

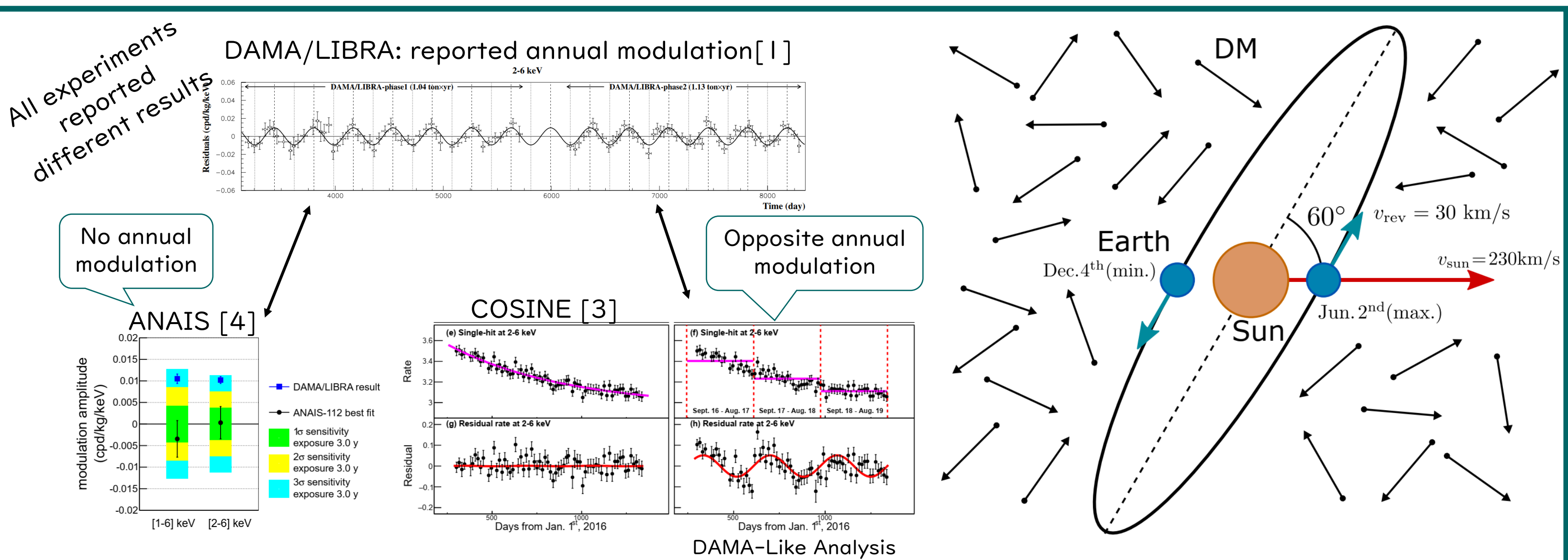
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The PICOLON Project

(Pure Inorganic Crystal Observatory for Low-energy Neut(ra)lino)

Current
Two groups reported different results for experiments using NaI(Tl) detectors.
Therefore, we need additional validation as soon as possible.

Our aim:
Dark matter research using ultra high-purity NaI(Tl) crystals, and verification of the annual modulations reported by DAMA/LIBRA[1].



Experimental Setup & Data Analysis

New Ingot#94 detector

We developed pure NaI(Tl) crystals(Ingot #85) in 2020 [2]

We produced a new NaI(Tl), Ingot#94, using the Ingot#85 purification method.

We measure the Ingot #94 detector BG in Kamioka. The Ingot#94 exposure is 28.3 day \times 1.3 kg.

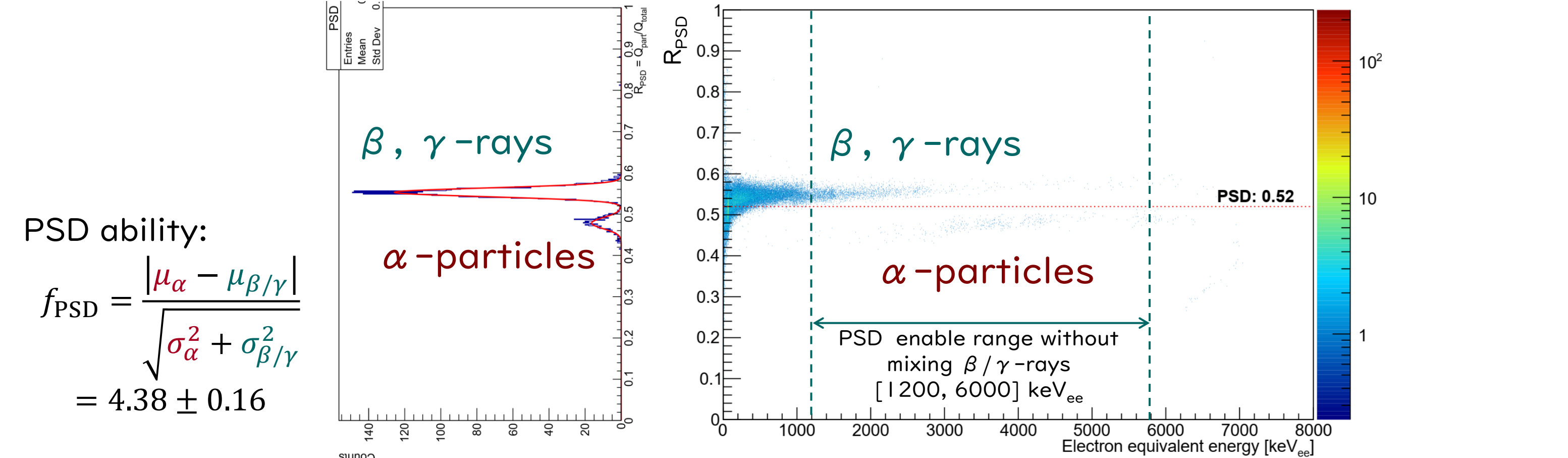
Pulse-shape discrimination

The difference in pulse shapes allows us to discriminate β/γ -events from those induced by α -particles.

$$R_{\text{PSD}} \equiv \frac{Q_{\text{part}}}{Q_{\text{Total}}} = \frac{\int_{0.2\mu\text{s}}^{1.2\mu\text{s}} I(t) dt}{\int_{0.0\mu\text{s}}^{1.2\mu\text{s}} I(t) dt}$$

We selected a R_{PSD} threshold to be 0.52.

PSD Histogram for [1200, 6000] keV_{ee}



Result: Radio-isotopes (RIs) Activity

The width of each peak was selected and the number of events for each radioisotope was calculated from the counts (see ref. [2])

RIs	Energy Range [keV _{ee}]	Events
A $^{238}\text{U}(\text{U}) + ^{232}\text{Th}(\text{Th})$	2210-2900	33 \pm 6
B $^{234}\text{U}(\text{U}) + ^{230}\text{Th}(\text{U}) + ^{226}\text{Ra}(\text{U})$	2950-3350	72 \pm 9
C $^{228}\text{Th}(\text{Th}) + ^{224}\text{Ra}^*(\text{Th}) + ^{222}\text{Rn}(\text{U}) + ^{210}\text{Po}(\text{U})$	3380-3970	118 \pm 11
D $^{218}\text{Po}(\text{U}) + ^{212}\text{Bi}(\text{Th}) + ^{224}\text{Ra}^*(\text{Th}) + ^{220}\text{Rn}(\text{Th})$	4000-4480	71 \pm 9
E $^{216}\text{Po}(\text{Th})$	4690-5150	15 \pm 4

The RI activity C_{RI} is calculated:

$$C_{\text{RI}} = \frac{\text{Events}}{\text{LiveTime} \times \text{IngotMass}} = \frac{\text{Events}}{28.3 \text{ day} \times 1.3 \text{ kg}}$$

The RIs Activity in NaI(Tl) crystals.

	DAMA/LIBRA (NIM A592 (2008) 297.)	Ingot #85 (2020) [2]	Ingot #94 (This work)	Goal
Crystal size	10.2 \times 10.2 \times 25.4 cm ³	7.62 ϕ \times 7.62 cm ³		
^{232}Th [$\mu\text{Bq/kg}$]	2 \sim 31	0.3 \pm 0.5	4.6 \pm 1.2	<10
^{226}Ra [$\mu\text{Bq/kg}$]	8.7 \sim 124	1.0 \pm 0.4	7.9 \pm 4.4	<10
^{210}Po [$\mu\text{Bq/kg}$]	5 \sim 30	< 5.7	19 \pm 6	<50

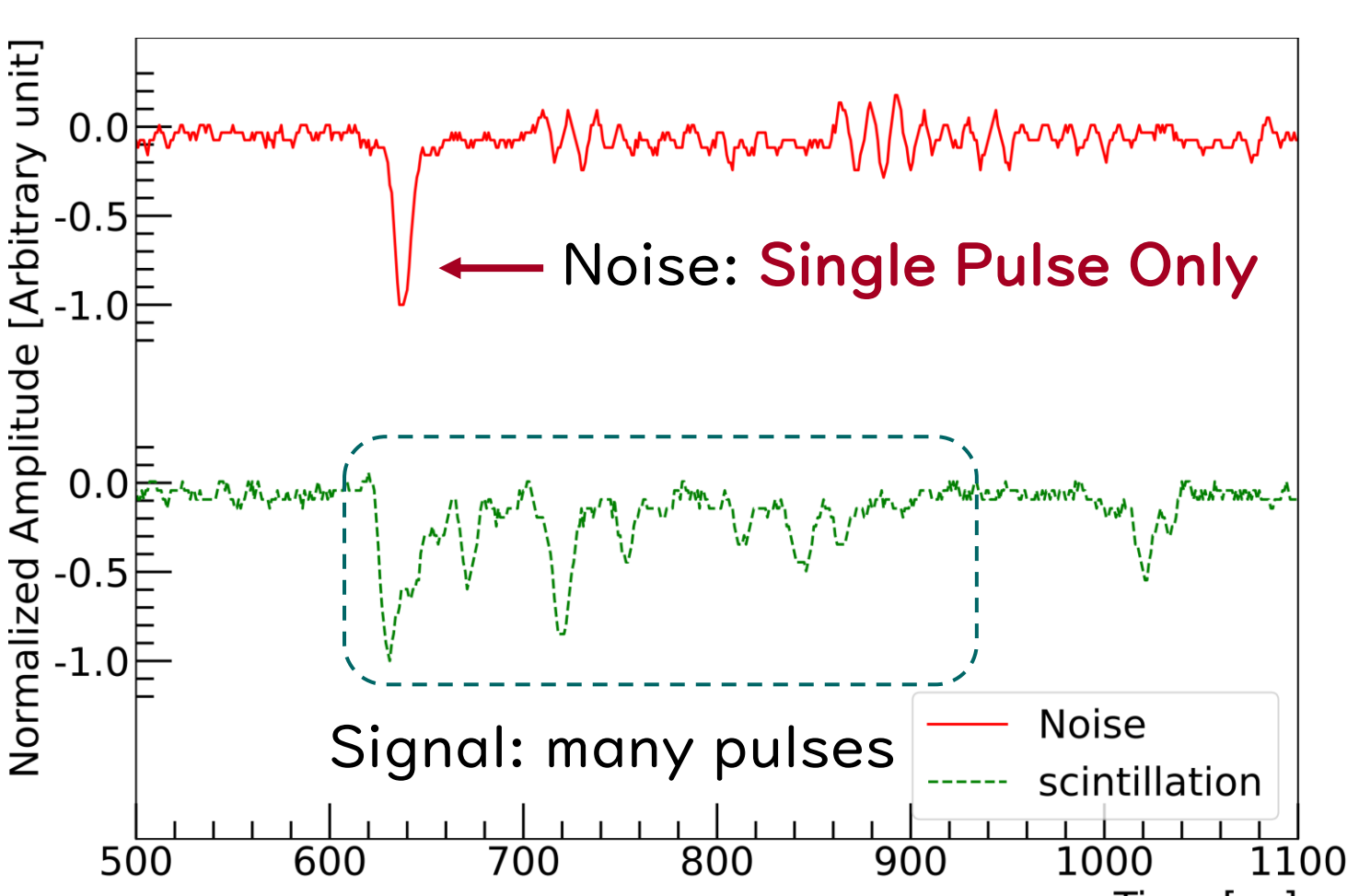
We developed ultra high-purity NaI(Tl) crystal that matches the radio-isotope activity of DAMA/LIBRA's crystals.

The background at low energies ($\leq 100 \text{ keV}_{\text{ee}}$)

Noise reduction

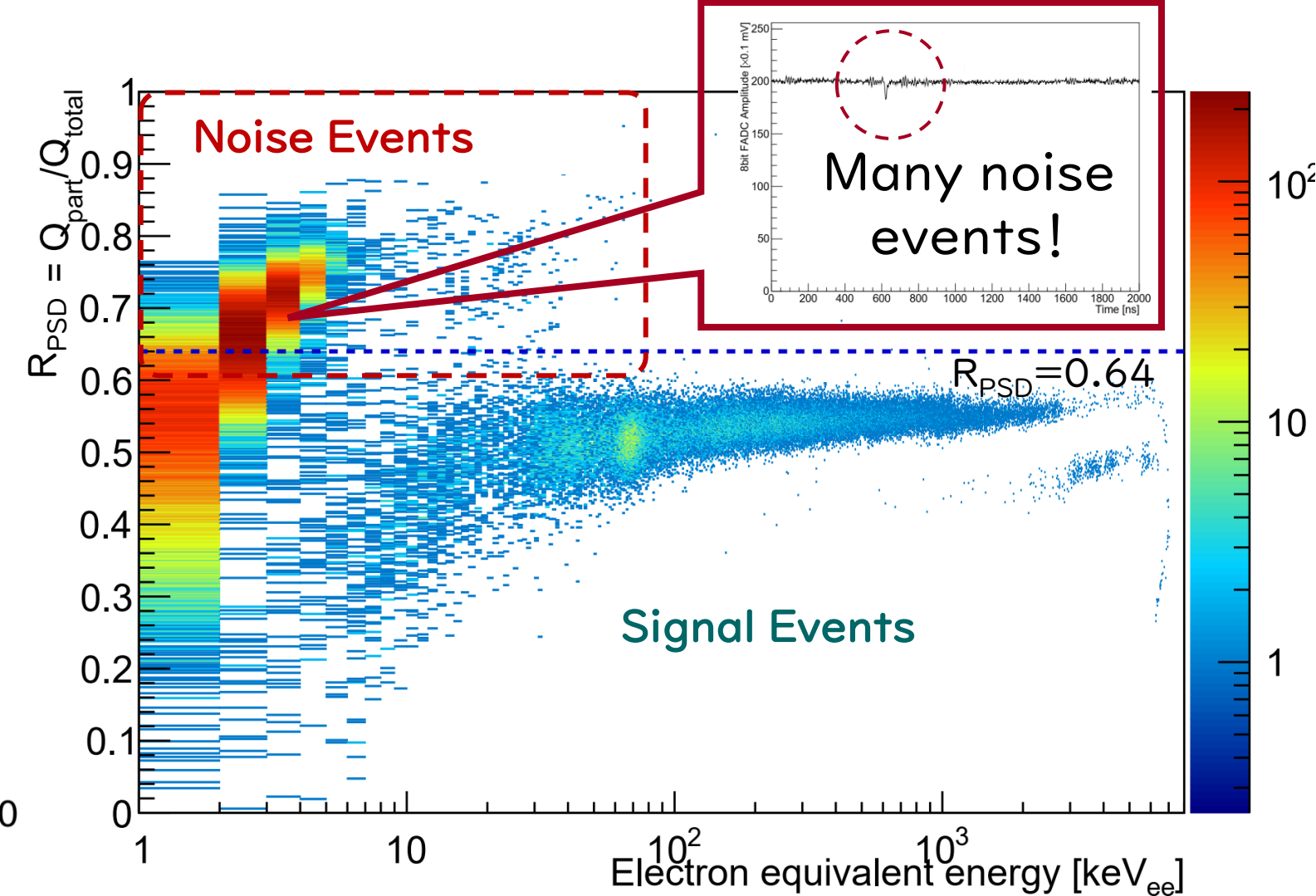
We used two noise reduction methods.

1. Single pulse noise reduction.



The noise event is only a single pulse for 200 ns from the pulse start point. In contrast, a scintillation signal consists of many pulses within the same time interval. Therefore, scintillation events are clearly discriminated from the noise.

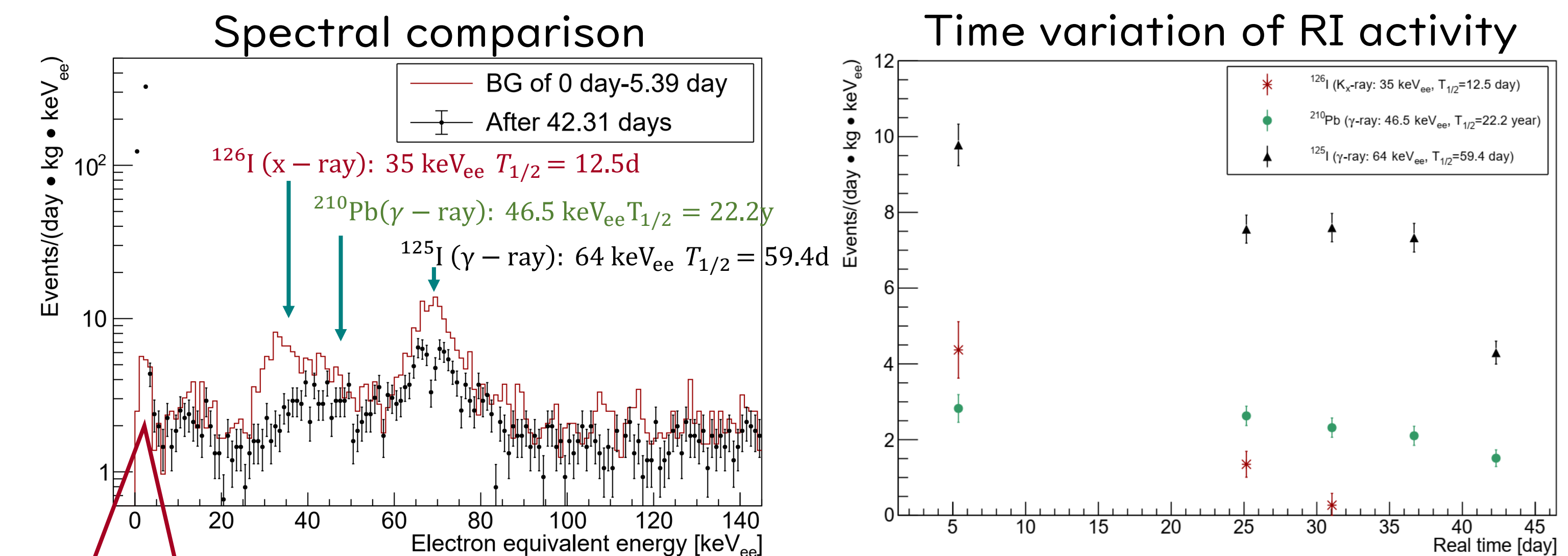
2. PSD noise reduction.



Below 100 keV_{ee}, we verify two clearly separated event distributions. Investigating events with energies < 100 keV_{ee} and $R_{\text{PSD}} > 0.64$ reveals many noise events. We applied a simple noise threshold.

BG Analysis and BG rate of ROI

We verify 3 peaks(^{125}I , ^{126}I , ^{210}Pb), ^{125}I , ^{126}I peaks decreasing.



Around 3 keV_{ee}: residual noise

Background rate of ROI (2-6 keV_{ee})

We calculated the average BG rate and error in the ROI.

Energy region [keV _{ee}]	BG rate [day ⁻¹ kg ⁻¹ keV ⁻¹]	Upper limit of BG error
[2, 6]	3.42 \pm 0.35	0.94
[2, 4]	5.12 \pm 0.73	0.94
[4, 6]	1.73 \pm 0.63	0.80

However, since the BG rate is higher around 3 keV_{ee} due to PMT noise, We divided event rates into three ROIs.

→ 2 \sim 5 Events/(day \cdot kg \cdot keV_{ee})

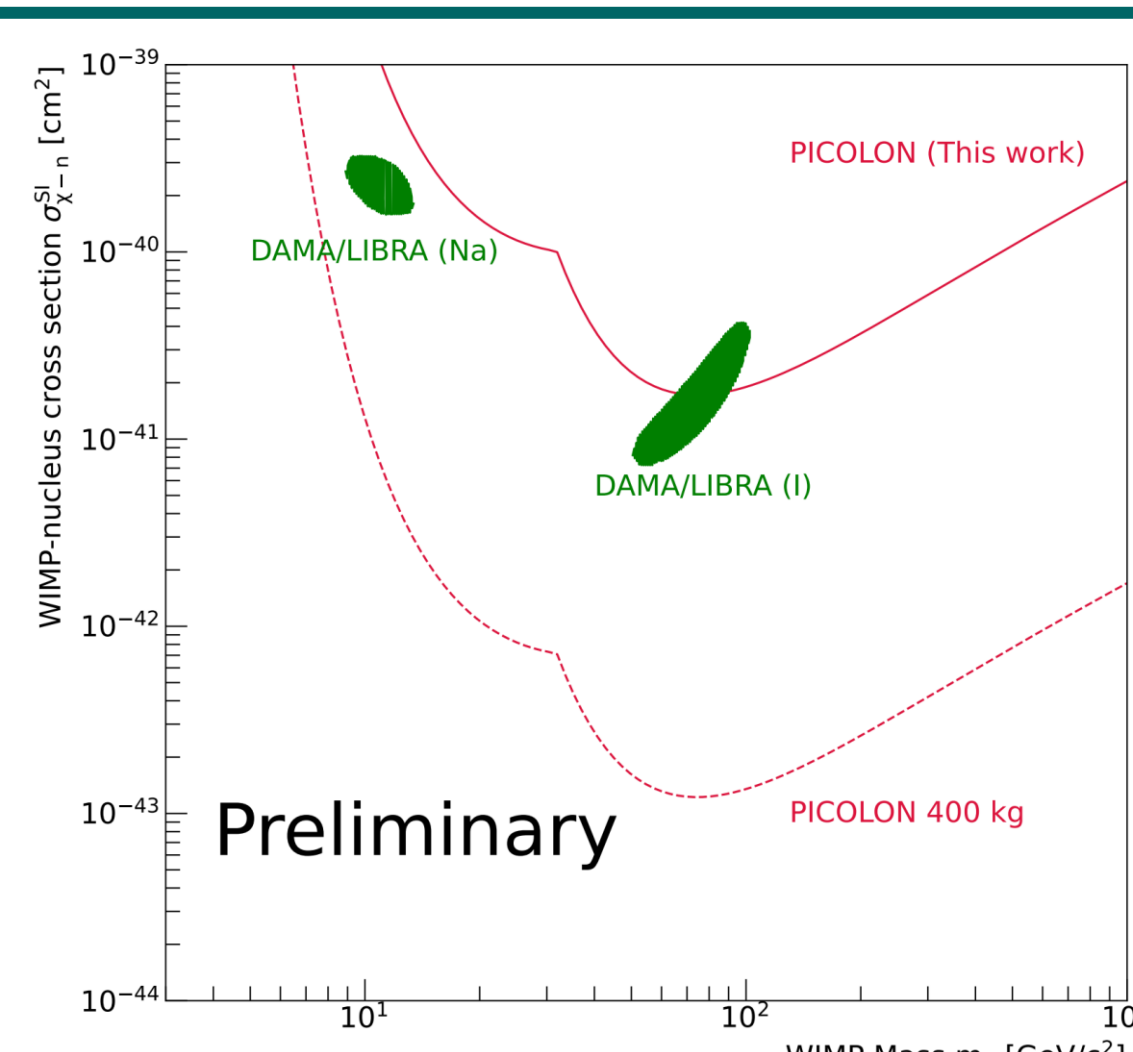
Detector sensibility

We calculate the cross-section for the BG rate.

The upper limit of the BG rate was assumed to correspond to 90% C.L. events of the error in the BG rate in the non-noisy region [4,6] keV_{ee}.

Ingot #94 crystals are one order less sensitive than DAMA/LIBRA crystals.

→ We need to optimize noise reduction and BG reduction.



Summary

- We have developed high-purity NaI(Tl) crystals with the same activity as DAMA/LIBRA crystals.
- We need to reduce the background below 10 keV_{ee}.
 - We will identify noise events around 3 keV_{ee} by machine learning.
 - We develop an active shield detector.
 - and we are investigating tagging discrimination efficiency.

Reference

- [1] R. Bernabei et.al. Nucl. Phys. At. Energy, **307-325**, (2018).
- [2] K. Fushimi et.al. Prog. Theor. Exp. Phys. **2021**, 043F01.
- [3] G. Adhikari et.al. Scientific Reports vol.13, **4676** (2023)
- [4] J. Amaré et.al 2021 J. Phys., Conf. Ser. **2156**, 012024.

