Dark matter search by highly radiopure NaI(Tl)

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1. COMMENT ON XENON 1T RESULT
2. PURIFICATION OF NAI(TL)
3. RESULT OF PURIFICATION
4. DISCUSSION

XENON 1T result

arXiv:2006.09721v2

Fiducial mass = 1.042 ton

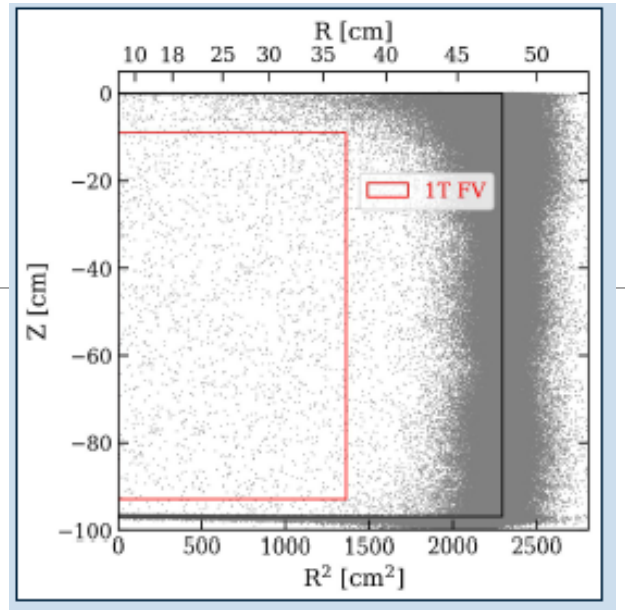
Live time = 226.9 days

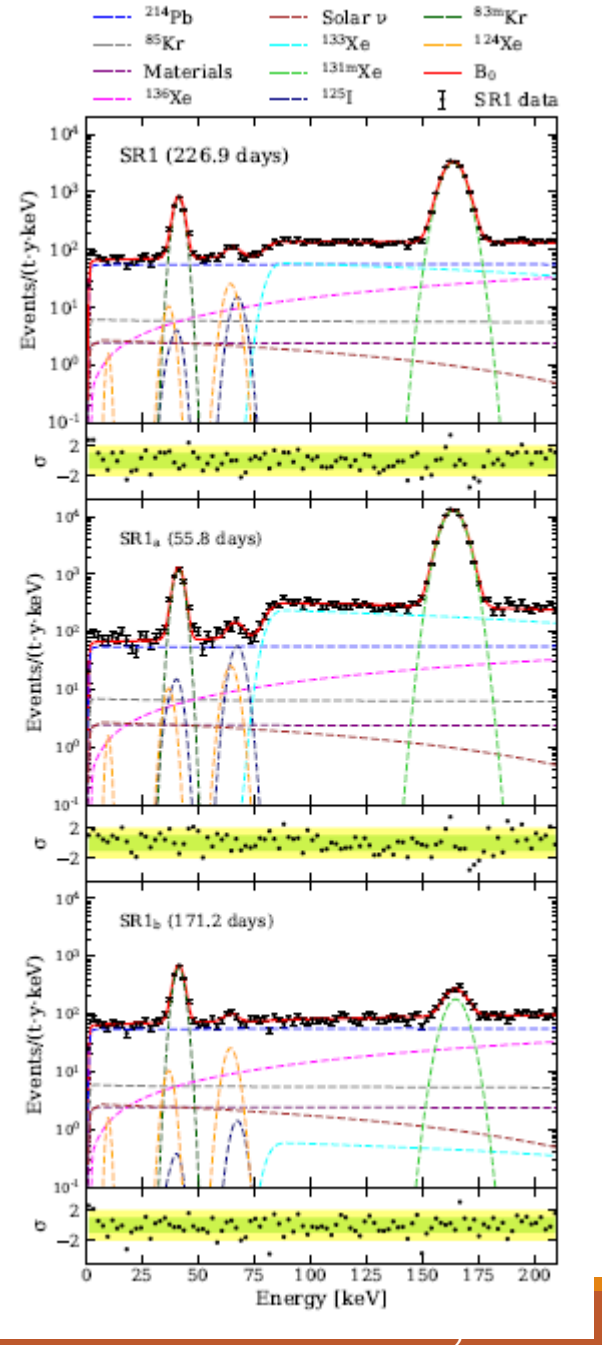
0.647 ton·y

BG model = Fitted in high energy region.

BG rate = (76±2) /ton/y/keV (1~30 keV)

= (2.1±0.1) × 10^{-4}/kg/day/keV





Low energy

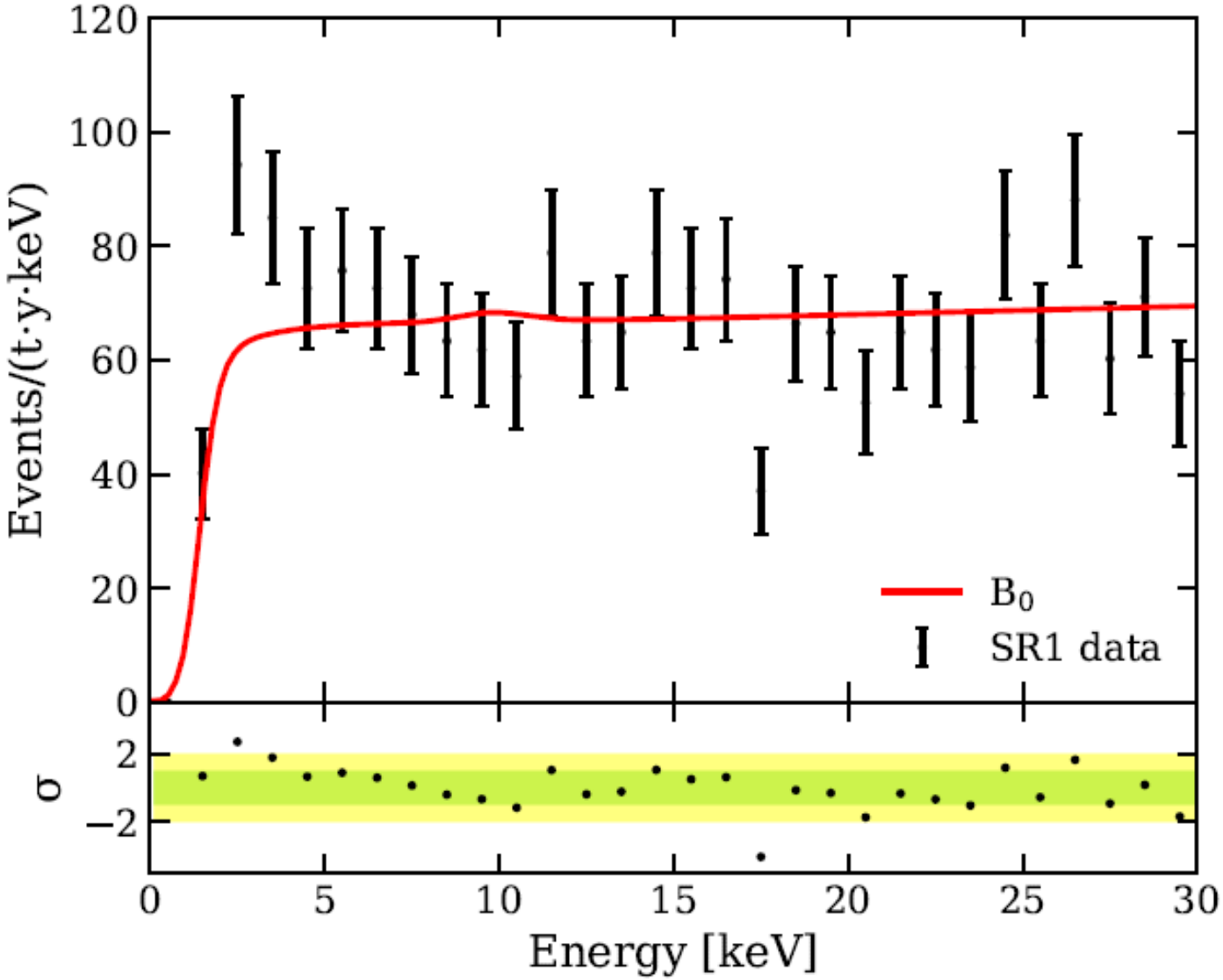
Significant excess below 7 keV.

1~7 keV

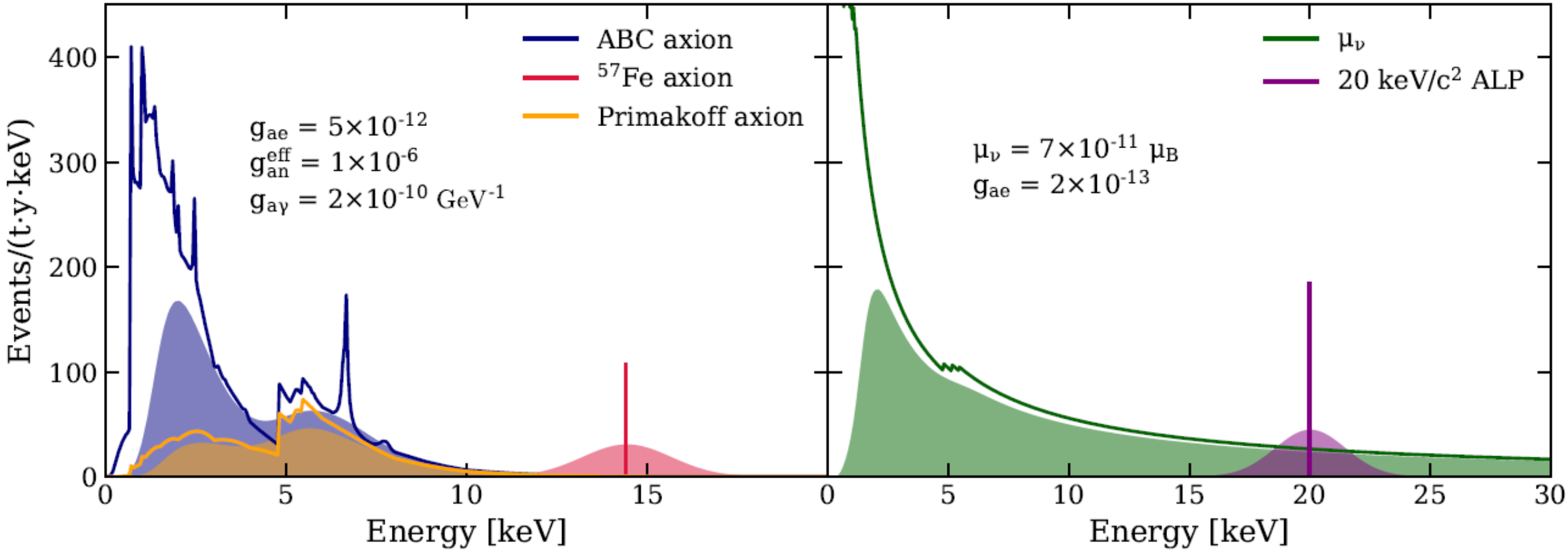
Observed = 285 events

BG expected = 232±15 events

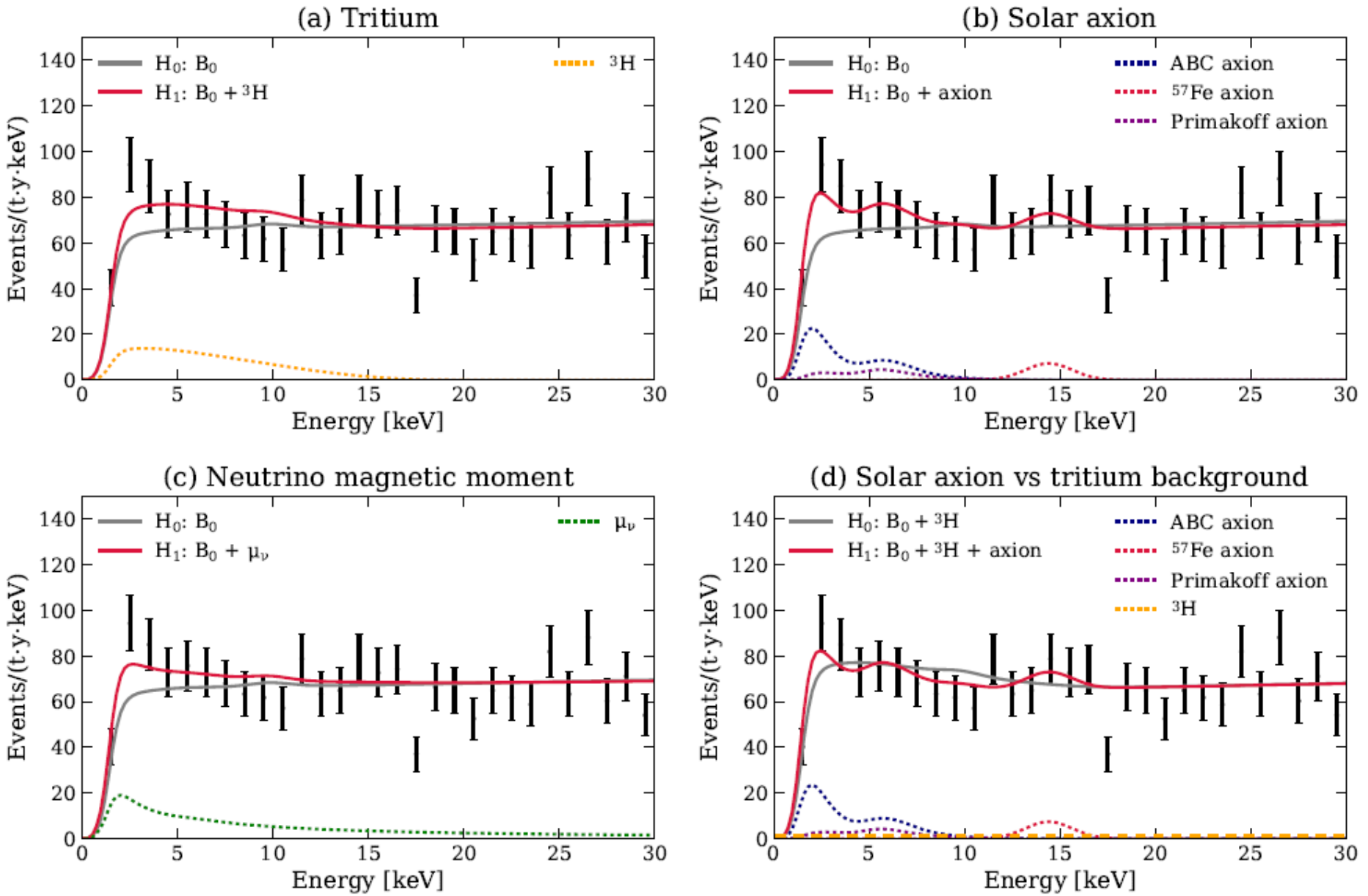
3.5σ fluctuation



Expected signal of Solar axion in XENON 1T



Various fits



XENON 1T results

Solar axion (90% C.L.)

$$\begin{cases} g_{ae} < 3.7 \times 10^{-12} \\ g_{ae} g_{an}^{eff} < 4.6 \times 10^{-18} \\ g_{ae} g_{a\gamma} < 7.6 \times 10^{-22}\ \mathrm{GeV}^{-1} \end{cases}$$

and

$$\begin{cases} g_{ae} \neq 0 \\ g_{ae} g_{a\gamma} = g_{ae} g_{an}^{eff} \neq 0 \end{cases}$$

Neutrino magnetic moment (90% C.L.)

$\mu_\nu \in (1.4, 2.9) \times 10^{-11} \mu_B$

Next step after XENON 1T

Verification of their result by

- Other group of Xe
  - LZ: Construction in progress.

- Other group of other target
  - Need low BG ~ 10^{-4} dru and 1-ton mass
  - NaI(Tl) is one of the lowest BG target.

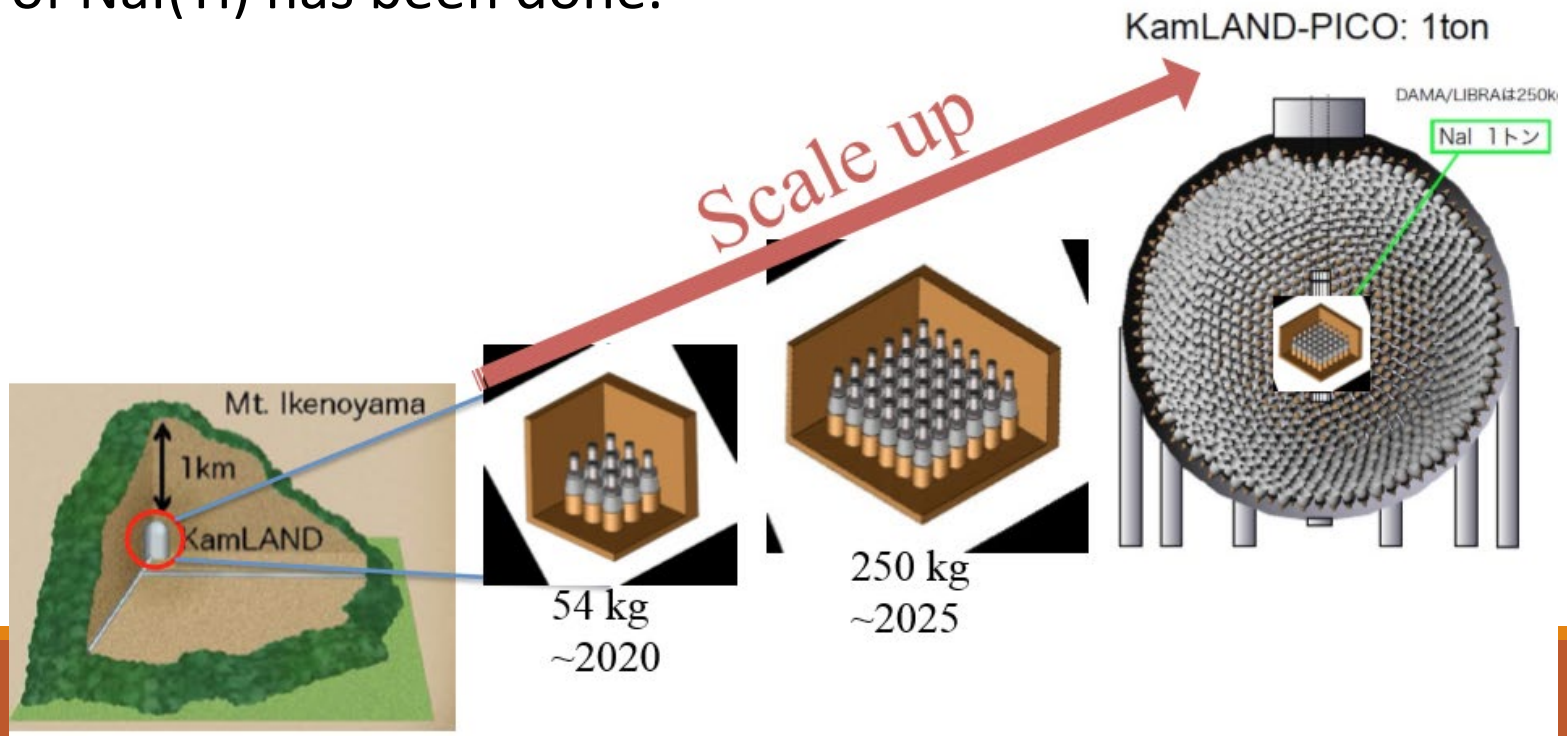
PICOLON

Pure Inorganic Crystal Observatory for LOw-energy Neutr(al)ino

Aim

Search for dark matter and fundamental processes in nuclear and particle physics.

Purification of NaI(Tl) has been done.



Previous results on purification

	Ingot26 (2015)	Ingot37 (2016)	Ingot53 (2017)	Ingot68 (2018)	Ingot71 (2018)	Goal
Crystal size	3”ϕ×3”	4”ϕ×3”	5”ϕ×4”	3”ϕ×3”	3”ϕ×3”	5”ϕ×5”
^{nat}K (ppb)	2630	～120	～130	～120	～20	<20
^{232}Th (ppt)	0.4±0.5	3.7±0.5	2.9±0.6	3.1±3.3	1.7±0.2	<4
^{238}U (ppt)	4.7±0.3	5.9±0.3	29±1	7.6±0.3	9.7±0.8	<10
^{210}Pb (μBq/kg)	29.4±6.6	～2300	7565	7519	1076	<50
Purification methods	Pb resin + Cation exchange resin	Pb resin + Cation exchange resin	Pb resin + Cation exchange resin	Pb resin + Cation exchange resin	Re-crystallization×2	-

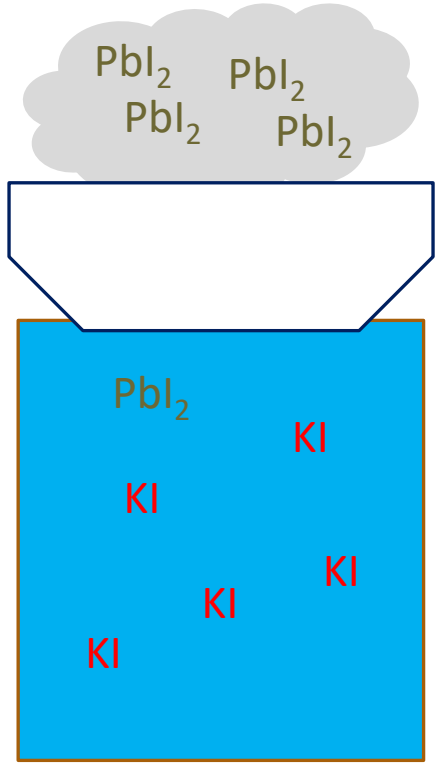
Ingot #83 (Previous NaI(Tl))

Double re-crystallization

- Remove ^{40}K in NaI powder.
- KI is well soluble in water.

Cation exchange resin

- Remove Pb ion in NaI powder.
- PbI_2 is not well soluble in water.



Re-crystallization

Result of purification for Ingot #83

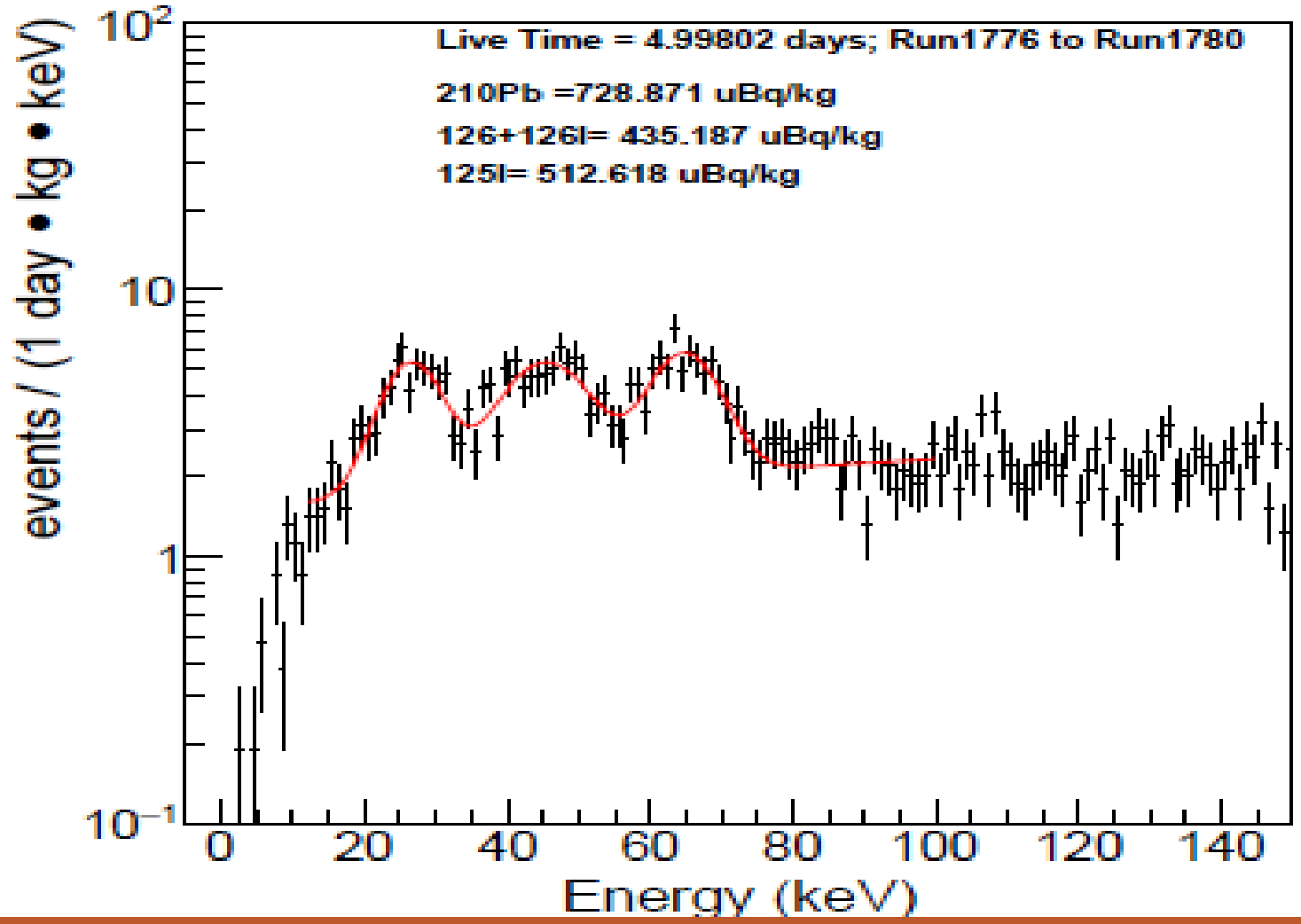
Clear locus of Alpha ray.

^{210}Pb remains in the ingot.

~ 1000 μBq/kg

Low energy region

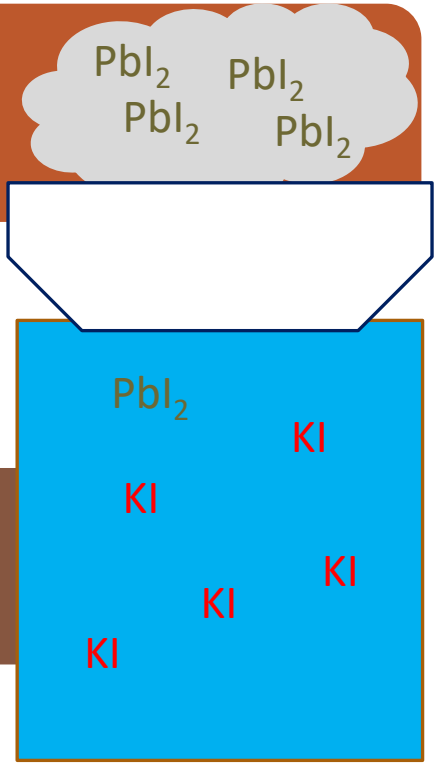
2~3 dru around 10 keV



Investigation of purification methods

Pb removal by re-crystallization

- PbI_2 is not water soluble.
- Pb remains in NaI powder.



K removal by re-crystallization

- KI is well soluble in water.
- K moved to water and removed from NaI powder.

Test of resin effectiveness
(K.Kanemitsu JPS meeting March 2020)

The effectiveness was verified by measuring the Pb concentration in NaI solution before and after resin processing.

◆ Procedure

- Make PbI2 added NaI solution.
- Pour NaI solution through the resin.

◆ Resins

A : For Ingot 26 to 83

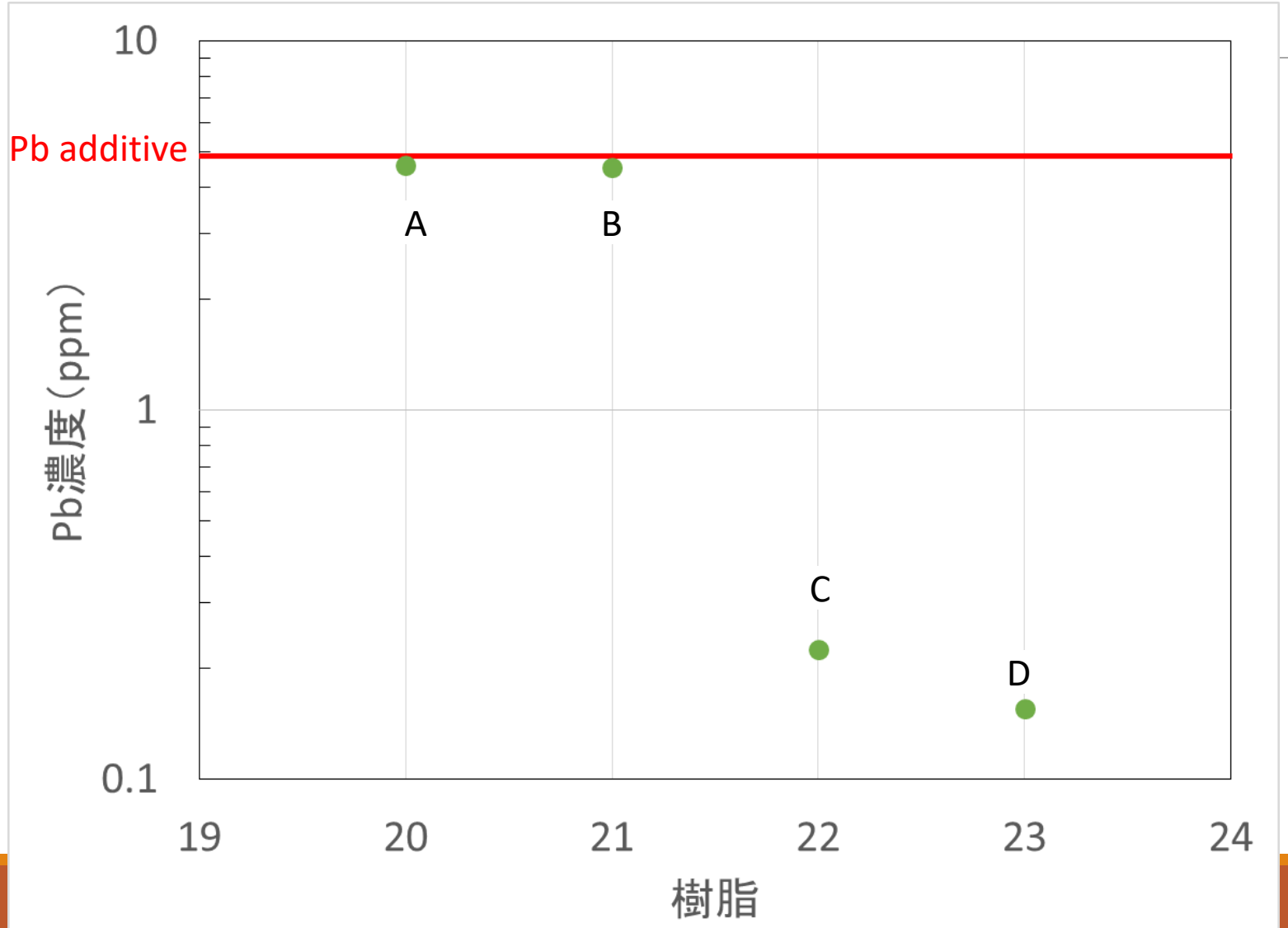
B : A similar resin to A.

C,D : Other new resins for Pb removal.

ICP-MS（Agilent7900）

Test of resin effectiveness

(K.Kanemitsu JPS meeting March 2020)

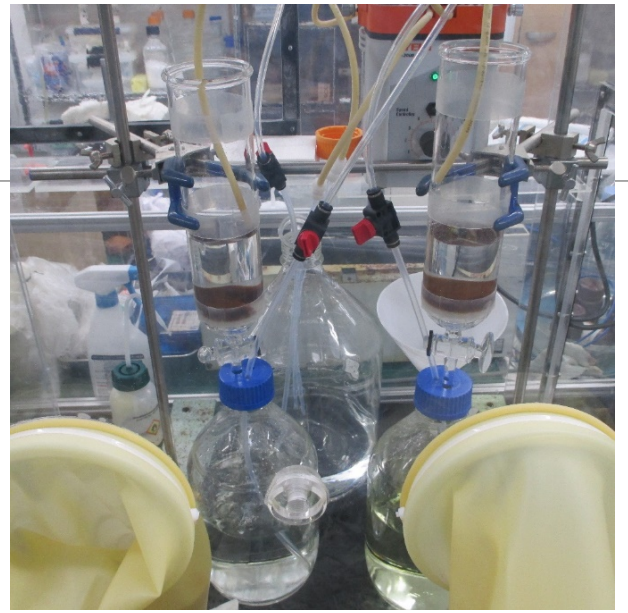


A,B : Not sufficiently effective

C : Pb reduced 1/20

D : Pb reduced 1/30

Purification of Ingot #85

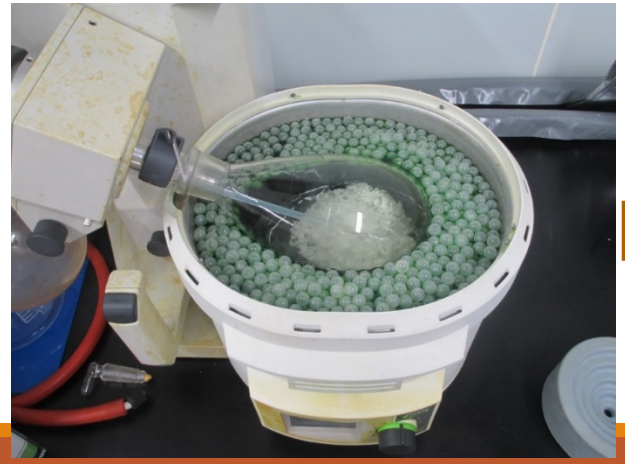


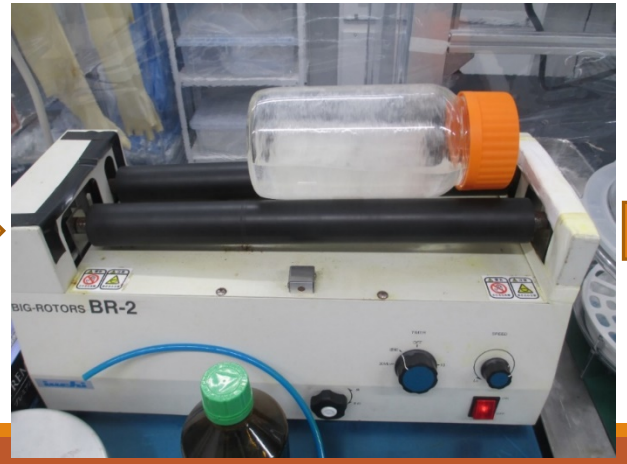
- Re-crystallization

1. Spatulated NaI solution at 100 ℃.
2. Pure NaI crystallize and KI remains in water.
3. Get the NaI by suction filtration.

- Resin for Pb reduction

1. 2 resins “C” and “D”
2. Clean booth filled with pure N_2 gas.





Crystal condition of Ingot #85

Clear and no bubble

Experimental setup (At Tokushima)

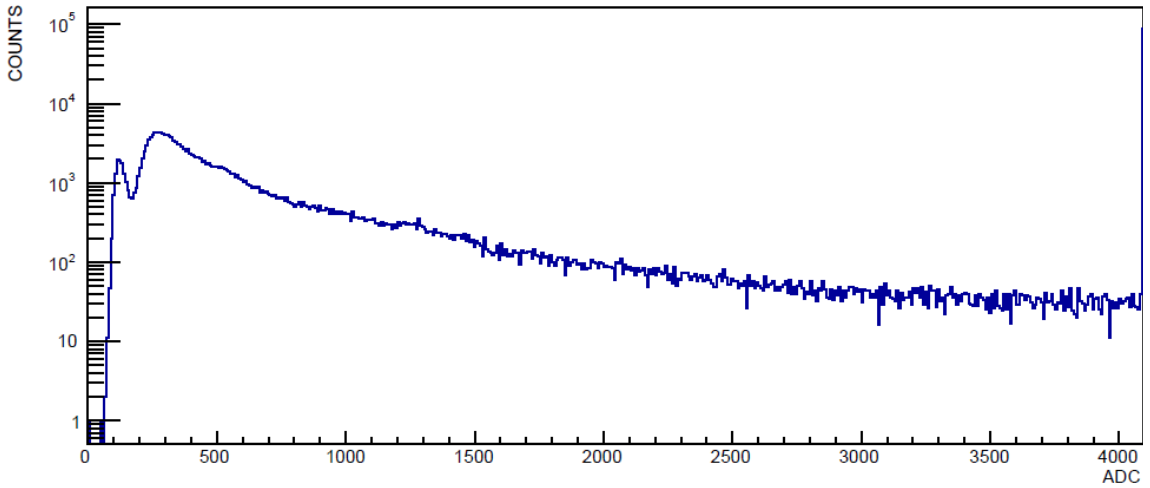
Shield: Pb 20 cm and OFHC 1 cm

Circuit and DAQ:

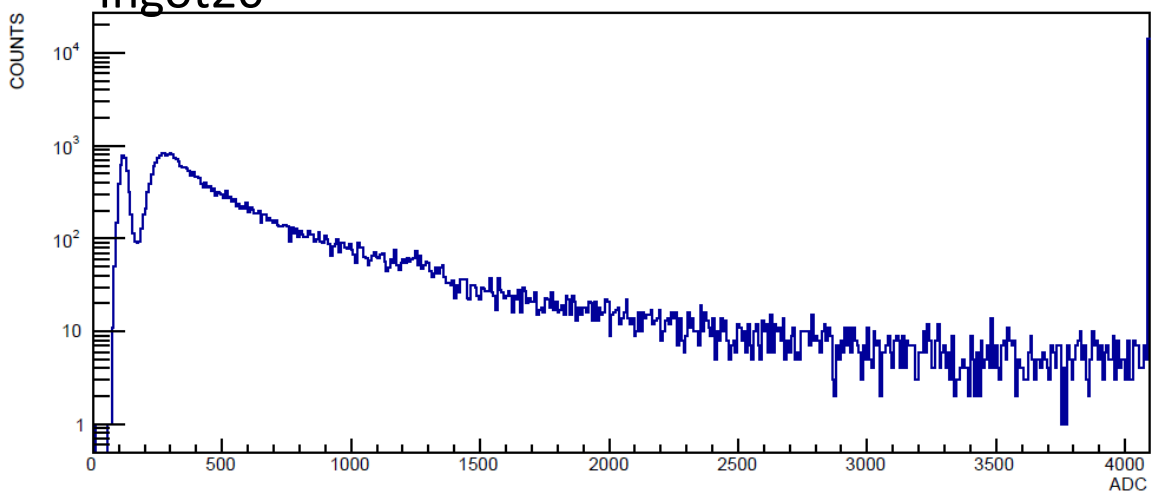
- Data taken by CAMAC.
- Pulse shape discrimination (PSD) is as described in NIMA.
  - K.Ichihara et al., Nucl. Instr. & Meth. in Phys. Res. **A 515** (2003) 651.

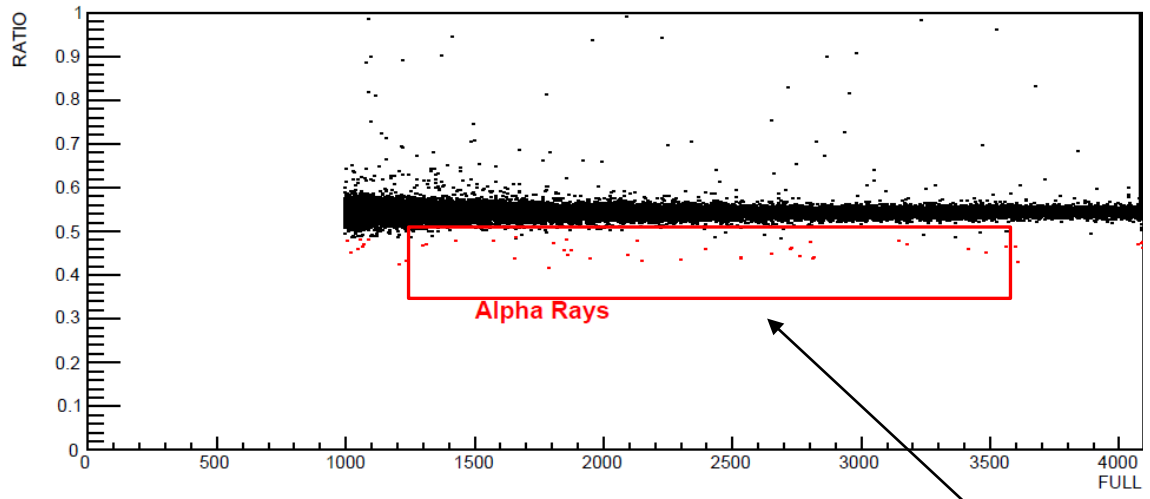
Ingot85 PSD

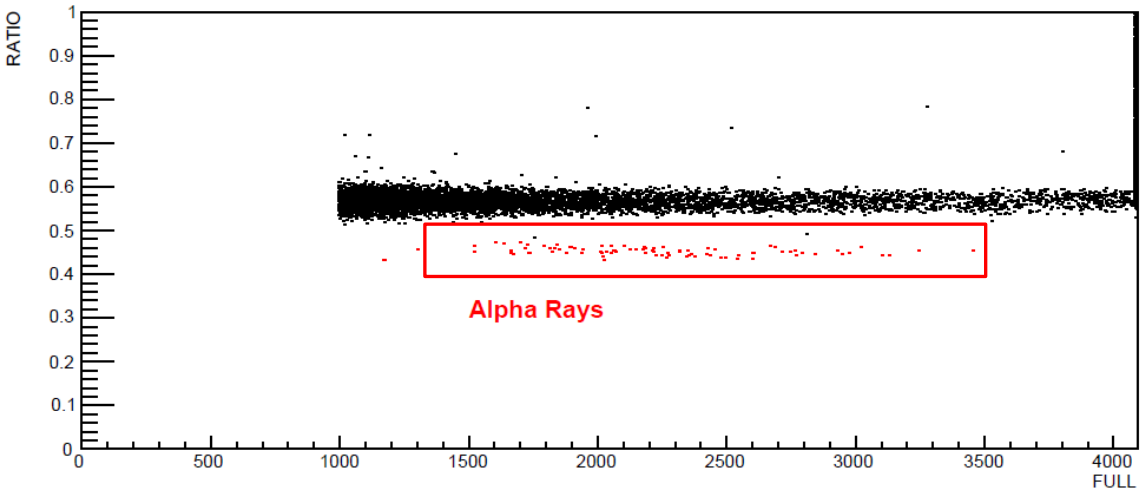
Ingot85



Ingot20





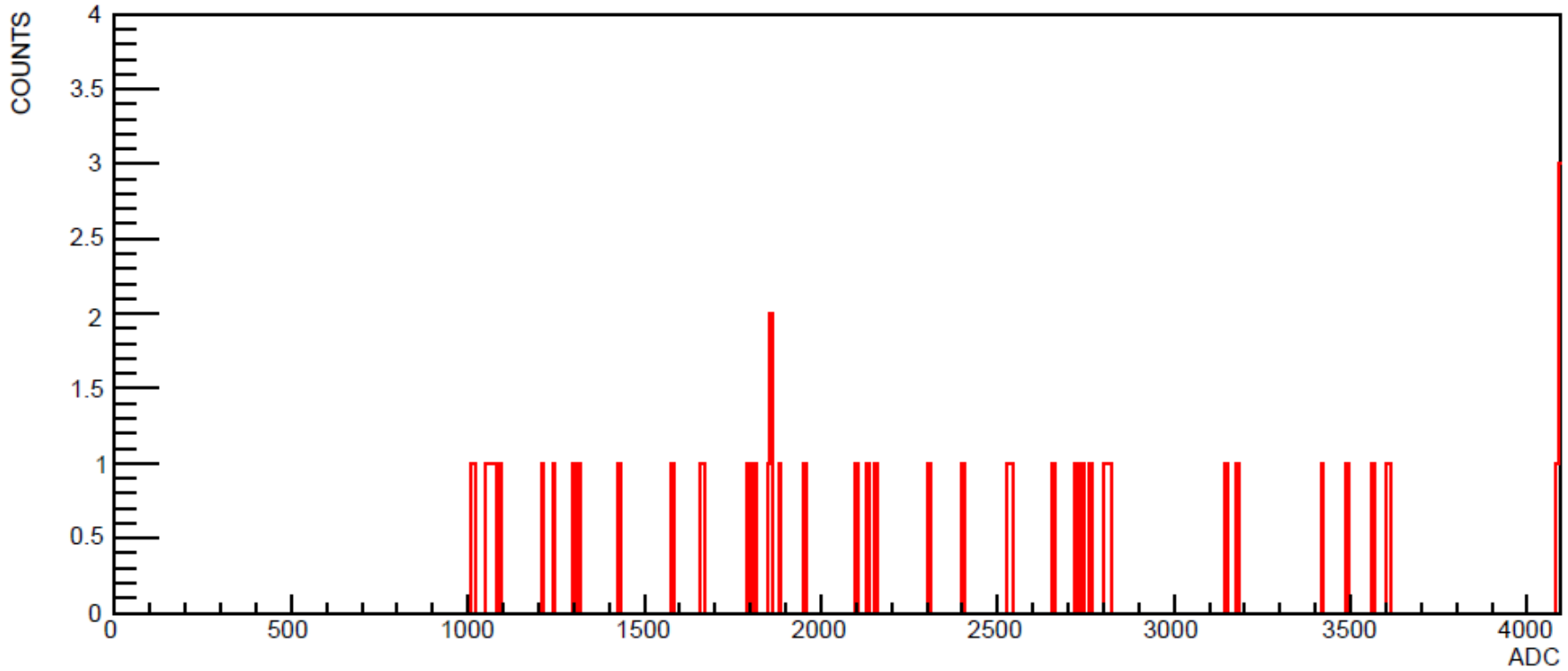


Not clear locus and event rate is small !!

Standard NaI(Tl)

Present NaI(Tl) Ingot #85

Alpha ray events decreased!!

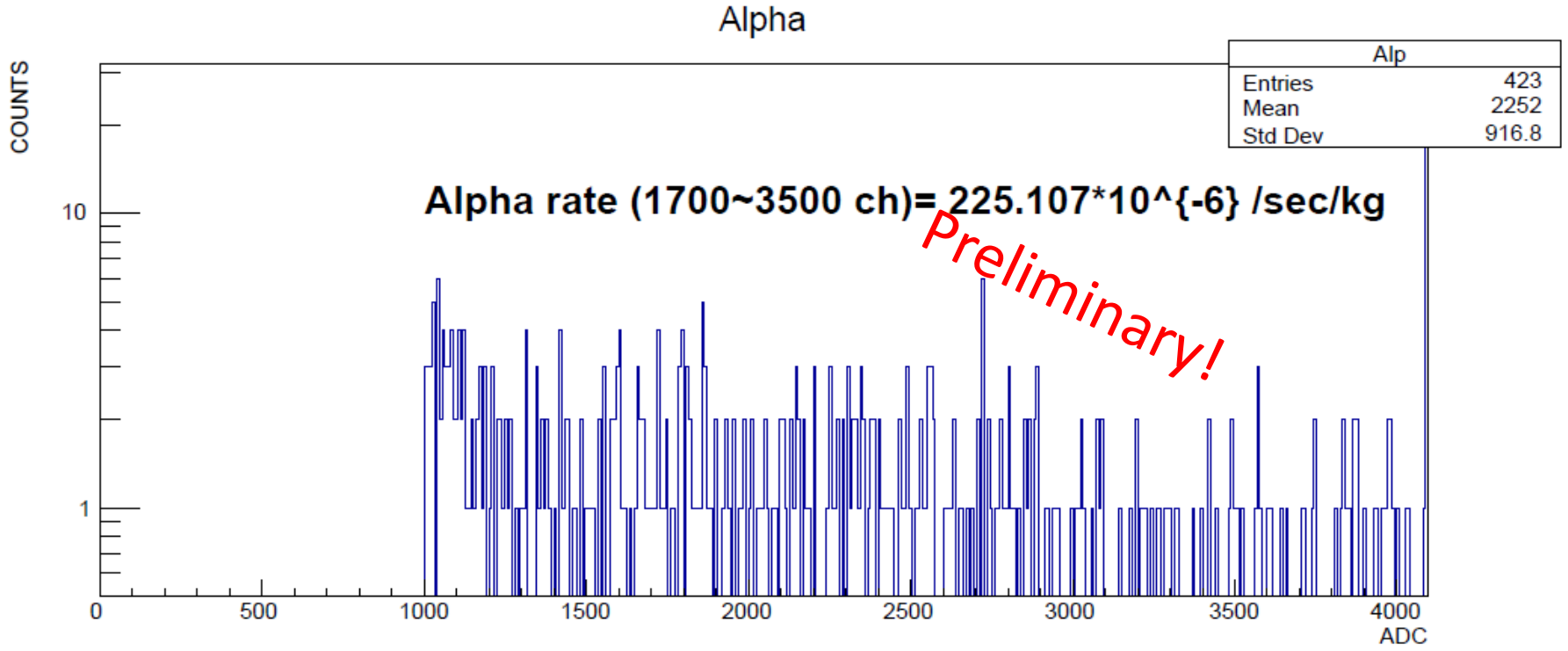


Alpha ray events

2 ~ 4 MeV_{ee}

No prominent peak observed!!

^{210}Po is supposed to be less than 50 μBq/kg.

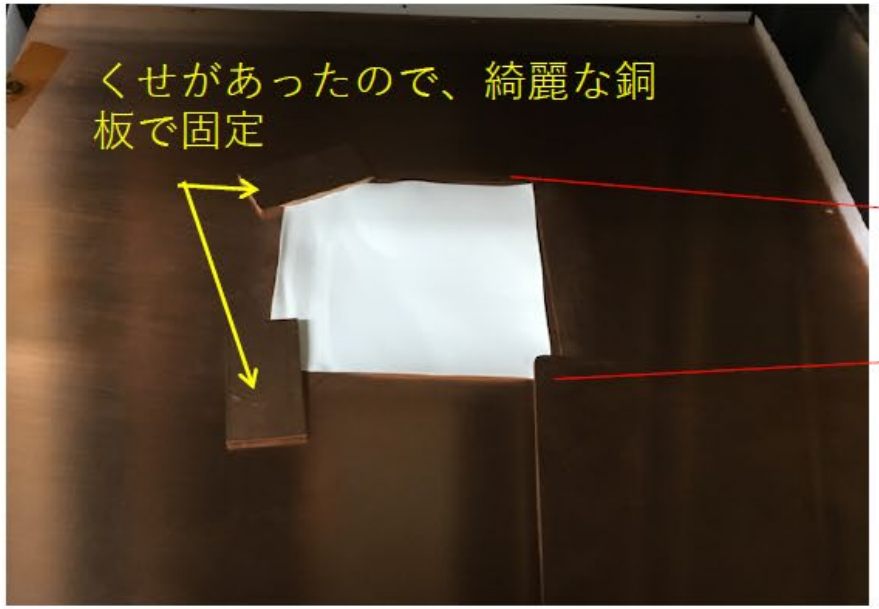


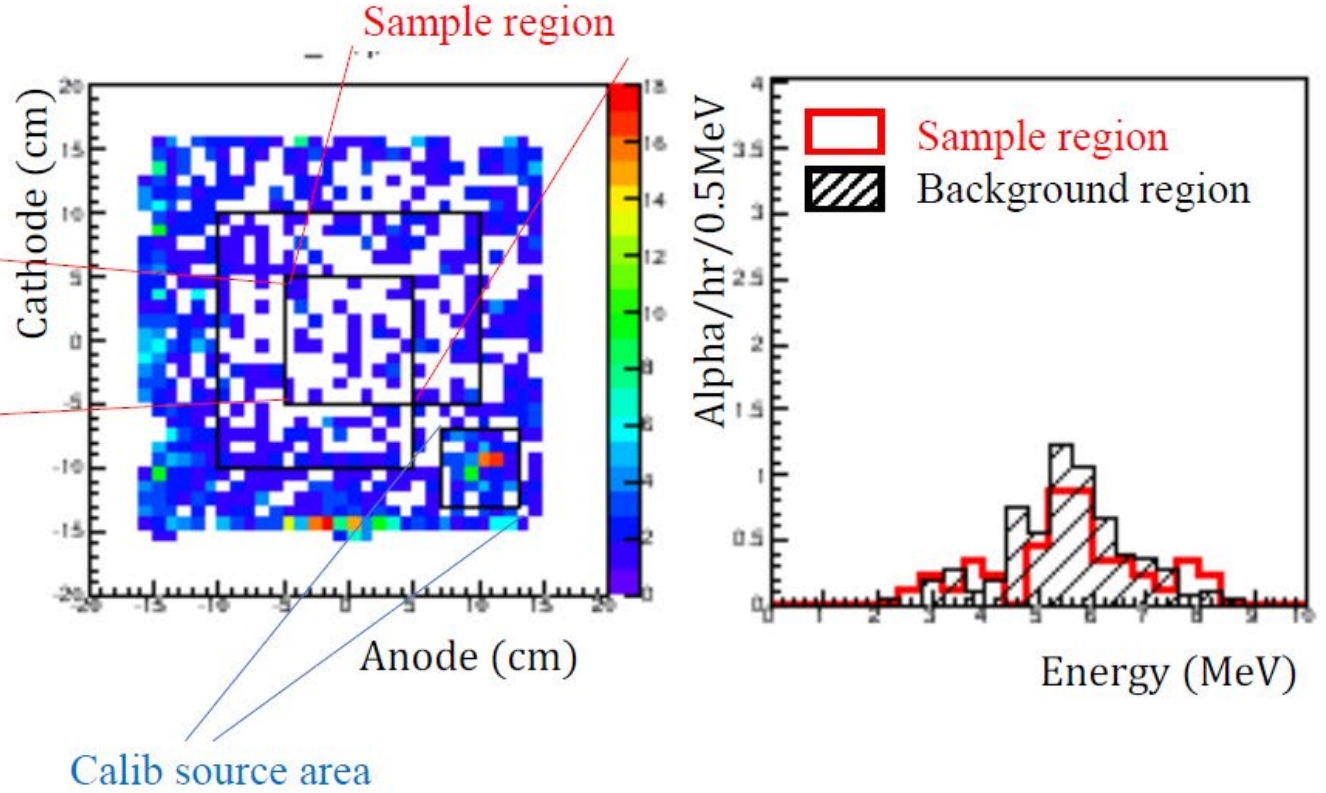
Origin of continuous alpha ray

By H.Ito (ICRR)

Alpha ray detection by μPIC. NIMA 977 (2020)16285

$\alpha < 3.03 \times 10^{-3}$ /hr/cm2 (90% CL) → Agree with continuous rate.





Schedule of PICOLON-I construction

The concentration of ^{210}Po will be precisely calculated after taking more data.

New and large ingot will be constructed immediately.

Installation of Kamioka Underground lab.

- The large volume module will be installed. (After September)
- The number of modules will be 4. (I mentioned that we install more than 9 modules in Kakenhi application…)
- COVID-19 situation is worrisome problem.

Future prospect of solid-state scintillators

Purification method is established.

Further purification will be done.

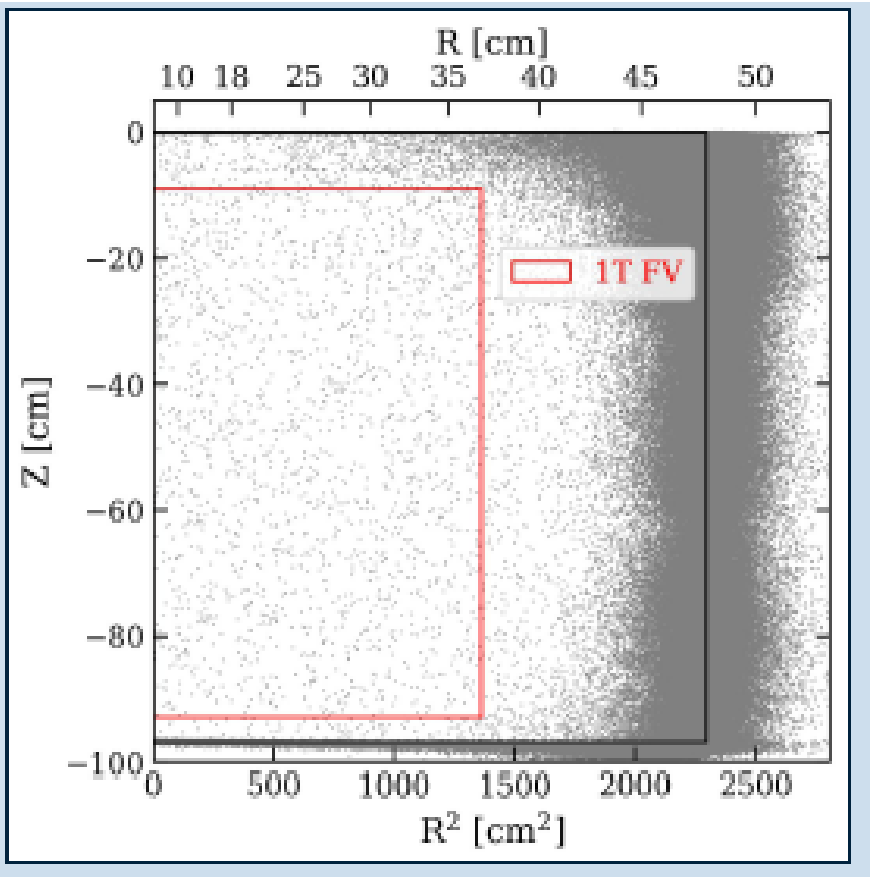
Application to other scintillator materials.

Still high BG ~ 1 /keV/day/kg.

We need 10^{-4} /keV/day/kg

BG from out of the NaI(Tl) crystal is the main component.

We need to get the low BG fiducial.

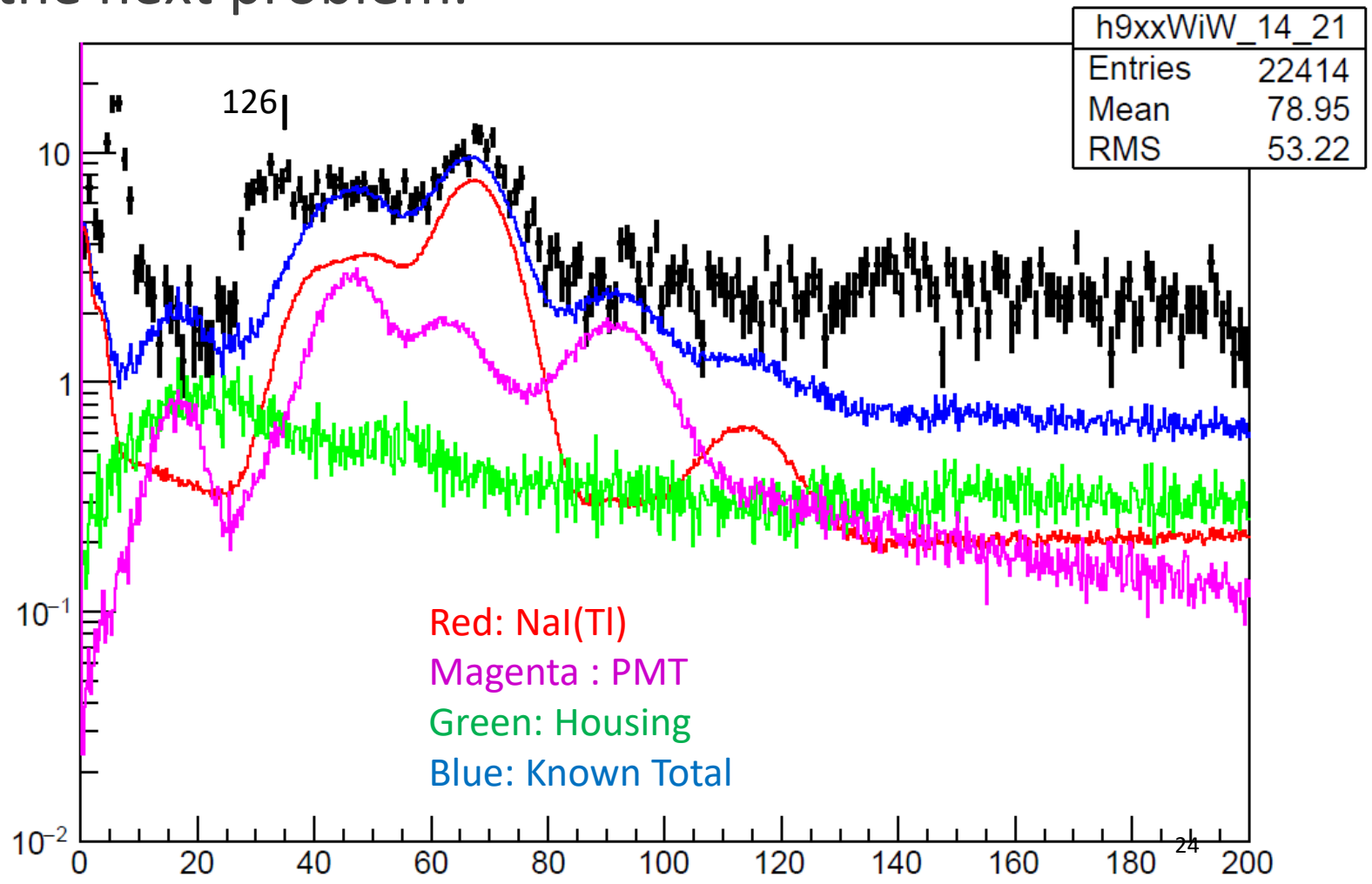


XENON 1T: Presentation on June 17, 2020

BG component of Ingot 71 (^{210}Pb = 800 μBq/kg)

BG from out of the NaI(Tl) is the next problem.

1. Purification = hard work
2. Put them far from NaI(Tl)
3. Active veto by LS.

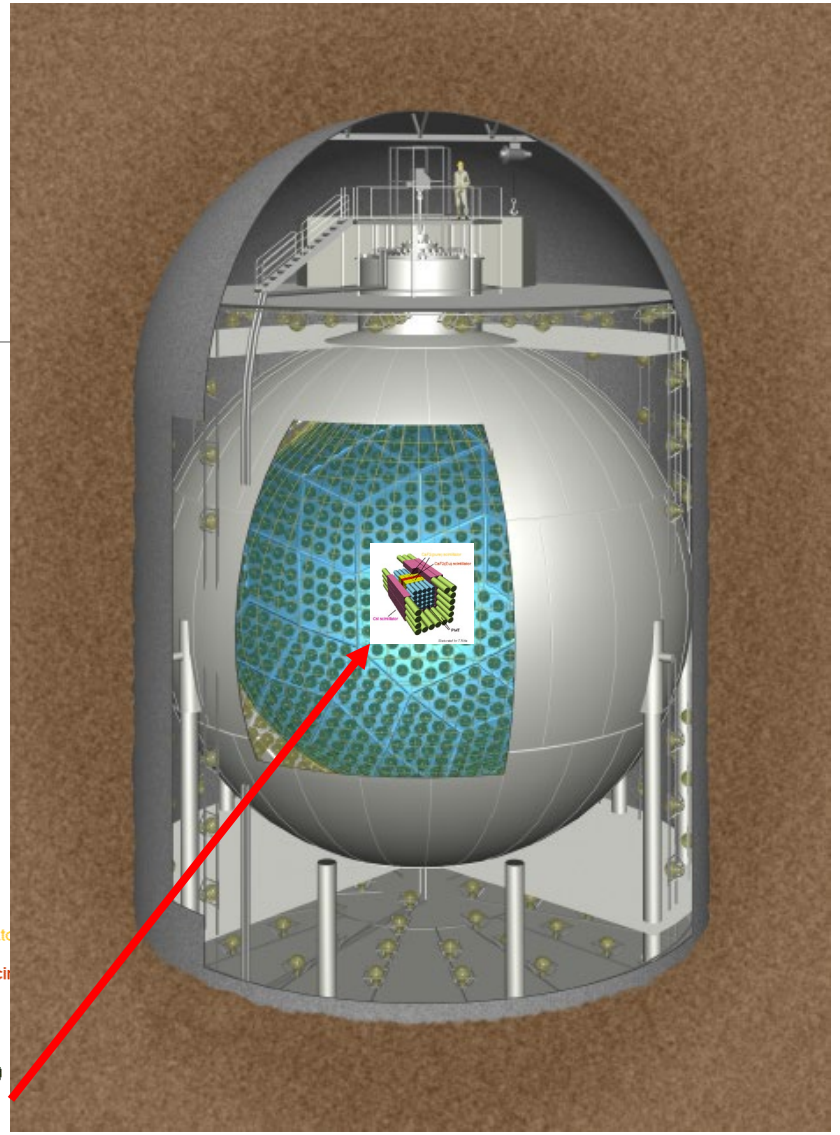


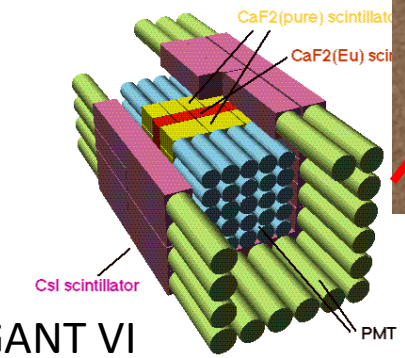
Prospects

- 4π active shield.
  - KamLAND or similar detector system is the best active shield.
  - A new tank will be constructed in Kamioka.

- Active shield between surroundings and the FV.
  - ELEGANT V and ELEGANT VI
  - FV was far from the PMTs.

We need collaborators!!





ELEGANT VI

Illustorated by T.Nitta