P03 Application of gamma Transition-Edge Sensor (TES) to ^{112}Sn two-neutrino double electron capture search

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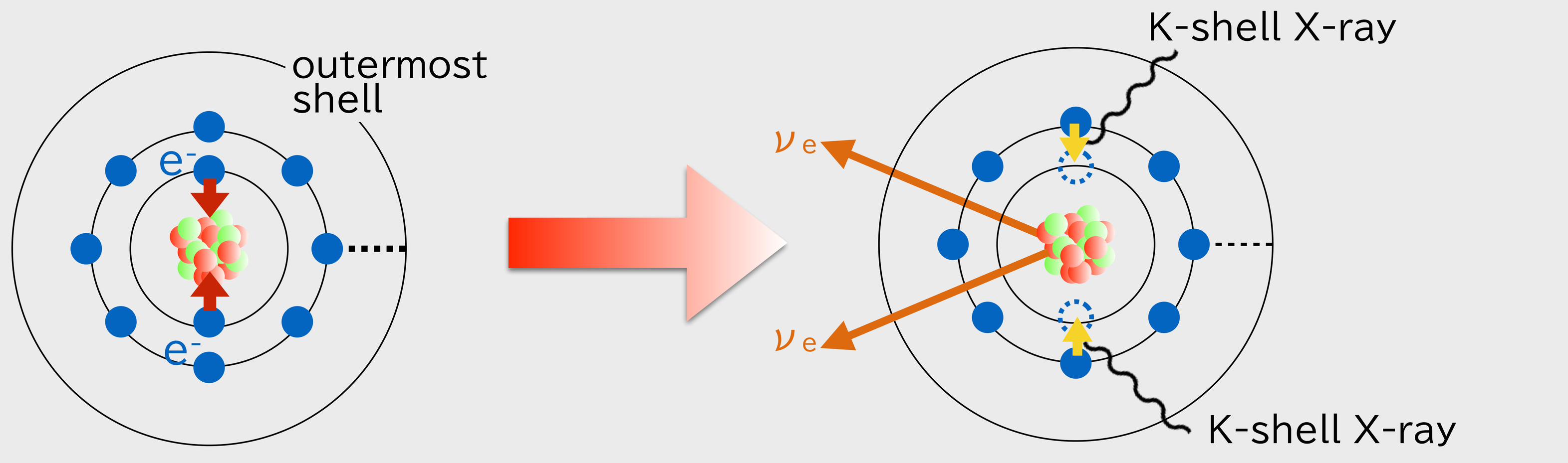
I. Introduction : Double electron capture (ECEC)



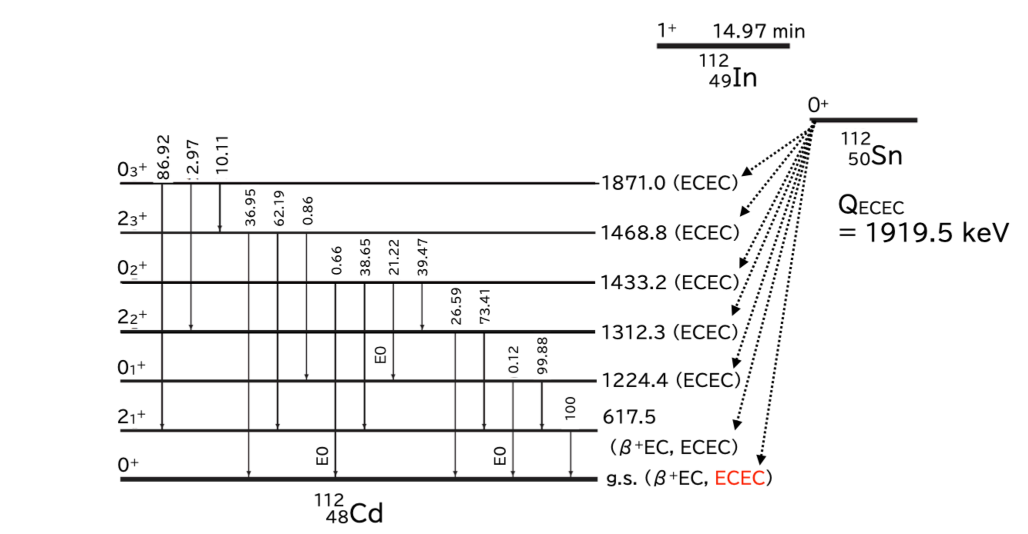
Two-neutrino two K-shell electrons capture case

- ✓ Zero-neutrino ECEC : $(A,Z)+2e^- \rightarrow (A,Z-2)$
  - Beyond the standard model : lepton number violation, Majorana nature of neutrino
- ✓ Two-neutrino ECEC : $(A,Z)+2e^- \rightarrow (A,Z-2)+2\nu_e$
  - Rare decay, but allowed in the standard model
  - Only ^{124}Xe ECEC is observed so far ([1])
  - The observation of 2νECEC gives some inputs for nuclear matrix element
  - Need to observe 2 X-rays or Auger electrons.

[1]Nature 568, 532-535 (2019)

II. Introduction : ^{112}Sn ECEC

Decay scheme of ^{112}Sn [2]



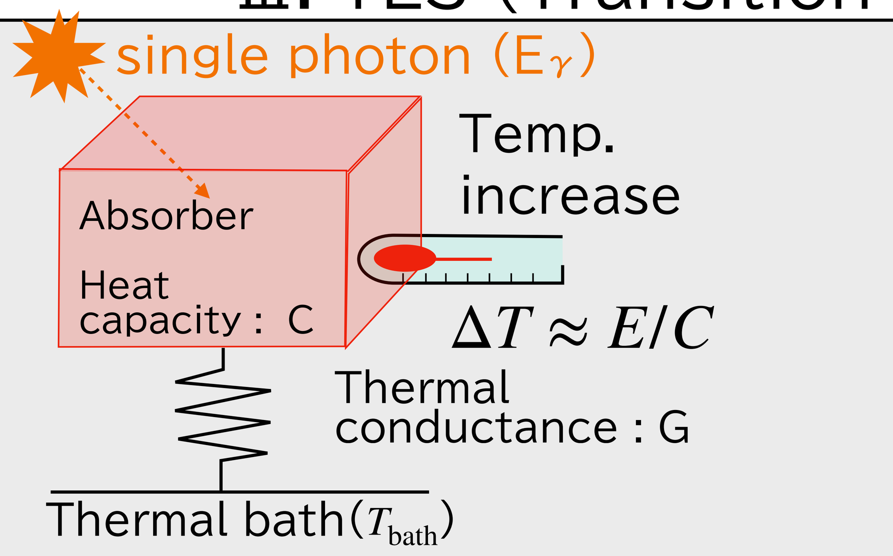
Expected half life [4]
(K-shell electrons capture case)

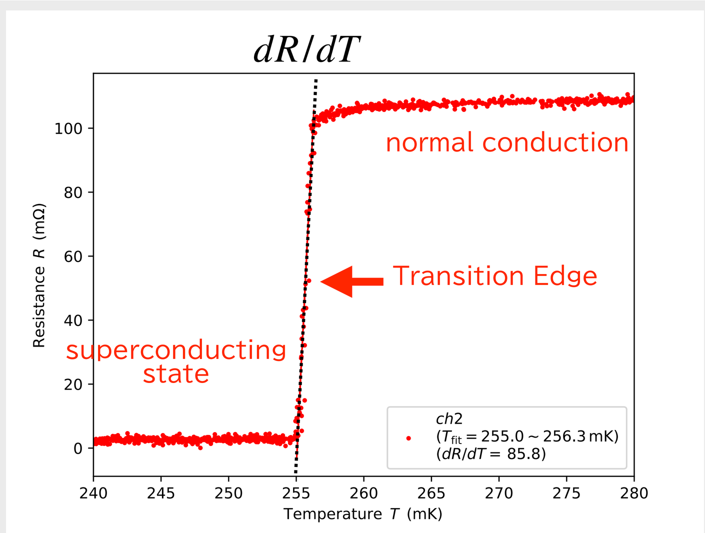
^{112}Cd energy level	$T_{1/2}(2\nu\beta^+EC)$	$T_{1/2}(2\nu ECEC)$
g. s.	3.8×10^{24} yr	1.7×10^{22} yr
617.5 keV	2.3×10^{32} yr	4.9×10^{28} yr
1224.4 keV	—	7.4×10^{24} yr
1312.3 keV	—	1.9×10^{32} yr
1468.8 keV	—	6.2×10^{31} yr
1871.0 keV	—	5.4×10^{34} yr

- ✓ $^{112}\mathrm{Sn}\,(g.s.,0^+)+2e^- \rightarrow {}^{112}\mathrm{Cd}\,(g.s.,0^+)+(2\nu_e)+1.919$ MeV
- ✓ Current experimental search : enriched sample (disk shape) + HPGe [2,3]
  - Sensitive to de-excitation γ, annihilation γ from β^+
  - Not sensitive to 2νECEC to g.s. (shortest half life mode in ^{112}Sn decay)[4]
    - Due to X-ray absorption in sample
- ✓ We propose new method to search for 2νECEC to g.s. decay mode

[2] Phys. Rev. C 80, 035501 (2009), [3]Phys. Rev. C 78, 035504 (2008), [4]Nucl. Phys. A 753 (2005) 337-363

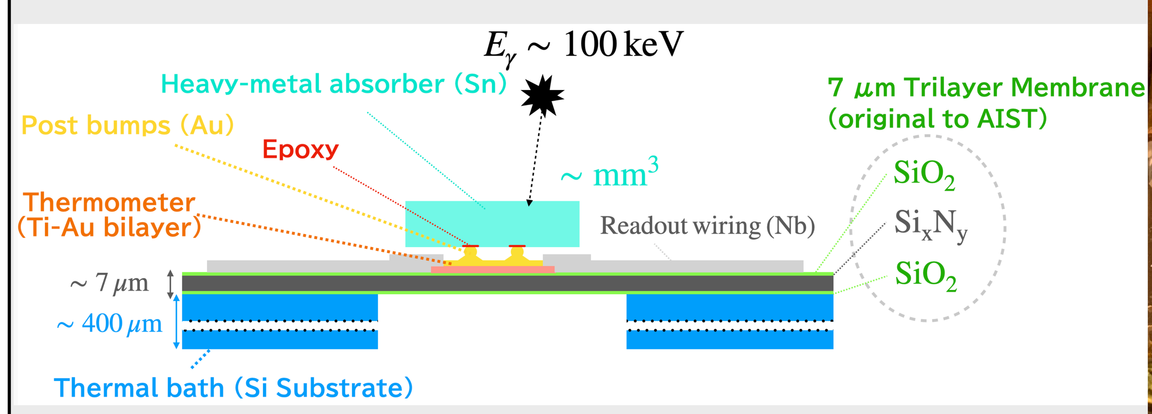
III. TES (Transition-Edge Sensor)

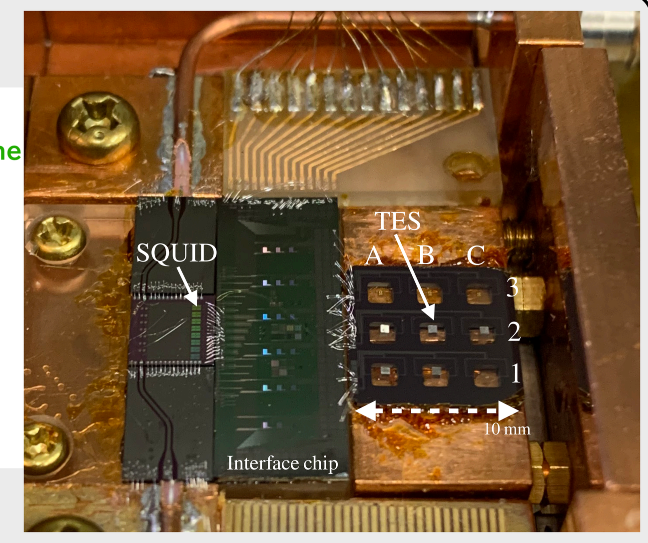


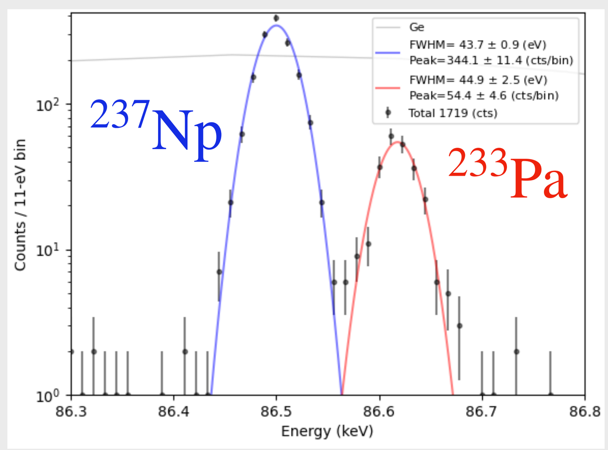


- ✓ One of the superconducting detectors (SNSPD, MKID, MMC, STJ, etc.)
- ✓ γ-TES calorimeter : detects individual photons, converts their energy into heat
  - Small temperature rise → large resistance change
  - Relatively fast pulse (T_{fall} : O(msec))
- ✓ Ultra high energy resolution : ×20 better than semiconductor detector
- ✓ Application of γ-TES :
  - Measurement of isotopic composition of nuclear materials
  - Monitoring transuranic radionuclides inside the human body
  - Rare event search (source = absorber)
    - High detection efficiency with high energy resolution

IV. AIST γ—TES with Sn absorber





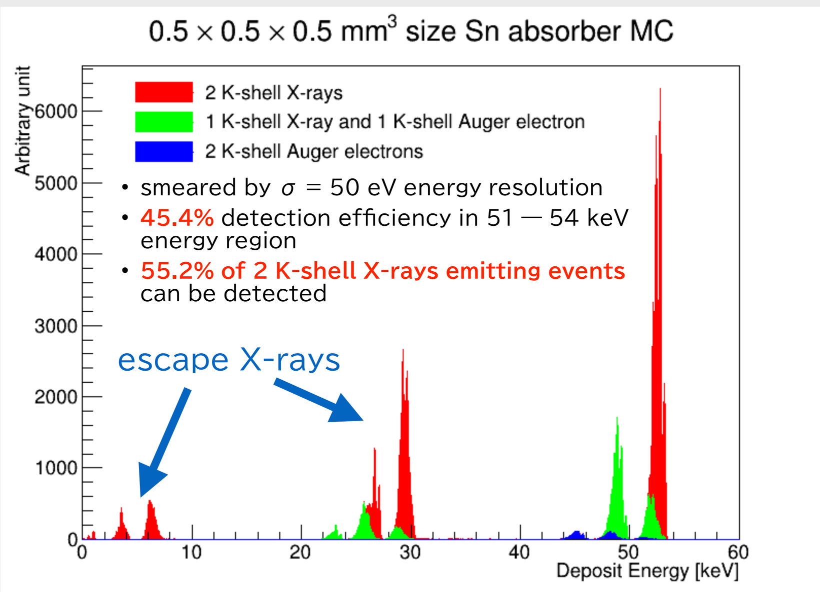


- ✓ Four (0.5 × 0.5 × 0.5 mm³) pixels Sn absorber
  - A2, B1, B2, C2 pixel
- ✓ Demonstrates good ^{237}Np/^{233}Pa γ separation with O(40 eV) FWHM [5]
- ✓ Trilayer membrane structure : unique development by AIST
  - 7 μm thickness : suitable for heavy/large size absorber
  - Conventional SiN membrane : 1 μm thickness

➡ In this work, 90 hr, 4 pixels ^{237}Np calibration source data is used for 2νECEC to g.s. analysis

[5]T. Kikuchi et. al., J. Low. Temp. Phys. 211, 207-213 (2023)

V. Signal simulation

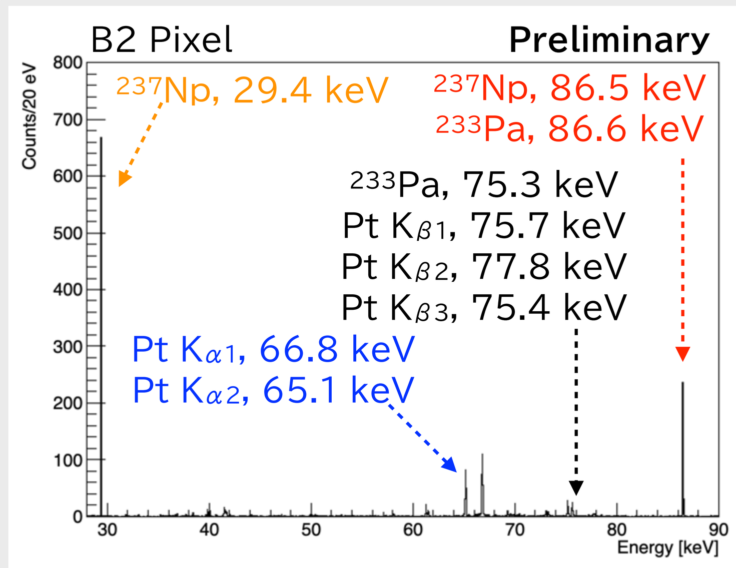


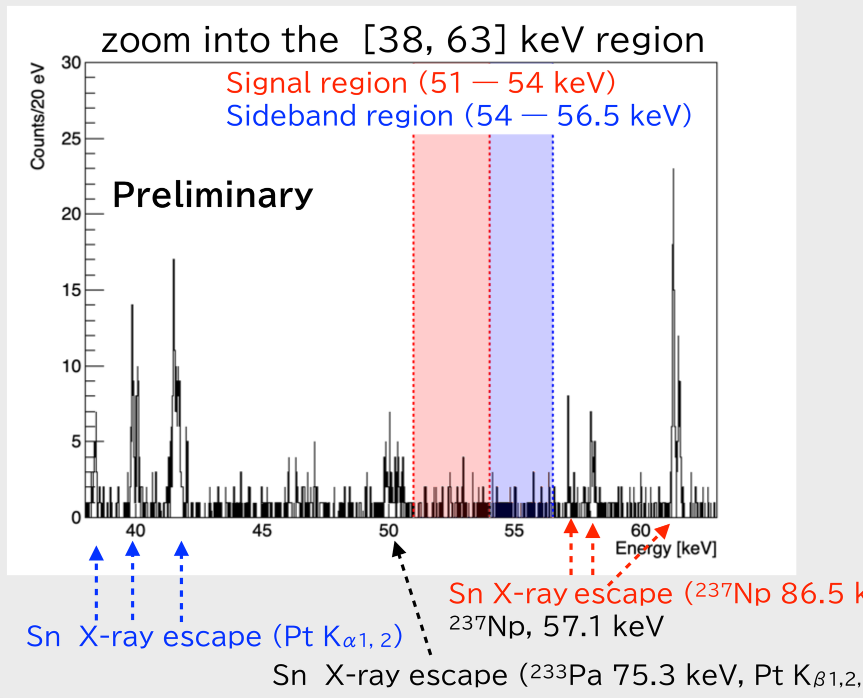
Absorber size	Detection efficiency (ROI : 51 — 54 keV)
$(0.5)^3$ mm³	45.4%
$(0.8)^3$ mm³	55.8%
$(1.0)^3$ mm³	59.9%
$(2.0)^3$ mm³	69.1%

- ✓ MC based on the atomic relaxation package in Geant4
- ✓ Signal MC : two Cd atoms with a single K-shell vacancy, uniformly generated in the Sn absorber
  - 2 × Cd K-shell binding energy = 53.42 keV
  - 53.74 keV after considering energy correction
    - The difference in the binding E of all electrons of the parent/daughter nuclei
  - The relative capture ratio of two K-shell vacancy :
    - 70.9% (considering K and L1 shell), 73.4% (up to N5 shell) (following [6])

[6]Phys. Rev. C 106, 024328 (2022)

VI. Analysis



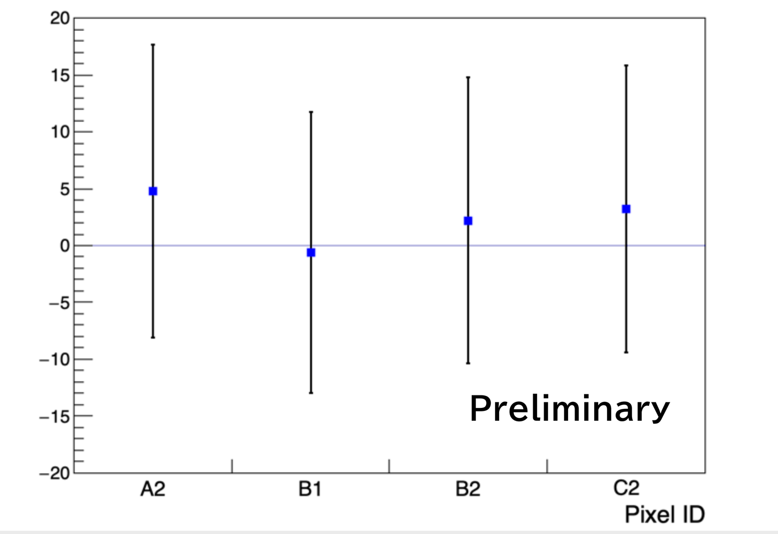


- ✓ Analyzed ^{237}Np source data used in Ref. [5]
  - 4 pixels, 90 hours data (in Ref. [5], 4 pixels, 60 hours data)
  - Clearly observed ^{237}Np γ, ^{233}Pa γ and Pt-Xray (it wraps and protects the ^{237}Np source)
- ✓ Assume flat BG in signal region and sideband region
  - Continuum component : Compton scattering of high E γ from source and environmental, minimum ionization of cosmic μ
- ✓ Count rate of signal region subtracted by the sideband region is used for this analysis

Energy info : taken from ENSDF database and table of isotopes

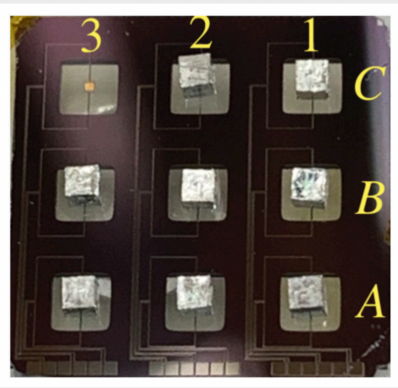
VII. Preliminary result and future prospect

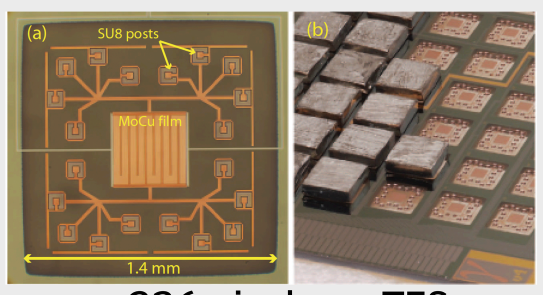
Count in Signal region - Sideband region
(Energy bin width is corrected)



- ✓No excess from continuum BG
- ✓Combined analysis : < 1110 counts/yr/pixel @ 90% C. L.(preliminary)
- Corresponds to $T_{1/2}$ (2νDEC) > 9.0×10^{12} yr @ 90% C.L.(preliminary)
- ✓Systematic uncertainties evaluation is ongoing

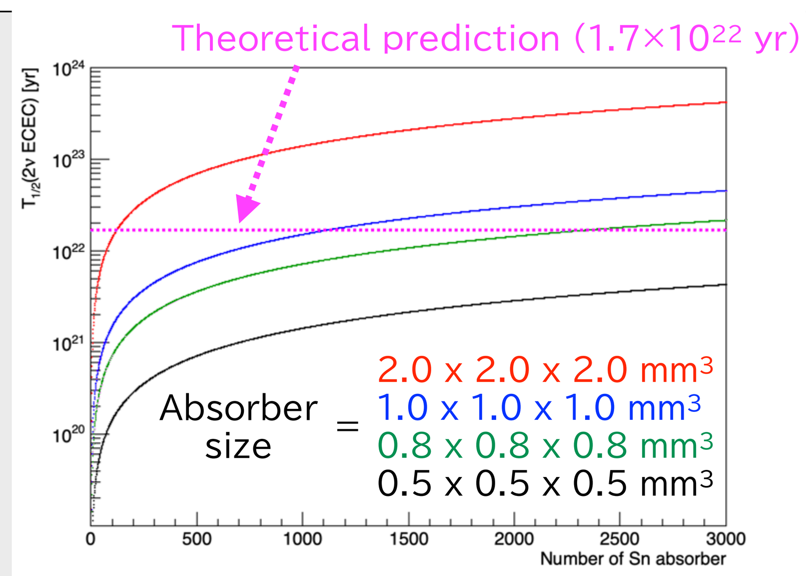
8 pixel
$(0.8)^3$ mm³ Sn absorber





236 pixels γ-TES
(Bennett et al., Rev. Sci. Instr. 83, 093113(2012))

- ✓ We have taken 8 pixels data
  - 0.8 x 0.8 x 0.8 mm³ size Sn absorber
  - w/ and w/o outer calibration source
    - calibration source : ^{22}Na, ^{133}Ba, ^{137}Cs
  - details can be found in R. Smith's doctor thesis (2023)
    - (The Univ. of Tokyo)
  - Now analysis is ongoing
  - Eventually take data w/ many pixels in Kamioka
  - O(100 ~ 1000) pixels TES detector is not unrealistic



AIST's thick membrane structure
→ Suitable for this search

- ✓ Optimistic assumption :
  - No events in ROI for all pixels(< 2.3 counts @ 90% C. L.)
  - 100% ^{112}Sn enrichment absorber
    - (n. a. = 0.97%) : 94.32% [2], 99.5%[3] enrichment is achieved
  - 3 year data taking

➡ Could reach the theoretical prediction

*: presenter

International workshop UGAP2024, 4 — 6 March, Tohoku Univ. Sendai, Japan

This work is supported by JSPS Kakenhi 19H05809, 22K18709, Tohoku University—AIST matching research support project