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The ISAI experiment Investigating Solar Axion by Iron-57

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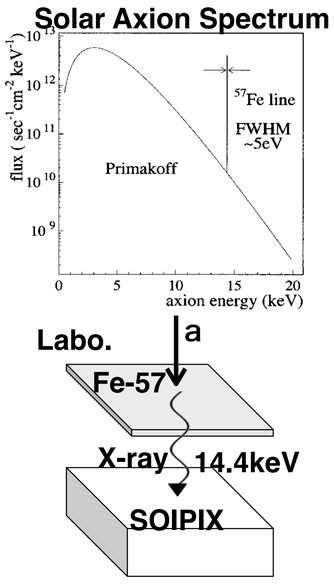
ISAI (Investigating Solar Axion by Iron-57)

Solar Axion Spectrum



- Monochromatic axions emitted from the sun by M1 transition of the excited Fe-57 through a-N coupling
- Detect 14.4 keV X-rays from the reverse reaction in Fe-57 targets placed in a laboratory.

a + ^{57}Fe → ^{57}Fe* → ^{57}Fe + γ (14.4keV)

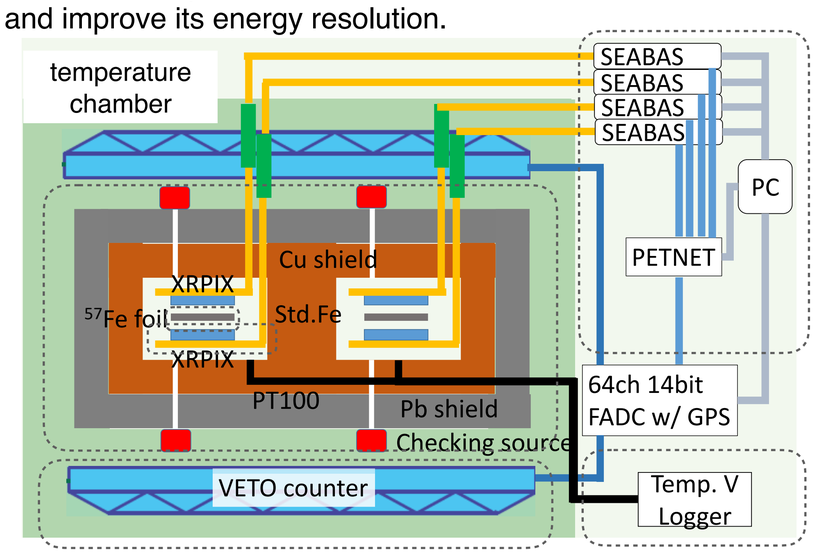
- Dependent only on a-N coupling
- No ambiguity due to mixing of a-e or a-γ coupling

Previous and on-going works
- Moriyama (1995). PRL 75, 3222
- Namba (2007), Phys.Lett.B, 645, 398
- Derbin (2011), Phys.At.Nucl.74, 596
- B04 group of DM学術変革領域 etc.

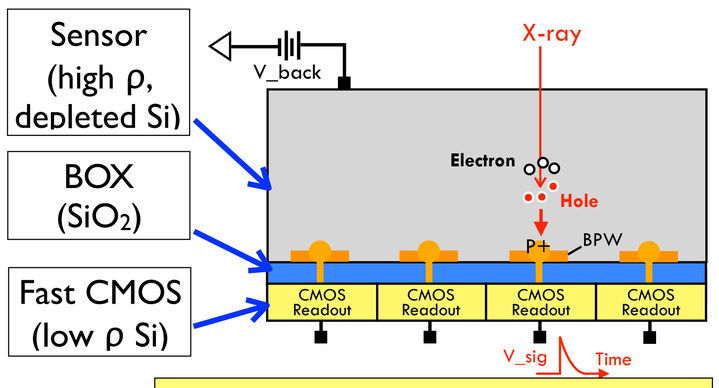
From the point of view of experimentation, Detection of X-ray emission lines in a low BGD environment

Configuration of the ISAI experiment

- Table top level experiment running in a temperature chamber placed in our laboratory at Kyoto University.
- New and unique sensors, SOI pixel sensors (SOIPIXs), detect 14.4 keV X-rays from Fe-57.
- Surrounded by passive shield of O-free-Cu & low BGD Pb, and VETO counter of plastic scintillators.
- The camera is installed in a temperature chamber and cooled down to reduce the readout noise of SOIPIXs and improve its energy resolution.

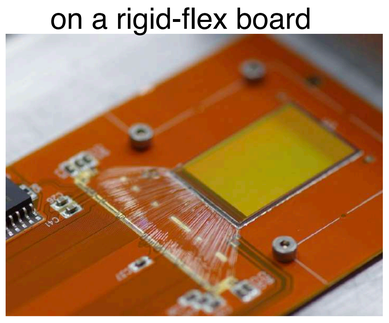


The sensor : "XRPIX" Event-driven SOI pixel sensor



Each pixel has its own trigger logic and analogue readout CMOS circuit.

XRPIX7 assembled on a rigid-flex board

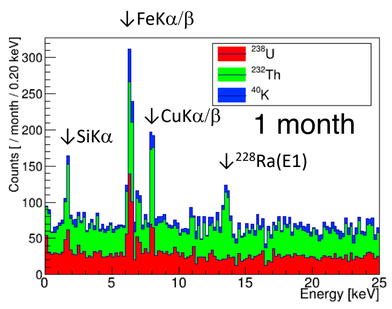


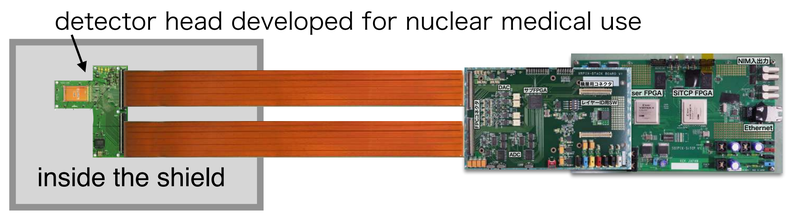
- format 608 × 384
- pixel size 36μm × 36μm
- sensor size 13.8mm x 21.9mm
- trigger time resolution better than 10μsec

- We have developed X-ray SOI pixel sensors, "XRPIXs".
- SOI pixel sensor is monolithic using bonded wafer of high resistivity depleted Si layers for X-ray detection, SiO2 insulator, and low resistivity Si for CMOS circuits.
- In XRPIX, each pixel has its own trigger logic circuit and analog readout CMOS circuit.
- The trigger function realizes low BGD by anti-coincidence with surrounding scintillators.
- Thick depletion layer ~300μm is thick enough to detect 14,4 keV X-rays.
- XRPIX is an ideal sensor for the ISAI experiment,

Low BG Readout Board

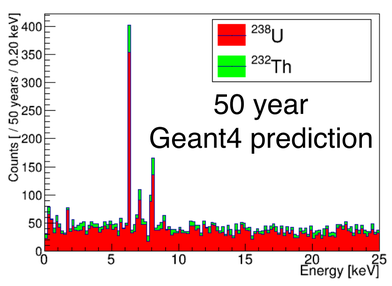
The sensor itself must be very low BGD in ISAI.





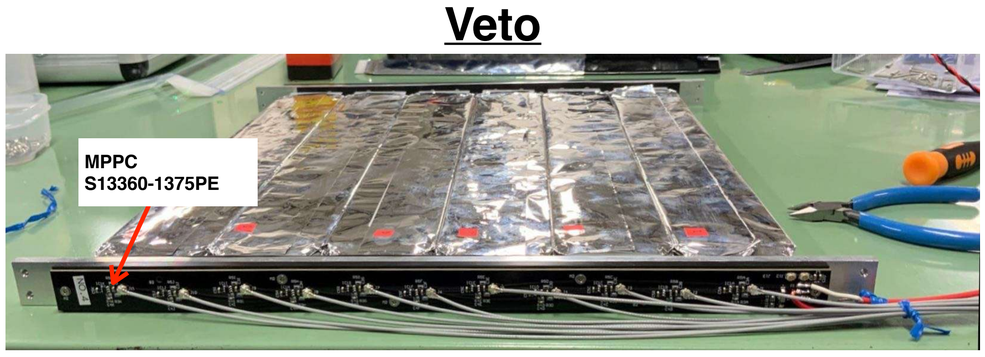
- Radioactivity of the detector head is dominated by G10 PCB (Onuki+19, NIMA, 924, 448)
- Change G10 PCB to rigid FPC
  Only the rigid FPC is placed inside the shield

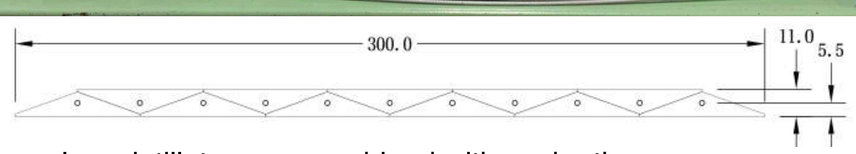
1/1000



- Measure γ-rays from each circuit part with HPGe at UT to select and use quiet parts (Ose M-thesis,UT,2017).

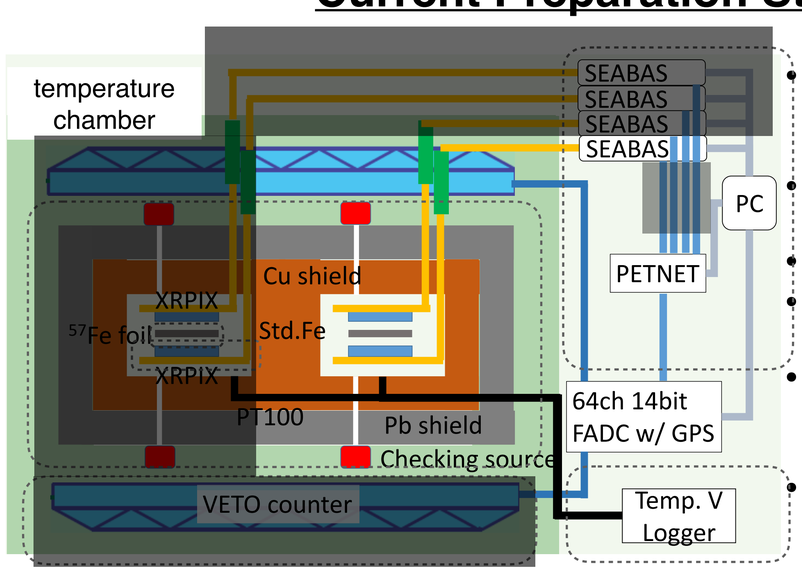
Veto





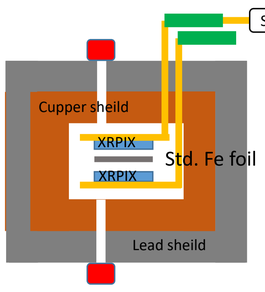
- Triangular scintillators are combined with each other
- The ratio of adjacent scintillator signals yields a position resolution higher than the scintillator size

Current Preparation Status



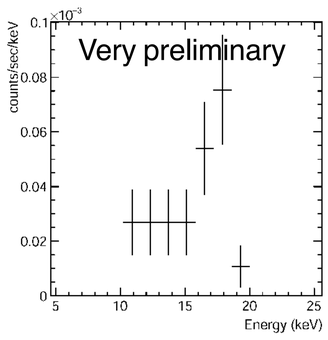
- Half ISAI system without VETO is installed in the temperature chamber.
- One XRPIX sensor read out by SEABAS.
- Slow monitor
- Calibration source though a pin-hole.
- Position sensitive plastic scintillator VETO counter read out by PETNET.
- Anti-coincident between XRPIX and VETO is still in preparation

Background Run

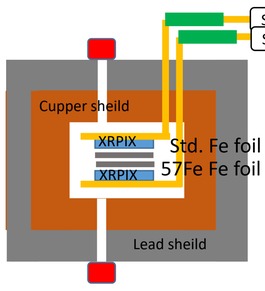


- BG module without veto.
- 2023/07/13-2023/08/10
- Livetime 10.07days

~4.3 counts/day/2.8keV@14.4keV

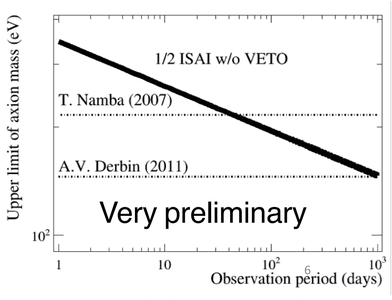


Predicted Sensitivity



- ←Assume 1/2 ISAI without veto.
- Assume 2% detection eff.

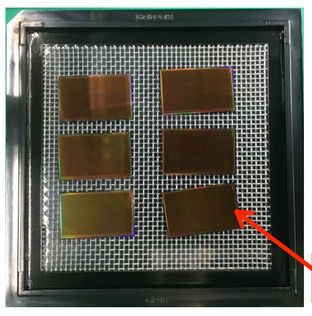
Predicted upper limit @95% C.L. →



- 1/2 ISAI detector to full detector
- BG reduction by timing-veto
- Recovery of the detection efficiency

are essential to precede the current limit.

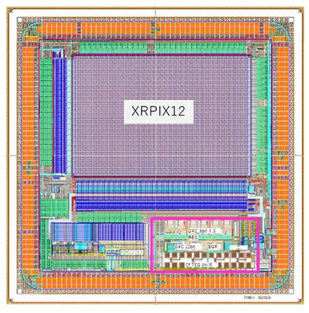
New Large Size Sensors: XRPIX11



- "XRPIX7" currently used in ISAI was developed in 2017. XRPIX7 has issues with detection sensitivity and energy resolution.
- We have developed larger XRPIXs, "XRPIX10" and "XRPIX11" that improves on these issues. Evaluation tests are currently underway.
- In near future, XRPIX10 or XRPIX11 will be used in ISAI experiments.

XRPIX11 are delivered yesterday !

Digital XRPIX: XRPIX12



- External parts are sources of residual radioisotopes.
- We will integrate ADCs and other components into the XRPIX device itself (Digital XRPIX).
- The first Digital XRPIX, "XRPIX9", developed in 2020, has succeeded in readout by built-in ADC.
- XRPIX12 is the first device that has built-in ADCs and DACs. Evaluation tests are currently underway.
- We plan to develop a a large-scale "Digital XRPIX" in 2026.