Highly radio-pure NaI(Tl) for PICOLON dark matter search experiment

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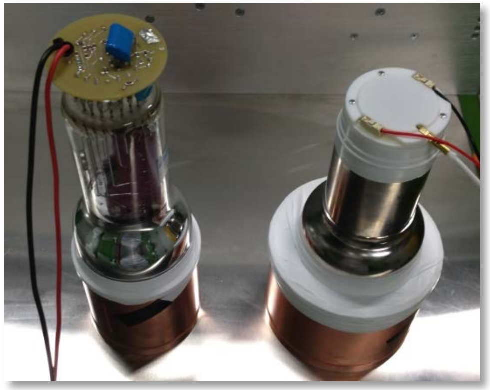
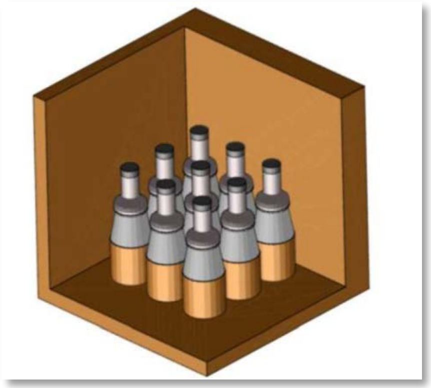
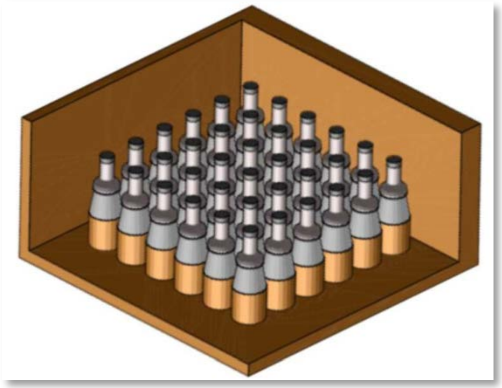
PICOLON / KamLAND-PICO Project

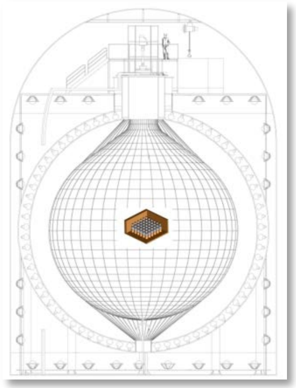
Pure Inorganic Crystal Observatory for Low Background Neutr(al)ino

Dark Matter Search with highly radio-pure NaI(Tl)
- Test the annual modulation signal (DAMA/LIBRA)
- Detection of dark matter candidates
- Simple & Scalable detector design









- 3”ϕx3”, 4”ϕx3” crystal for RI reduction study
- 5”ϕx5” crystal for realistic DM measurement
- 5”ϕx5” x9 modules for test DAMA
- 5”ϕx5” x42 modules inside KamLAND for further DM search

Today’s topic

PICOLON / KamLAND-PICO Collaborators

Pure Inorganic Crystal Observatory for Low Background Neutr(al)ino

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  K. Imagawa, K. Yasuda

PICOLON NaI(Tl) History

3”ϕx3” (I23) (TAUP2013)

- Pure crucible w/ Pt coating
- Pb reduction resin

3”ϕx3” (I26) (TAUP2015)

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- Ra reduction resin
- N_2 bubbling on purification
- OFC housing
- Rehousing after shock absorber was main RI source

4”ϕx3” (I37) (TAUP2017)

\+

- K reduction resin
- x4 purification
- Rehousing after bubble was found inside grease

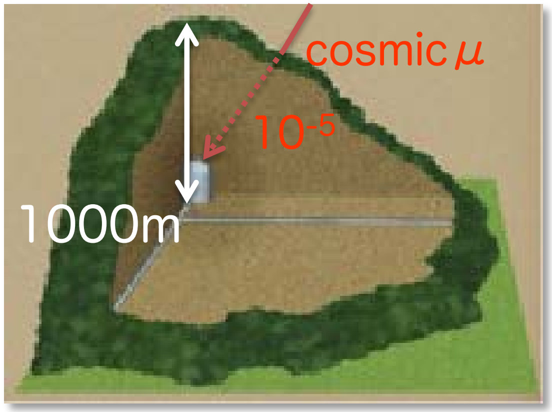
5”ϕx5” (I53) (TAUP?)

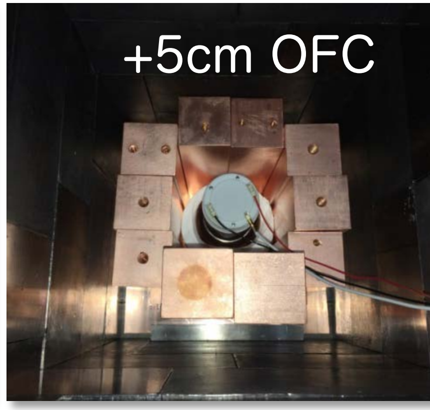
\+

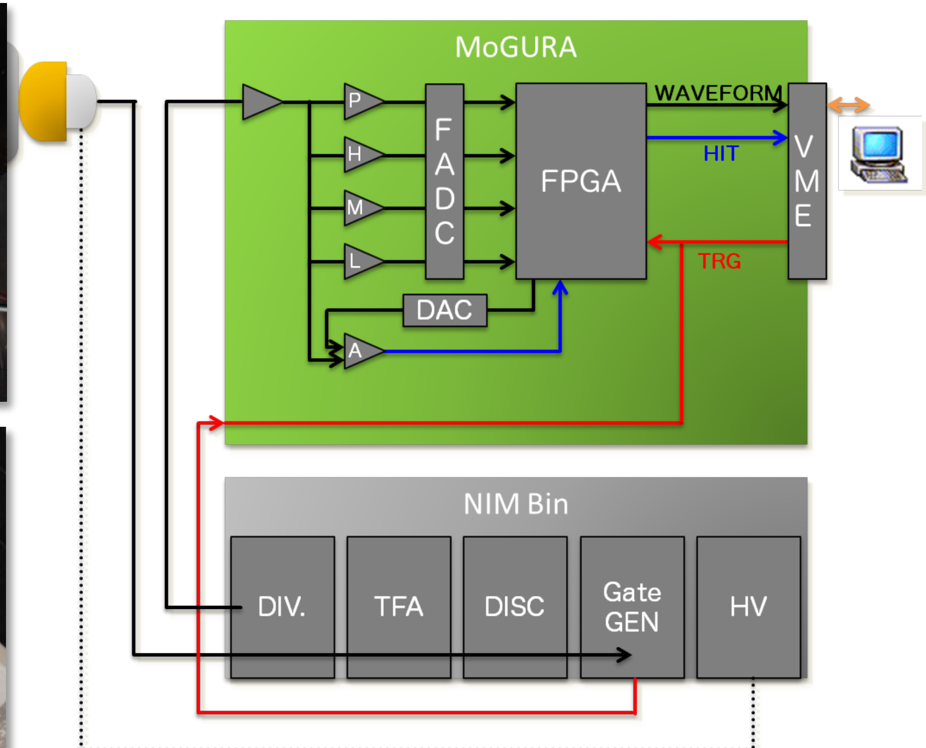
- x1 long and large amount resin purification
- Multiple filtering
- Optimized drying
- On crystallization

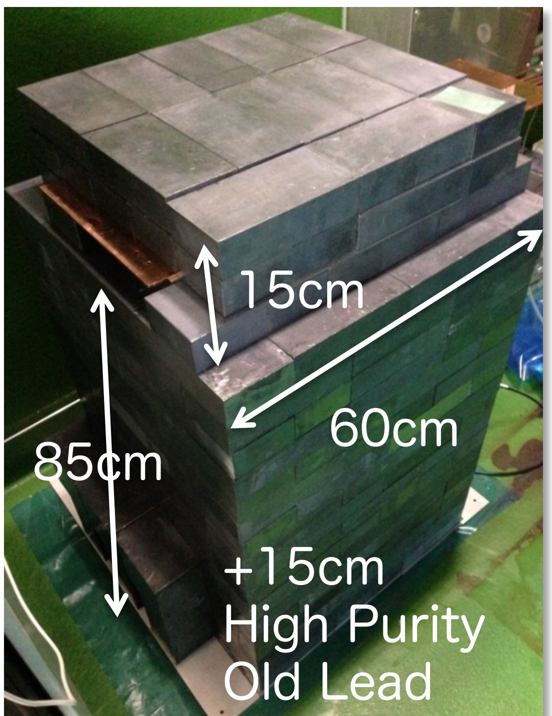
Many operation, parameters have been kept optimizing.

4” ϕ x 3” NaI(Tl) : Measurement Setup



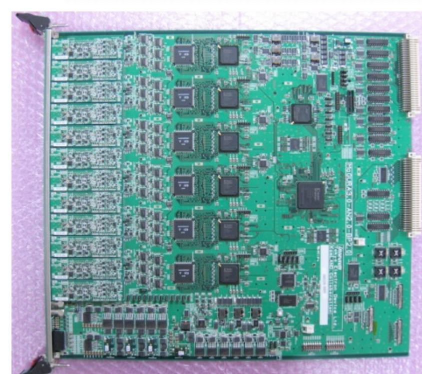






45cm Pb below
cupper shield

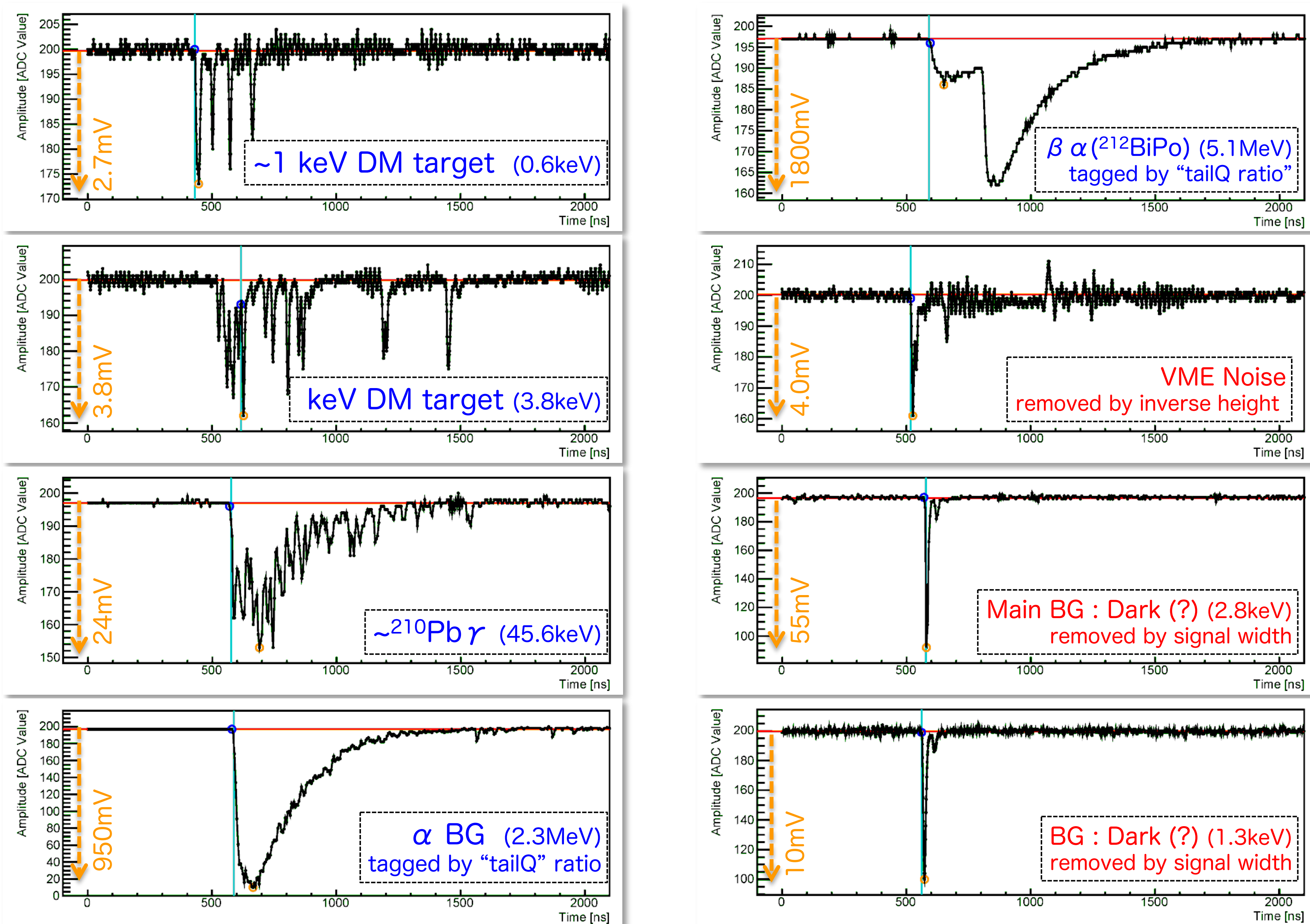
Radon-free air
w/ HEPA in room.
GN_2 flow inside Pb.



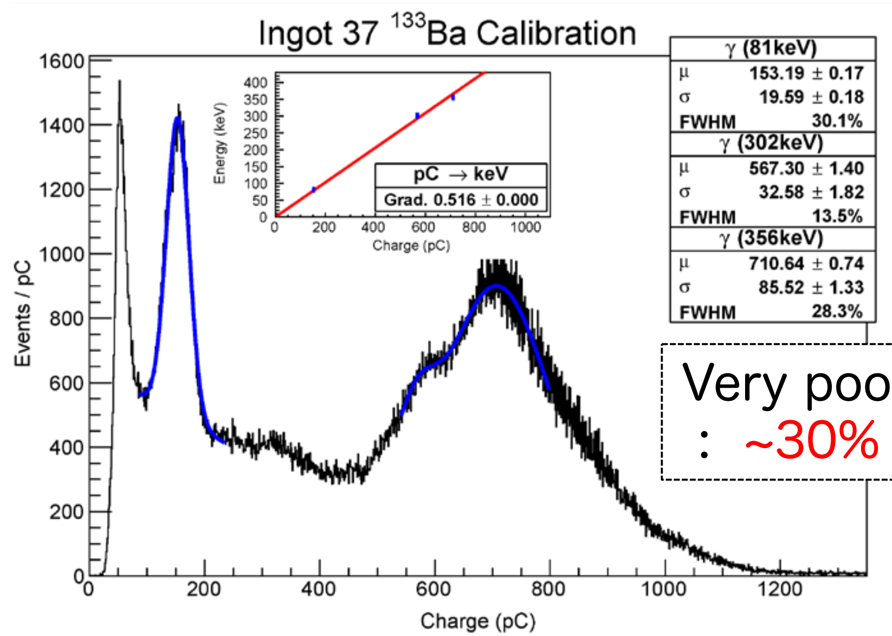
KamLAND MoGURA
- 1GSPS
- 4us waveform
- 0.1mV-10V
- Ana/Digi discri.

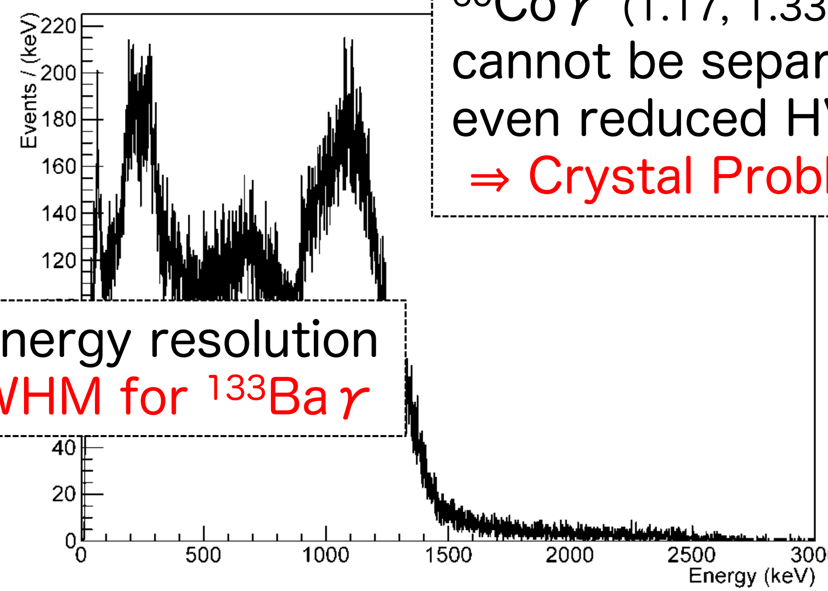
\+
ORTEC TFA 474
reduce PMT noise

4” ϕ x 3” NaI(Tl) : Signal Characteristics



4” ϕ x 3” NaI(Tl) : Calibration (Problem)



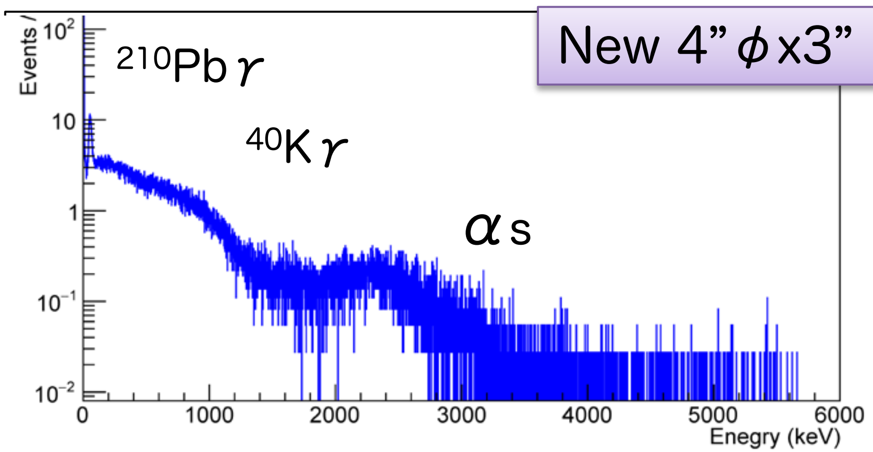


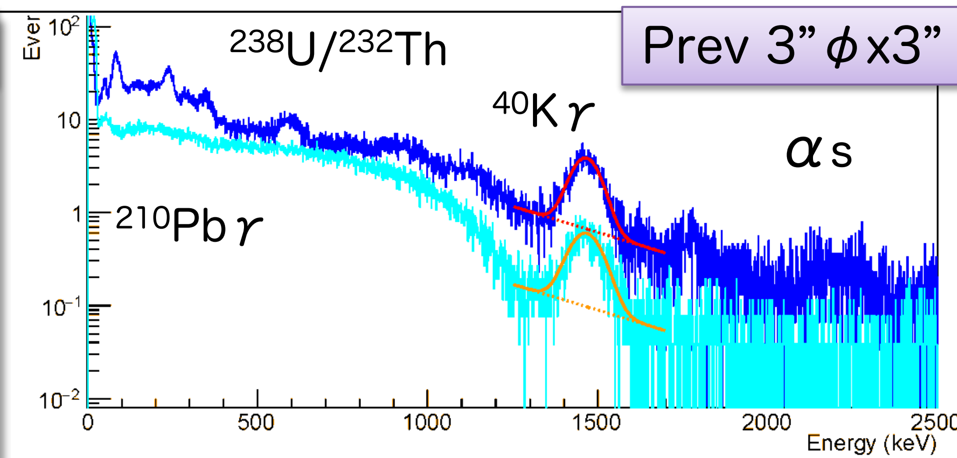
^{60}Co γ (1.17, 1.33MeV) cannot be separated even reduced HV

⇒ Crystal Problem

Very poor energy resolution

: ~30% FWHM for ^{133}Ba γ



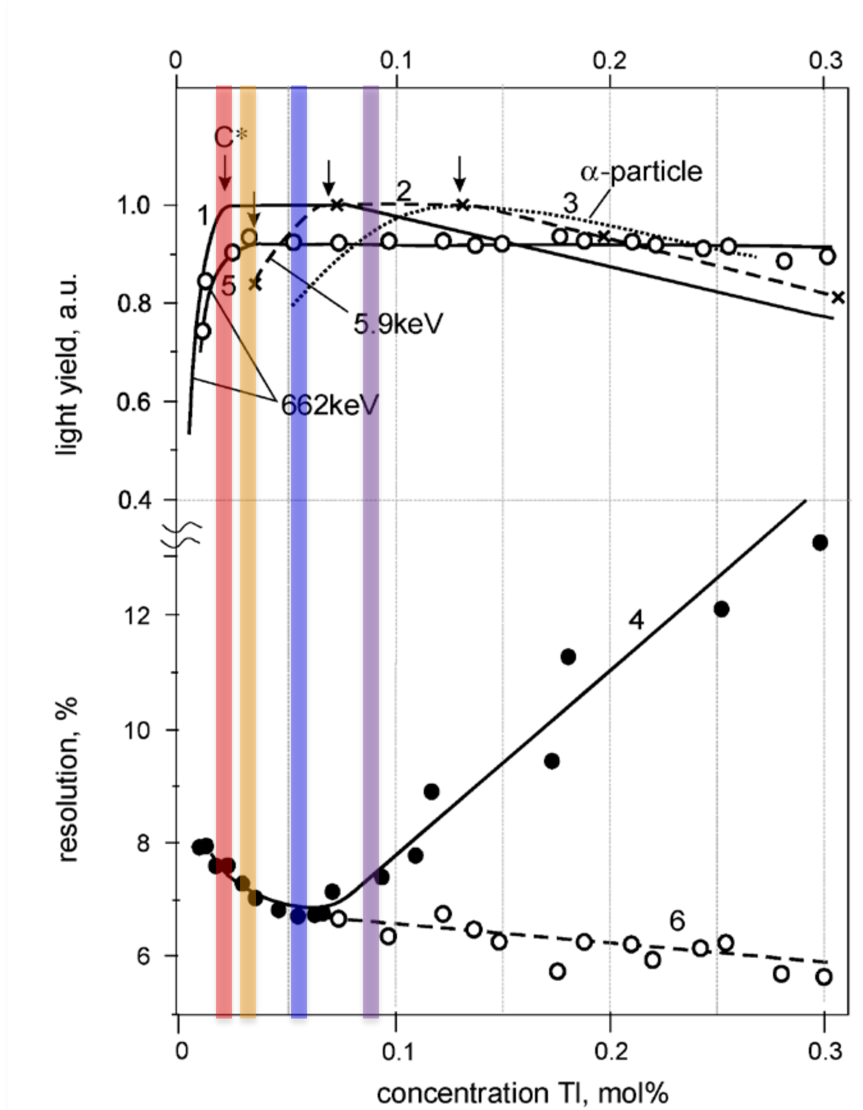


BG seems to show almost no ^{40}K γ at first glance w/ significant BG suppression, turned out to show serious energy resolution, energy quenching problem

4” ϕ x 3” NaI(Tl) : Low Energy Resolution

ICP-MS meas. Agilent 7700	$^{205}Tl/^{23}Na$ ratio
4” Over Top	0.0875
4” Side Top	0.0347
4” Side Bottom	0.0260
3”	0.0524

- false temp. control introduced steep Tl concentration gradient.
- Energy-Position dependence caused low energy resolution, caused energy non linearity.
- effect is significant @ DM energy.
- next NaI will have 0.05-0.07 ratio, with already refurbished temp control.



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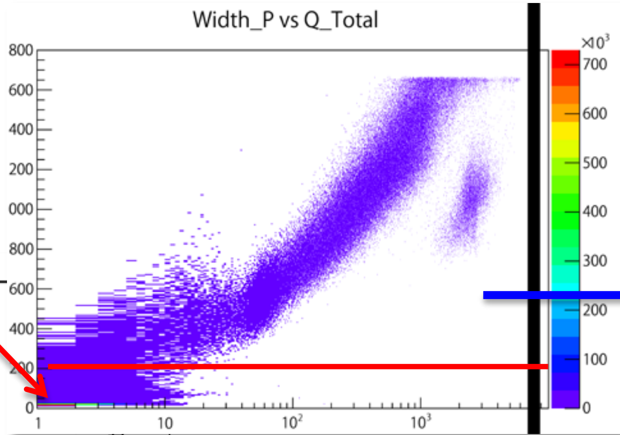
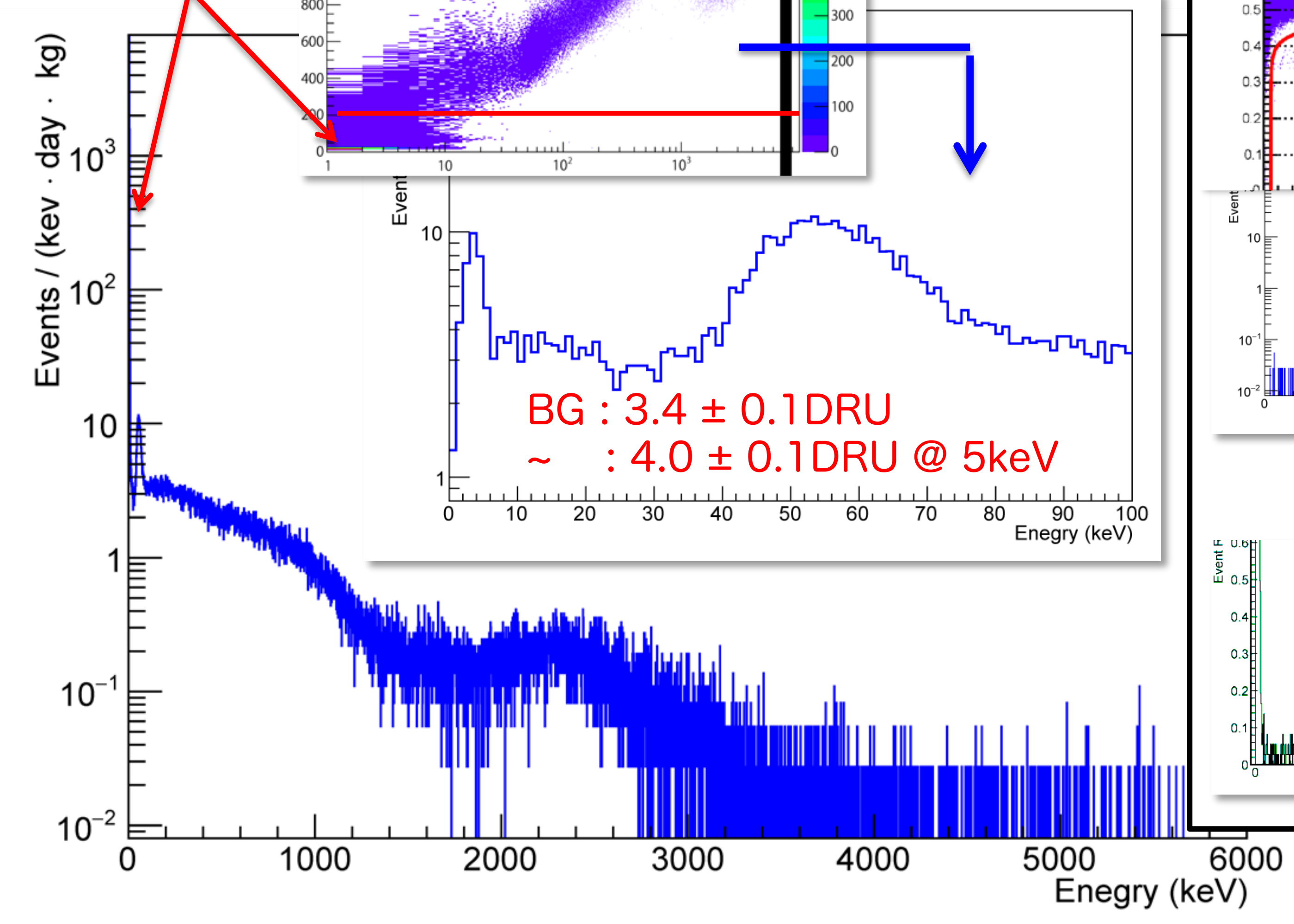
4” ϕ x 3” NaI(Tl) : BG Spectrum (2.27kg x 16.7d)

>99.9% data @ < 5keV, < 200ns

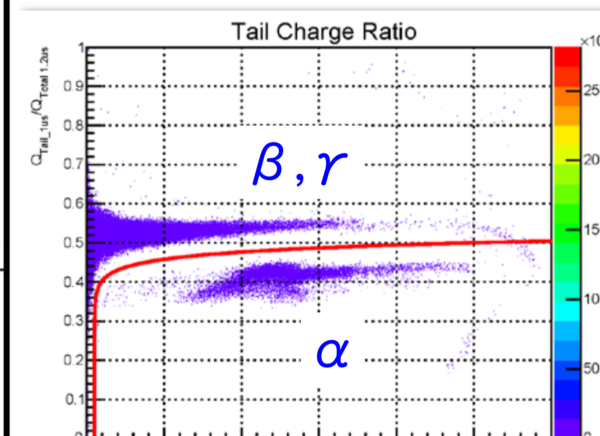


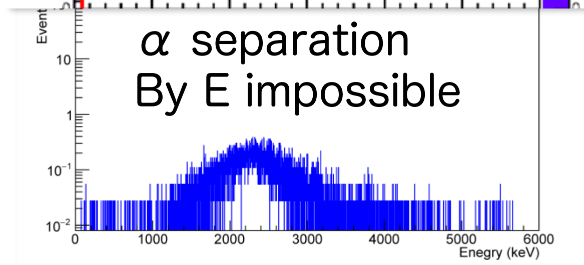
Events Width > 200ns are discussed later



BG : 3.4 ± 0.1DRU

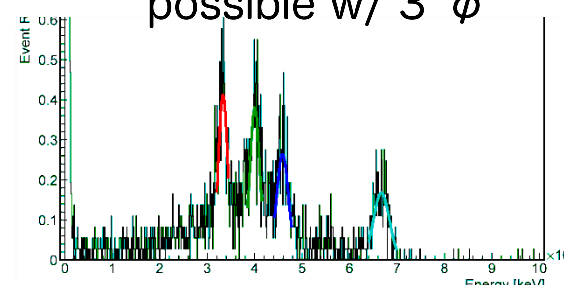
~ : 4.0 ± 0.1DRU @ 5keV



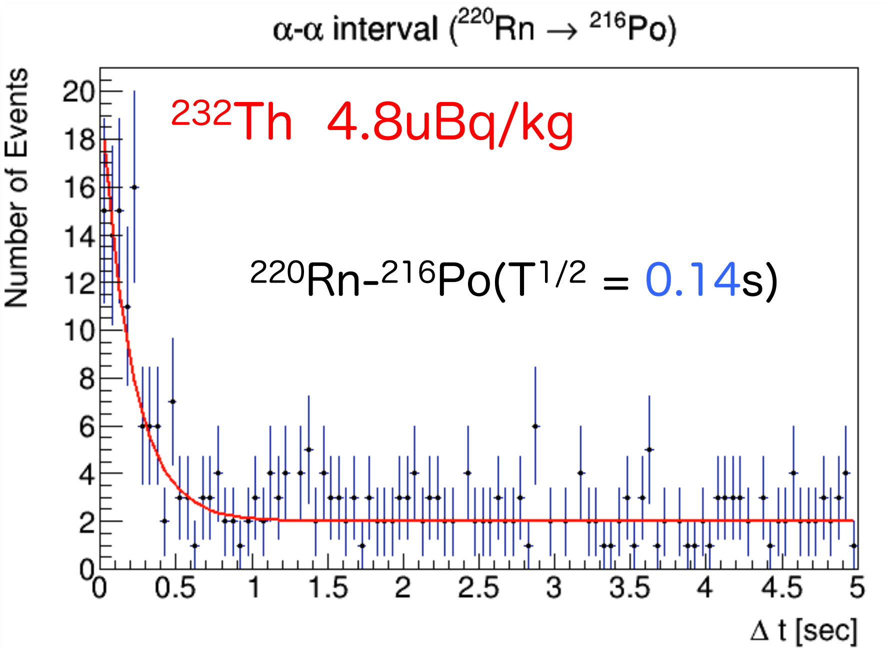


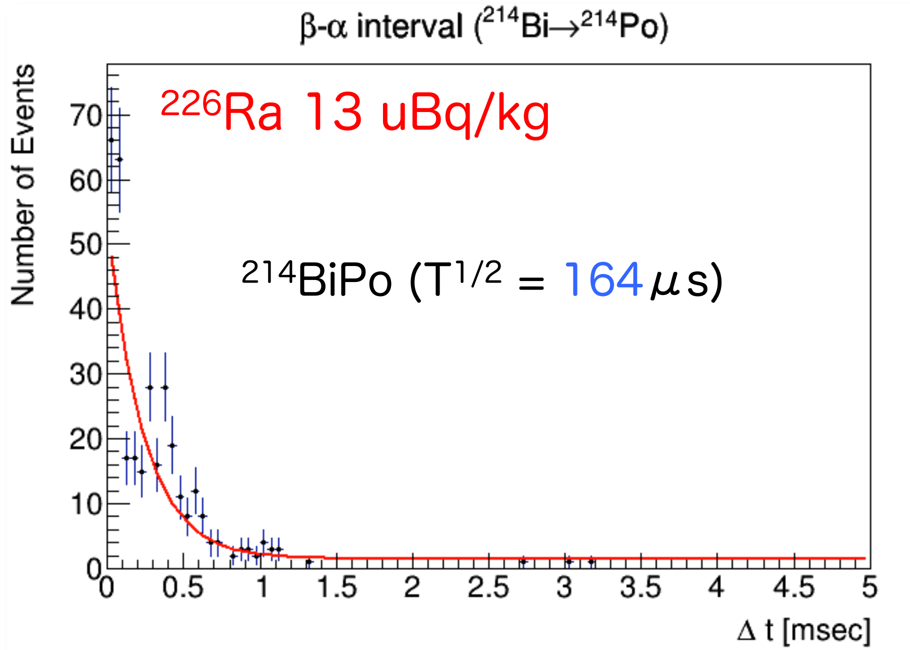
α separation By E impossible

used to be possible w/ 3” ϕ



4” ϕ x 3” NaI(Tl) : Radio Impurities

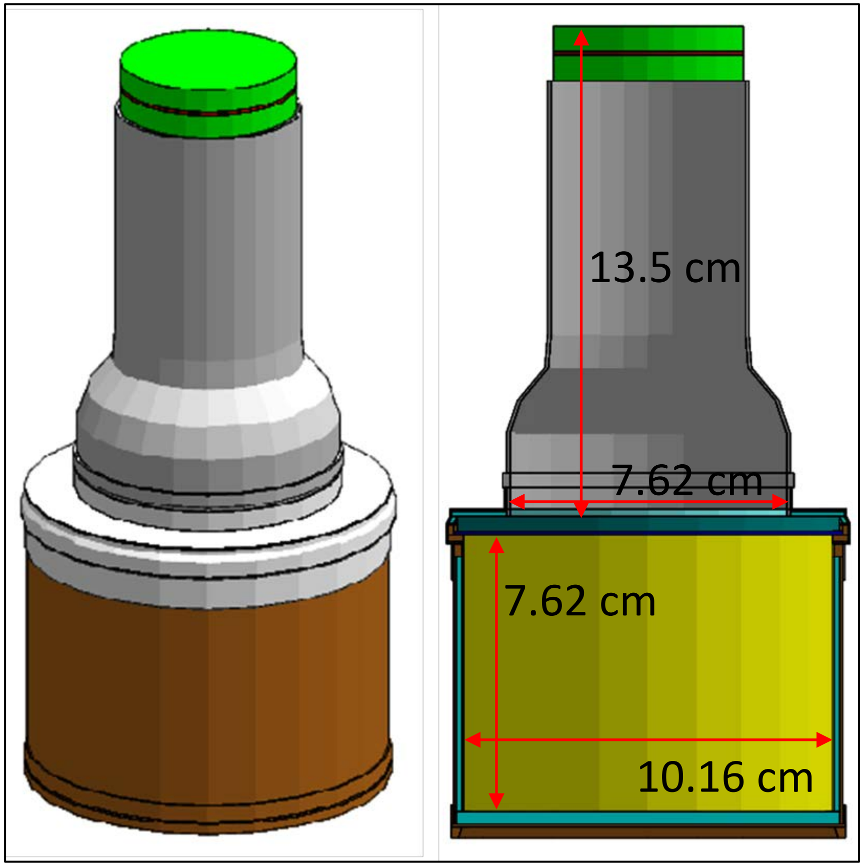




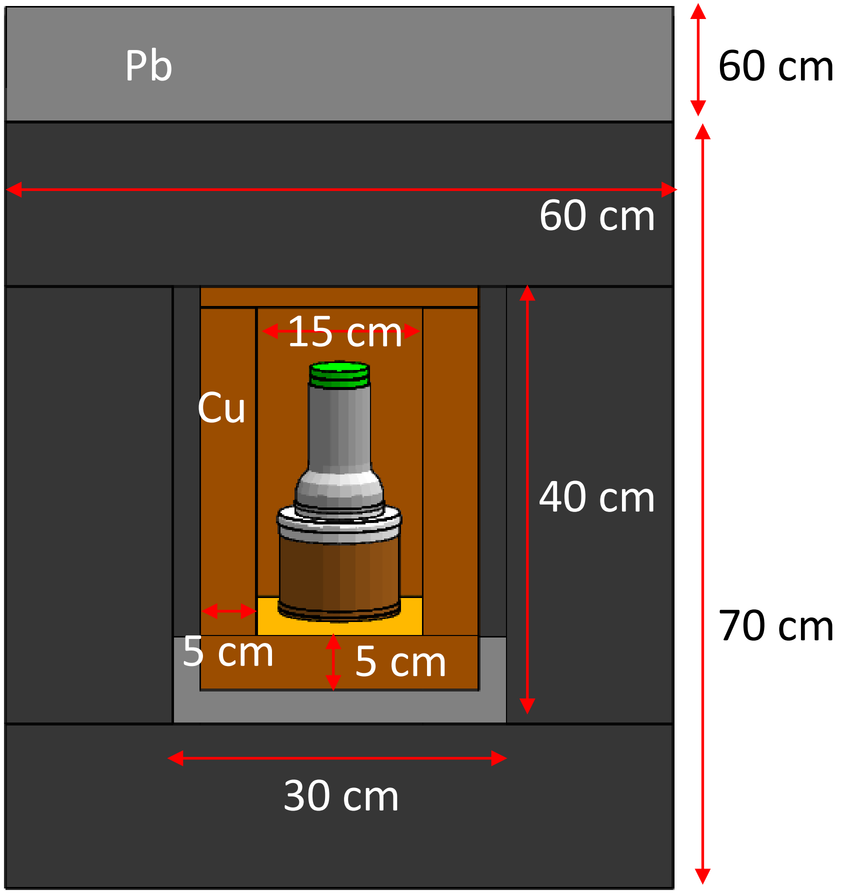
	DAMA	DM-Ice	3”φx3”	4”φx3”	Goal
^{nat}K (ppb)	<20	660	2630	120*	<20
^{232}Th (ppt)	0.5-0.7	2.5	0.4±0.5	~1.2	<4
^{238}U (ppt)	0.7-10	1.4	4.7±0.3	~1.1	<10
^{210}Pb (uBq/kg)	5-30	1470	29.4±6.6	~2300	<5

(1ppt : ^{238}U 12.3uBq/kg, ^{232}Th 4.0uBq/kg, ^{210}Pb 2.5kBq/kg
^{nat}K 1ppb = ^{40}K 31uBq/kg) (* eval from MC)

4” ϕ x 3” NaI(Tl) : Monte Carlo Simulation



4” ϕ NaI(Tl) + R11065-20

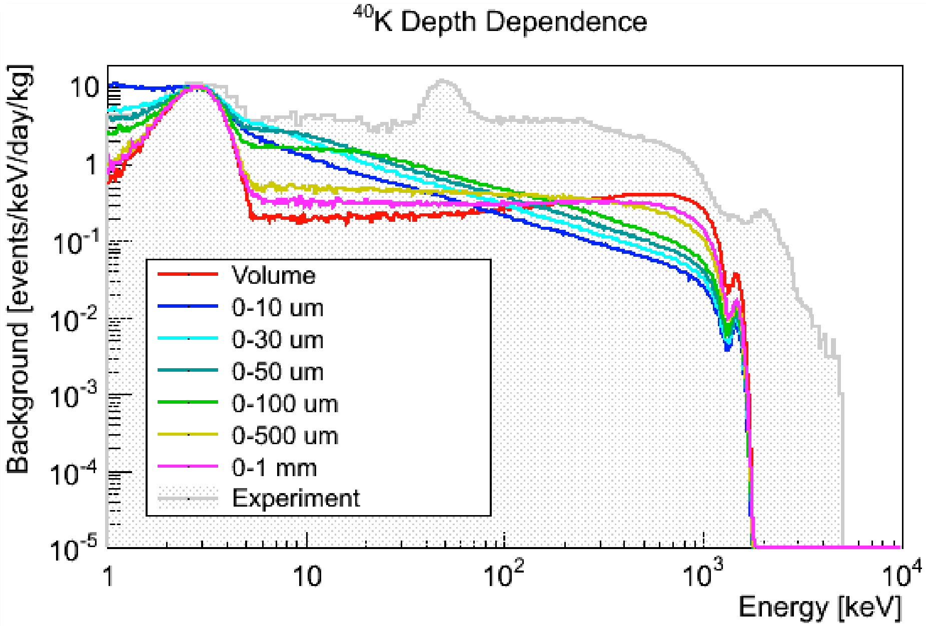


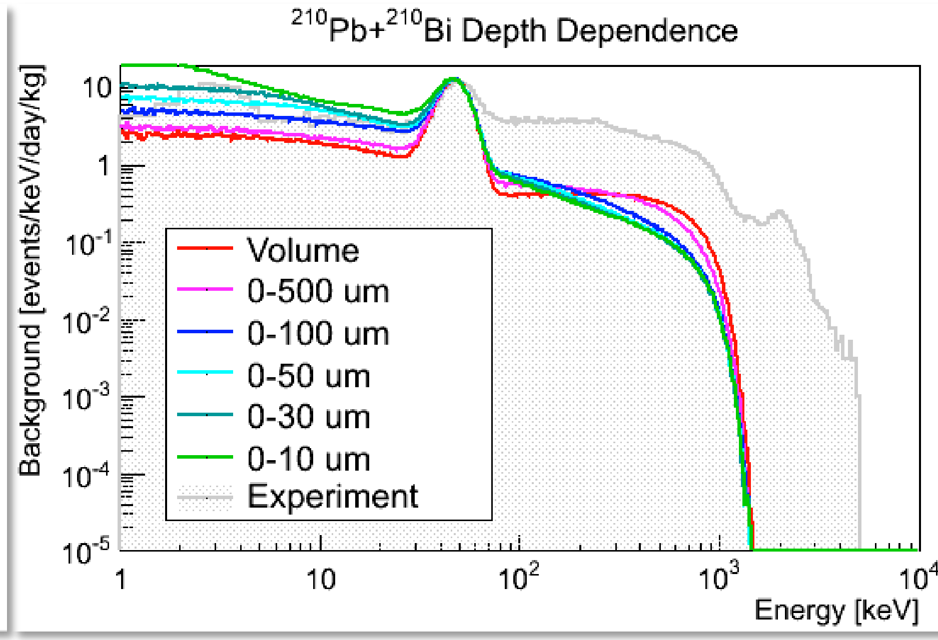
Shield

NaI(Tl) detector : Bulk/Surface NaI(Tl), reflector, optical window, grease,

Motivation : origin of ^{40}K, ^{210}Pb for next crystal.

4” ϕ x 3” NaI(Tl) : Sim : ^{40}K, ^{210}Pb dist.



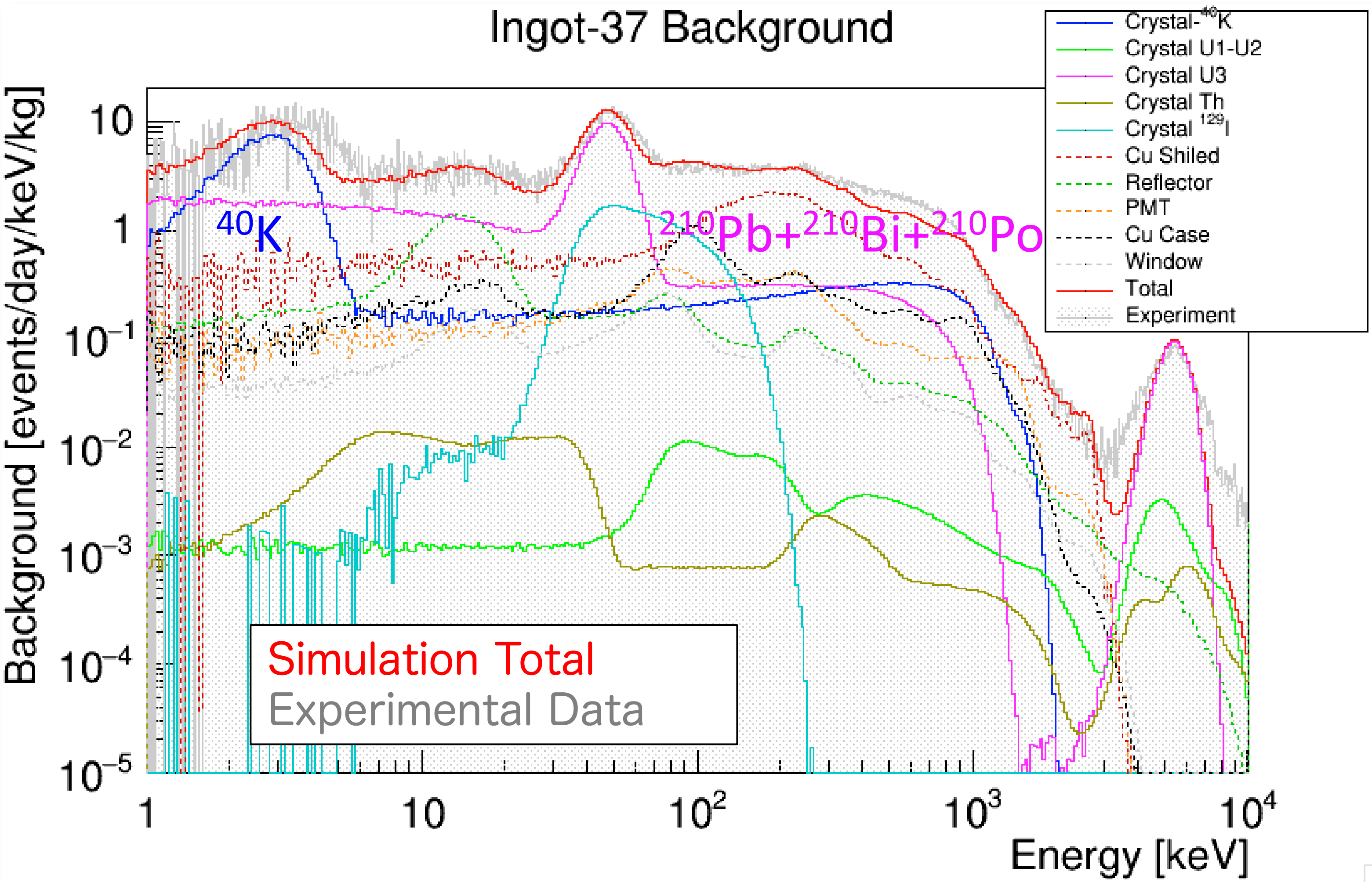


- Energy spectrum requires ^{40}K @ 50um+ deep or uniform distribution.
- Crystal polisher cannot enter such deep. (by HORIBA)
- Polisher could be the cause only when 10-20g remains on the surface (Ge; 465-885mBq/kg)
- Uniform ^{40}K. ⇒ 3.8mBq/kg (120ppb)

- Energy spectrum requires ^{210}Pb @ 100um+ deep or uniform distribution.
- Crystal polisher or radon-air during assembly cannot enter such deep and with large amount
- Uniform ^{210}Pb. ⇒ 2.3 mBq/kg

Preparing high sensitive ICP-MS

4” ϕ x 3” NaI(Tl) : Sim : Whole BG



- If we recover ^{210}Pb rate as in previous 3” ϕ crystal; 30uBq/kg, BG will be reduced to 1.5 DRU.
- ^{40}K detection with external LS detector is under study.

Preparation for 5”ϕx5”

New large crucible.

Special coating on inner surface.
Crystallization on process till Jul. 28.
Housing will be finished end of Aug.
Housing material will be acrylic, and under RI evaluation.

New ultra-low RI 4” PMTs.

Body is under Ge evaluation.
RI check for voltage divider components are also on going.

x500 20x10x5 cm old Lead.

Surface was washed by Nitric acid, pure water, ethanol.

600kg fresh 4N OFC.

Exposed on ground only 1 month during production.
Will be cleaned as well

Summary & Prospects

- Radio activity reduction has almost reached the goal.
  - $^{238}U/^{232}Th$: ~1ppb : ~DAMA
  - ^{210}Pb increased 0.030 ⇒ 2.3mBq/kg, (cause : not enough resin)
  - ^{40}K still a bit high (~^{nat}K 130ppb), (cause : not enough resin)

- 4”ϕx3” NaI(Tl)
  - Low resolution due to small Tl rate,
  - 3.4 DRU has been accomplished : ~ world top level.
  - 1.5 DRU is feasible with next crystal.

- Future
  - 5”ϕx5” NaI(Tl) is under crystallization.
  - Material RI assessment is still on going.
  - Measurement will be done within a couple of month.
  - ⇒ 5”ϕx5” x 42 module experiment!