DAQ optimization, signal processing and simulations for an ultra low background HPGe detectors Array

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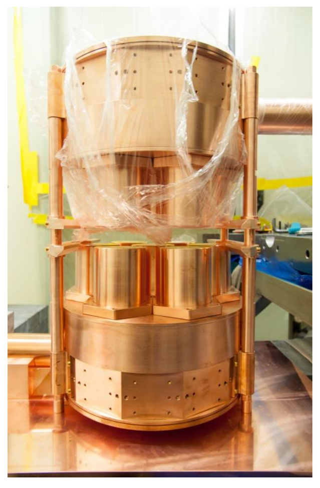
ARRAY : An array of 14 HPGe detectors

An array of 14 HPGe detectors (ARRAY) at Y2L

[ARRAY]



- The Center for Underground Physics(CUP), IBS has developed in collaboration with CANBERRA an array of 14 HPGe detectors (ARRAY).
- The ARRAY is composed of top and bottom arrays facing each other and each array has 7 p-type coaxial HPGe detectors.
- The main purpose of the ARRAY is to do a **rare decay search** by measuring gamma-rays. Tantalum is one of the candidate isotopes since ^{180m}Ta decay has never been observed to date.

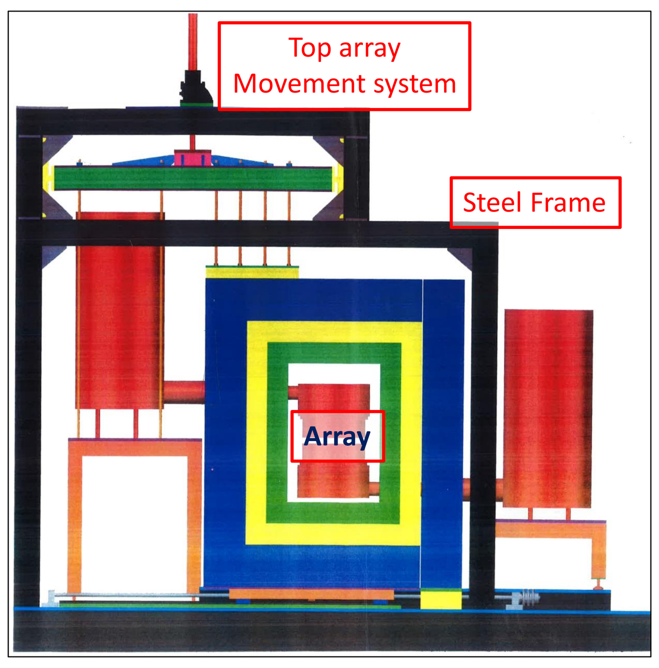
Shielding system

- Component

	layer	Material	Thickness
Inside	1st	Copper	10 cm
↓	2nd	Goslar lead	10 cm
Outside	3rd	Lead	20 cm

- This shielding has 2 side doors which can be opened and closed with a motor system .
- Top array can be moved for sample replacement in the detector. The gap between top and bottom arrays can be adjusted between 2.5 cm and 7.5 cm.

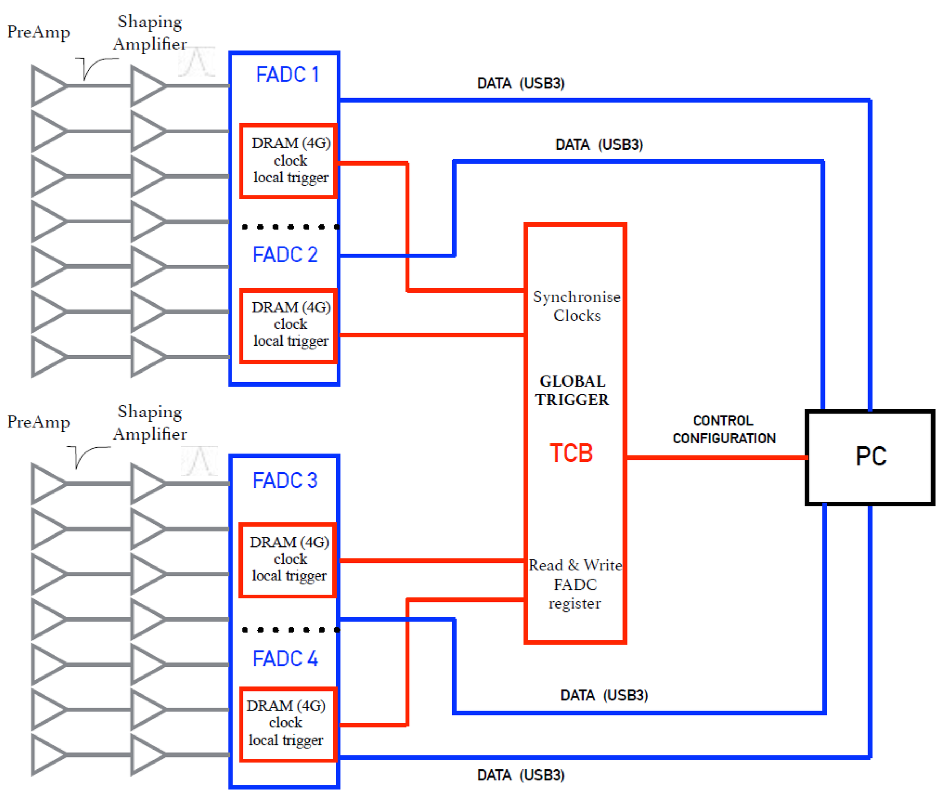
▼[Shielding structure]



DAQ system

- FADC 500 from NOTICE Korea
  - Sampling rate : 500 Ms/s (Max),
  - 12 bit resolution
  - 2.5V dynamic range
  - 4 channels in a FADC module
- Specific FADC setting for the ARRAY
  - 64.5 Ms/s sampling rate
  - Time window of a wave form: 64 µs

▼[FADC and TCB]



Status and Plan

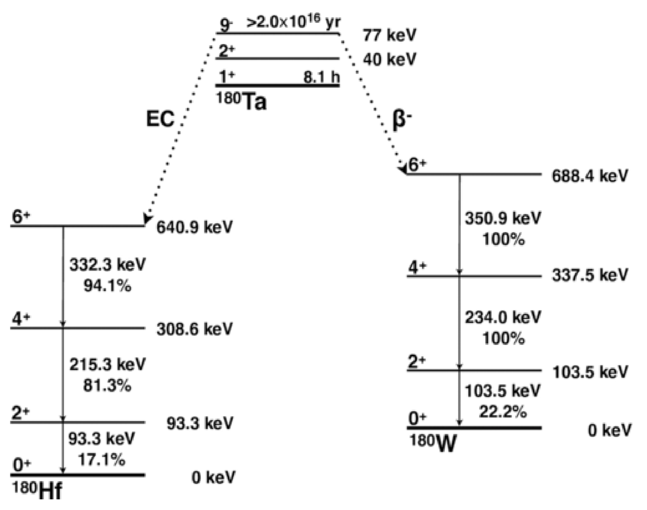
- The ARRAY is currently running in a background mode for about 2 months.
- Future run plan
  - MoO_3 powder for the AMoRE experiment, Tantalum disk to search for a ^{180m}Ta decay

Monte Carlo simulation for ^{180m}Ta

Geant4 Simulation

- It is impossible to simulate isotopes decay modes in Geant4 simulation tool since there are no libraries of the ^{180m}Ta decay. 3 coincident gamma rays are from both of electron capture(EC) and beta- decay(B-). In this simulation, only 2 gammas over 100keV are considered.
- Particle generation
  - 1 million random events from sample volume
  - 1 event has 2 gammas
    - case 1 (EC) : 332.3 & 215.3 keV gammas
    - case 2 (B-): 350.9 & 234.0 keV gammas
  - This poster only reports the case 1(EC) simulation result.

▼[Decay schema of ^{180}Ta][1]

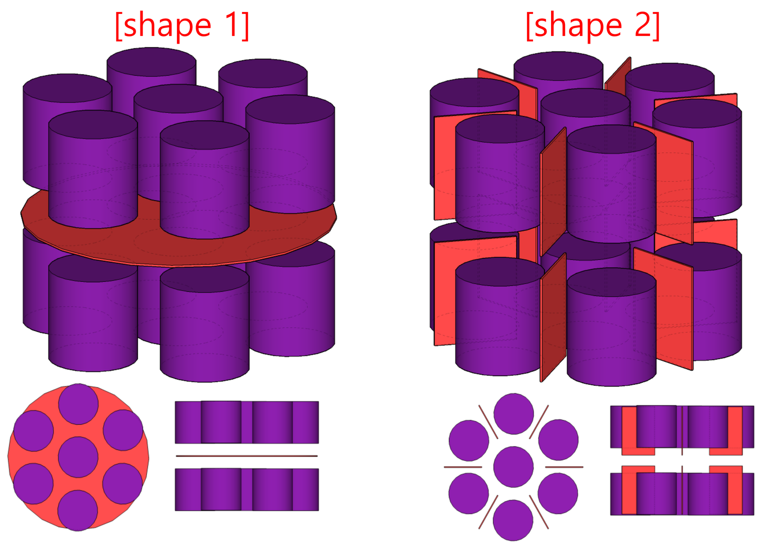


- Sample shape
  The lower limit of the half-life of the ^{180m}Ta is 4.5x10^{16}yr[1] and the space for the measurement sample is limited. It is important to find the best shape of the tantalum sample for high efficiency. Here are candidate shapes for the tantalum measurement.

[Candidate sample shapes]

No.	Shape	Size
1	1 disk	R 15cm, H 0.2cm
2	12 square boards	8 X 10 X 0.2cm (12)
1+2	1 disk + 12 square boards	- R 15cm, H 0.2cm - 8 X 10 X 0.2cm (12)

[shape 1] [shape 2]



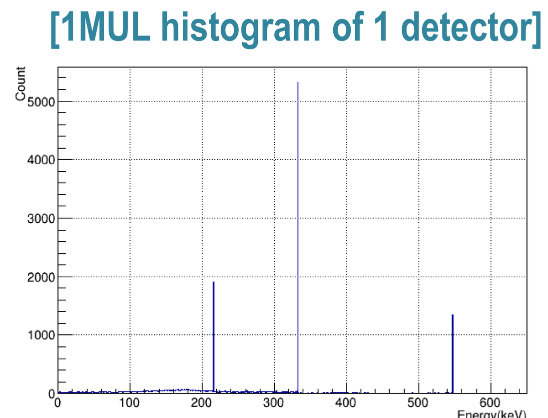
1MUL(Multiplicity) event detection

- Efficiency(Eff)* and expected event counts(N)**

Shape	Volume (cm^3)	Mass (kg)	1MUL events	215kev	332kev	548kev
			Eff (%)	Eff (%)	Eff (%)	Eff (%)
1	141.4	2.36	23.9	2.34	5.93	1.58
2	192.0	3.20	21.9	2.09	5.40	1.47
1+2	333.3	5.56	20.1	1.92	5.03	1.33

Shape	N (counts/yr)*		
	215kev	332kev	548kev
1	340	861	229
2	412	1064	290
1+2	657	1721	456

[1MUL histogram of 1 detector]



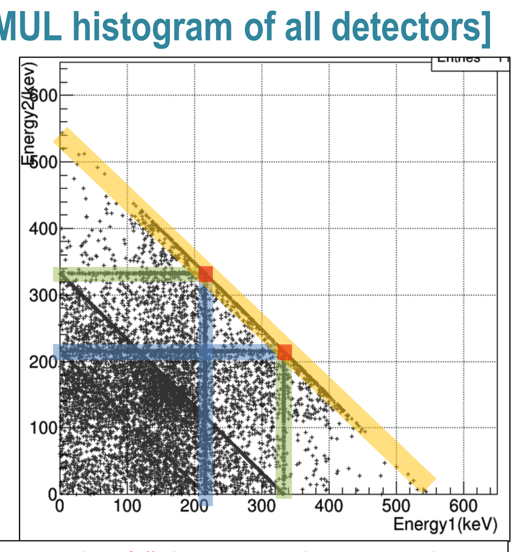
2MUL(Multiplicity) event detection

- Efficiency(Eff)* and expected event counts(N)**

Shape	Volume (cm3)	Mass (kg)	2MUL events	P1	P2	P3	P4
			Eff (%)	Eff (%)	Eff (%)	Eff (%)	Eff (%)
1	141.4	2.36	1.17	0.022	0.080	0.170	0.108
2	192.0	3.20	0.93	0.013	0.063	0.118	0.074
1+2	333.3	5.56	0.47	0.008	0.029	0.064	0.039

Shape	N2 (counts/yr)			
	P1	P2	P3	P4
1	3.2	11.6	24.7	15.7
2	2.6	12.4	23.3	14.6
1+2	2.7	9.9	21.9	13.3

[2MUL histogram of all detectors]



- P1 detection distribution

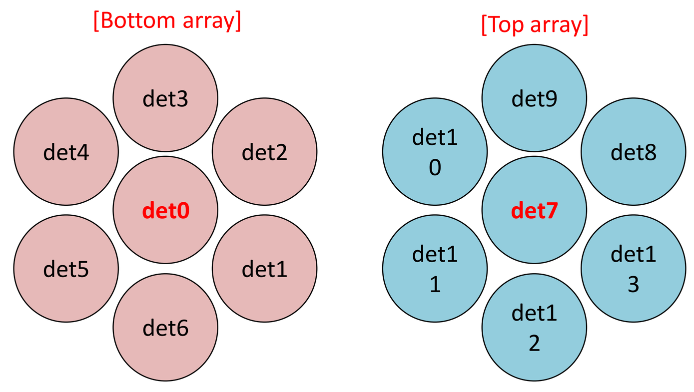
Shape 1

P1 event		0	1	2	3	4	5	6	7	8	9	10	11	12	13	
		Bottom Det.							Top Det.							
B Det.	0		12	13	8	7	9	9								58
	1	12		7				6								25
	2	13	7		10											30
	⋮															
T Det.	7				1					10	3	11	10	10	10	55
	8								10		6	1	1		12	30
	⋮															

Shape 2

P1 event		0	1	2	3	4	5	6	7	8	9	10	11	12	13	
		Bottom Det.							Top Det.							
B Det.	0		2	1	2	1	2	2	1	2		1	1		1	16
	1	2		3				2		1			1	1	9	19
	2	1	3		3					12	1				1	21
	⋮															
T Det.	7	1	0			1	1			1	4	2	1	2	2	15
	8	2	1	12		1			1		4					21
	9			1	12	1			4	4		3				25
	⋮															

[Detector number and location]



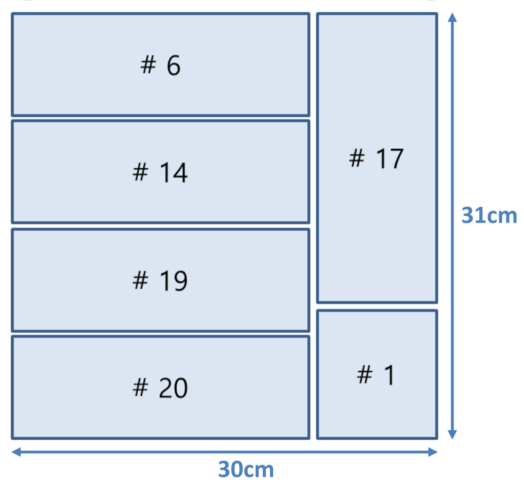
Summary and Plan

- In case of 1MUL event detection, the efficiency of 'shape 1' is the highest of three cases. But the best expected count number is 'shape 1+2' because of its biggest mass.
- In case of 2MUL, the efficiency of 'shape 1' is also higher than the other cases. But 'shape 1+2' is not the best expected event counts. As shown in the P1 detection distribution table, there are almost no back to back events. It is very difficult for the gammas to pass through 2mm sample since Ta density is very high(16.69g/cm^3) and the gammas have low energies. It means that the very effective factors are the surface area and thickness of the sample.
- The 2MUL event detection is important for a ^{180m}Ta decay study since it studies the coincidence event. 'shape 1' is the best sample shape among the three cases from a simulation result. An additional simulation will be start with (1)same shapes but more thinner one and (2)different shape for more high efficiency.

A Monte Carlo simulation of MoO_3 powder

- MoO_3 powders for growing crystals are very important materials for the AMoRE experiment. ^{238}U and ^{40}K levels of this powder already was measured by a single HPGe detector(CC1) at Y2L but ^{232}Th level with only a limit (<1.0mBq/kg). The ARRAY will be used to obtain more accurate number of the ^{232}Th level.
- Sample shape
  There are many clean vinyl MoO_3 powder bags, and 6 samples (#1, 6, 14, 17, 19, 20) are selected. These samples all have the same thickness(25mm) and will make a big box shape with an acrylic supporter. Combined sample size is 30 x 31 x 2.5cm with a mass of 3.9 kg.

[Candidate sample shape]



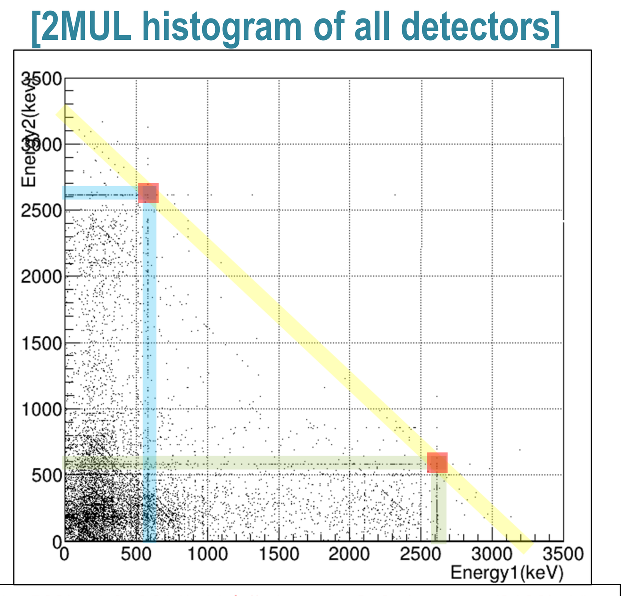
^{232}Th Efficiency*

Isotopes		Peak (keV)	Efficiency (%) w/o acrylic	w/ 1mm acrylic	w/ 2mm acrylic	CC1 1.6kg
^{232}Th	^{228}Ac	911	5.8	5.8	5.4	3.1
		968	6.0	5.5	5.3	3.0
	^{212}Pb	238	9.9	9.7	9.7	5.7
	^{212}Bi	727	7.2	6.8	7.5	3.6
	^{208}Tl	2614	2.1	2.0	2.0	1.6
		583	4.6	4.7	4.5	4.0
		860	4.4	4.7	4.5	3.2

Coincidence event (583 & 2614 keV) Efficiency*

case	Coincidence efficiency (%) w/o acrylic	w/ 1mm acrylic	w/ 2mm acrylic
P1	0.16	0.13	0.13
P2	0.19	0.14	0.14
P3	1.05	0.91	0.97
P4	1.93	1.90	1.80

[2MUL histogram of all detectors]



Summary and Plan

- The single HPGe detector(CC1) can measure only about 1.6 kg at once. The measurement MoO3 with ARRAY can get more accurate ^{232}Th level because (1)It can be mounted 3.9kg sample and (2)efficiency is little higher than CC1. And ARRAY has another useful number which is the coincidence event of ^{208}Tl. We expect to get more accurate ^{232}Th level of the MoO_3 powder.
- The acrylic supporter thickness is not so much affecting the efficiency number but It seems better to be as thin as possible. MoO_3 powder measurement will be start after ARRAY background measurement for 2 months.

***Efficiency : detected events in range(±1 keV error range) /total generated events**

****Calculation of expected event counts (ex :^{180m}Ta)**

$$-\frac{dN}{dt} = \lambda N = A[Bq]$$

$$\lambda = \frac{\ln 2}{T_{1/2}}$$

$$M_A = \frac{N}{N_A}[mol] \times m[g/mol]$$

$$a[Bq/g] = \frac{\lambda N}{M_A} = \frac{\lambda N_A}{m}$$

$$a[counts/kg \cdot yr] = \frac{\ln 2 \times N_A}{T_{1/2} \times m}$$

- T1/2 = 4.5E+16 [yr]
- NA = 6.022E+23 [/mol]
- m = 181[g/mol]
  → **NA of ^{180m}Ta = 0.012 %**
  → **m' = 0.0217 [g/mol]**

λ = decay constant
$T_{1/2}$ = half life
N_A = Avogadro's constant
m = mass number
M_A = mass of the radionuclide
NA = natural abundance
A = activity
a = specific activity

$$a = \frac{\ln 2 \times N_A}{T_{1/2} \times m'} = \frac{0.693 \times 6.022 \times 10^{23}}{4.5 \times 10^{16} \times 0.0217} \simeq 6.15 \times 10^3 [counts/kg \cdot yr]$$

$$N[counts/yr] = a[counts/yr \cdot kg] \times Mass[kg] \times efficiency$$

[1] B.Lehnert ec al. Phys. Rev. C 95, 044306 (2017)