Status of LiF Experiment for keV Sterile Neutrino Search

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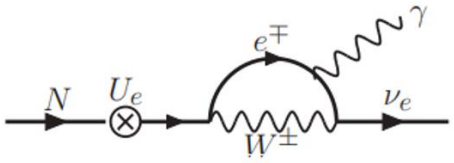
keV Sterile Neutrino

- $\nu_4 = \cos\theta\,\nu_s + \sin\theta\,\nu_e$
- ν_s : SM neutral, $m_{\nu_4} \sim \mathcal{O}(keV)$
- Neutrino mass
- Can constitute dark matter
- Limits from x-ray experiments

$E_\gamma = m_{\nu_4}/2$

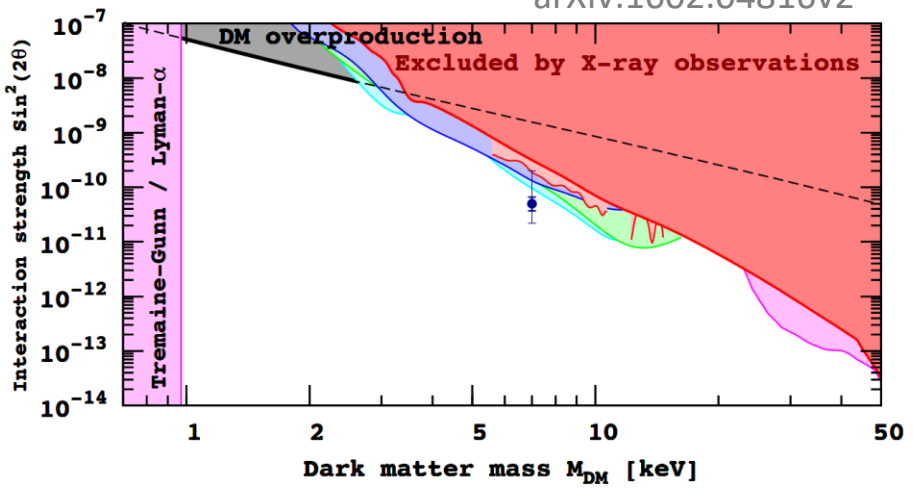


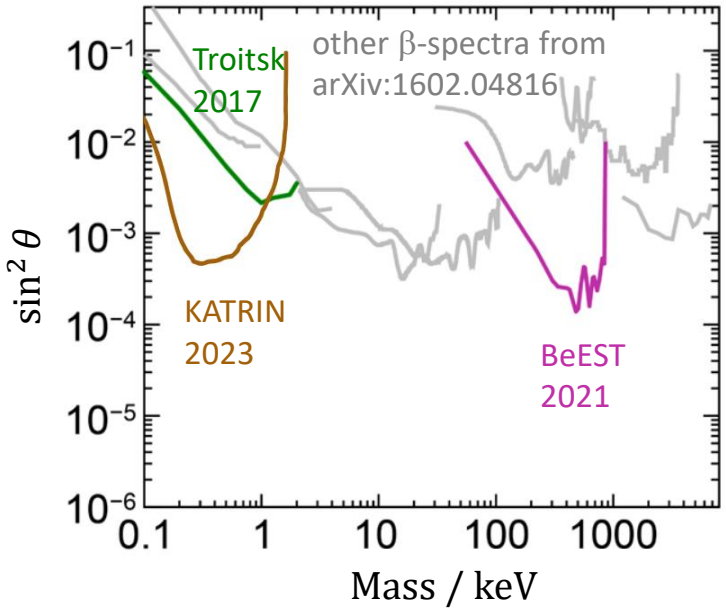
- Strong exclusion limit: $\sin^2\theta < \mathcal{O}(10^{-11})$
- Possible cosmological models allow larger mixing angle: $\sin^2\theta \sim \mathcal{O}(10^{-5})$

PHYS. REV. D 100, 115035 (2019)

- Ground experiments : nuclear decay energy measurement
- KATRIN(TRISTIAN), BeEST, ECHo, MAGNETO- ν,

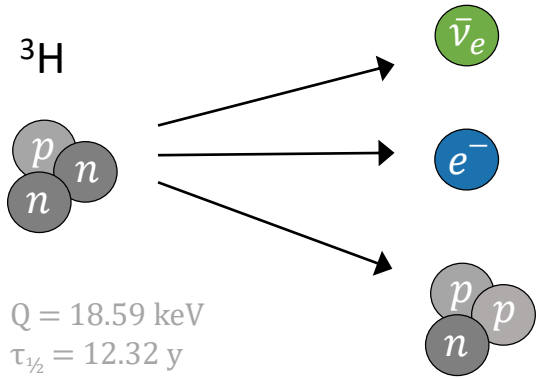
arXiv:1602.04816v2





^{3}H β-decay Spectrum with Sterile ν

β-decay of ^{3}H

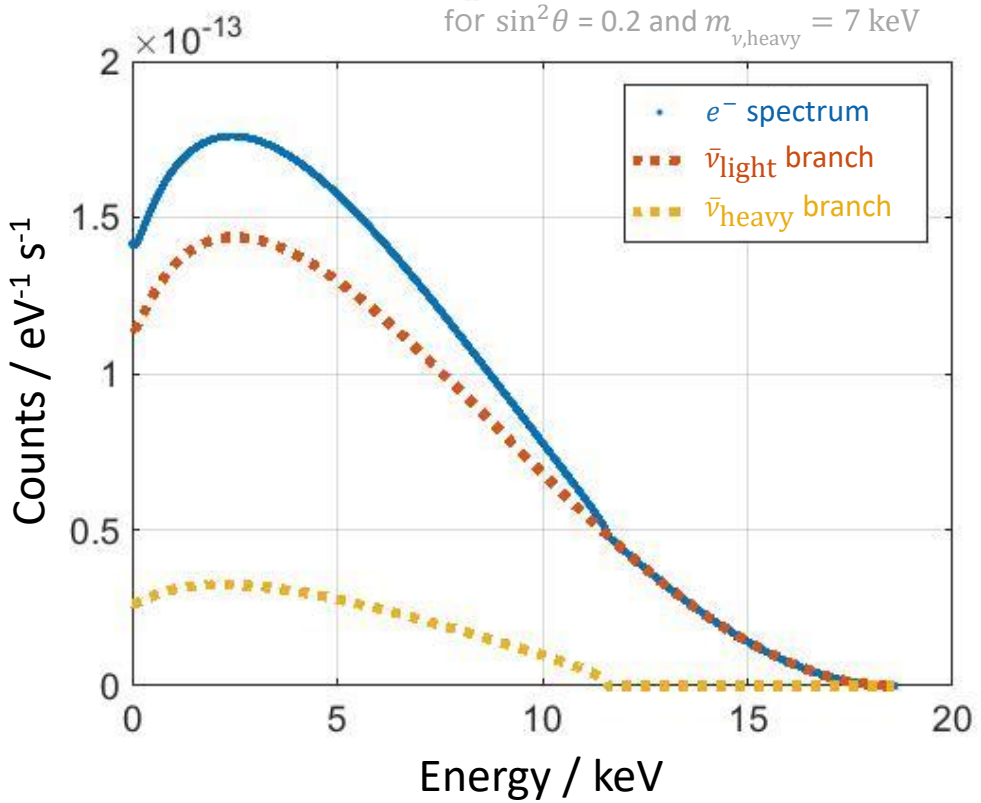


possible mixing:

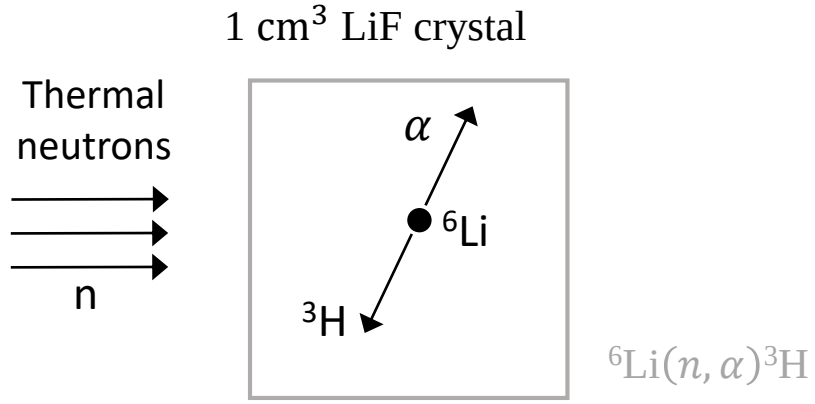
$$\bar{\nu}_e = \cos\theta\,\bar{\nu}_{light} + \sin\theta\,\bar{\nu}_{heavy}$$

$$\bar{\nu}_s = -\sin\theta\,\bar{\nu}_{light} + \cos\theta\,\bar{\nu}_{heavy}$$

We can search for sterile neutrinos by measuring the β-decay spectrum:



^{3}H Production in LiF Crystals

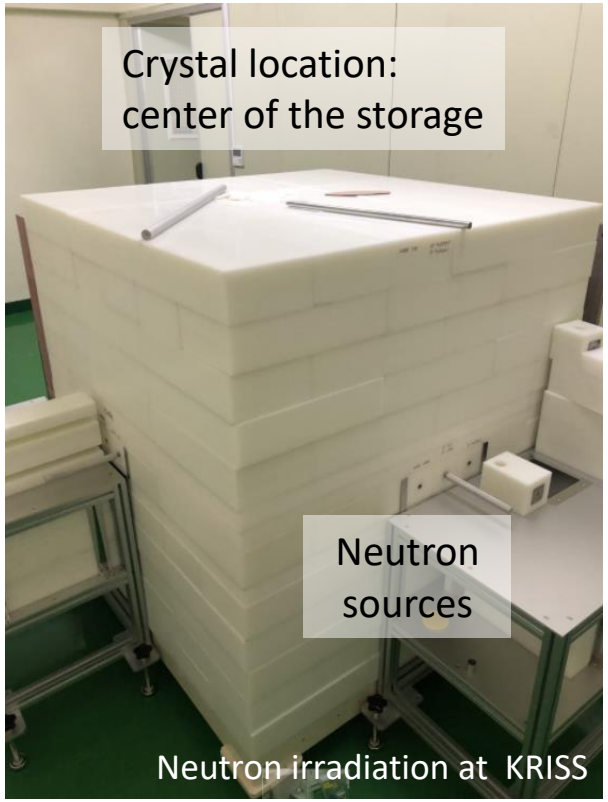


$^6\mathrm{Li}(n,\alpha)^3\mathrm{H}$

- Capture of thermal Neutrons in a ^{6}Li target
- Mean free path: 2.3 mm in 7.6% ^{6}Li crystal

First LiF Crystal:

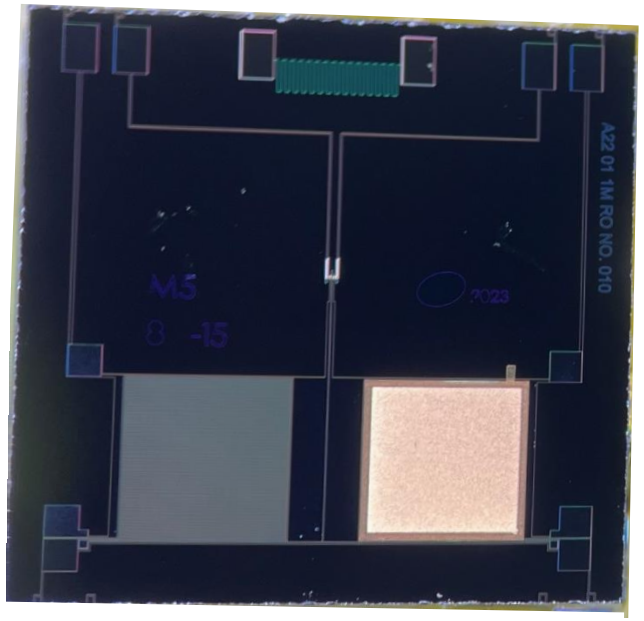
Irradiation time: 7 days
22 ^{3}H β-decays per second



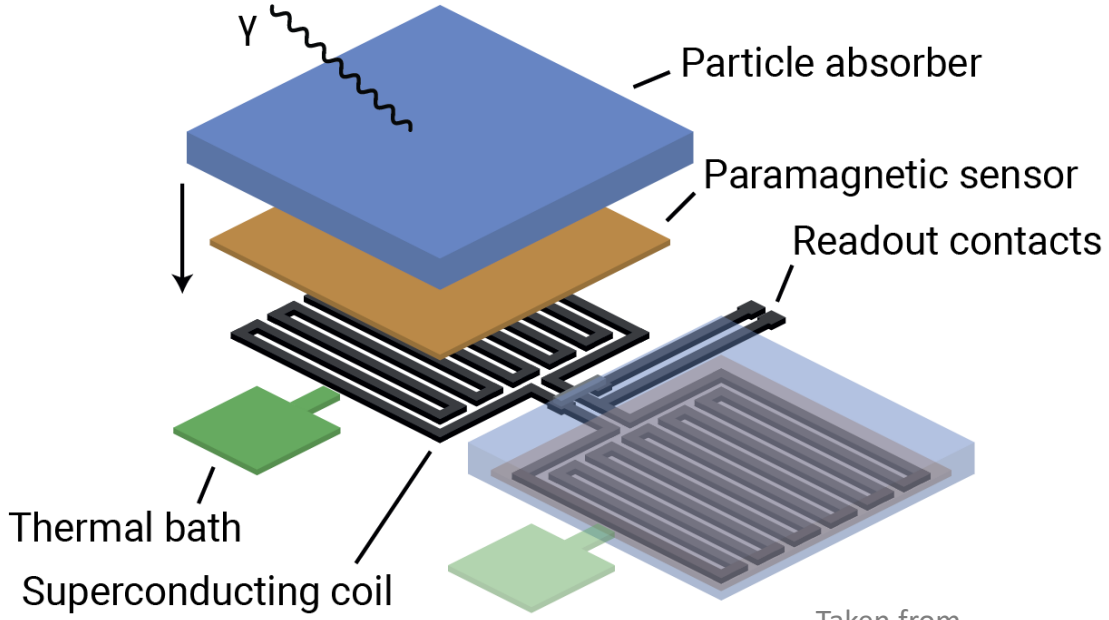
Neutrons are thermalized with PE and afterwards enter the crystal isotropically

MMC-based Low Temperature Detector

- Cryogenic micro-calorimeter
- Usually cooled down well below 100 mK
- Temperature sensing based on a paramagnetic sensor



AMoRE MMC



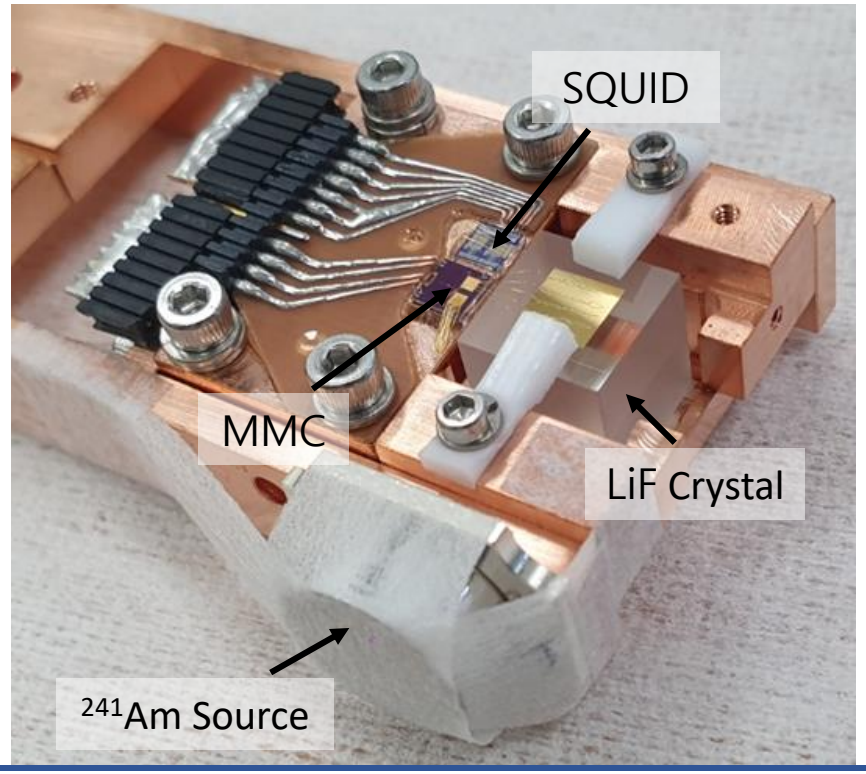
Taken from
JINST 16 (2021) P06006

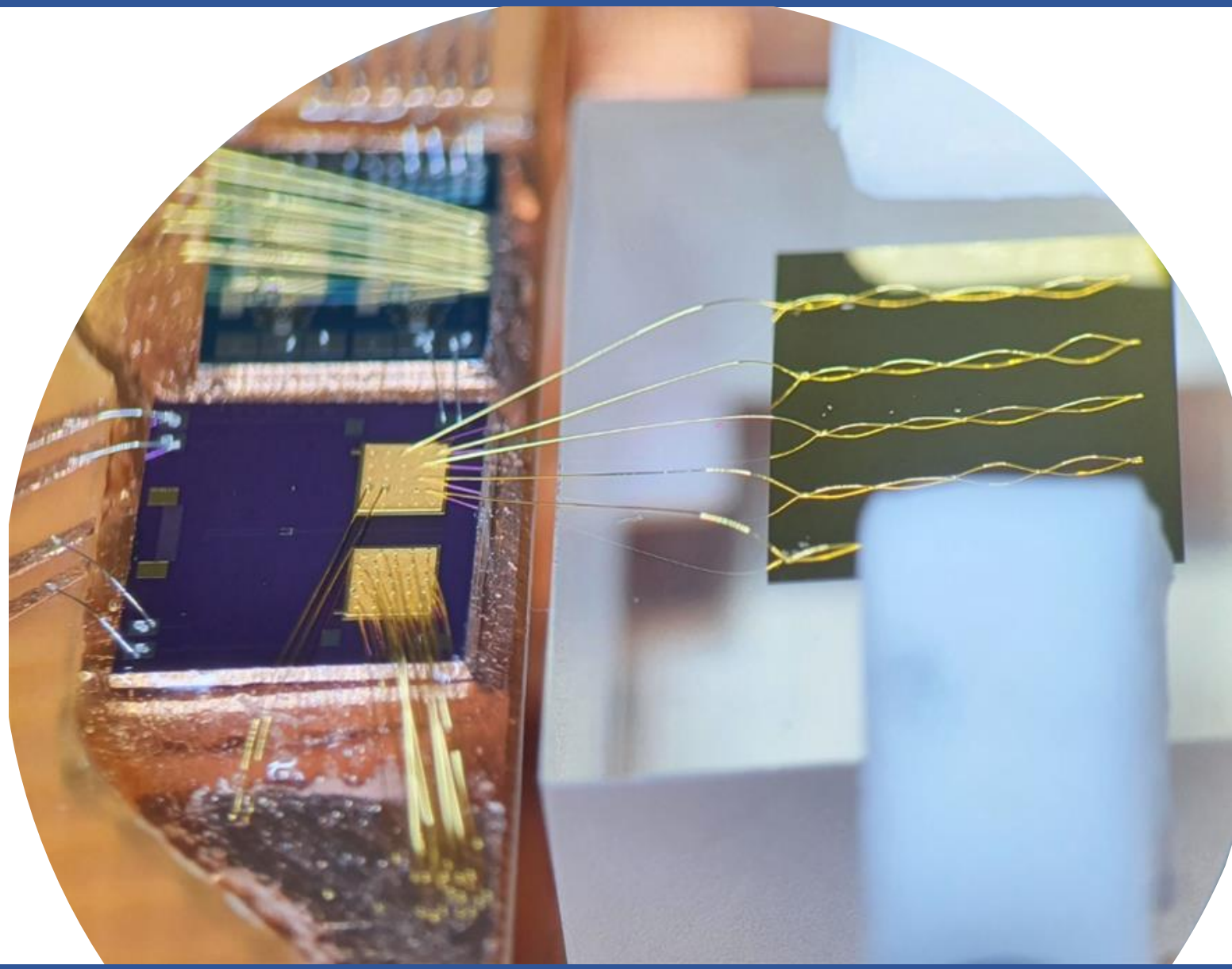
$$\delta E \longrightarrow \delta T = \frac{\delta E}{C} \longrightarrow \delta M = \frac{\partial M}{\partial T}\delta T \longrightarrow \delta\Phi \propto \delta M$$

Energy deposition → Temperature increase → Magnetization decrease → Change of magnetic flux

Low Temperature Setup

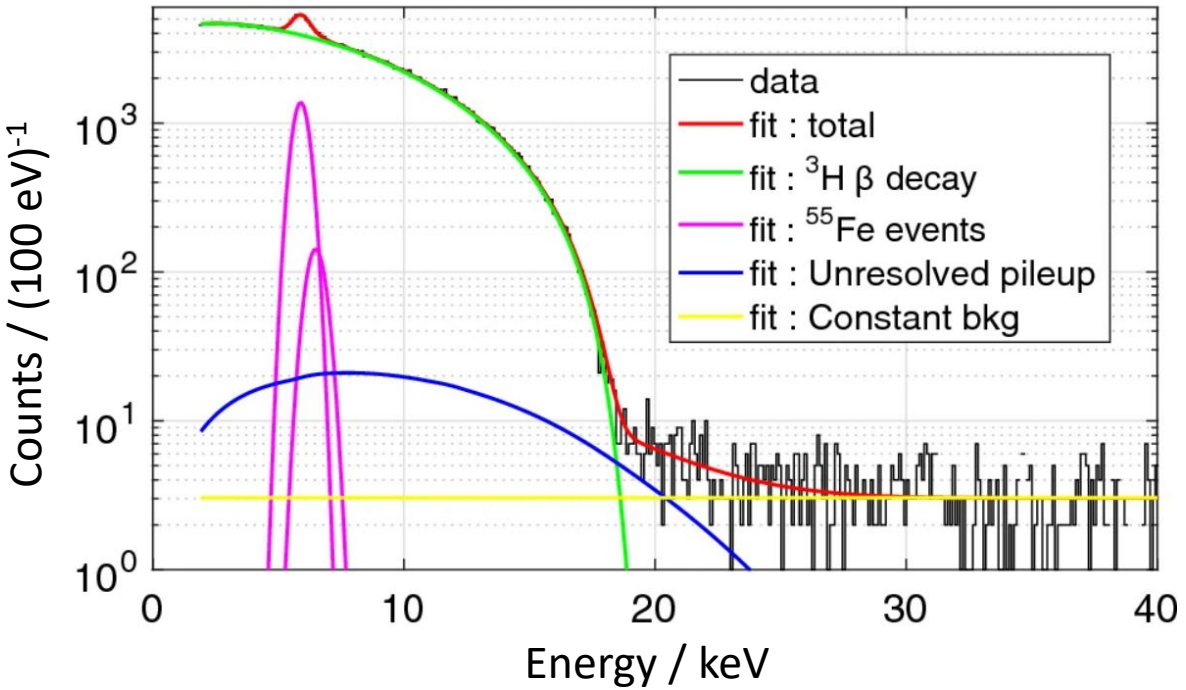
- 1 cm^3 LiF crystal with embedded ^3H
- Phonon collector on the crystal is thermally coupled to an MMC
- MMC readout via SQUIDs from PTB

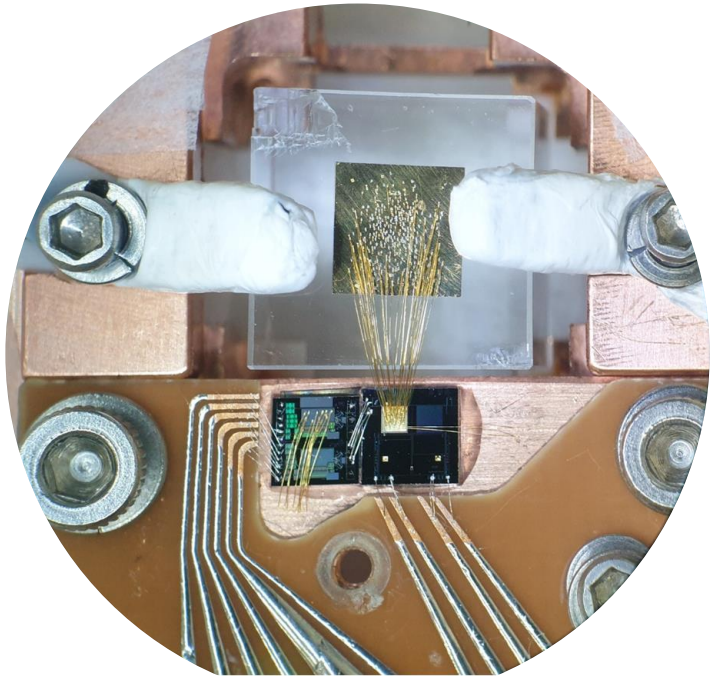




Preliminary Setup: Proof-of-Principle

10 hour ^{3}H β-spectrum with calibration sources

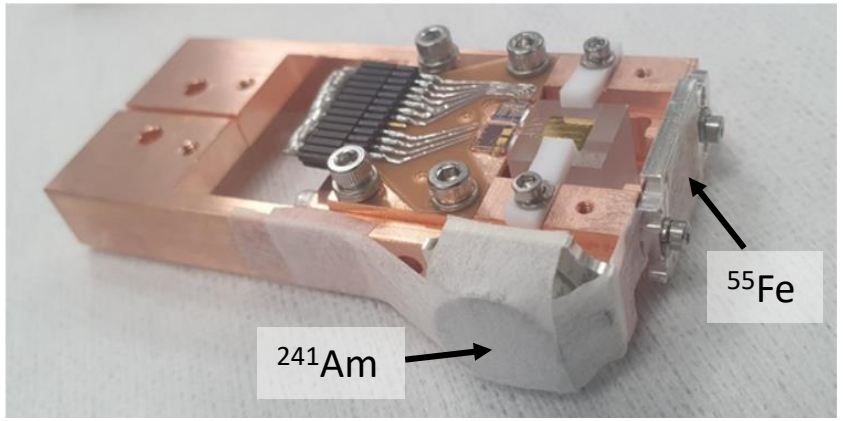


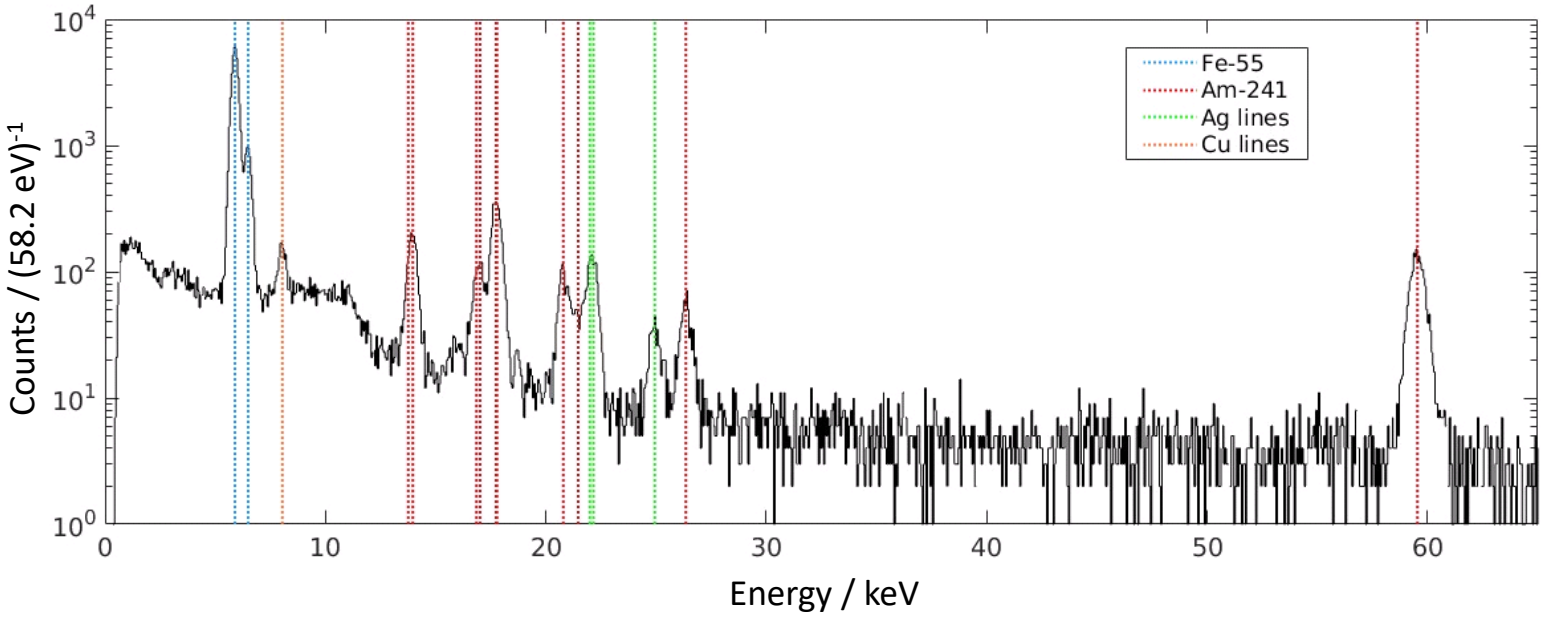


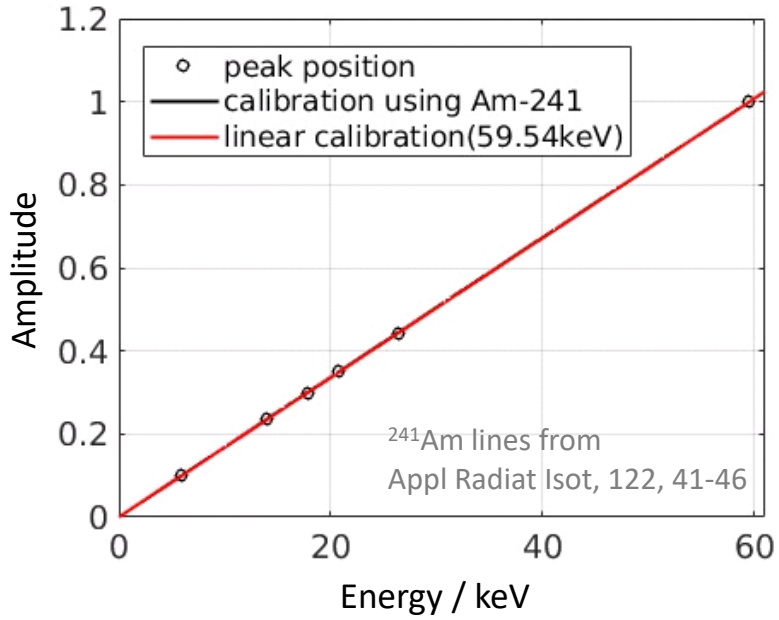
- Measured spectrum matches well with the standard model expectation
- Sources: ^{55}Fe and external ^{241}Am
- Further investigation of the Energy calibration was required:
  preliminary calibration method led to false local minima when searching for sterile neutrinos

Energy Calibration: Study with Improved Setup

- Measurement with internal ^{55}Fe and ^{241}Am calibration sources
- A quadratic energy calibration function can be fitted to the position of the calibration lines

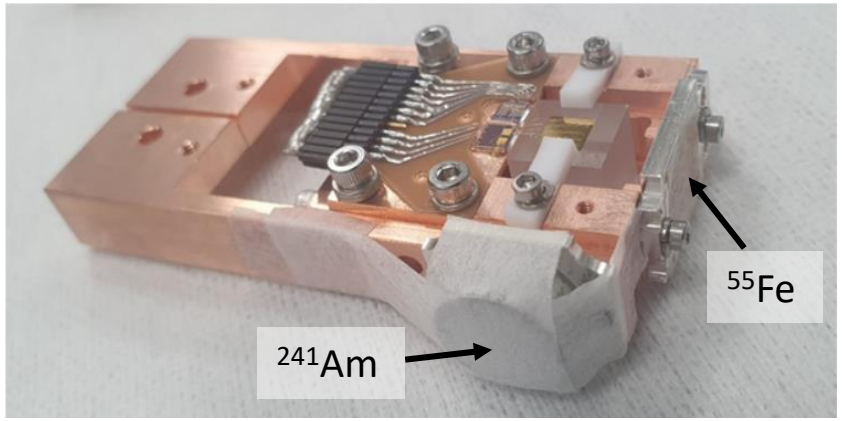


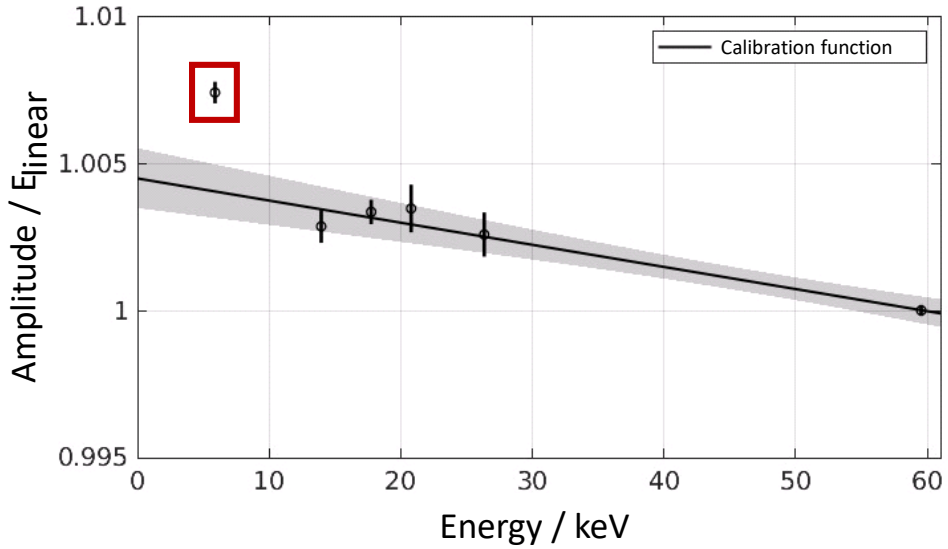




Energy Calibration: Calibration Mismatch

- Position of the 6 keV ^{55}Fe line significantly differs from the fit function
- A smaller mean free path at that energy hints a position depended amplitude



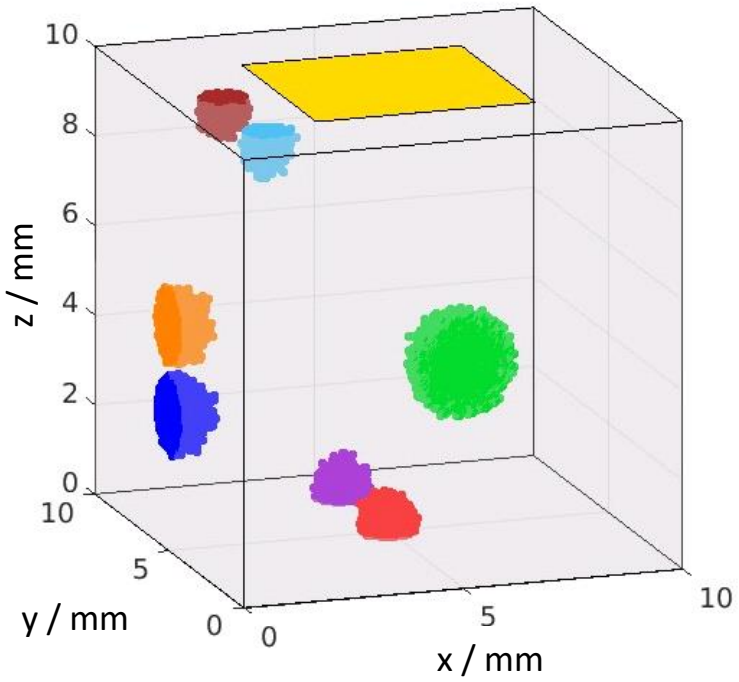


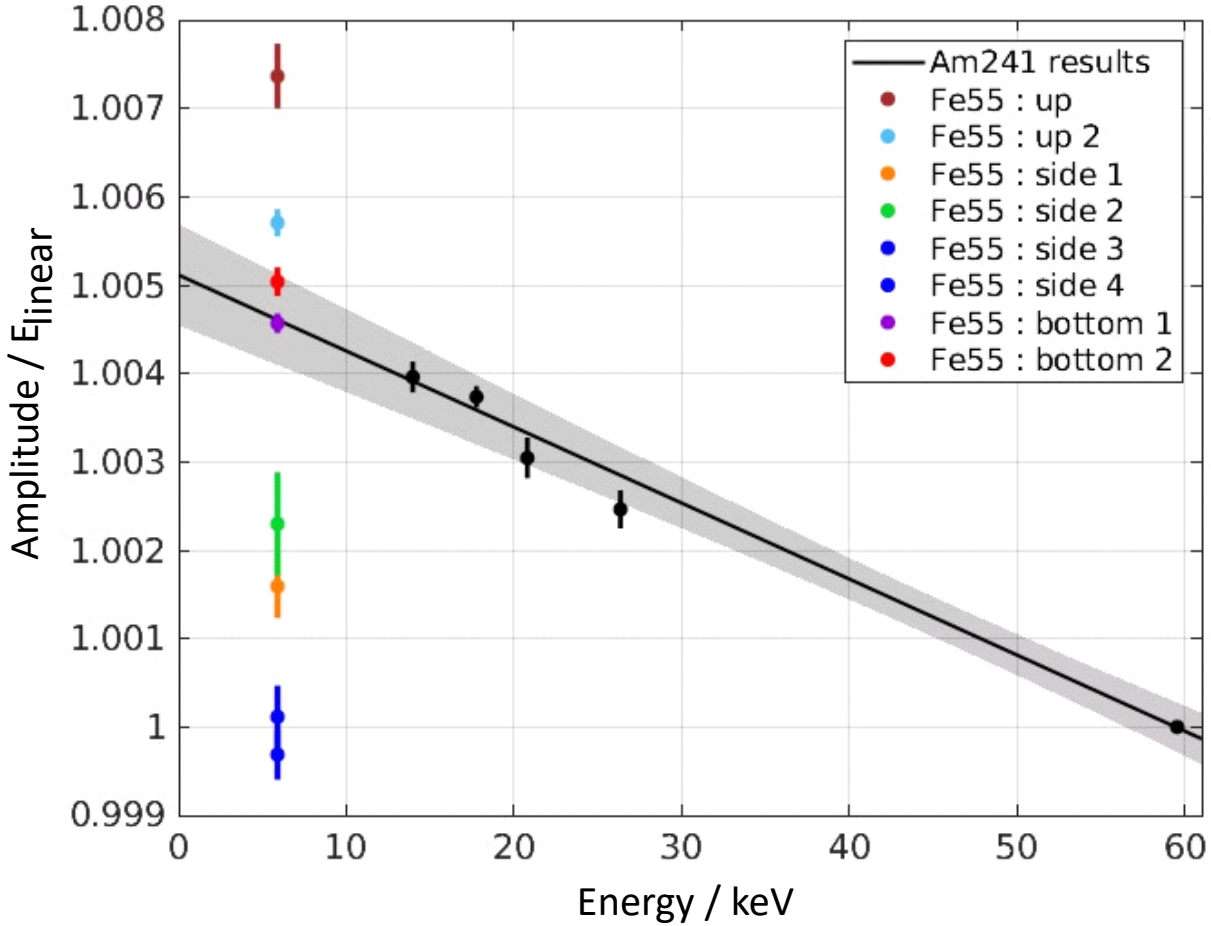
Photon energy keV	Mean free path mm
5.8953	0.129
13.962	1.64
17.758	3.15
20.793	4.69
26.345	7.73
59.5409	21.08

Energy Calibration: Position Dependent Events

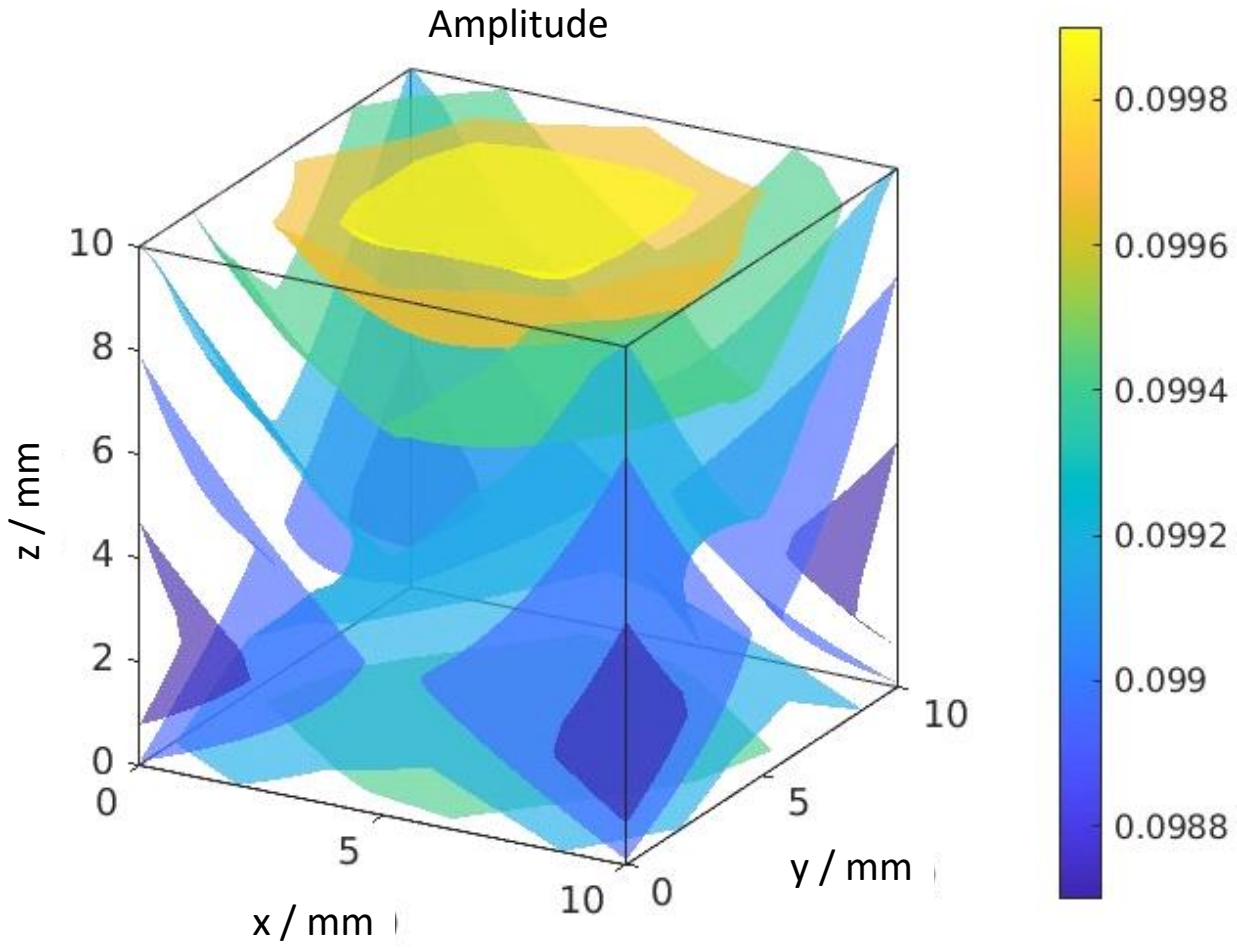
- Measurements with a ^{55}Fe source collimated to different positions
- Fixed ^{241}Am source for calibration

Positions of 5.9 keV X-ray events





Energy Calibration: 4D Interpolation



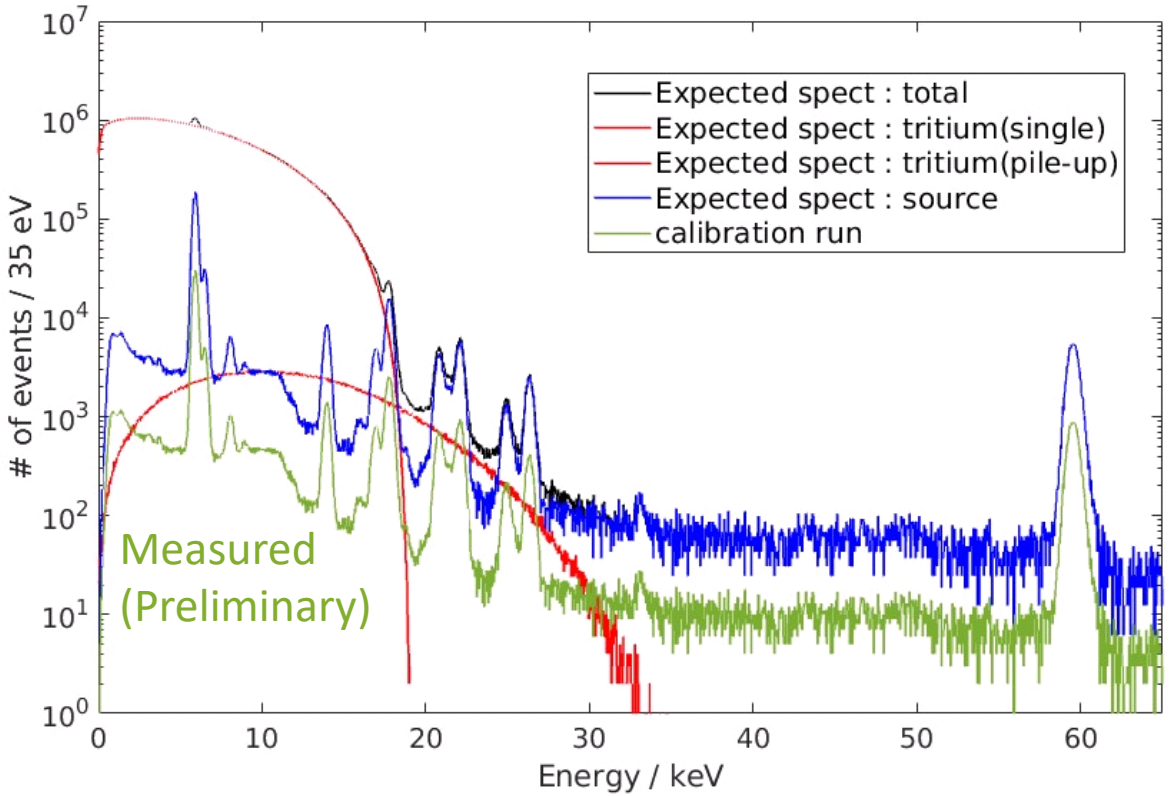
Result:

- 4D interpolation from measured point
- We assume rotation symmetry and presume a uniform amplitude at the phonon collector

Next steps:

- We want to investigate the X-ray amplitude when collimated to the phonon collector
- Combine the result with other X-ray energies as well as considering the tritium position

Project Plan



Dilution refrigerator measurement:

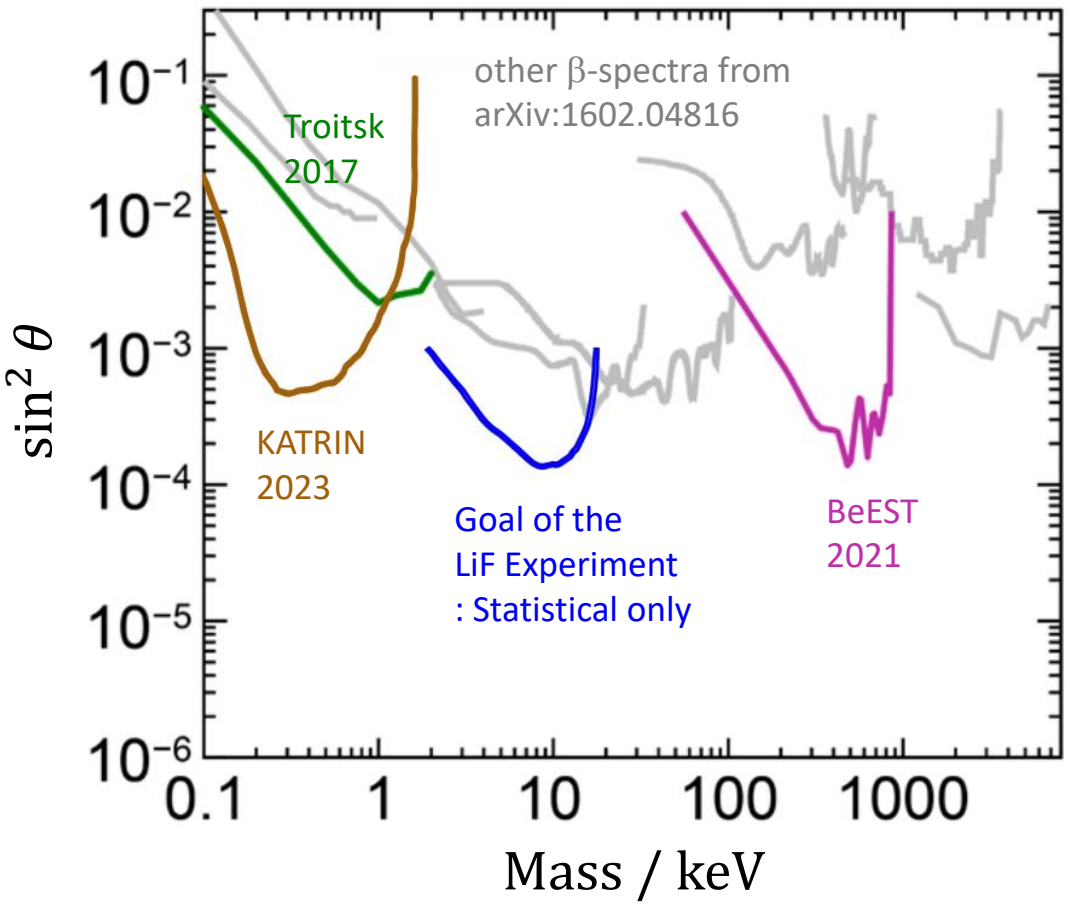
- for the next long-term experiments
- calibration data with ^{55}Fe and ^{241}Am as a background measurement

Next Steps:

- one month neutron irradiation on the crystal at KRISS
- afterwards measuring the Tritium spectrum for 3 months with sources

Goal: 2 detectors × 40 Bq × 3 month

Project Plan



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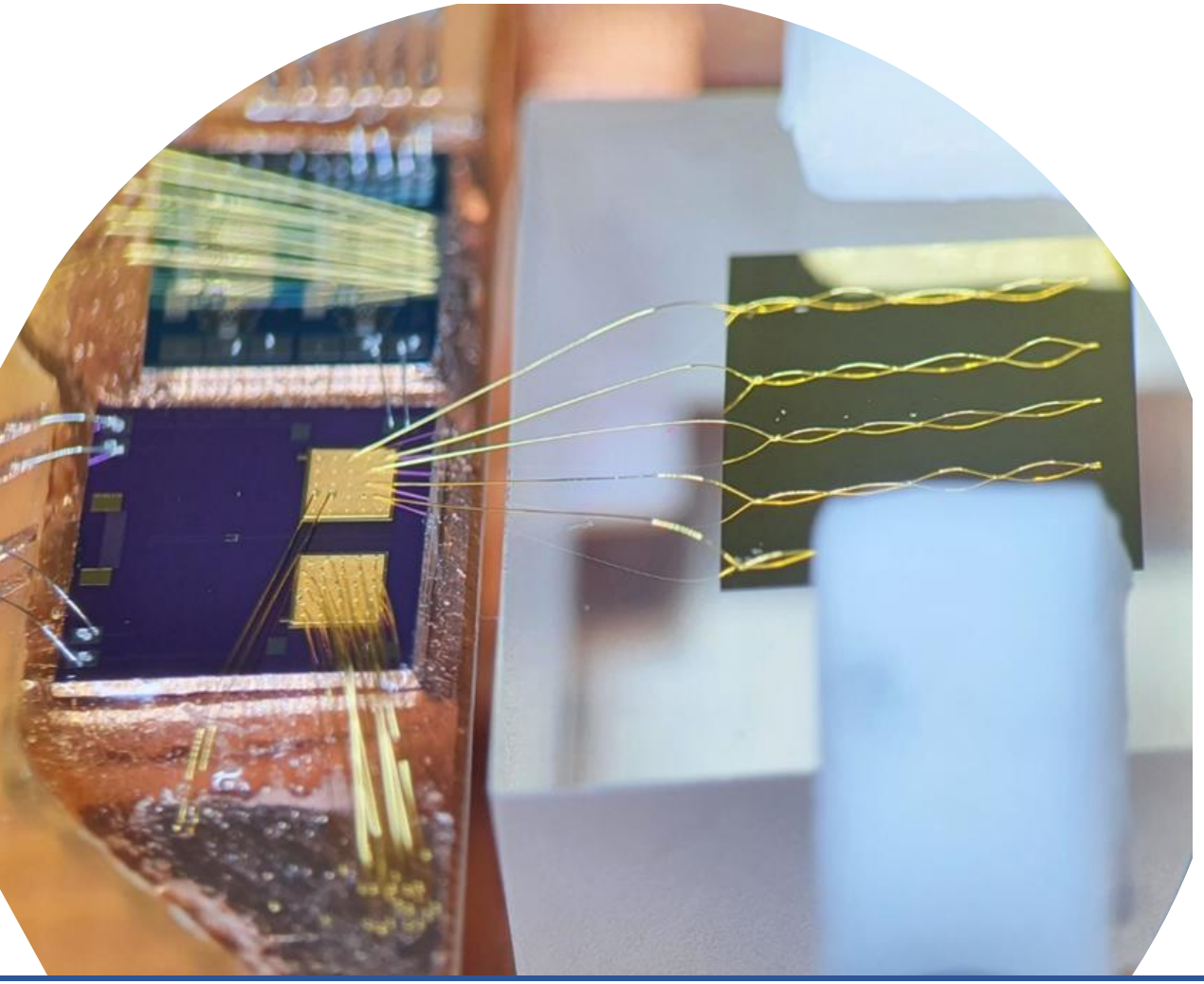
Conclusion



- Energy calibration study ongoing
- We are preparing a long-term measurement of the tritium spectrum with the improved setup

Acknowledgement

Institute for Basic Science:
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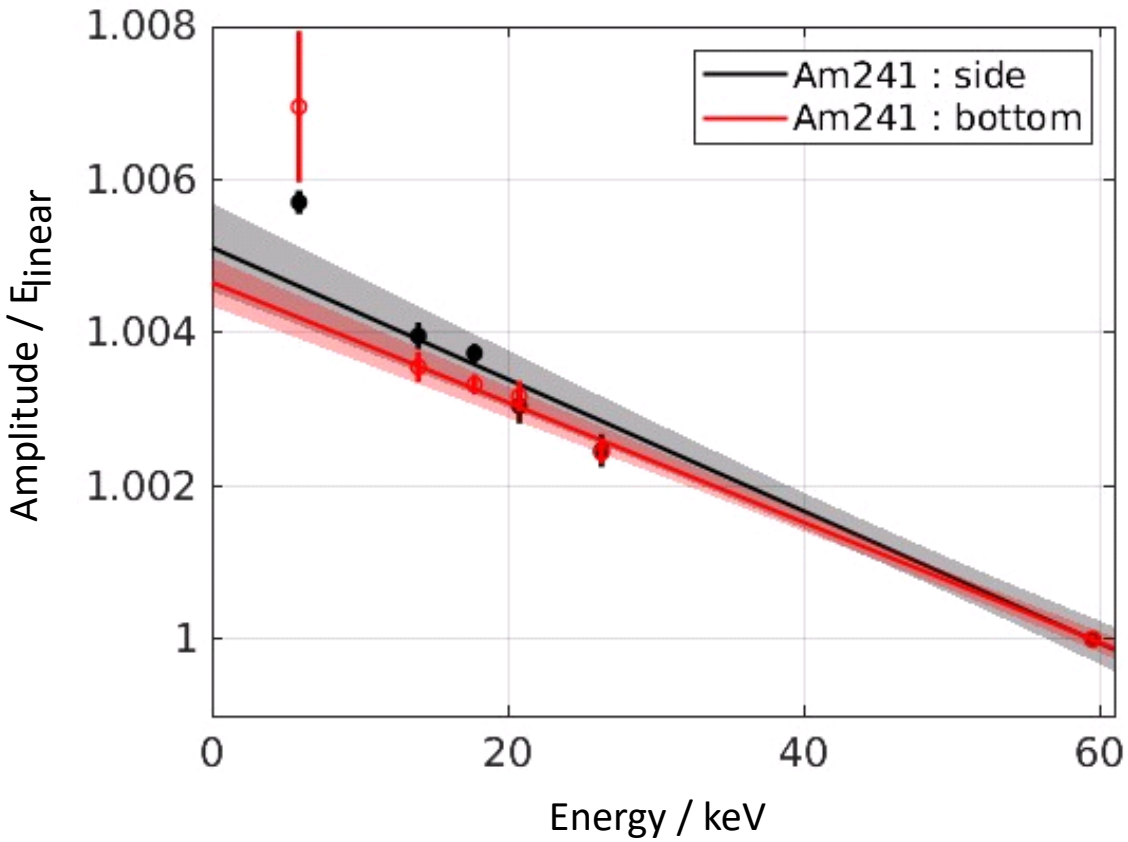
Seoul National University:
Sun-Kee Kim

Korea Research Institute of Standards and Science:
Young-Soo Yoon, Hyun-Seo Park

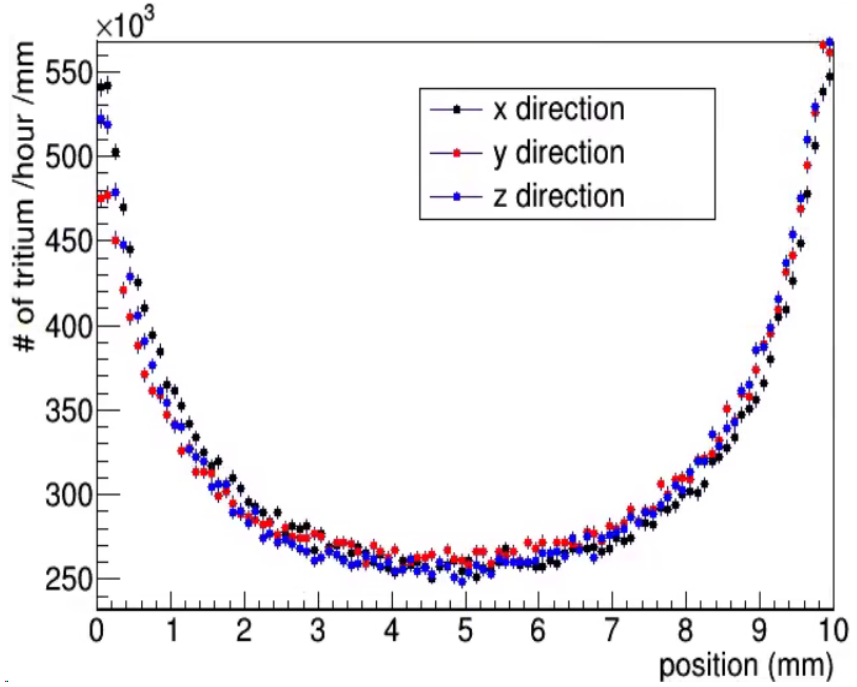
Energy Calibration: Position Dependent Events for ^{241}Am



- To check the position dependence of ^{241}Am events, data with ^{241}Am collimation at bottom side of the crystal was taken when ^{55}Fe collimation is up2
- It's not huge, but there seems to be some difference
- Analysis will be performed by applying the Fe55 results

^{3}H Location in Crystal, Detector Performance

Simulated ^{3}H location in 1 cm^3 LiF cube



Detector performance (@ 40 mK)

- Rise time : 240 us ($10 - 90\%$)
- Decay time : 0.9 ms ($90 - 50\%$)
- Energy resolution in FWHM

@ 6 keV : 350 eV

@ 60 keV : 770 eV