ Also plan to measure the ${}^{3}_{\Lambda}$H gamma-rays using the Hyperball-J

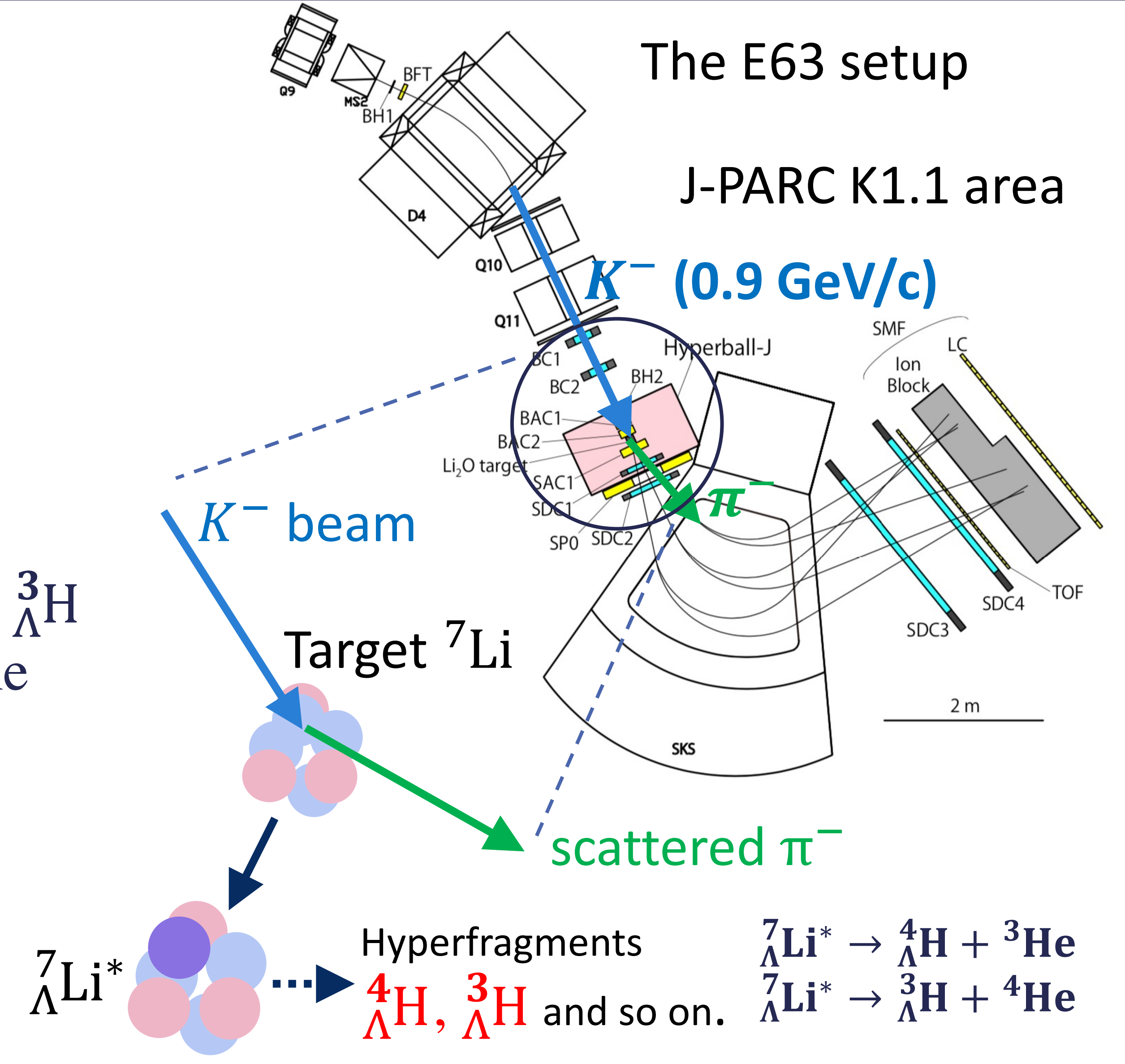


Production of $^{4}_{\Lambda}$H and $^{3}_{\Lambda}$H

- ✦ Difficult to produce $^{4}_{\Lambda}$H and $^{3}_{\Lambda}$H directly from hadron interactions of (K^-, π^-) or (π^+, K^+).

- ✦ Produce $^{4}_{\Lambda}$H and $^{3}_{\Lambda}$H as hyperfragments from ^{7}Li$(K^-, \pi^-)^{7}_{\Lambda}$Li* reaction.

- ✦ Possible to enhance the production of $^{4}_{\Lambda}$H and $^{3}_{\Lambda}$H by selecting the excitation energy of $^{7}_{\Lambda}$Li* in the ^{7}Li(K^-, π^-) missing mass.



Triple coincidence of $^{7}\mathrm{Li}(K^{-},\pi^{-})$, gamma-ray, and weak decay

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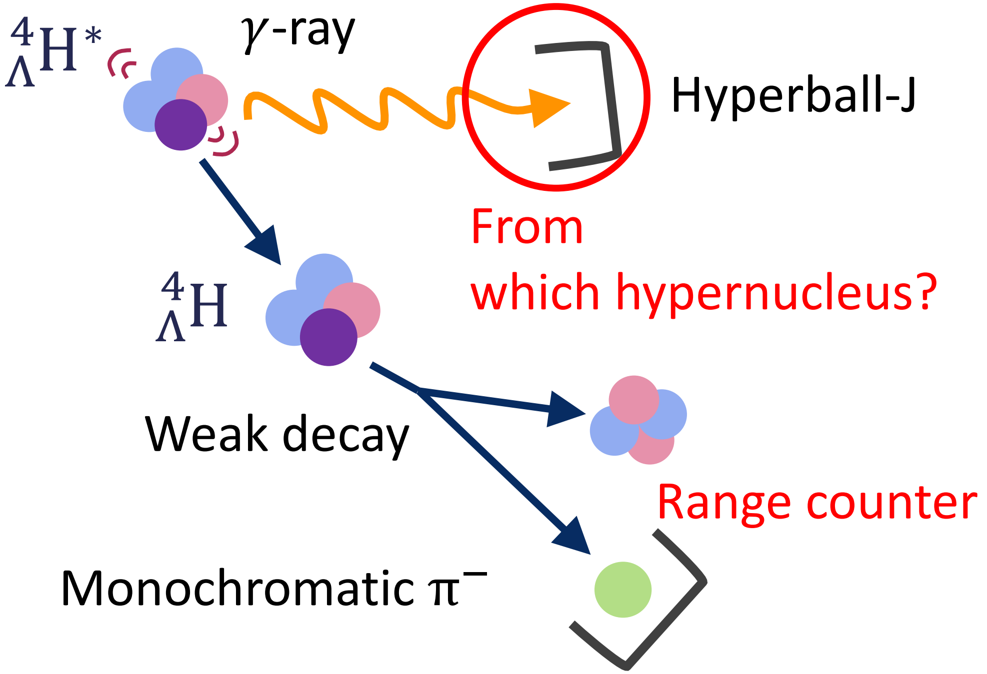
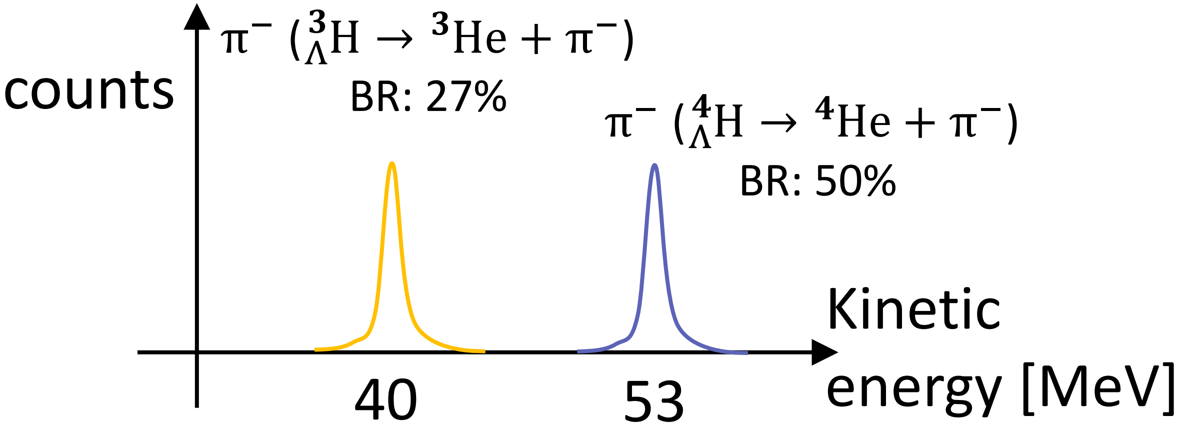
✦ Hard to identify which hypernucleus emitted the gamma-ray.

✦ Detect monochromatic pions from weak decay of $^{4}_{\Lambda}\mathrm{H}$ and $^{3}_{\Lambda}\mathrm{H}$ and measure the kinetic energy by a range counter system.

✦ Triple coincidence of in-flight (K^{-},π^{-}) reaction, gamma-ray, and weak decay for the first time!

✦ Requirement: To separate two peaks from these two π^{-}s w/ a confidence level of more than 3σ





Range counter system

Range Counter (RC)

24 layers × 6 mm of plastic scinti.

Readout:

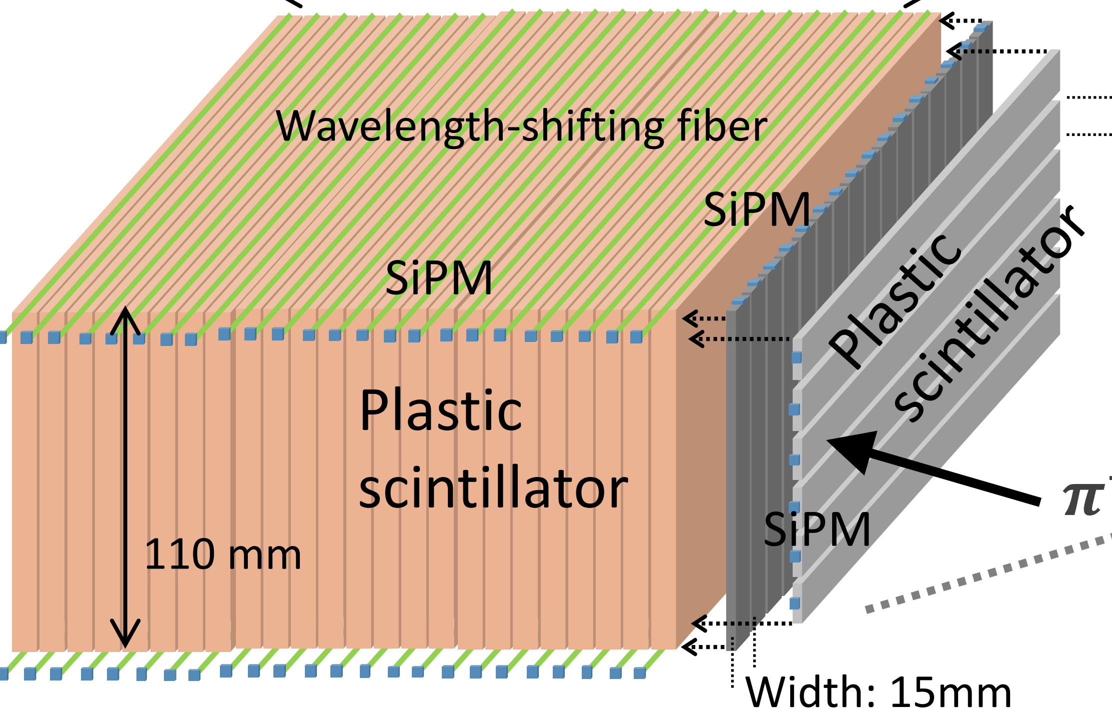
Scinti.+WLSFiber+SiPM

Tracking Device (TD)

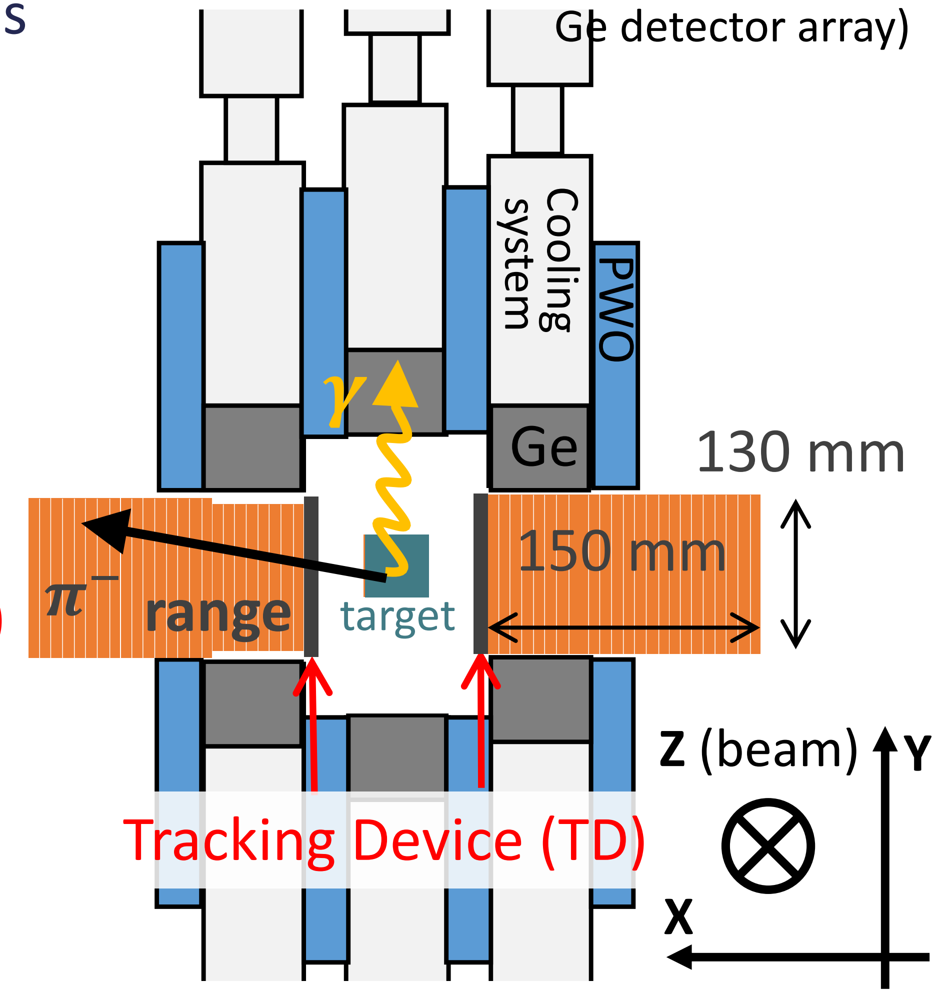
Two layers of hodoscopes for tracking pions

TD-Y (6seg.)

TD-Z (16seg.)



Range Counter (RC)



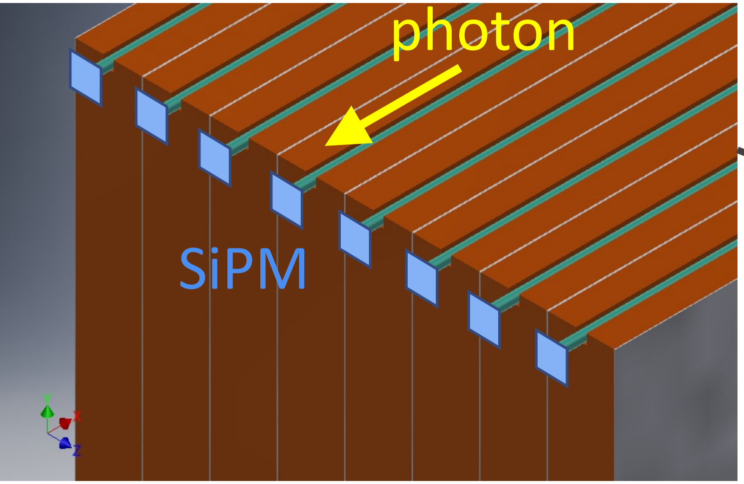
Fabrication of a prototype range counter

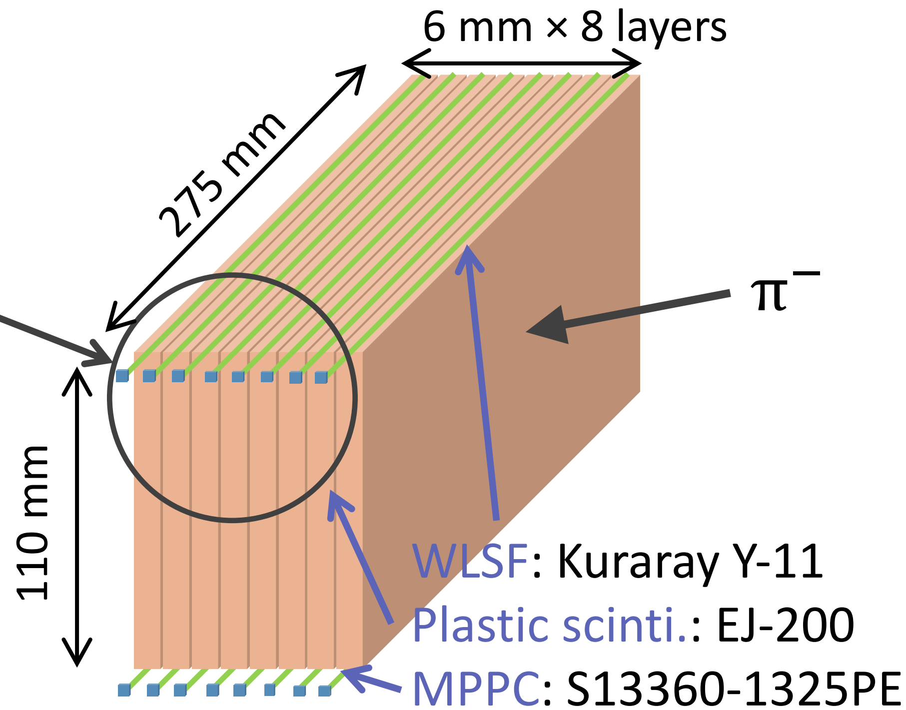
Fabrication of a prototype RC

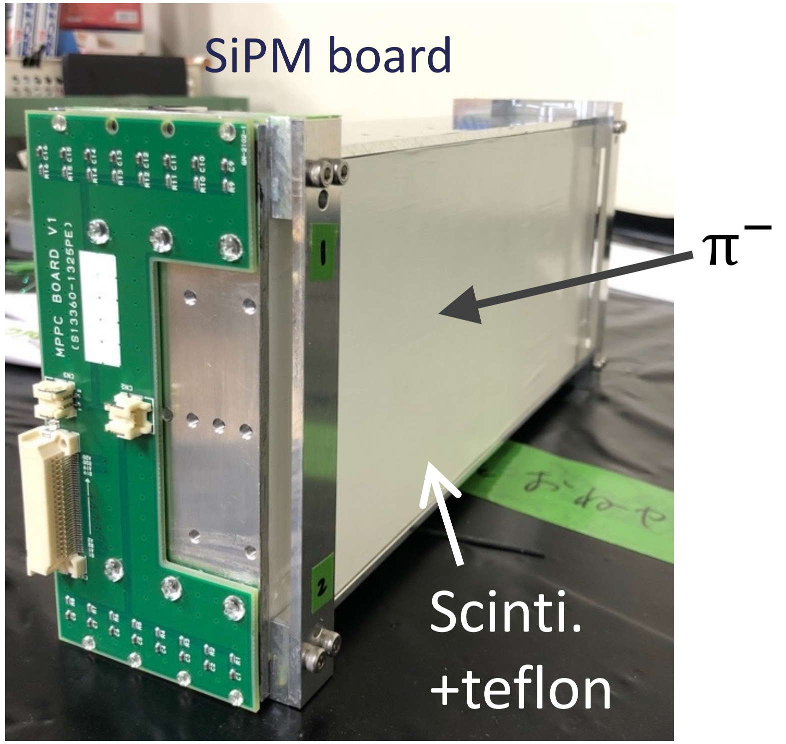
- ✦Readout method:

  scintillator + wavelength-shifting fiber (WLSF) + SiPM

- ✦ Thickness: 6 mm × 8 layers (1/3 of the full RC for E63)







Test experiment / Setup & Result 1

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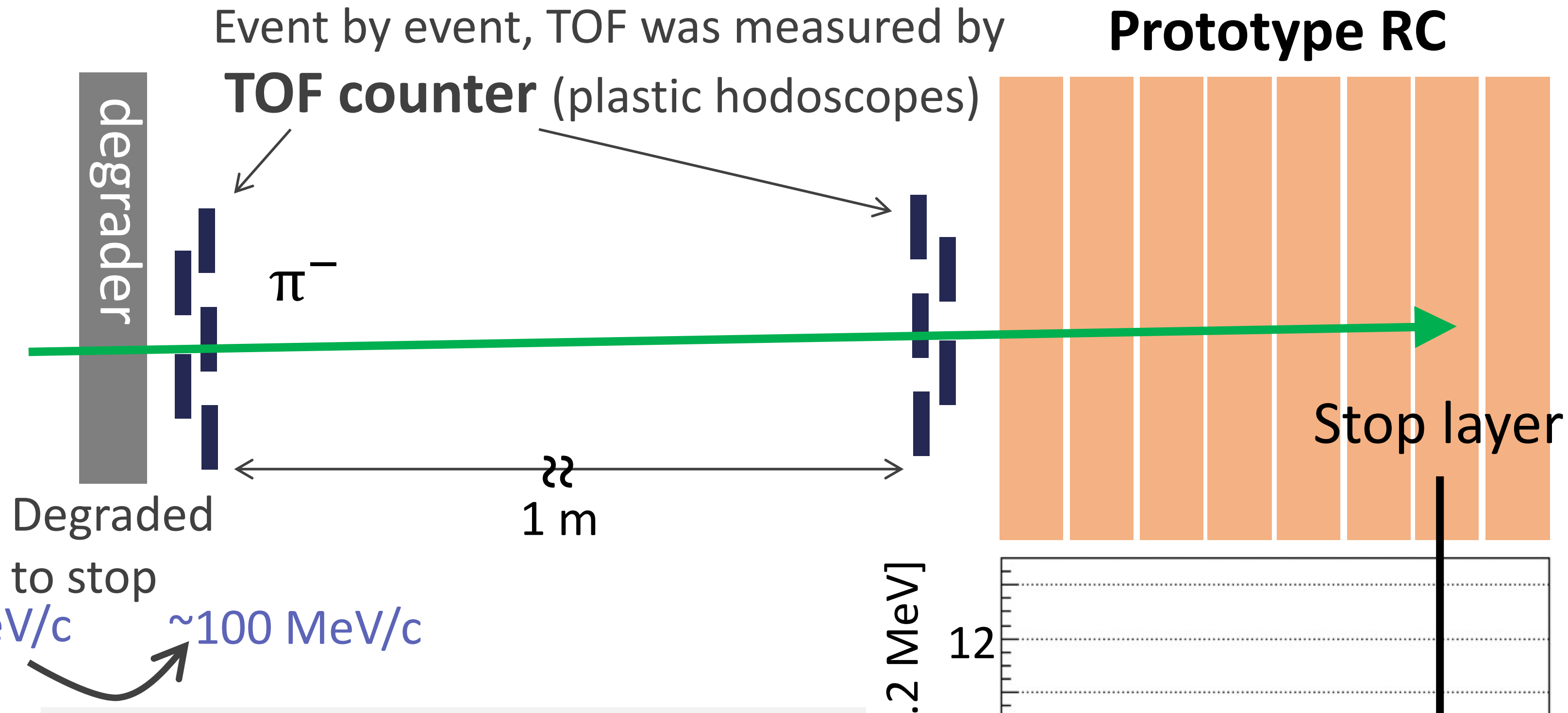
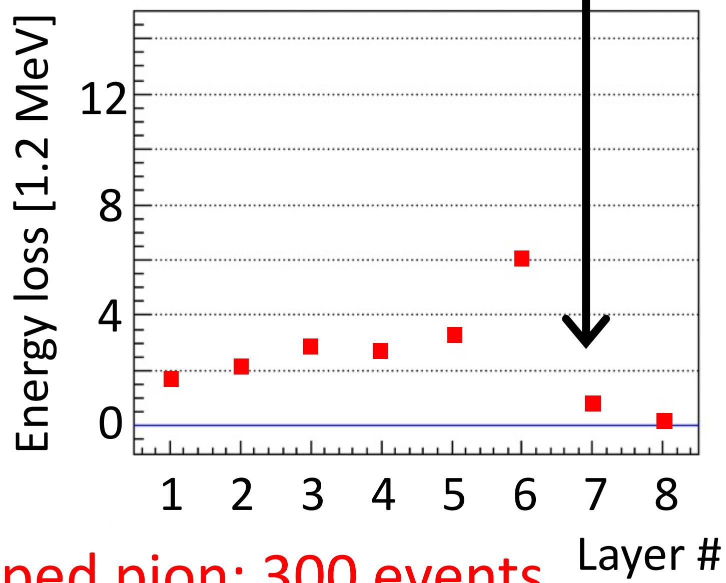
An experiment at J-PARC

- ✦ Purpose: To test the prototype & evaluate its performance
- ✦ The downmost-stream side of K1.8 beamline at J-PARC
- ✦ Particle: beam pion



Pions fly with various velocities
→Incident energy: NOT uniform

Select slow-pion events using TOF
→ plot the energy loss in each layer for each event
→ select stop events



Stopped pion: 300 events

Test experiment / Result 2

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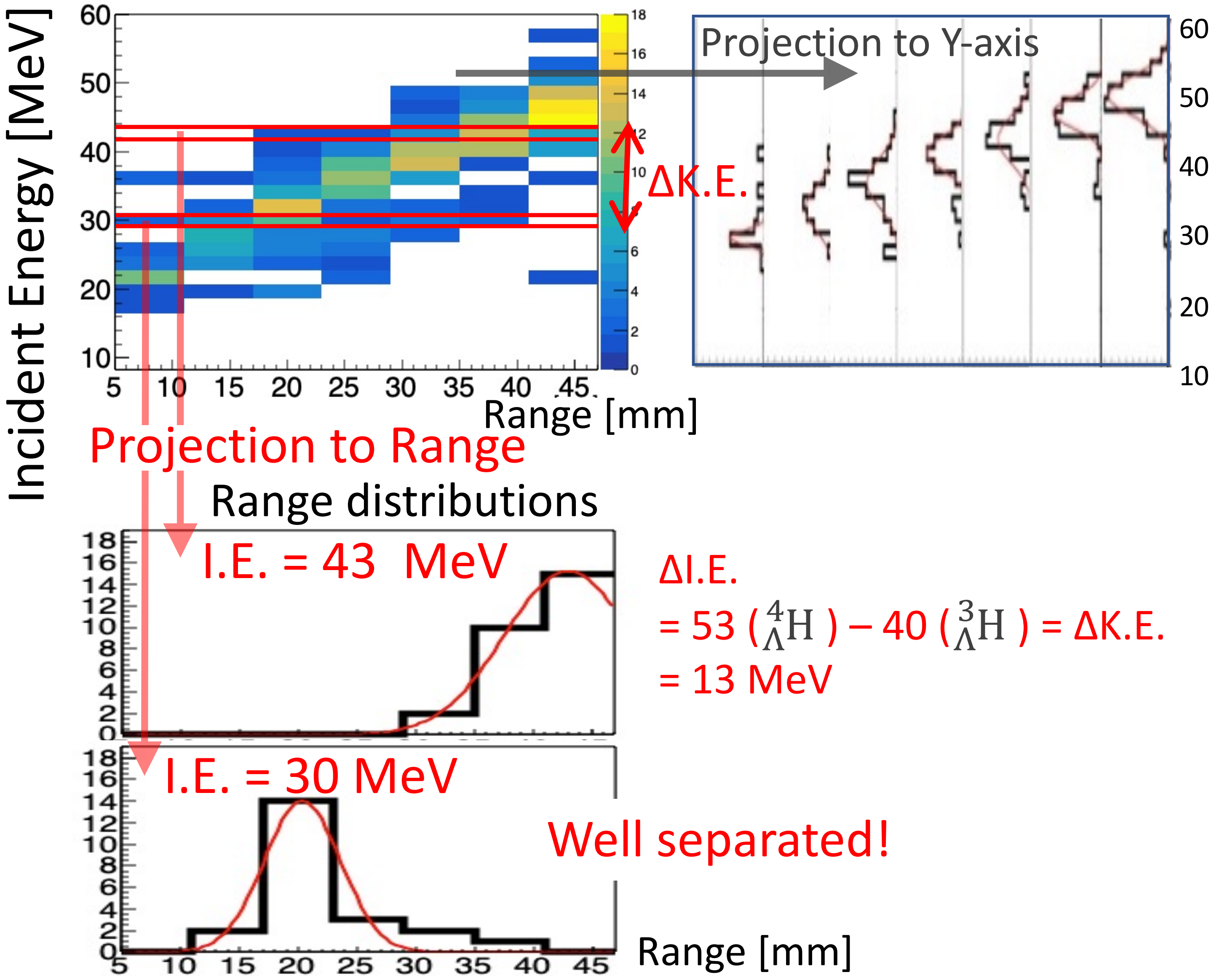


43 & 30 MeV pions are well separated by range

In the E63 experiment,

measure π^- with higher energy than the test exp.

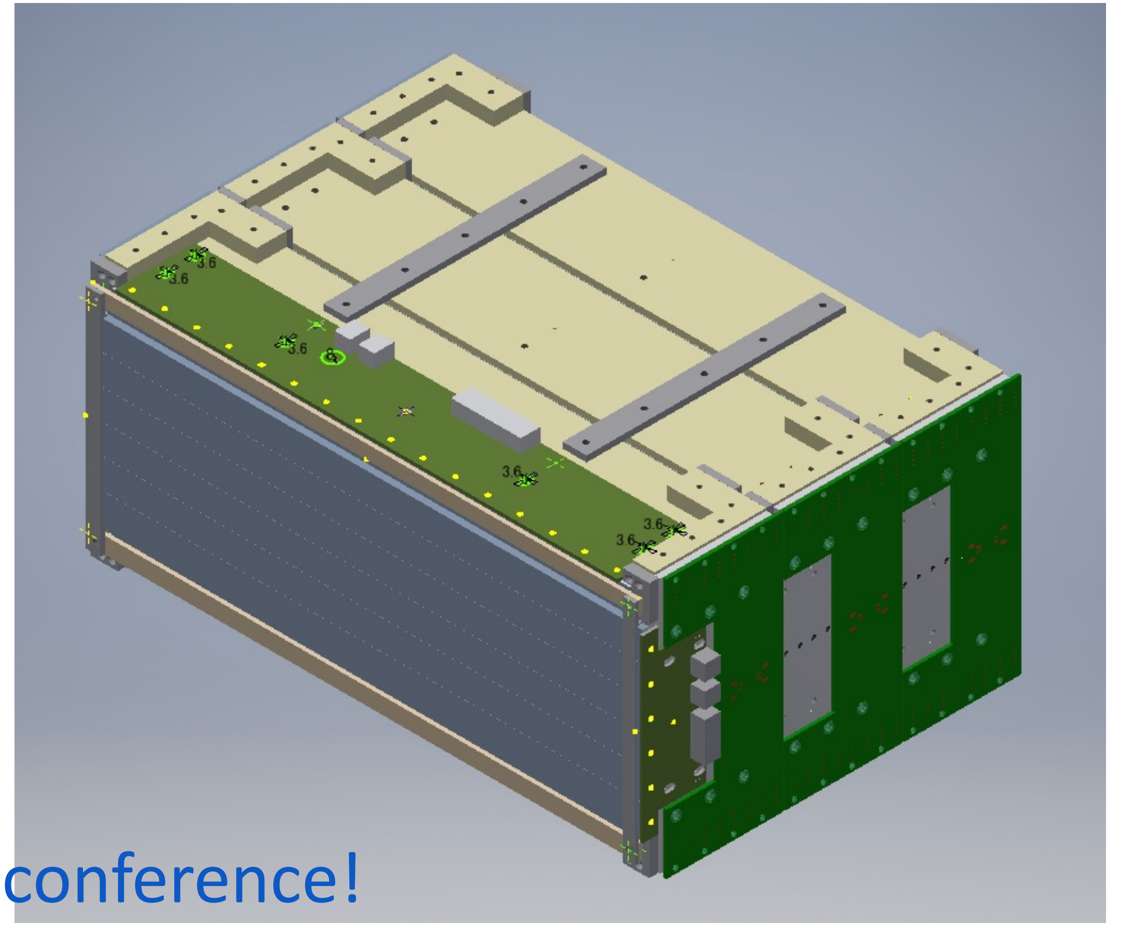
→ easier to separate these π^-s

→ Sufficient performance for identification of $^{4}_{\Lambda}$H & $^{3}_{\Lambda}$H in the E63

Summary

- ✦ Study of the CSB, for deeper understanding of baryon-baryon interaction.
- ✦ We plan to precisely measure the energy of gamma-ray from ${}^{4}_{\Lambda}\mathrm{H}(1^{+} \rightarrow 0^{+})$ transition.
- ✦ By triple coincidence of in-flight (K^{-}, π^{-}) reaction, gamma-ray, and weak decay for the first time!
- ✦ A prototype was fabricated and a test experiment was performed.
- ✦ The full of the detector system is being constructed.

The full of the system of the range counter and the tracking device



Thank you very much.
I'm happy to come to Prague and talk in this conference!

Backup

Spectra of ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{He}$

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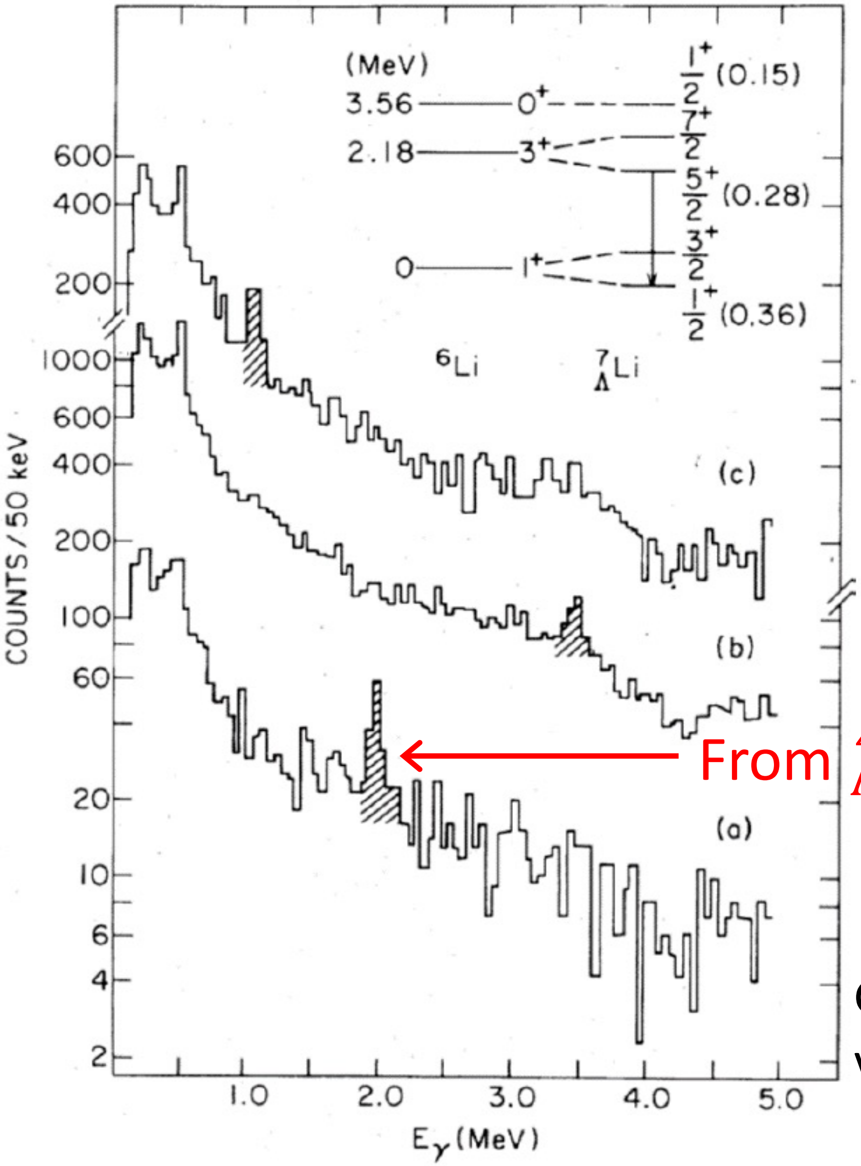
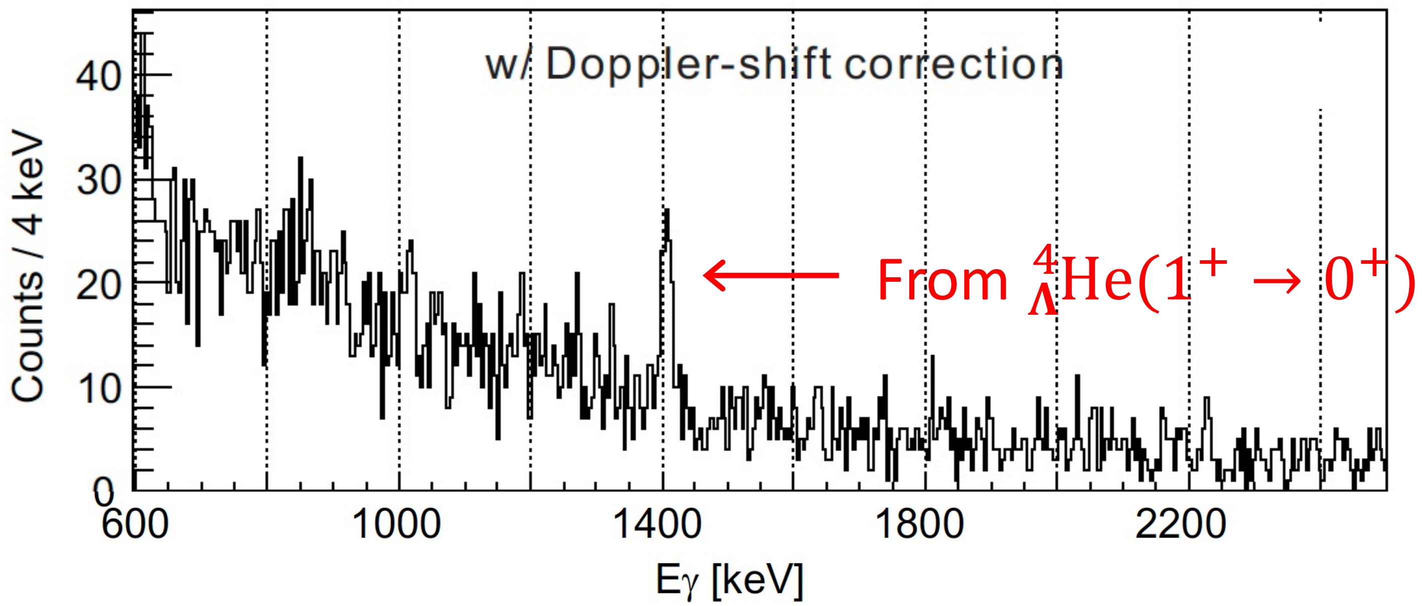


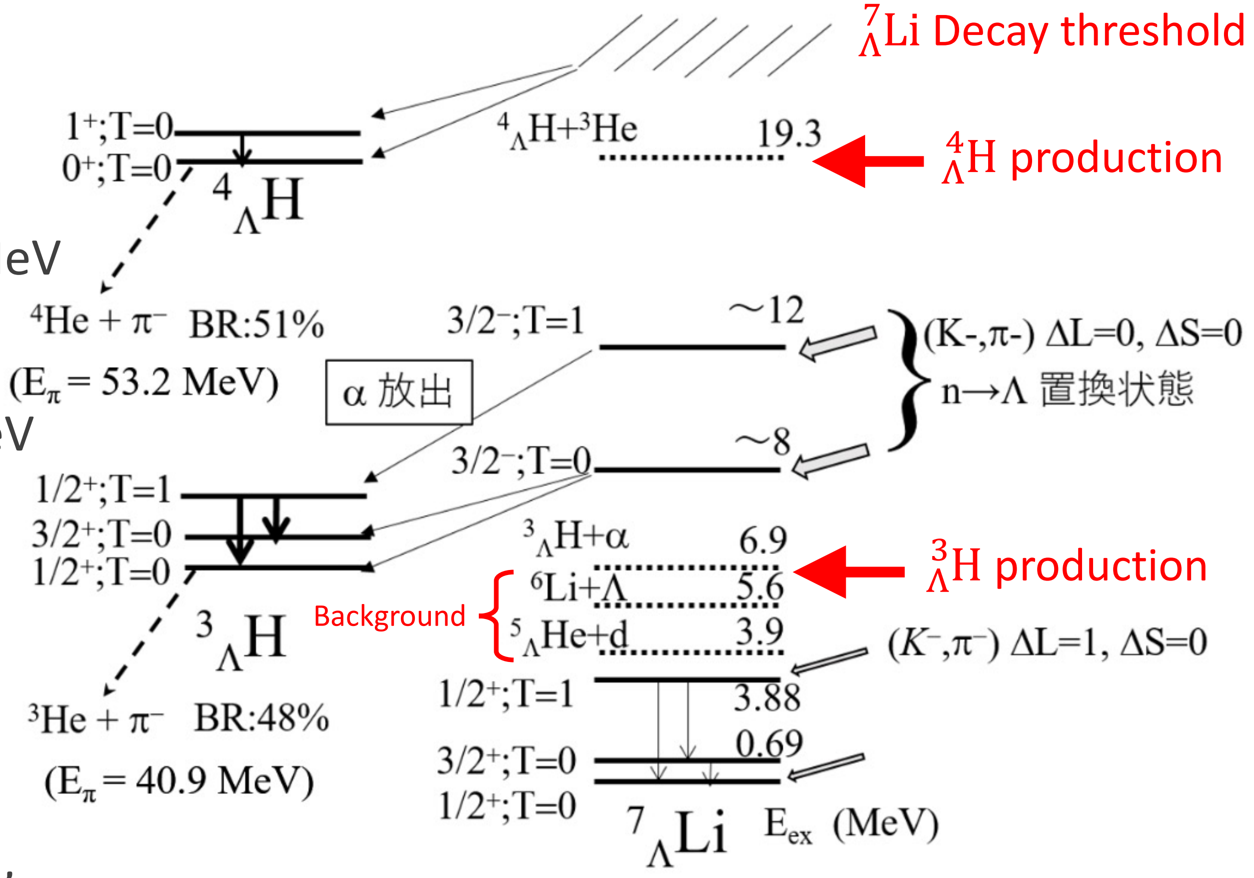


Gamma-ray spectrum in the spectroscopy
via the reaction of ${}^{4}\mathrm{He}(K^-, \pi^-)$ at J-PARC in 2015

Gamma-ray spectra in the spectroscopy
via the reaction of ${}^{7}\mathrm{Li}(K^-, \pi^-)$ at BNL in 1983

Energy structure of ${}^{3}_{\Lambda}\mathrm{H}$

- In analysis, selecting the region of missing mass of ${}^{7}_{\Lambda}\mathrm{Li}$, the excitation energy can be cut.
- ${}^{4}_{\Lambda}\mathrm{H}$: excitation energy of ${}^{7}_{\Lambda}\mathrm{Li}$ is equal or more than 20 MeV
  $({}^{7}_{\Lambda}\mathrm{Li}^{*} \rightarrow {}^{4}_{\Lambda}\mathrm{H} + {}^{3}\mathrm{H}e)$
- ${}^{3}_{\Lambda}\mathrm{H}$: excitation energy of ${}^{7}_{\Lambda}\mathrm{Li}$ is equal or more than 7 MeV
  $({}^{7}_{\Lambda}\mathrm{Li}^{*} \rightarrow {}^{3}_{\Lambda}\mathrm{H} + {}^{4}\mathrm{H}e)$



Energy stracture and decay modes of ${}^{7}_{\Lambda}\mathrm{Li}$

- However,
  under the threshold of production of these hypernuclei,
  other hypernuclei are produced.

→ By only missing mass, it might not be able to identify which hypernucleus emitted gamma ray.