

# A study of high energy gamma intensities from the $^{208}\text{TI}$ decay with $\text{ThO}_2$ powder

*Low Radioactivity Techniques (LRT) 2019*

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**Center for  
Underground Physics** 

# Motivation

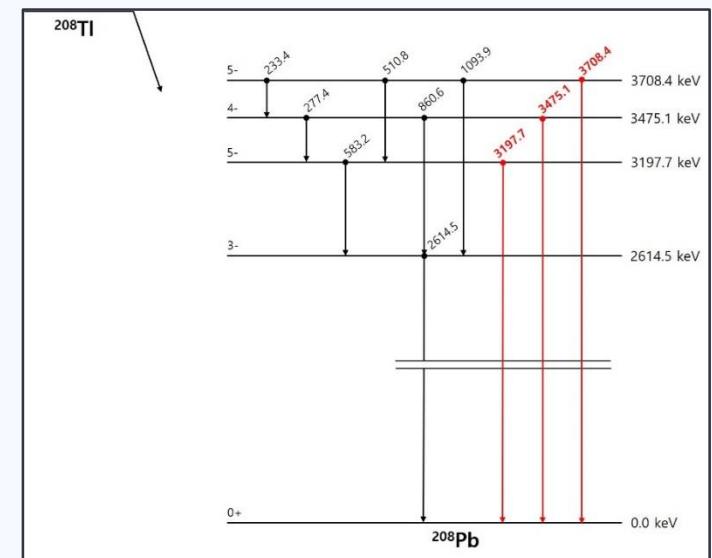
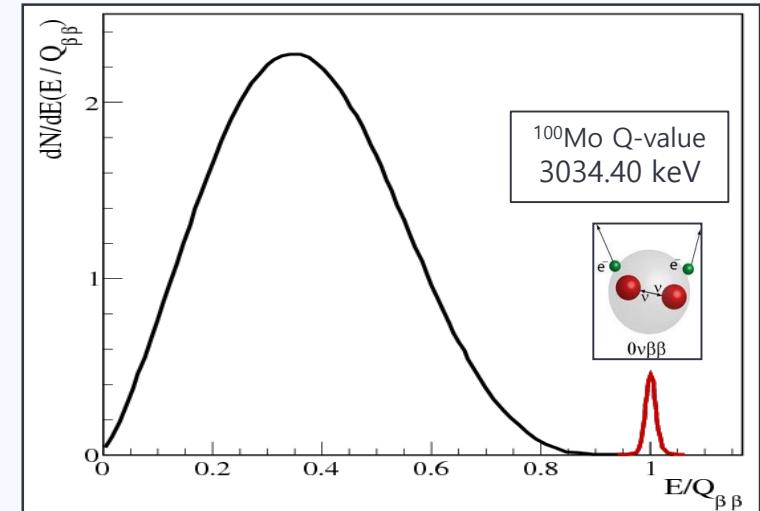
- **0νββ**

- Most Q values of **0νββ** decay are less than 3.1 MeV.
- Ex :  $^{100}\text{Mo}$  ( $Q=3034$  keV) is an ideal candidate for the  $0\nu\beta\beta$  search because most background events from gamma emissions are below 2700 keV.
- $^{208}\text{TI}$  decay Q value = 4999 keV -> a main background for the  $0\nu\beta\beta$  decay experiment.

- **Gamma transitions with  $E > 3$  MeV from the  $^{208}\text{TI}$  decay**

Energy (keV)	3198	3475	3708
Intensity (%)	< 0.007*	< 0.003*	< 0.004*

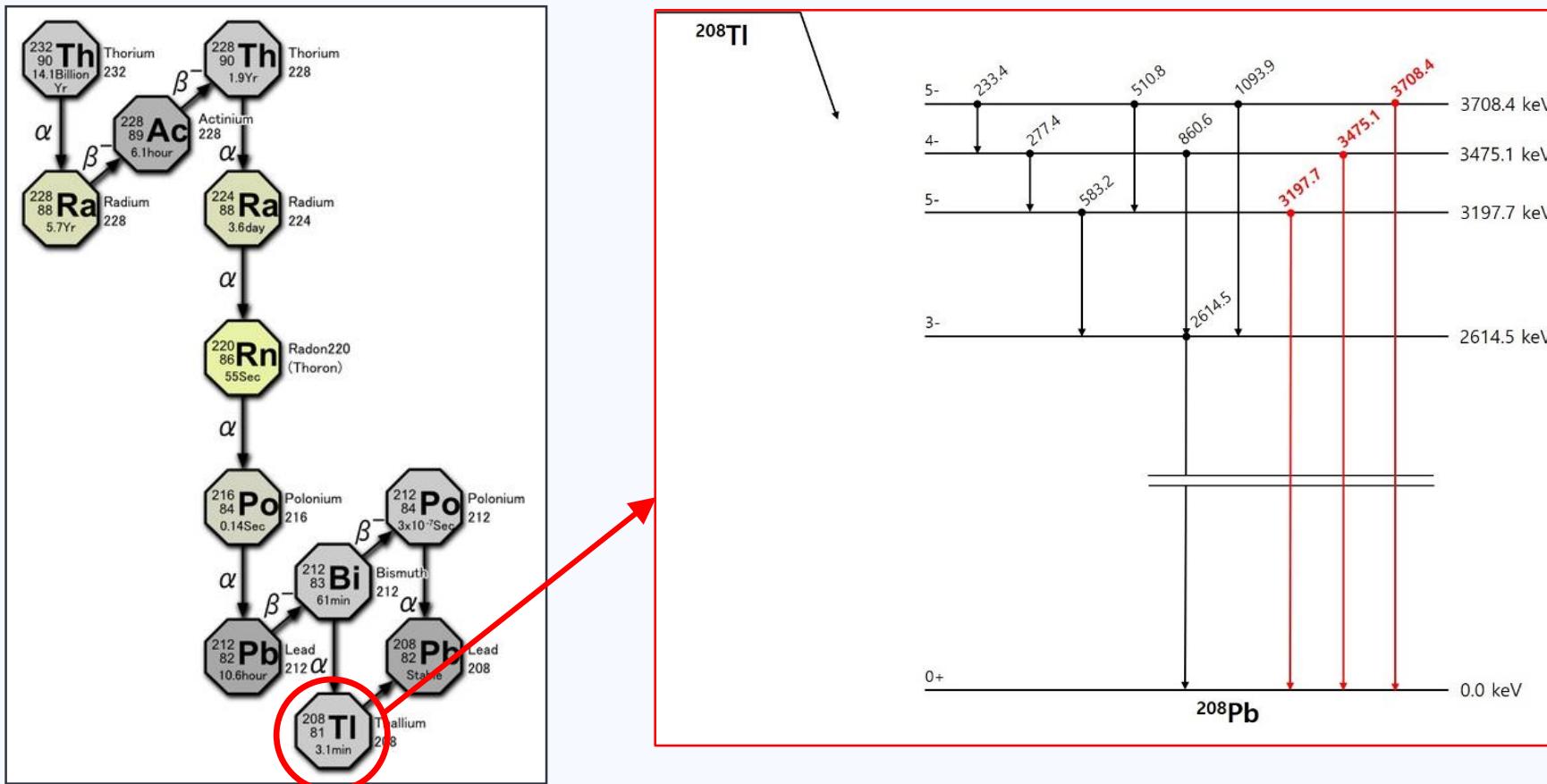
- Gamma intensities with  $E > 3$  MeV are not known.
- The current limits are not negligible for zero background experiment.



\* NNDC database, S. I. Vasil'ev et al., Instruments and Experimental Techniques 49, 34 (2006).

# $\text{ThO}_2$ Experimental concept

- $\text{ThO}_2$  powder measurement using an HPGe detector to identify unknown intensities of rare gamma transitions.
- Transitions of interest : three gamma transitions with  $E > 3 \text{ MeV}$ , after the  ${}^{208}\text{TI}$  decay.



# Laboratory & Detector

- **Y2L**

The underground laboratory of CUP which is located at depth of 700m (2000 m.w.e) in an underground tunnel at Yanyang in Korea.

- **HPGe detectors**

CC1, a single HPGe detector with 100% relative efficiency, was used for this experiment.

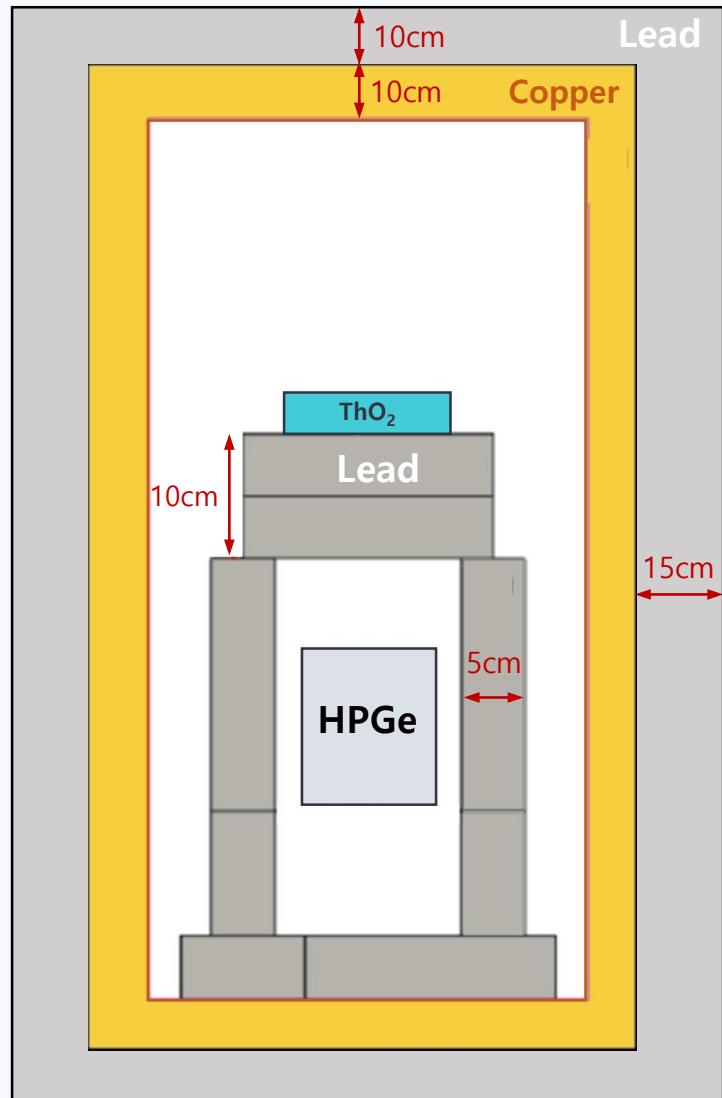


- Minimum depth: 700 m
- Access to the lab by car (~2km)



▲ [CC1]

# Experimental setup

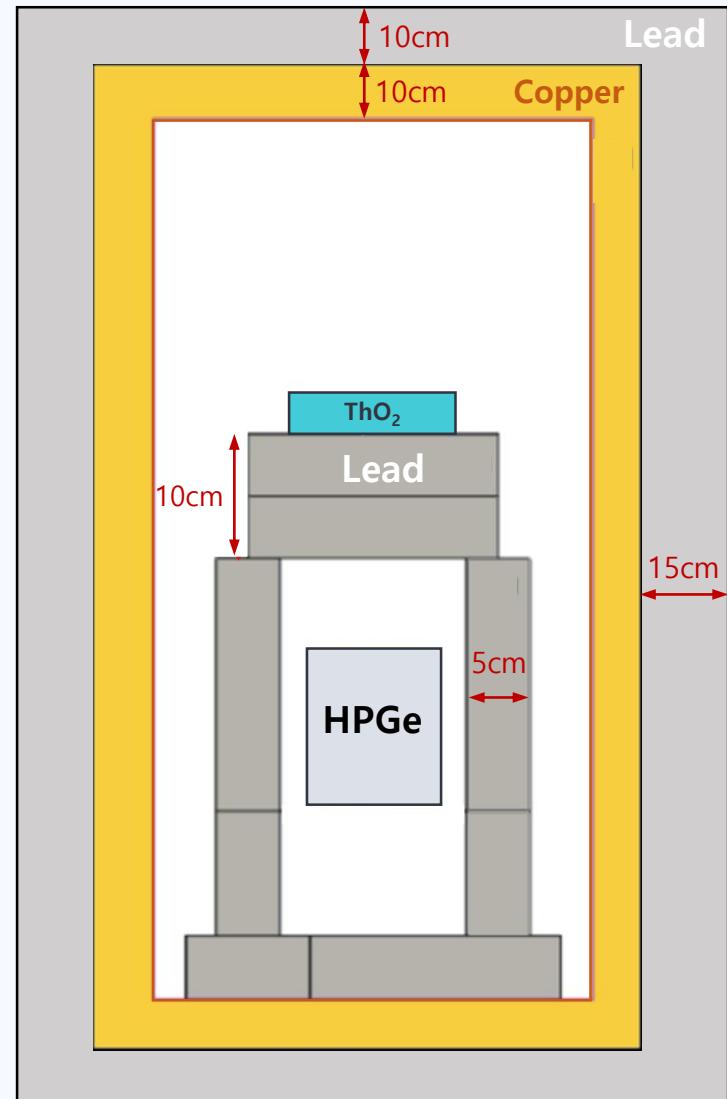


▲ [HPGe detector structure & sample set up]

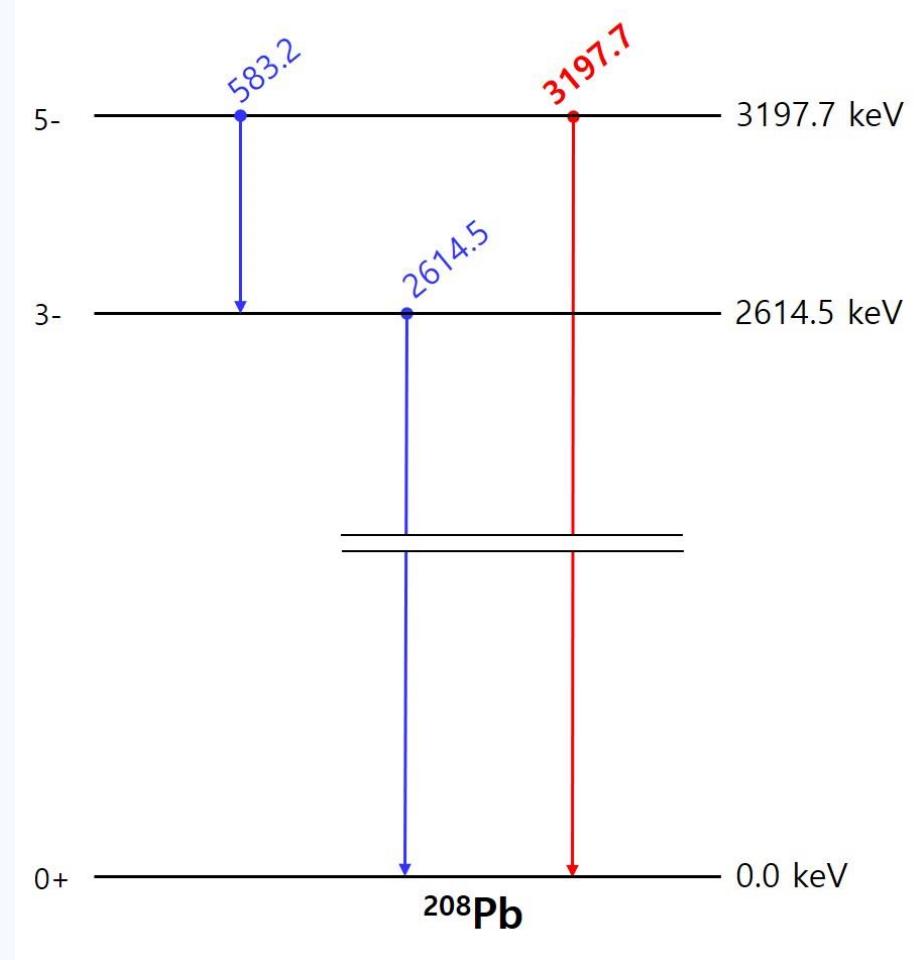


<b>Sample</b>	ThO <sub>2</sub> powder 2kg (1kg pack 2ea)
<b>Size (2ea)</b>	17.5 x 13 x 5.6 (h) cm <sup>3</sup>
<b>M. period</b>	39.5 day

# Experimental setup



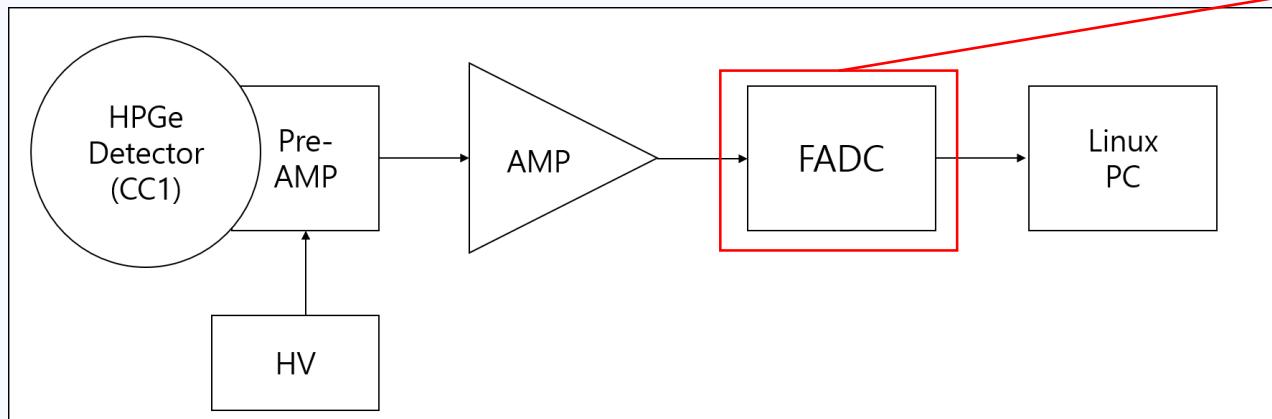
▲ [HPGe detector structure & sample set up]



[ex] 3198 keV peak

- (1) Coincidence with 583 keV and 2614 keV gamma rays
- (2) 3198 keV gamma transition

# Experimental setup



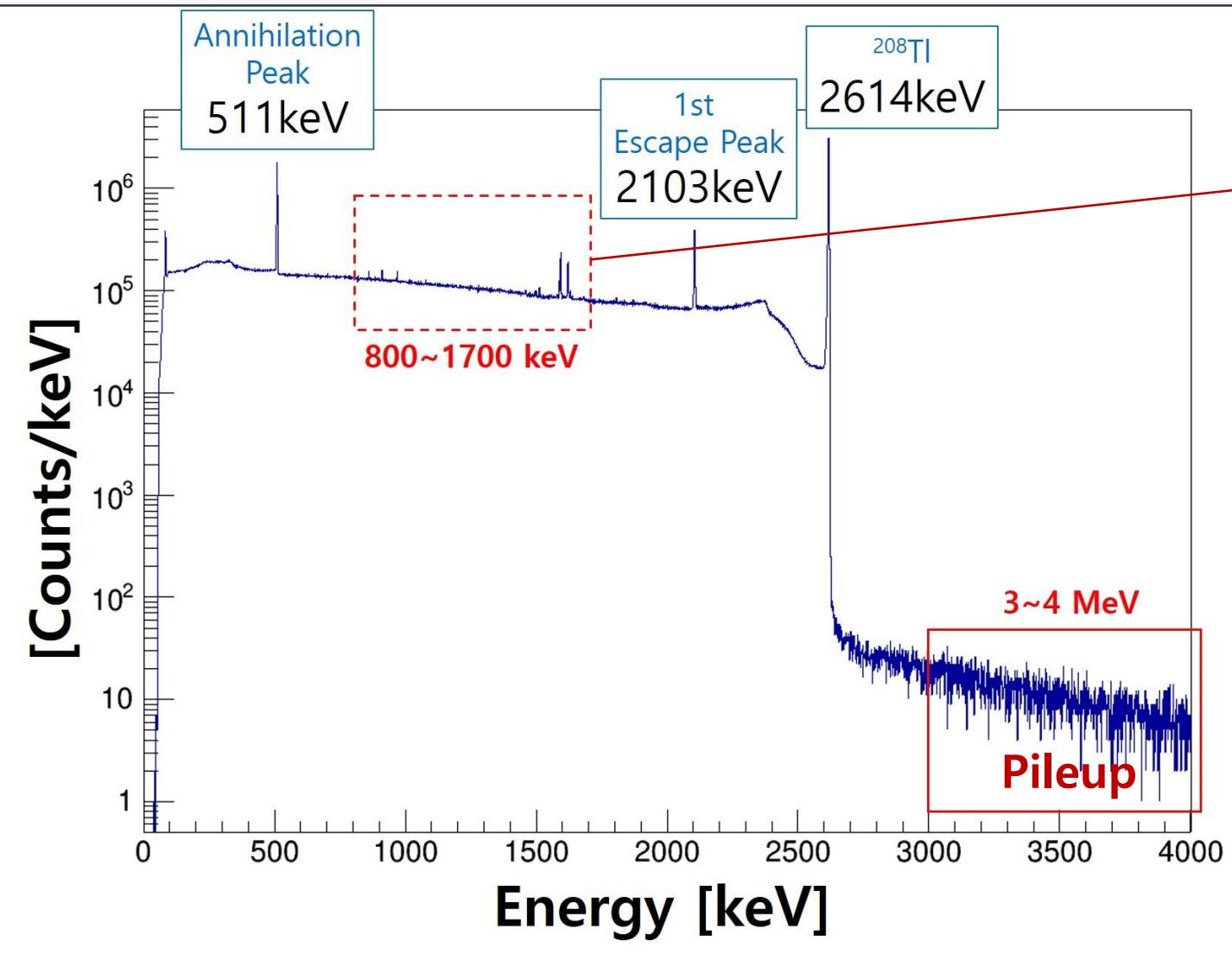
▲ [Electronics diagram]



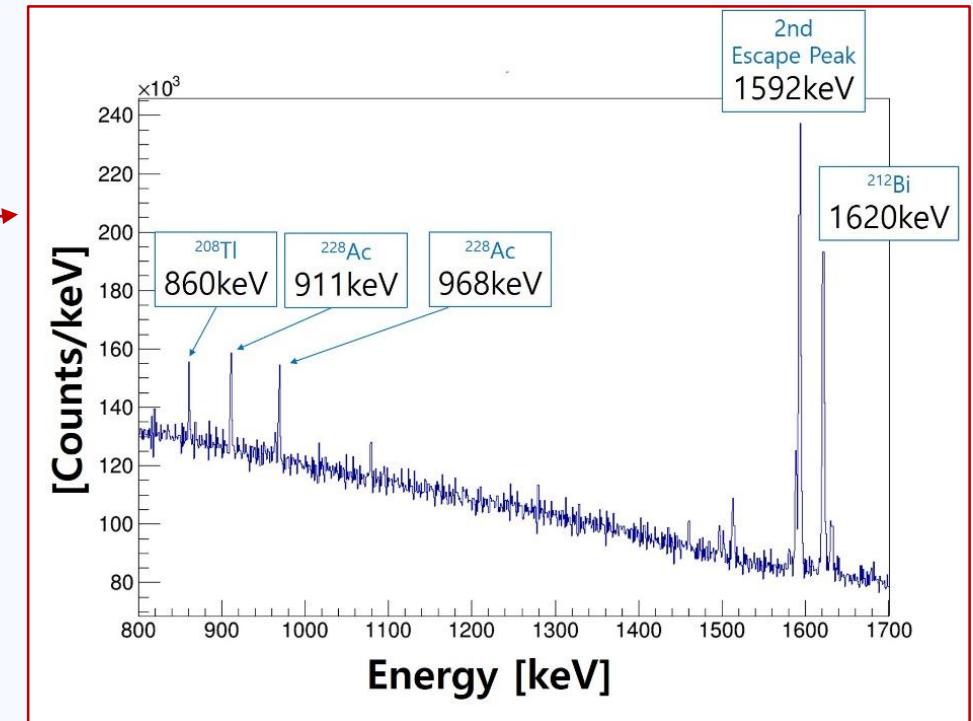
Sampling rate	25 Ms/s
Resolution	12 bit

▲ [FADC]

# Data analysis : Energy histogram (39.5 days)



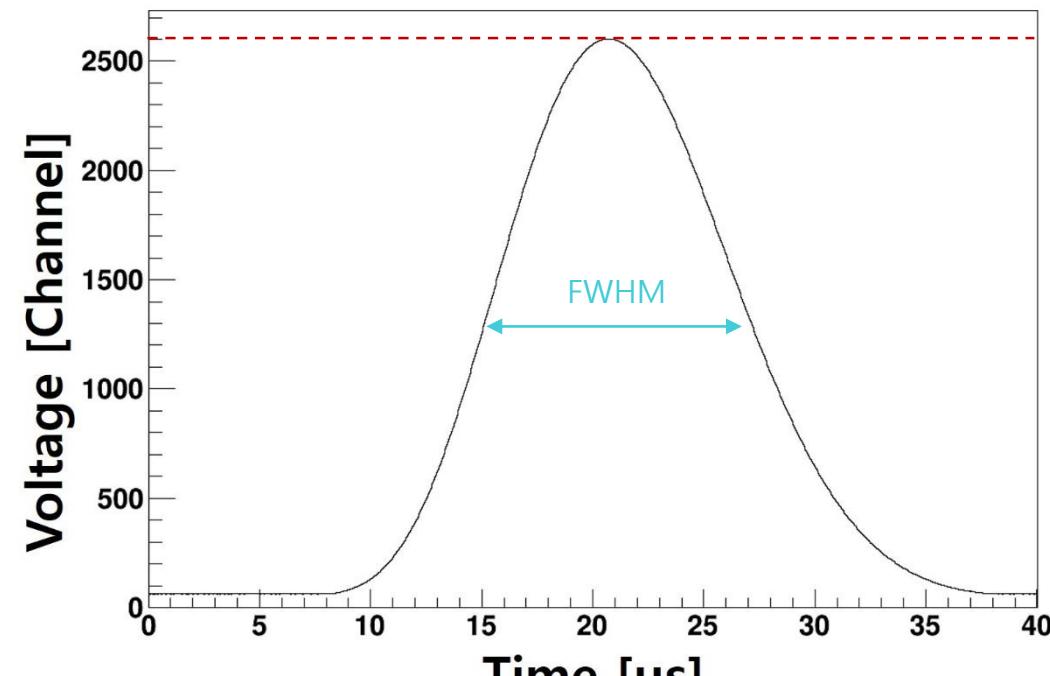
▲ [Energy histogram / 1keV bin]



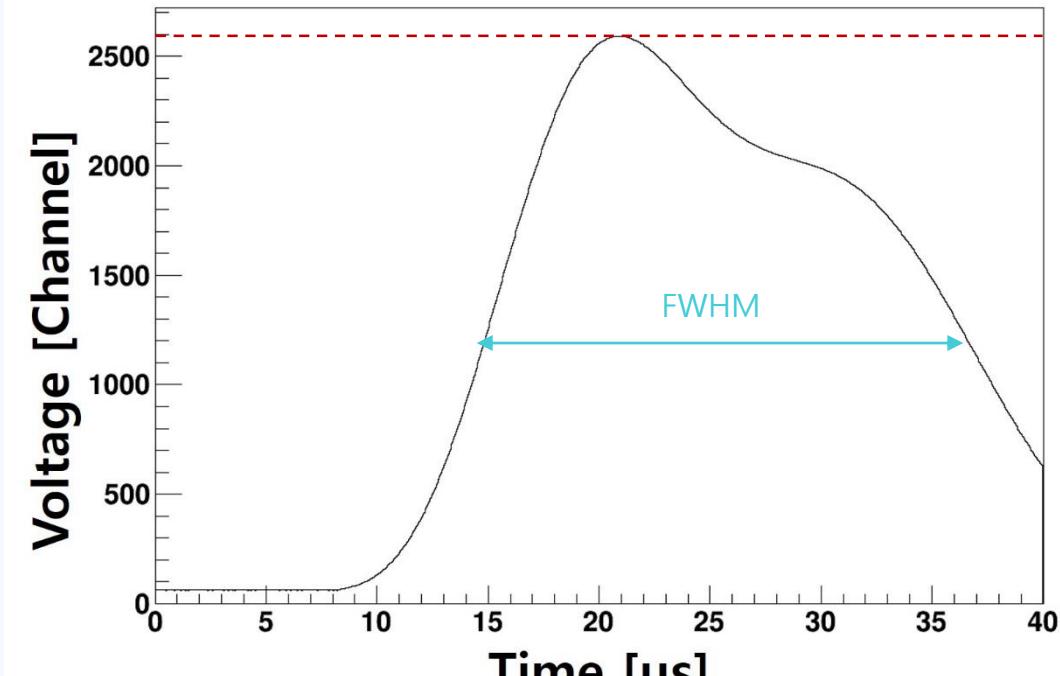
- Peaks with  $E < 600$  keV were not founded except 511 keV caused by 10cm lead.
- Pileup events make background at  $E > 3$  MeV regions

# Data analysis : Pileup rejection

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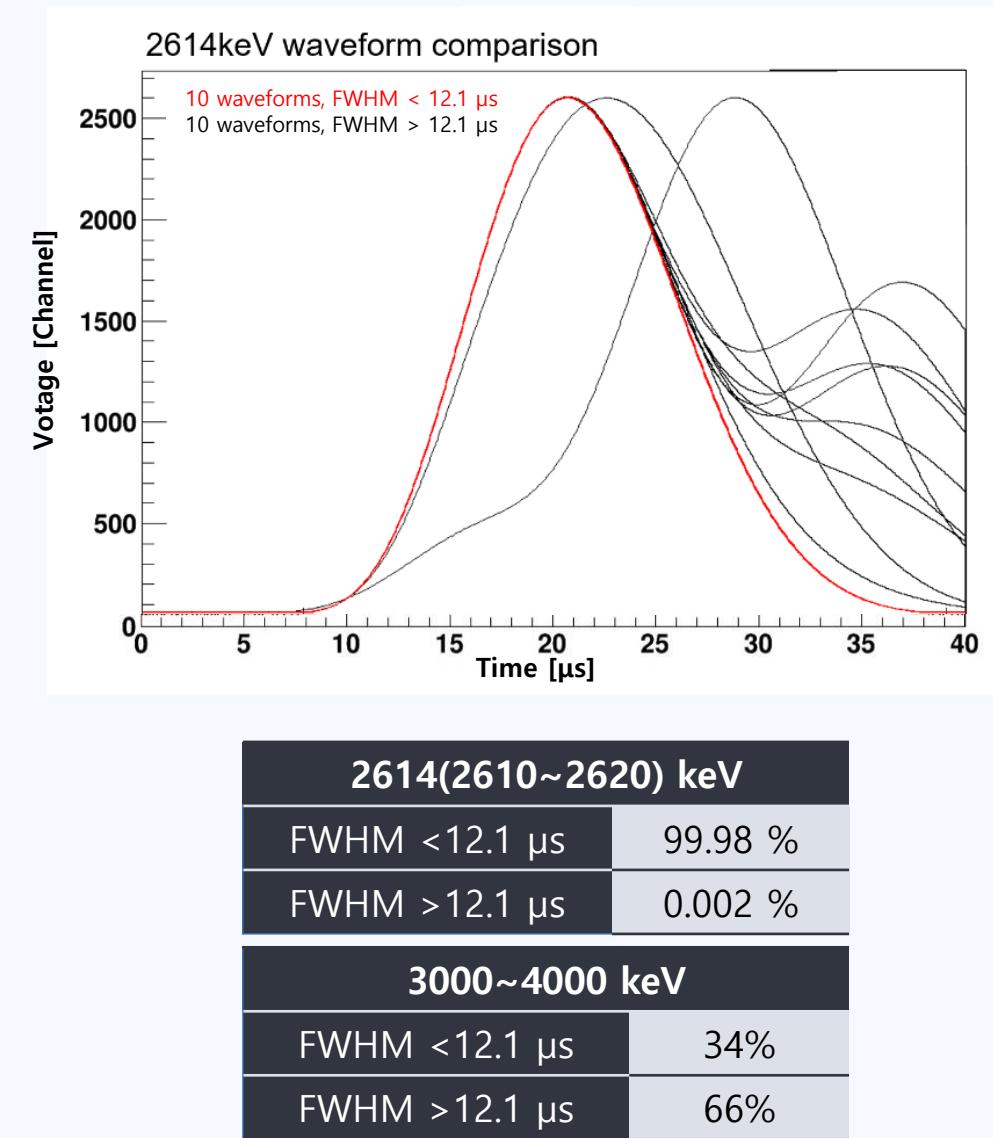
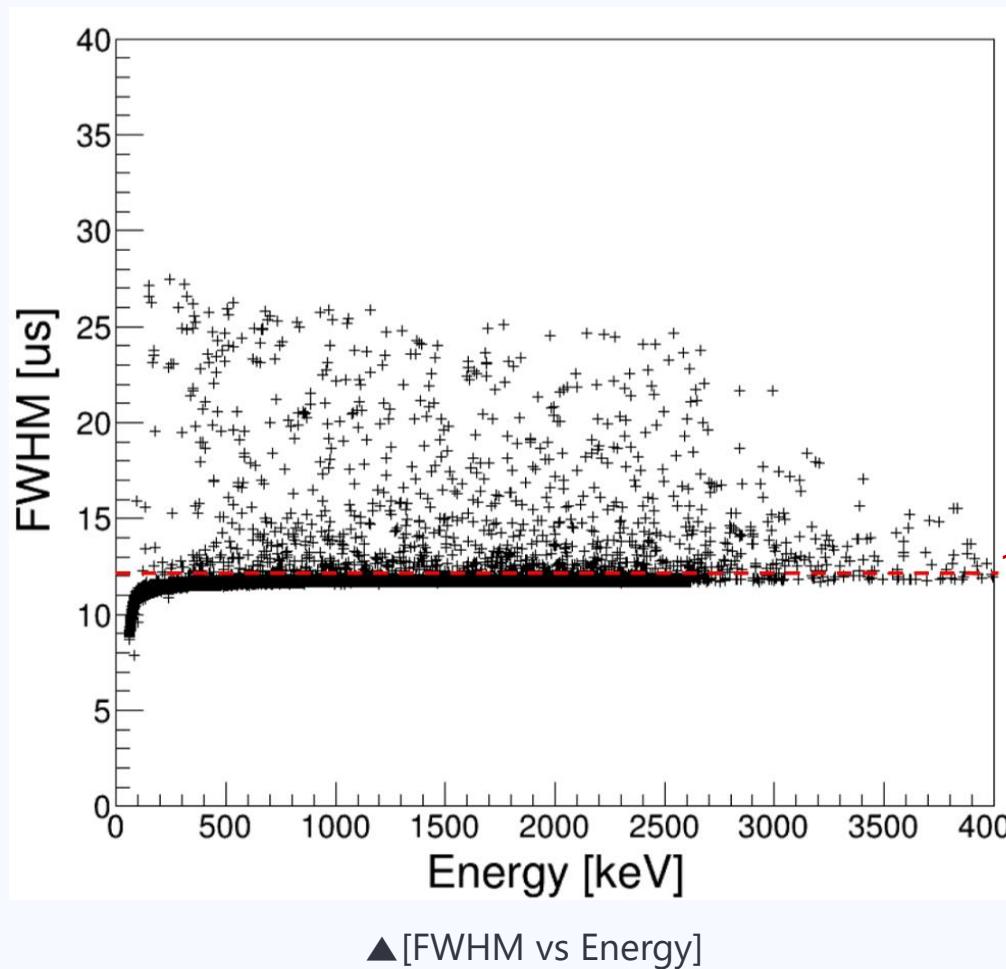


▲ [Normal waveform]



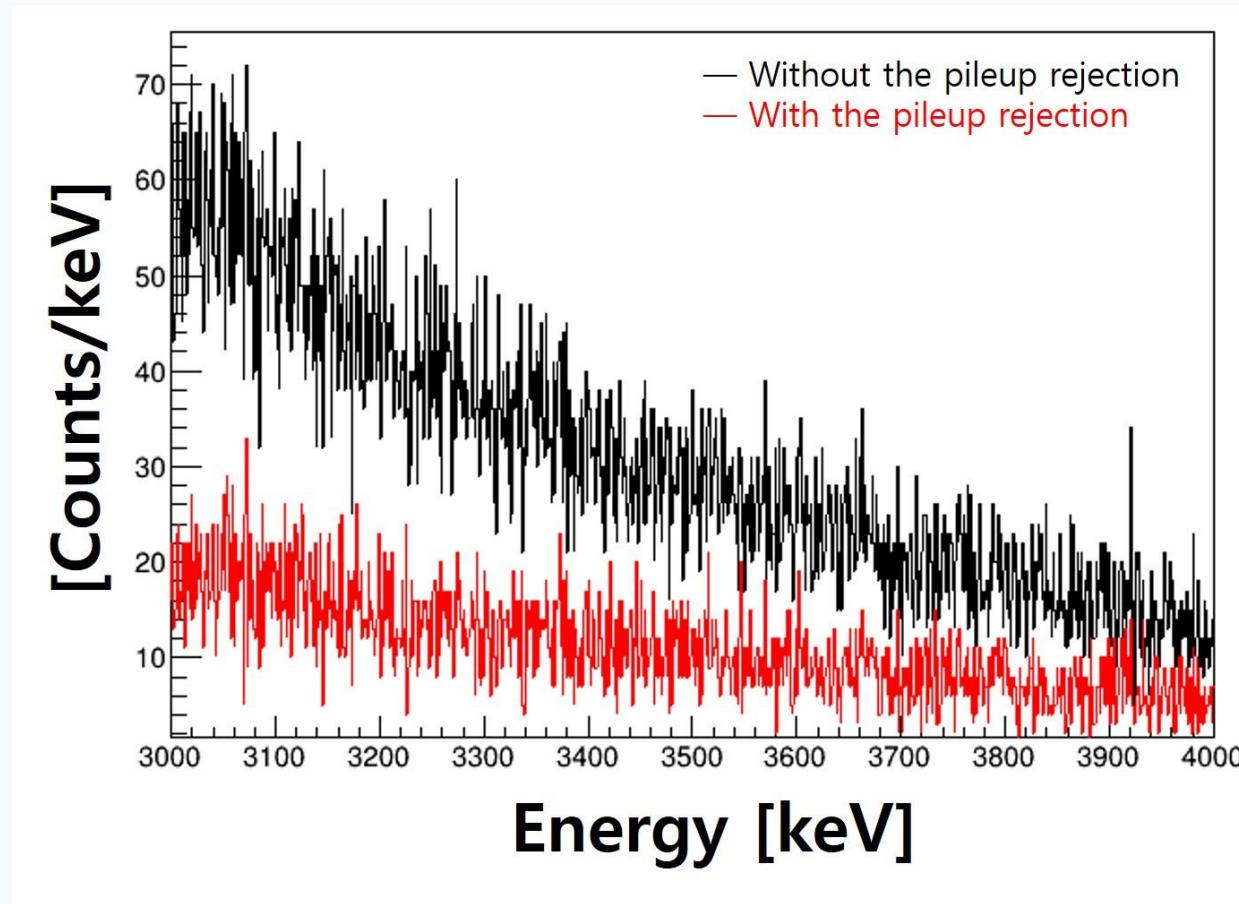
▲ [Pileup waveform]

# Data analysis : Pileup rejection



▲ [FWHM comparison between 2614 keV and pileup events]

# Data analysis : Pileup rejection

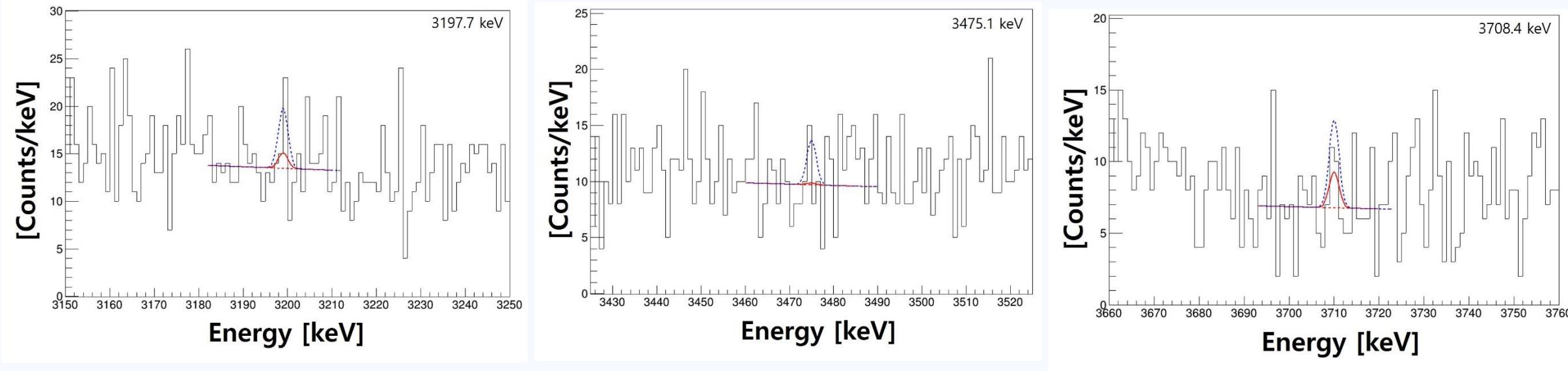


▲ [Energy spectrum in 3-4 MeV region]

- Cut condition for pileup rejection :  $\text{FWHM} < 12.1 \mu\text{s}$

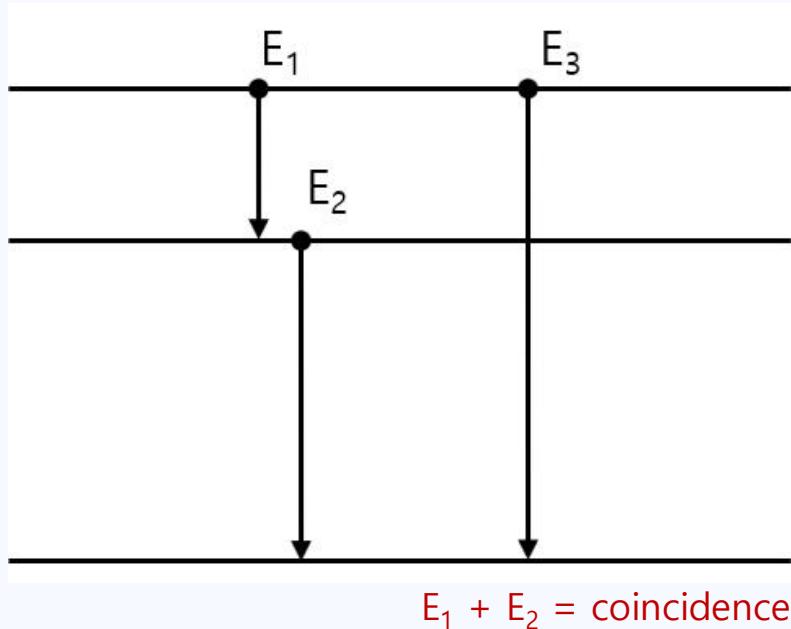
# Data analysis : Peak fitting

— Best-fit curve  
— Limit estimation curve (90% C.L.)



Energy (keV)	Count rate (CPD)
3198	< 0.38
3475	< 0.31
3708	< 0.33

# Result : Equation



Energy (keV)	Efficiency
861	1.80(18)E-07
2614	6.76(68)E-06
3198	5.95(60)E-06
3475	5.85(59)E-06
3708	5.40(54)E-06

$N_{3'} = E_3$  peak counts  
 $N_{decay} = \text{Total number of decay}$   
 $I_i = \text{transition intensity}$   
 $\varepsilon_i = \text{detection efficiency for } E_i \text{ peak}$

- Intensity calculation

$$N_{3'} = N_{decay} \times (I_3 \times \varepsilon_3) + I_1 \times \varepsilon_1 \times I_2 \times \varepsilon_2$$

E3 transition      E1+E2 coincidence

$$\rightarrow I_3 = \frac{1}{\varepsilon_3} \times \left( \frac{N_{3'}}{N_{decay}} \right)$$

- Calculation for  $^{208}\text{Tl}$  decay

$$N_{^{208}\text{Tl}} = \frac{N_{2615}}{\varepsilon_{2615} \times I_{2615}}$$

$$\rightarrow I_3 = \frac{N_{3'} \times \varepsilon_{2615} \times I_{2615}}{\varepsilon_3 \times N_{2615}}$$

# Result

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Energy (keV)	Intensity (%)	
	NNDC	This work
3198	< 7E-03	< 1.6E-04
3475	< 3E-03	< 1.3E-04
3708	< 4E-03	< 1.5E-04

- Current intensities are from the NNDC database. ([S. I. Vasil'ev \*et al\*](#))
- Our result are at least 20 times lower than current results.

# Discussion

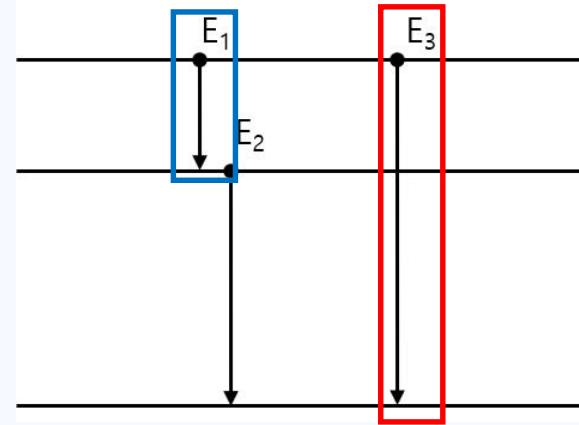
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$$B_{sp}(EL) = \frac{1.2^{2L}}{4\pi} \left( \frac{3}{L+3} \right)^2 A^{\frac{2L}{3}} e^2 fm^{2L}$$

$$B_{sp}(ML) = \frac{10}{\pi} 1.2^{2L-2} \left( \frac{3}{L+3} \right)^2 A^{2L-2} 2 \left( \frac{e\hbar}{2Mc} \right)^2 fm^{2L-2}$$

Multipolarity	Electric Transition Rate ( $s^{-1}$ )	Magnetic Transition Rate ( $s^{-1}$ )
1	$1.0 \times 10^{14} A^{2/3} E_\gamma^3$	$3.1 \times 10^{13} E_\gamma^3$
2	$7.3 \times 10^7 A^{4/3} E_\gamma^5$	$2.2 \times 10^7 A^{2/3} E_\gamma^5$
3	$3.4 \times 10^1 A^2 E_\gamma^7$	$1.0 \times 10^1 A^{4/3} E_\gamma^7$

▲ [Weiskopf Single-Particle Transition rate ( $\lambda$ )]



$$I_1 : I_3 = \lambda_1 : \lambda_3$$

I : intensity (%)  
 $\lambda$  : transition ratio ( $s^{-1}$ )

Energy (keV)	Decay Mode	Intensity (%)	
		Result	Theoretical estimation
3198	E5	< 1.6E-04	< 6.43E-07
3475	M4	< 1.3E-04	< 6.52E-10
3708	E5	< 1.5E-04	< 1.25E-12

## Summary

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- We measured 2kg ThO<sub>2</sub> powder using a single HPGe detector to identify **intensities for 3198 keV, 3475 keV, and 3708 keV gamma transitions** after the <sup>208</sup>Tl decay.
- We got a **new upper-limit** numbers for the three gamma intensities, and our result are at least 20 time lower than current results.
- With this improved upper-limit numbers, the zero-background experiments are not effected from the gamma transitions with  $E > 3$  MeV from the <sup>208</sup>Tl decay.

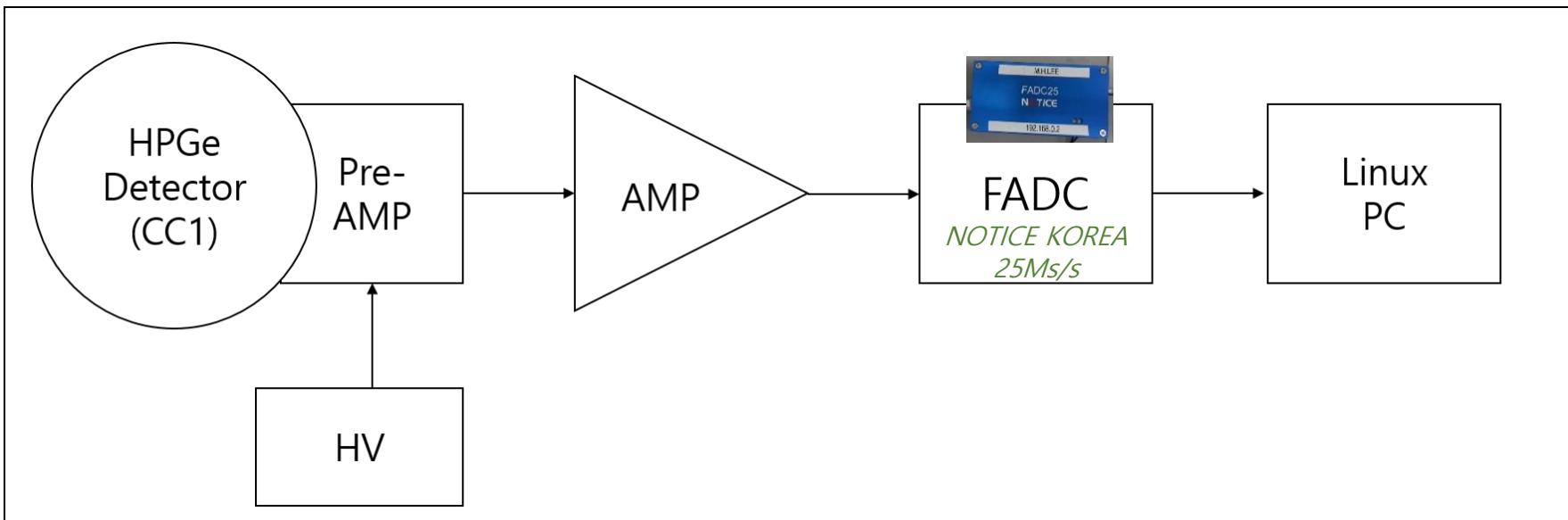
Energy (keV)	Intensity (%)		
	NNDC	This work	Theoretical estimation
3198	< 7E-03	< 1.6E-04	< 6.43E-07
3475	< 3E-03	< 1.3E-04	< 6.52E-10
3708	< 4E-03	< 1.5E-04	< 1.25E-12

# BACK UP

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# Experimental setup : equipment

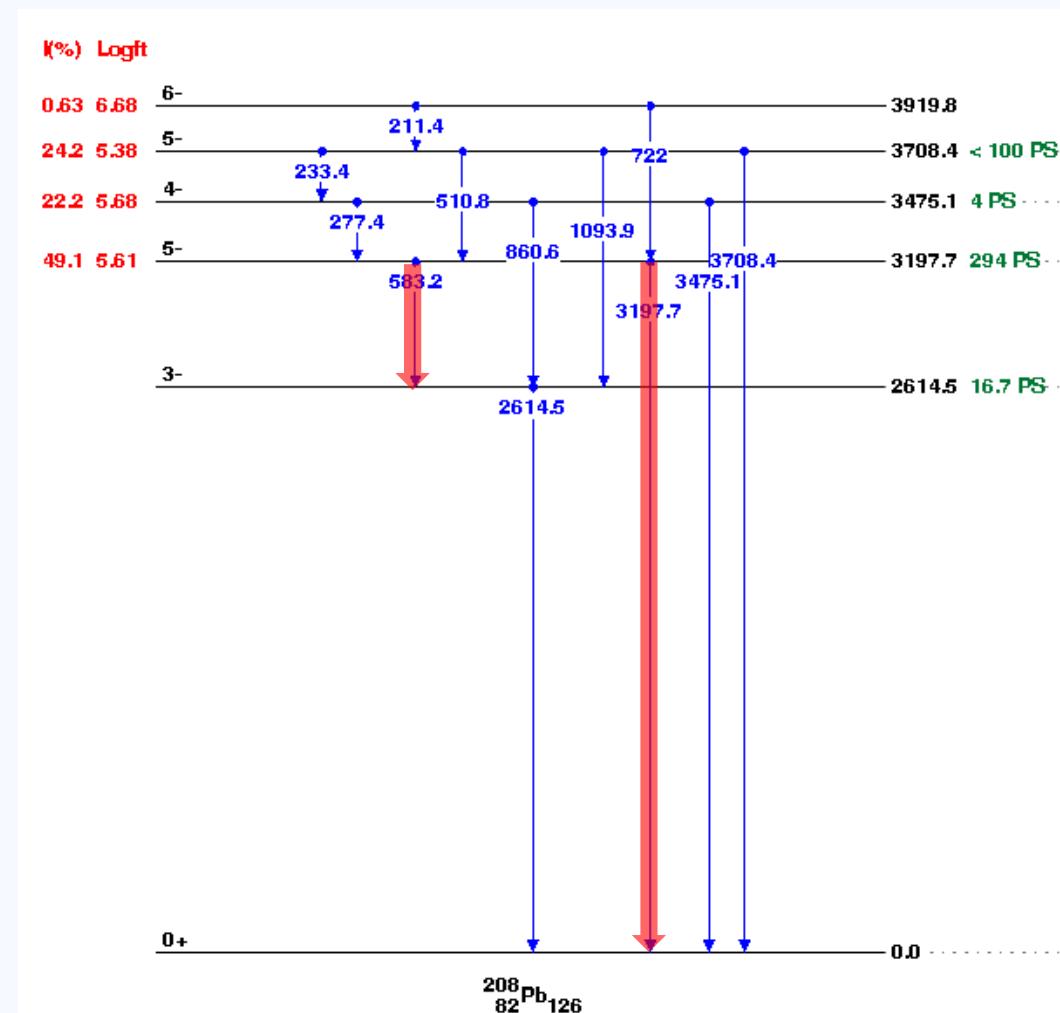
## Electronics & DAQ



	Company	Model name
HPGe det.(CC1)	CANBERRA	EPGC-100
HV	ORTEC	600 Dual 5kV Bias Supply
AMP	ORTEC	671 Amplifier
FADC	NOTIC	FADC25

Module name	FADC25
company	NOTICE
type	Flash ADC
Sampling rate	25 Ms/s
resolution	12 bit

# Theoretical consideration : 3198 keV



## (1) Theoretical transition rate ( $\lambda$ )

E(keV)	T-mode	W.Transition rates (s <sup>-1</sup> )
583	E2	6.04 E 09
3198	E5	4.57 E 01

## (2) Intensity comparison

$$I_1 : I_2 = \lambda_1 : \lambda_2$$

I : one of the ratio related to  $^{208}\text{Tl}$  decay

$\lambda$  : one of the ratio related to  
transition @ 3198 keV state

$$0.85 : I_x = 6.04\text{E}09 : 4.57\text{E}01$$

$$\rightarrow I_x = 6.43\text{E}-09$$

Intensity		
NNDC	Exp.	Theory
< 7.00E-05	< 1.59E-06	6.43E-09

## Data analysis : Detection efficiency

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Energy (keV)	Simulated efficiency	Measured efficiency
861	1.80(18)E-07	2.11(14)E-07
1621	4.00(40)E-06	4.77(30)E-06
2614	6.76(68)E-06	6.92(44)E-06
3198	5.95(60)E-06	-
3475	5.85(59)E-06	-
3708	5.40(54)E-06	-

- $^{228}\text{Th}$  activity of the sample was measured independently.
- Data are compared with GEANT4 simulation.
- The simulation and data agree well.
- Simulated efficiencies for 3198, 3475, and 3708 keV gamma rays are justified.