

Performance Evaluation of Ultra-Low-Radioactivity PMTs and Impurity Evaluation of High-Purity GAGG Crystal in the PIKACHU experiment

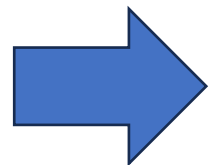
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UGRP2026, 28-30 September 2026, Institute of Science Tokyo



introduction

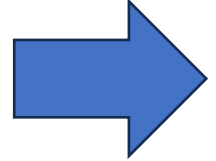
- The PIKACHU experiment searches for the double-beta decay of ^{160}Gd using GAGG ($\text{Ce}:\text{Gd}_3\text{Al}_2\text{Ga}_3\text{O}_{12}$) scintillator.
- Major Backgrounds (BG) : ^{40}K and upstream part of the ^{238}U decay series ($^{238}\text{U}_{\text{up}}$)

^{40}K : **External** ^{40}K makes it difficult to accurately estimate the **internal** ^{40}K .

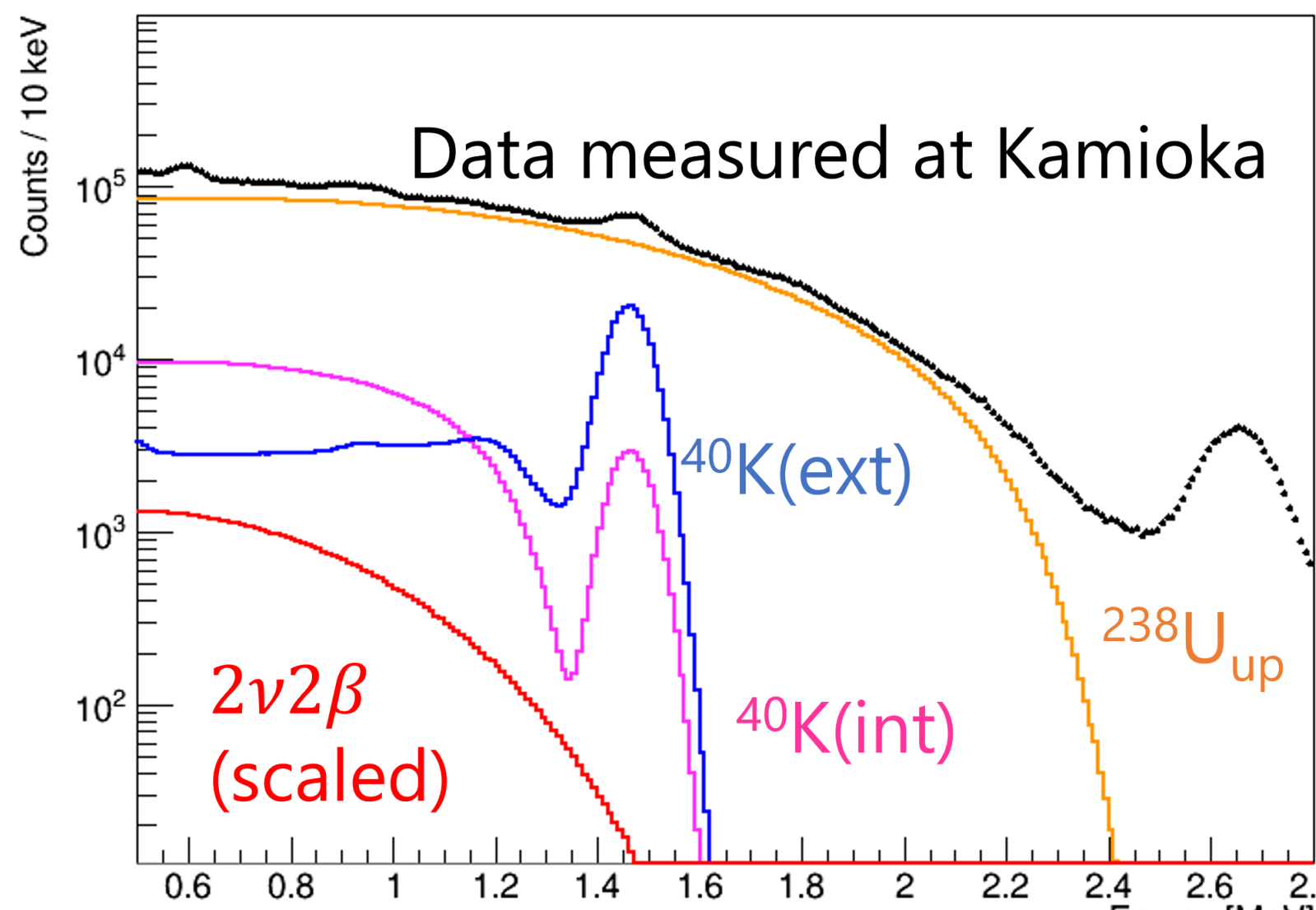


Reduce external ^{40}K by introducing a New PMT with lower ^{40}K content.

$^{238}\text{U}_{\text{up}}$: The dominant background in the $2\nu\beta\beta$ search region.



Reduce internal ^{238}U by improving the radiopurity of the GAGG crystal.



Performance Evaluation of Ultra-Low-Radioactivity PMTs

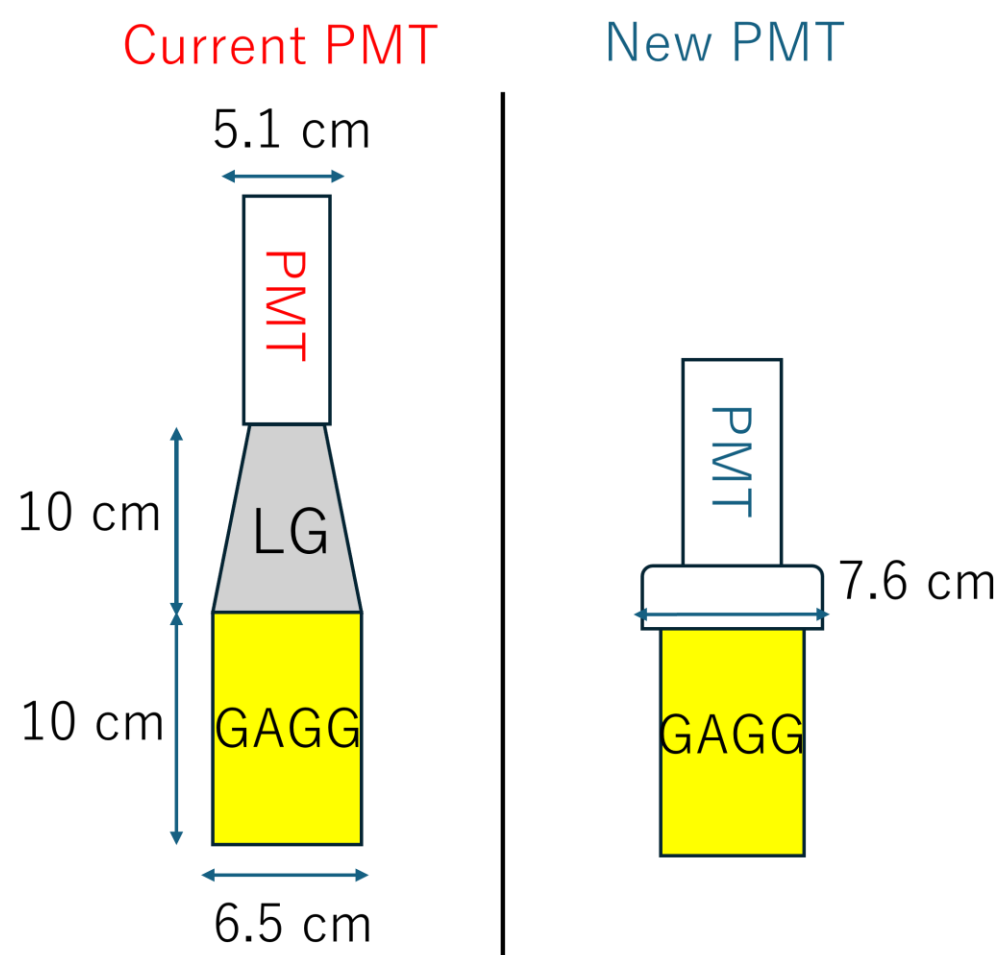
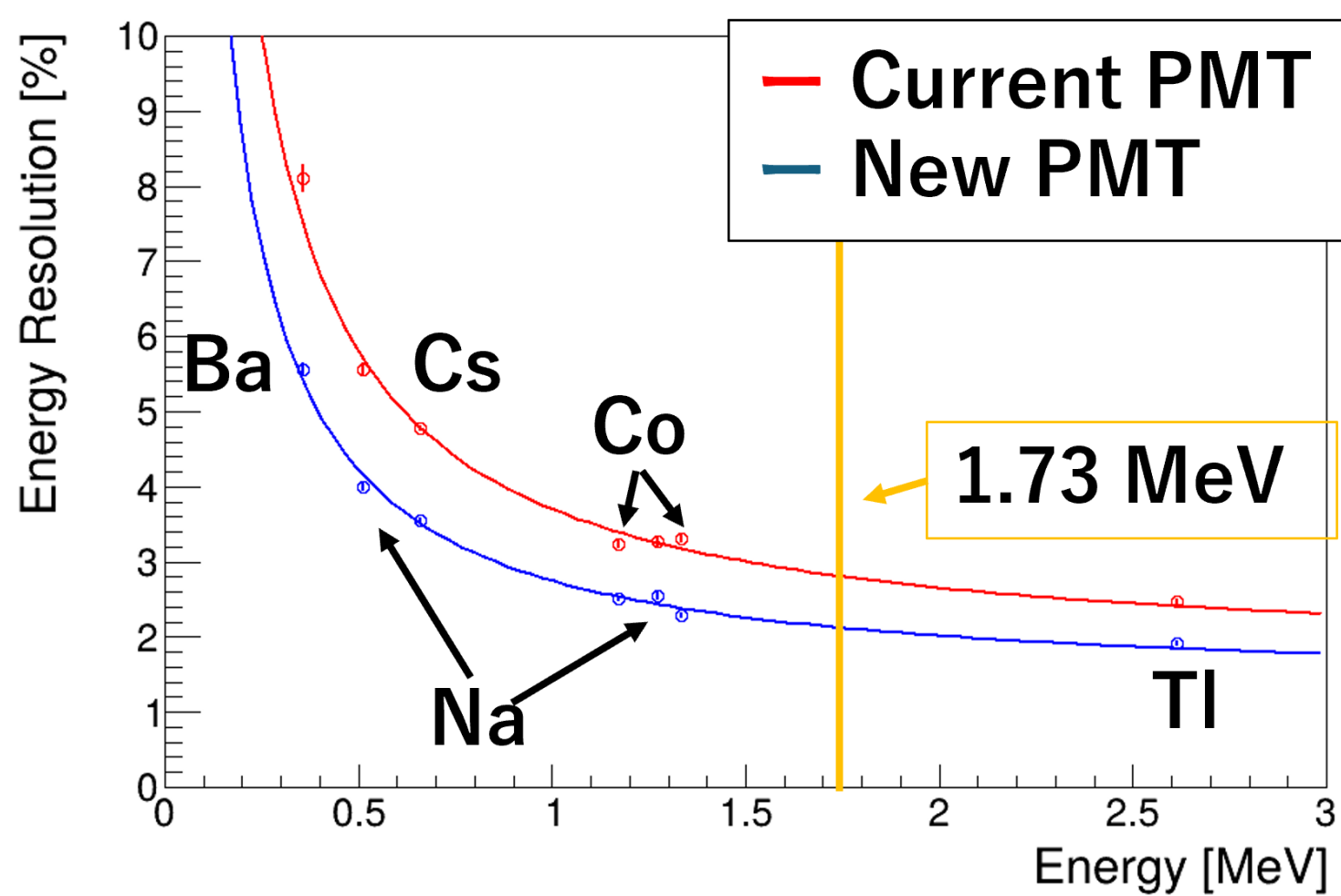
< PMT >

- Current PMT** : Low-Radioactivity PMT with borosilicate glass (R6231-04).
- New PMT** : Ultra-Low-Radioactivity PMT with quartz glass (R11065-20).
- The **New PMT** has approximately $\frac{1}{10}$ the ^{40}K content of the **Current PMT**.

< Measurement >

Multiple radioactive sources were used for energy calibration, and the Energy Resolution and Pulse-Shape Discrimination (PSD) performance of each PMT were evaluated.

< Energy Resolution >



$$\text{Energy Resolution [\%]} = \frac{\sigma}{E}$$

	Energy resolution at 1.73 MeV
Current PMT	2.82%
New PMT	2.13%

(^{160}Gd Q value : 1.73 MeV)

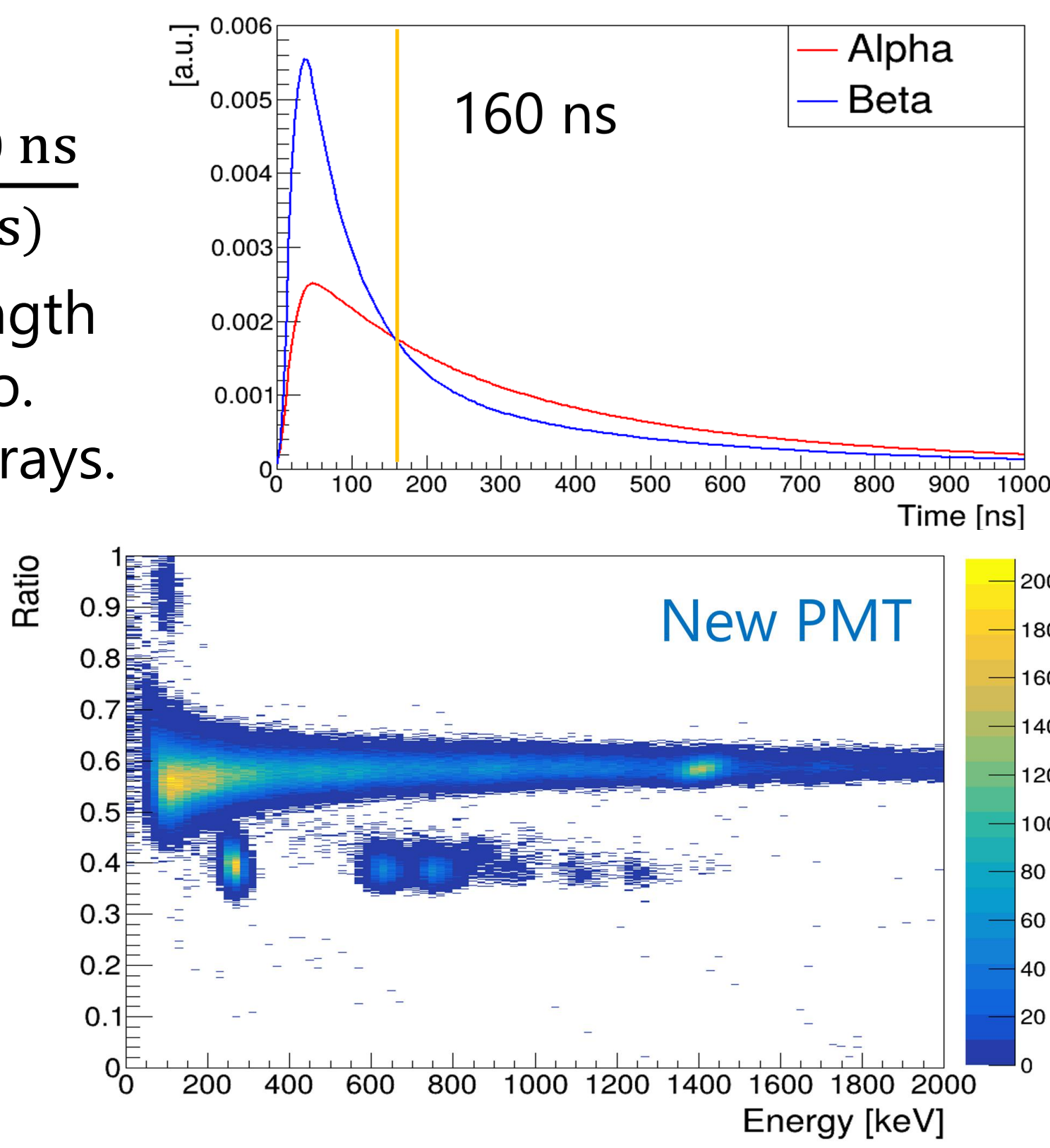
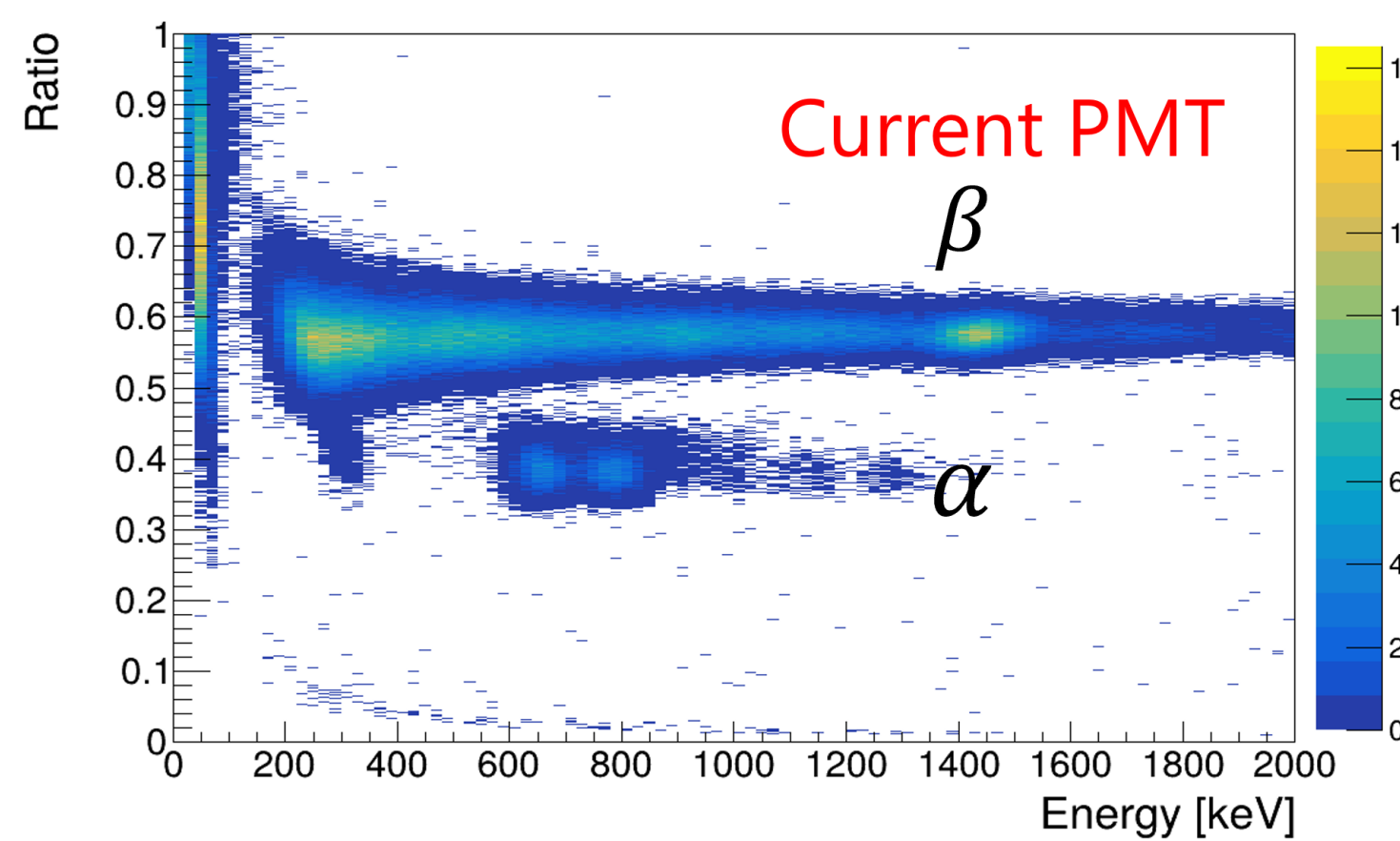
The **New PMT** shows better energy resolution than the **Current PMT**.

< PSD performance >

Ratio : parameter used for PSD

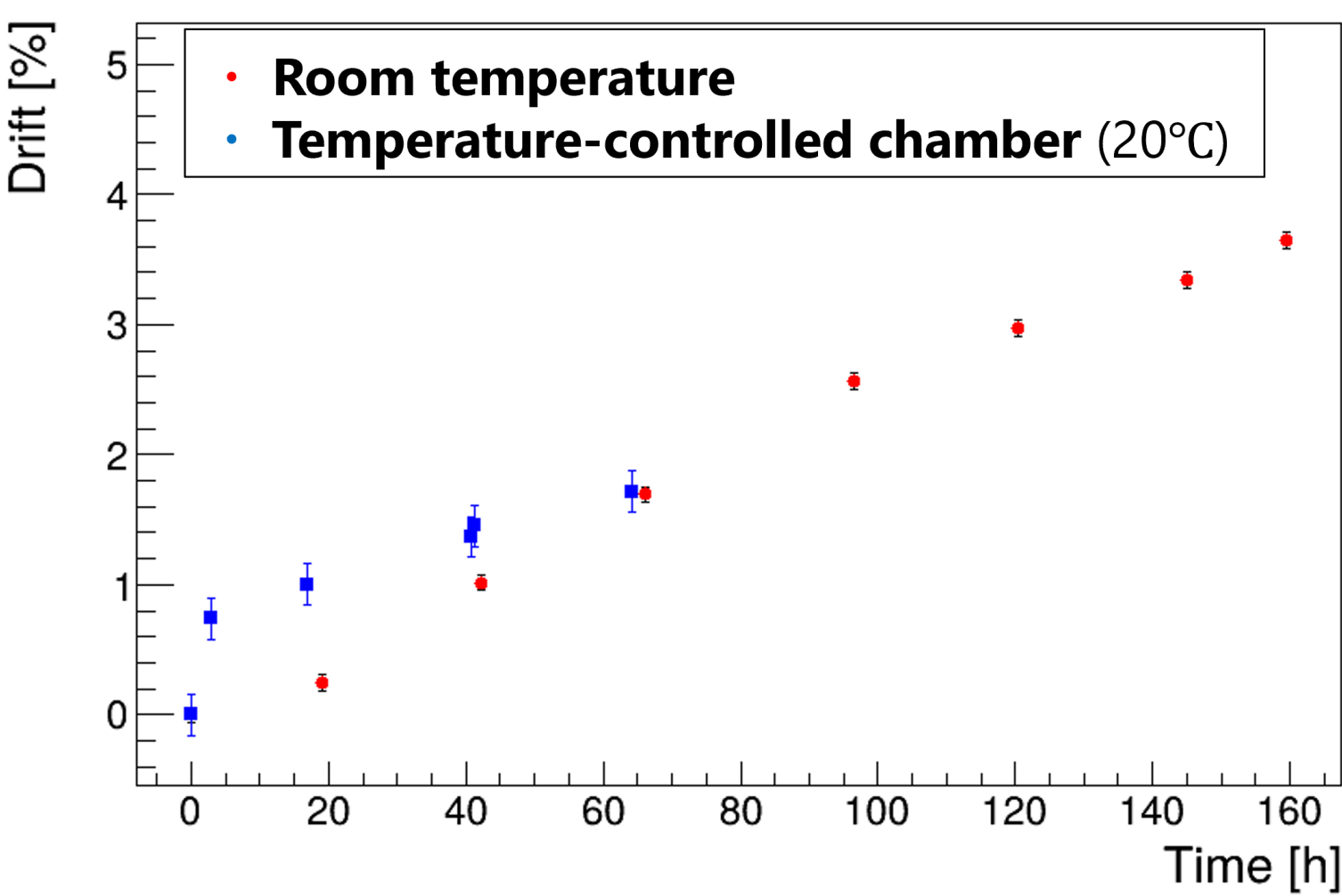
$$\text{Ratio} = \frac{\text{Waveform area in the first 160 ns}}{\text{Total waveform area (1000 ns)}}$$

- β rays have a shorter attenuation length than α rays, resulting in a larger Ratio.
- Ratio enables PSD between α and β rays.



The **New PMT** shows better PSD performance than the **Current PMT**.

< Long-term stability >



- $\text{Drift [\%]} = \frac{\text{Peak}(i) - \text{Peak}(1)}{\text{Peak}(1)} \times 100$
(Peak(1) : Initial ^{137}Cs photopeak)
- $\frac{\sigma}{E} = 3.54\%$ (at ^{137}Cs 662 keV peak)
- A significant gain variation was observed.
- The circuit section may be responsible for the observed variation.

Introduction of the New PMT was postponed.

Conclusions

- The **New PMT** has approximately $\frac{1}{10}$ the ^{40}K content of the **Current PMT** and shows better energy resolution and PSD performance.
- However, a significant variation in energy resolution was observed during the long-term stability test, and its introduction was postponed.
- The radioactive impurity levels in the crystal were reduced to approximately $\frac{1}{4}$ for the U series and $\frac{1}{100}$ for the Th series.

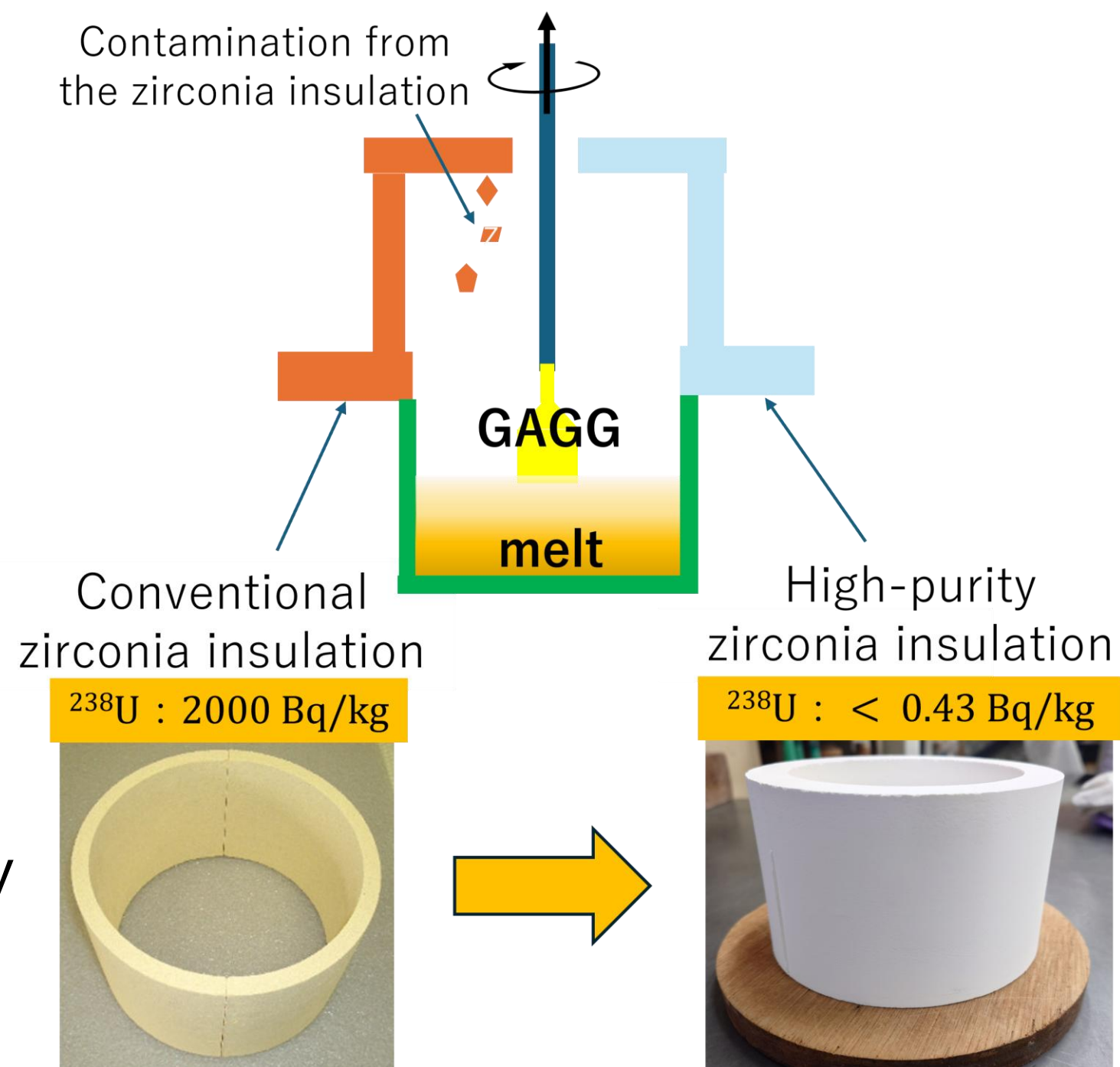
Development of High-Purity GAGG Crystal

< GAGG crystal >

- Czochralski method
- ^{238}U concentration raw materials : **< 16 mBq/kg**

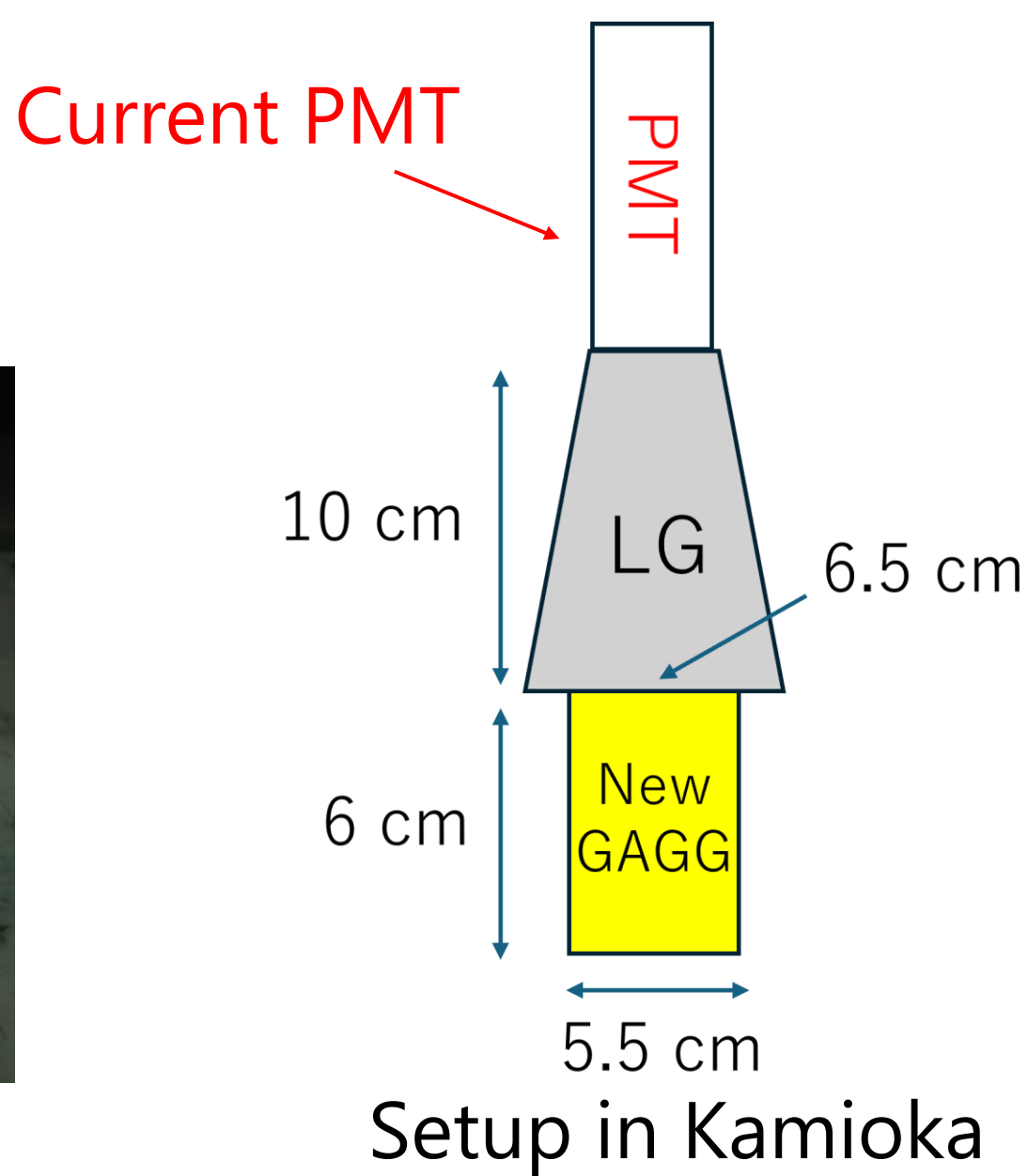
grown crystal : **125 mBq/kg**

- ^{238}U contamination occurred during crystal growth.
- The source is the zirconia insulation material.
- Developed and introduced a high-purity insulation material

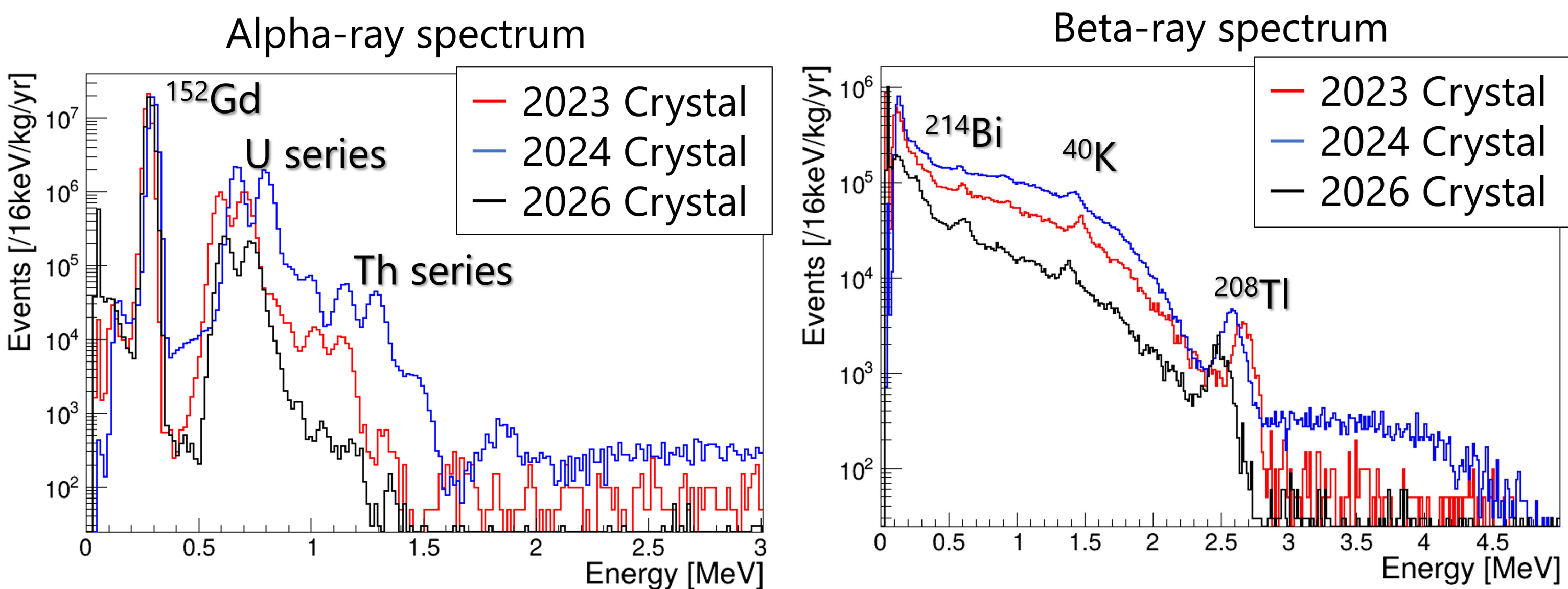


**New crystal completed in July 2026
and
installed at Kamioka in late August 2026**

2026 Crystal :
 ϕ 5.5 cm , L 6 cm



< Estimation of Impurity >



	^{238}U [mBq/kg]	^{234}U [mBq/kg]	Downstream of ^{232}Th [mBq/kg]
2023 Crystal	125.2 ± 1.6	154.6 ± 2.4	10.3 ± 0.8
2026 Crystal	33.7 ± 0.3	34.2 ± 0.3	< 0.24
raw material	< 16	-	< 0.96

(The U and Th decay series impurity levels were estimated from the α ray spectrum.)

- The U series was reduced by approximately $\frac{1}{4}$, while the Th series was reduced by at least $\frac{1}{100}$ compared with the 2023 crystal.
- The beta-ray background level at 1 MeV was reduced to approximately $\frac{1}{4}$ compared with the 2023 crystal.

Future Prospects

Toward the introduction of the ultra-low-radioactivity PMT

- Develop a new circuit and re-evaluate the long-term stability.
- Toward further reduction of the major β ray background, $^{238}\text{U}_{\text{up}}$
- Further improve the radiopurity of the crystal to reduce radioactive impurities and achieve levels comparable to those of the raw materials.