Center for Underground Physics ibs

TAUP 2017 Topics in Astroparticle and Underground Physics

An ultra-low radioactivity measurement facility at the Center for Underground Physics in Korea

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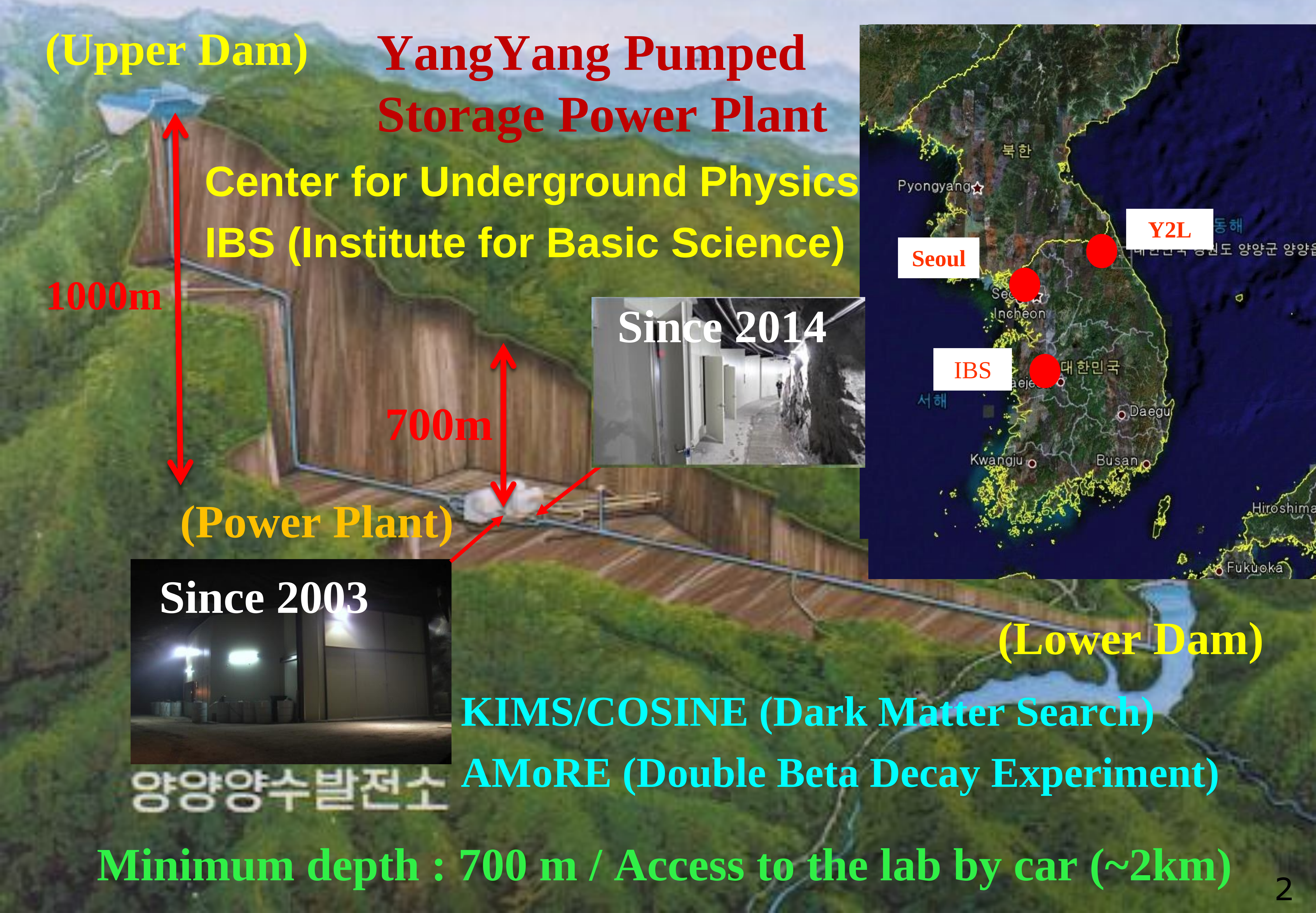
On behalf of CUP measurements groups

Center for underground Physics,
Institute for Basic Science, Korea

2017. 07. 26

TAUP2017 @ Sudbury, ON, Canada

YangYang(Y2L) Underground Laboratory



YangYang Pumped Storage Power Plant

Center for Underground Physics

IBS (Institute for Basic Science)

KIMS/COSINE (Dark Matter Search)

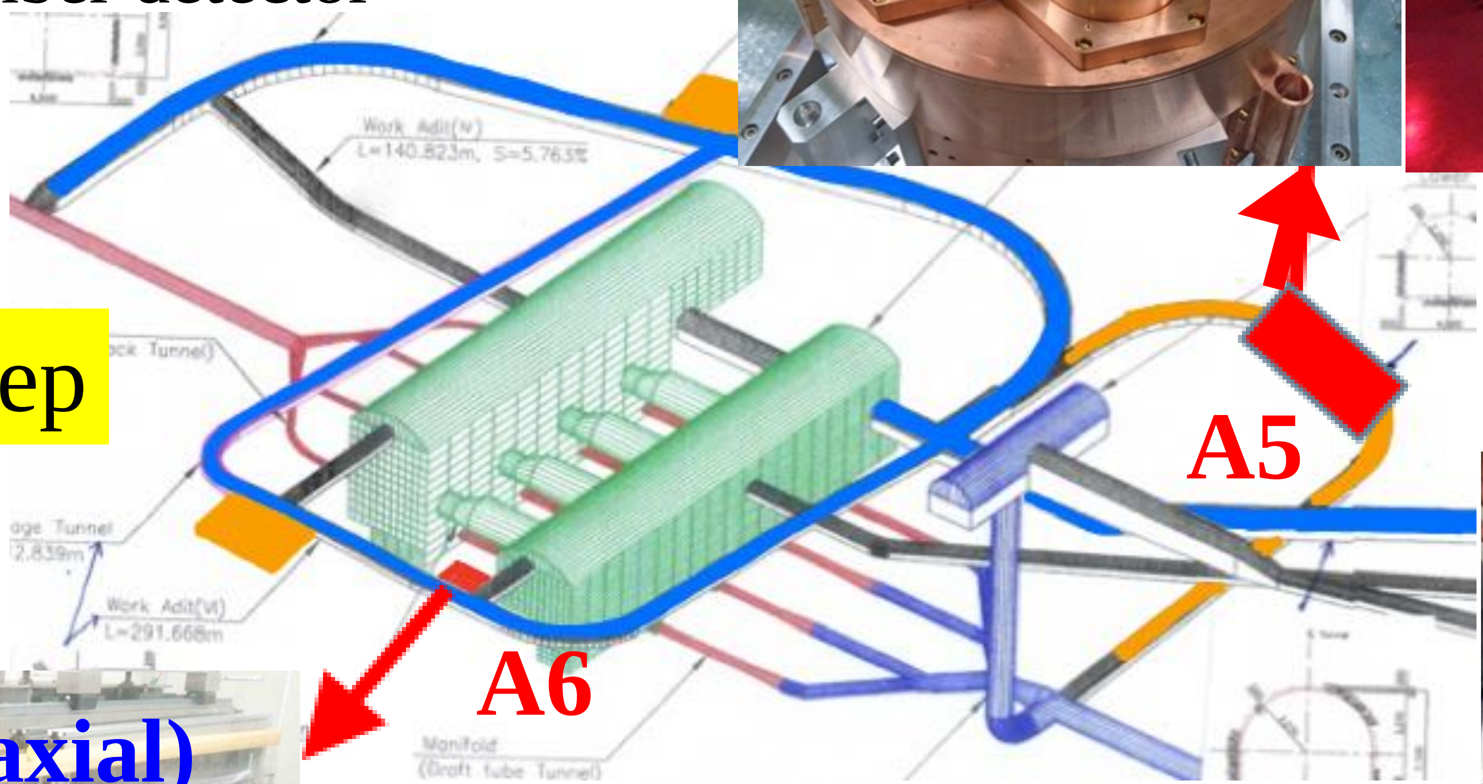
AMoRE (Double Beta Decay Experiment)

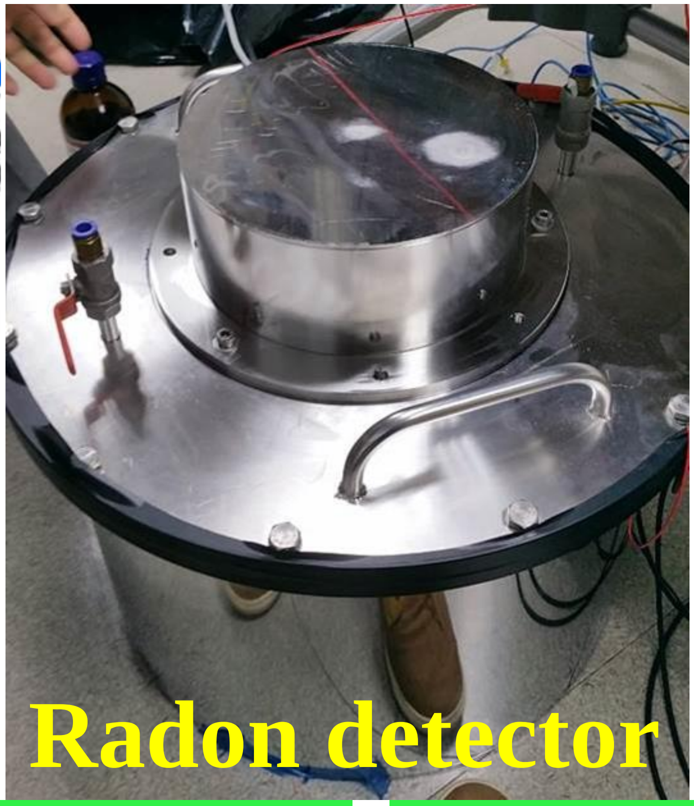
Minimum depth : 700 m / Access to the lab by car (~2km)

Detectors at the Y2L

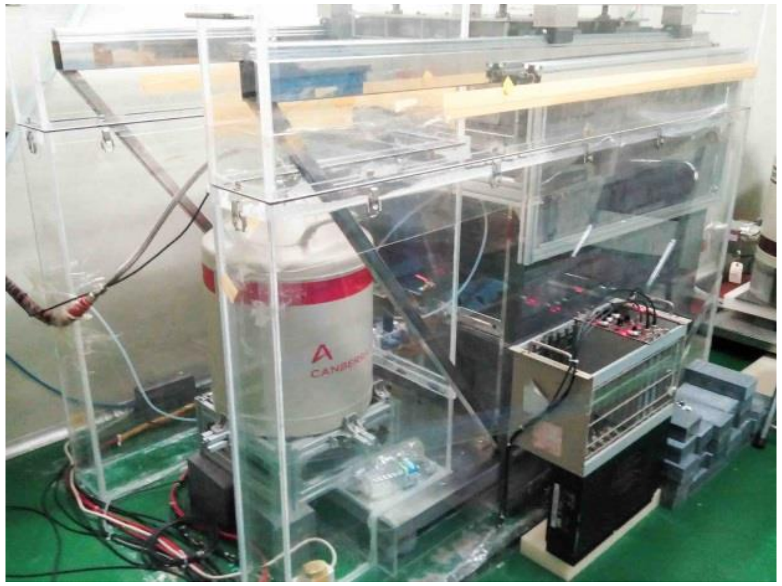
- 3 HPGe detectors (2 Coax, 1 Well)
- 1 Array with 14 HPGe detectors
- Alpha ionization counter
- Radon chamber detector

~700 m deep

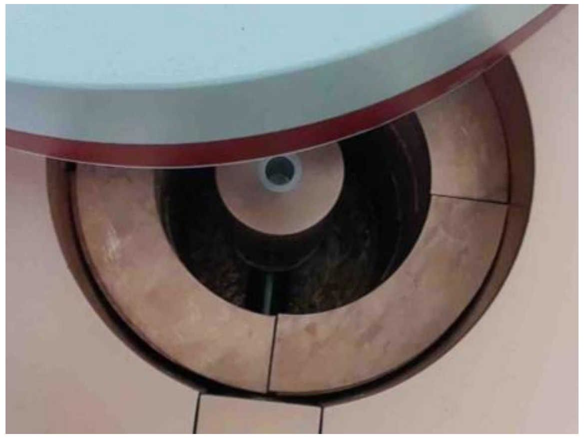




HPGe detectors



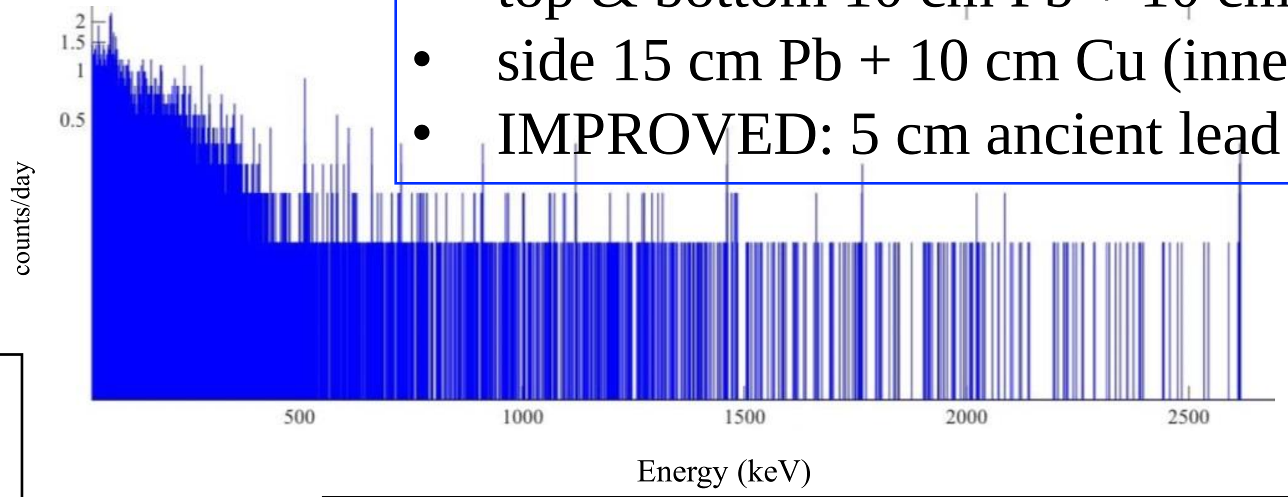
Well type ORTEC
110 cc of ACTIVE VOLUME



CANBERRA 777 Ultra Low Background Shield
- Outer 9.5 cm thick low carbon steel
- 15 cm of low background Pb
- 1.5 mm high purity low background copper
- Additional ~5 cm copper disks on the side and on top

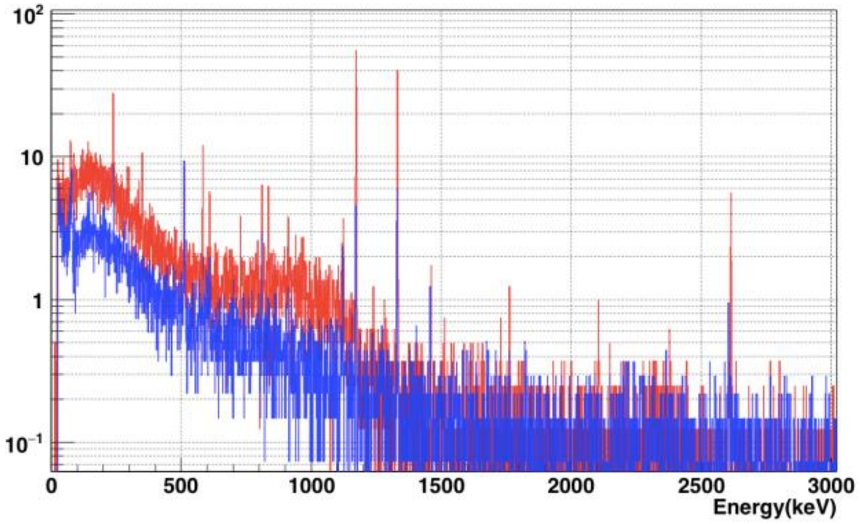
CC1: 100% HPGe CANBERRA

- Dedicated shielding:
- top & bottom 10 cm Pb + 10 cm Cu (inner)
- side 15 cm Pb + 10 cm Cu (inner)
- IMPROVED: 5 cm ancient lead near the detector

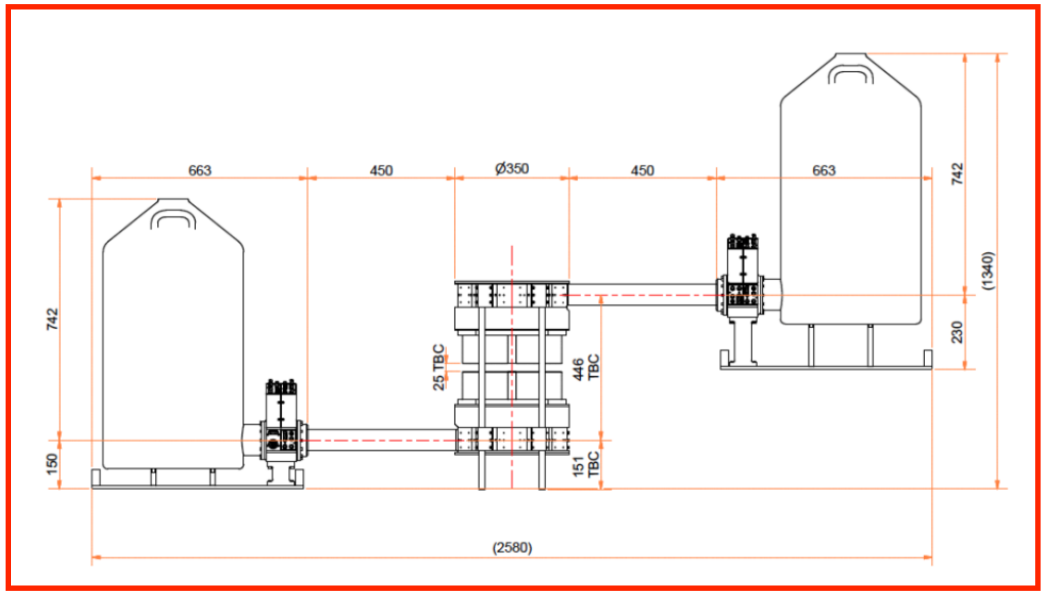


CC2: 100% HPGe CANBERRA

- A new installation with an improved new shielding



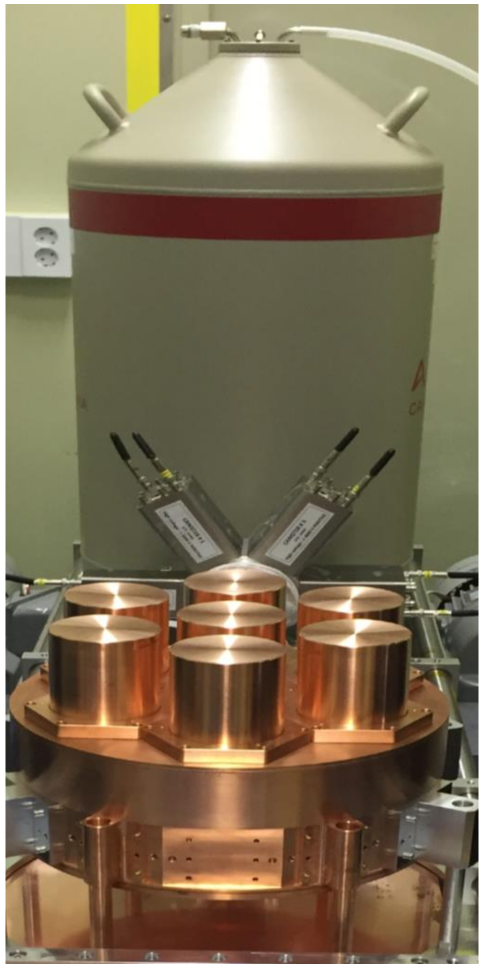
HPGe Array



- Developed in collaboration with CANBERRA,
- **2 ARRAYS** placed one above the other with 7 HPGe (70% relative efficiency) each.
- Total detectors: **14 HPGe**

- Improving the sensitivity is mandatory to reduce the intrinsic background

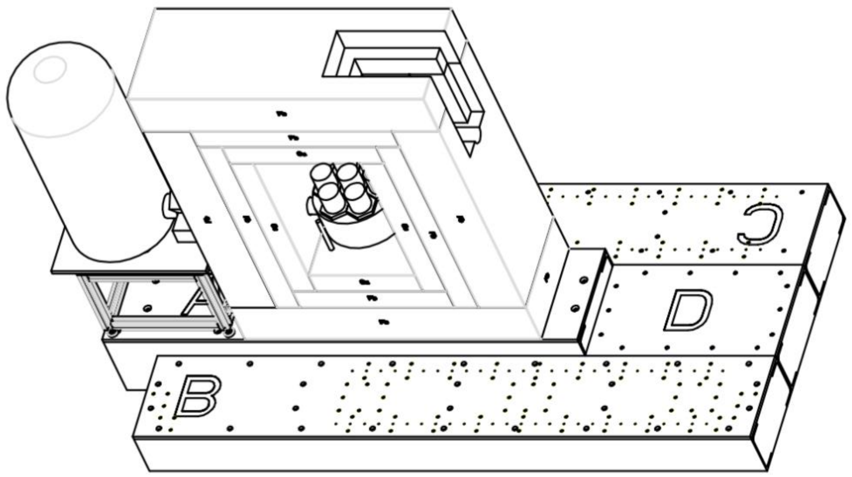
- Careful and accurate selection of **O-rings**
  - O-rings generally have high contamination in 40K
  - Our selection has very low contamination in Th and U: 16 ± 4 & 13 ± 4 mBq/kg respectively
- Aluminum has been replaced by **copper** everywhere considering the efficiency loss at low energies
  - End Cap & Holder surrounding the crystals are made of copper, machined as thin as possible for a total of 2 mm dead layer



SHIELDING

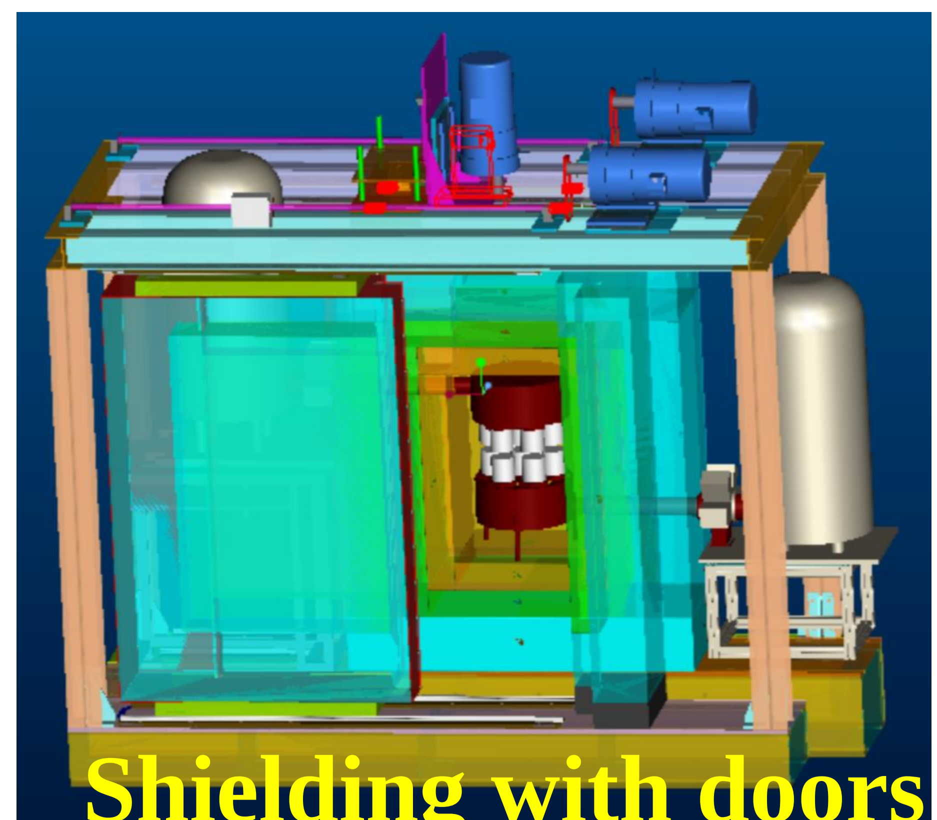
Main Structure from outside: 20cm Lead + 10cm Goslar Lead + 10cm Copper

Two doors on the side can slide on rails using a motor system



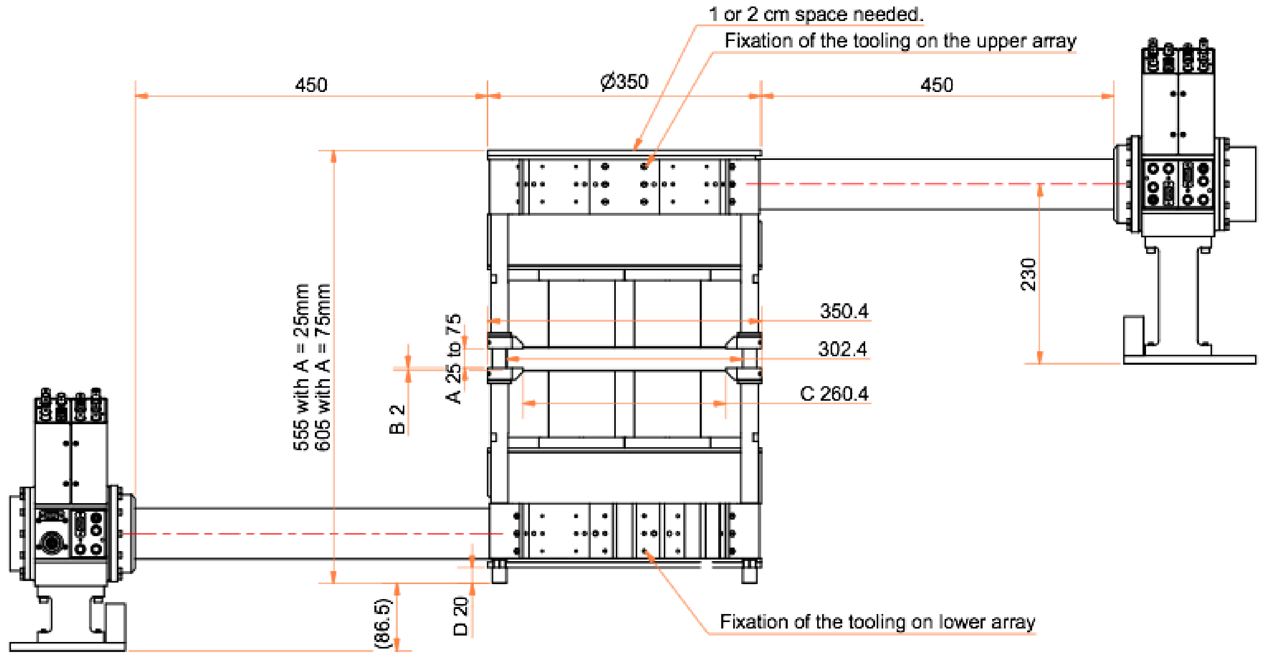
- The top array should be lifted to place samples with different sizes.
- Specific tools are made to lift the dewar and the array together.
- A part of the shielding will also be lifted to prevent any damages on the cold finger

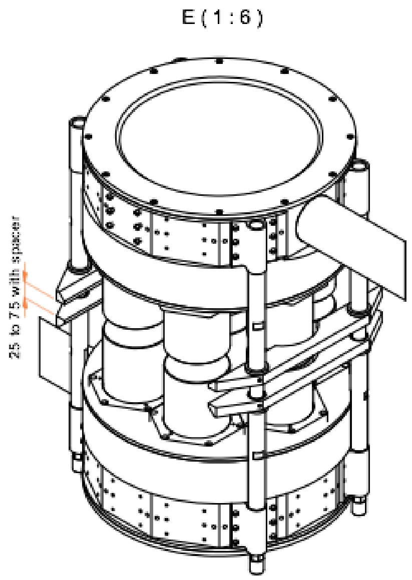
Shielding w/o doors

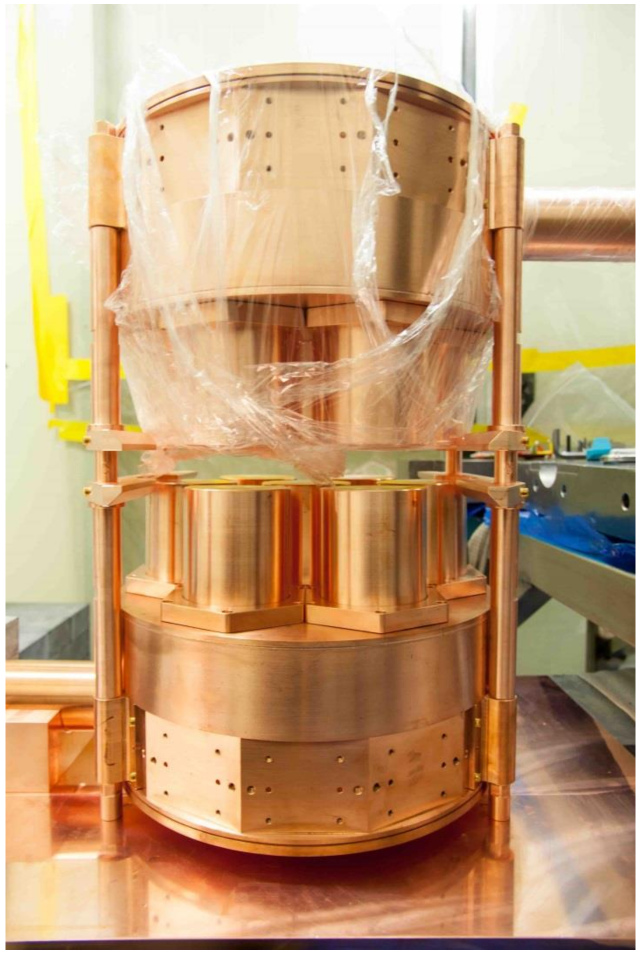


Shielding with doors

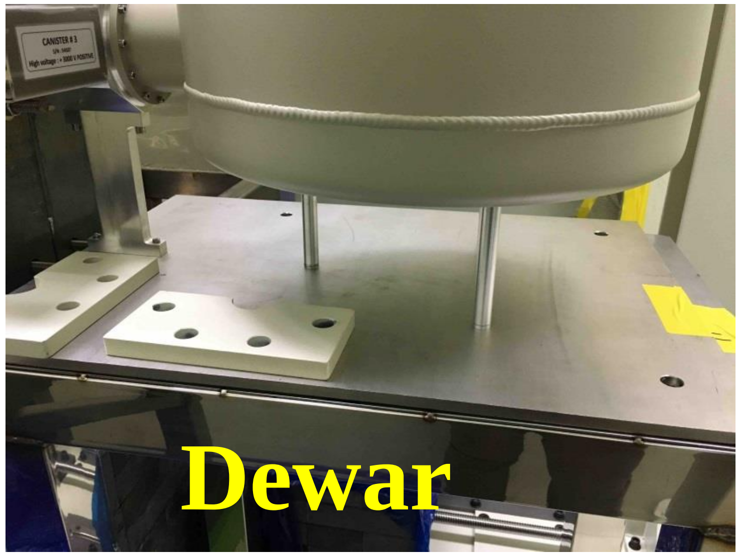
Lifting scheme





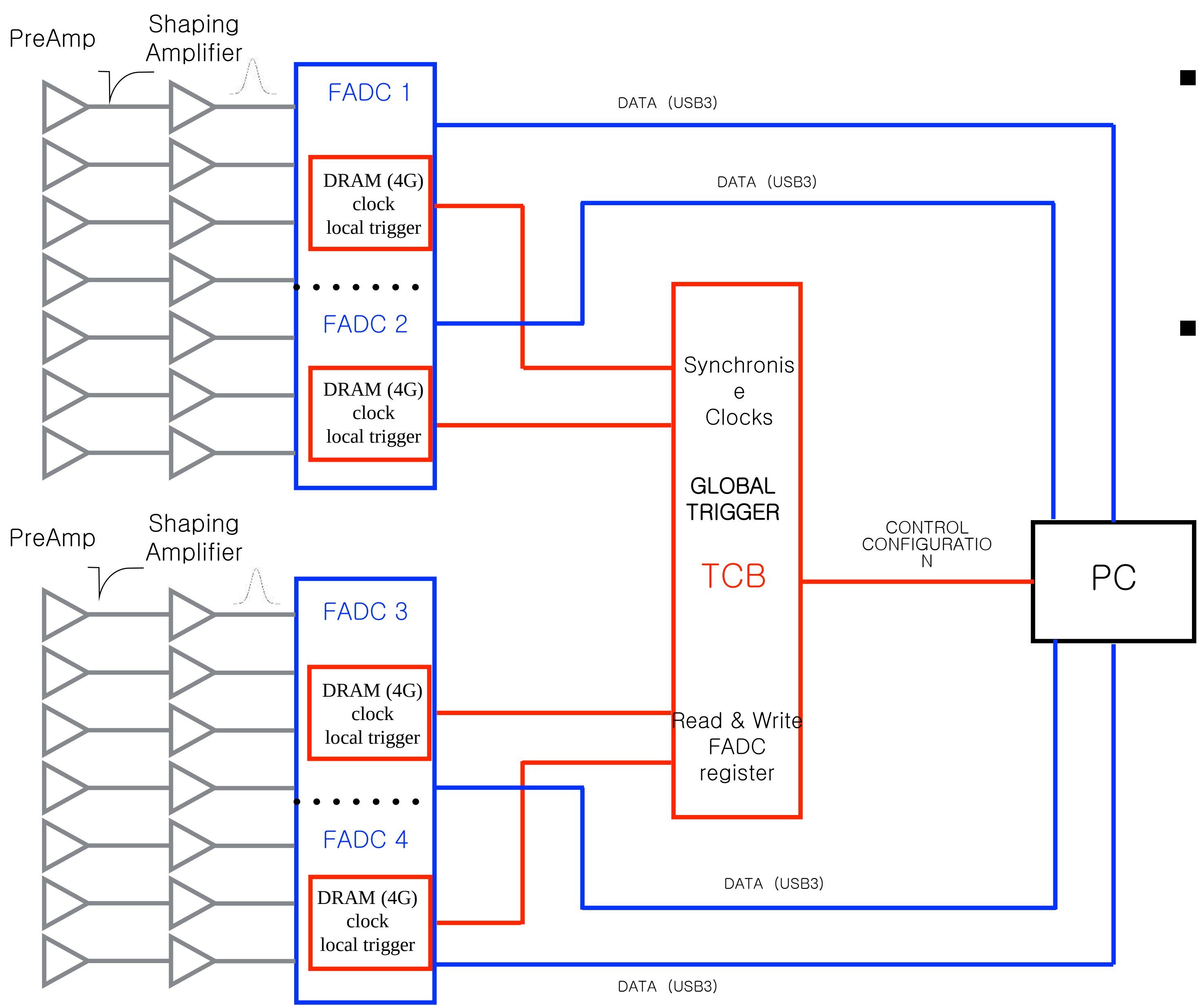


- Lifting 3 parts simultaneously
– Top Array, Shielding, Dewar
– Design of a Tool to lift the array
– 2mm each step (cold finger “safe” stress)
- Adjustable spacers between the bars to fix the height
– from 2.5 up to 5 cm
– Support for samples



Electronics & DAQ

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

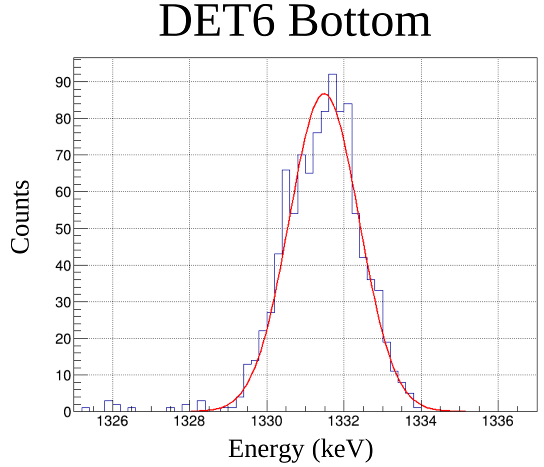


- Flash Analog to Digital Converter
  - 500MS/s 12bit dynamic range 2.5V
  - 2 modules with 4 channels each
- Local trigger signals generated in the FADCs are sent to the Trigger Control Board (TCB)
- TCB will decide and generate a GLOBAL TRIGGER to be sent back to FADCs in 500ns via a LAN cable connection
- TCB synchronize the FADCs clocks and access to the FADCs register to send the information to PC

Energy Resolution & BKG runs

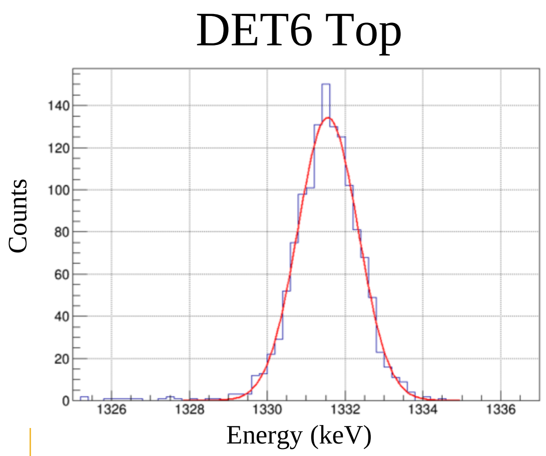
BOTTOM ARRAY

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

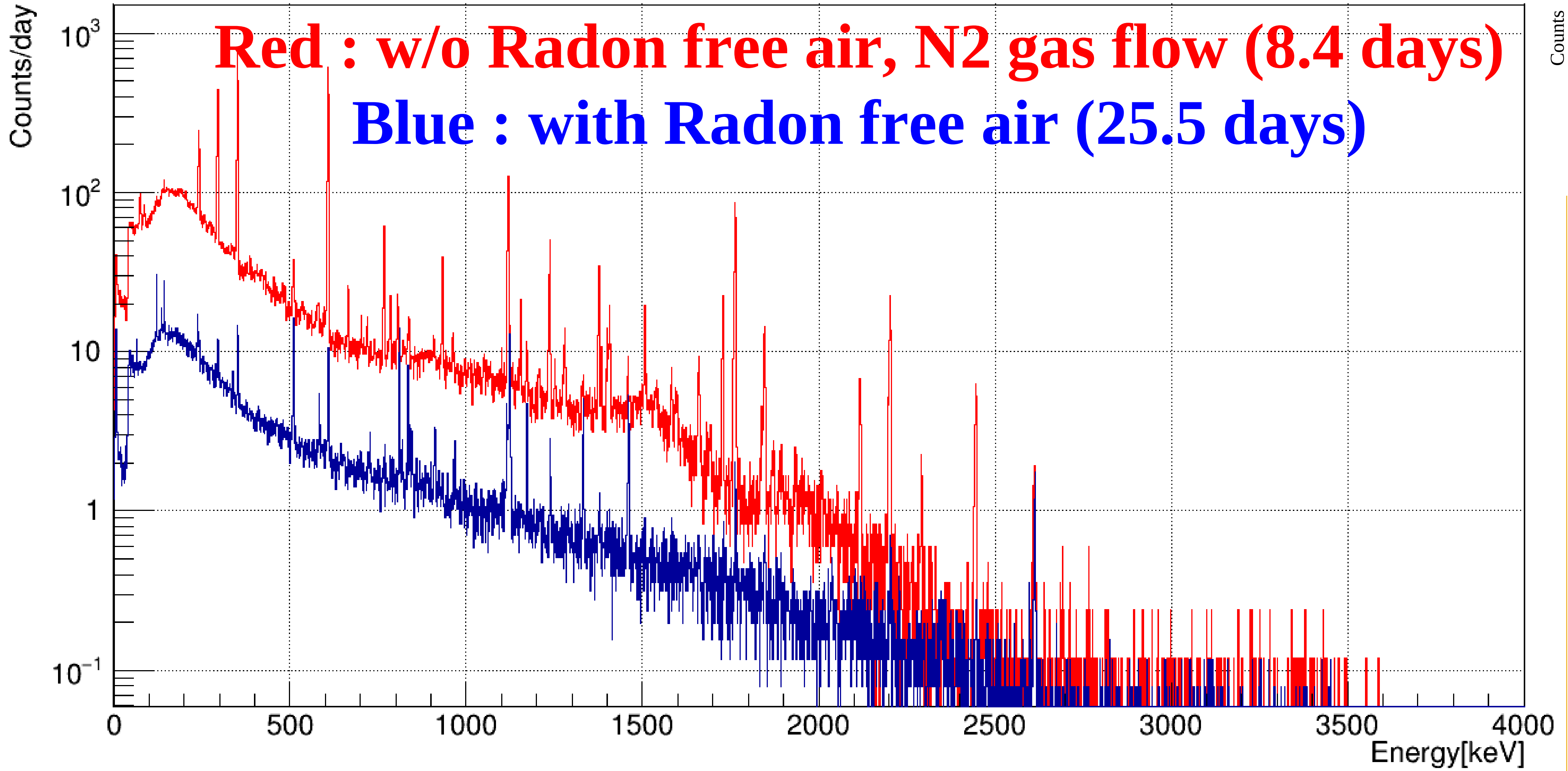


TOP ARRAY

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



BKG spectra



Application & MC

The Ultra Low Background Facility

- 2 arrays of 7 HPGe detectors with 70% of relative efficiency designed for **the detection of low contaminations.**
- The sensitivity can be improved thanks to coincidence measurements.

- Materials selection for rare physics events experiments
- Detection of low level contamination in samples

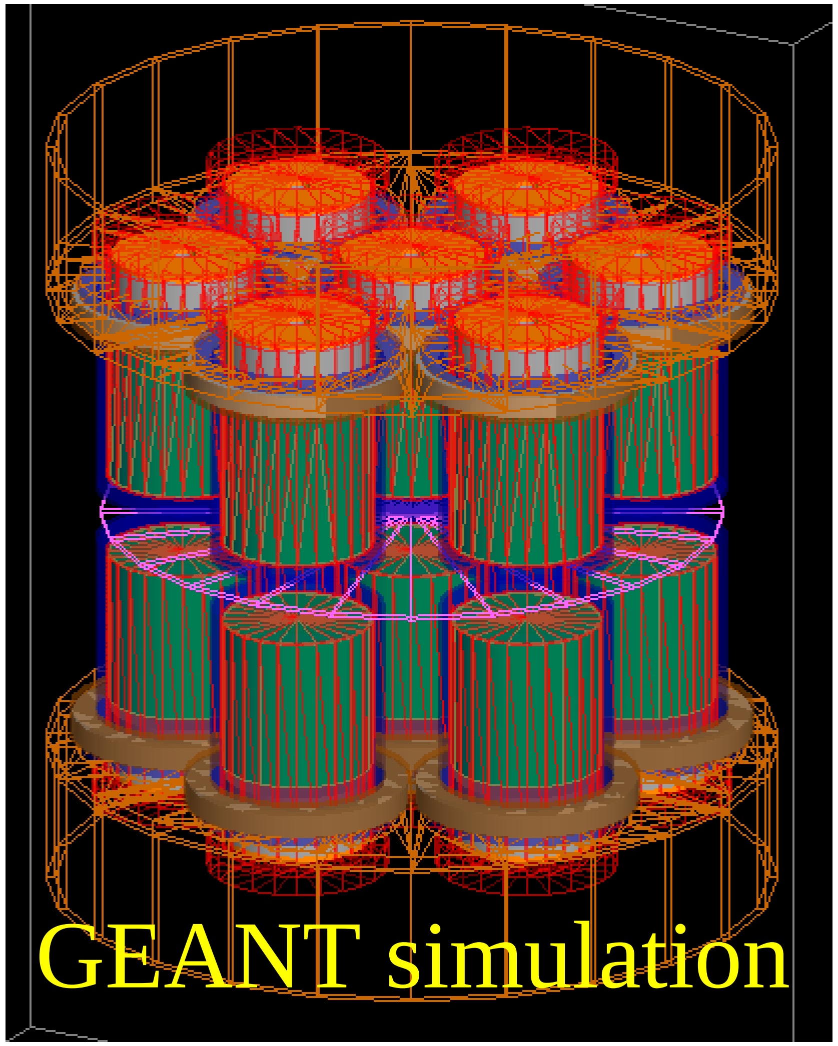
^{232}Th in Copper, MoO_3 powder

Expecting high **sensitivity**

RARE DECAYS SEARCHES

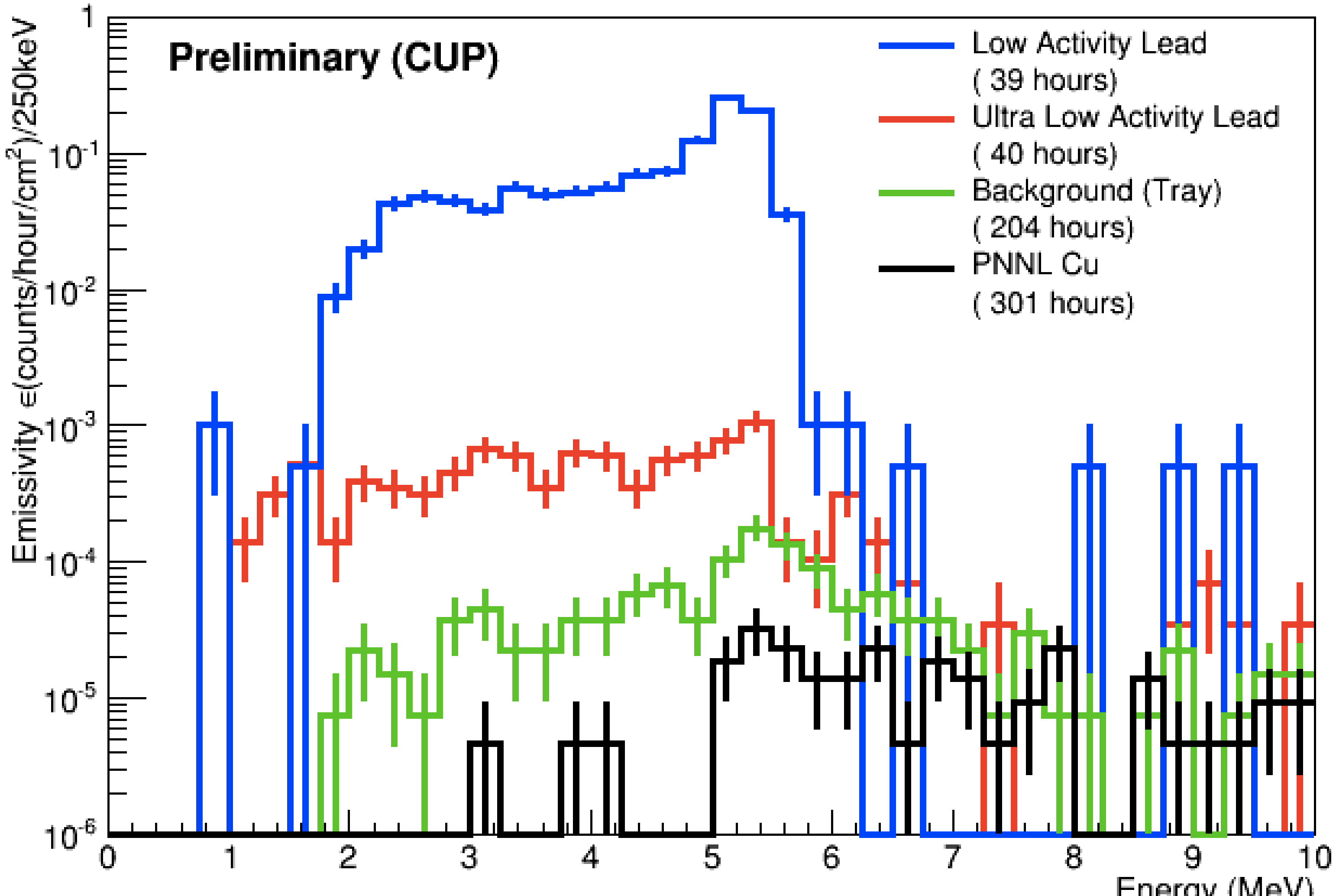
^{180m}Ta rare beta decay

Resonant 0ν Double Electron Capture (^{156}Dy)



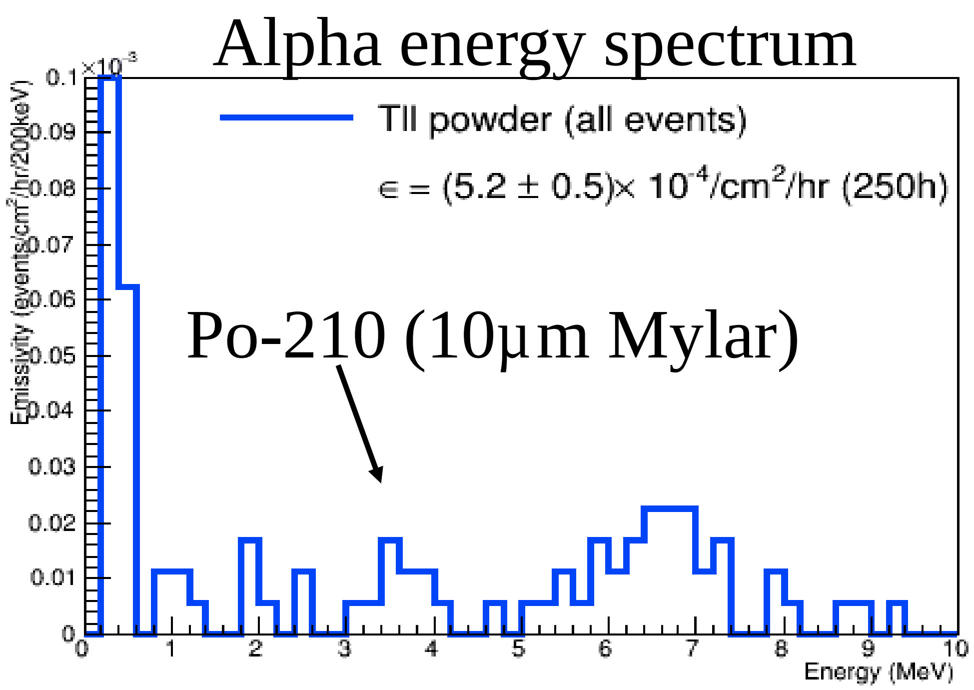
Alpha Counter

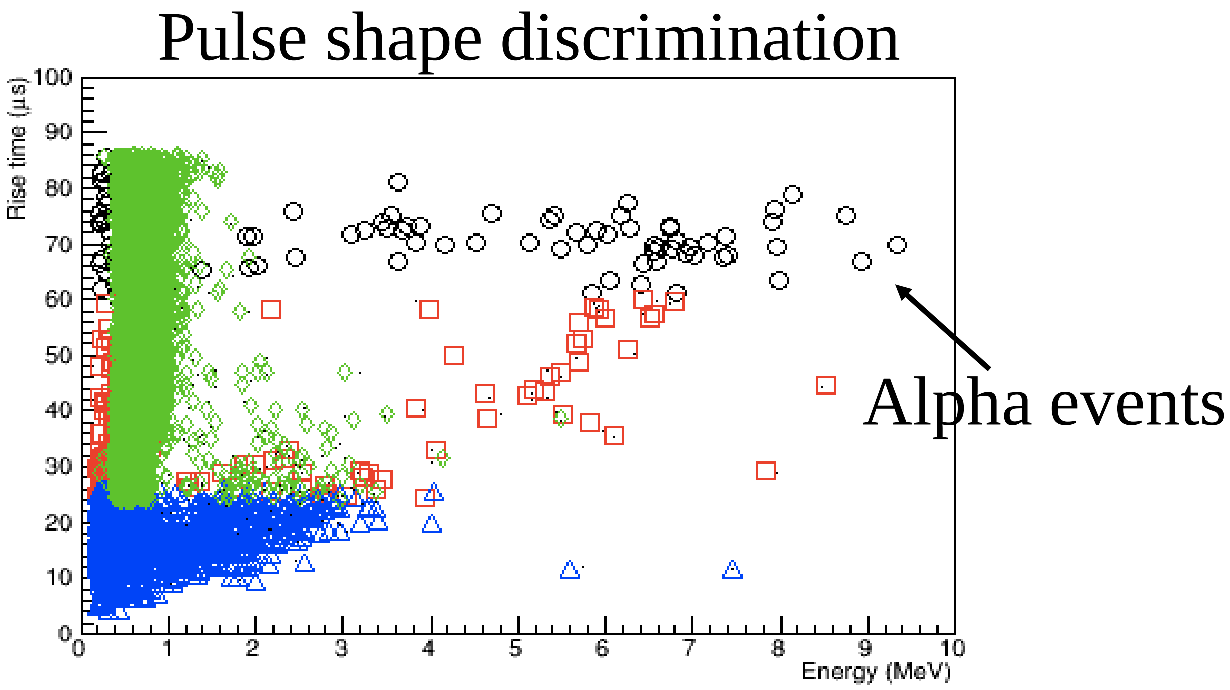
- An extremely sensitive alpha counter (gas ionization chamber) is purchased from XIA and installed at Y2L in May 2015.
- Background rate : ~ 0.0001 alphas/cm^2/hour.
- Essential to study Pb-210 surface contamination for rare process experiments.



TlI powder measurement

- **TlI (and NaI) powders measurements**
- **Pb-210 contamination in powder estimated before crystal growth**



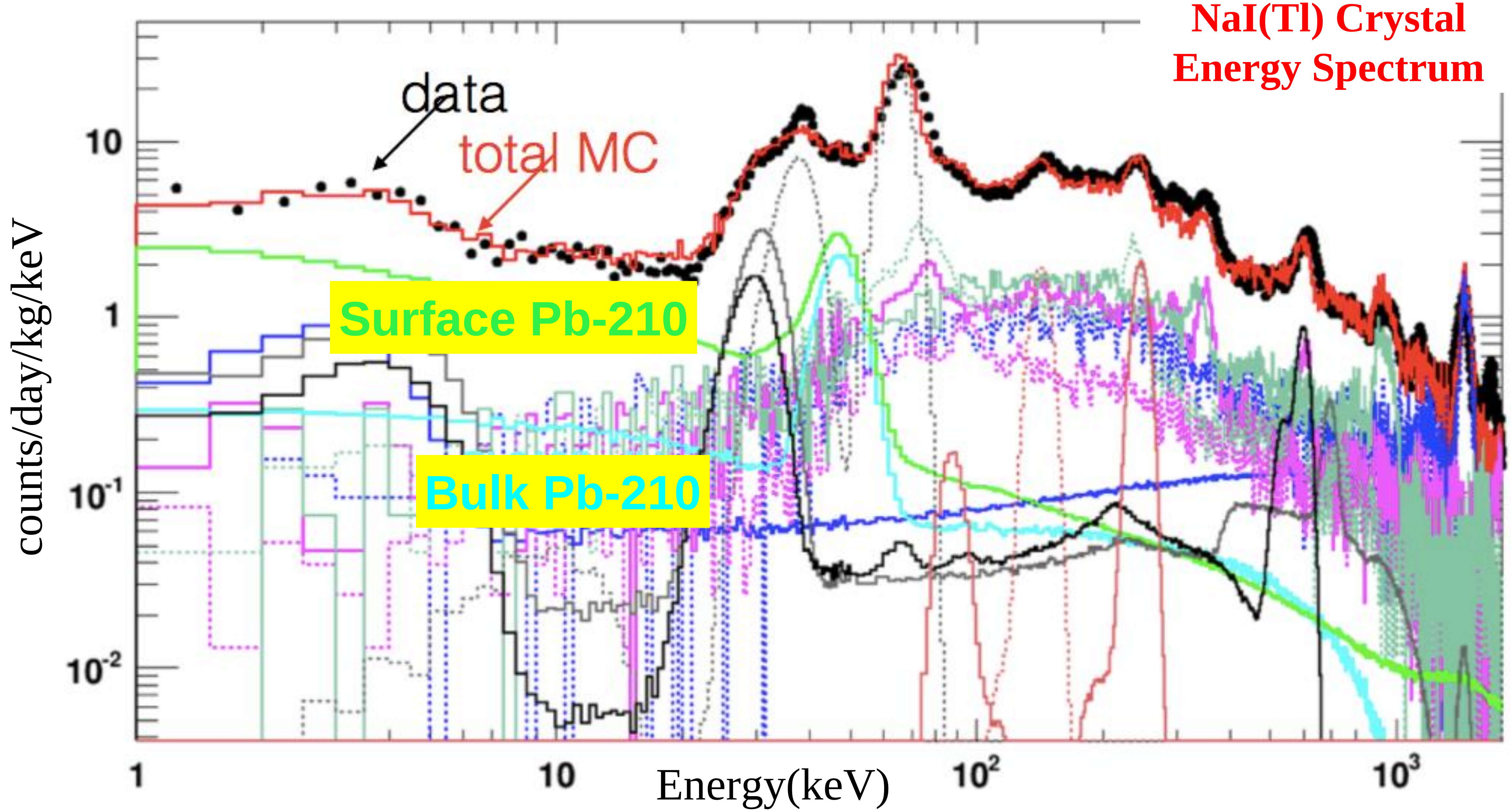


- The Po-210 activity is estimated to be

  $1.1\text{x}10^{-4}$ counts/cm^2/h
  (< 4 mBq/kg)

Pb-210 in the Dark Matter search

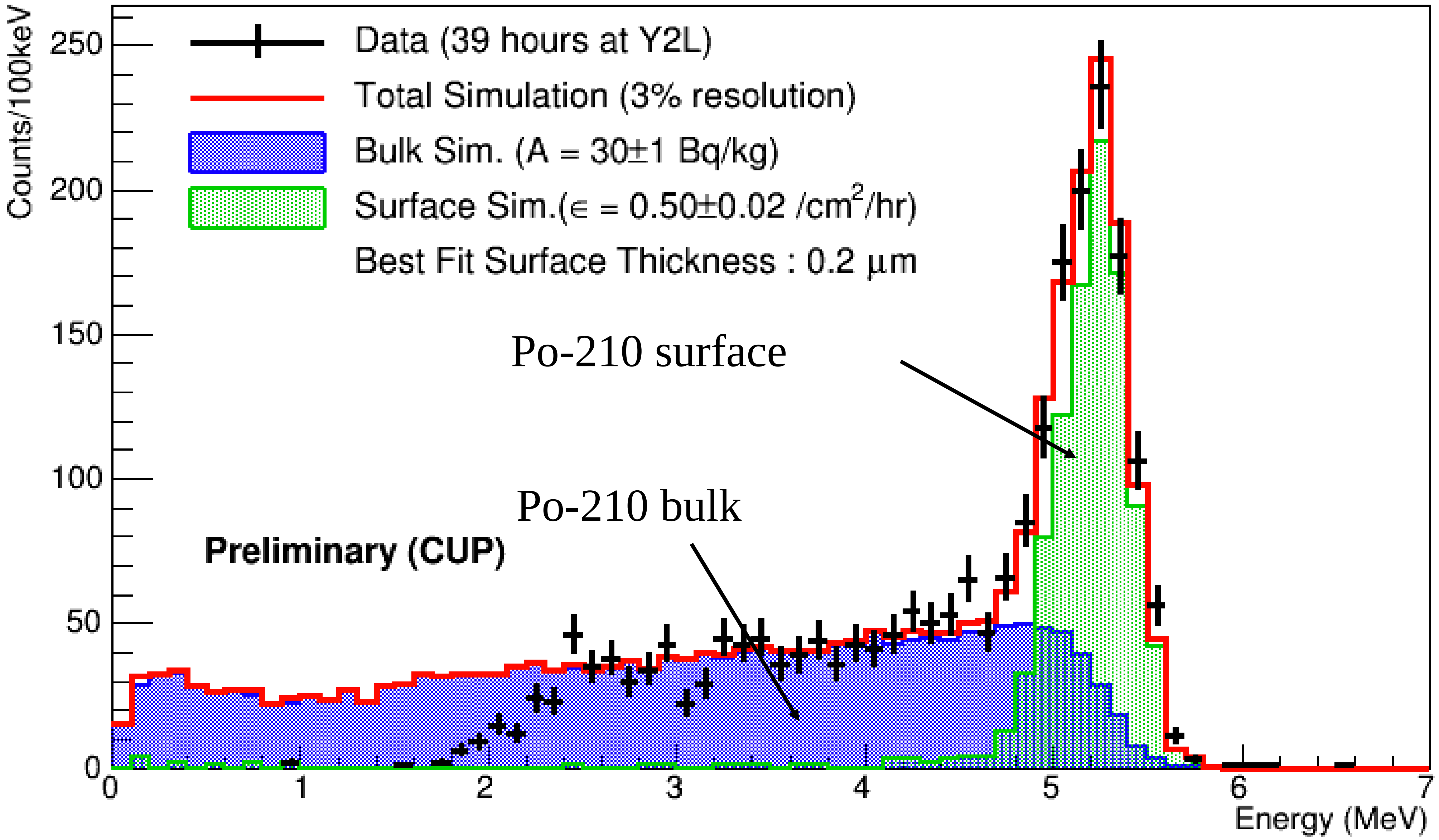
NaI(Tl) Crystal Energy Spectrum



At low energies below 20 keV, Pb-210 is the main background source. Where the contamination is (bulk or surface) is also important.

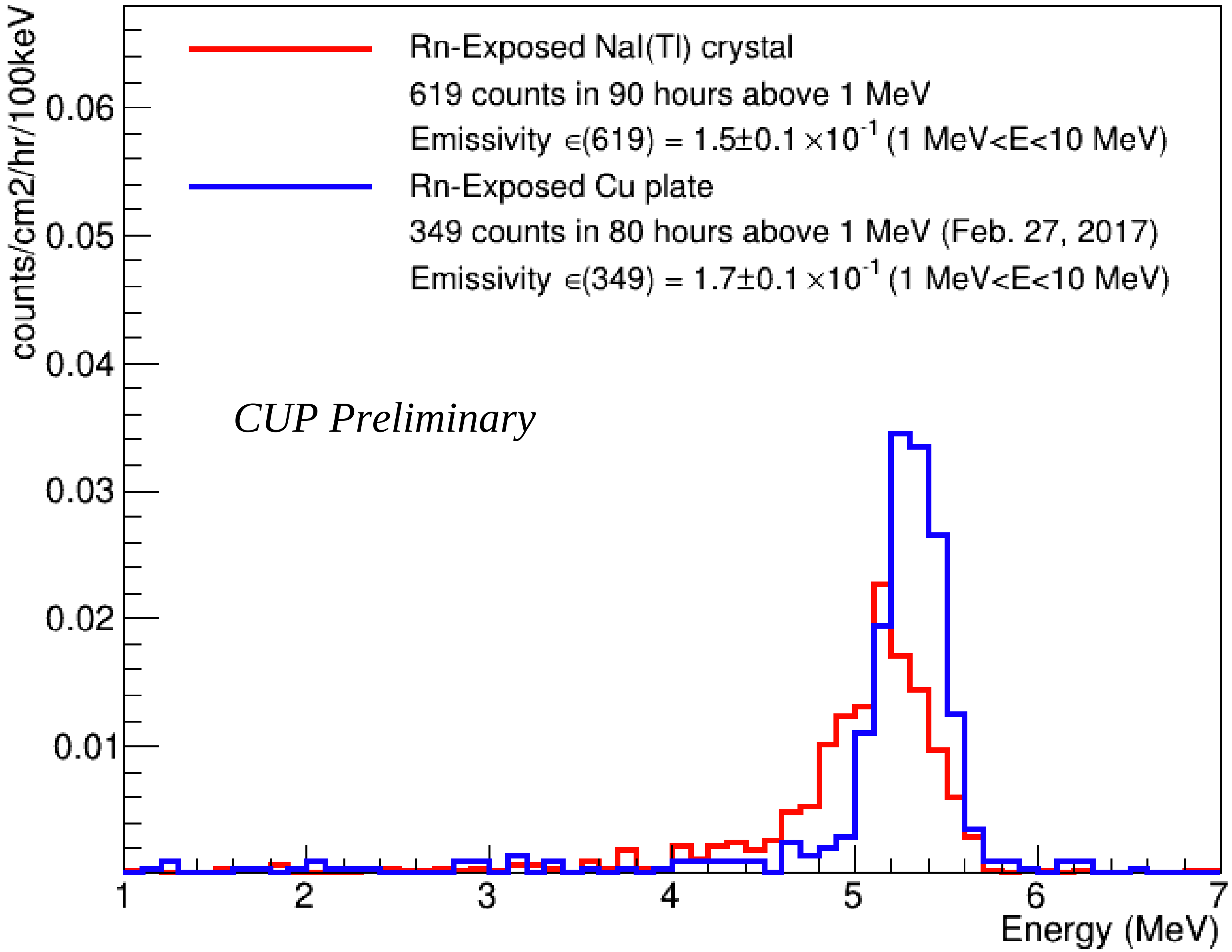
Surface vs Bulk

- **Surface component from bulk component can be separated by using a maximum likelihood fit**
- **Can pinpoint where the contamination happens**



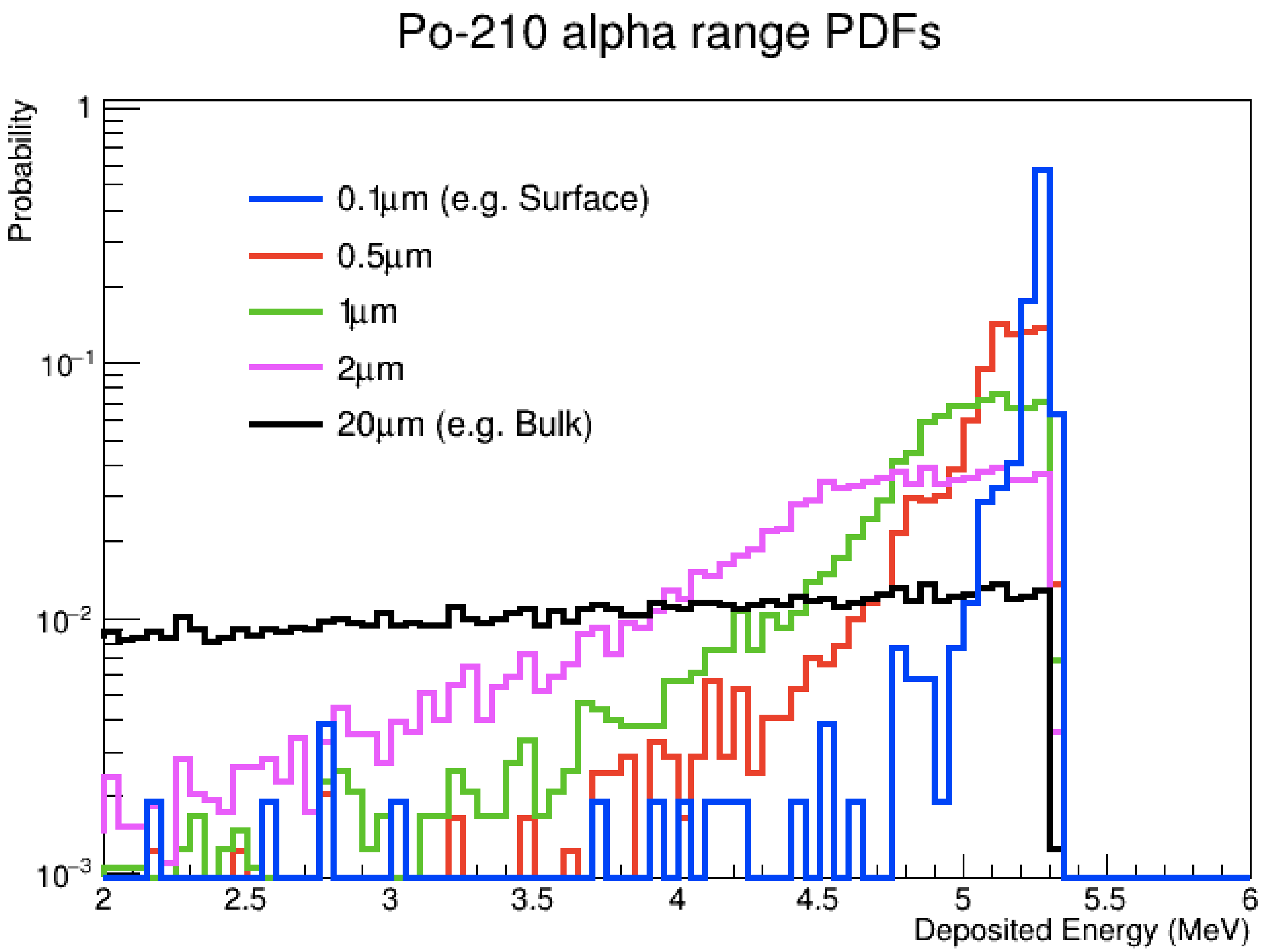
Lead Bar Dimension : 10cm x 5cm x 0.5cm

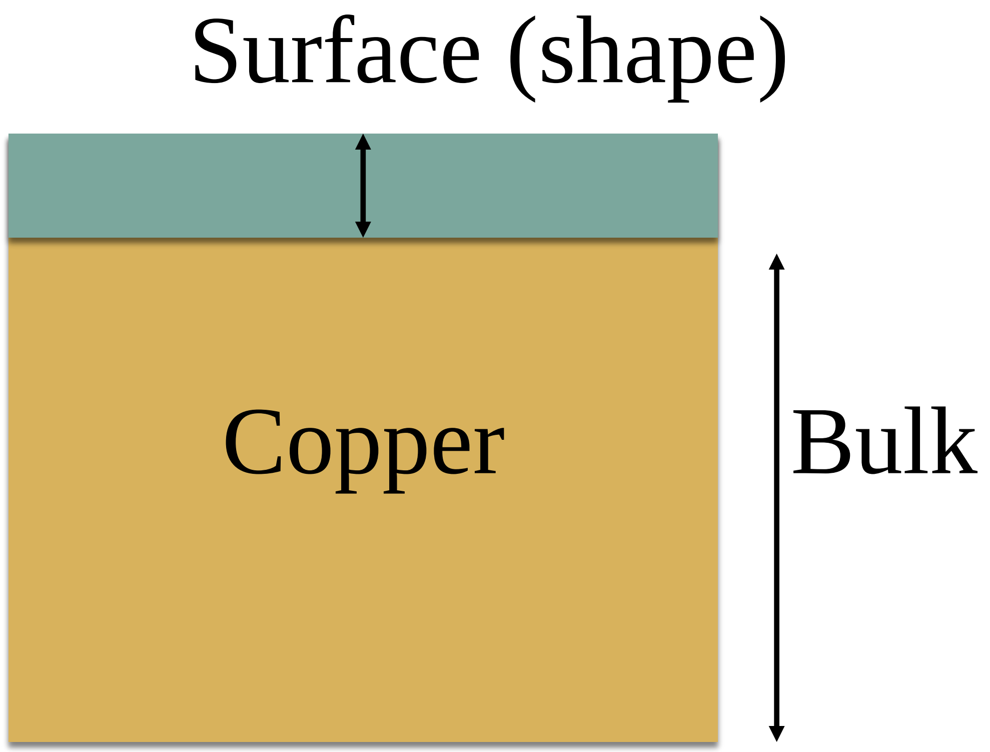
NaI(Tl) crystal vs. Cu plate

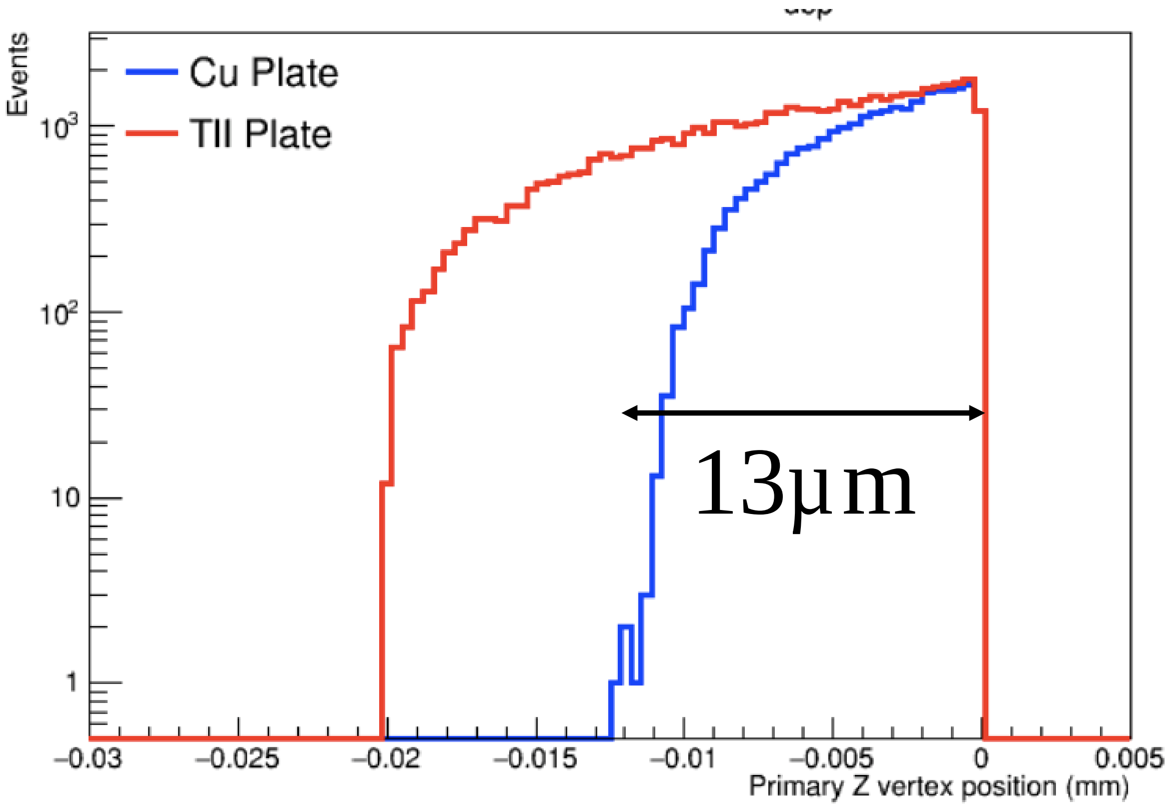


A similar emissivity between two samples.
NaI(Tl) crystal full peak shifted towards lower energy →
Deeper surface penetration of Po-210 in the crystal

PDFs vs surface depths from Geant4



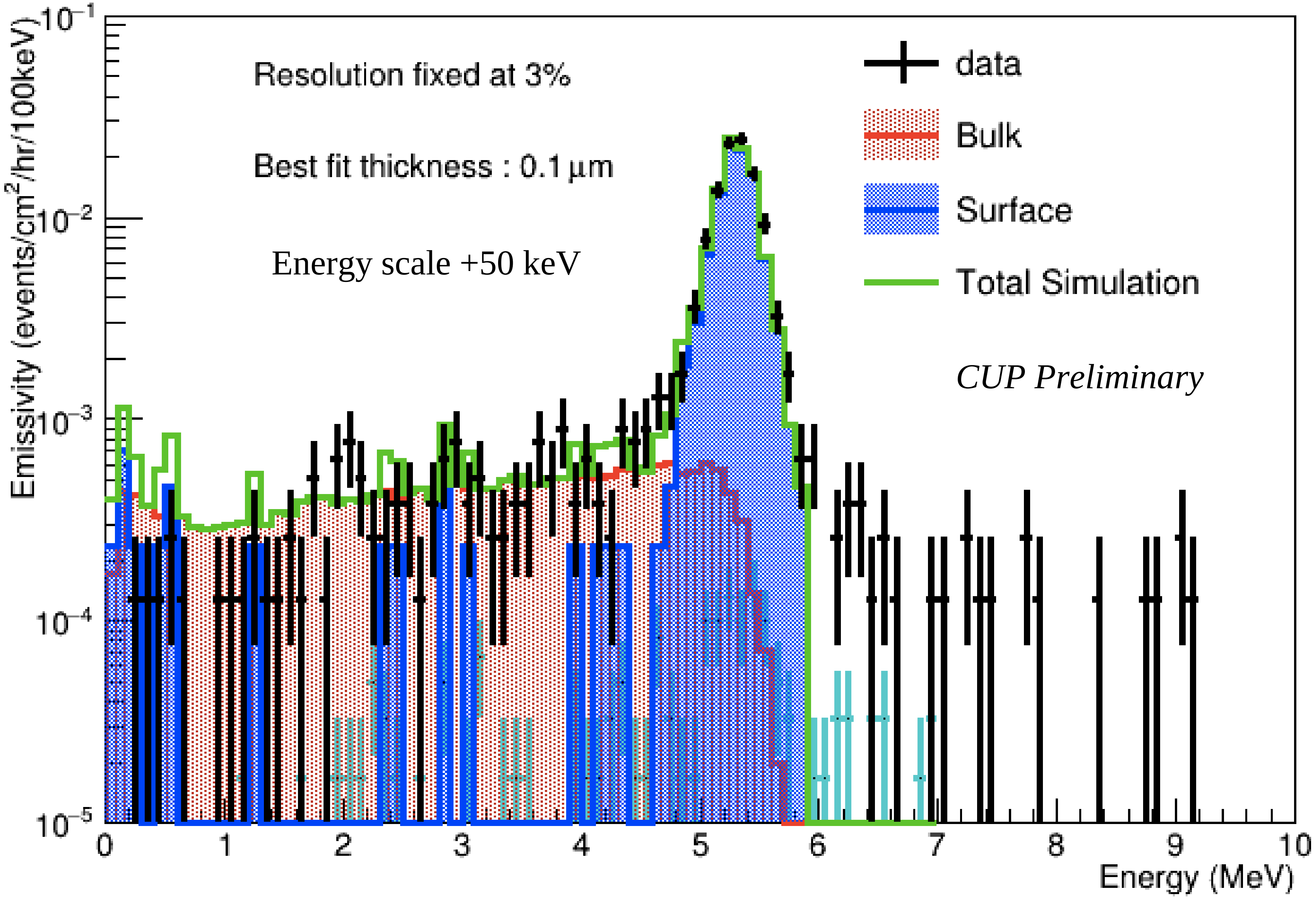




- Max. depth of Po-210 alpha for copper is around 13 μm.
- A linear decrease in Po-210 population with surface depth is assumed.

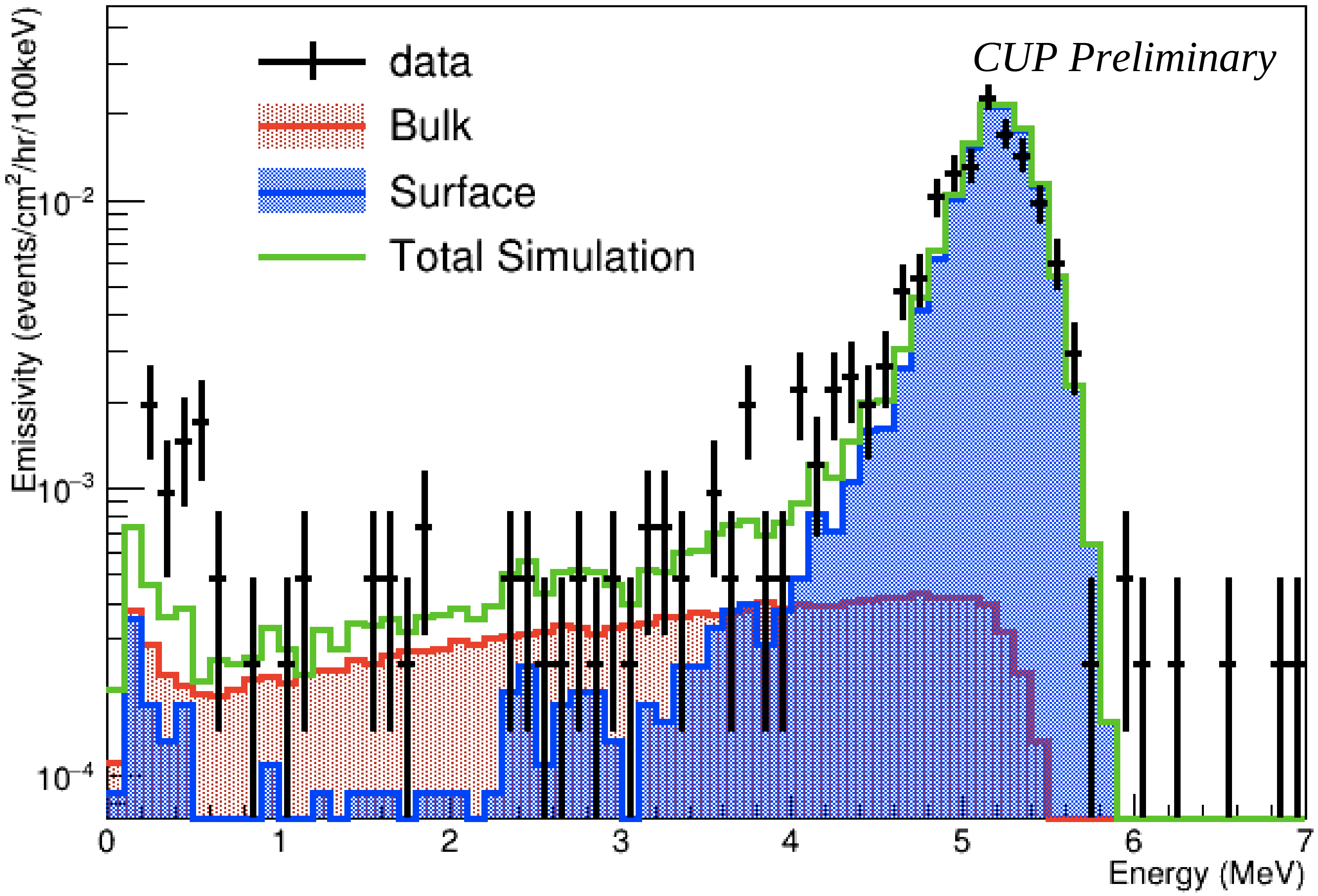
Pb-210 in the copper surface

(Maximum Likelihood Fit to separate surface from bulk)



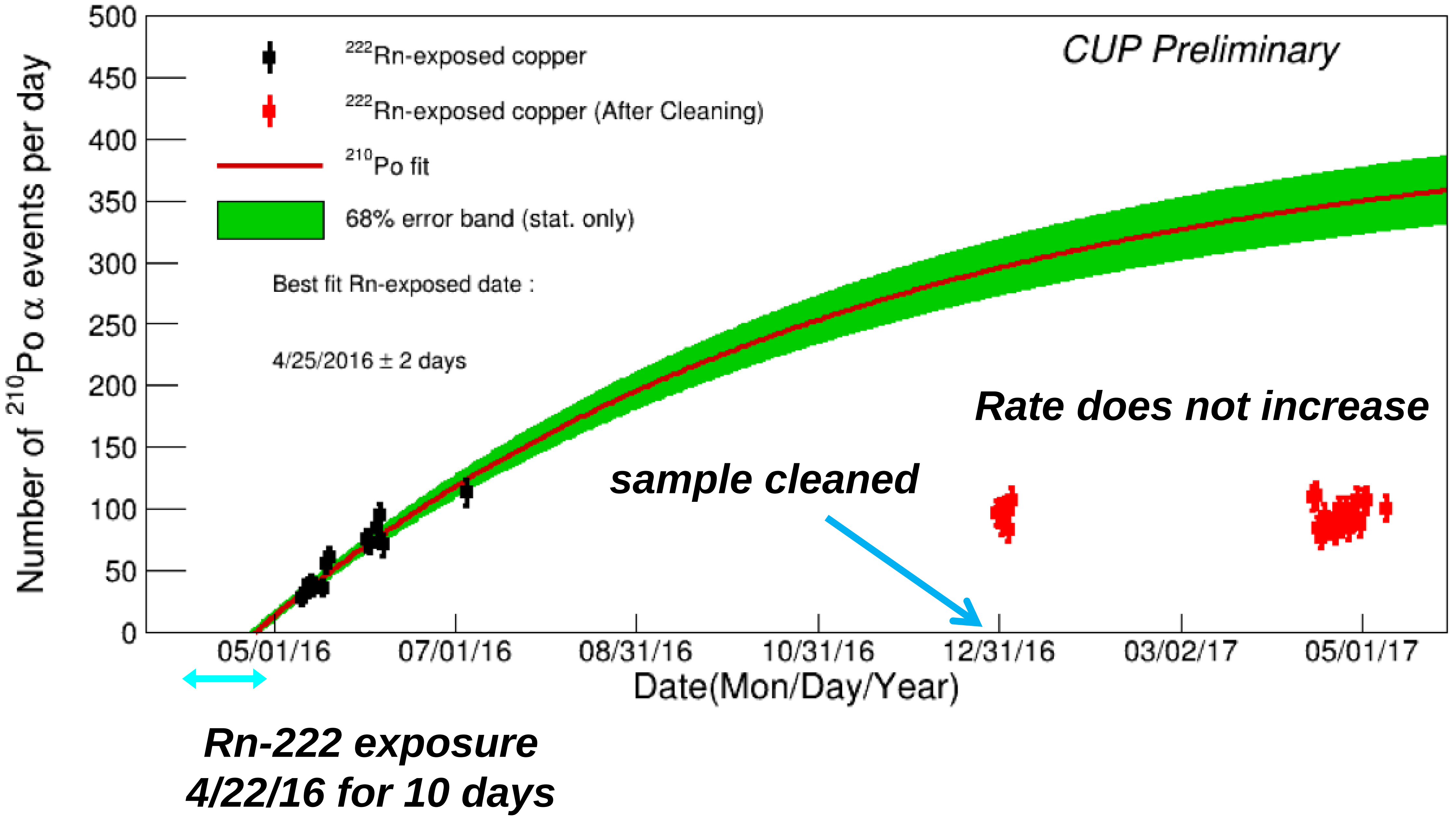
The best fit thickness of the bulk component shows the Po-210 diffusion depth is shallow (0.1 μm) for this sample.

Pb-210 in the NaI(Tl)



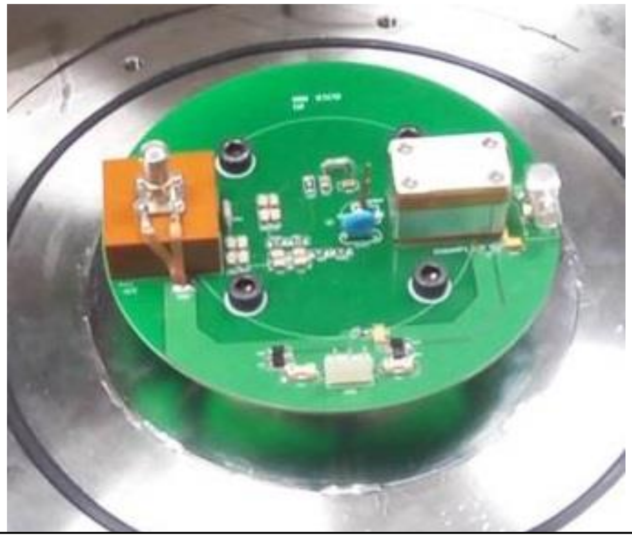
Po-210 depth is estimated at around 1.2+/-1.0 μm (stat. only) in the NaI(Tl) crystal. More accurate estimation requires to understand how particle diffusion happens in the surface.

Rn-exposed Copper plate

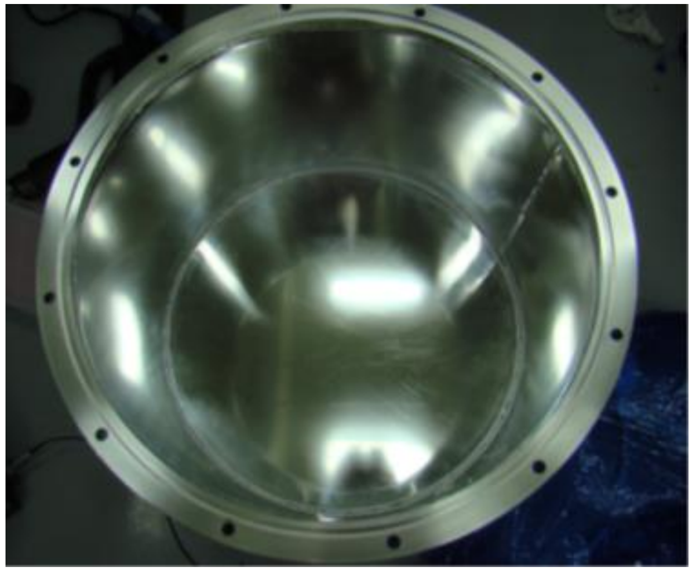


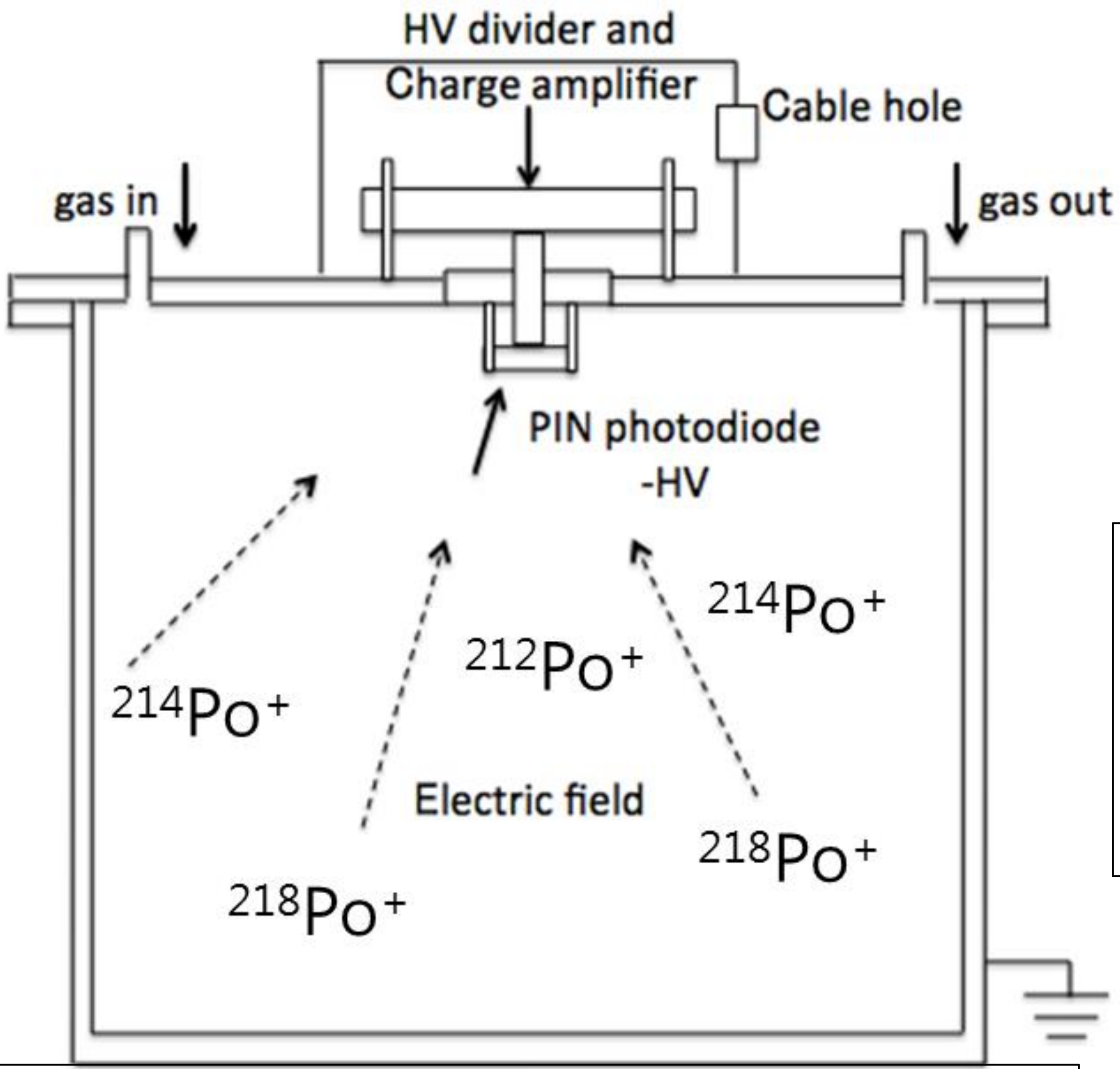
Radon contamination date can be pinpointed with alpha data.
Chemical surface cleaning shows removal of contamination.

Ultra-sensitive Radon detector

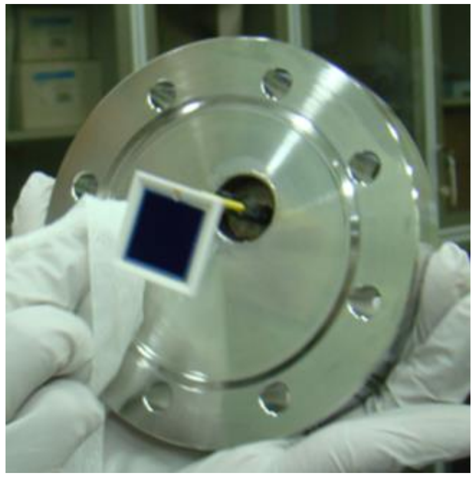


- Hamamatsu charge sensitive amplifier (H4083)
- HV divider circuit

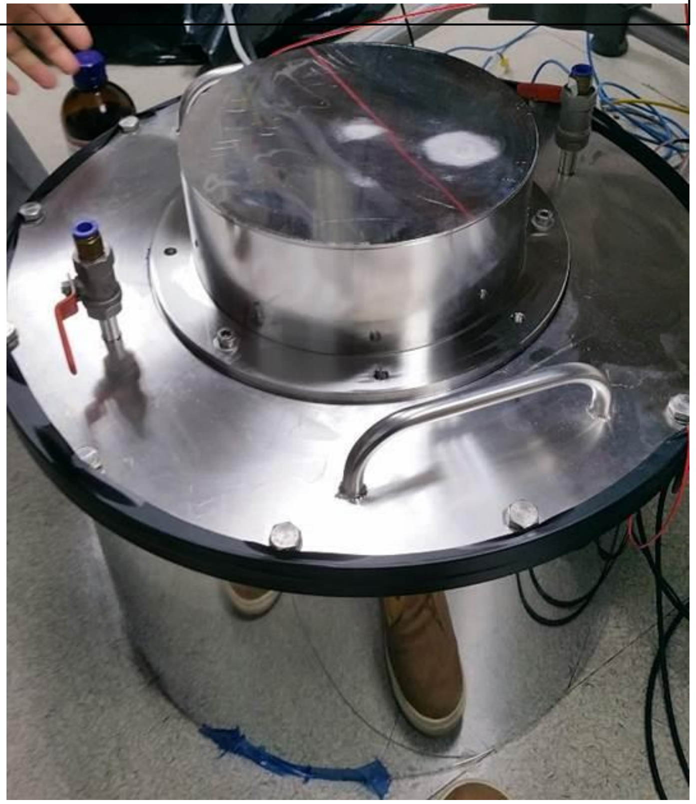




- Volume = 70 L
- High Voltage = –1,000 V
- Bias = 30 V
- Stainless steel with electro-polished inside surfaces
- Shaping amplifier with ×12 gain
- 12 bit 25 MS/s FADC

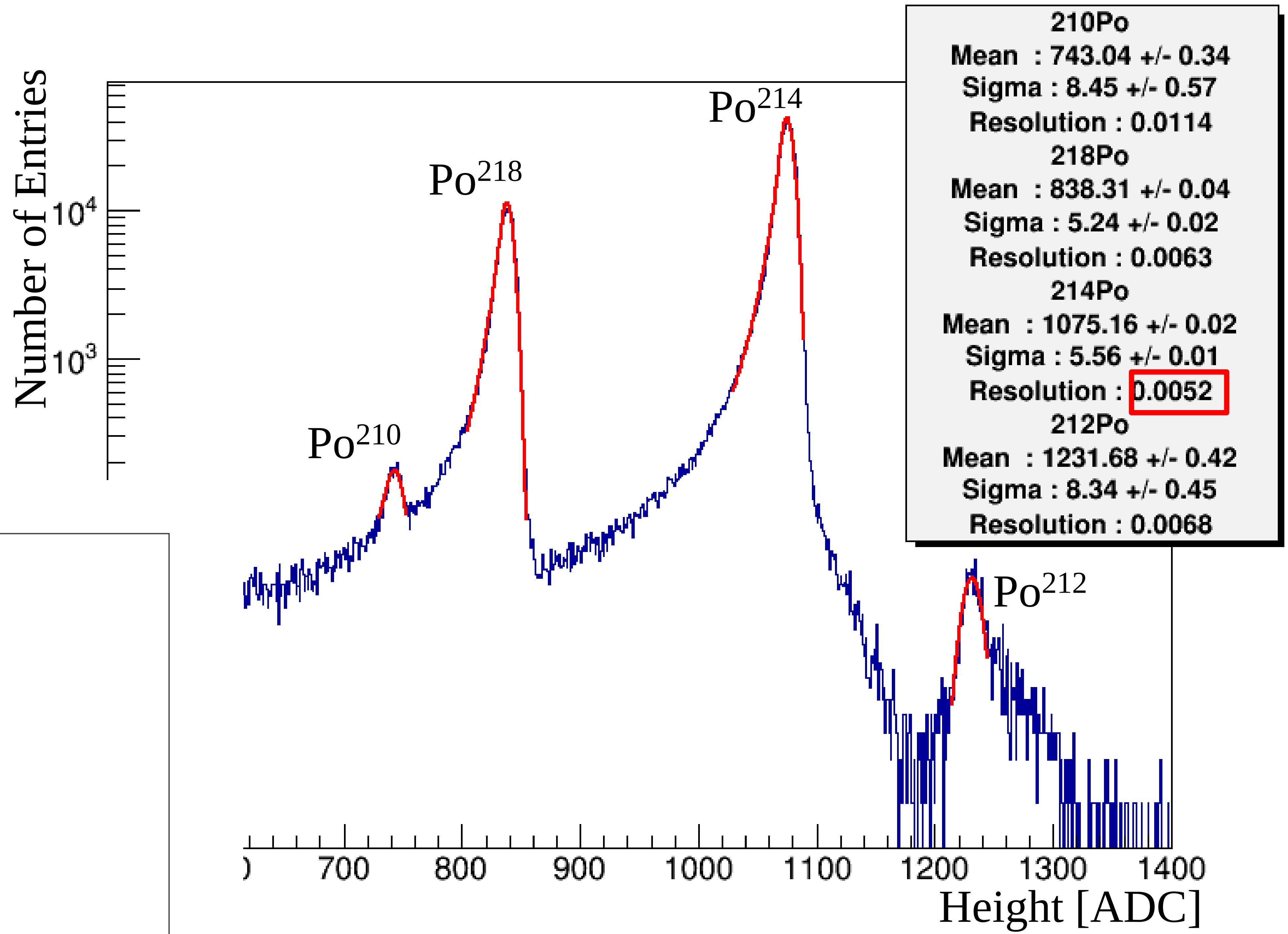


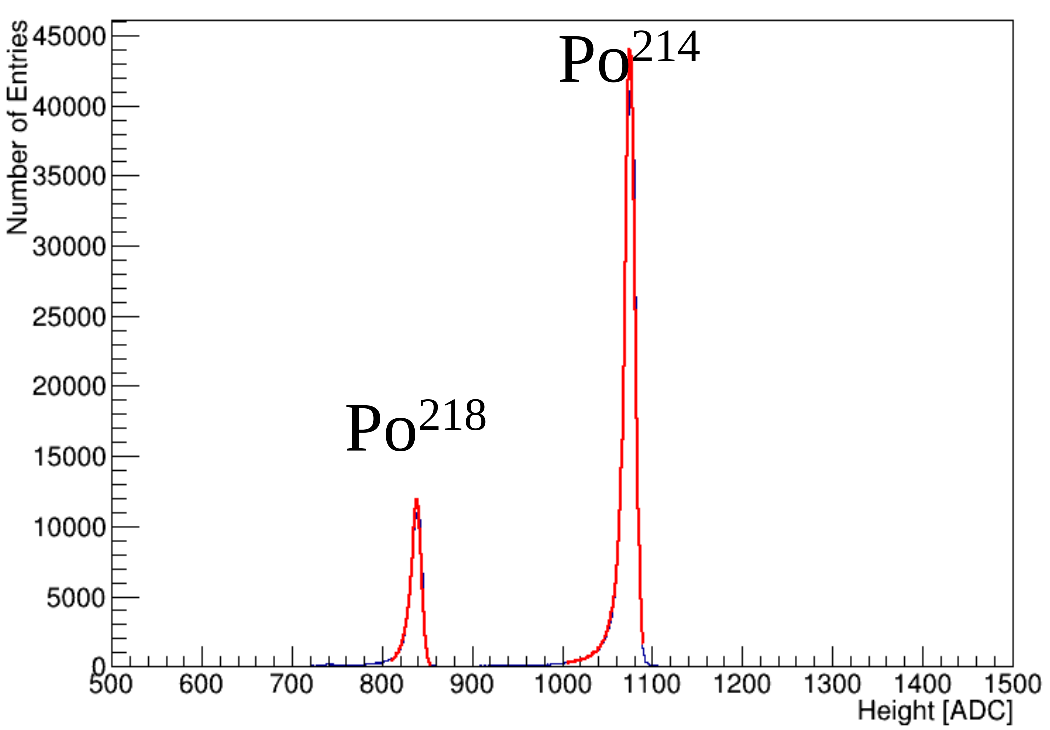
- Hamamatsu silicon PIN photodiode (S3204-9) 18 × 18 mm^2



Pulse height distribution

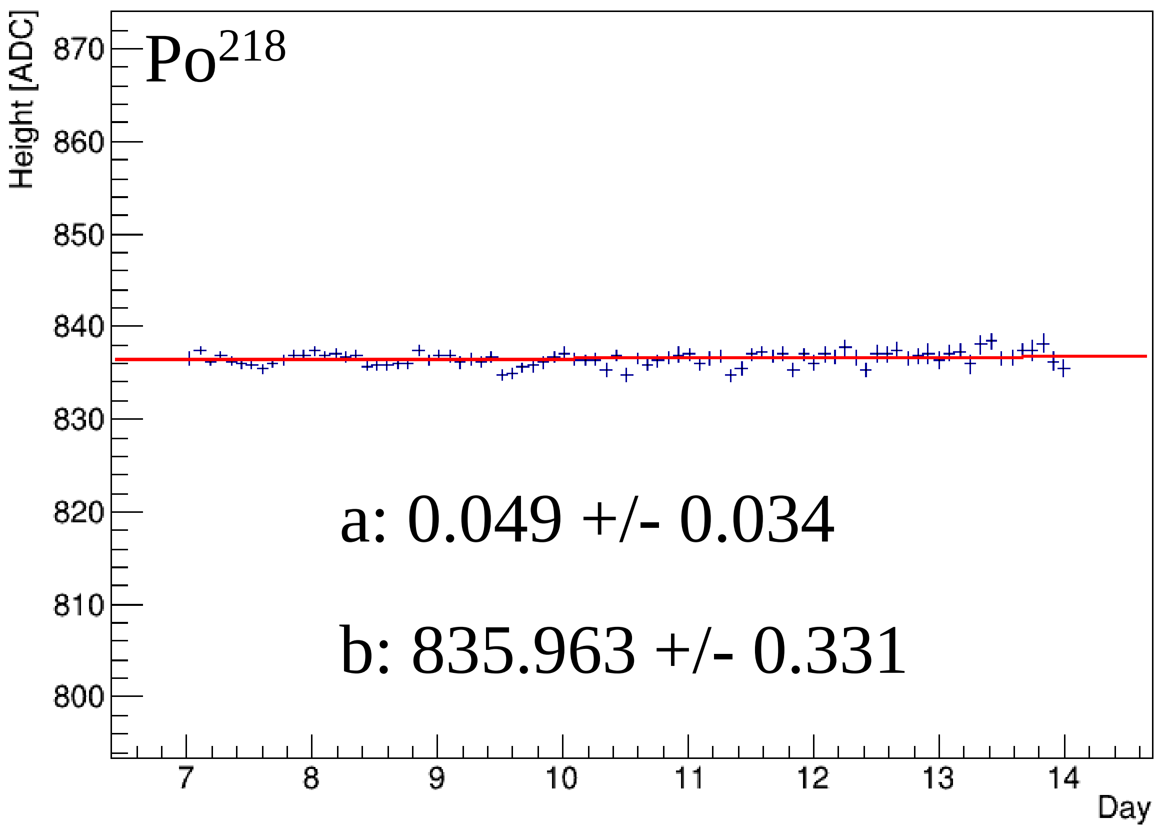
- Pulse height distribution using data of 90 days. No humidity control.
- Crystal ball function is used for all peaks.
- (Sigma) Resolution is less than or equal to **1 %** for each peaks.

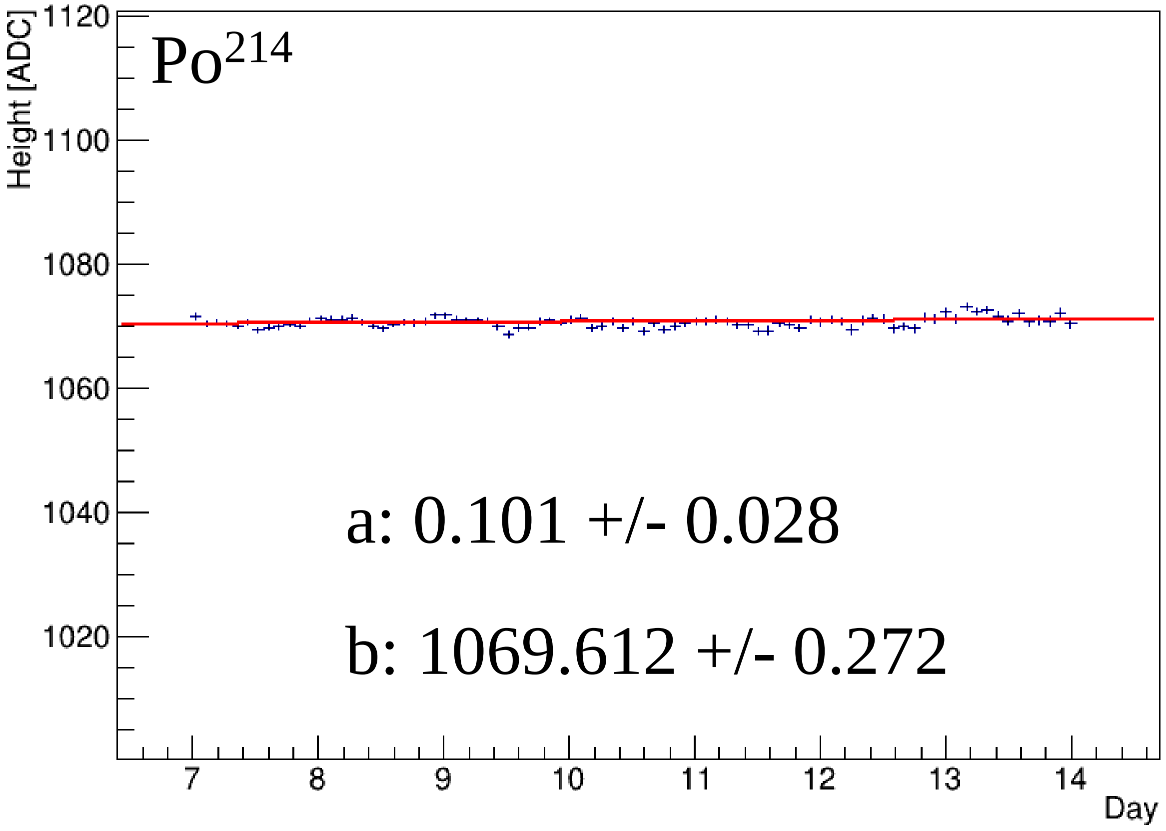




Stability check

- Profiles of Po^{214} & Po^{218} (selected within 2 sigma) with time
- Linear function fit (ax + b)





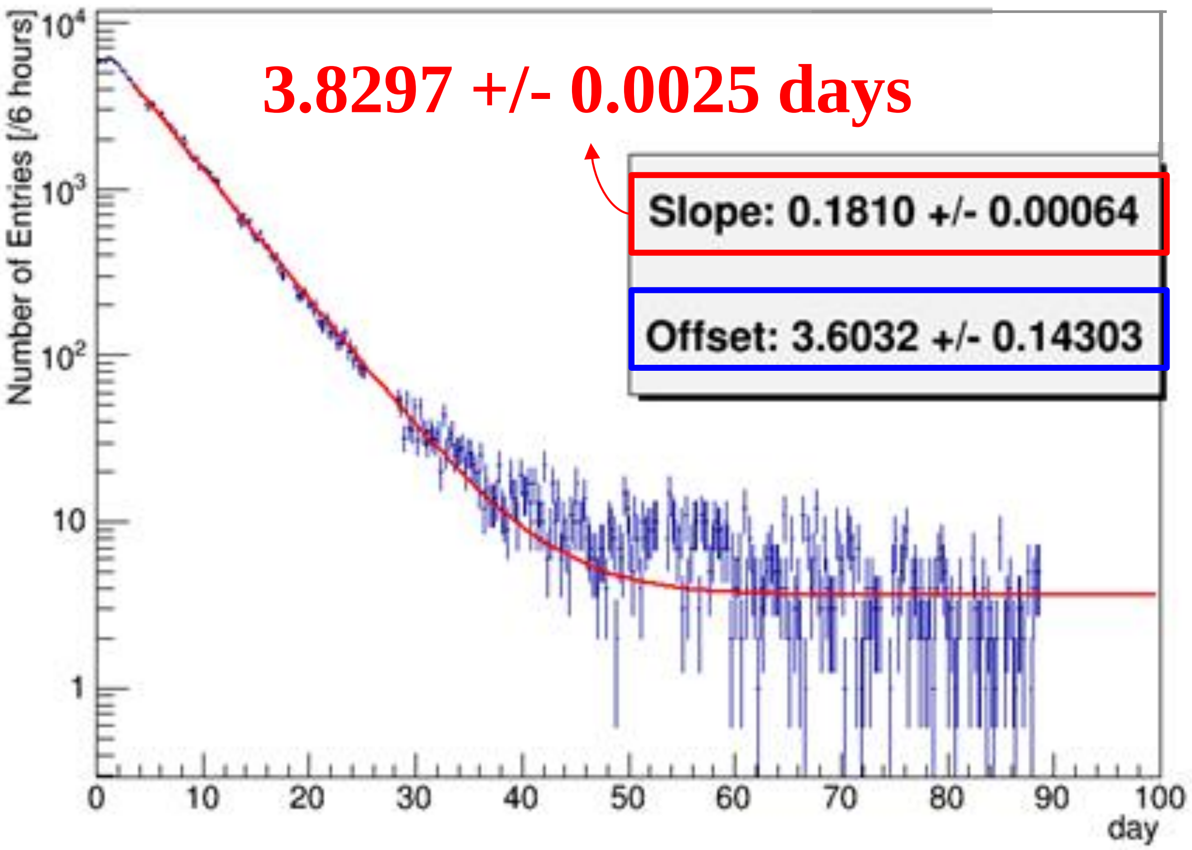
Test setup is stable

Half lifetime measurements

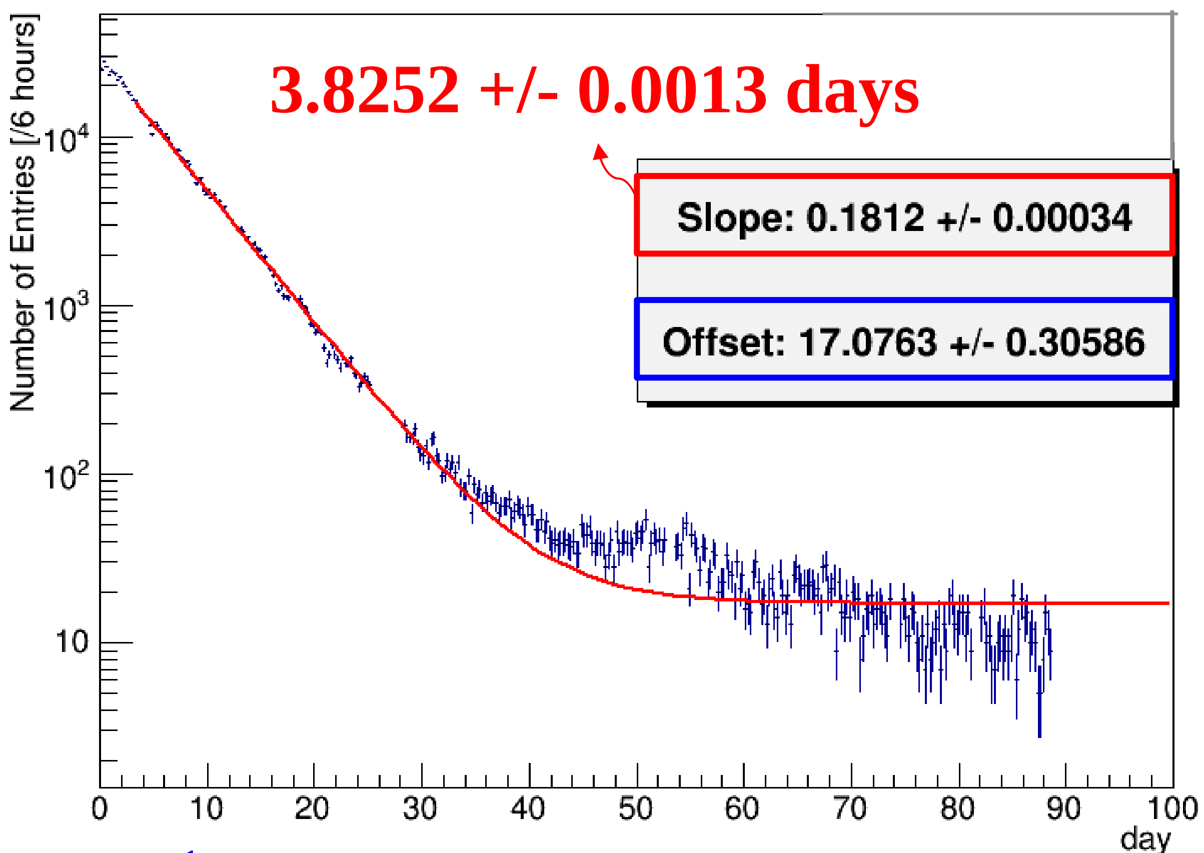
- Measured the half lifetime of Rn^{222} using Po^{214} & Po^{218} events (within 2 sigma).
- Fitting function: $ae^{-bt} + c$

$T_{1/2}$ (NNDC): 3.8235 days NNDC: National Nuclear Data Center (BNL)

Po²¹⁸



Po²¹⁴

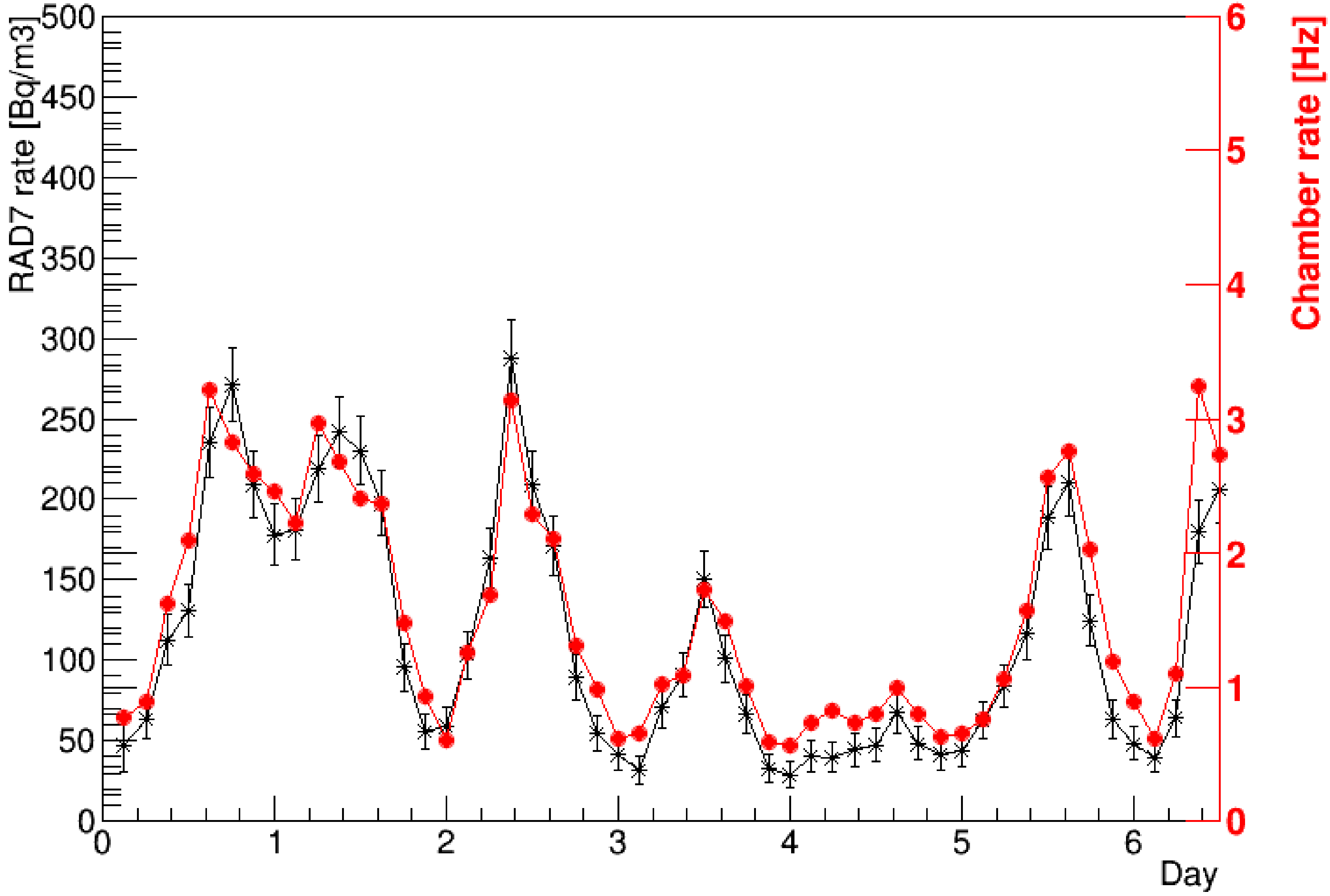


The background level obtained from the offset is $\sim \frac{1}{2000} \times \text{Max}$

Radon concentration of the initial air (RAD7): 150 Bq/m³ ⇒ **0.075 Bq/m³ BKG level**

A comparison with RAD7 data

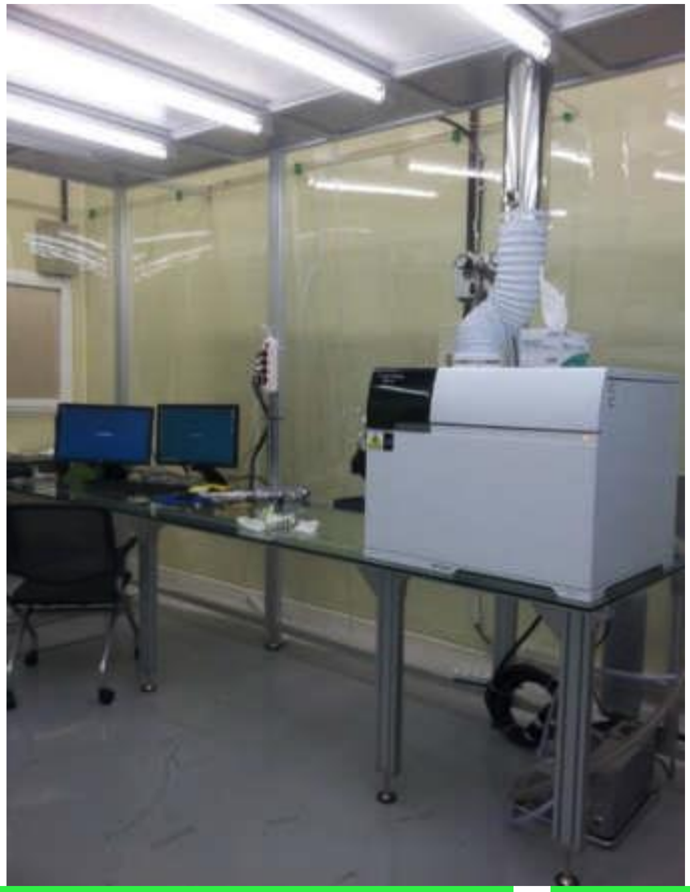
June 5 – 16, 2017 runs
no humidity control, 2hr runs, 2 hr circulation



A full system with dew point meter, filter, flow meter, barometer, etc.. is being prepared.

ICP-MS (Agilent 7900)

- Agilent 7900 is operating since Oct. 2015.
- In a cleanroom nominally designed as class 1000 with >150 air changes/hour.
- A Millipore DI system, in-house acid distillation with a 3 linear meters of chemical hood space.
- Dissolve sample in liquid form, uptake in argon (Ar) gas stream, ionize gas, extract into mass spectrometer, measure trace contaminants.
- Confirmation of purification methods by measuring isotopic or chemical tracers.
- Confidence in systematics at ultra-trace levels is not easily achievable through outsourced measurements.



Crystals for AMoRE-II

- $^{dep48}Ca^{100}MoO_4$ crystals: $^{dep48}CaCO_3$ & $^{100}MoO_3$ powders
- Li_2MoO_4 crystals: Li_2CO_3 & $^{100}MoO_3$ powders
- $Na_2Mo_2O_7$ crystals: Na_2CO_3 & $^{100}MoO_3$ powders

	ppt		mBq/kg		
Samples	^{232}**Th**	^{238}**U**	^{226}**Ra (U)**	^{224}**Ra (Th)**	^{40}**K**
^{100}Mo (99.997%)	< 46	73	8.3	< 1	9
	< 61	149	3.8	< 0.8	36
^{dep48}Ca	< 1000	< 1000	51	1	-
Li_2CO_3 (99.998%)	9.6	414	0.95	0.41	9.0
Na_2CO_3 (99.997%)	<52	<52	4.15	0.52	31.5

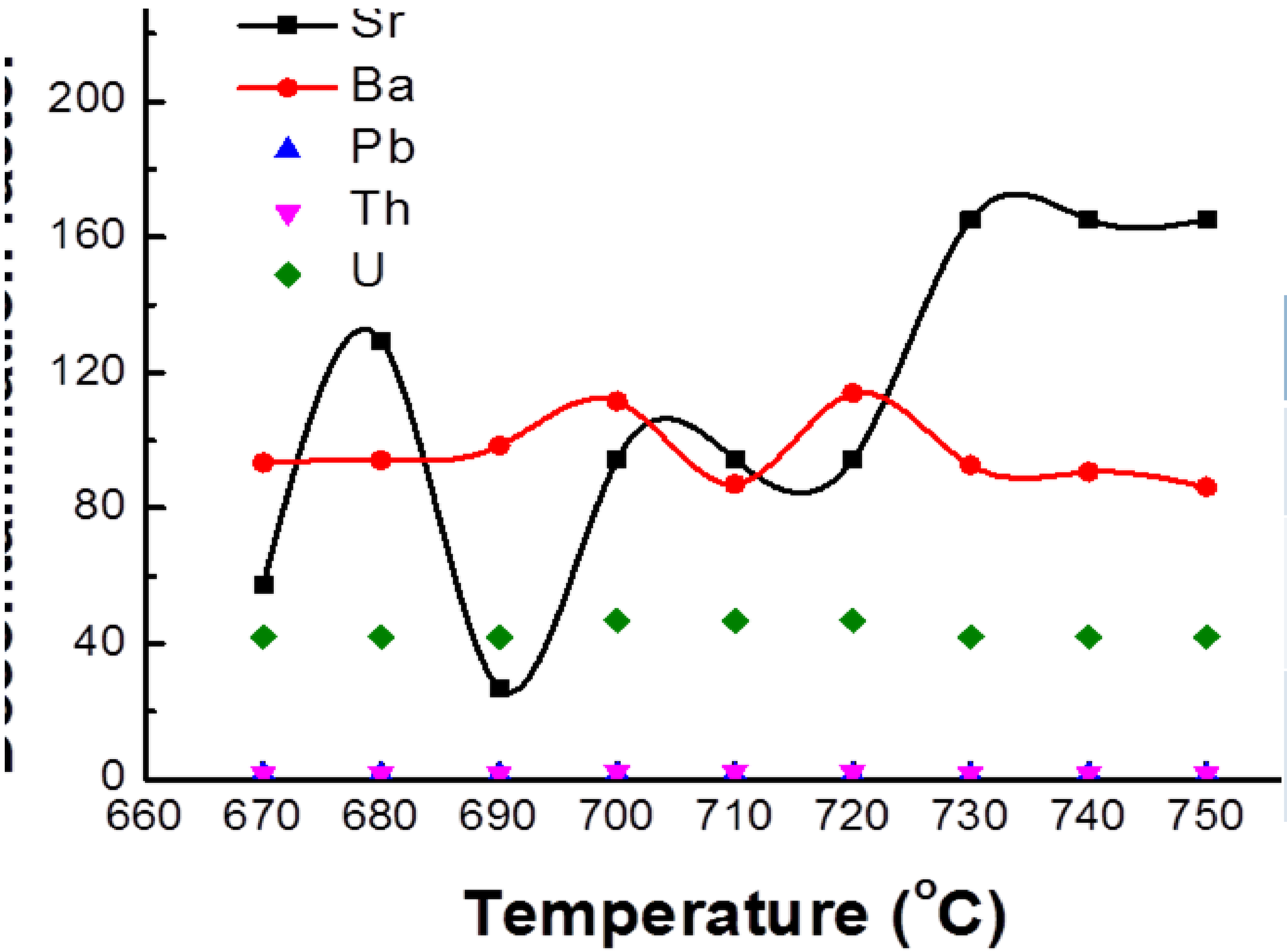
Requirements for ^{238}U & ^{232}Th: ~ µBq/kg in crystals
→ ~1,000 reduction

Purification of MoO_3 powder

- MoO_3 has the transition from the solid to the gas phase around 700 ^oC. → Some impurities, U/Th, are still in the solid phases.

- Decontamination factor (DF) in sublimation

  D.F. = (initial impurity)/(final impurity)



ICP-MS results at 720 ^oC

	Sr	Ba	Th	U
Initial	6,605	1.37M	224	4,205
final	<70	0.012M	<100	<90
D.F.	>94	113	> 2	> 46

Note: Sr, Ba & Ra are the same family in periodic table

Summary

- Two of 100% HPGe detectors are running for measurements of various detector materials (i.e., crystals, copper, powders,..) after improving their shielding.
- A well-type Ge detector is available for measurements of samples obtained in the purification processes of raw materials.
- An array of 14 HPGe detectors is constructed in March 2017 for ultra-low background measurements and rare decay experiments. Background runs are on-going.
- A gas type alpha counter is running actively for measurements of alphas from the surfaces and bulks of detector materials since May 2015.
- A refurbished radon detector with an excellent resolution being prepared for the measurement of the air from the radon reduction system.
- An ICP-MS (Agilent 7900) is running well to test samples of detector materials and purification processes since Oct. 2015.