Center for Underground Physics

An Ultra-Low Radioactivity Measurement HPGe (High Purity Germanium) Facility at the Center for Underground Physics

MooHyun Lee

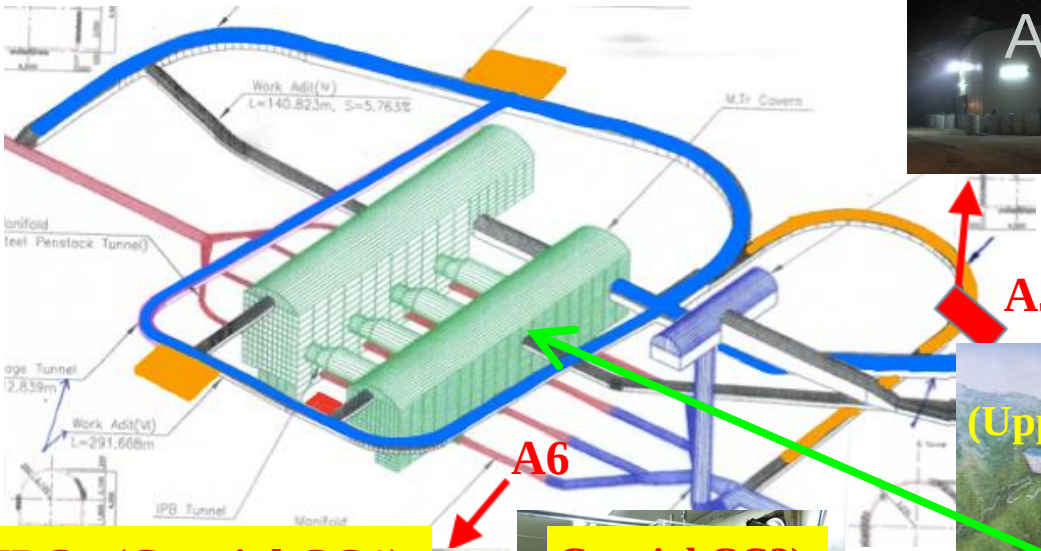
Center for Underground Physics (CUP)
Institute for Basic Science (IBS)
Daejeon, Korea

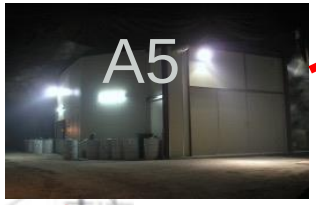
2018.7.6

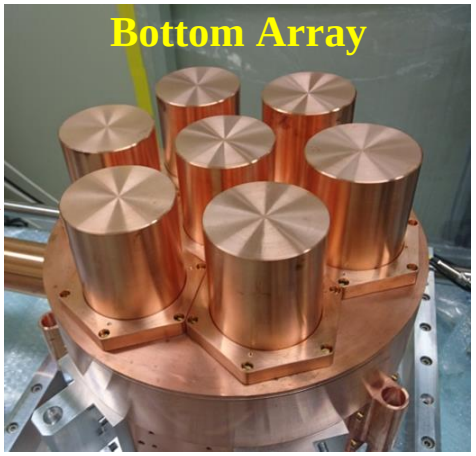
ICHEP 2018, COEX, Seoul, Korea

HPGe facility at Yangyang Underground Lab (Y2L)

- Two HPGe detectors (Coaxial type) at A6
- An array of 14 HPGe detectors at A5







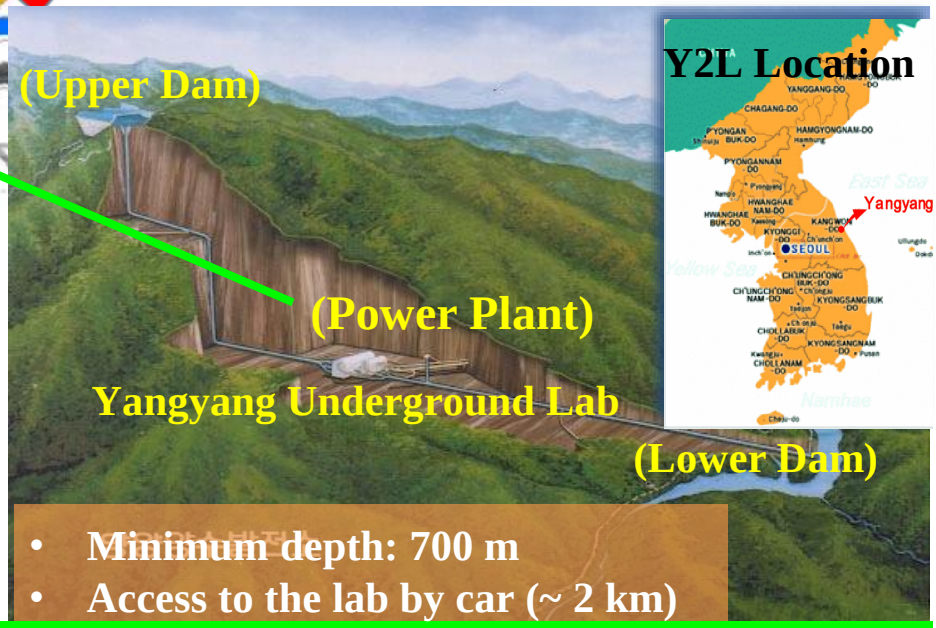
Please visit IBS CUP booth #1!

A5

A6

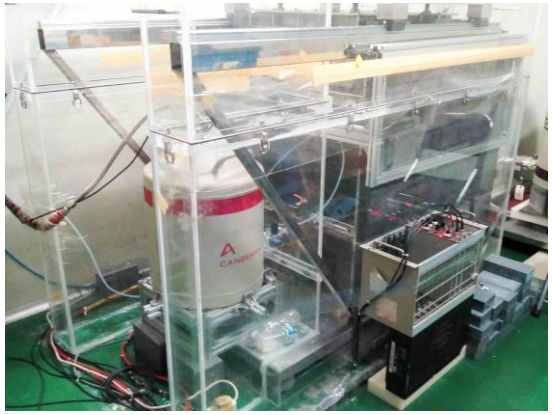
HPGe (Coaxial CC1)

Coaxial CC2)



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

Two single HPGe detectors: Screening of raw materials

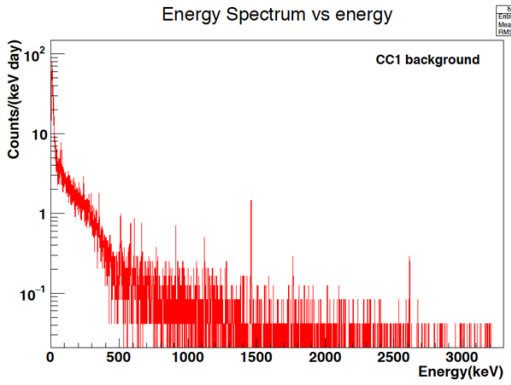


CC1: 100% HPGe CANBERRA

Dedicated shielding:
- Top & bottom 10 cm Pb + 10 cm Cu (inner)
- Side 15 cm Pb + 10 cm Cu (inner)

IMPROVED using 5 cm thick ancient Pb closer to the detector

Total count rate: 6.9 mHz @ 50 – 3200 keV



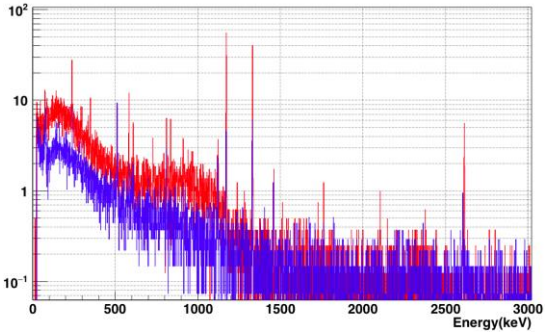
P-709 EunKyung Lee's poster

CC2: 100% HPGe CANBERRA

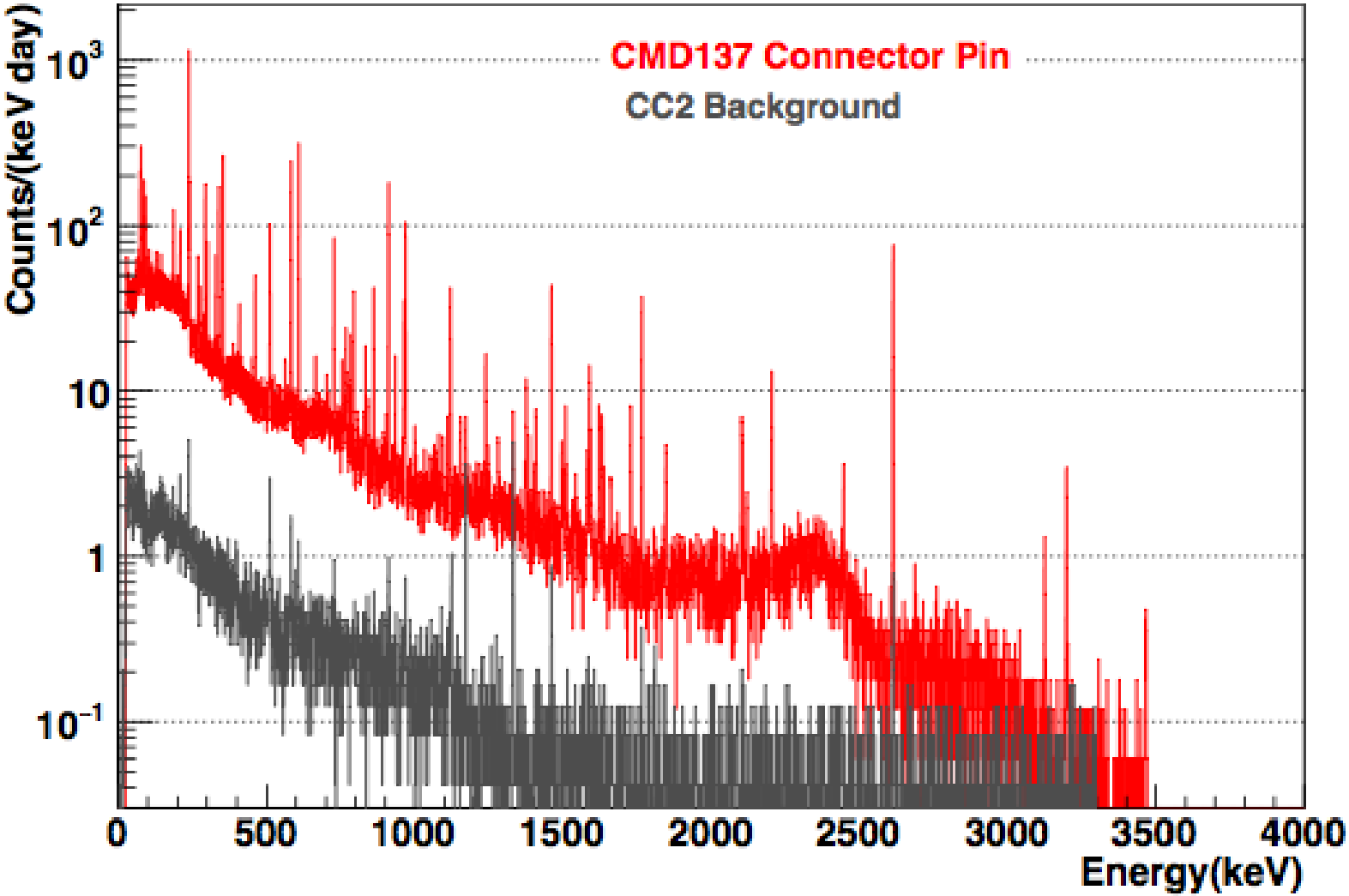
Dedicated shielding:
- General Pb (10 cm) + Goslar Pb (10 cm) + Cu (10 cm)

IMPROVED by installing acrylic globe box for preventing Radon contamination

Total count rate: 8.2 mHz @ 50 – 3200 keV



CC2 spectrum of a pin connector (CMD137)



AMoRE-pilot LT detector component
Replaced in the current setup.

CC2: CMD137 Pin connector test summary

Center for Underground Physics

238U	40K	228Ac	228Th
1.94 +/- 0.39 Bq/kg	3.70 +/- 0.75 Bq/kg	3.56 +/- 0.71 Bq/kg	3.1 +/- 0.62 Bq/kg

Mass : 119g M. day : 9.5day

Nucleus		Peak (keV)	G	Eff	sample cpd	sample dcpd	back ground cpd	back ground dcpd	A(mBq/kg)	dA	Distribution A/dA	Detection limit (90% C.L.)	weighted mean dA	weighted mean A	error
238U	226Ra	186	0.0364	19.82	126.33	5.56	0.00	0.00	1702.90	74.88	22.74	1825.70	74.9	**1702.9**	**348.7**
	214Pb	352	0.3560	7.92	568.62	8.22	0.91	0.35	1958.34	28.37	69.02	2004.87	17.6	**1938.4**	**388.1**
		295	0.1842	9.28	315.29	6.50	0.65	0.34	1790.03	37.01	48.37	1850.73			
	214Bi	609	0.4945	4.04	434.96	7.15	1.30	0.36	2109.65	34.81	60.61	2166.73			
		1764	0.1530	2.95	85.29	3.15	0.44	0.16	1830.78	68.15	26.86	1942.54			
		1120	0.1492	3.26	88.71	3.51	0.27	0.23	1767.90	70.31	25.14	1883.22			
40K		1460	0.1066	2.97	122.51	3.86	2.02	0.34	3701.25	118.89	31.13	3896.23	118.9	**3701.2**	**749.7**
232Th	228Ac	911	0.2580	4.00	369.97	6.54	2.24	0.37	3469.09	61.76	56.17	3570.37	50.4	**3559.2**	**713.6**
		968	0.1580	3.52	215.25	4.99	1.28	0.29	3739.78	87.39	42.79	3883.10			
	212Pb	238	0.4330	9.92	1318.64	12.40	7.60	0.77	2967.72	28.13	105.49	3013.86	23.2	**3099.6**	**620.4**
	212Bi	727	0.0659	5.48	116.00	4.32	0.71	0.28	3105.19	116.73	26.60	3296.63			
	208Tl	2614	0.3591	1.63	205.77	4.73	1.94	0.33	3393.10	78.88	43.02	3522.47			
		583	0.3060	4.31	462.63	7.40	2.46	0.42	3394.34	54.67	62.08	3484.01			
		860	0.0447	3.56	63.69	3.19	0.10	0.22	3882.33	195.17	19.89	4202.42			

CC1 sample test list (2017)

Center for Underground Physics

2017 Data list - HPGe detector

File Edit View Insert Format Data Tools Add-ons Help All changes saved in Drive

=E36-D36

CMD #	sample #	data file name	Start date	Stop date	period (days)	Count rate > 50keV	Mass (kg)	projects	file number	analysis result	updated	note
102	2	170104-moo3-sublimation-720deg	1/4	1/16	12	0.0385	0.5	Crystal	000~056			
102	3	170117-CMD00102C-moo3	1/17	2/10	24	0.014	0.432	Crystal	000~113			
111	1	170210-CMD00111-LMO	2/10	2/23	13	0.0117	0.438	Crystal, AMoRE	000~056			
111	1	170224-TEST-LMO	2/24	3/3	7	0.0118	0.438	Crystal	000~026			
104		170303_Ta_CMD104	3/3	3/21	18	0.0275	0.675	HPGe	000~085			
125		170321_Ta_CMD125	3/21	4/4	14	0.0313	0.658	HPGe	000~064			
126		170404-MoO3_CMD126	4/4	4/13	9	0.0328	1.136	Crystal	000~042			
126		170413-MoO3_CMD126	4/13	4/27	14	0.0275	1.136	Crystal	000~066			
124		170427-CMO_CMD124	4/27	5/19	22	0.0125	0.592	Crystal,AMoRE	000~104			
Background	w neutron	170519_CC1BG	5/19	6/1	13	0.0119		HPGe	000~060			
Background	w/o n	170601_CC1BG	6/1	6/8	7	0.0102		HPGe	000~033			
Background	w/o n	170609-CC1BG	6/9	6/26	17	0.0081		HPGe	000~080			
132		170626-CMD132_Na2Mo2O7Cry	6/26	7/12	16	0.0089	0.364	Crystal,AMoRE	000~075			
123		170713-CMD123-phosphor-bronze-spring	7/13	7/19	6	0.0351	2	AMoRE	000~026			
123		170721-CMD123-phosphor-bronze-spring	7/21	8/10	20	0.0343	2	AMoRE	000~095			
136		170810-CMD136_PCB	8/10	8/16	6	0.0329	0.106	AMoRE	000~026			
148		170816-CMD148_RefractoryPowder	8/16	8/16	0.2	1.3327	2.756	Crystal	1			
165	1kg	170816_ThO2Powder_1kg	8/16	8/16	0.2	705.3991	1	HPGe	1			5cm Pb block
165	1kg	170816_ThO2Powder	8/16	8/17	1	54.5734	1	HPGe	000~044			0~3.2MeV energy range
165	1kg	170817_ThO2Powder	8/17	9/5	19	53.632	1	HPGe	000~915			0~4 MeV energy range
Background		170906-CC1BG	9/6	9/11	5			HPGe	000~022			10cm Pb Shield
151	1	170911-CMD151a_RefracProduct	9/11	9/13	2	0.1709	0.223	Crystal	000~008			
151	2	170913-CMD151b_RefracProduct	9/13	9/14	1	0.1549	0.224	Crystal	000~003			
155	w sensor	170914-CMD155_squid	9/14	9/21	7	0.0089	0.00022	AMoRE	000~032			
155	case only	170921-CMD155_squid_case	9/21	9/29	8	0.0083	0.00022	AMoRE	000~036			
165	2kg	170929_ThO2powder_2kg	9/29	9/29	0.1	88	2	HPGe	1			gammavision
172	1	171122-CMD172_KA_0138_8inchPMT	11/22	11/24	2	0.1065		LZ	000~007			KA-0138
172	1-down	171127-CMD172_Down_KA_0138_8inchPMT	11/27	12/1	4	0.2179		LZ	000~016			KA-0138 Downward
172	2	171201-CMD172_KA_0157_8inchPMT	12/1	12/4	3	0.1086	?	LZ	000~008			KA-0157
172	2	171204-CMD172_KA_0157_8inchPMT	12/4	12/6	2	0.1093		LZ	000~008			KA-0157
172	3	171206-CMD172_KA_0190_8inchPMT	12/6	12/8	2	0.1067		LZ	000~008			KA-0190
172	4	171208-CMD172_KA_0205_8inchPMT	12/8	12/11	3	0.0968		LZ	000~012			KA-0205
172	5	171211-CMD172_KA_0148_8inchPMT	12/11	12/13	2	0.1029		LZ	000~008			KA-0148
172	6	171213-CMD172_KA_0195_8inchPMT	12/13		1/15							KA-0195
172	7											
Int. days					279.5							

AMoRE (0νββ decay)
COSINE (WIMP DM)

More than 30 samples per year, ~320 days of integrated running time.

CC2 sample test list (2017)

Center for Underground Physics

CMD #	sample #	data file name	Start date	Stop date	period (days)	Count rate > 50keV	Mass (kg)	projects	file number	analysis result	updated	note
Background		170105_cc2_bg	1/5	1/16	11	0.0094		HPGe	000~032			
Background		170123_cc2_bg	1/23	2/3	11	0.0085		HPGe	000~047			
Background		170203_cc2_bg	2/3	2/16	13	0.0093		HPGe	000~035			
MCA Test		170216_MCA_test	2/16	2/17	1			HPGe	000~468			new computer, new MCA
103		170217-CMD00103_Ta-China	2/17	2/24	7	0.0211	0.66	HPGe	000~022			
103		170224-CMD00103_Ta-China	2/24	3/9	13	0.0224	0.66	HPGe	000~060			
105		170309-CMD00105_Ta-Korea	3/9	3/23	14	0.0198	0.666	HPGe	000~065			
83		170323-CMD00083_LS	3/23	4/13	21	0.0204	0.791	COSINE	000~099			
123		170413-CMD00123_phosphor-bronze	4/13	4/27	14	0.0402	2	AMoRE	000~065			
71		170427-CMD71-FKM-Orings	4/27	5/8	11	0.0723	0.093	HPGe	000~049			
119	1	170508-CMD119-1	5/8	5/10	2	2.5609	1.864	Crystal	000~009			
119	2	170510-CMD119-2-al203sio2	5/10	5/11	1	48.6762	0.627	Crystal	000~003			
119	3	170511-CMD119-3-sio2	5/11	5/17	6	0.0181	1.458	Crystal	000~027			
122		170517-CMD122-cosine-nai-cable	5/17	5/19	2	0.0479	1.296	COSINE	000~008			
131		170519-CMD131-MoO3Powder	5/19	5/29	10	1.1886	1.722	Crystal, AMoRE	000~046			
Background		170529-hpge-cc2-bg	5/29	6/1	3	0.013		HPGe	000~012			
Background		170601-hpge-cc2-bg	6/1	6/9	8	0.0085		HPGe	000~033			
Background		170609-CC2BG	6/9	6/26	17	0.0086		HPGe	000~080			
133		170626-CMD133_PMTbase	6/26	7/4	8	0.0498	0.83	COSINE	000~036			
		170704-CMD148_StainlessTube	7/4	7/12	8	0.0185	0.365	COSINE	000~036			no CMD#
118		170712-CMD118_Teflon	7/12	7/19	7	0.0096	2.09	COSINE	000~031			
Background		170728-cc2-bg	7/28	7/31	3	0.0082		HPGe	000~014			after install acrylic outer box
Background		170731-CC2-bg	7/31	8/10	10	0.0086		HPGe	000~046			
Background		17810-CC2-CountRateCheckup	8/10	8/10	0			HPGe	000~038			
142		170810-CMD142_OCV_Powder	8/10	8/11	1	0.304	0.865	AMoRE	000~004			
137		170811-CMD137_ConnectorPin	8/11	8/30	19	0.2691	0.119	AMoRE	000~088			
148		170830-CMD148_RefracMaterial	8/30	9/5	6	1.3329	2.756	Crystal	000~028			
145		170906-CMD145_CableTie	9/6	9/29	23	0.0101	0.6	COSINE	000~108			
156		171010-CMD156_OFE-Cu	10/10	10/30	20	0.0077	1.472	HPGe, AMoRE	000~086			
157		171101-CMD157_StainlessBolt	11/1	11/16	15	0.0137	1.796	AMoRE	000~070			
168	3	171116-CMD168a_QuartzFelt_USA	11/16	11/22	6	0.0373	0.162	Crystal	000~026			
162		171121-CMD162_Refractory	11/22	11/24	2	0.0122	0.164	Crystal	000~008			Stopped for install LN generator
162		171127-CMD162_Refractory	11/27	11/29	2	0.0126	0.164	Crystal	000~007			
162		171201-CMD162_Refractory	12/1	12/4	3	0.0113	0.164	Crystal	000~004			Black out occured
162		171204-CMD162_Refractory	12/4	12/6	2	0.0114	0.164	Crystal	000~003			Job file stopped
162		171206-CMD162_Refractory	12/6	12/15	9	0.0115	0.164	Crystal				
Int. day					300							

AMoRE (0νββ decay)
COSINE (WIMP DM)

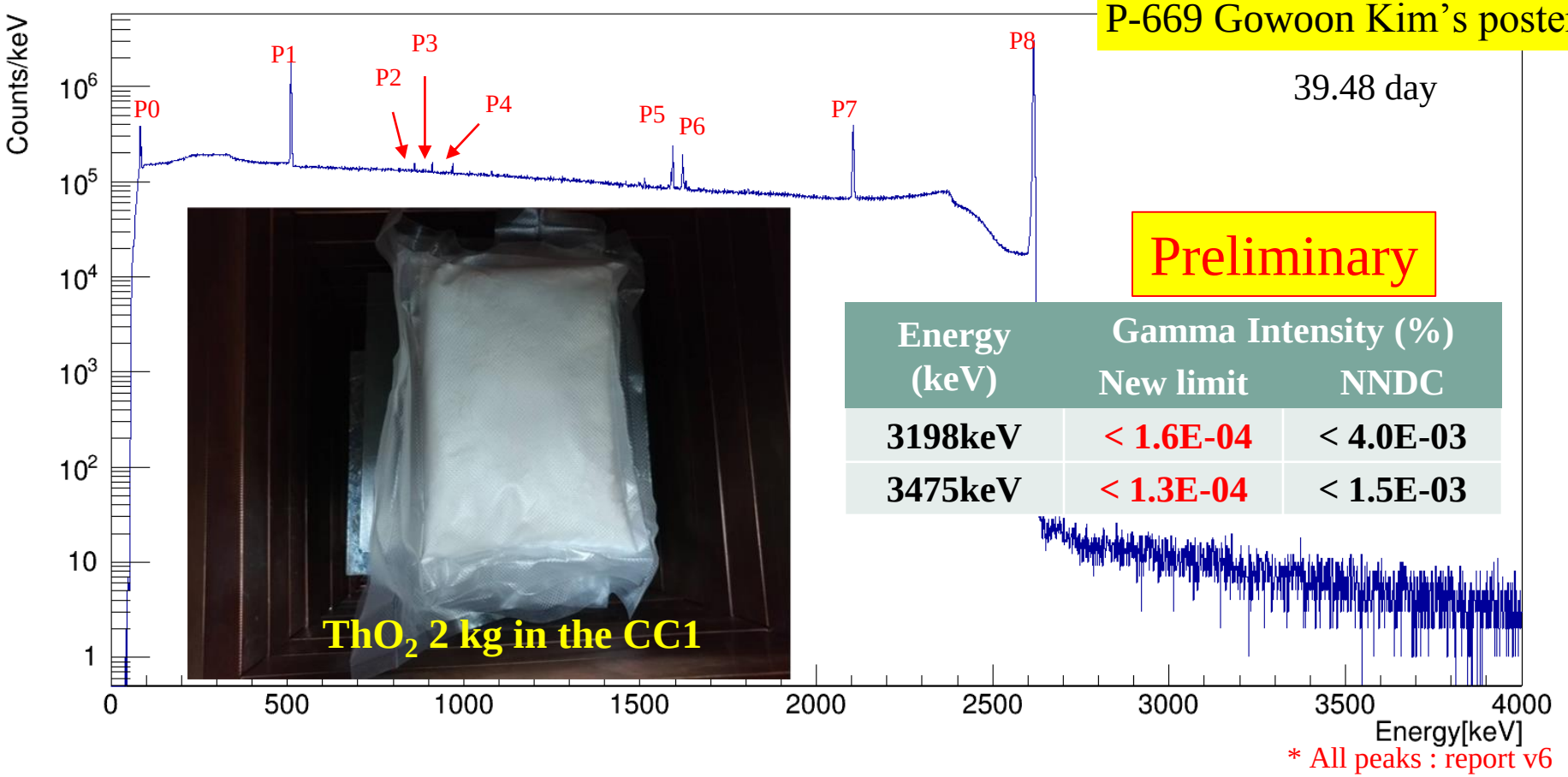
More than 30 samples, ~300 days integrated running time

CC1: ThO_2 spectrum and main peaks

Center for Underground Physics

P-669 Gowoon Kim's poster

39.48 day



Preliminary

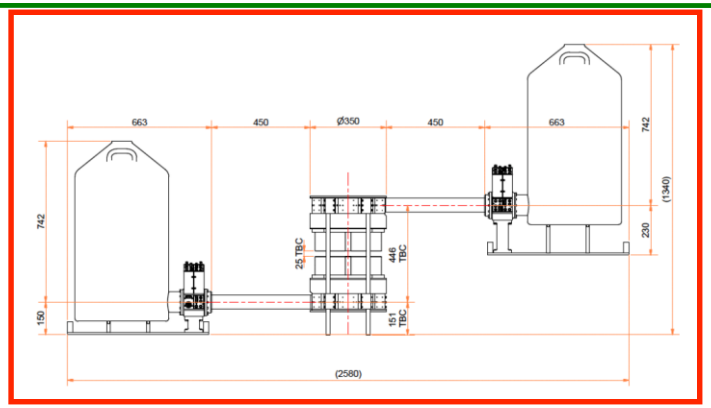
Energy (keV)	Gamma Intensity (%)	
	New limit	NNDC
3198keV	< 1.6E-04	< 4.0E-03
3475keV	< 1.3E-04	< 1.5E-03

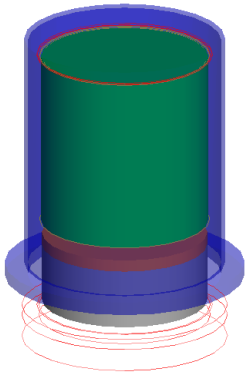
* All peaks : report v6

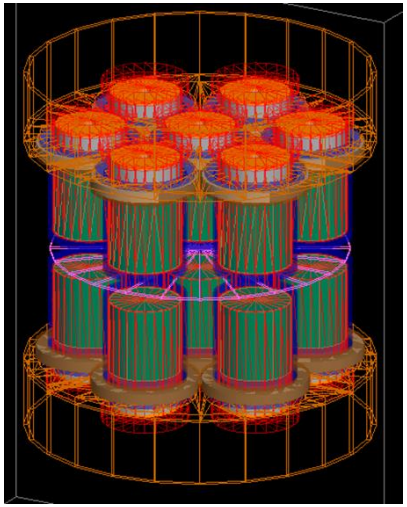
P#	P0	P1	P2	P3	P4	P5	P6	P7	P8
Nu.	^{228}Th	Annihilation Peak	^{208}Tl	^{228}Ac	^{288}Ac	2nd escape peak	^{212}Bi	1st escape Peak	^{208}Tl
keV	84.38	511	860	911	968	1592	1620	2103	2614

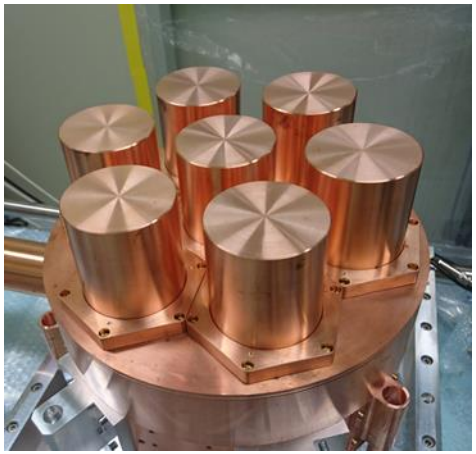
Array of 14 HPGe detectors

- Developed in collaboration with CANBERRA.
- **2 ARRAYS** placed one above the other with 7 HPGe (70% relative efficiency) each.
- Total # of detectors: **14 HPGe**
- **Low background copper** for endcap & holder.
- **O-rings** were screened from more than 20 samples.









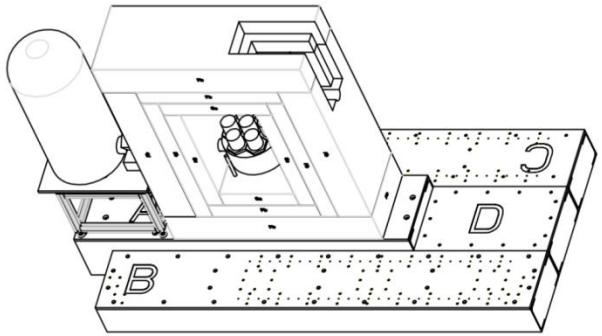
The Ultra Low Background Measurement

- 2 arrays of 7 HPGe detectors with total of 980% relative efficiency designed for **the detection of low contaminations**
- The sensitivity can be improved thanks to **coincidence** measurements.
- Raw materials screening such as **Mo-100** powder (AMoRE) or Copper.
- Rare decay search like ^{180m}**Ta** rare beta decay
- Resonant 0ν Double Electron Capture (^{156}**Dy**)

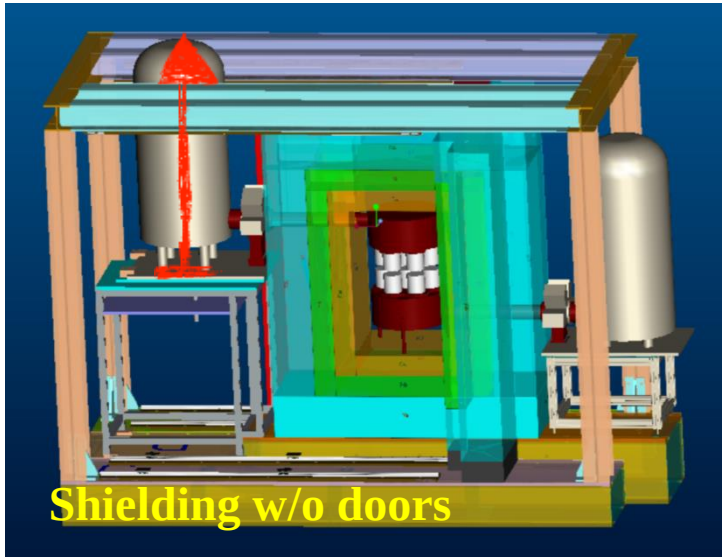
HPGe Array: SHIELDING

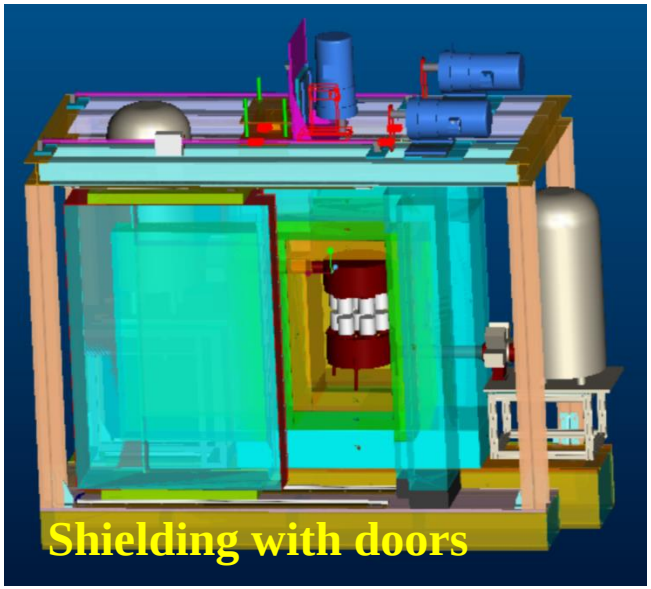
Main Structure from outside: 20 cm Lead + 10 cm Goslar Lead + 10 cm Copper

Two doors on the sides can slide on rails using a motor placed on top of the shielding



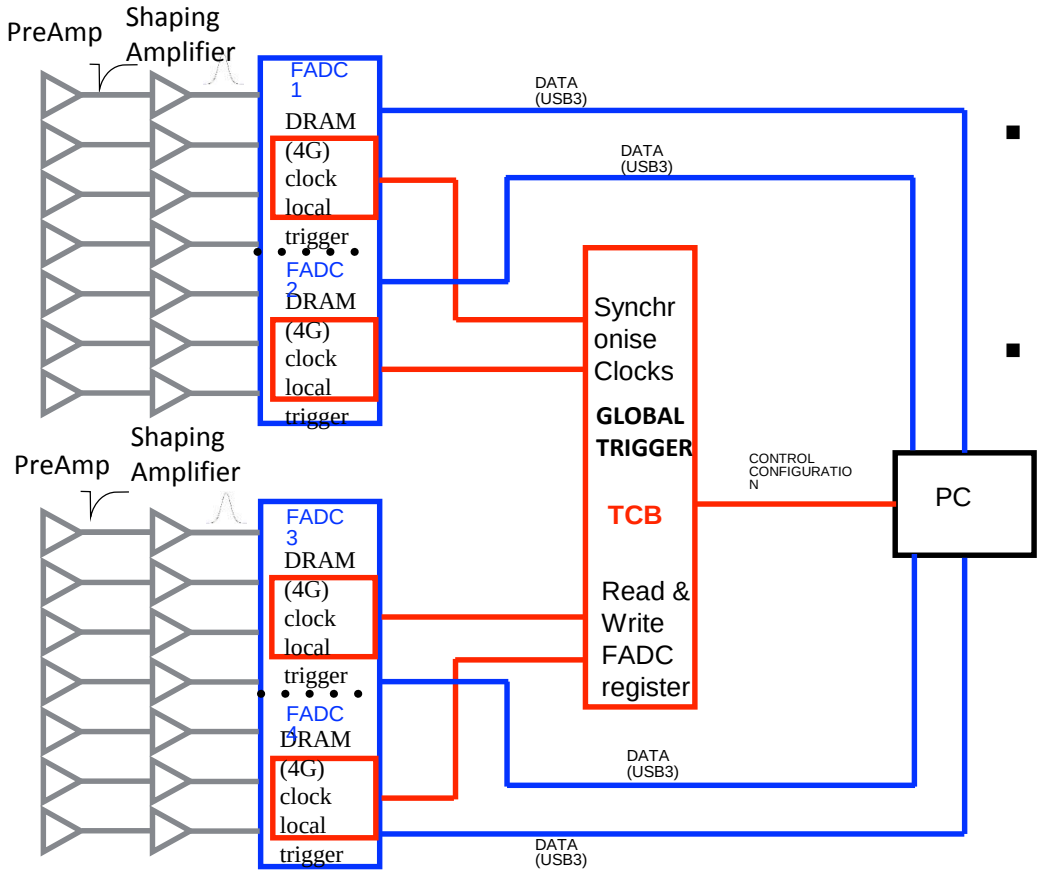
- The top array should be lifted to place samples with different sizes.
- Specific tools are made to lift the dewar and the array together.
- A part of the (movable) shielding also lifted together to prevent any damages on the cold finger.





HPGe Array: Electronics & DAQ

- Shaping Amplifier CANBERRA 2026
  Shaping time 6 μs
- HV power supply iseg NHS606
  6 channels, positive, programmable



- Flash Analog to Digital Converter
  - 500 MS/s 12 bit dynamic range 2.5V
  - 2 modules with 4 channels each

- Local trigger signals generated in the FADCs are sent to the Trigger Control Board (TCB)
- TCB will decide and generate a GLOBAL TRIGGER to be sent back to FADCs in 500ns via a LAN cable connection
- TCB synchronize the FADCs clocks and access to the FADCs register to send the information to PC

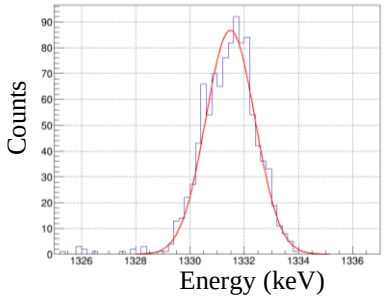
HPGe Array: Energy Resolution & BKG runs

Center for Underground Physics (ibs)

BOTTOM ARRAY

Energy Resolution (keV) for 1332 keV ^{60}Co						
DET0	DET1	DET2	DET3	DET4	DET5	DET6
1.96	1.98	X	3.16	2.22	1.83	2.10

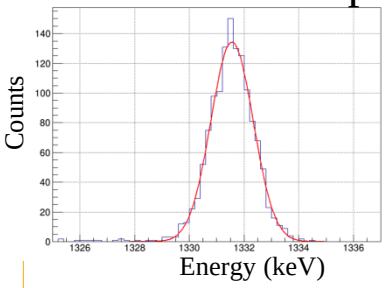
DET6 Bottom



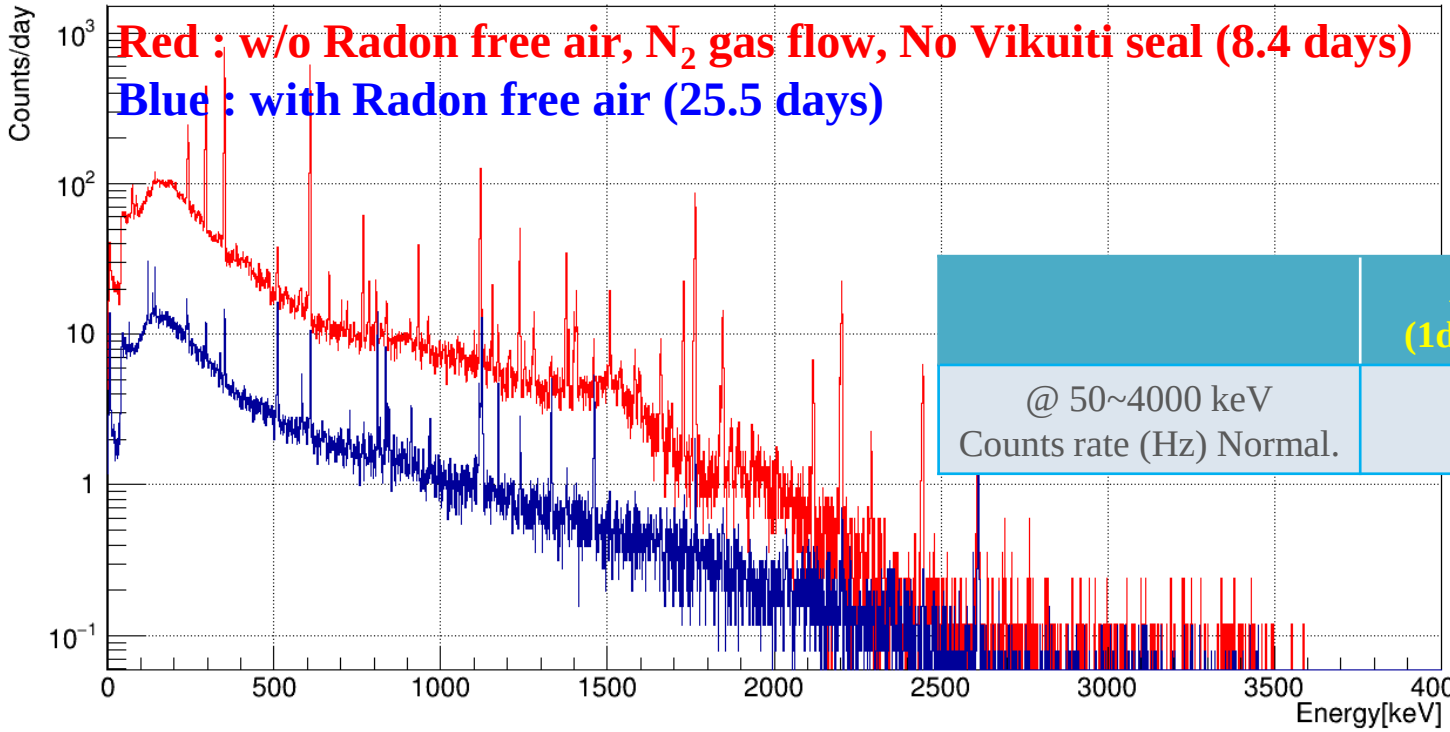
TOP ARRAY

Energy Resolution (keV) for 1332 keV ^{60}Co						
DET0	DET1	DET2	DET3	DET4	DET5	DET6
1.90	2.17	X	1.93	1.36	1.95	1.85

DET6 Top



BKG spectra

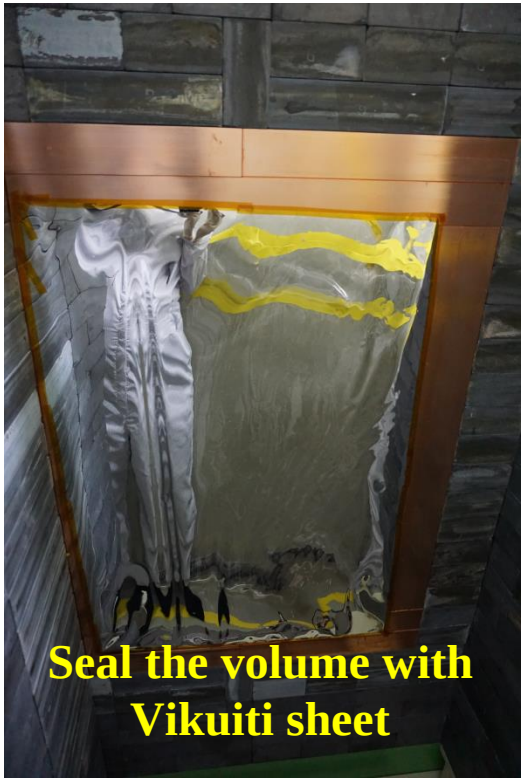


	ARRAY (1det./BG002)	CC1
@ 50~4000 keV Counts rate (Hz) Normal.	0.0003	0.0075

HPGe Array: Mo-100 powder test

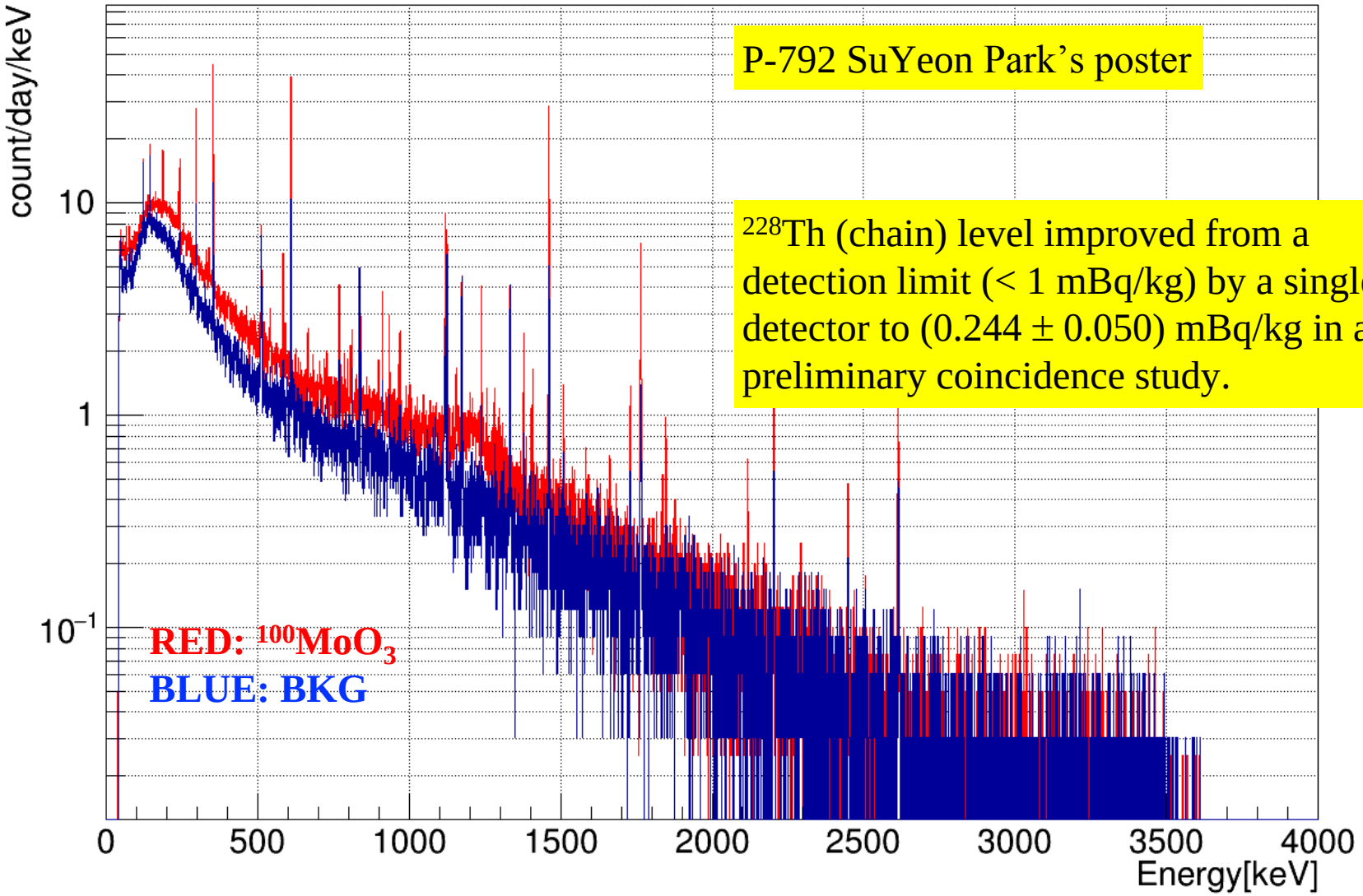
Center for Underground Physics ibs

$^{100}MoO_3$: Raw material to grow molybdate scintillating crystals for AMoRE (Advanced Mo-based Rare process Experiment) searching neutrinoless double beta decay of ^{100}Mo



P-792 SuYeon Park's poster

HPGe array: Mo-100 powder data

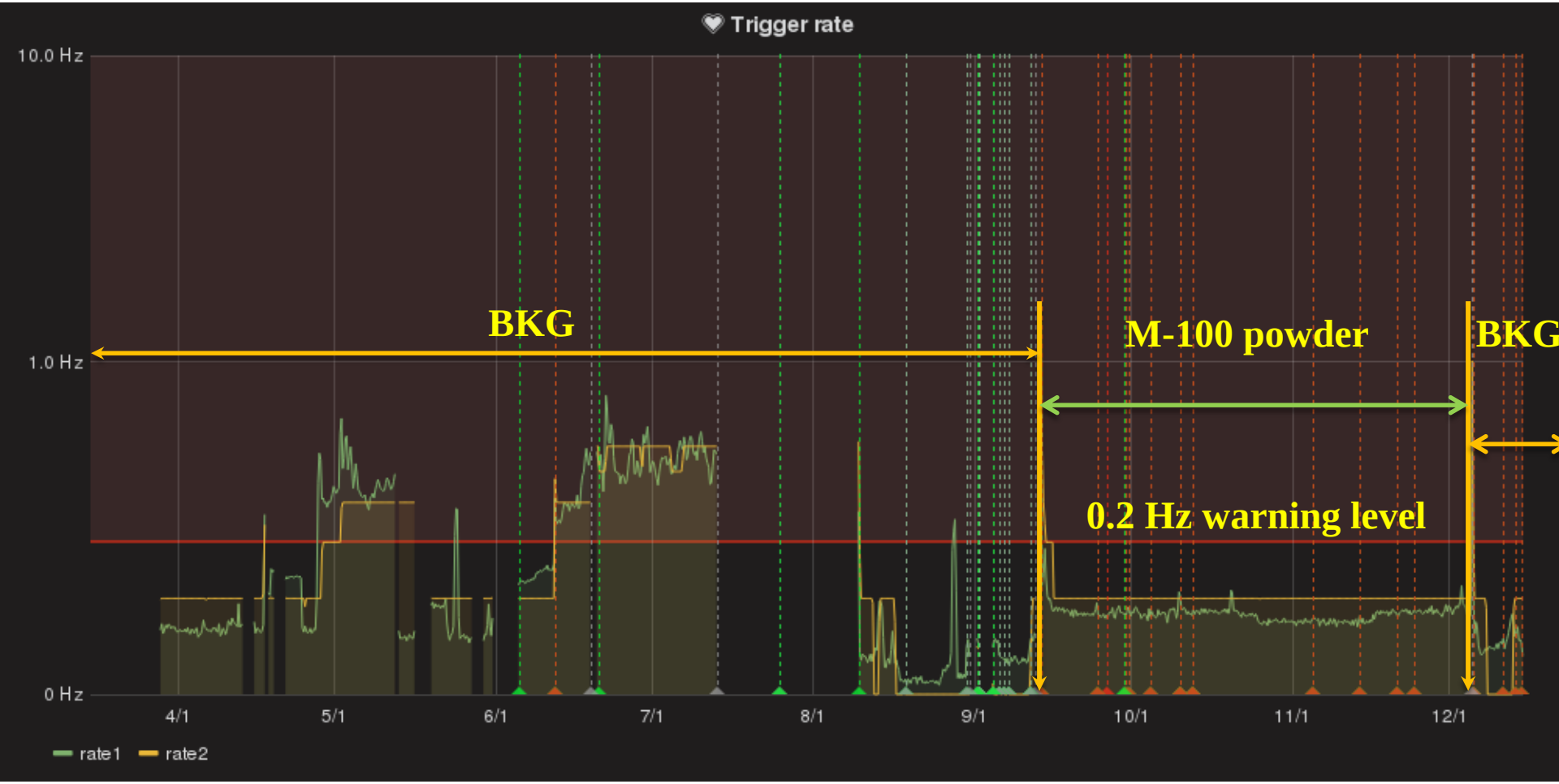


P-792 SuYeon Park's poster

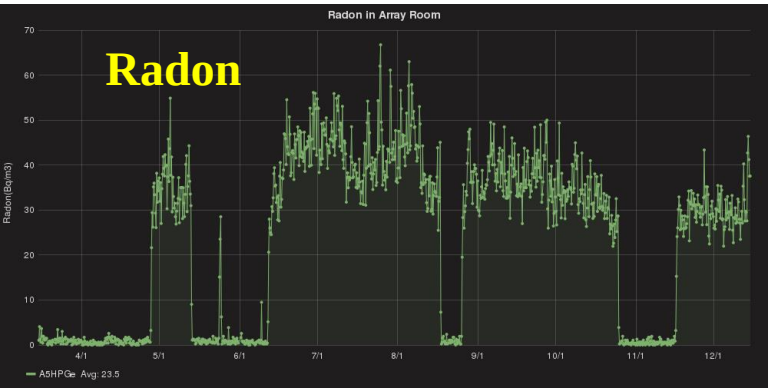
^{228}Th (chain) level improved from a detection limit (< 1 mBq/kg) by a single detector to (0.244 ± 0.050) mBq/kg in a preliminary coincidence study.

HPGe Array: Trigger Rate Monitoring

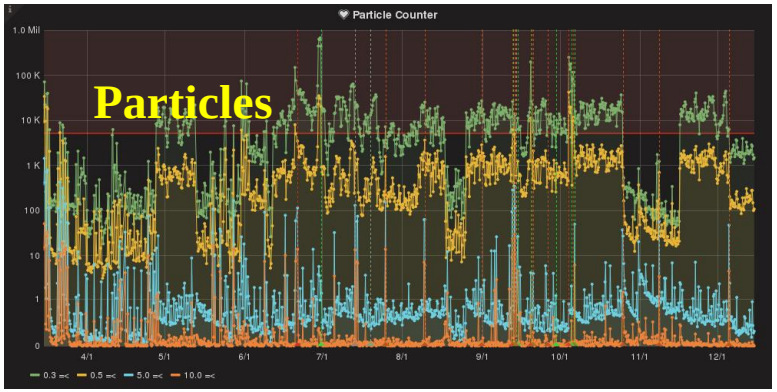
Center for Underground Physics



Radon, Particles (Dust) and CPU in array room

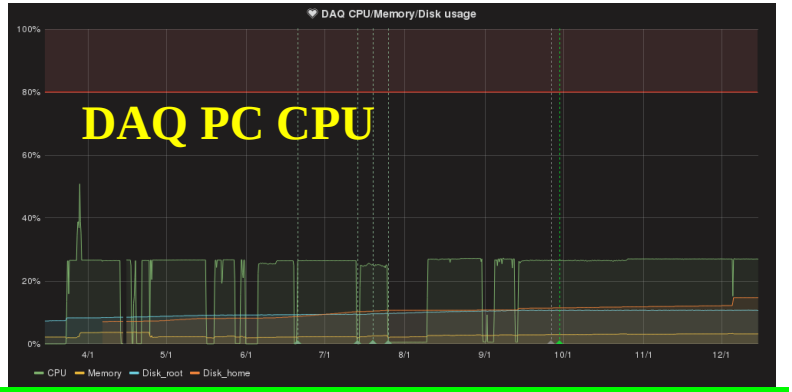


- Radon level ~ 40 Bq/m3 w/o Rn-free air.
- N2 gas from boil-off flow in ~15 L/min.

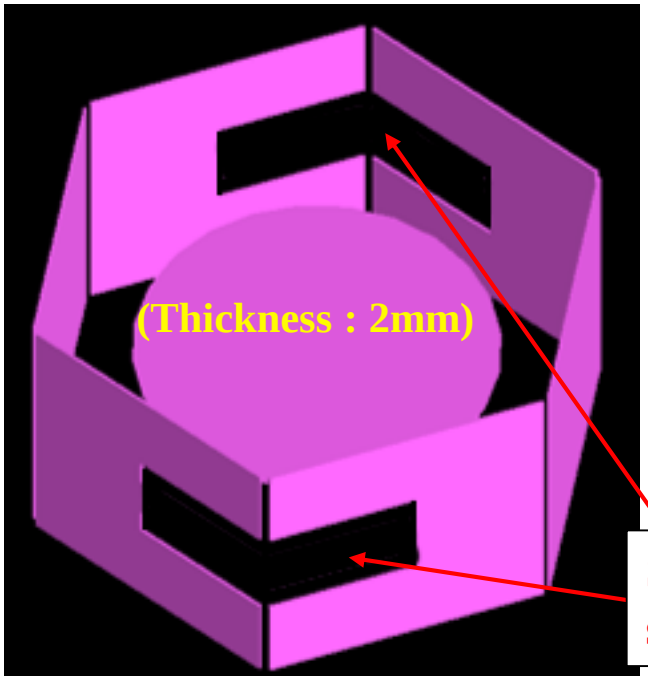


- Class 1000 level

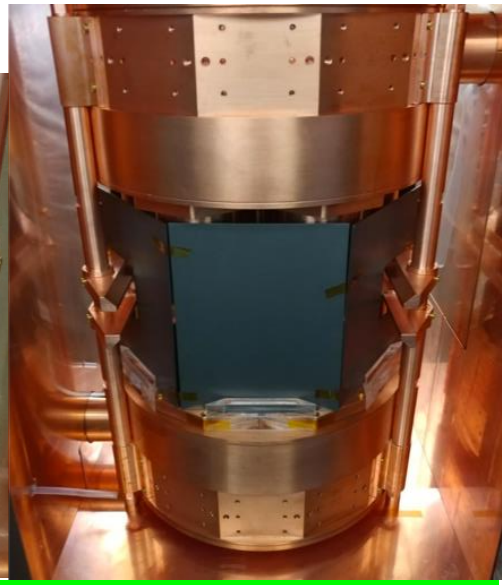
- DAQ PC CPU is about 25% busy during data taking



HPGe array: Tantalum test

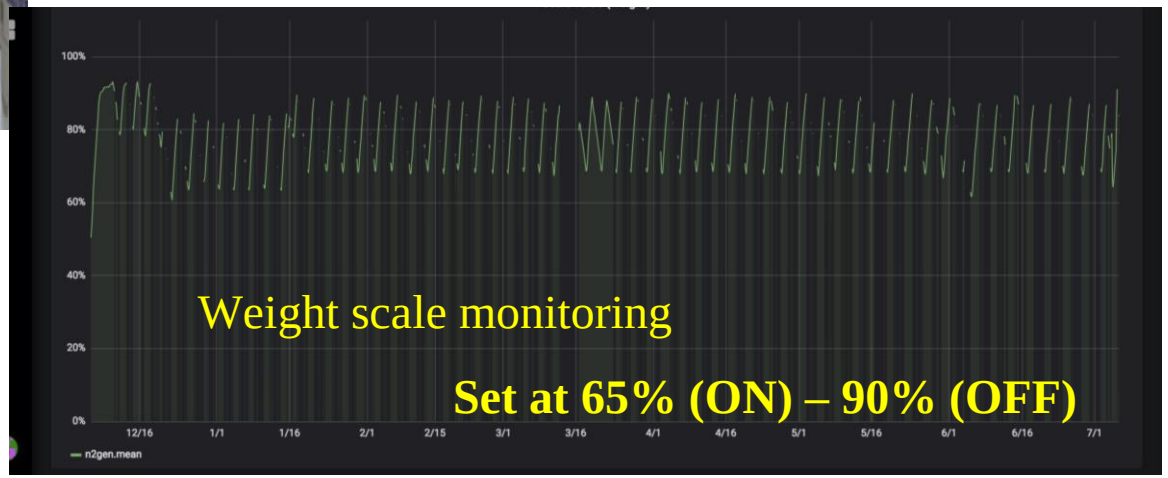


- **Tantalum** (Run 160 | running)
  To search a gamma ray from rare beta decay of ^{180m}Ta.



LN_2 (Liquid Nitrogen) generators for CC1/2

- LN_2 generator (2 ea., 8 L/d) purchased for the two single HPGe detector to reduce the LN_2 dewar exchanges.
- One (CC2) has been running for 7 months and the other one (CC1) has started from last week.
- The CC2 generator's weight scale has been being monitored on-line stably.



CUP ULRM HPGe facility: Summary

- CUP has two single HPGe detectors mainly for screening of samples and an array of fourteen HPGe detectors for rare decay measurements at Yangyang underground laboratory (Y2L) as an ultr-low radioactivity measurement facility.
- The two single HPGe detectors, CC1 & CC2, have measured more than 30 samples with more than 300 days of live time per year.
- The CC2 background was improved with a globe box type air sealing structure to protect from Rn contamination.
- ThO_2 (2 kg) powder was tested for 39.5 days with a FADC readout in the CC1 with an additional 10 cm lead shield to measure the high energy gamma background from Th. Preliminary results show ~10 improvements in two high energy gamma intensities.
- The array was installed in April 2017. After a few months of background running and tuning, the Mo-100 powder for AMoRE was measured for about 3 months stably. A preliminary result shows an improved sensitivity in Th isotope by a factor of three.
- The monitoring of the array environment and on-line trigger rate has been running well enough to have only on-line webpage monitoring.
- Tantalum sample is currently being measured in the array.
- Two LN_2 generators were purchased to reduce the load of changing the LN_2 dewars frequently. One has been running smoothly for last 7 months while the LN_2 level is being monitored with the weight of the dewar. Another generator has started from last week.