
# 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,**

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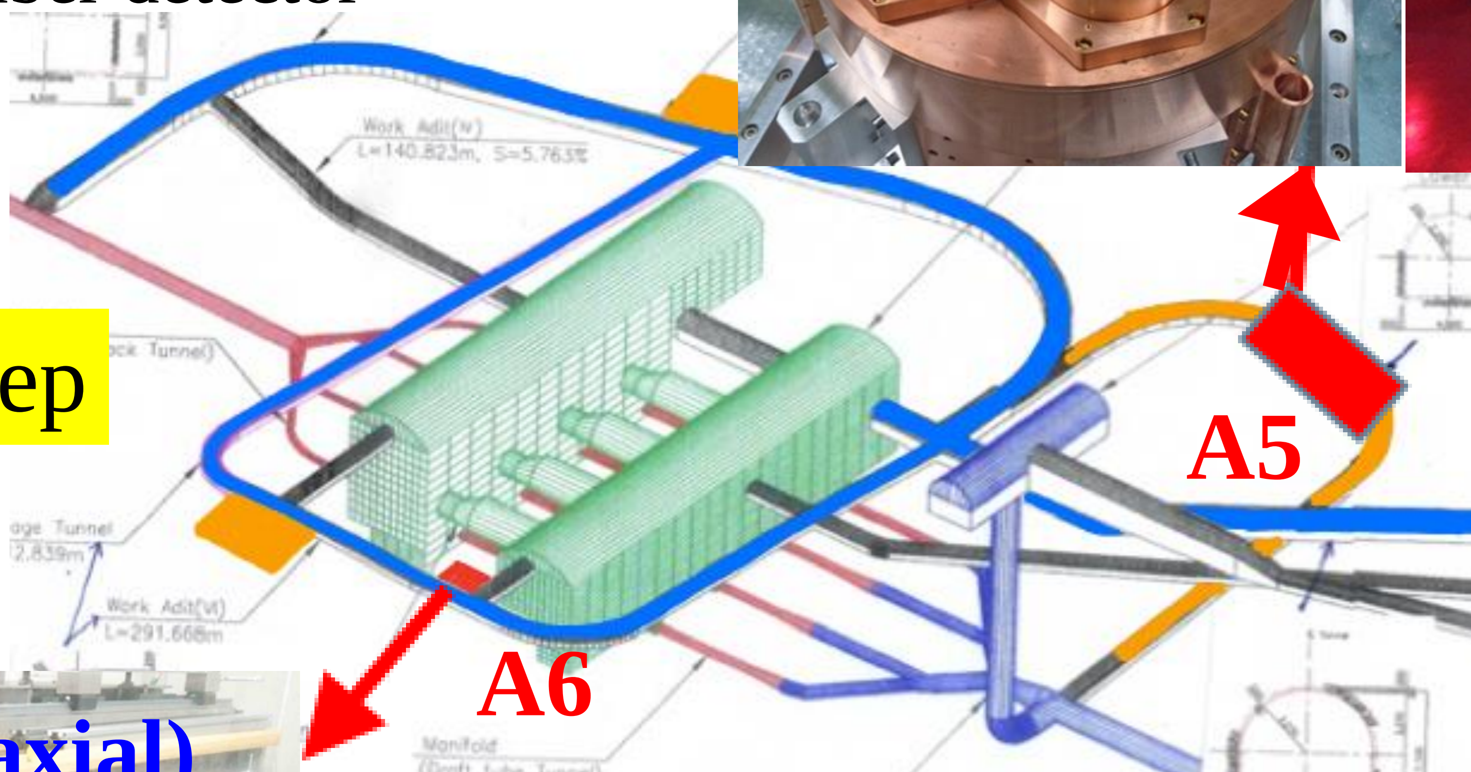
# Detectors at Yangyang Underground Laboratory

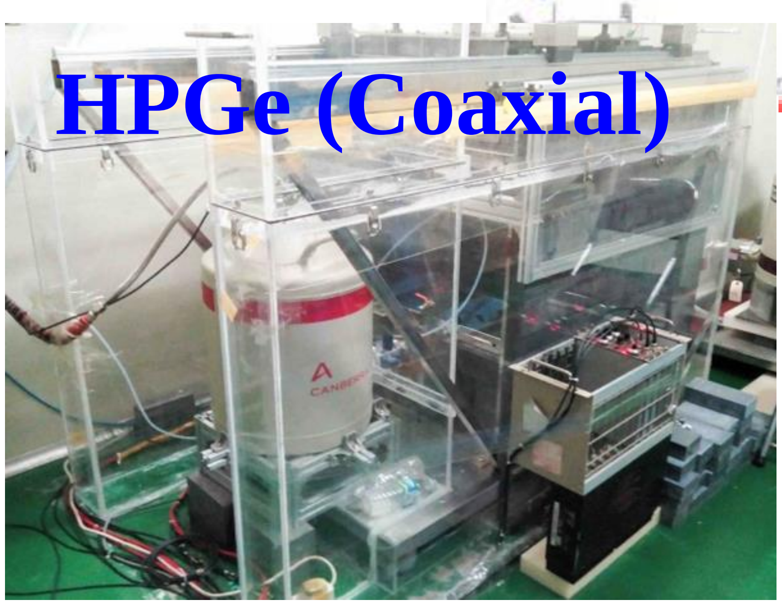


- 3 HPGe detectors (2 Coax, 1 Well)
- 1 Array with 14 HPGe detectors
- Alpha ionization counter
- Radon chamber detector



~700 m deep

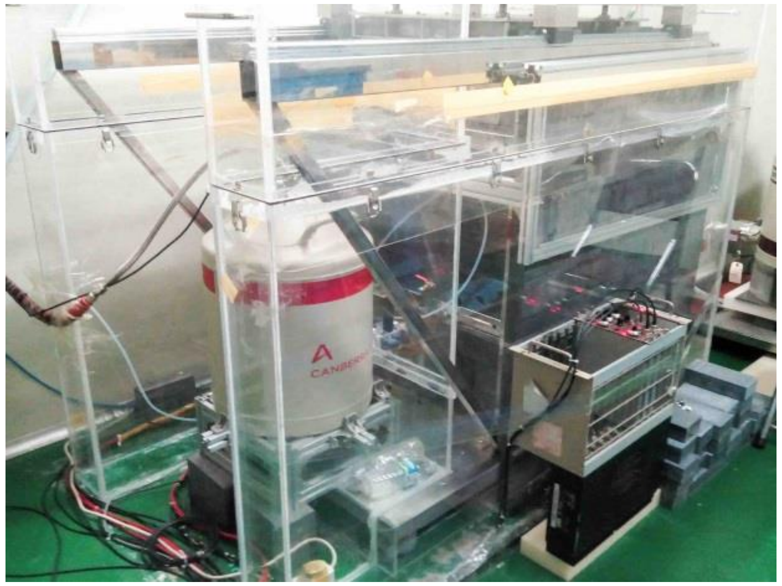




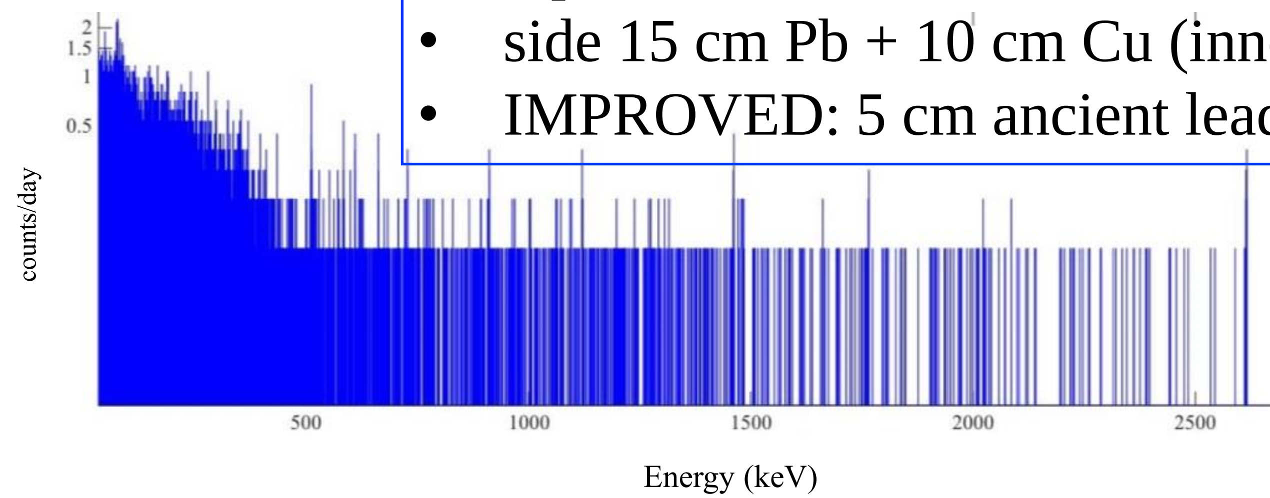
# HPGe detectors for sample measurements





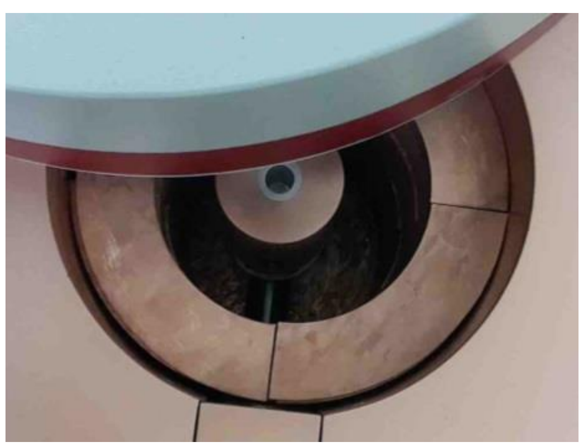
## CC1: 100% HPGe CANBERRA

- 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



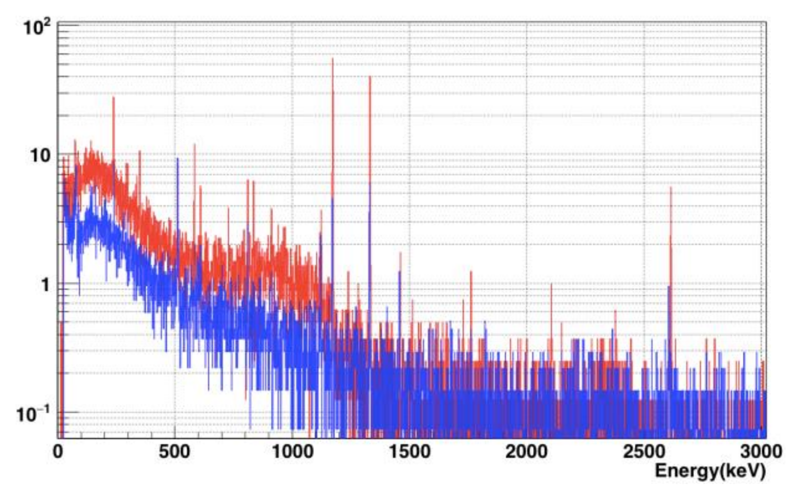

**Ge Well type detector**

**110** cc of ACTIVE VOLUME



## CC2: 100% HPGe CANBERRA

- A new installation with a new improved shielding



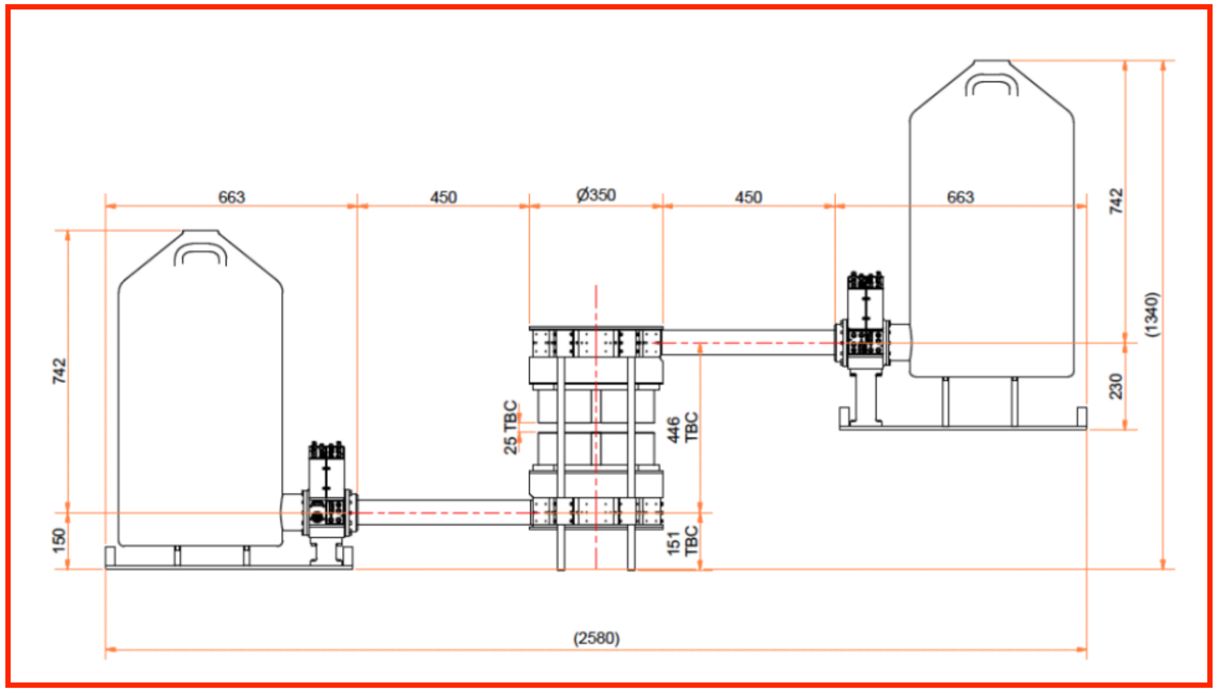

CANBERRA 777 Ultra Low Background Shield

- 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

# HPGe Array (*Elena Sala/*Gowoon Kim)

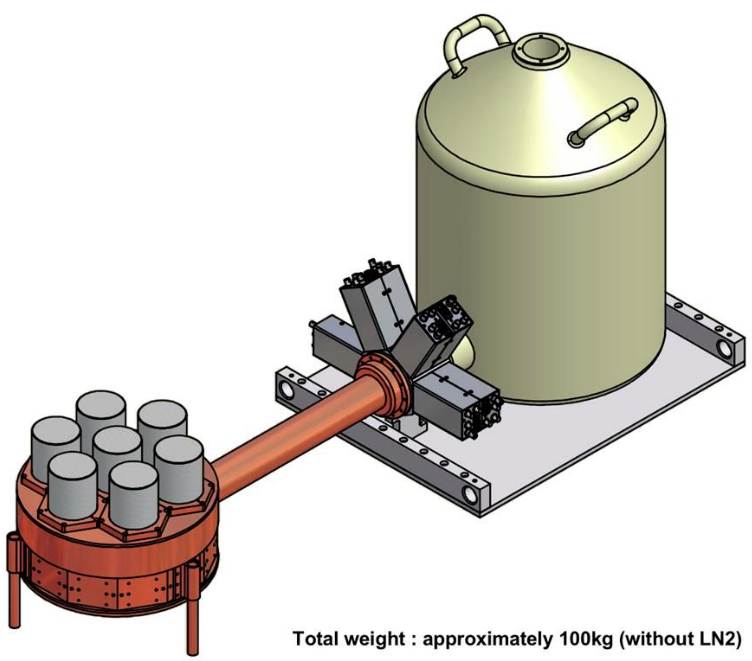


- Developed in collaboration with CANBERRA,
- **2 ARRAYS** placed one above the other with 7 HPGe (70% relative efficiency) each.
- total detectors: **14 HPGe**




- Improving the sensitivity is mandatory to reduce the intrinsic background

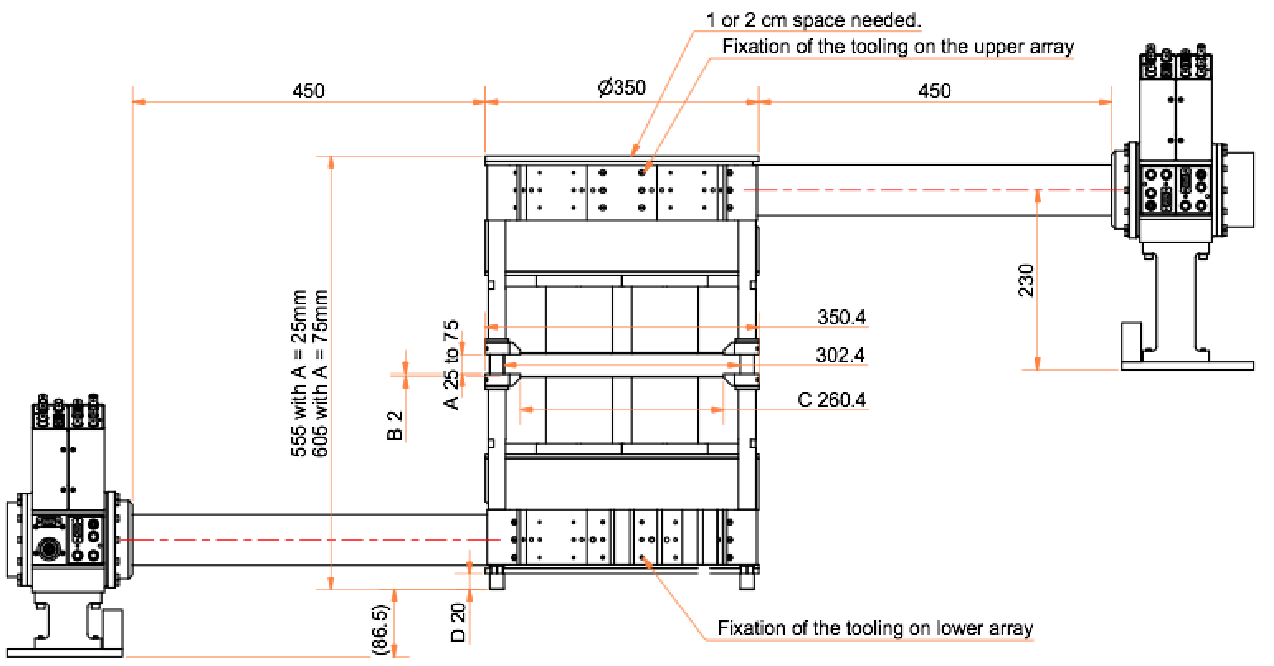
- Careful and accurate selection of **O-rings**
  - O-rings generally have high contamination in 40K
  - Our selection has very low contamination in Th and U: 16 ± 4 & 13 ± 4 mBq/kg respectively
- Aluminum has been replaced by **copper** everywhere considering the efficiency loss at low energies
  -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

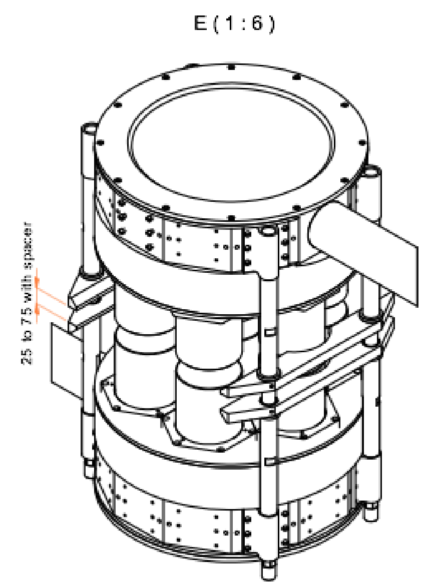


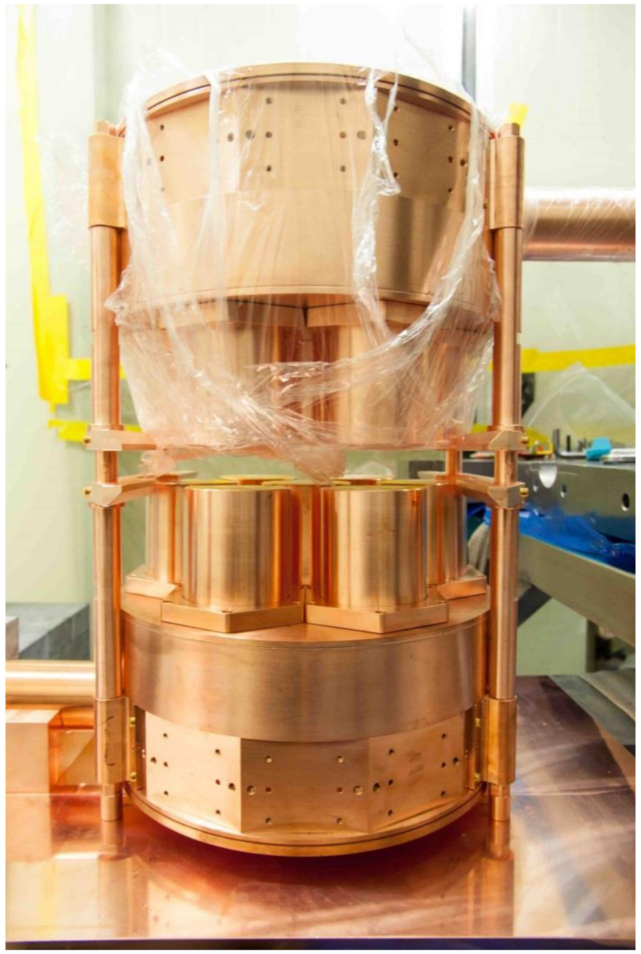
Total weight : approximately 100kg (without LN2)

# Lifting scheme

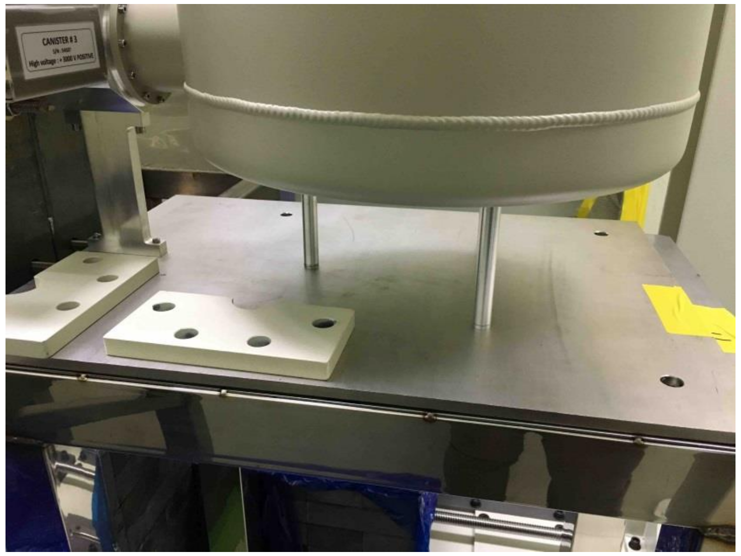




- Lifting 3 parts simultaneously
  - Top Array, Shielding, Dewar
  - Design of a Tool to lift the array
  - 2mm each step (cold finger “safe” stress)
- Adjustable spacers between the bars to fix the height
  - from 2.5 up to 5 cm
  - Support for samples

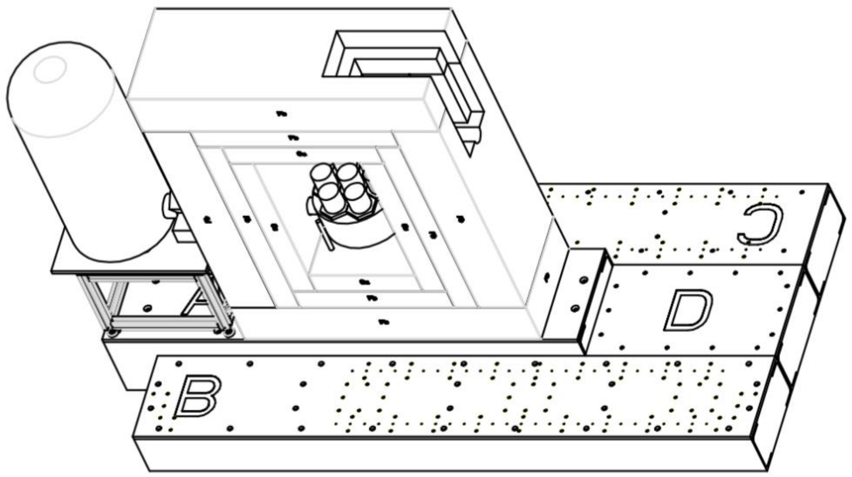


# SHIELDING

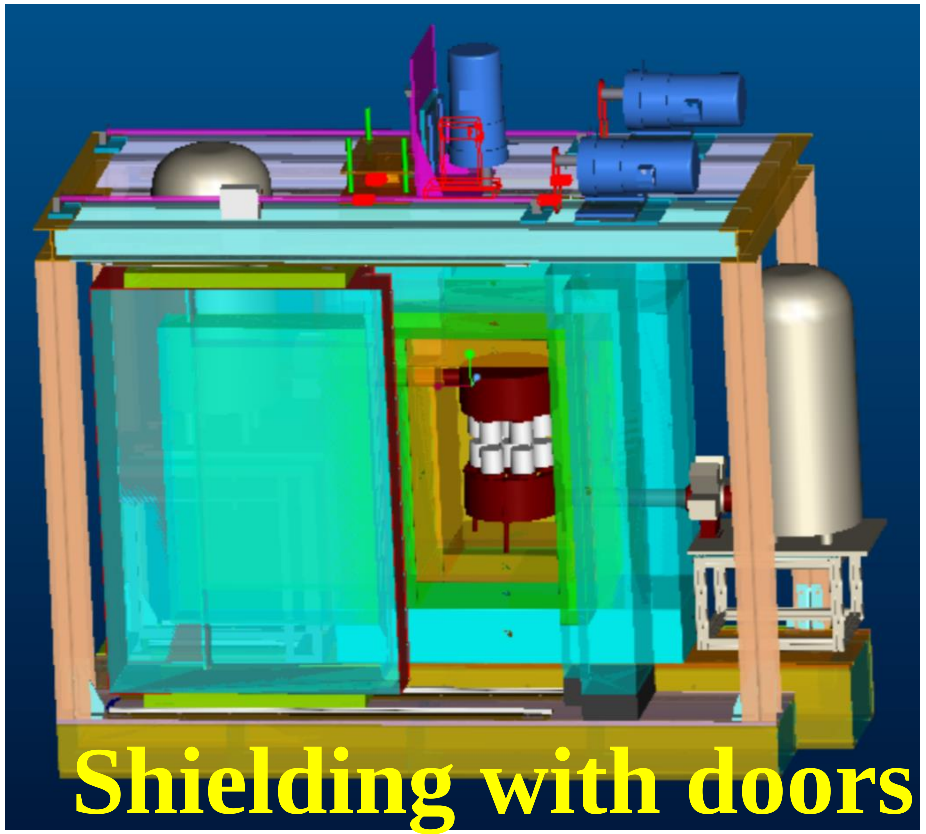


Main Structure from outside: 20cm Lead + 10cm Goslar Lead + 10cm Copper

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



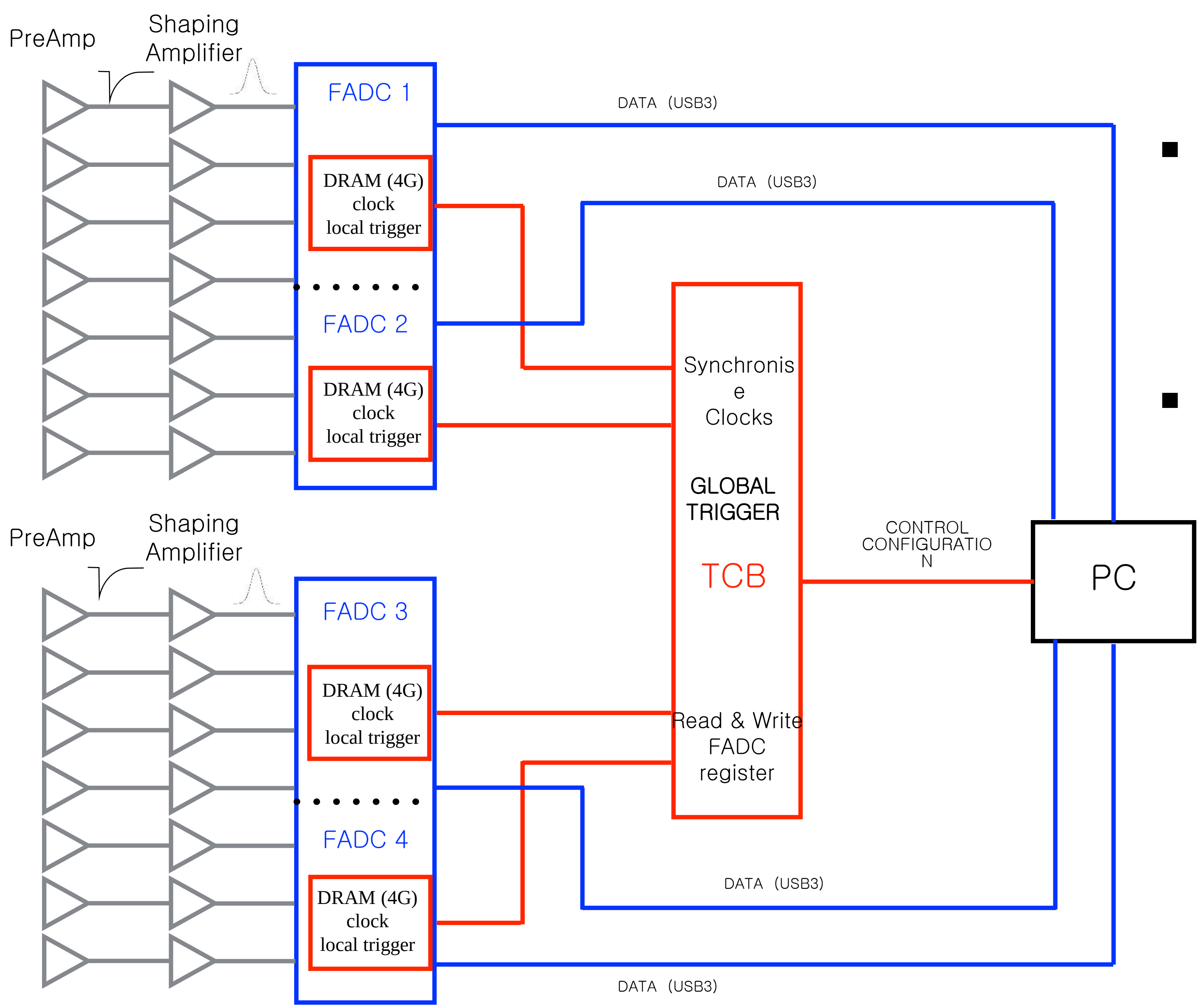

- The top array should be lifted to place samples with different sizes.
- Specific tools are made to lift the dewar and the array together.
- A part of the shielding will also be lifted to prevent any damages on the cold finger

# Electronics & DAQ



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

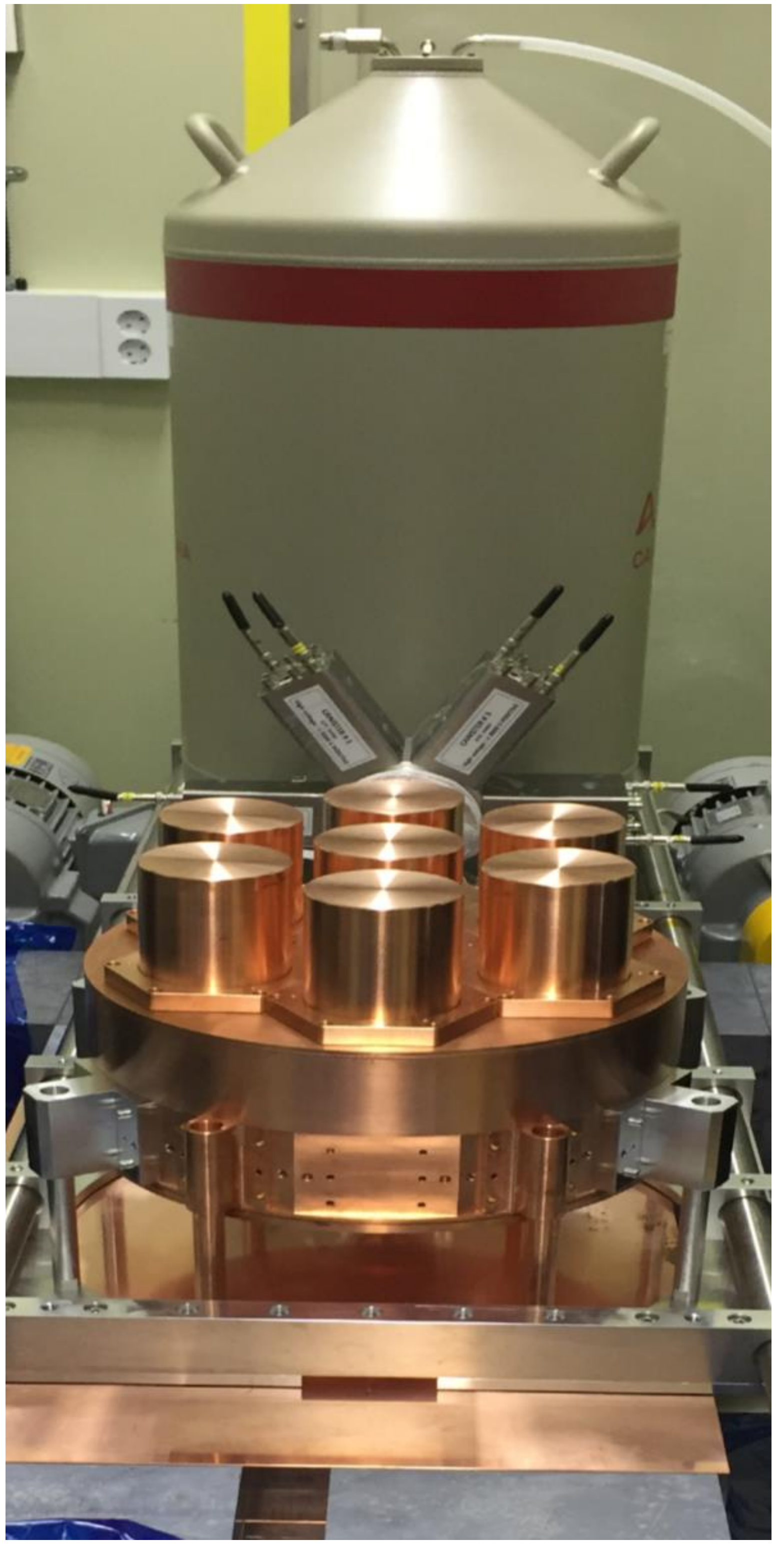



- Flash Analog to Digital Converter
  - 500MS/s 12bit dynamic range 2.5V
  - 2 modules with 4 channels each

- 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 synchronise the FADCs clocks and access to the FADCs register to send the information to PC

# Energy Resolution

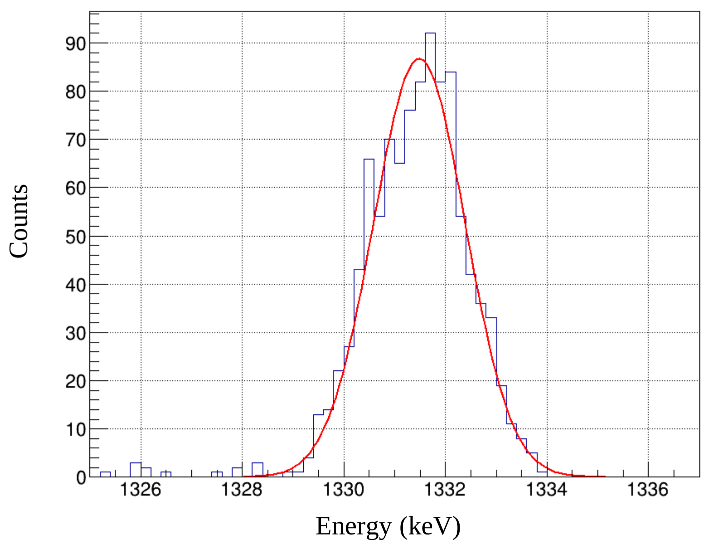




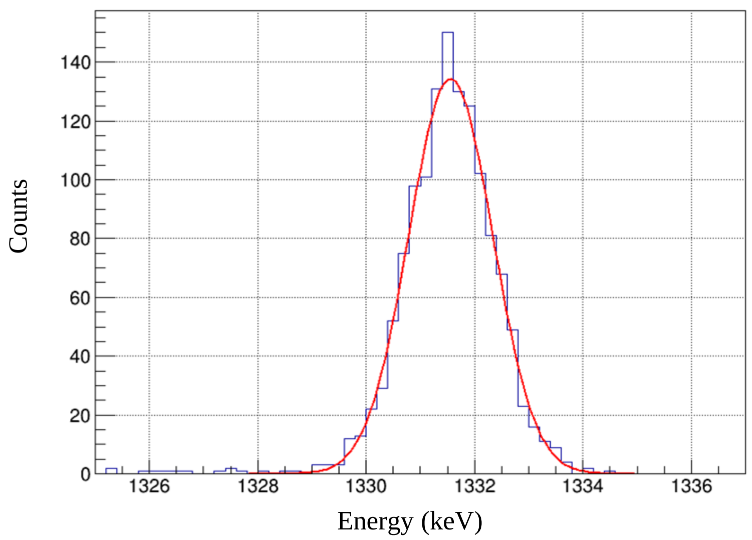
## TOP ARRAY Energy Resolution

| 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 Bottom




DET6 Top




## BOTTOM ARRAY Energy Resolution

| 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** |

# Application



## 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**

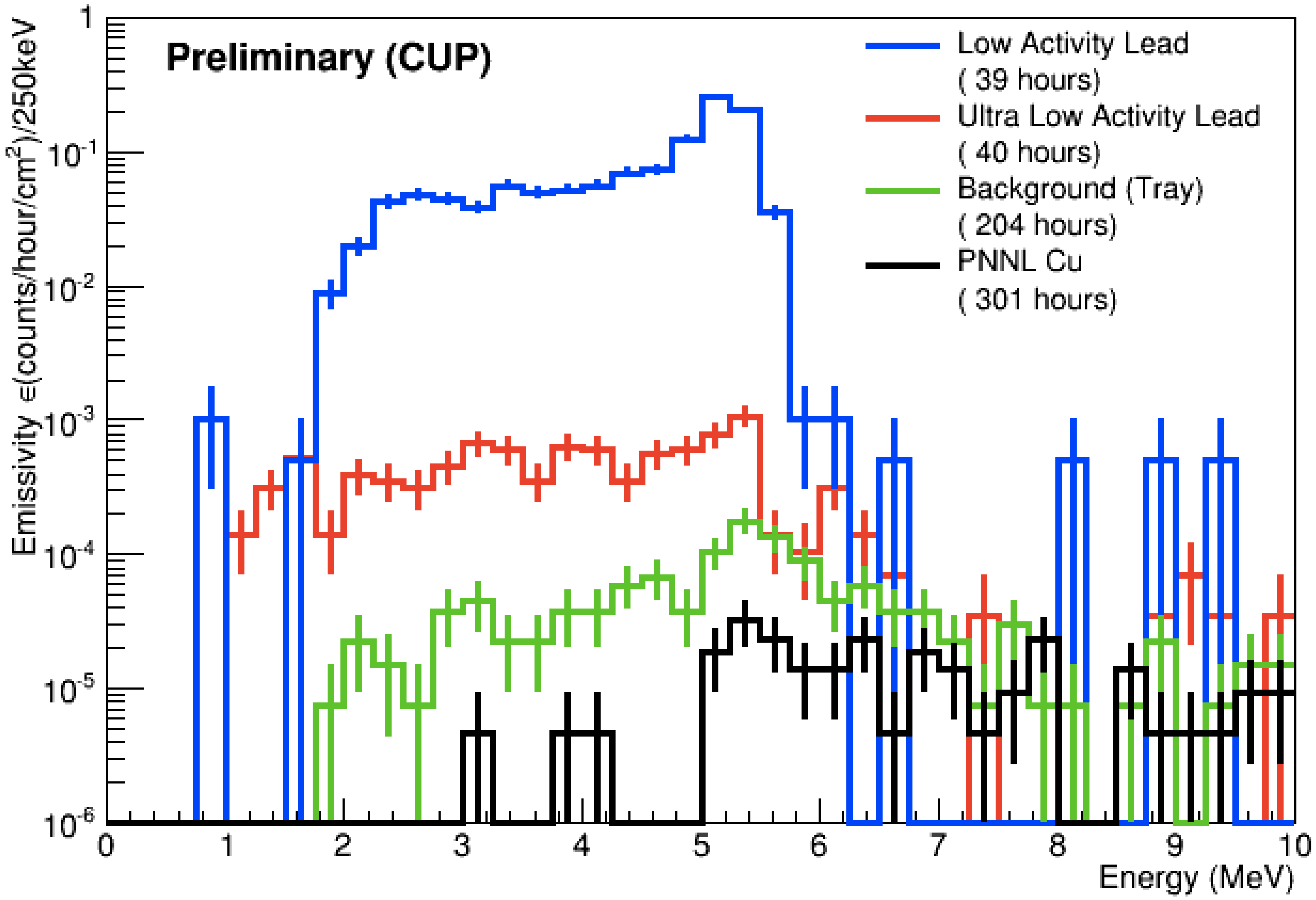
**$^{180m}$Ta rare beta decay**

Resonant 0$\nu$ Double Electron Capture ($^{156}$Dy)

# Alpha Counter (*ChangHyon Ha)



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

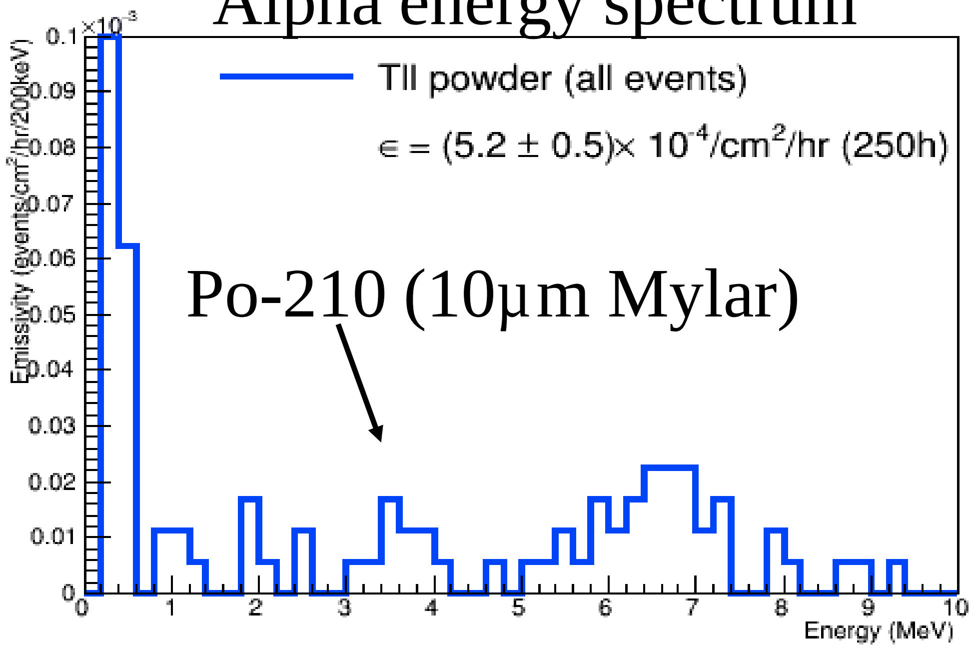


# Alpha Counter (Powder measurement)

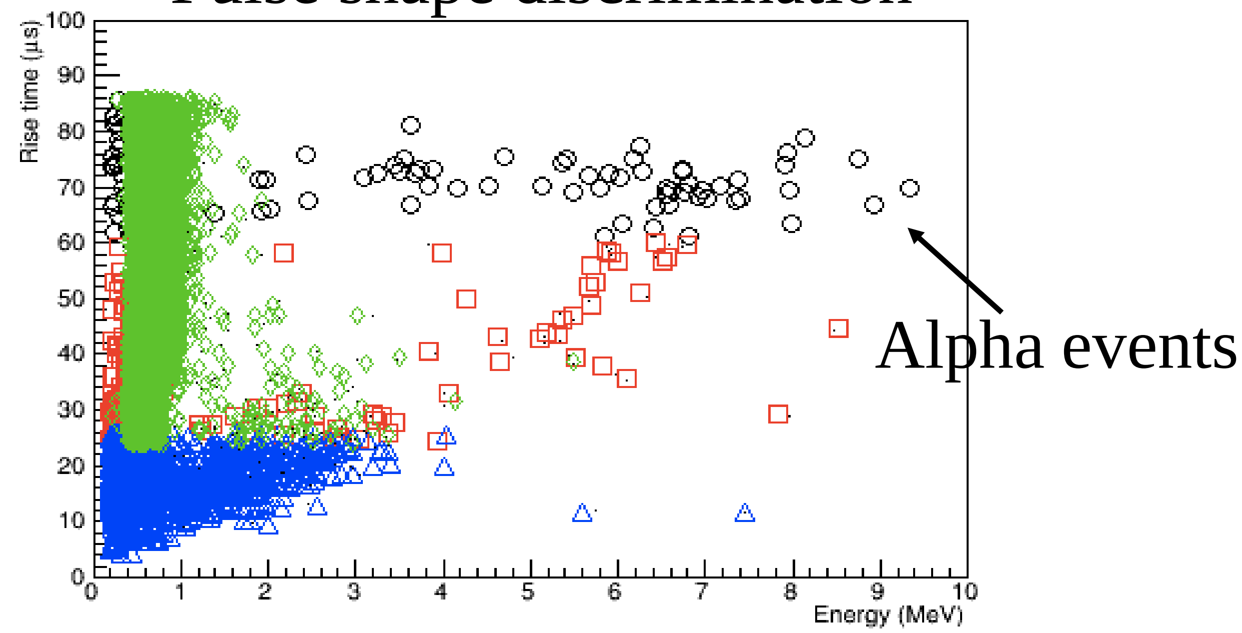


- **TlI and NaI powders measurements**
- **Pb-210 contamination in powder estimated before crystal growth**

Alpha energy spectrum




Pulse shape discrimination



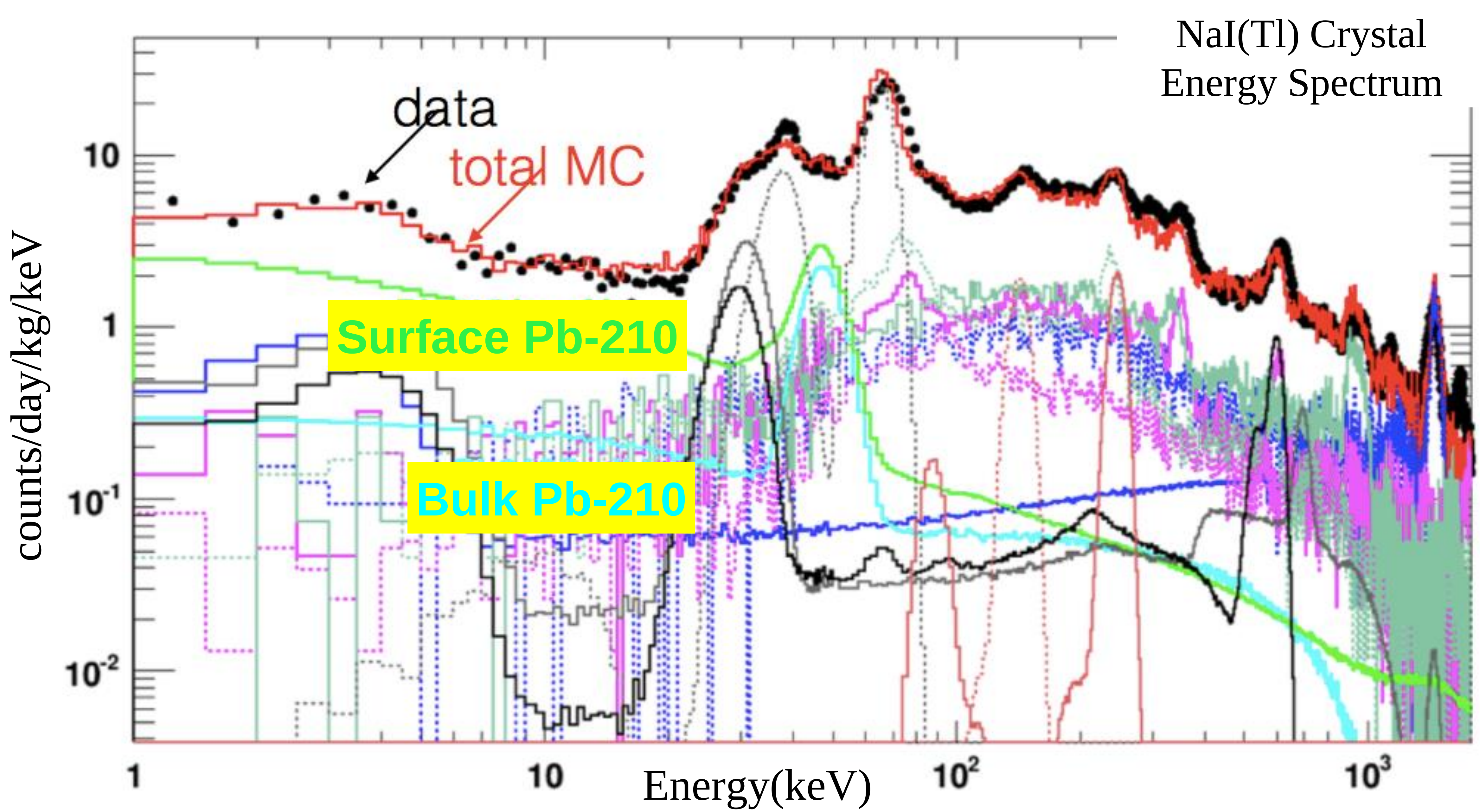


- The Po-210 activity is estimated to be

  1.1x10$^{-4}$ counts/cm$^2$/h
  (< 4 mBq/kg)

# Trouble with Pb-210 in the Dark Matter search

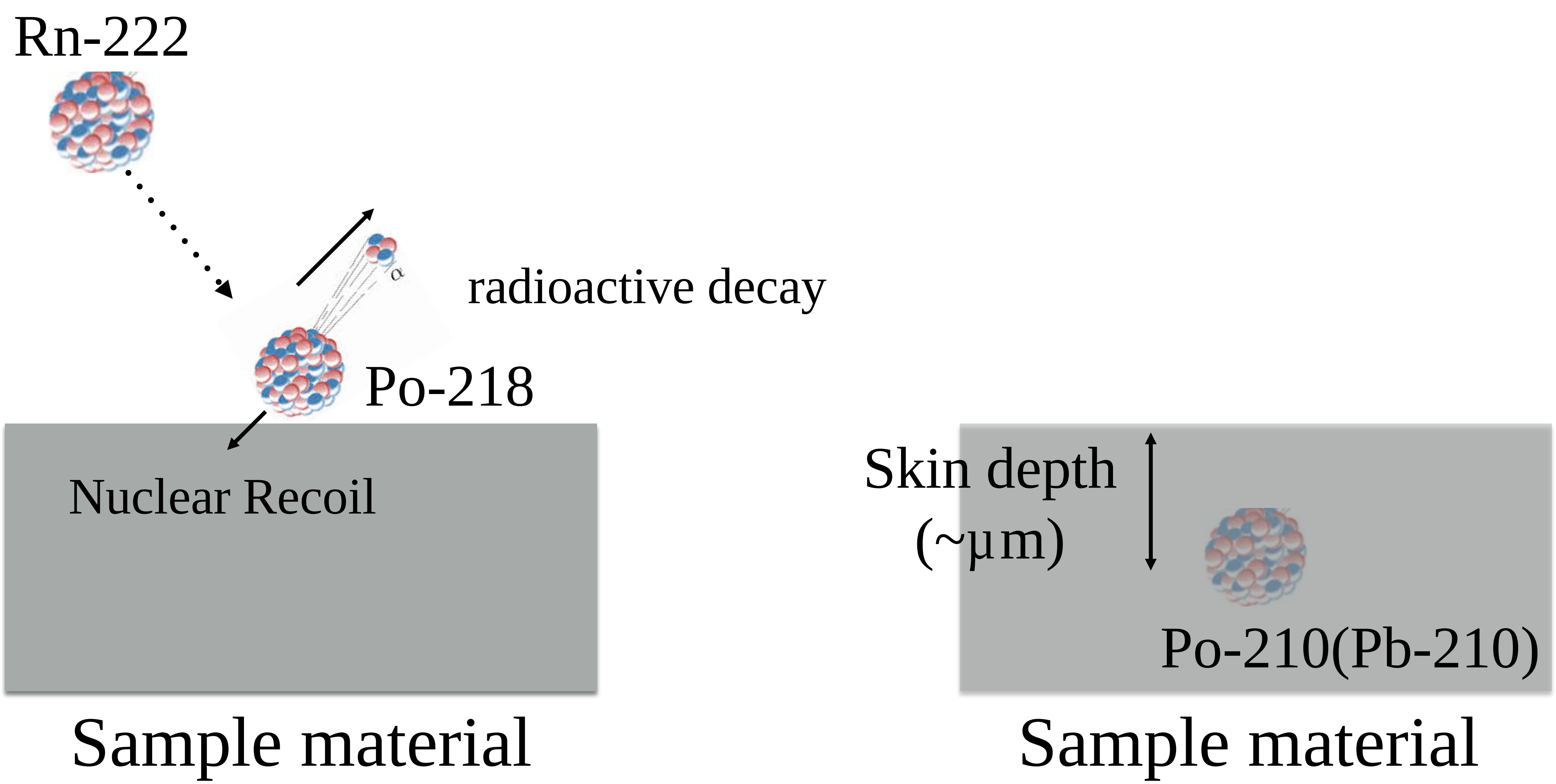





**At low energies below 20 keV, Pb-210 is the main background source. Where the contamination is (bulk or surface) is also important.**

# How deep can Po-210 diffuse in the sample surface?

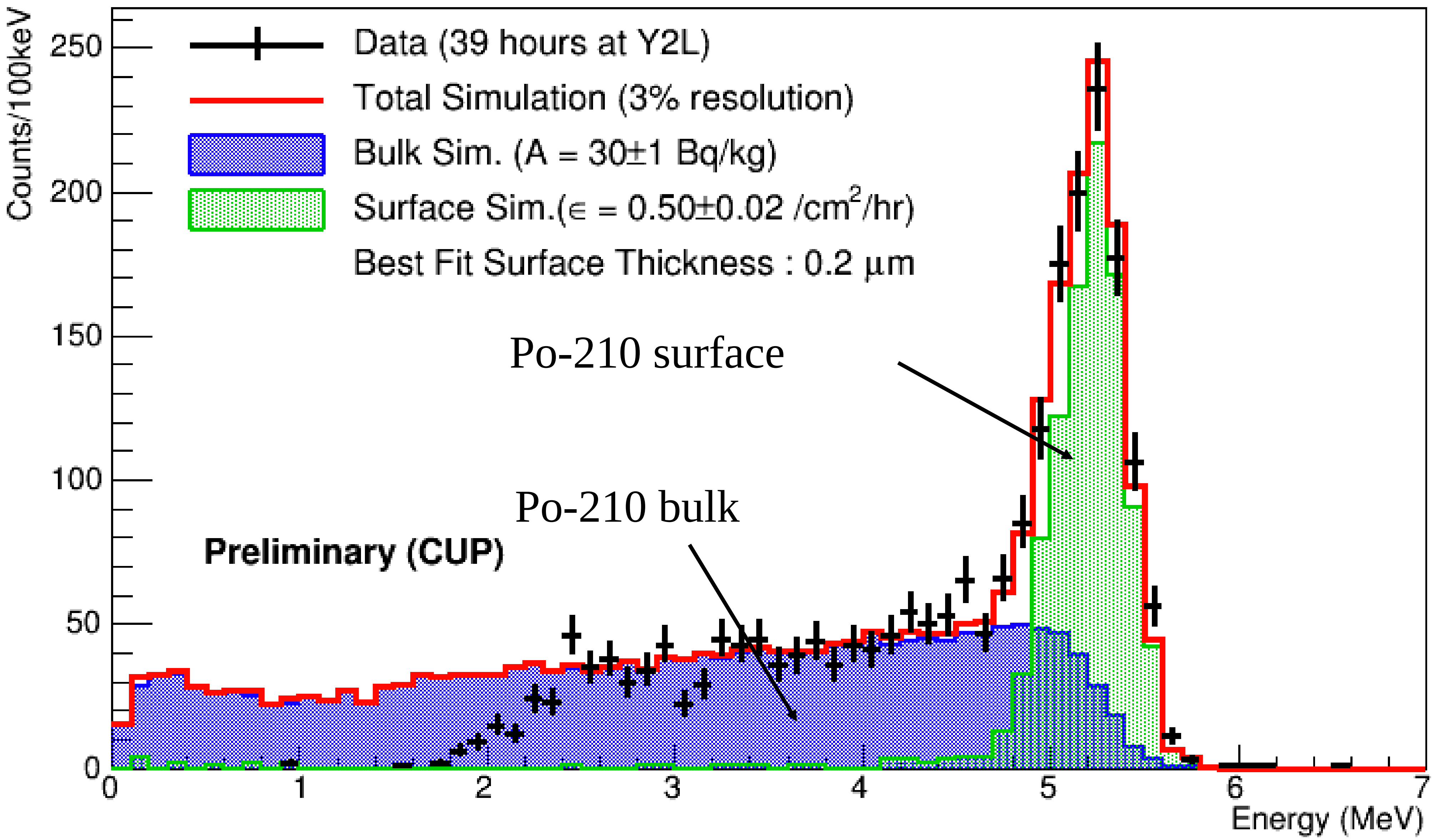




# Alpha Counter (surface vs bulk)



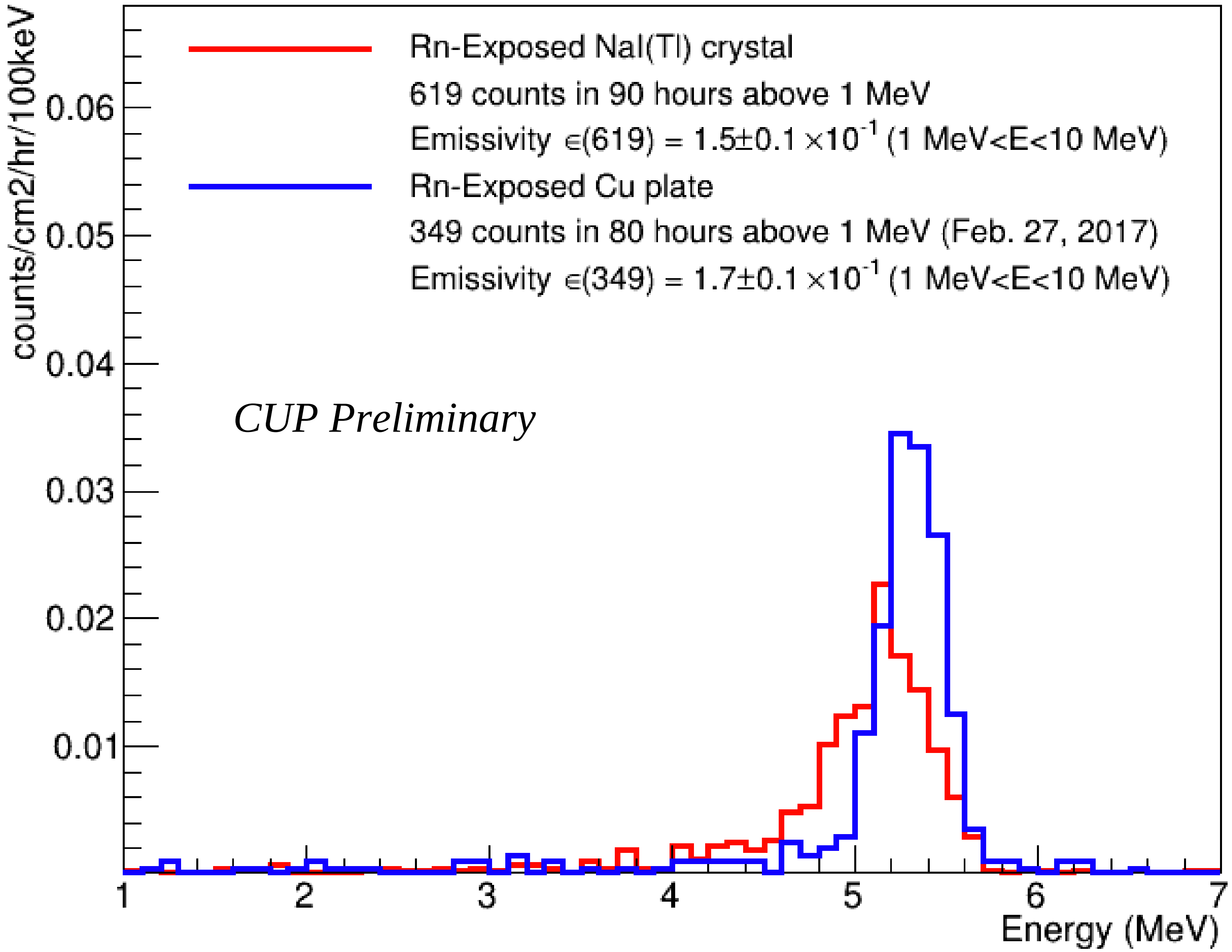
- **Surface component from bulk component can be separated by using a maximum likelihood fit**
- **Can pinpoint where the contamination happens**




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

# NaI(Tl) crystal vs. Cu plate

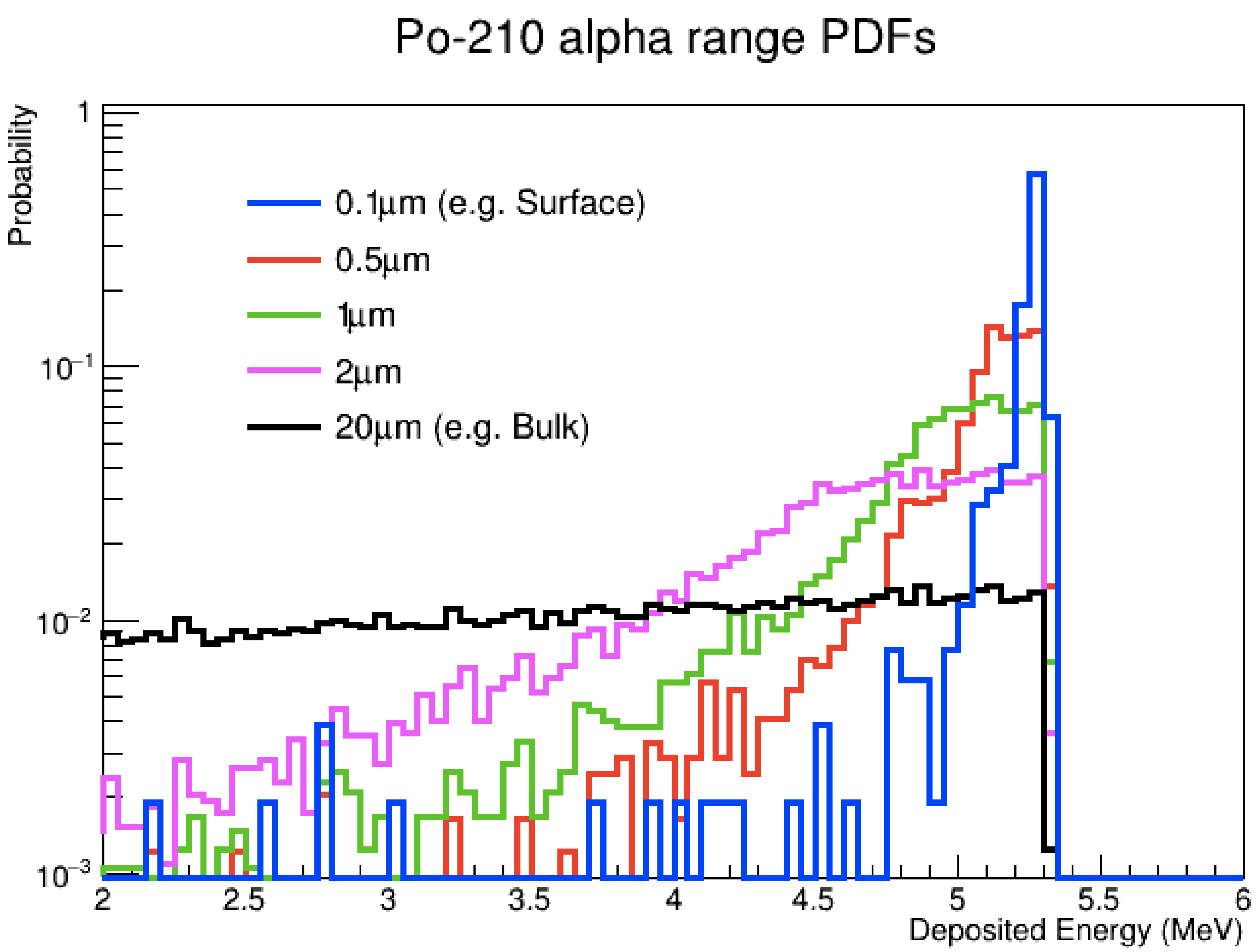


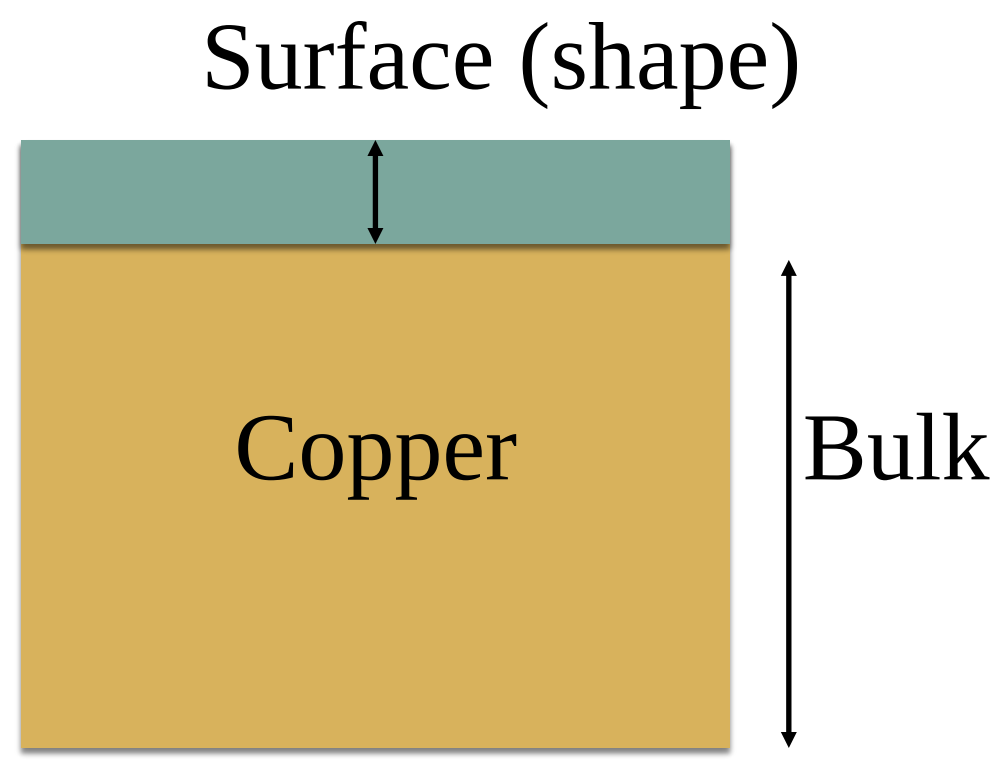


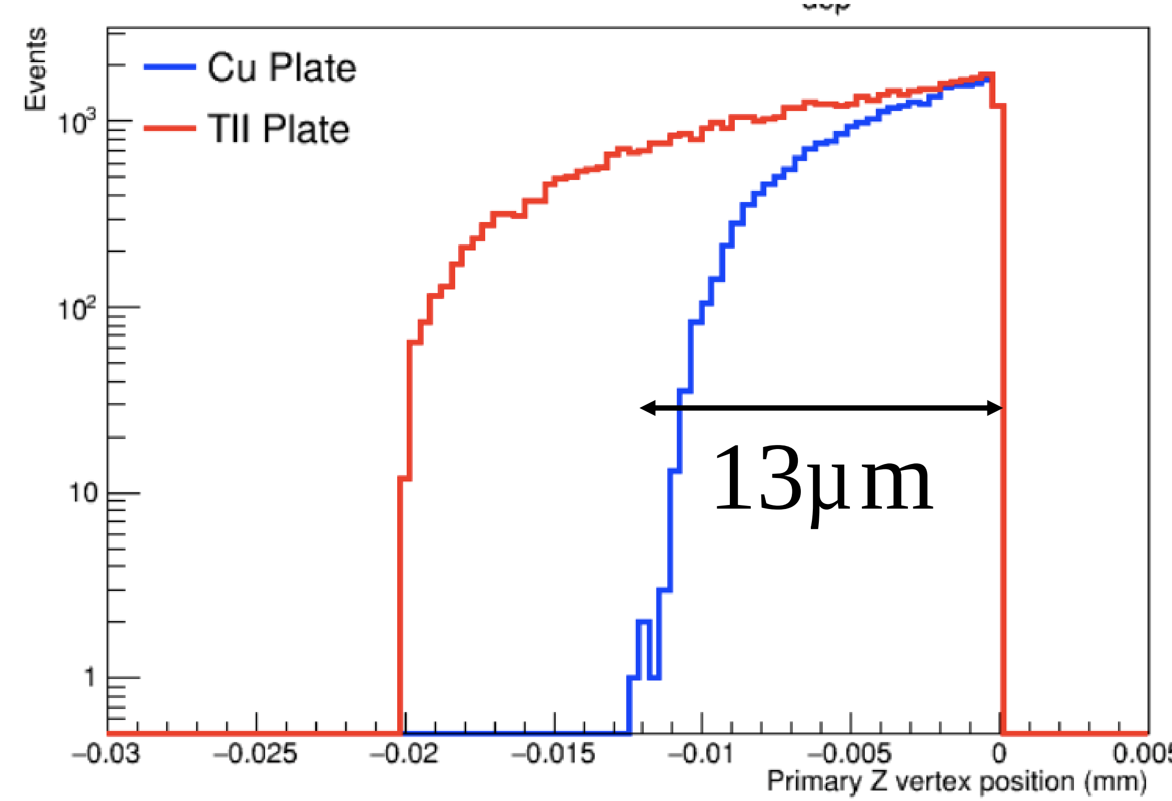

A similar emissivity between two samples.
NaI(Tl) crystal full peak shifted towards lower energy →
Deeper surface penetration of Po-210 in the crystal

# PDFs vs surface depths from Geant4





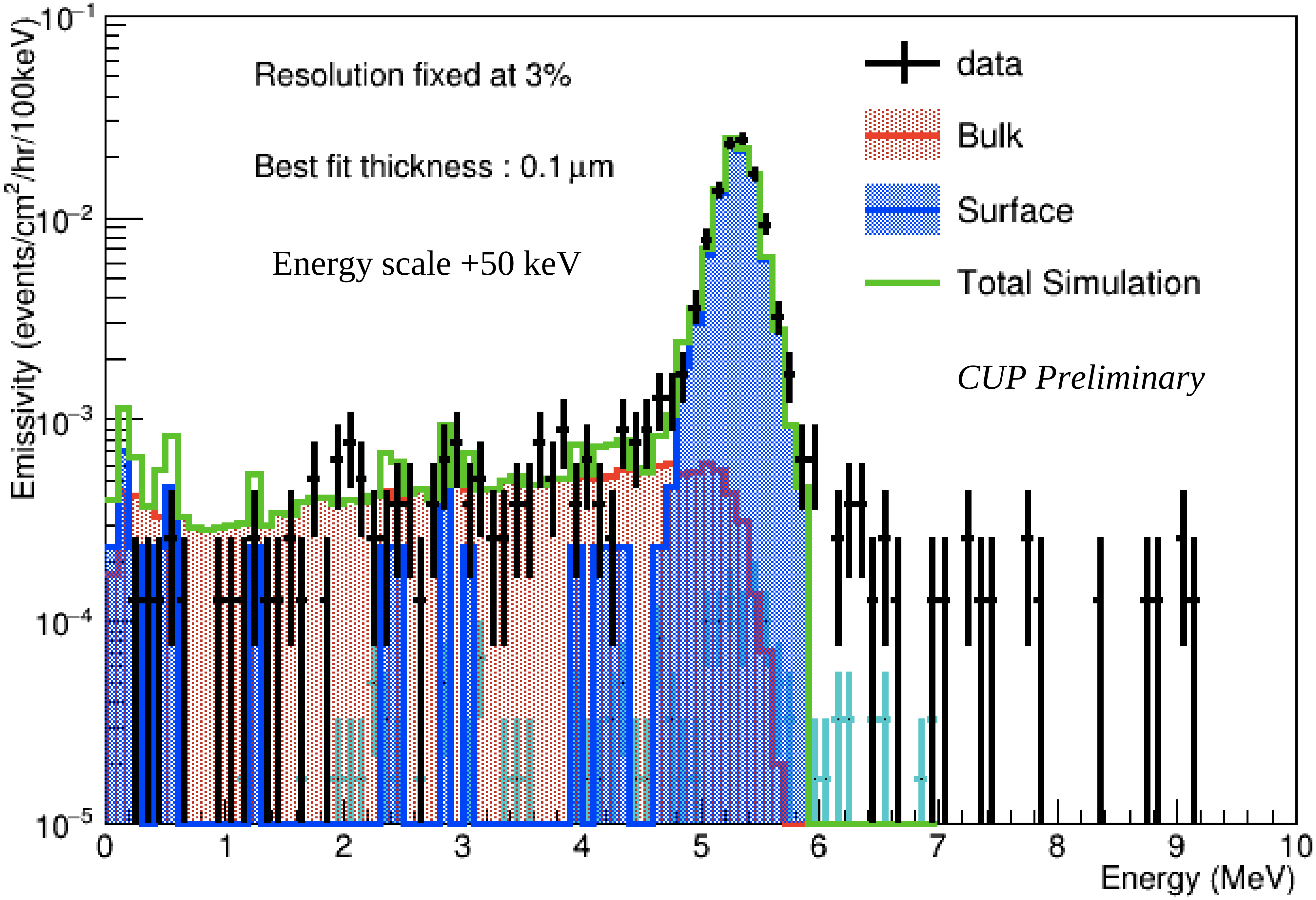




- Max. depth of Po-210 alpha for copper is around 13µm.
- A linear decrease in Po-210 population with surface depth is assumed.

# How deep can Pb-210 penetrate in the copper surface?



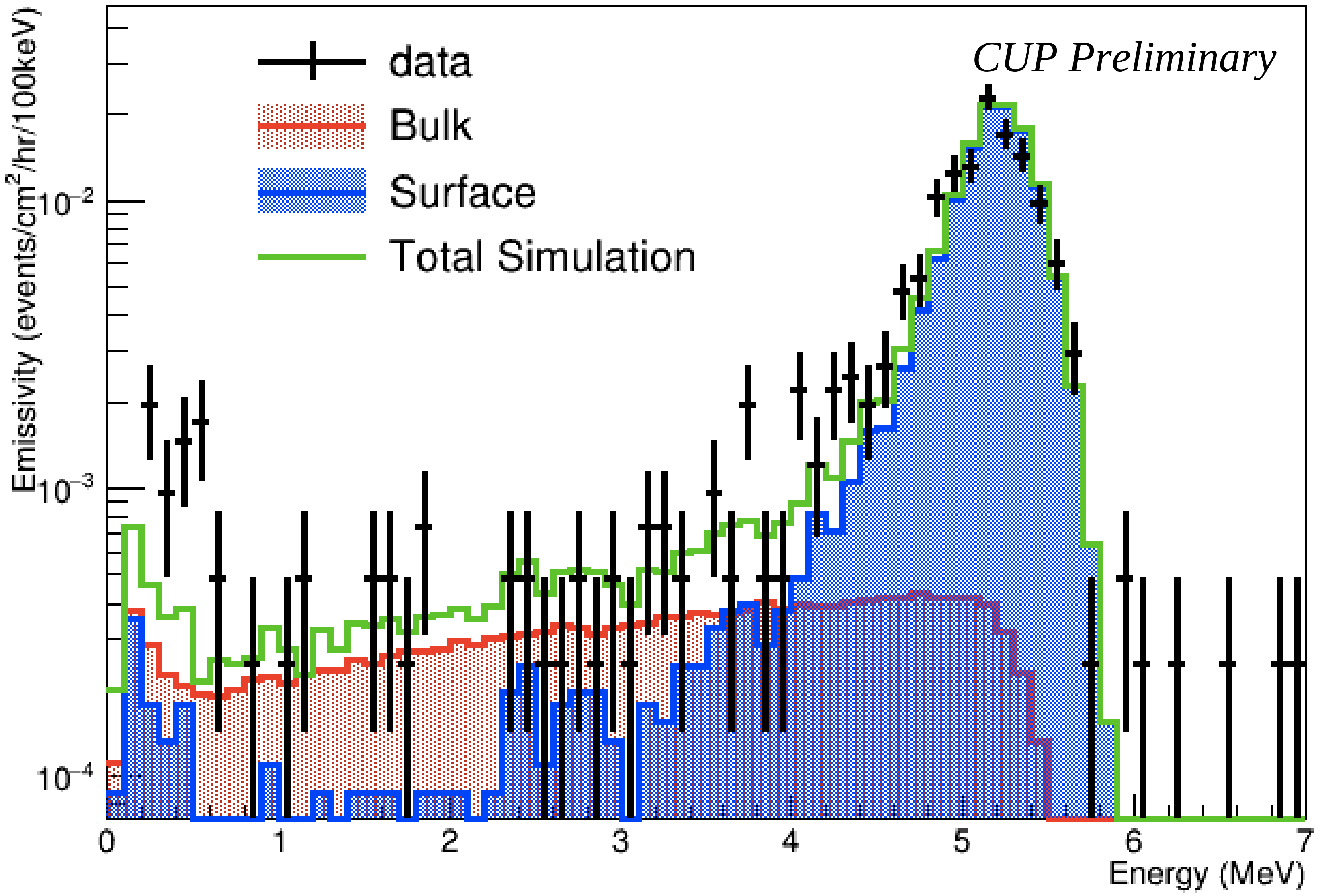
(Maximum Likelihood Fit to separate surface from bulk)




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

# How deep can Pb-210 penetrate in the NaI(Tl)?

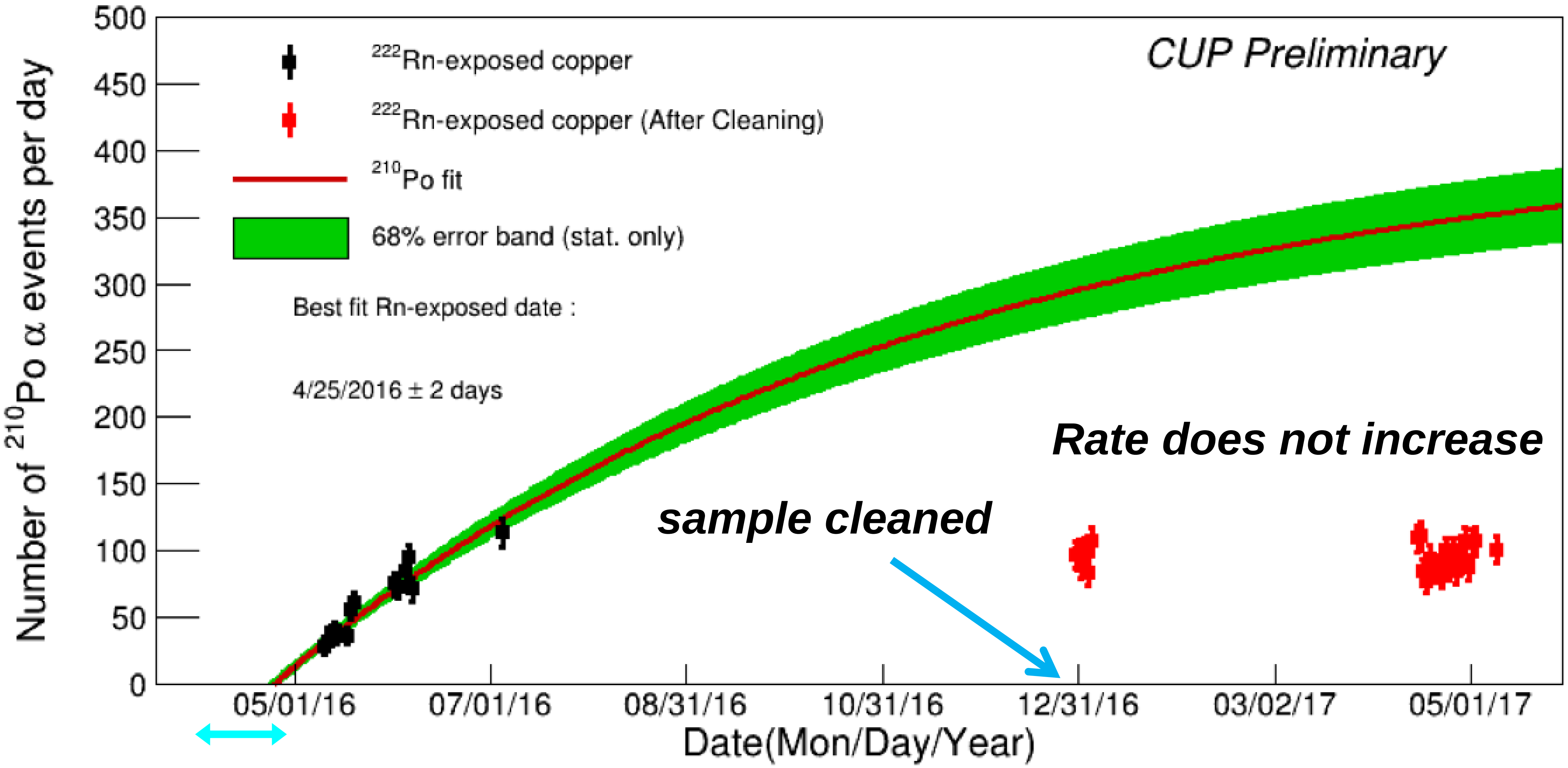





Po-210 depth is estimated at around 1.2+/-1.0 μm (stat. only) in the NaI(Tl) crystal. More accurate estimation requires to understand how particle diffusion happens in the surface.

# Radon contamination prediction (Rn-exposed Copper)



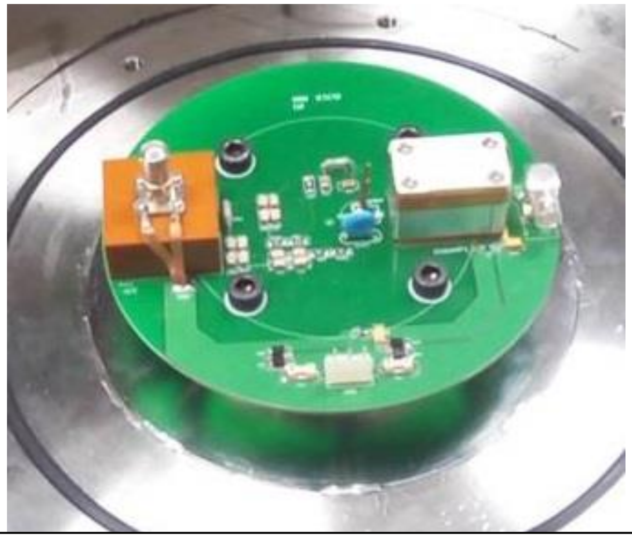



*Rn-222 exposure*
*4/22/16 for 10 days*

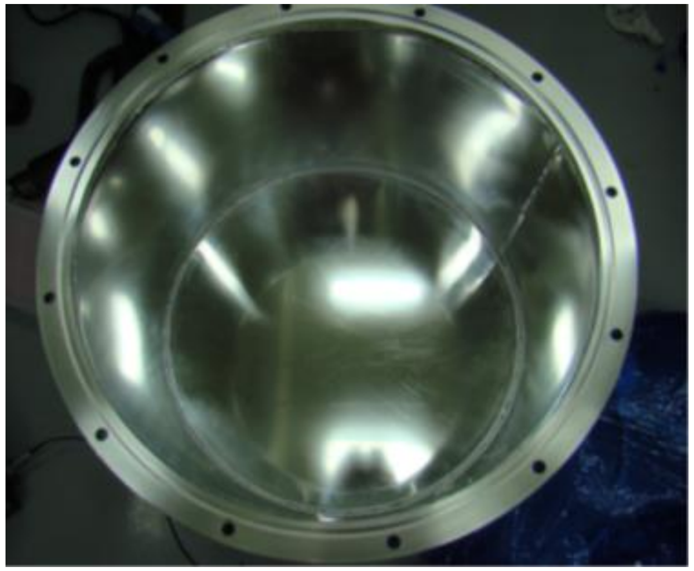
Radon contamination date can be pinpointed with alpha data.
Chemical surface cleaning shows removal of contamination.

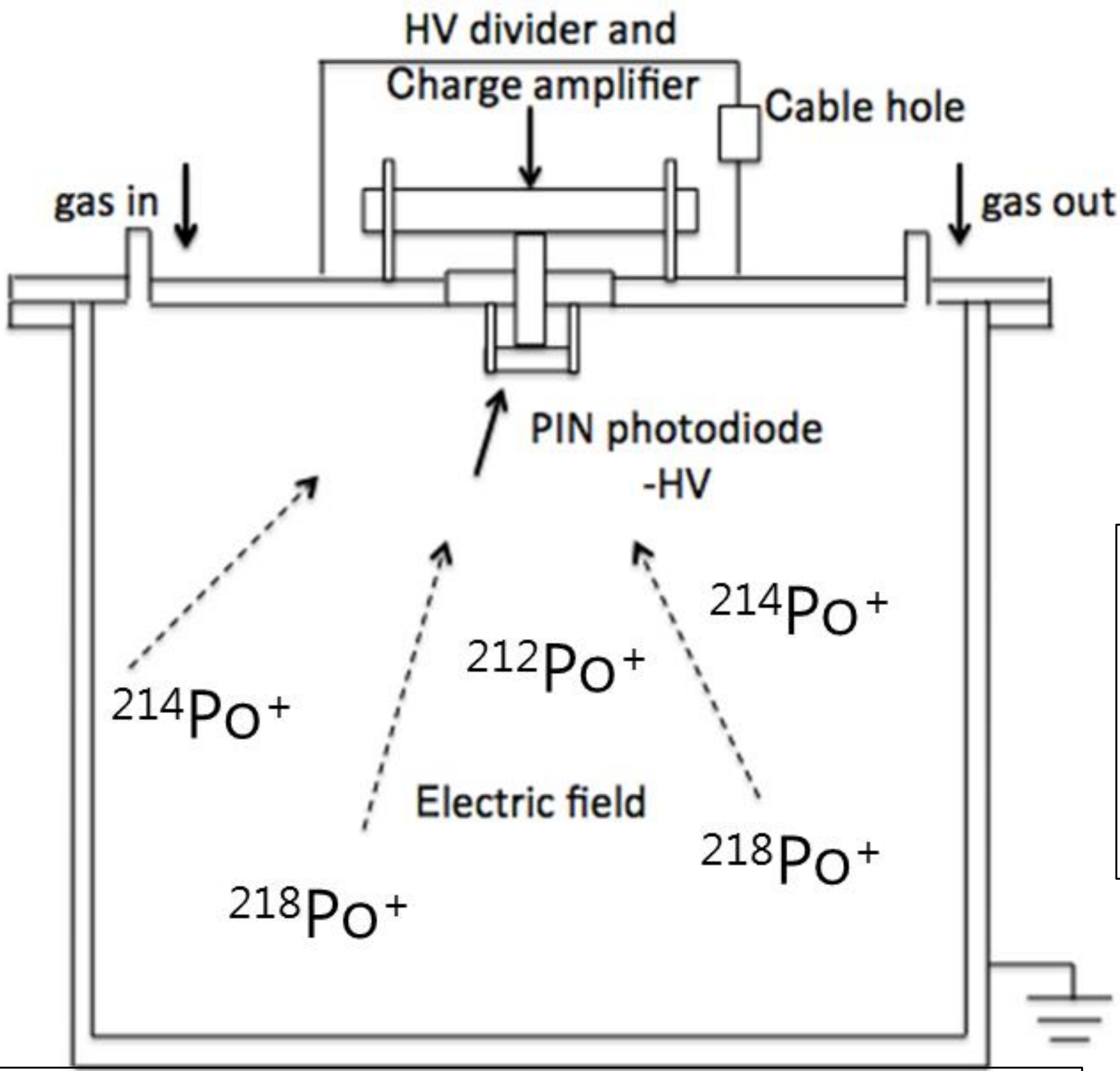
# Ultra-sensitive Radon detector (*Kyungmin Seo)



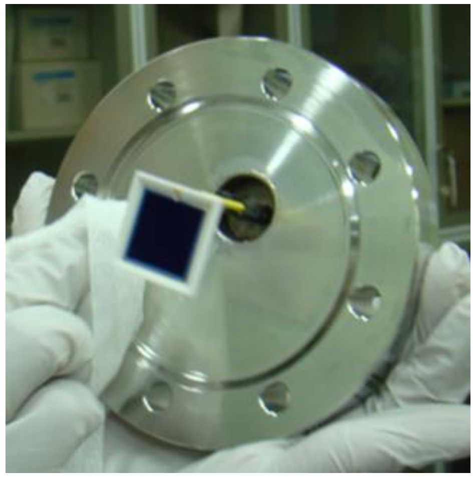


- Hamamatsu charge sensitive amplifier (H4083)
- HV divider circuit

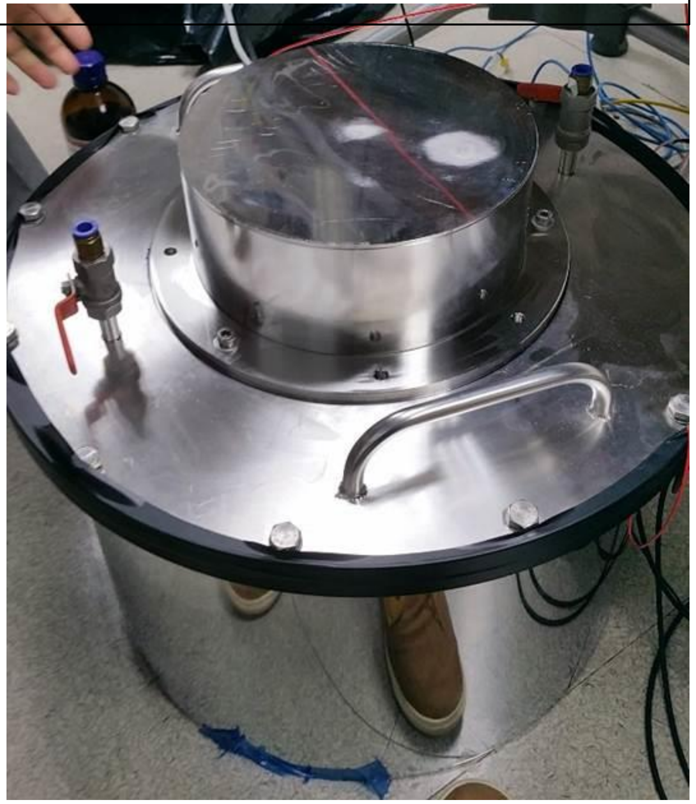





- Volume = 70 L
- High Voltage = –1,000 V
- Bias = 30 V
- Stainless steel with electro-polished inside surfaces
- Shaping amplifier with ×12 gain
- 12 bit 25 MS/s FADC



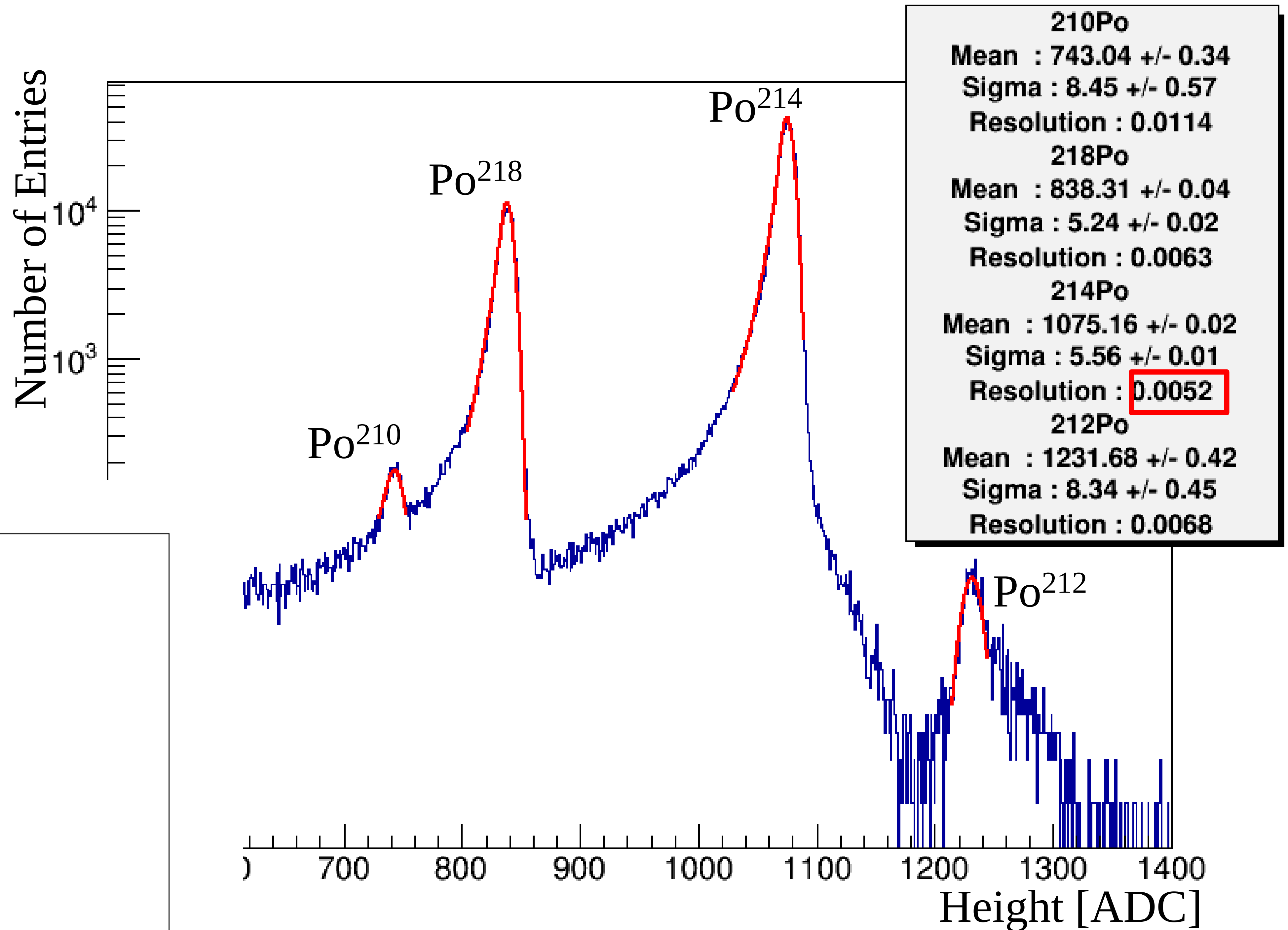
- Hamamatsu silicon PIN photodiode (S3204-9) 18 × 18 $mm^2$

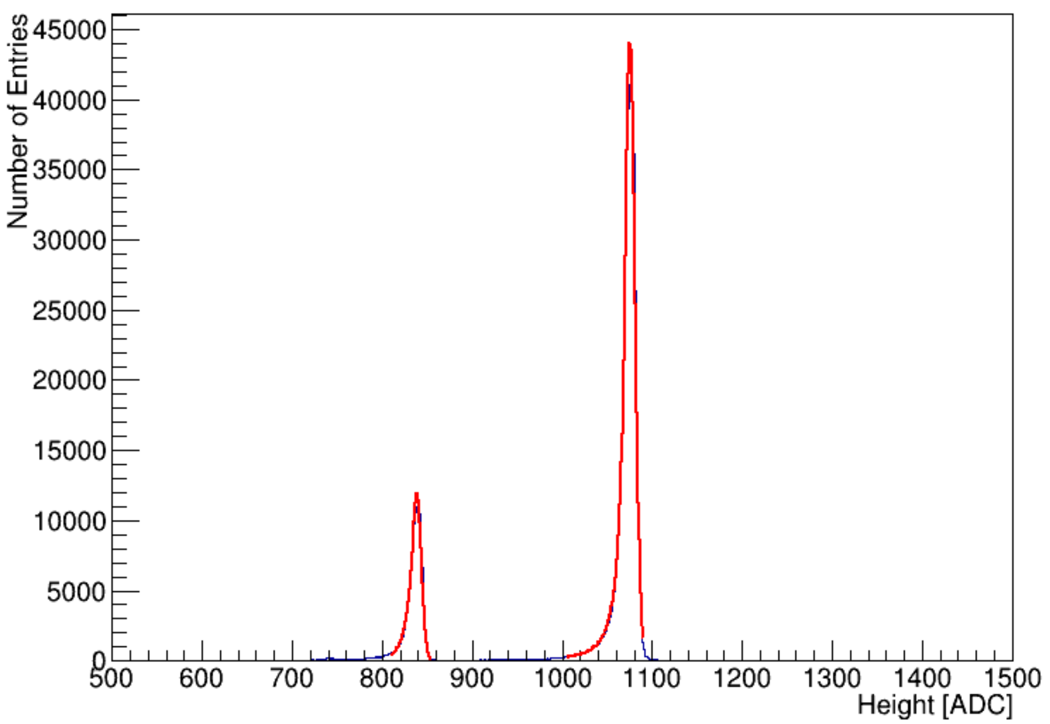


# Pulse height distribution



- Pulse height distribution using data of 90 days.
- Crystal ball function is used for all peaks.
- (Sigma) Resolution is less than or equal to **1 %** for each peaks.

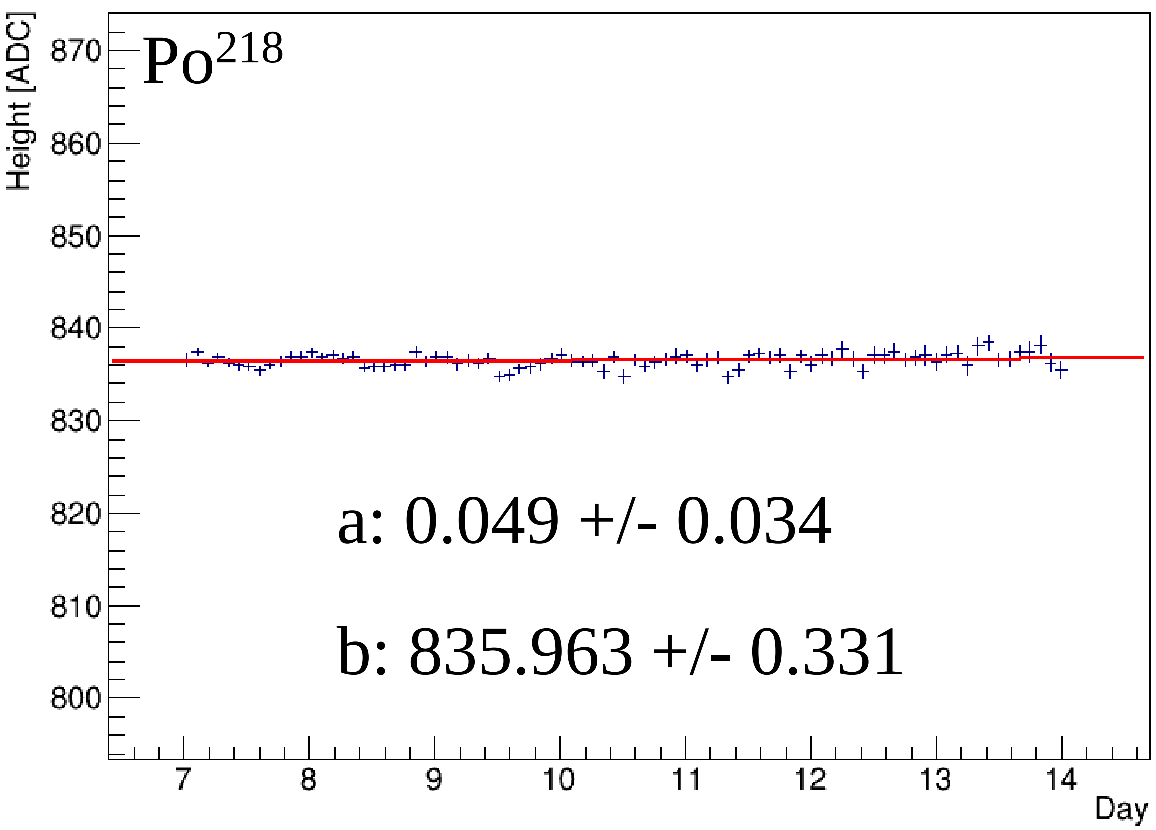


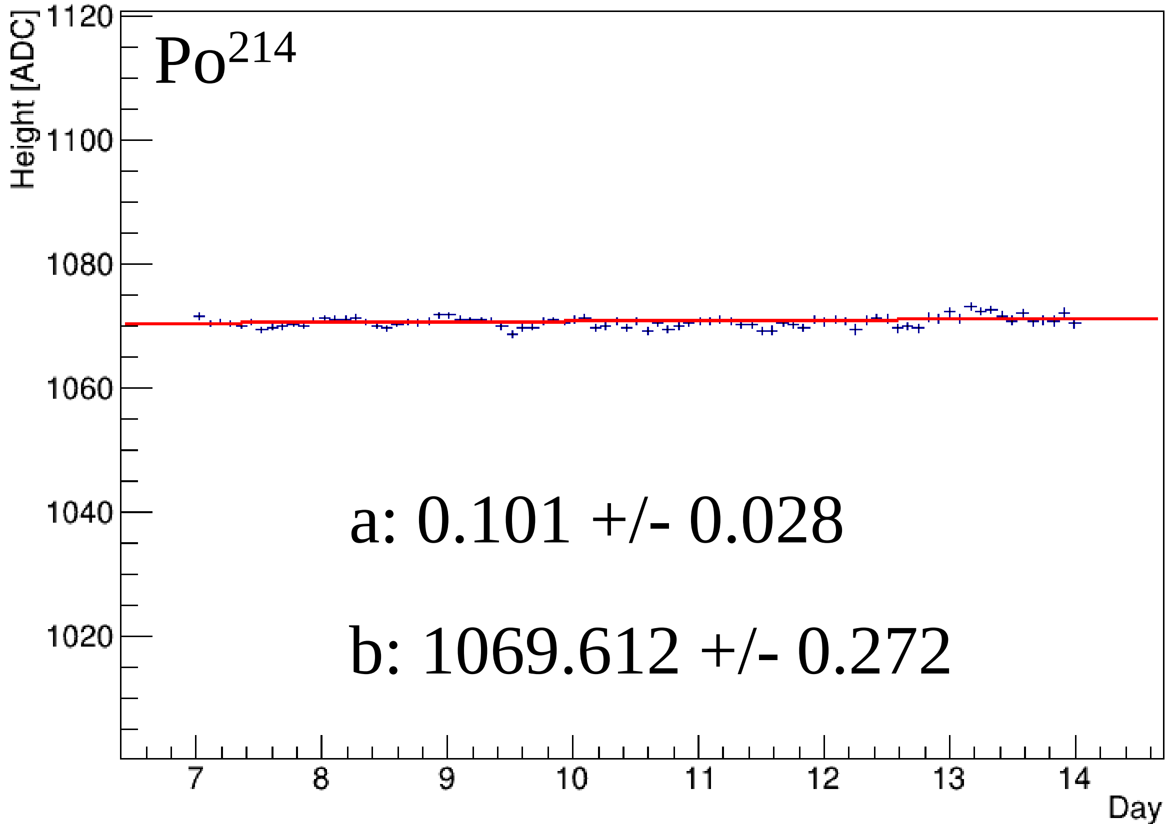



# Stability check



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




**Test setup is stable**

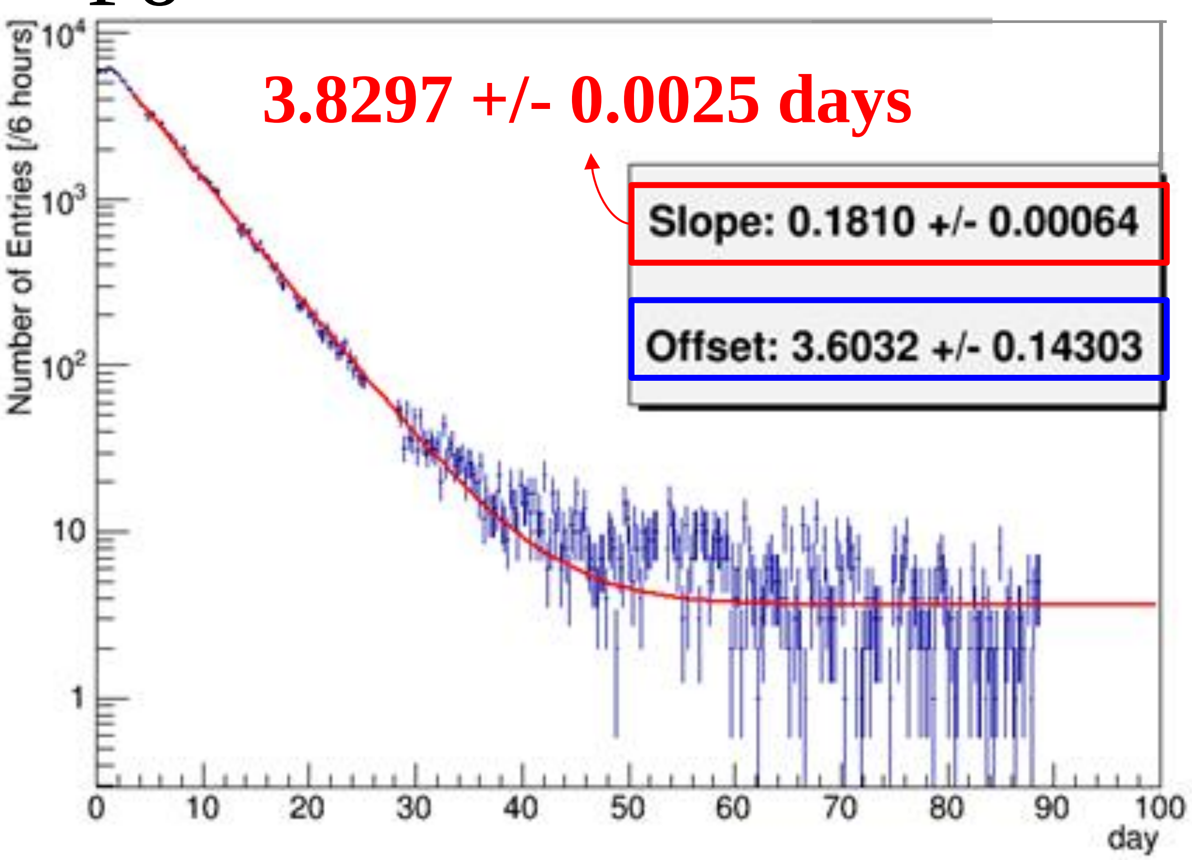
# Half lifetime measurements



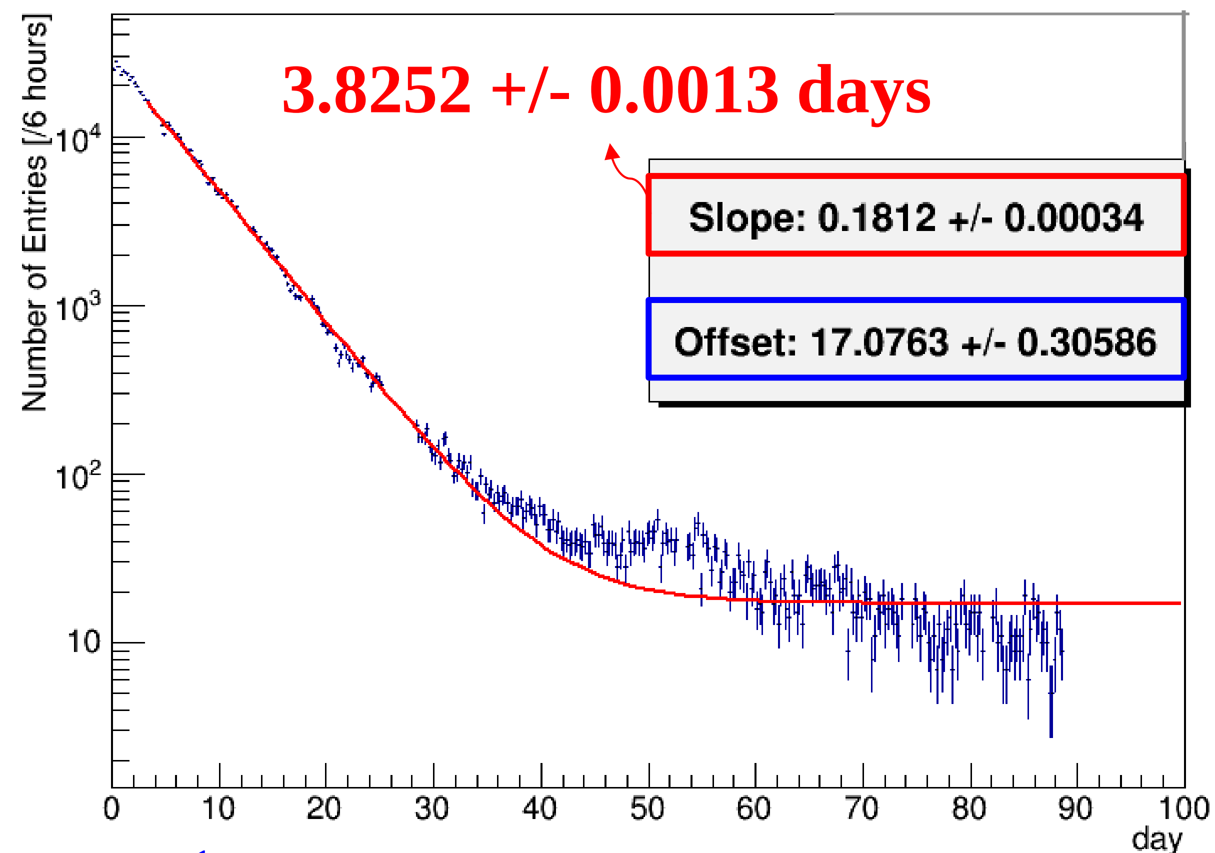
- Measured the half lifetime of $Rn^{222}$ using $Po^{214}$ & $Po^{218}$ events (within 2 sigma).
- Fitting function: $ae^{-bt} + c$

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

$Po^{218}$




$Po^{214}$




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

Radon concentration of the initial air (RAD7): 150 Bq/m$^3$ $\Rightarrow$ **0.075 Bq/m$^3$ BKG level**

# ICP-MS Lab (*D. Leonard/O.Gileva/K.Shin)



- Agilent 7900, the highest sensitivity single MS system in 2015 when purchased.
- Under operation since Oct. 2015.
- In a cleanroom nominally designed as class 1000, >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**

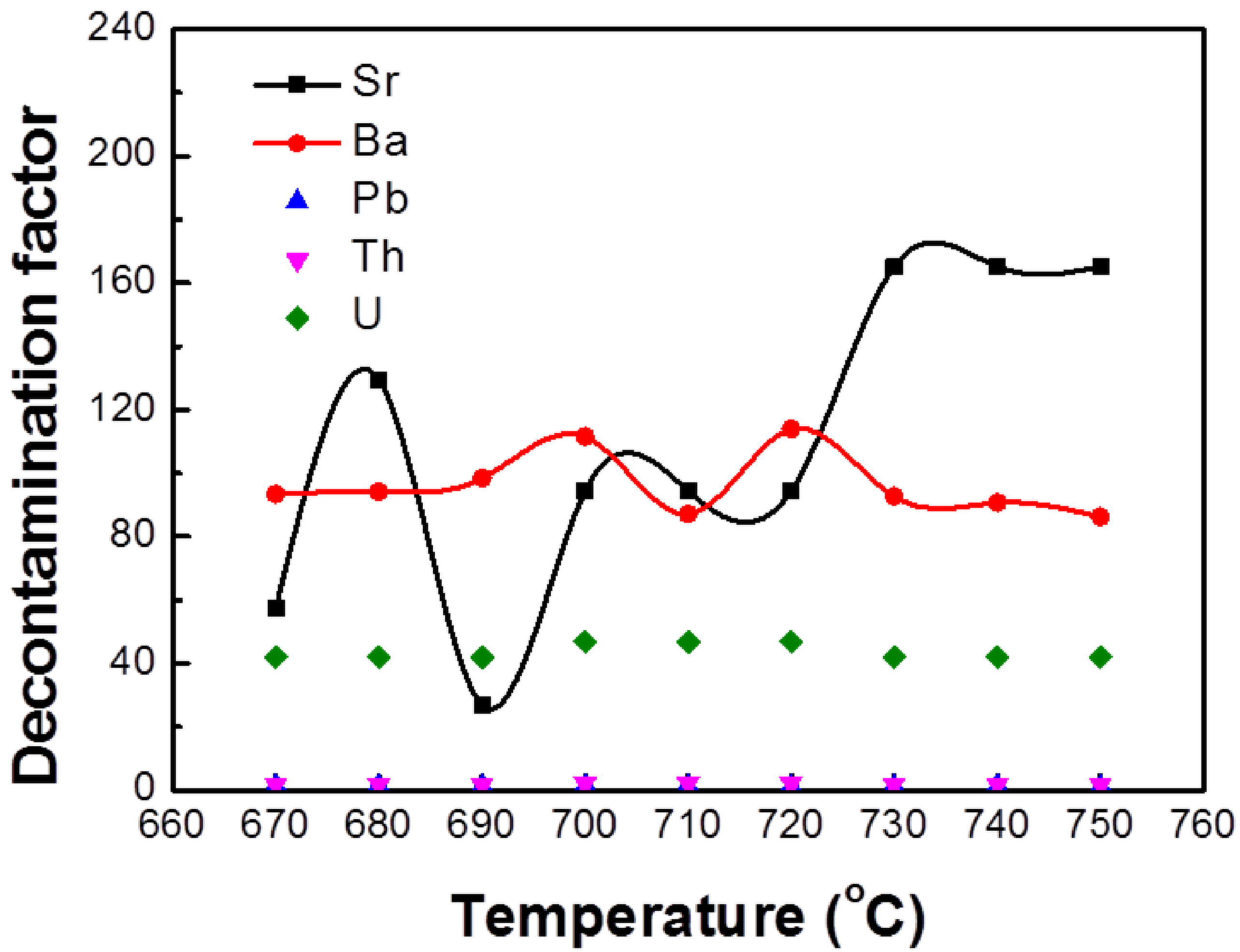
# Purification of $MoO_3$ powder: Sublimation method



- $MoO_3$ 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 from 670 $^oC$ to 750 $^oC$.

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 currently running for the background measurements of various detector materials (i.e., CMO, copper, powders,…) after improving their shieldings.
- A well-type Ge detector is being prepared for the background measurements of samples obtained in the purification processes of materials.
- An array of 14 HPGe detectors has just constructed for the ultra-low background measurements and rare decay experiments.
- A gas type alpha counter has been running for the measurements of alphas from the surfaces and bulks of materials to be used in the experiments.
- A radon detector has been refurbished and shows excellent resolutions and being prepared for the measurement of the air from the radon reduction system.
- An ICP-MS (Agilent 7900) has been testing samples of detector materials and purification processes.

# Thank you !