Sterile Neutrino Search at Underground mini-Workshop

1-2 July 2021
Virtual IBS

A lab-scale experiment for keV sterile neutrino search

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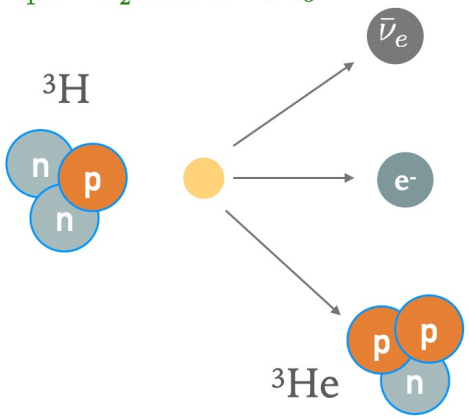
CUP, IBS

Lab scale experiment for sterile ν studies

β decay of ^{3}H

$$^3_1\mathrm{H} \longrightarrow ^3_2\mathrm{He} + e^- + \bar{\nu}_e$$



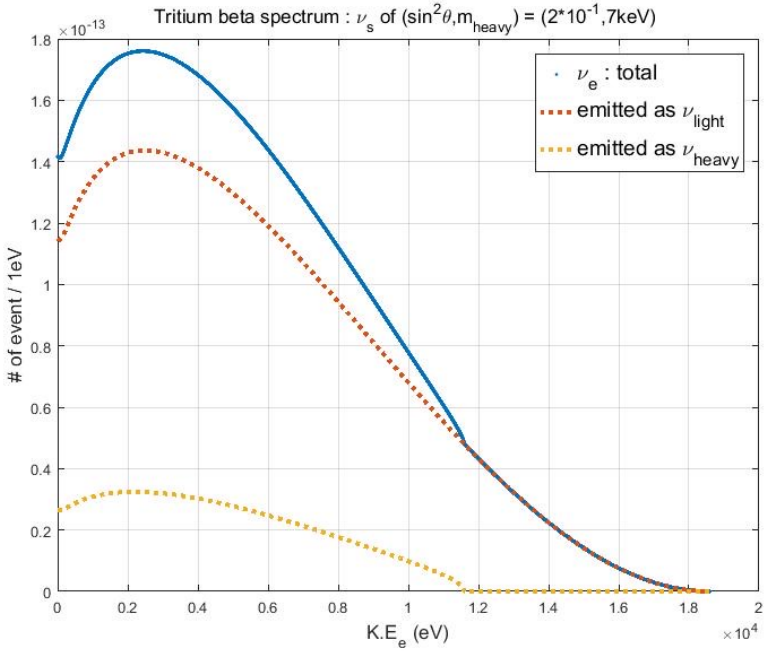
Q:18.59 keV, $\tau_{1/2}$: 12.32 y

Possible mixing

$$\nu_e = \cos\theta\,\nu_{light} + \sin\theta\,\nu_{heavy}$$

$$\nu_s = -\sin\theta\,\nu_{light} + \cos\theta\,\nu_{heavy}$$

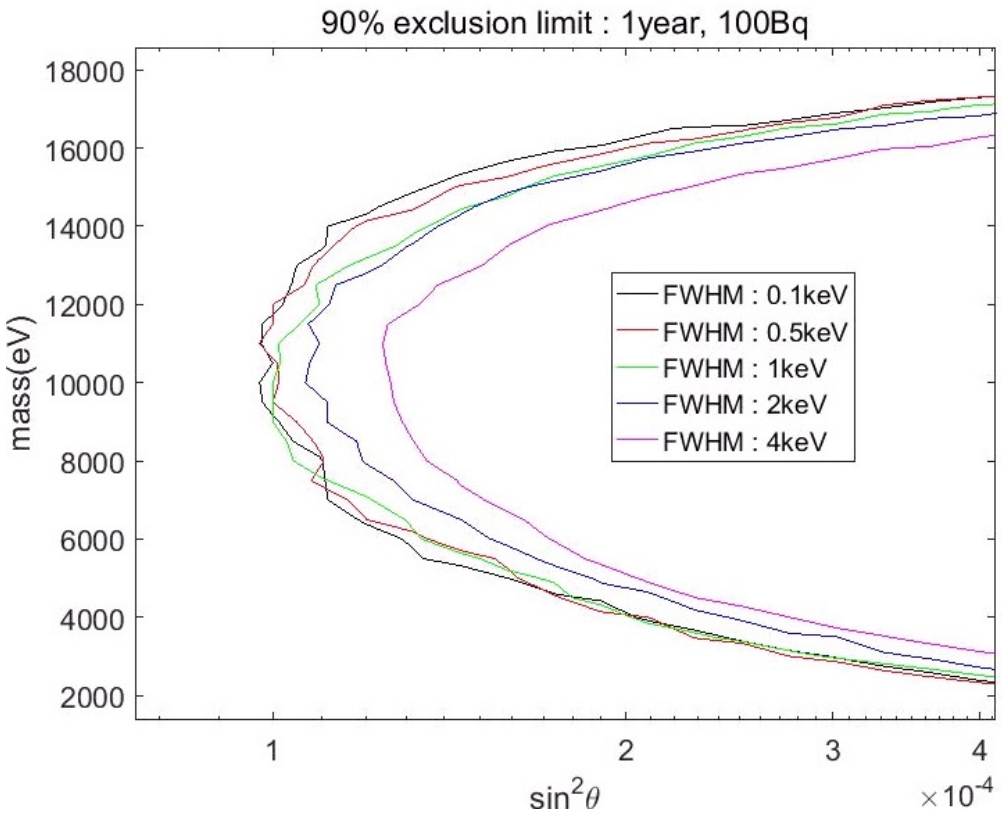
From β decay spectrums, we can investigate the presence of sterile neutrinos



For $\sin^2\theta = 0.2$, $m_{\nu,heavy} = 7$ keV

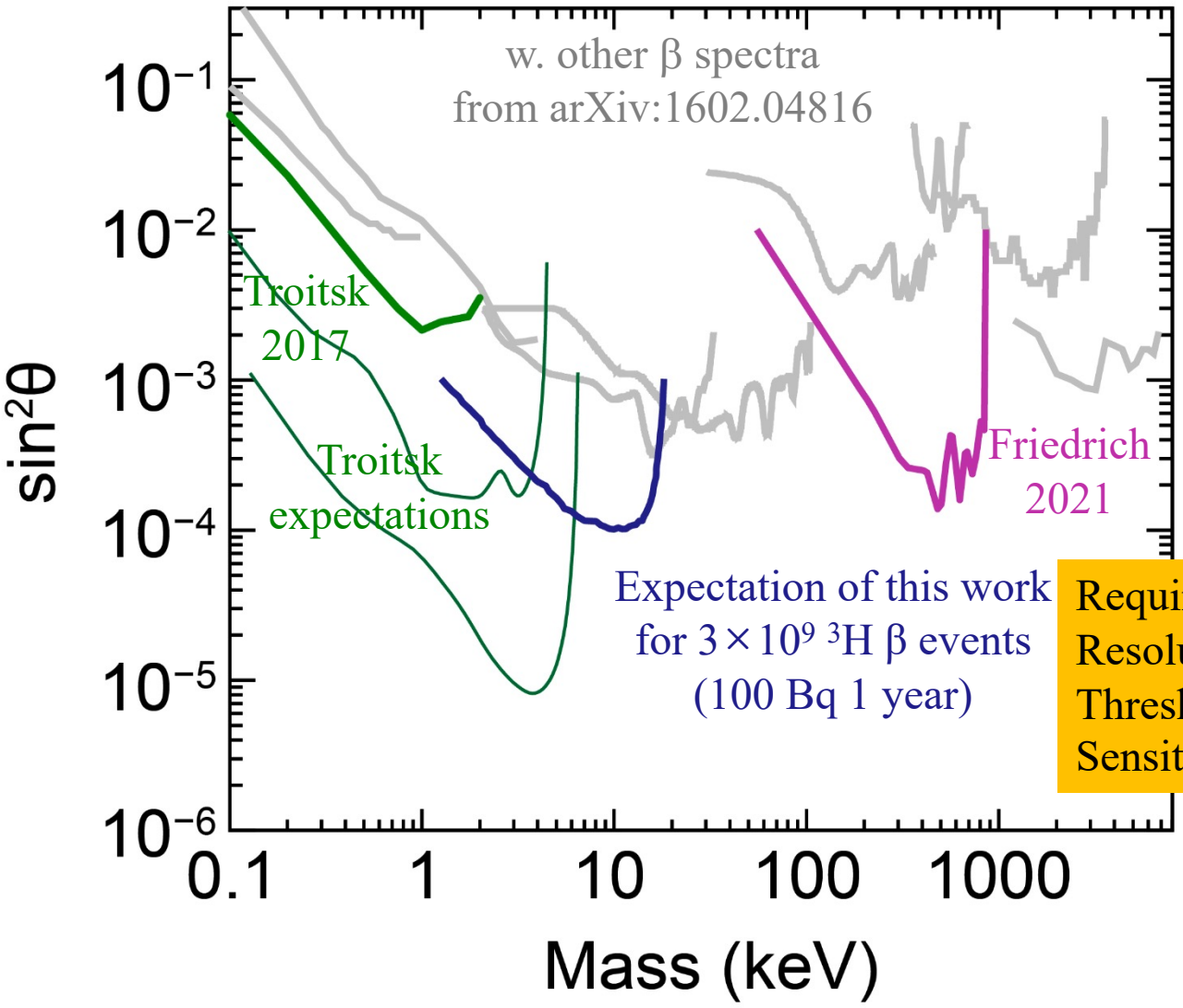
Statistical sensitivity and energy resolution

Pseudo experiments for the sensitivity limit using **3×10^9 ^{3}H β events**



- No apparent sensitivity difference with $\delta E_{\mathrm{FWHM}} < 1\mathrm{keV}$
- The # of events matters ~ $(N)^{1/2}$

Experimental bound



Requirement
Resolution: < 1 keV FWH
Threshold: < 2~3 keV
Sensitivity limit: $\sim (N)^{-1/2}$

KATRIN/TRISTAN

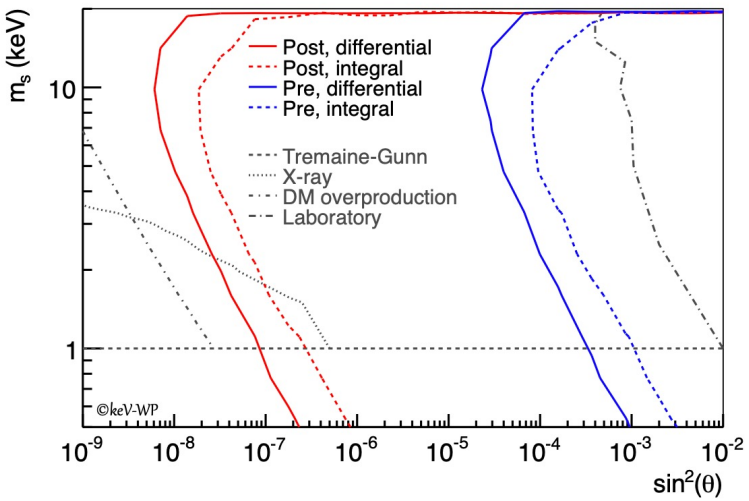
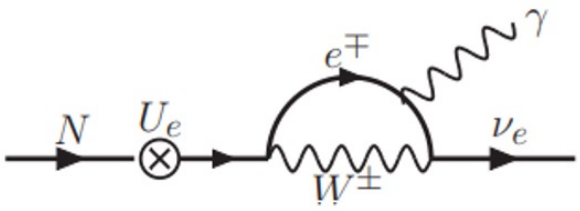


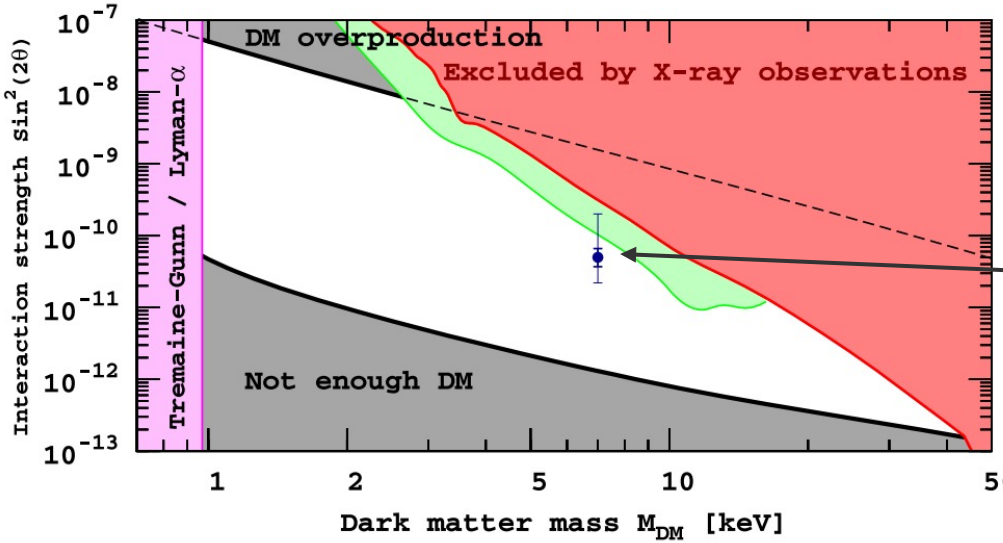
Figure 40. 90% statistical exclusion limit of a Pre- and Post-KATRIN-like experiment. The Post-KATRIN measurement is based on a 3-years measurement with the full KATRIN source strength. The Pre-KATRIN measurement assumes a factor 10^5 reduction of count rate and a measurement time of 7 days. The gray lines represent the current laboratory limits [642] and the parameter space excluded by astrophysical observations [397, 911].

Cosmology bound



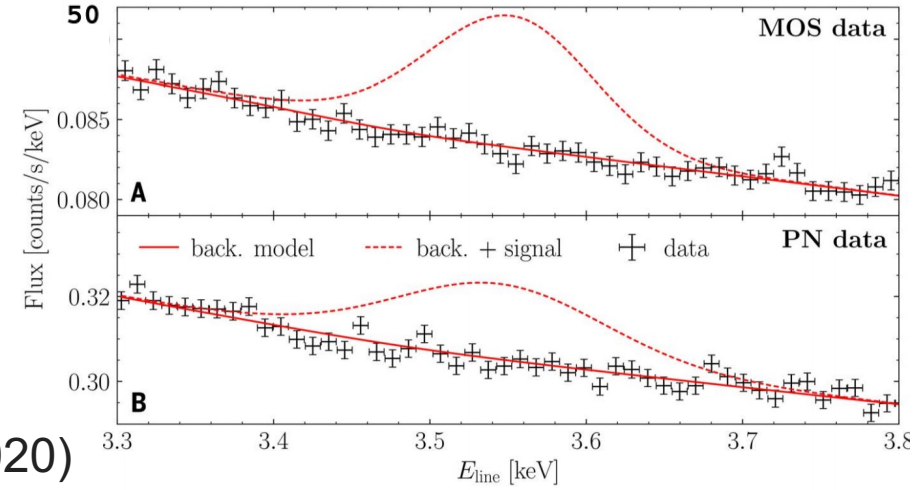
arXiv:1602.0

X-ray bound: assumes the present DM is all sterile ν's, regardless of its generation mechanism relevant with the mixing angle.



Not conclusive

<Milky way blank sky>



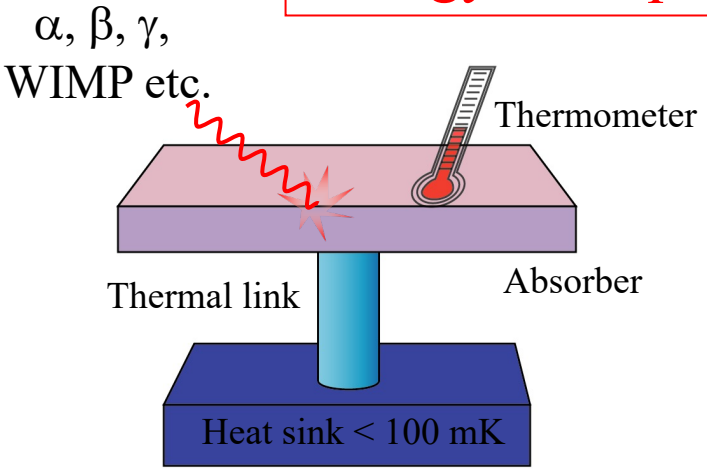
Dessert, *Science* (2020)

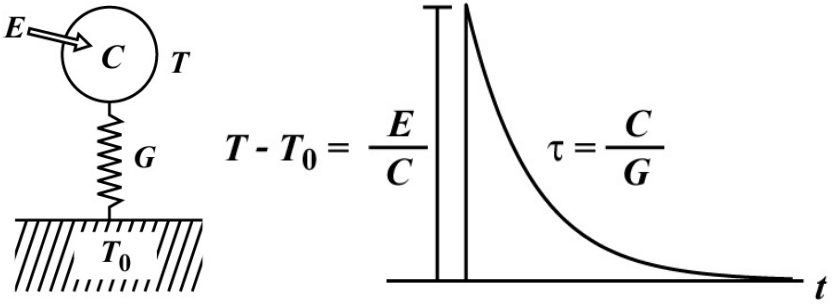
Detector technology

Thermal detectors (Calorimeters) at Low Temp.

"Calorimetric measurement of heat signals at mK temperatures"

Energy absorption ➔ Heat (Temperature)





Measurement of the energy ***E*** of individual particles as a temperature rise $\Delta T = E/C$

Temperature pulse with decay time $\tau = C/G$

Very low temperature(10–100 mK)

- Small C → Large ΔT
- Low noise

Sensor technologies

Choice of detector sensors (superconducting detectors)

- **Thermistors (doped Ge, Si)**
- **TES (Transition Edge Sensor)**
- **MMC (Metallic Magnetic Calorimeter)**

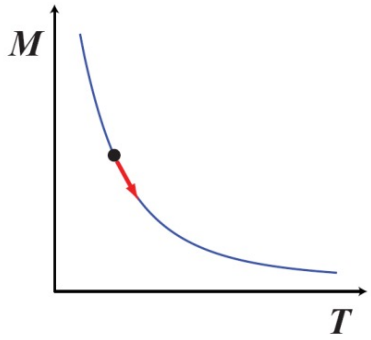
➔ Currently used as sensors for equilibrium thermal detectors

- **STJ (Superconducting Tunneling Junction)**
- **KID (Kinetic Inductance device)**
- **etc.**

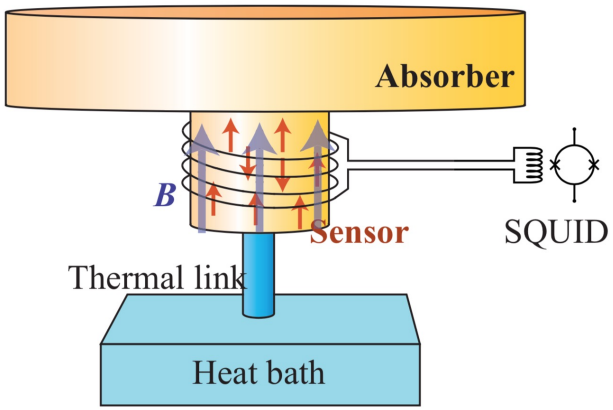
➔ Have great potentials useds for equilibrium thermal detectors

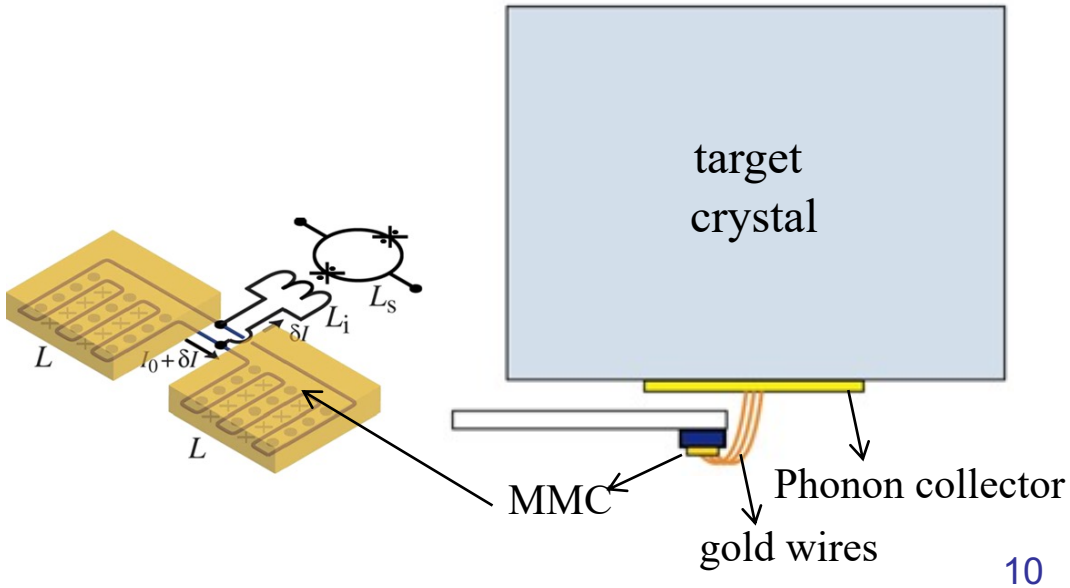
Metallic Magnetic Calorimeter (MMC)

- Paramagnetic alloy in a magnetic field
  Au:Er(300-1000 ppm), Ag:Er(300-1000 ppm)
  → Magnetization variation with temperature
- Metal host → Fast thermalization



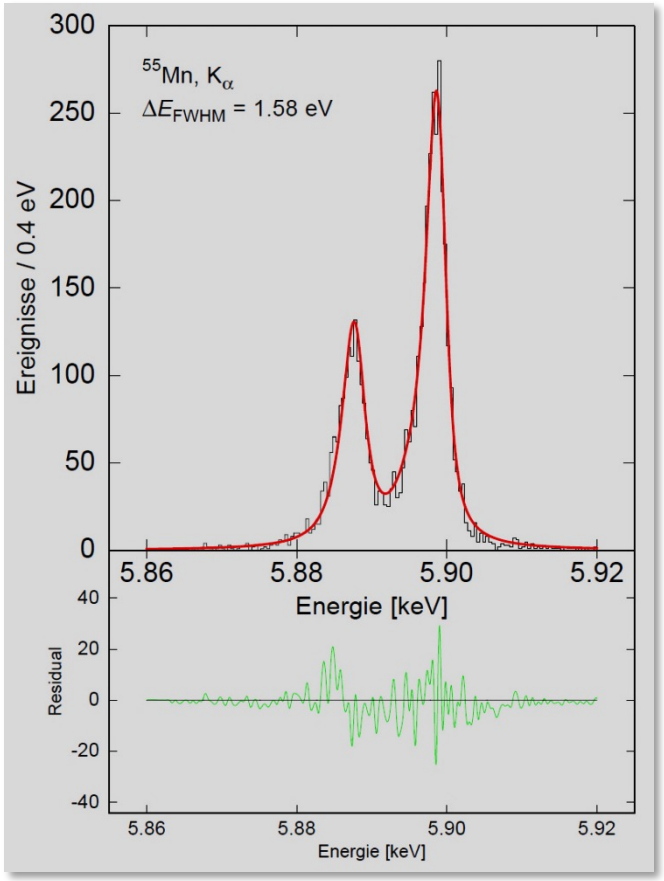
- Measurement: Superconducting circuit with SQUID readout
- High energy+time resolution, Good linearity, Large dynamic range,
  No bias heating, Absorber friendly, Fast



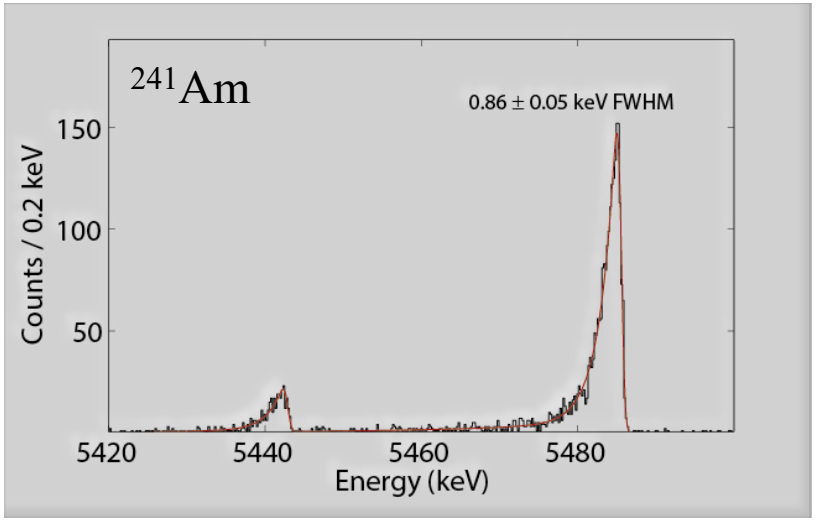


Best resolutions have been achieved with MMCs

1.6 eV FWHM for 6 keV X-rays
(Heidelberg)



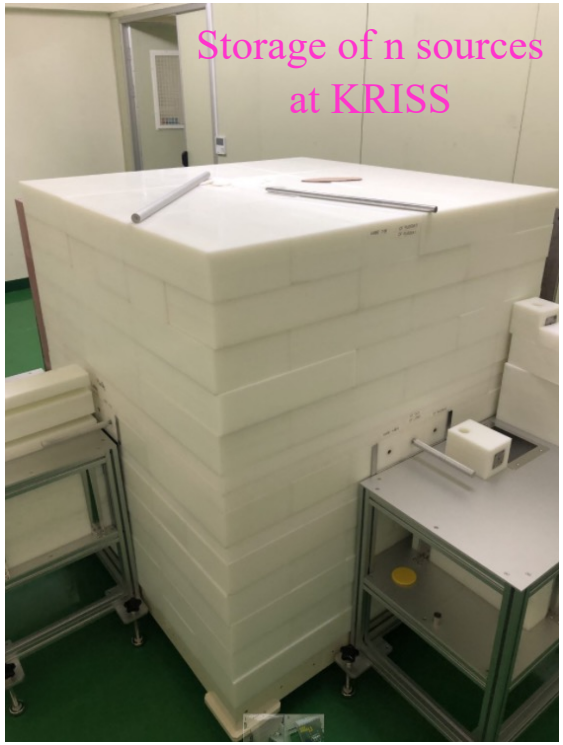
0.9 keV FWHM for 5.5 MeV α-rays
(IBS/KRISS)

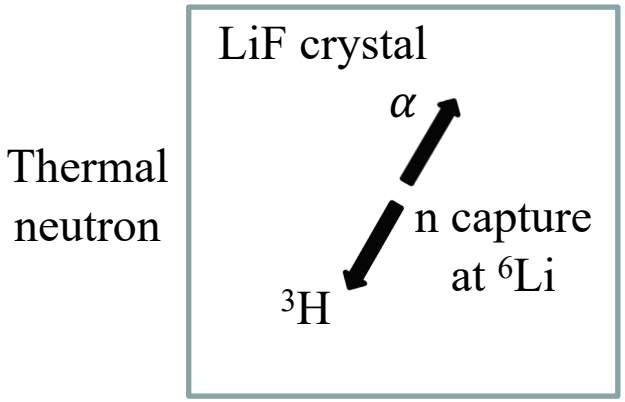


I Kim, et al., Supercon. Sci. and Tech. (2017)

Lab-scale experiment for sterile neutrino search

^{3}H generation in LiF crystals

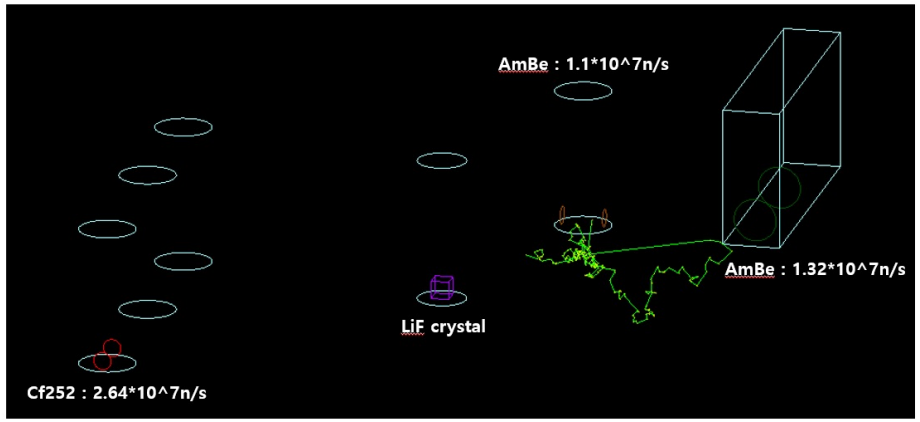




Mean free path : 2.3mm in LiF
(7.6% ^{6}Li)

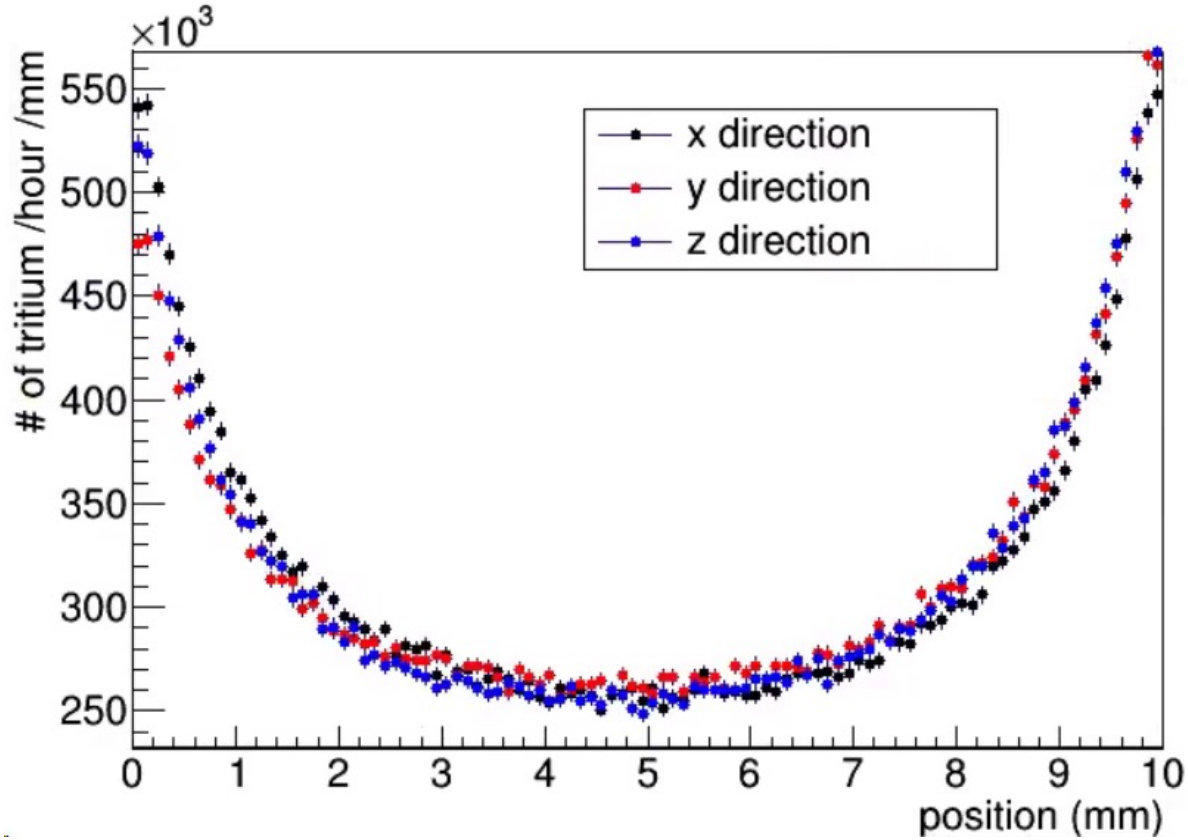
$$^6_3\mathrm{Li} + ^1_0\mathrm{n} \rightarrow ^3_1\mathrm{H} + ^4_2\alpha$$

- Irradiation time : 7days
- Event rate: ~ 20 Bq

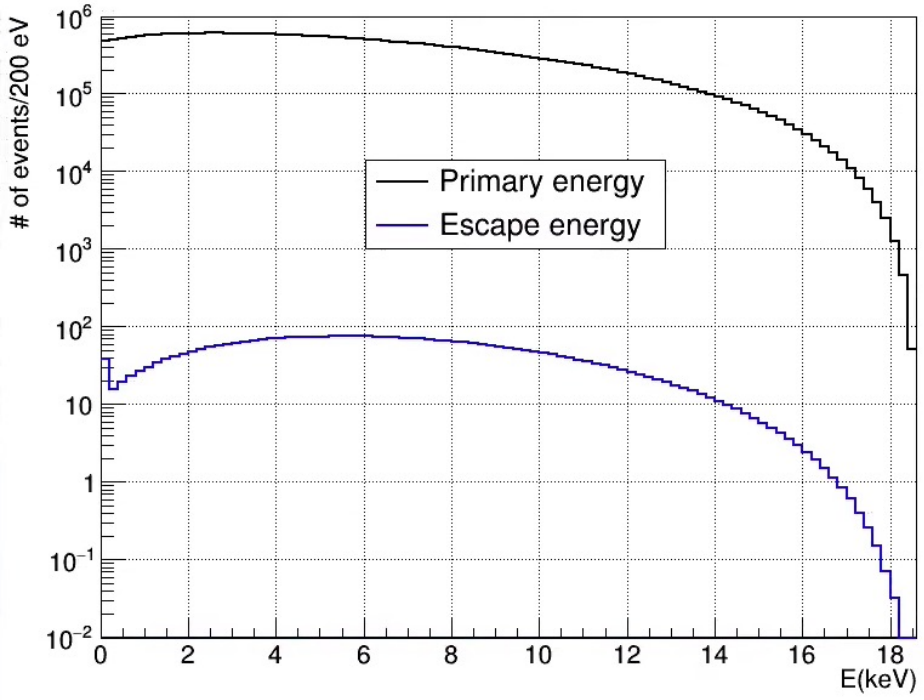


^{3}H distribution in LiF

^{3}H location in 1x1x1 cm^3 LiF

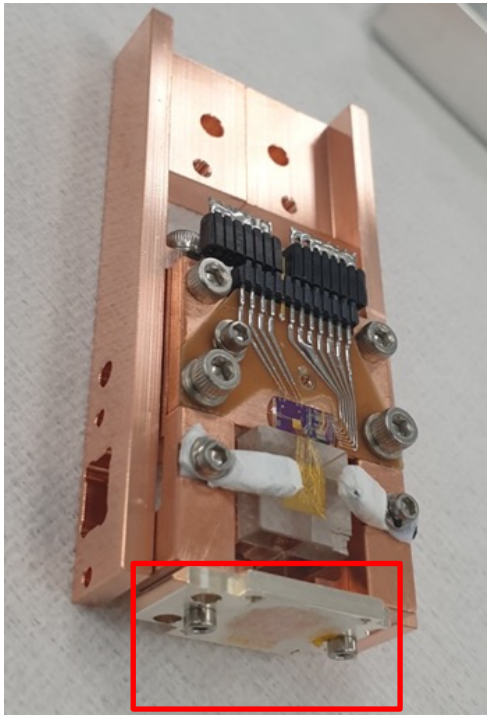


Energy loss at the surface

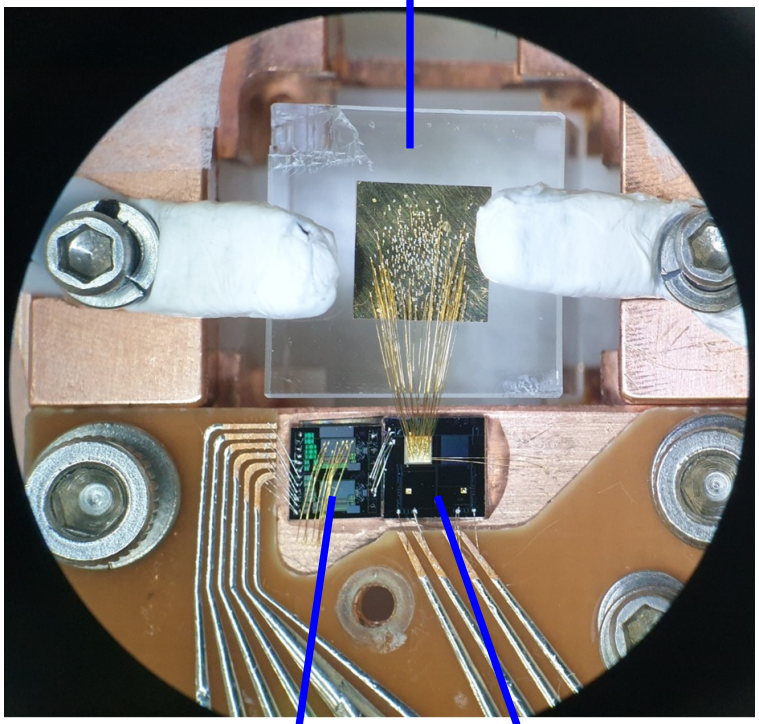


- Using the ^{3}H distribution, the MC shows a negligible effect would result in a spectrum for 10^{8} counts.
- The MC result should be compared with C omparison between the measured for high s ensitivity analysis

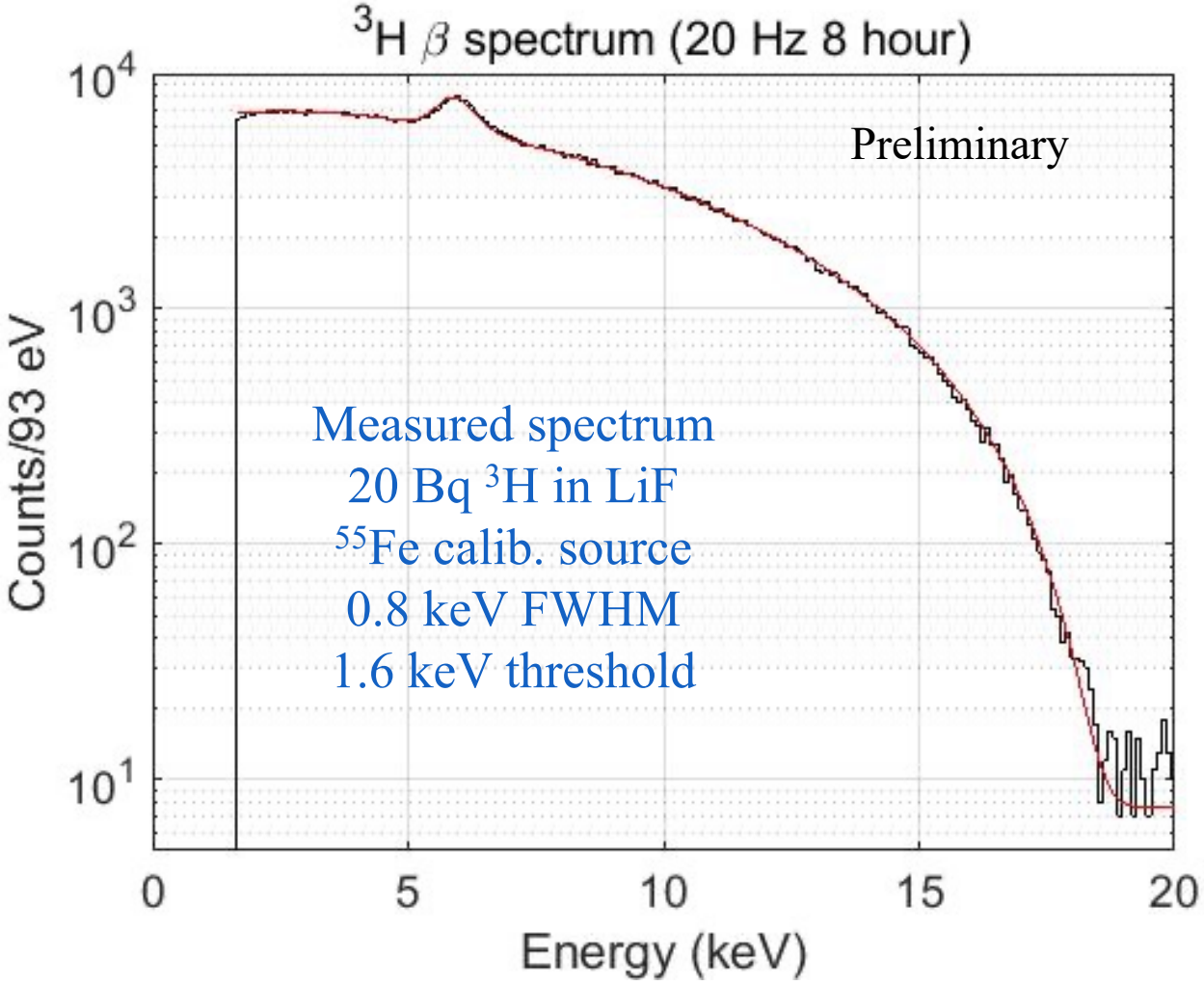
Low Temperature test setup



Fe55 source



Beta spectrum



Systematics on keV sterile ν study

- Surface effect:

  → Comparison between the measured and MC.

- Unresolved pileup:

  → Setup for fast risetime + MC studies

- Long term stability:

  → Drift correction + Calibration studies

- Possible backgrounds:

  → Measurement with no ^{3}H source

Summary

- ^{3}H was embeded in a LiF crystal with reasonable activty.
- The beta spectrum shows a good agreement with the expected.
- Further analysis to come for sterile neutrio presence.
- We plan a long term (several months) with multi-channel setups.