The search for rare events with cryogenic detectors

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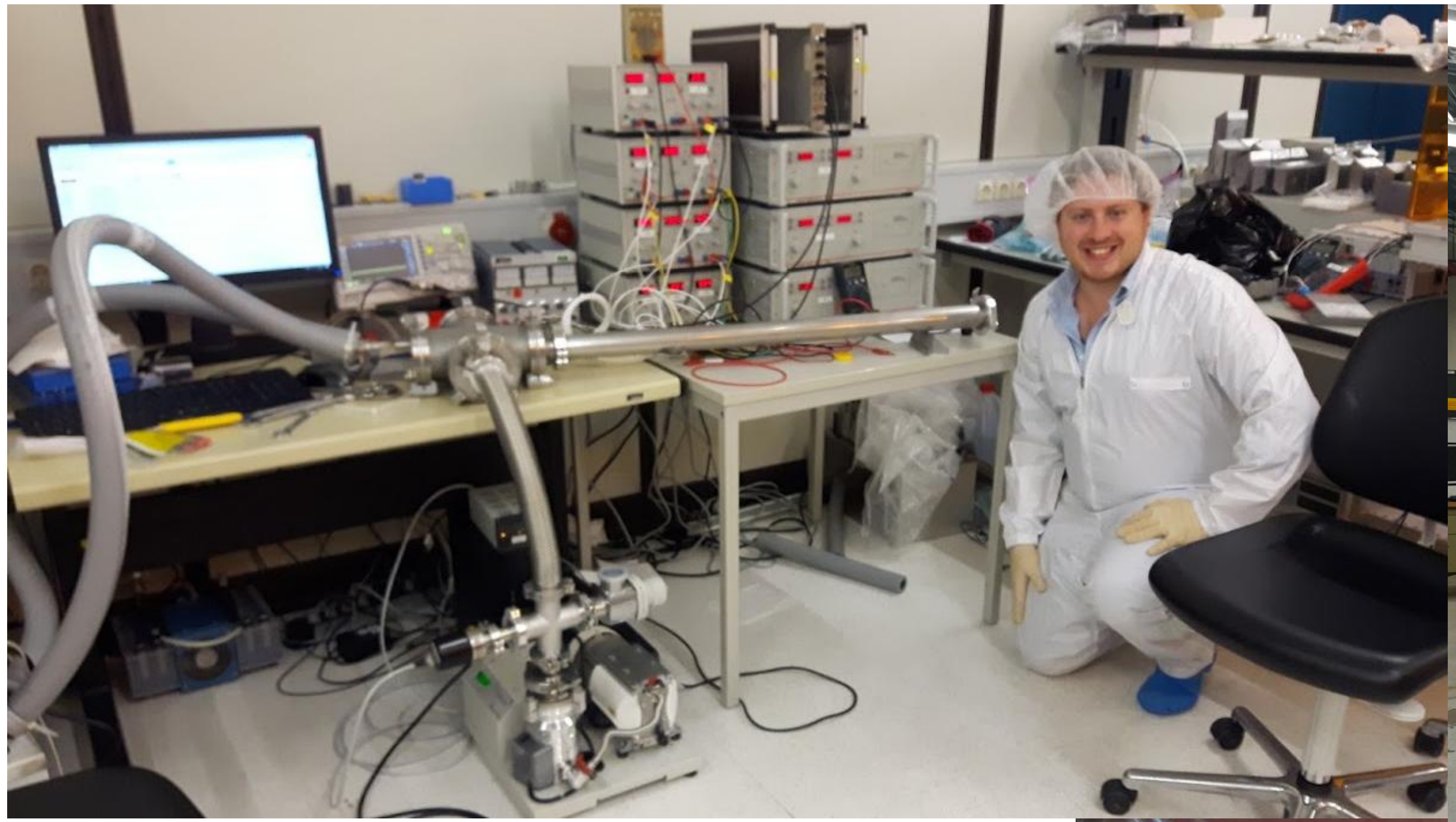
2026/07/29

Talk Overview

1. Intro
2. COSINUS
3. SuperCDMS
4. R&D Efforts

Intro: Queens University and KDK

Graduate Studies at Queens

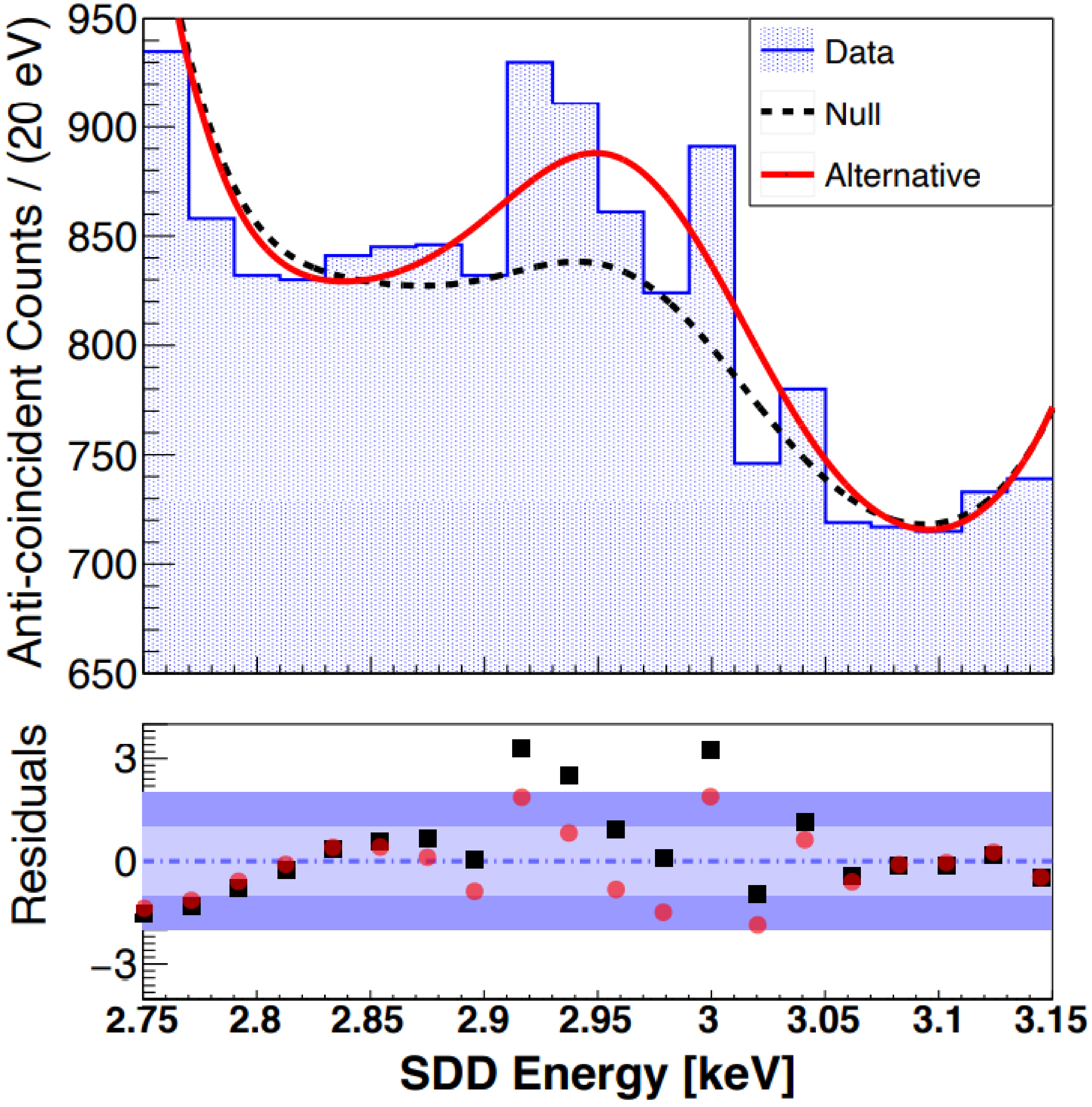


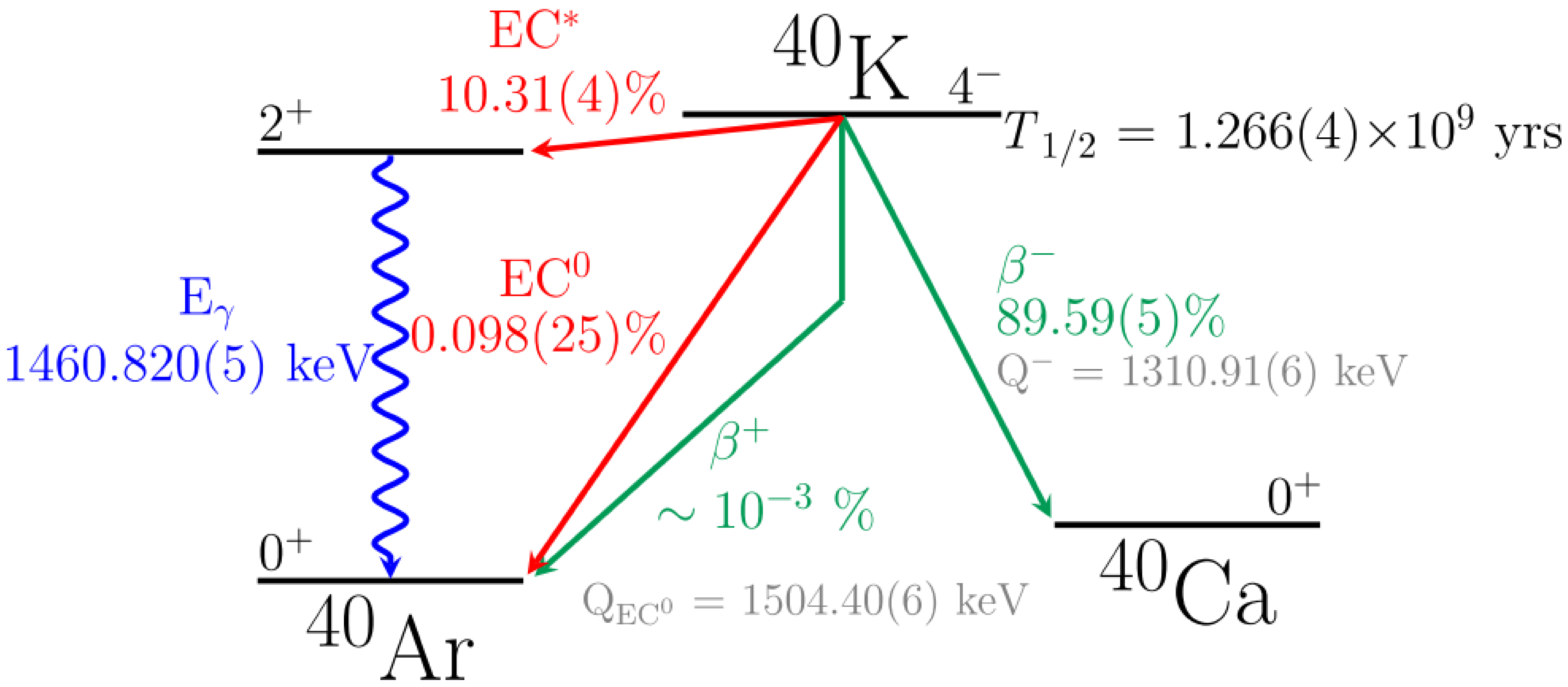
Potassium

KDK

"Decay"

KDK Experiment



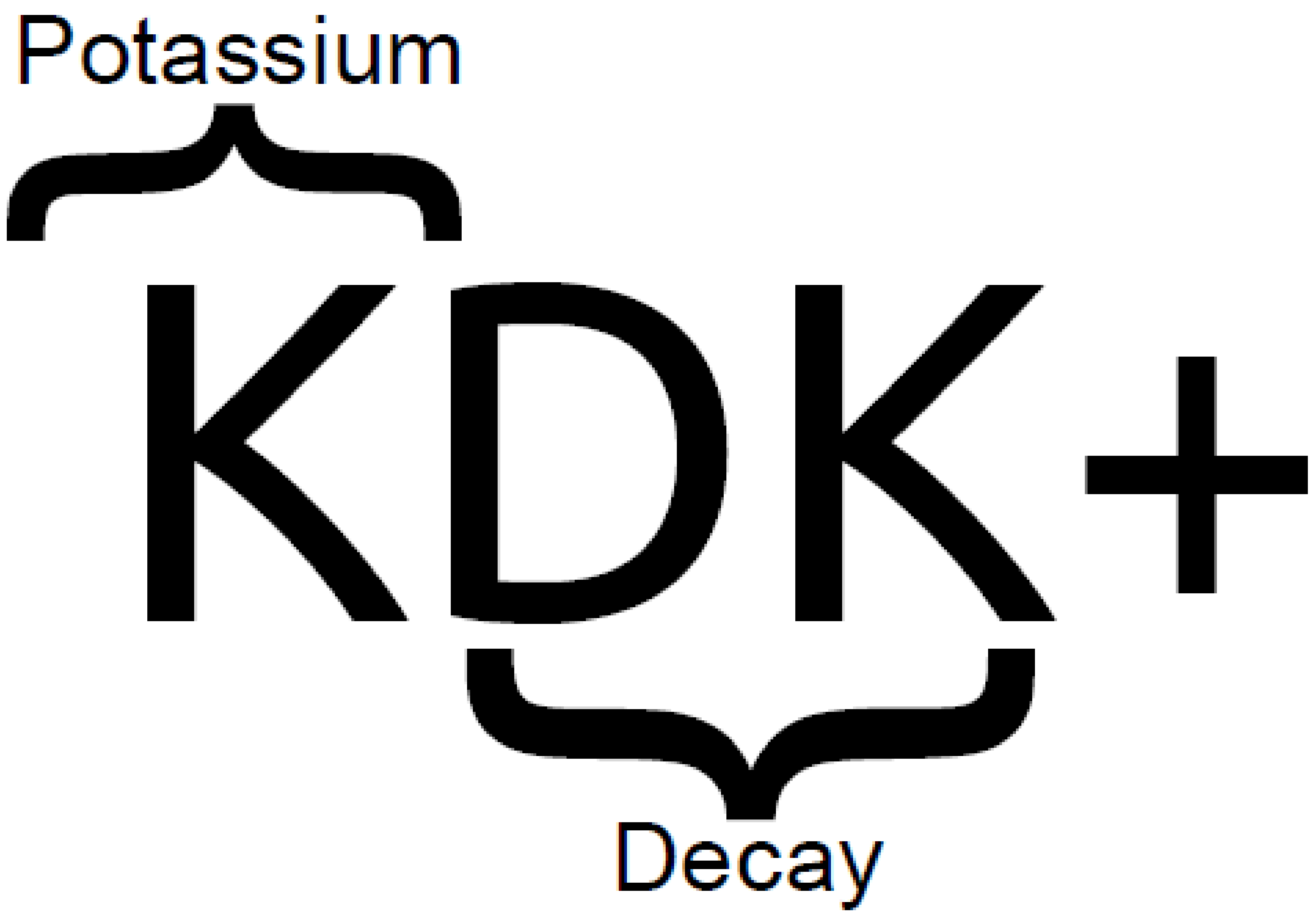


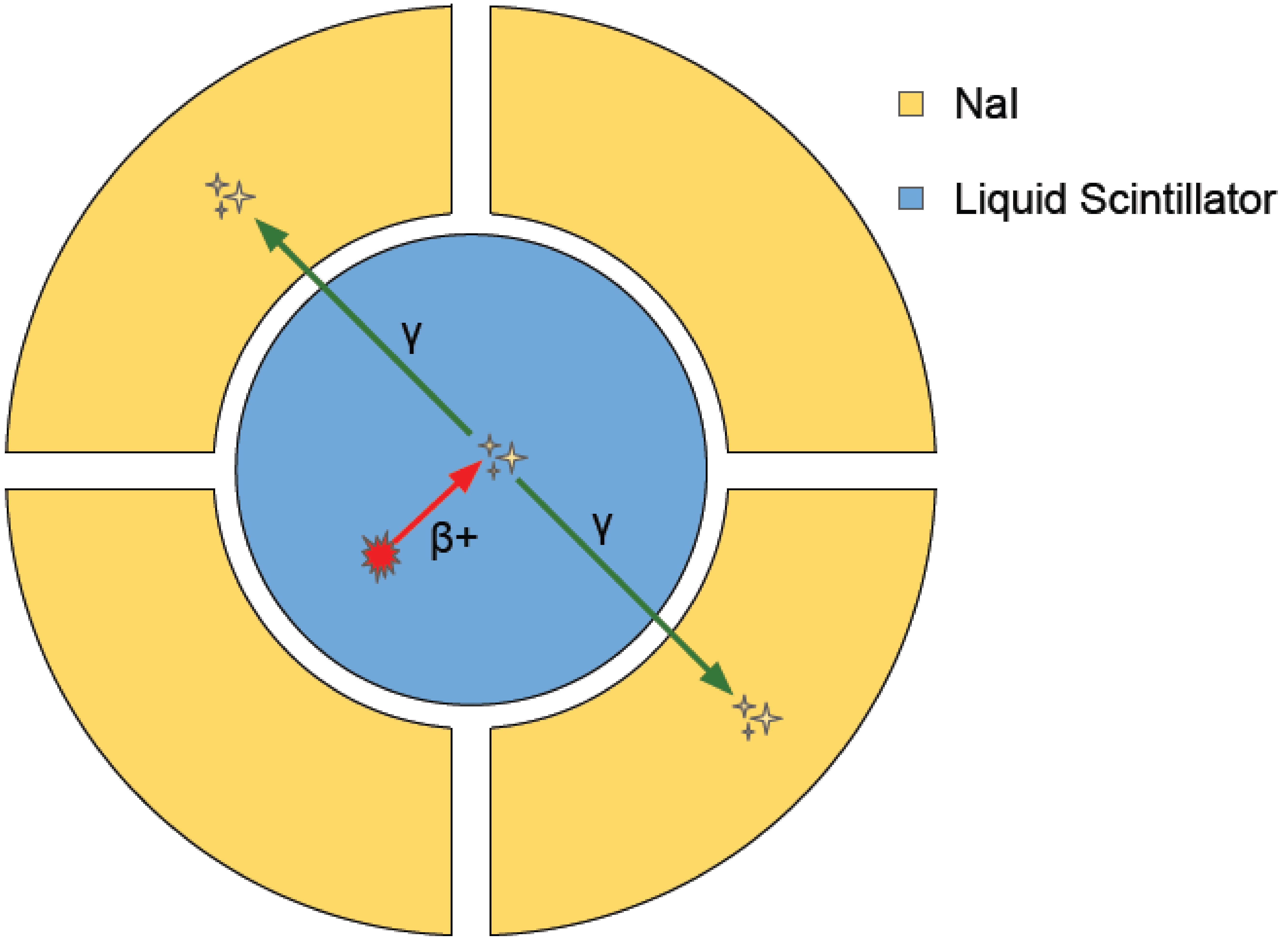
KDK Collaboration. (2023). Rare K 40 Decay with Implications for Fundamental Physics and Geochronology. *Physical Review Letters*, *131*(5), 052503.

KDK collaboration. (2023). Evidence for ground-state electron capture of K 40. *Physical Review C*, *108*(1), 014327.

- **Nuclear Theory:** Rare 3U EC transition
- **Particle Physics:** ^{40}K is a background in **rare-event searches:** especially in **NaI based detectors**
  - E.g. DAMA, COSINUS, COSINE-100, ANAIS-112 and PICO-LON
- **Geochronology:** ~10^9 years half-life, excellent for dating

KDK+ Experiment





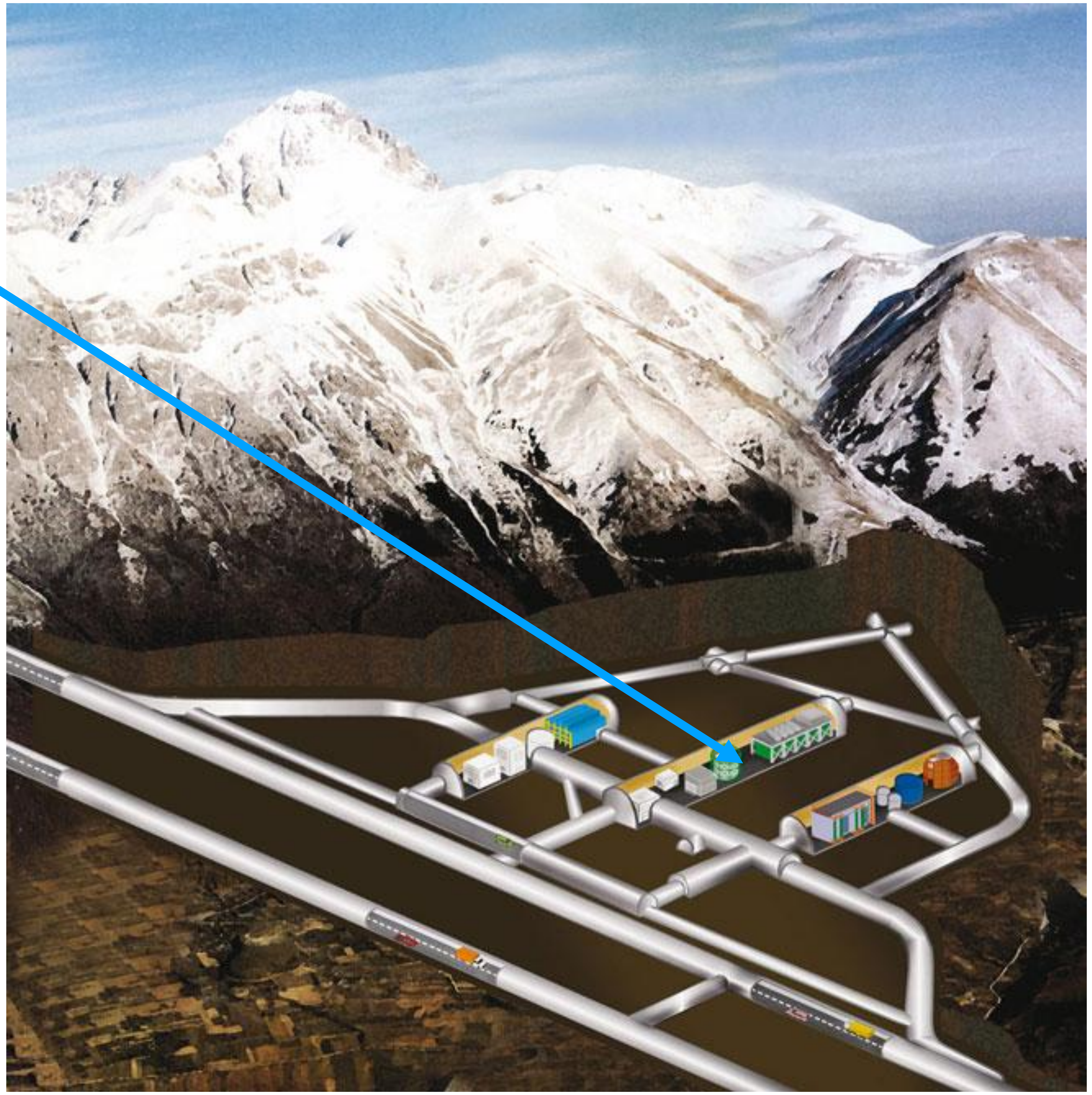
- KDK+ is a follow-up to the KDK experiment and is looking for the β^{+} decay of ^{40}K
- KDK+ will measure the β+ decay by using a triple coincidence setup
- Involved with the simulations and background studies

COSINUS

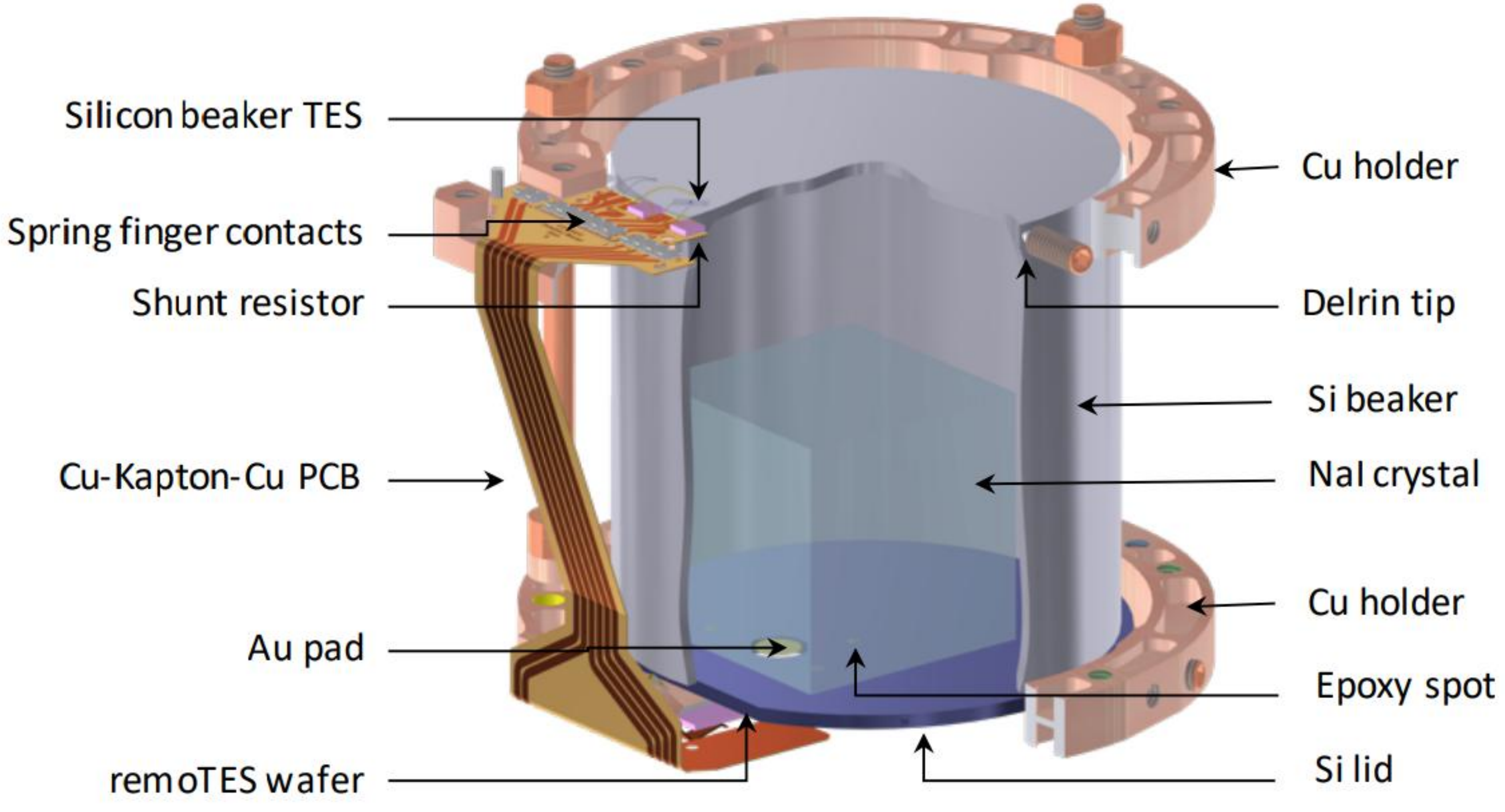
Cryogenic Observatory for SIgnatures seen in Next-generation Underground Searches

COSINUS Experiment

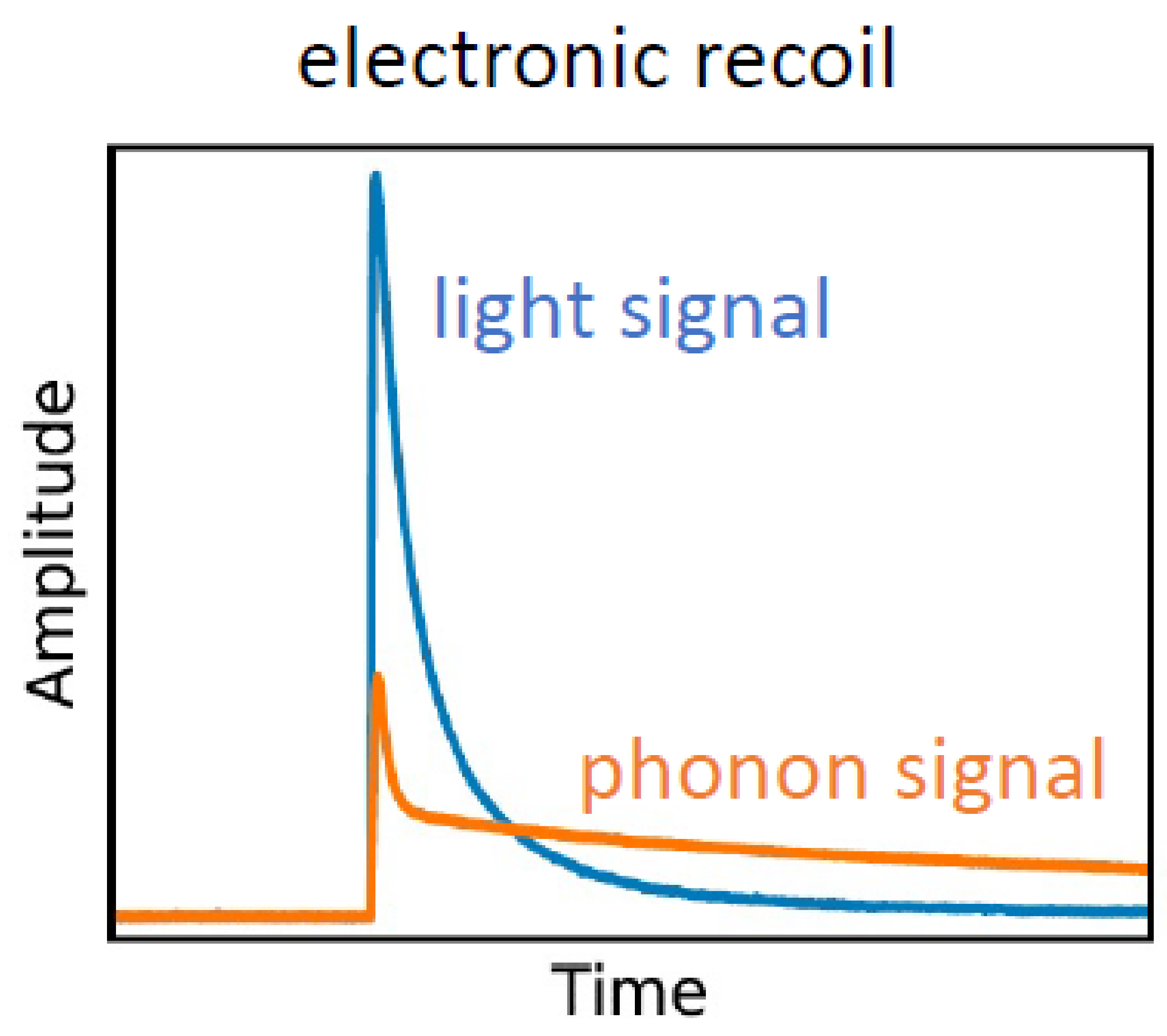
COSINUS
Location



COSINUS – Particle Discrimination I

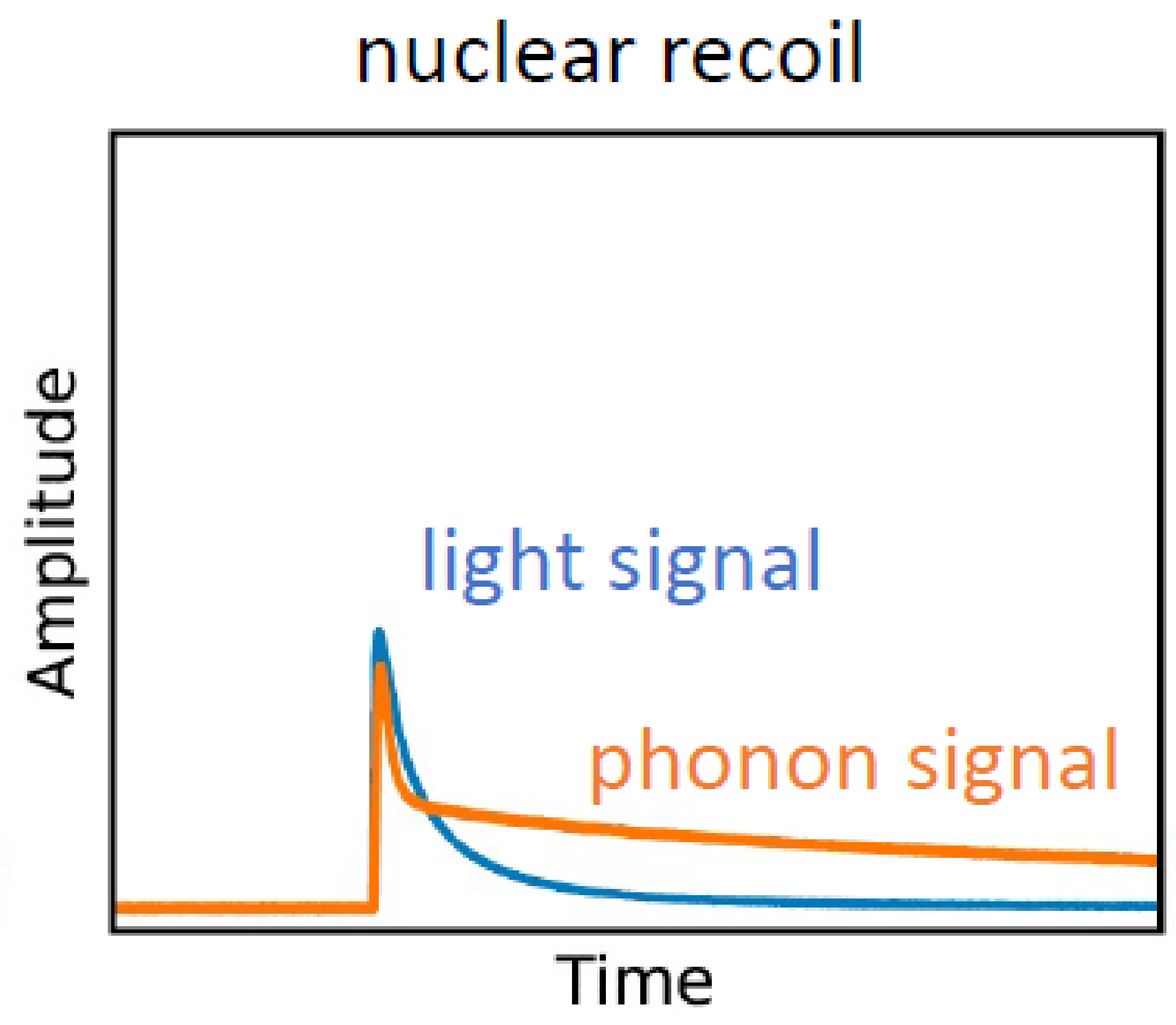


$$\text{Light Yield} = \frac{\text{Light Energy}}{\text{Phonon Energy}}$$



2.33 g Si-remoTES

<10 eV

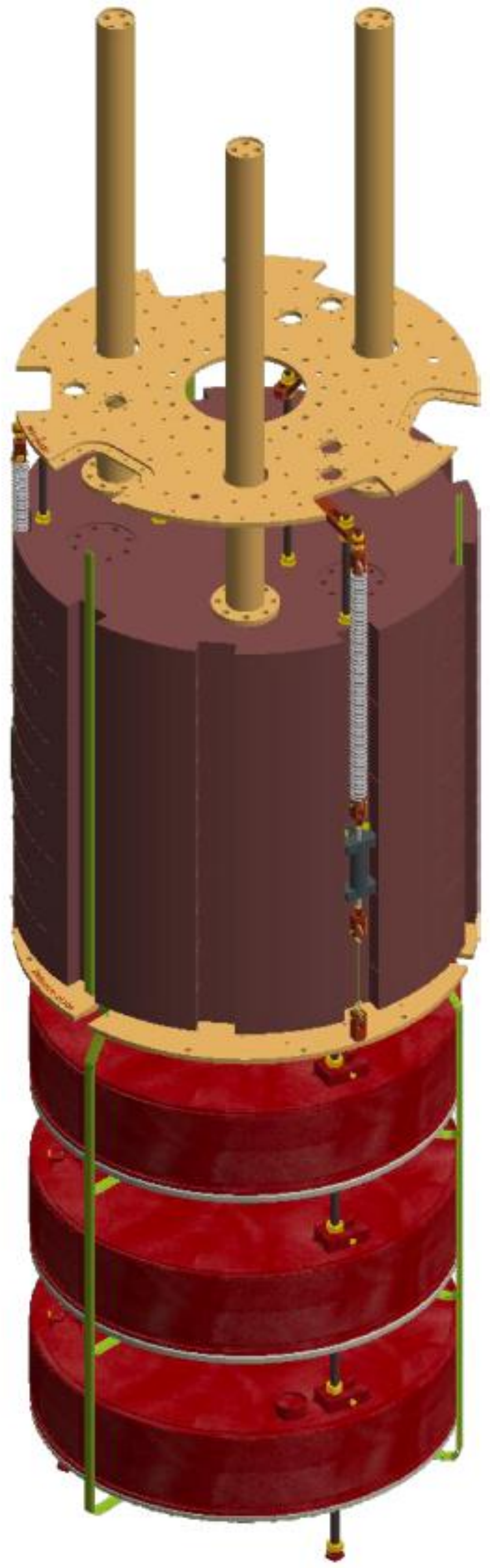


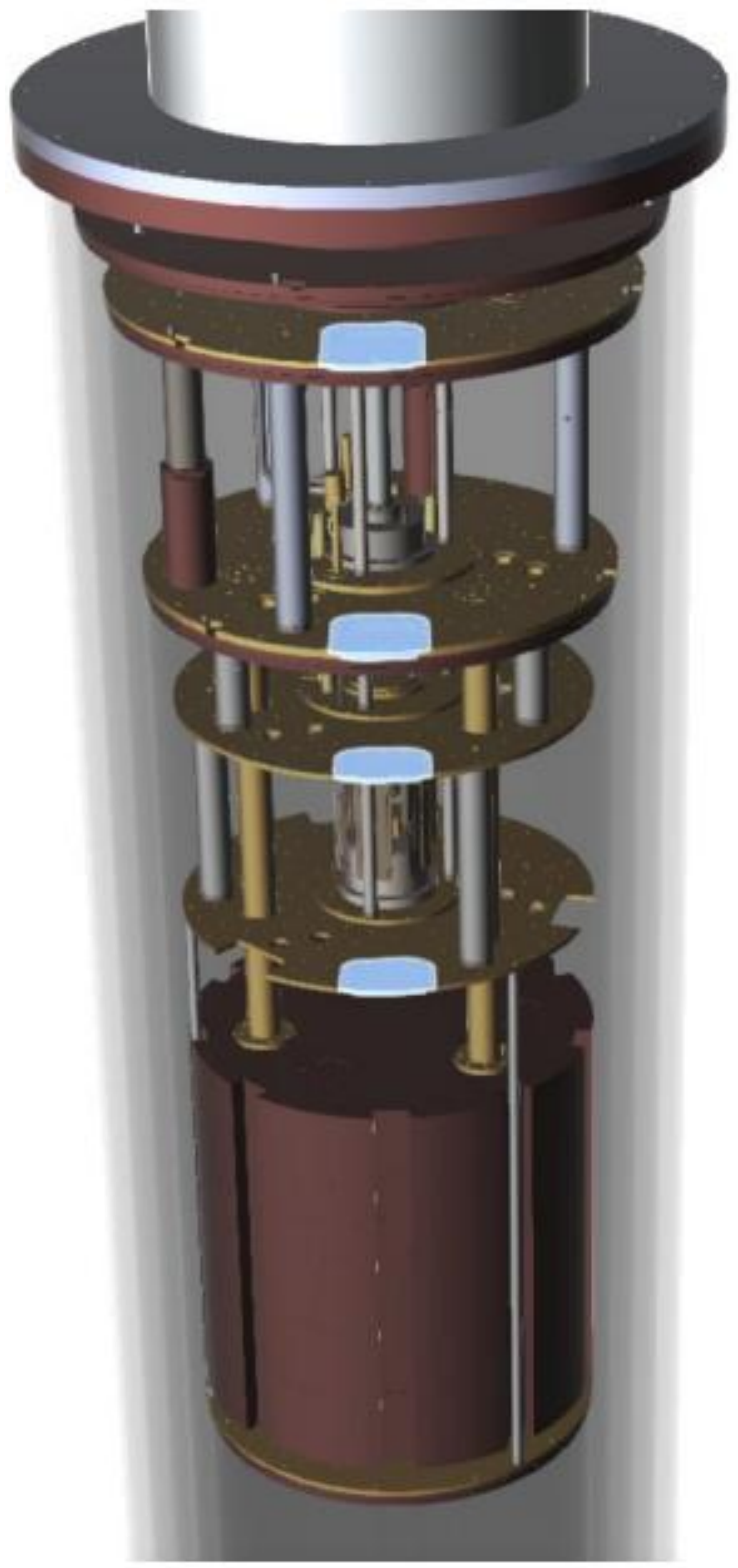
34 g NaI-remoTES

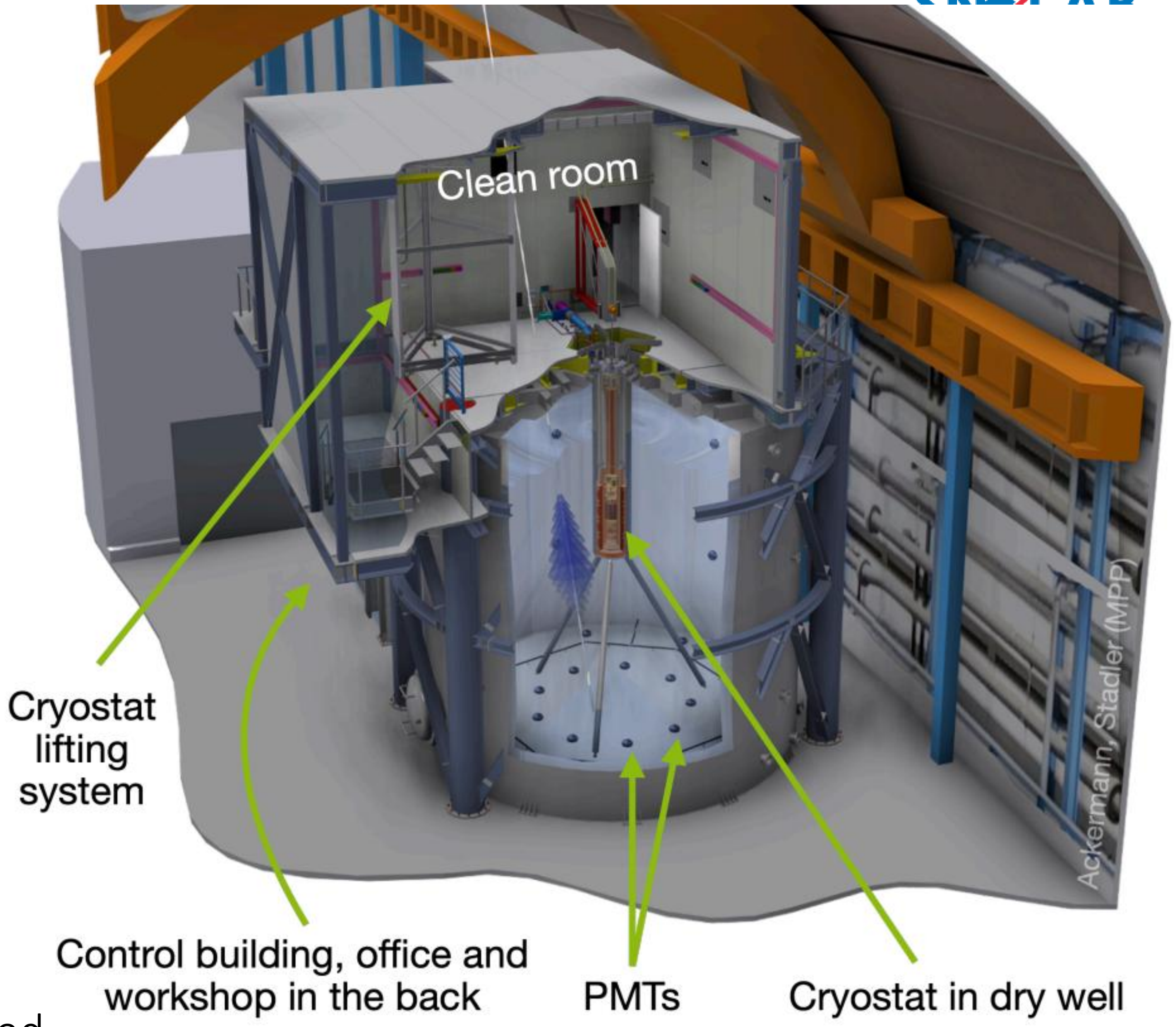
<500 eV

Credit to M. Kellermann

COSINUS – Experimental Setup

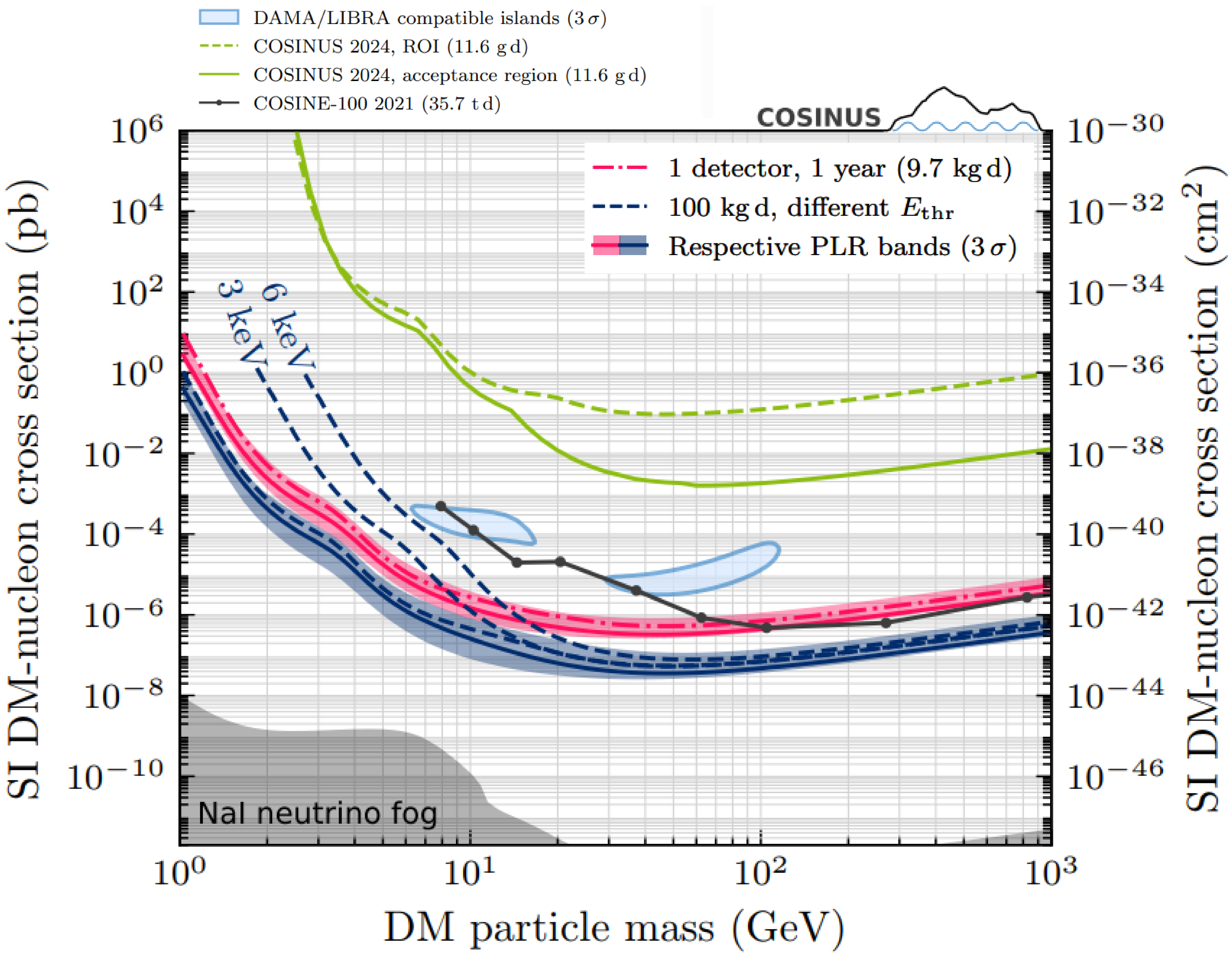






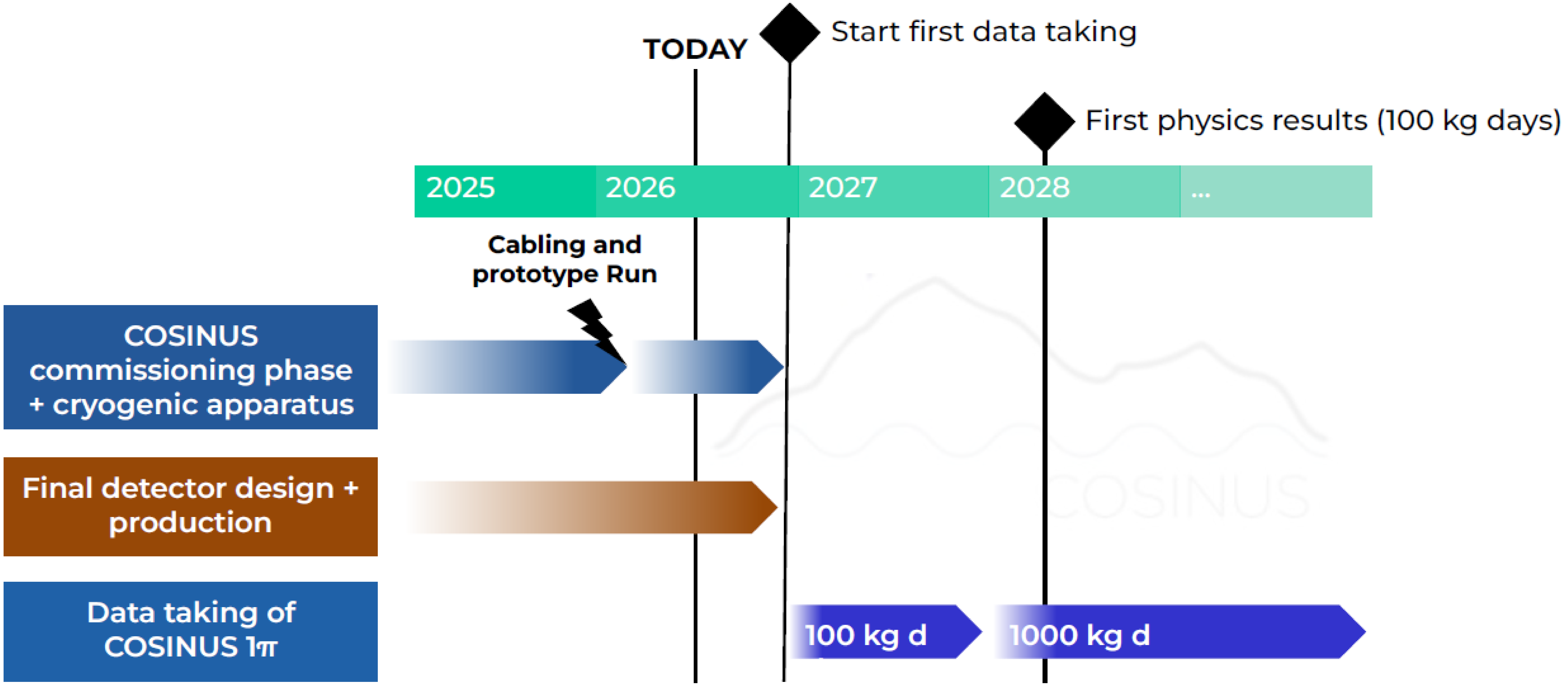
- Detectors housed in a dilution refrigerator (mK)
- Vibration decoupling: Isolated cryostat support stage, spring-based passive decoupling system
- Ultra-pure copper for shielding the detectors from cryostat radiogenics

COSINUS: Physics Reach



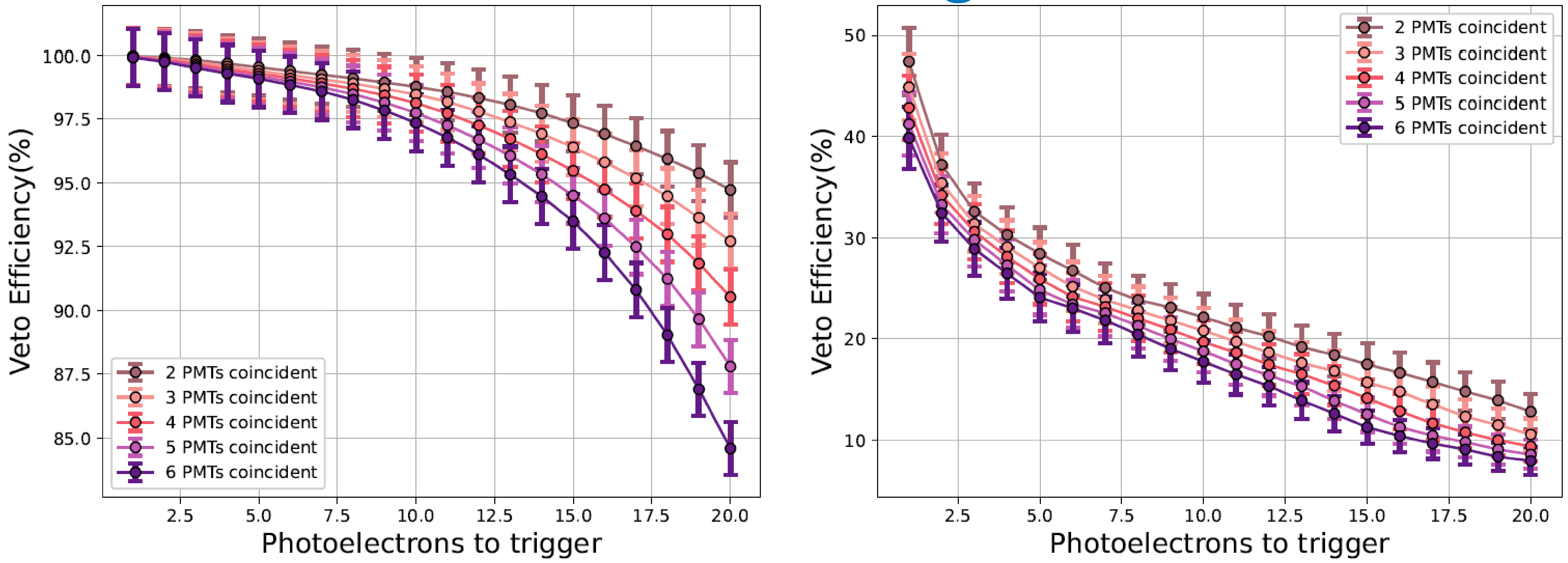
- 1 detector module and one year exposure is enough to exclude the DAMA/LIBRA result in the standard scenario
- Unfolding Paper: https://iopscience.iop.org/article/10.1088/1475-7516/2025/09/072/meta
- A full (3σ) model-independent exclusion of the nuclear recoil origin of the DAMA result can be achieved after <u>~ 300 kg days</u>
- If DAMA signal is confirmed: <u>150 kg days</u> for 5σ confirmation
- COSINUS-1π Run 1
  - 100 kg days
  - 8 modules: 34.8 g each of NaI
- COSINUS-1π Run 2
  - Target exposure 1000 kg days
  - 20 modules: 100g each of NaI

COSINUS: Current Status



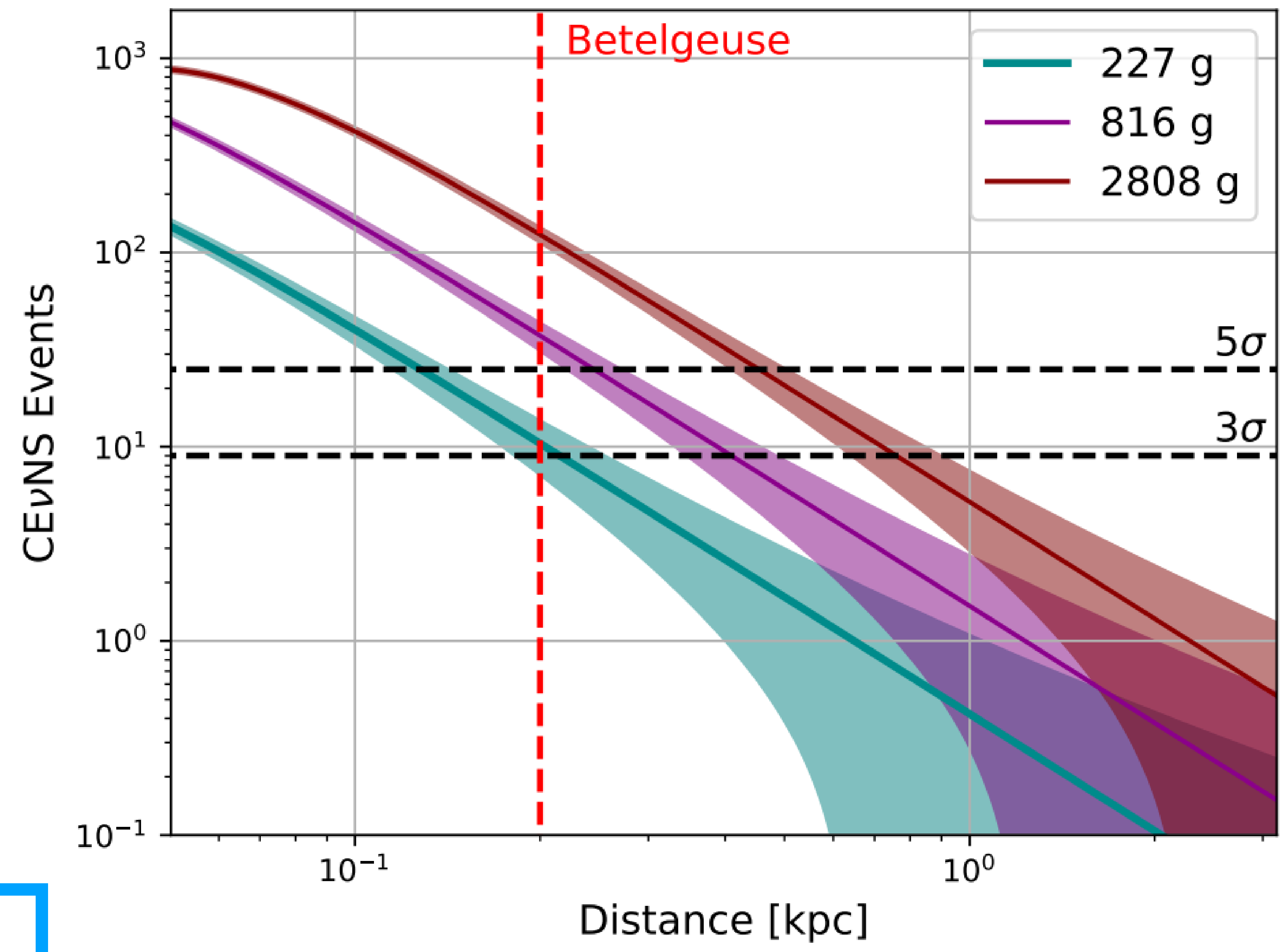
COSINUS: My Contributions

Active Muon Veto Design/Construction



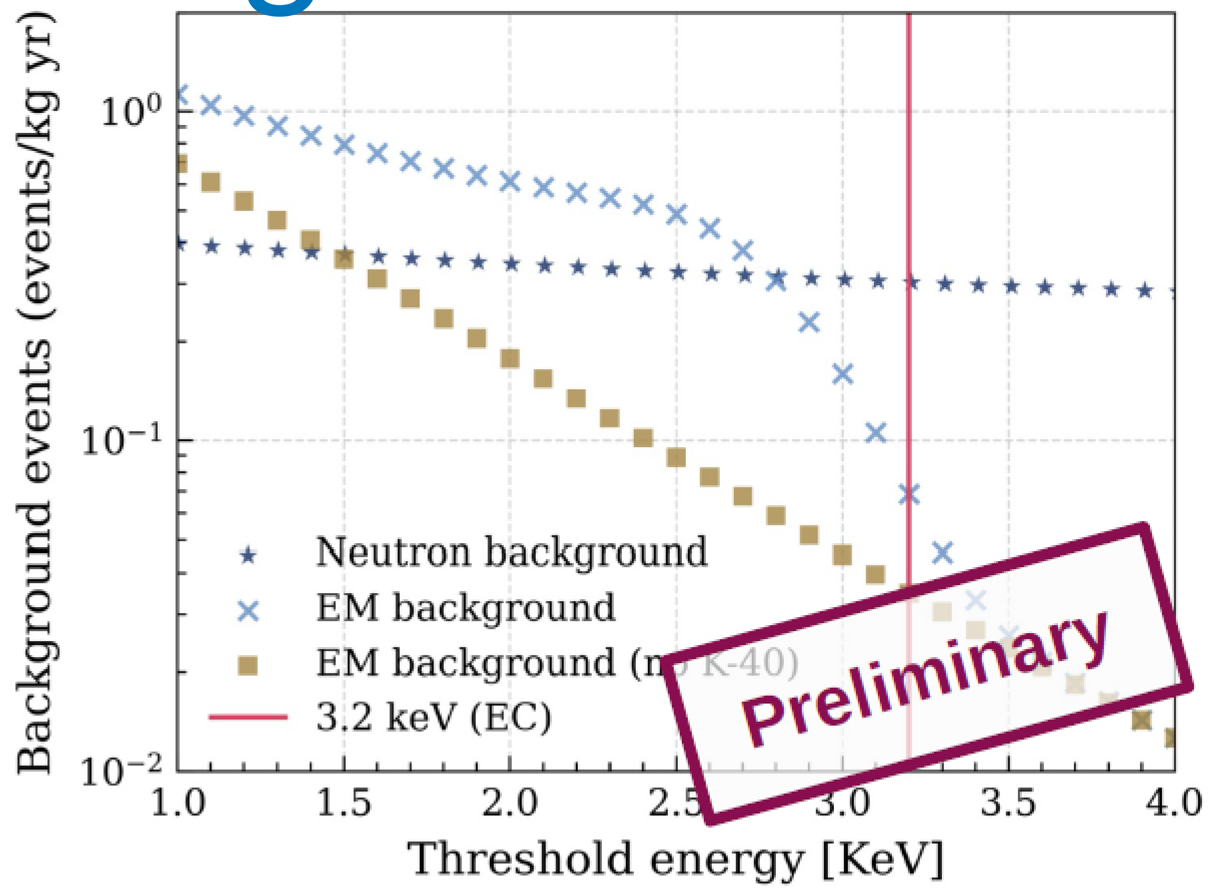
https://doi.org/10.1140/epjc/s10052-024-12923-2

Supernova Studies



https://dx.doi.org/10.1088/1475-7516/2025/03/037

Background Modelling/ Material Screening

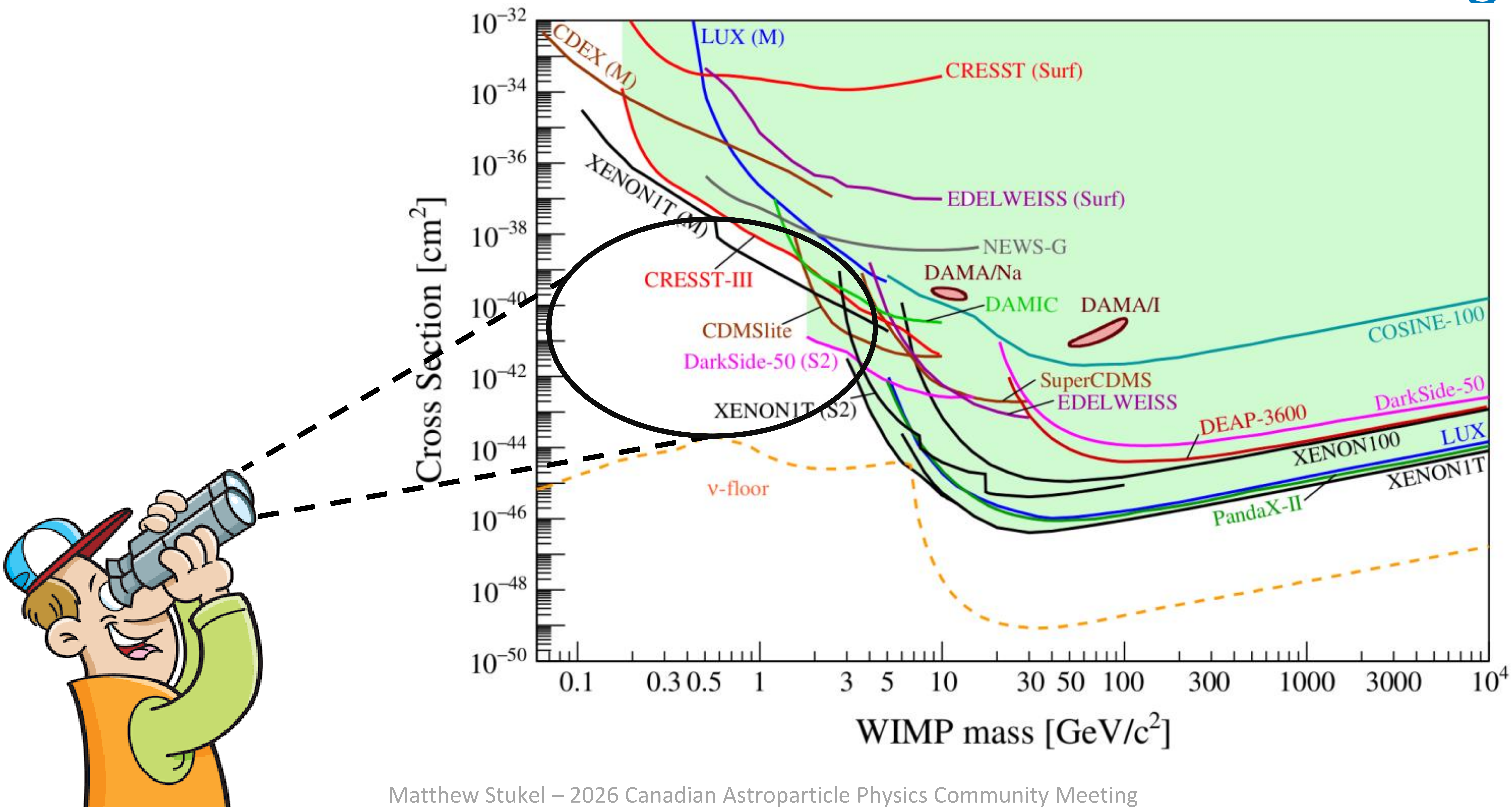


0.21 neutron events kg^{-1} $year^{-1}$ (for 1 keV threshold)

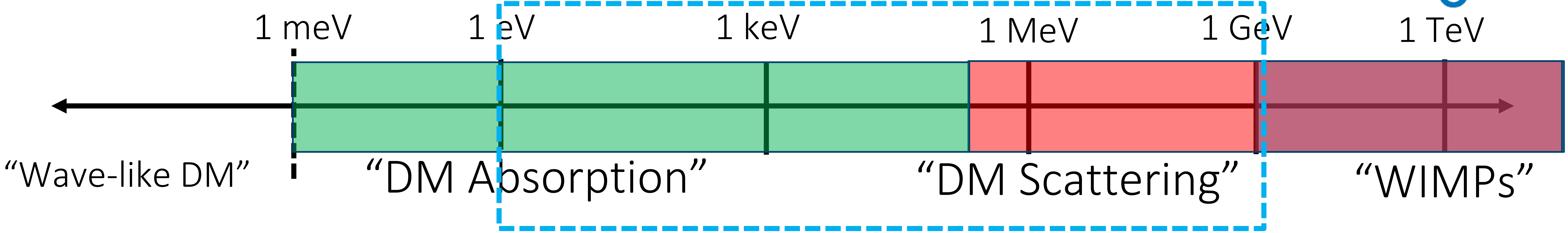
2 orders of magnitude below the DAMA/LIBRA modulation

SuperCDMS SNOLAB

Dark Matter: The Current Search



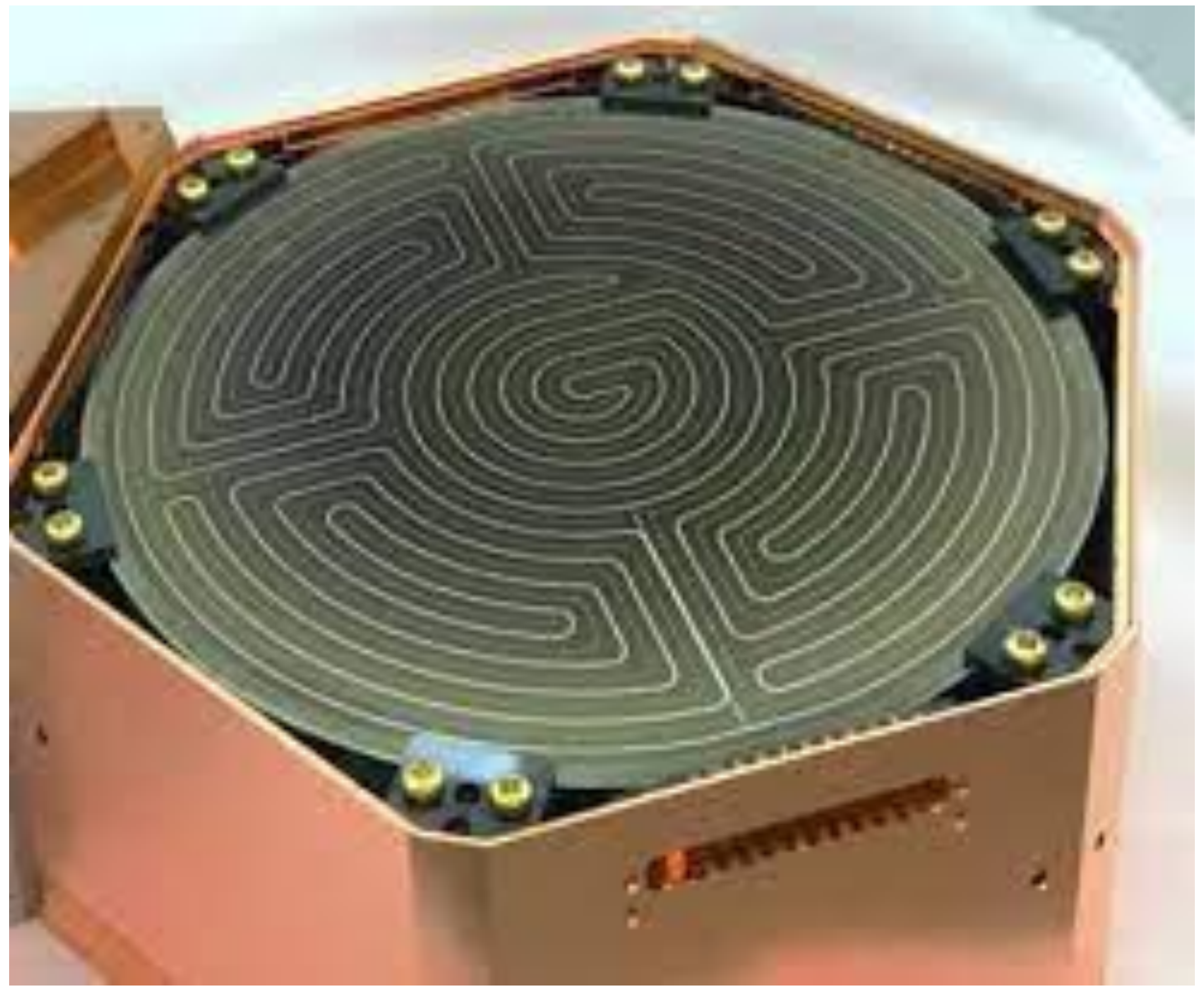
SuperCDMS Objectives



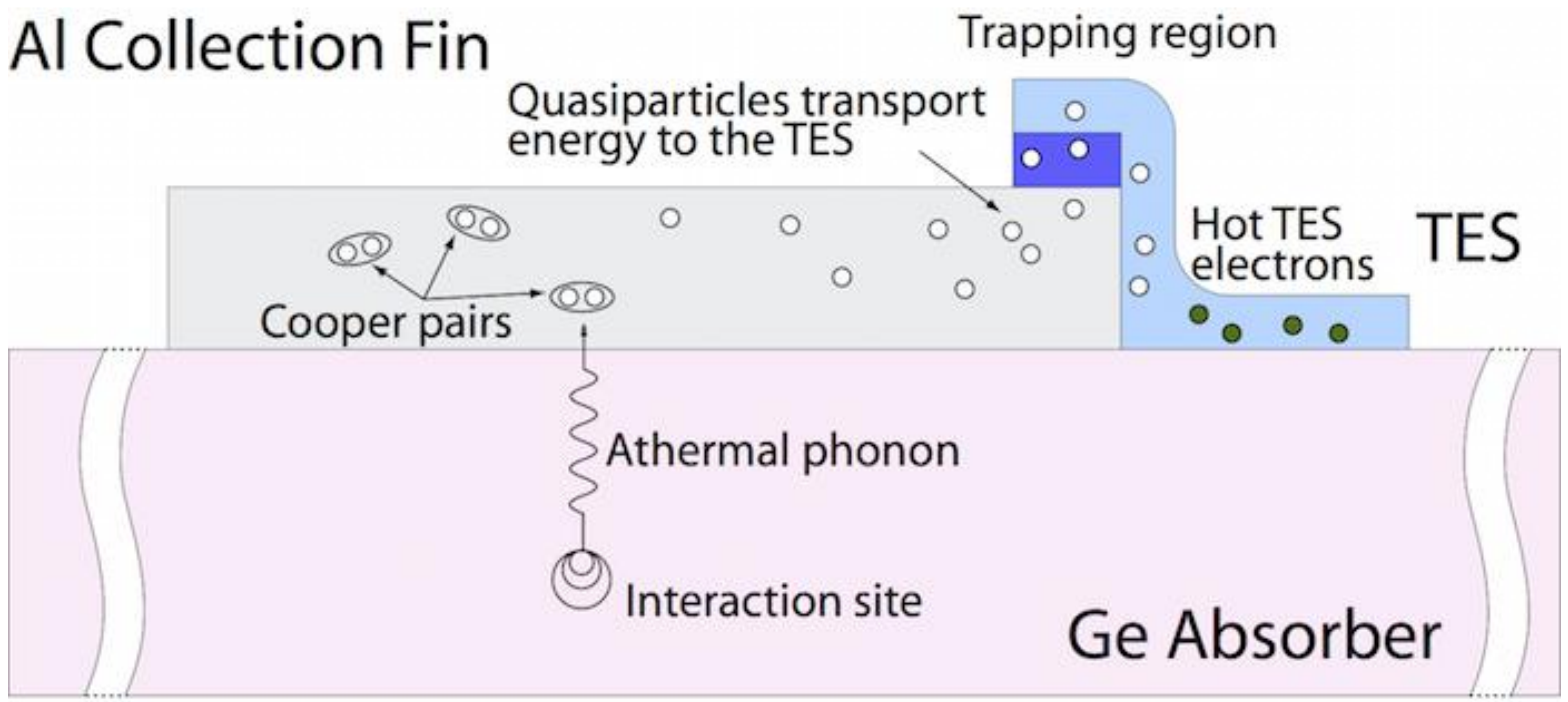
- Uses cryogenic detectors (O(mK)) to search for particle dark matter
- Nucleon coupling: 0.05 – 5 GeV/c^2
- Dark photon-coupled light dark matter: 1 – 100 MeV/c^2
- Dark photon absorption : 1 – 100 eV/ c^2
- Axion-like particles absorption: 1 – 100 eV/ c^2

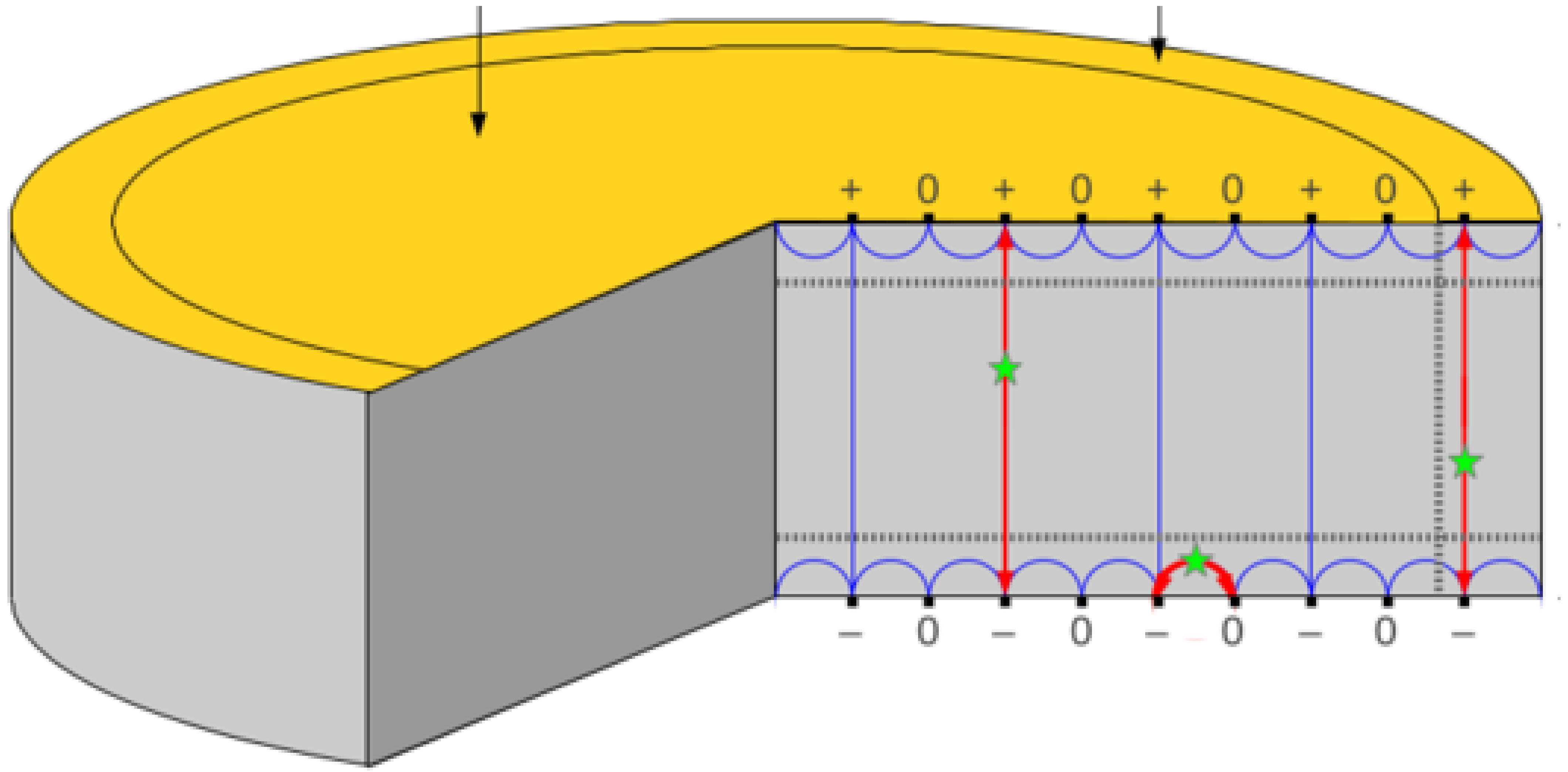
Adapted From: https://indico.cern.ch/event/1188759/contributions/5044015/

SuperCDMS Detectors

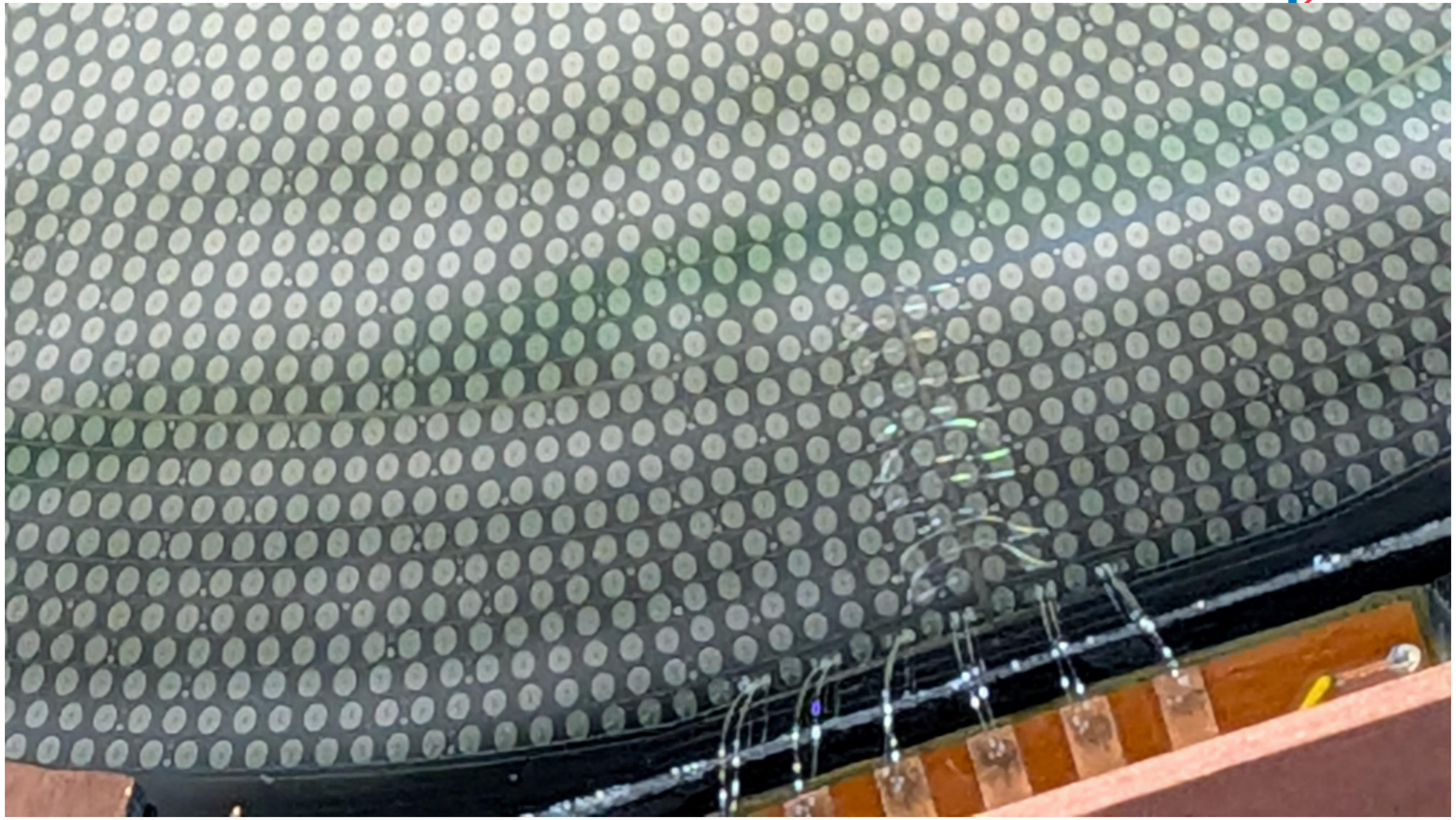


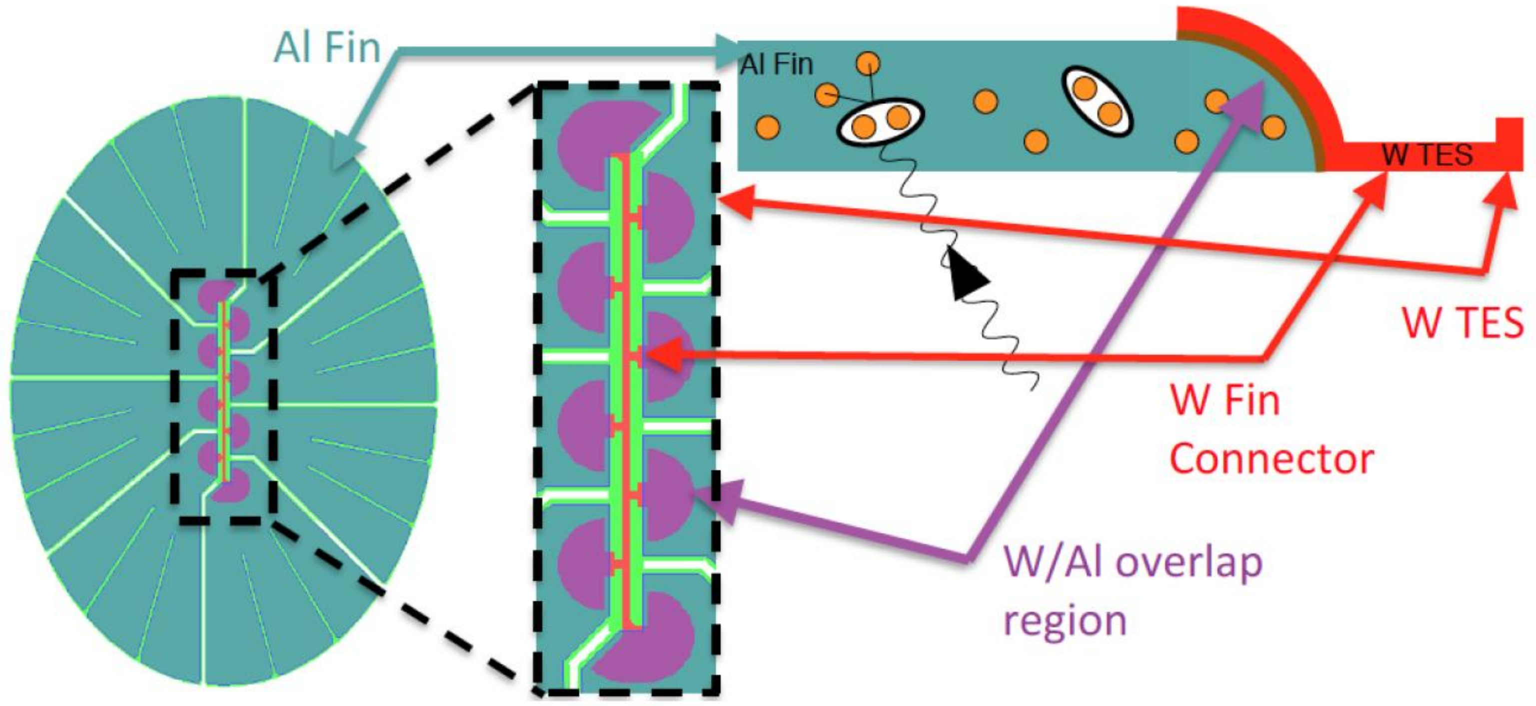
- Upgrade from CDMS and SuperCDMS Soudan (bigger and higher purity)
- Si(0.6 kg)/Ge (1.4 kg) cryogenic detectors
- Measure of <u>**heat (phonon)**</u> and <u>**ionization**</u>
- Heat is measured through Quasi-particle trap assisted electrothermal Feedback Transition Edge sensors (TES)
- Charge is measured through interleaved electrodes



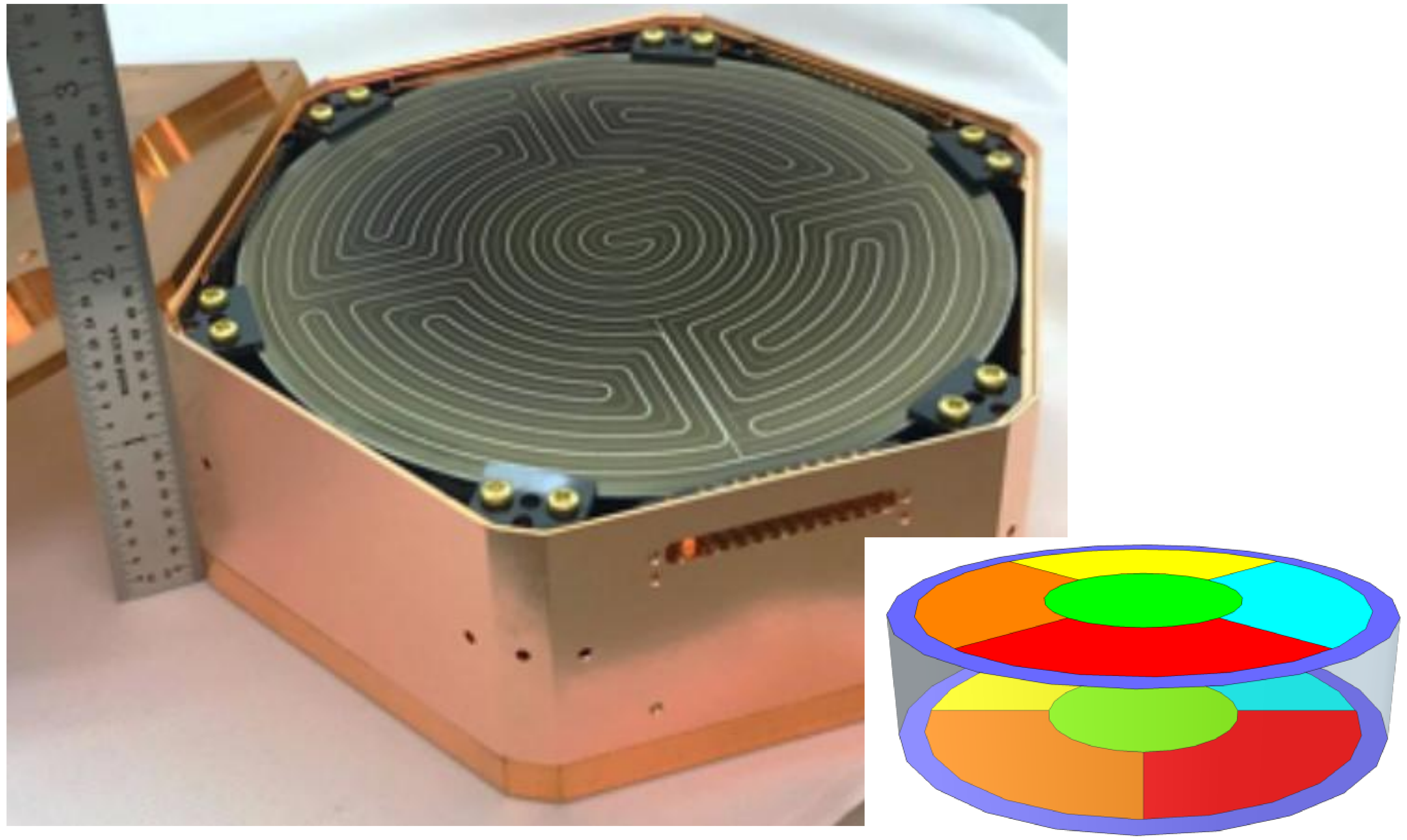


SuperCDMS Detectors up close

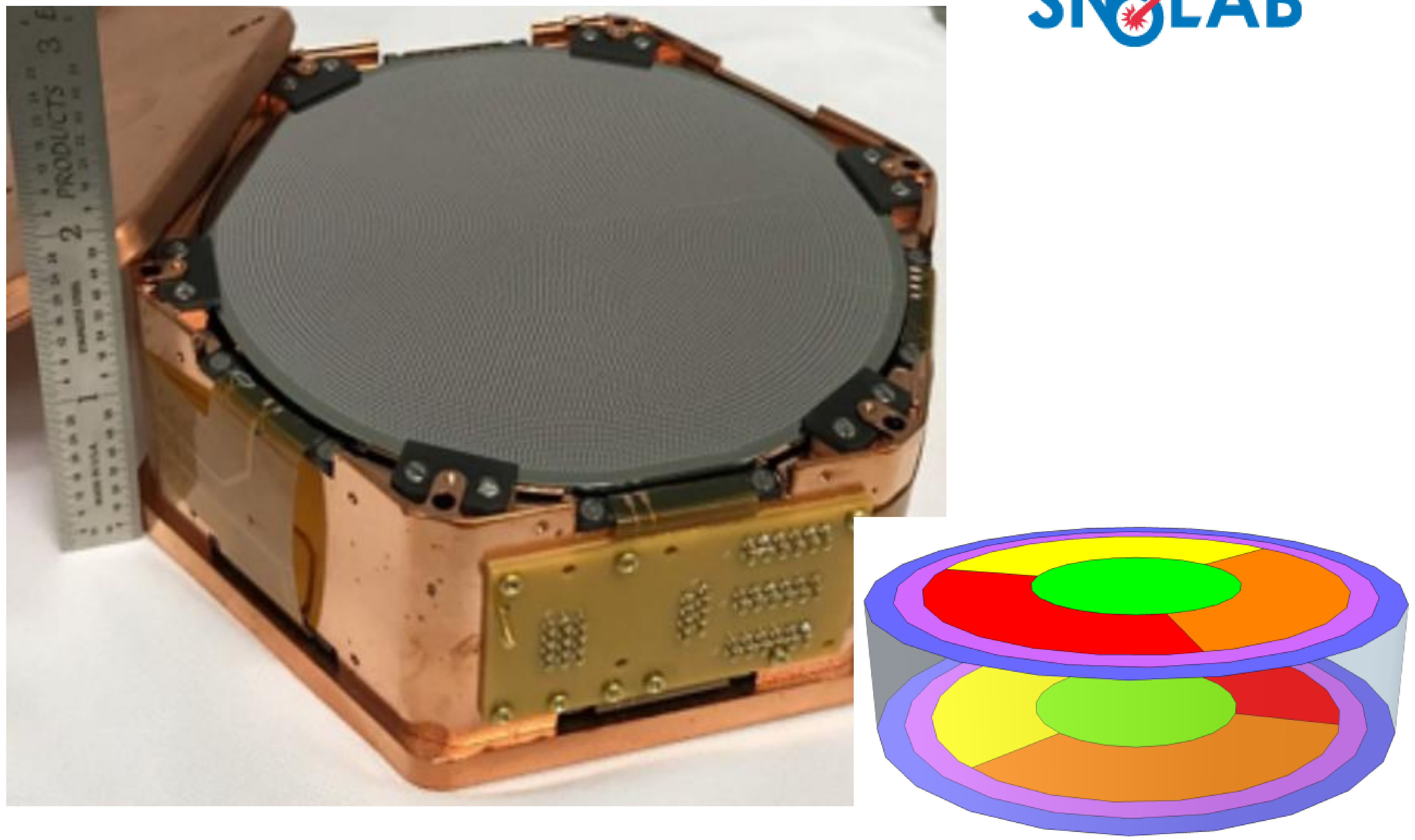




iZIP and HV SuperCDMS Detectors

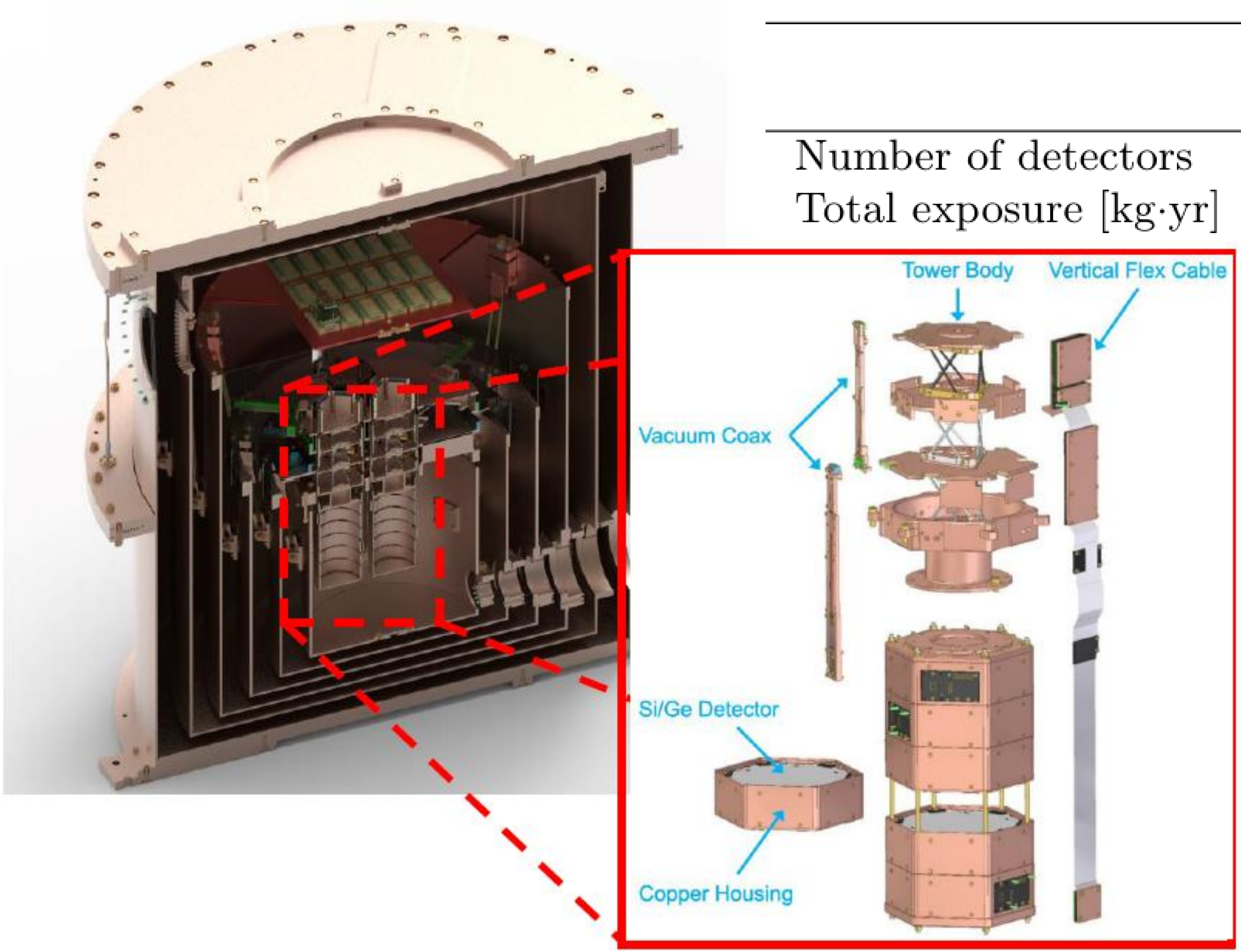


- <u>iZIP</u> (interleaved Z-sensitive Ionization and Phonon detector)
- 12 phonon, 4 charge channels
- Phonon and ionization channel allow for particle discrimination ER vs. NR

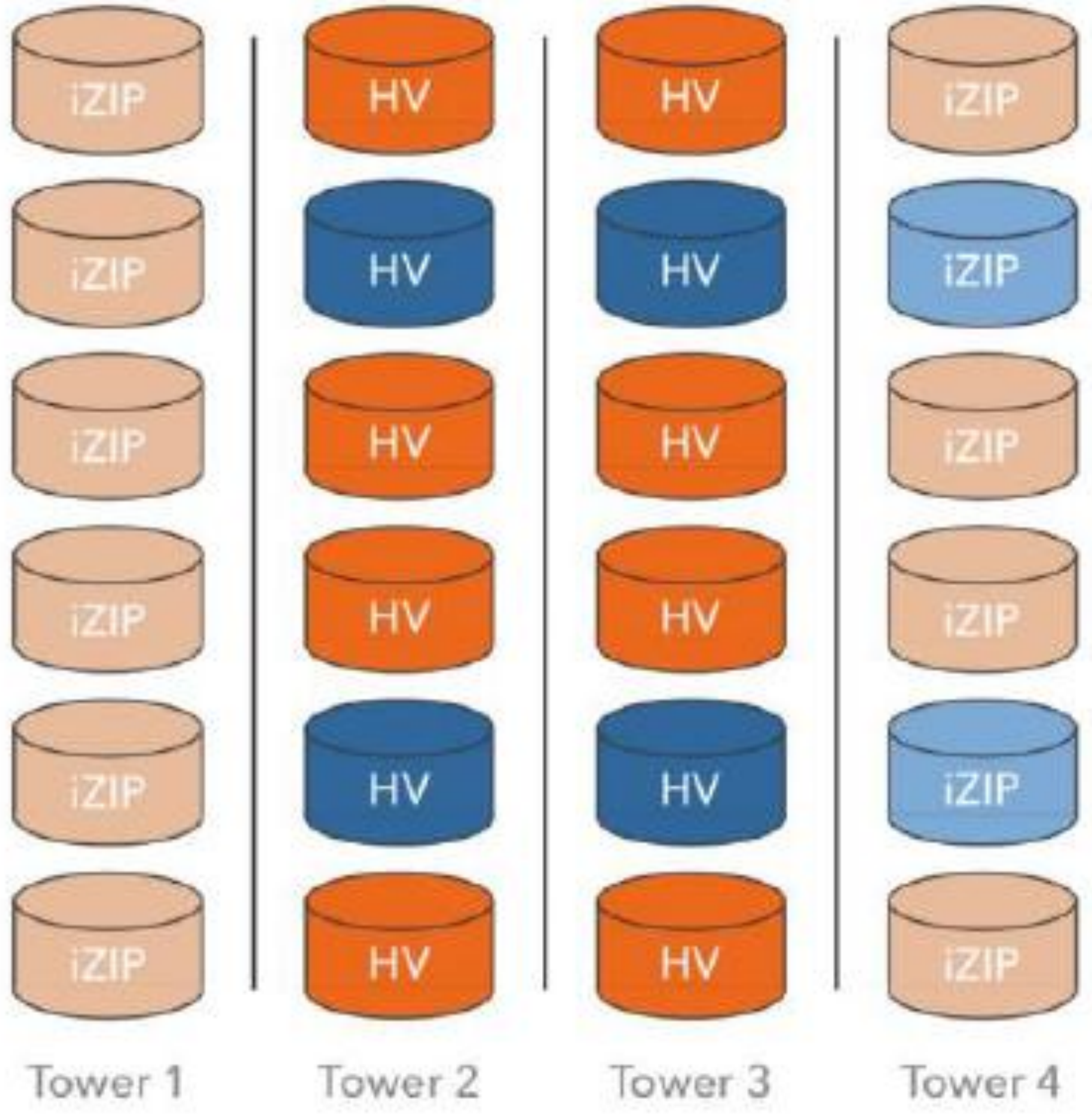


- <u>HV</u> (High Voltage detector)
- 12 phonon channels
- 100 V across the detector to exploit the Neganov-Trofimov-Luke <u>(NTL)</u> Effect

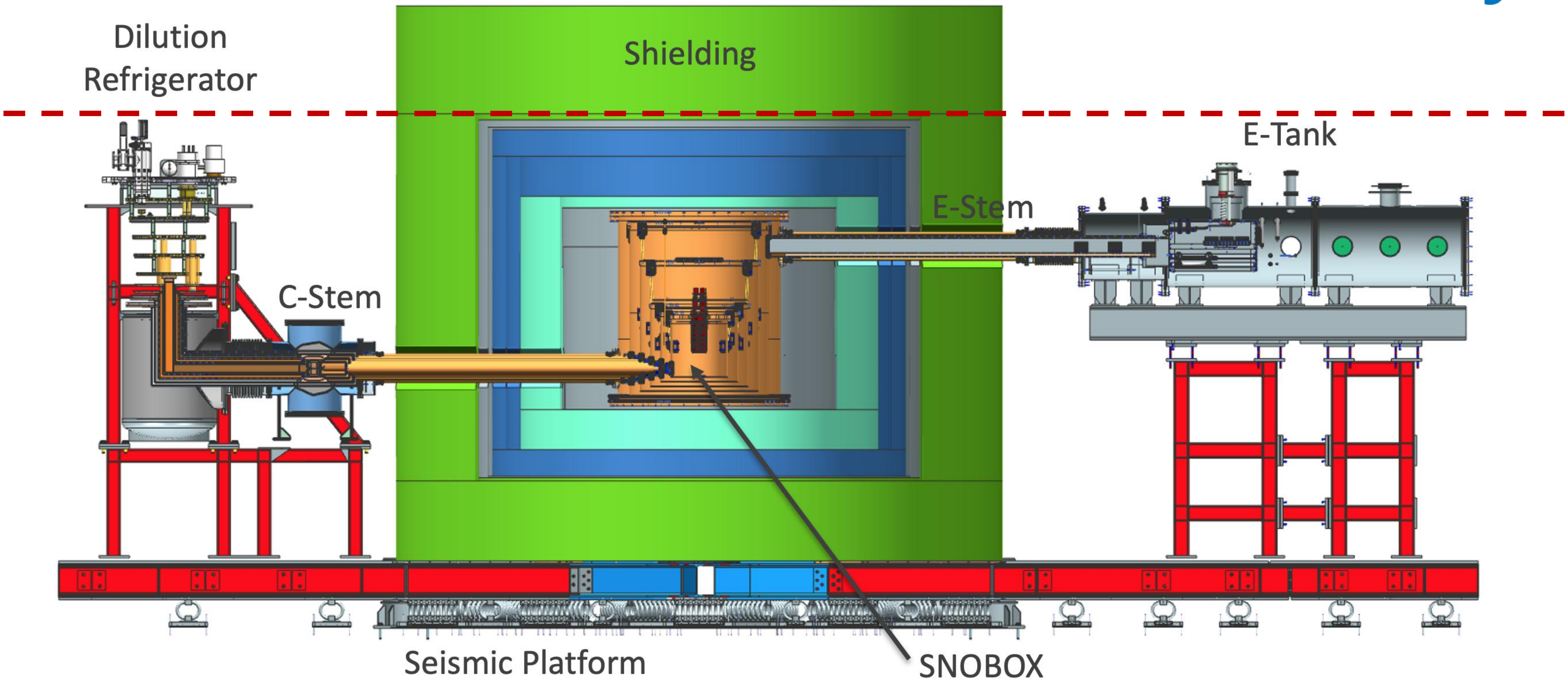
iZIP and HV SuperCDMS Detectors



	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure [kg·yr]	45	3.9	36	7.8



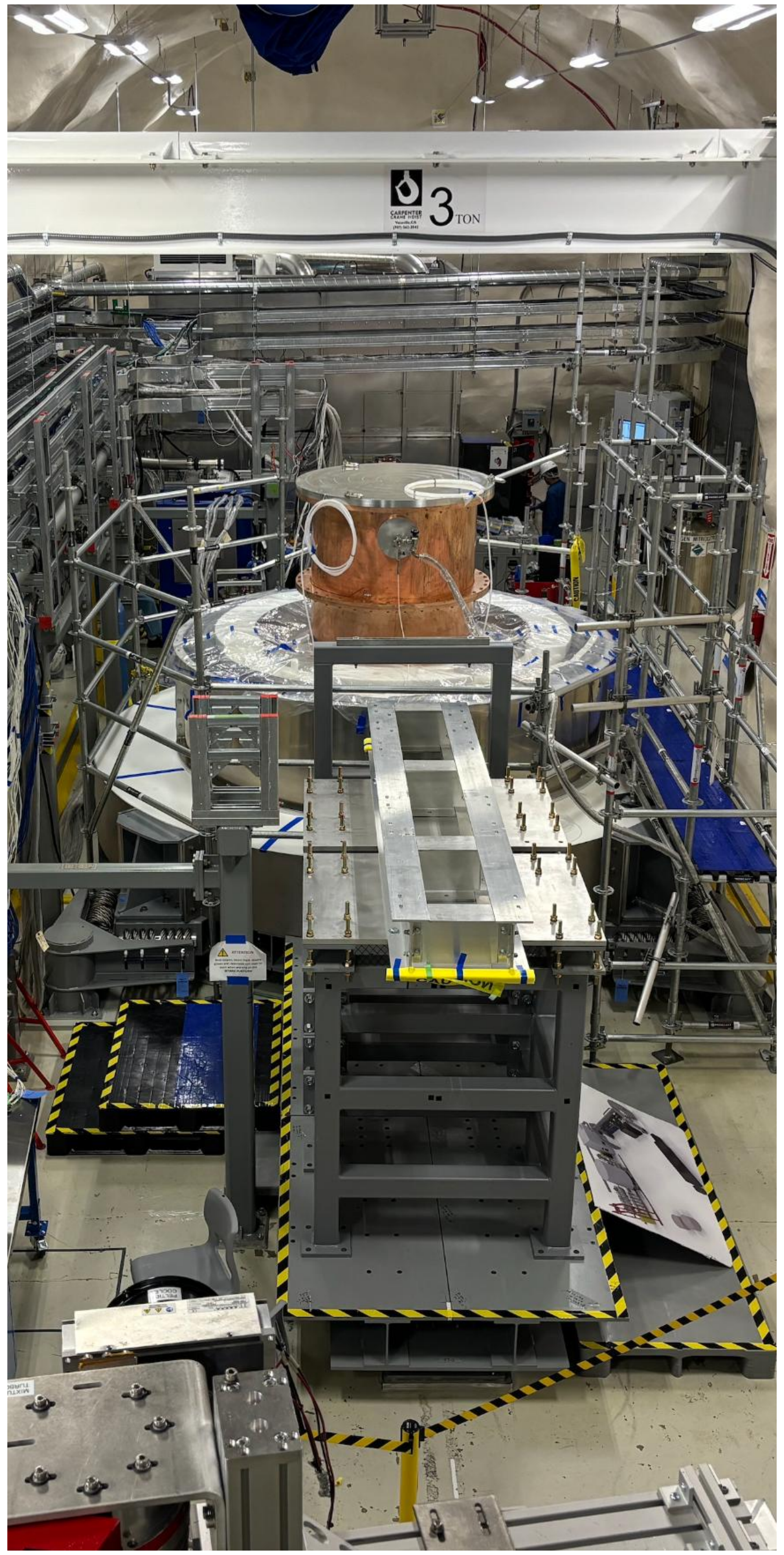
SuperCDMS Experimental Setup



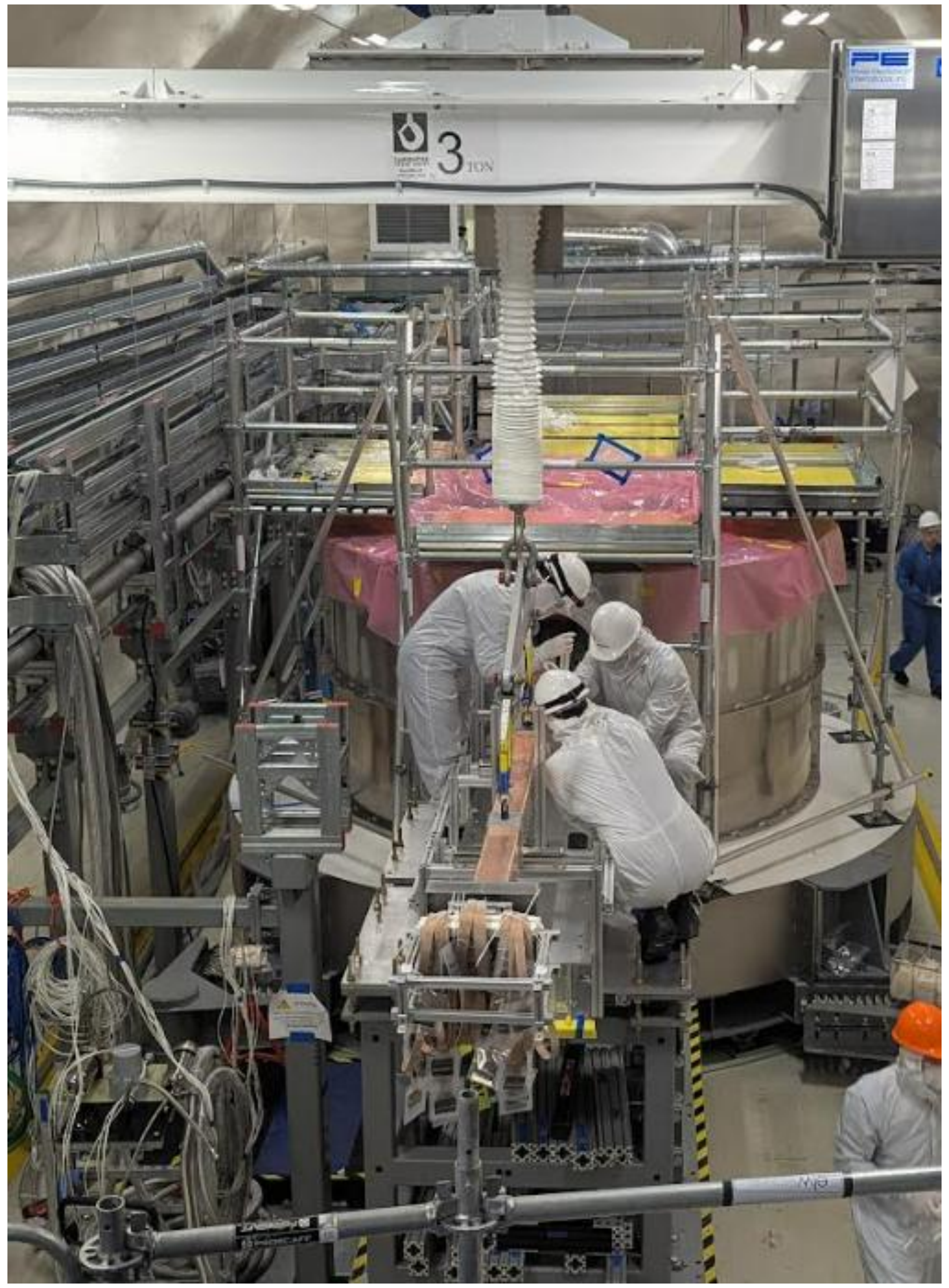
Current Construction

2022

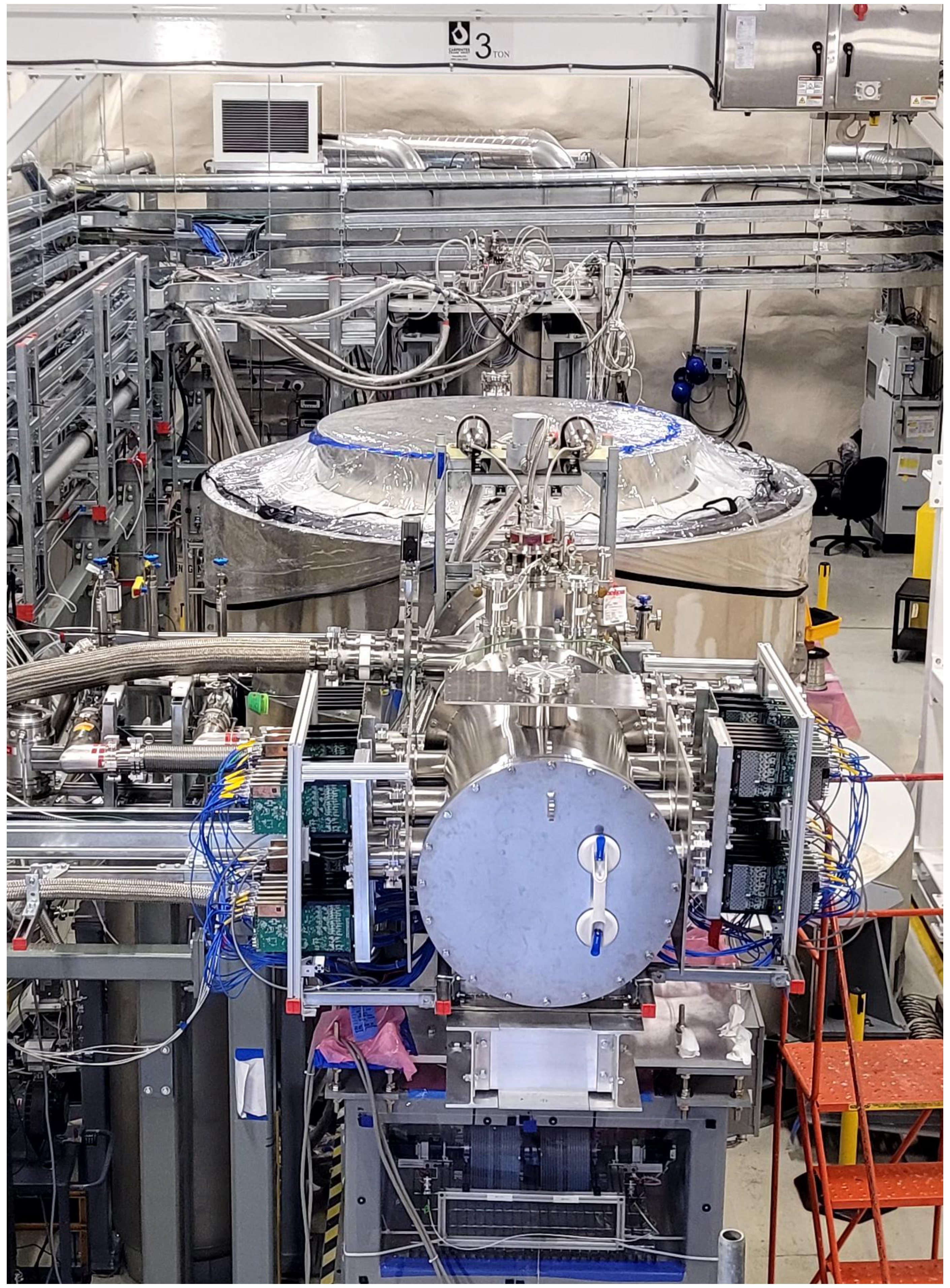
2024



May 2025



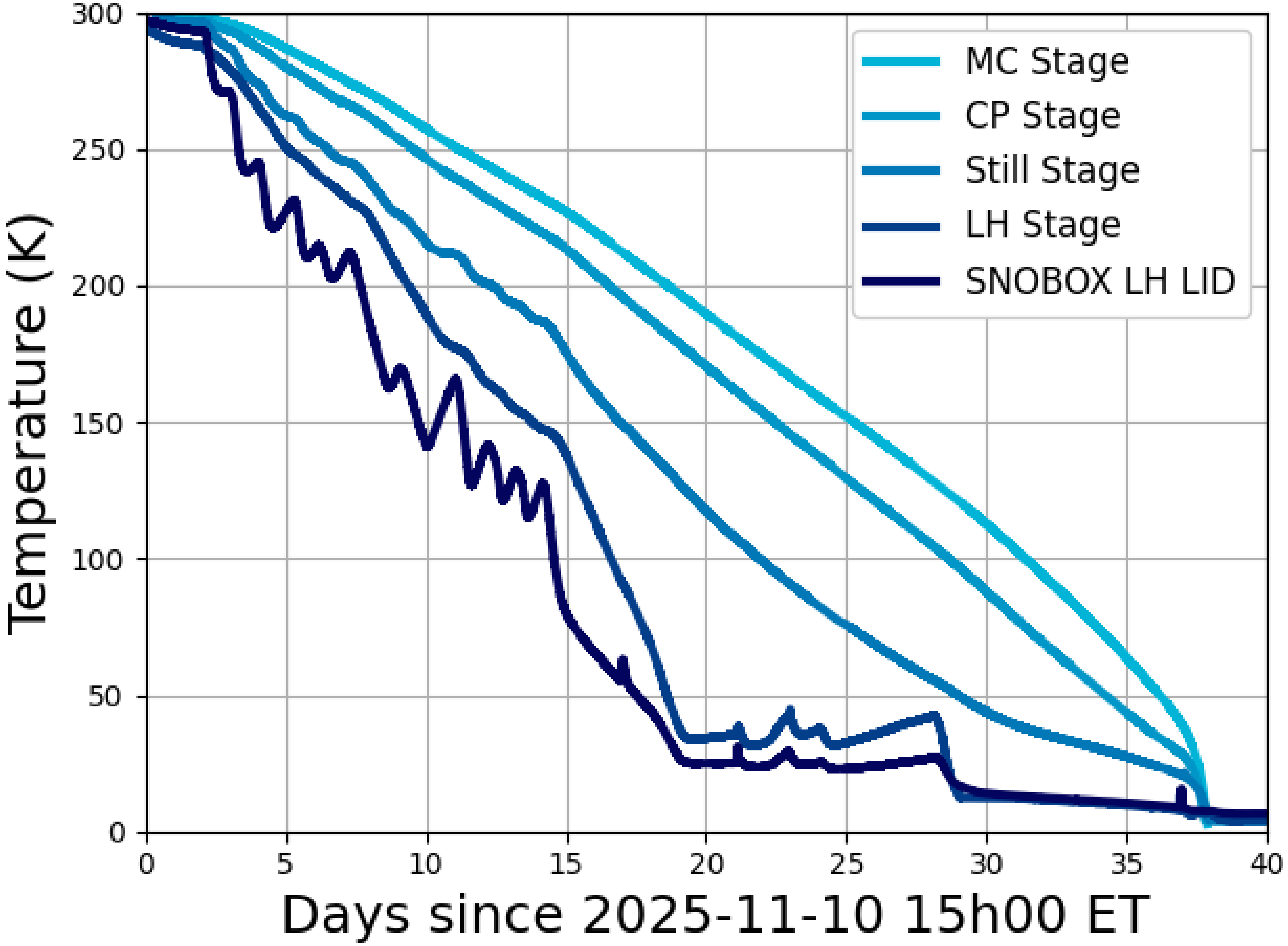
Feb. 2026



First cooldown and commissioning began this Winter!!!

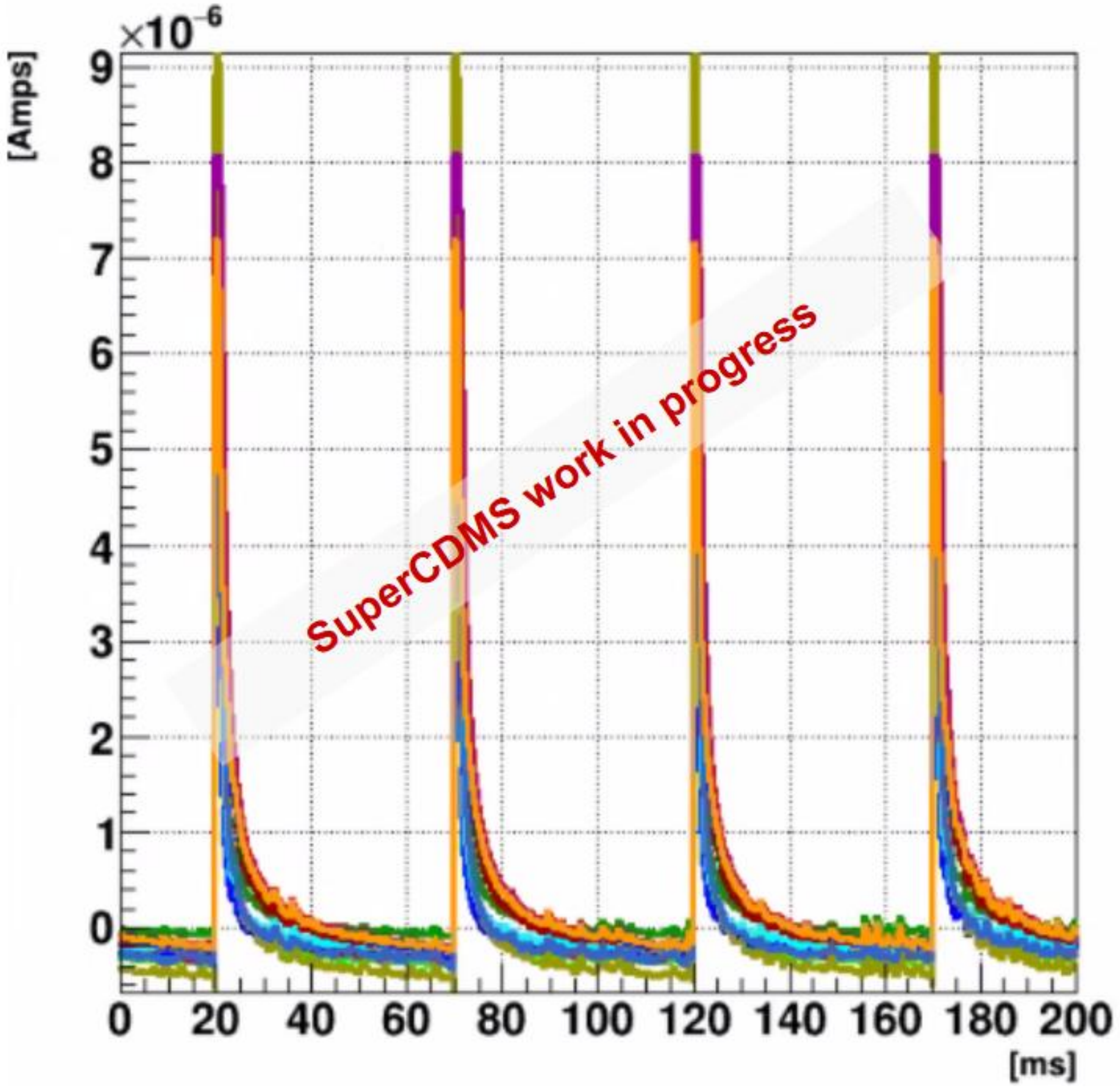
Current Construction: July 2026

SuperCDMS Cooldown (Sept. 2025-Jan. 2026)



- Currently operating detectors!!!
- Commissioning ~8 months
  - Detector characterization, calibration, noise hunting+++
- Cooldown to operating temperature took > 60 days
- <u>**First run has begun!**</u>

SuperCDMS Commissioning Begins!



- Ge HV LED pulses

SNOLAB

SNOLAB officially becomes one of the coolest places on Earth

March 17, 2026 — Astrophysics News

Deep underground in Sudbury's SNOLAB, a major new experiment has just reached a critical milestone. The very centre of a series of large, nested copper vessels that make up the heart of the newest and one of the most sensitive detectors in the world has now reached a temperature a hundred times colder than outer space.

Universe Today

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SuperCDM Experiment Reaches Critical Temperature, Bringing it One Step Closer to Detecting Dark Matter

By Matthew Williams - April 07, 2026 10:07 PM UTC | Physics

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Chilly SNOLAB experiment reaches near absolute zero

The experiment is part of Super Cryogenic Dark Matter Search, a project aimed at finding the sub-atomic particle believed to comprise up to 85 per cent of the mass of the univers

Sudbury.com Staff
Mar 19, 2026 8:00 PM

PHYS.ORG

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MARCH 18, 2026

Dark matter experiment reaches ultracold milestone

by Amanda Morris, Northwestern University

edited by Lisa Lock, reviewed by Andrew Zinin

Editors' notes

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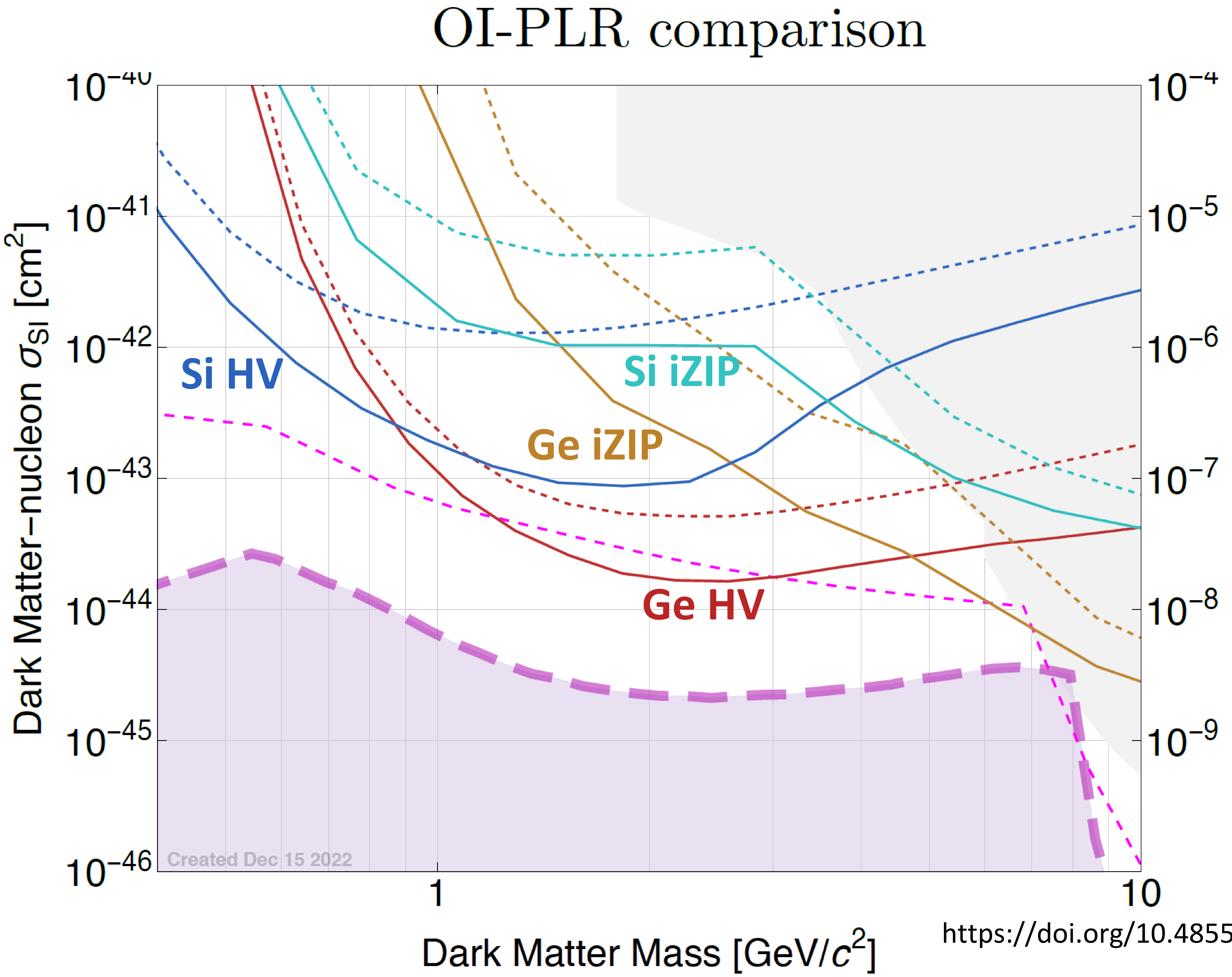
SuperCDMS NRDM Sensitivity



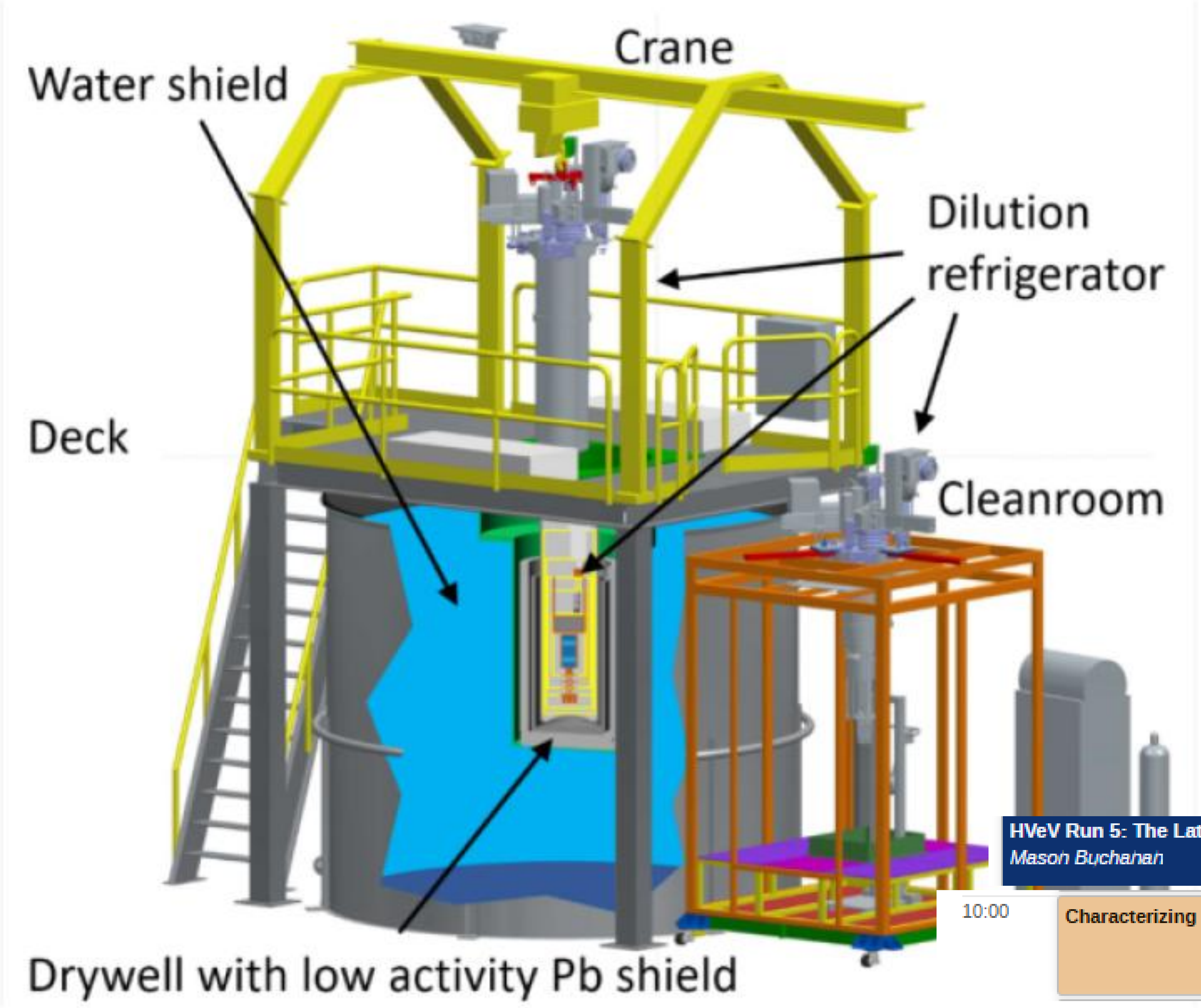
- 90% C.L. exclusion sensitivity using the optimal interval (dashed) and profile likelihood ratio (solid)
- Uses current estimate for detector performance and backgrounds
  - 4-year exposure

	iZIP Ge	iZIP Si	HV Ge	HV Si
Number of detectors	10	2	8	4
Total exposure [kg·yr]	45	3.9	36	7.8
Phonon resolution [eV]	33	19	34	13
Ionization resolution [eV$_{ee}$]	160	180	–	–
Voltage Bias $(V_+ - V_-)$ [V]	6	8	100	100

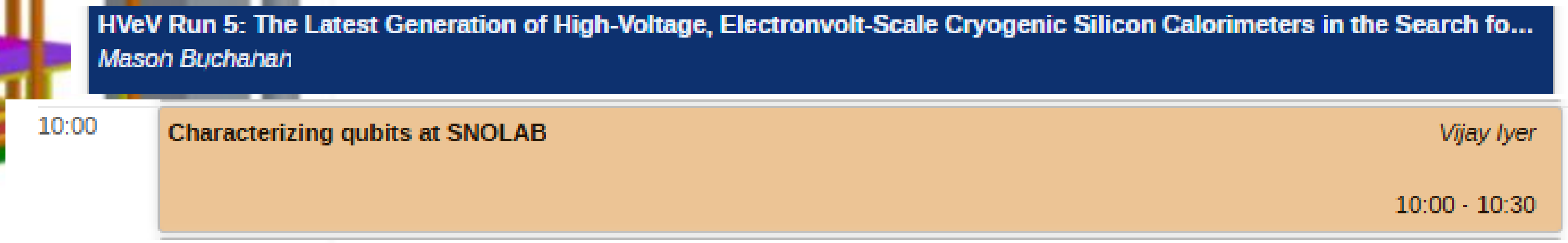
https://doi.org/10.48550/arXiv.2203.08463

SuperCDMS Detector Testing

Testing at the CUTE Facility

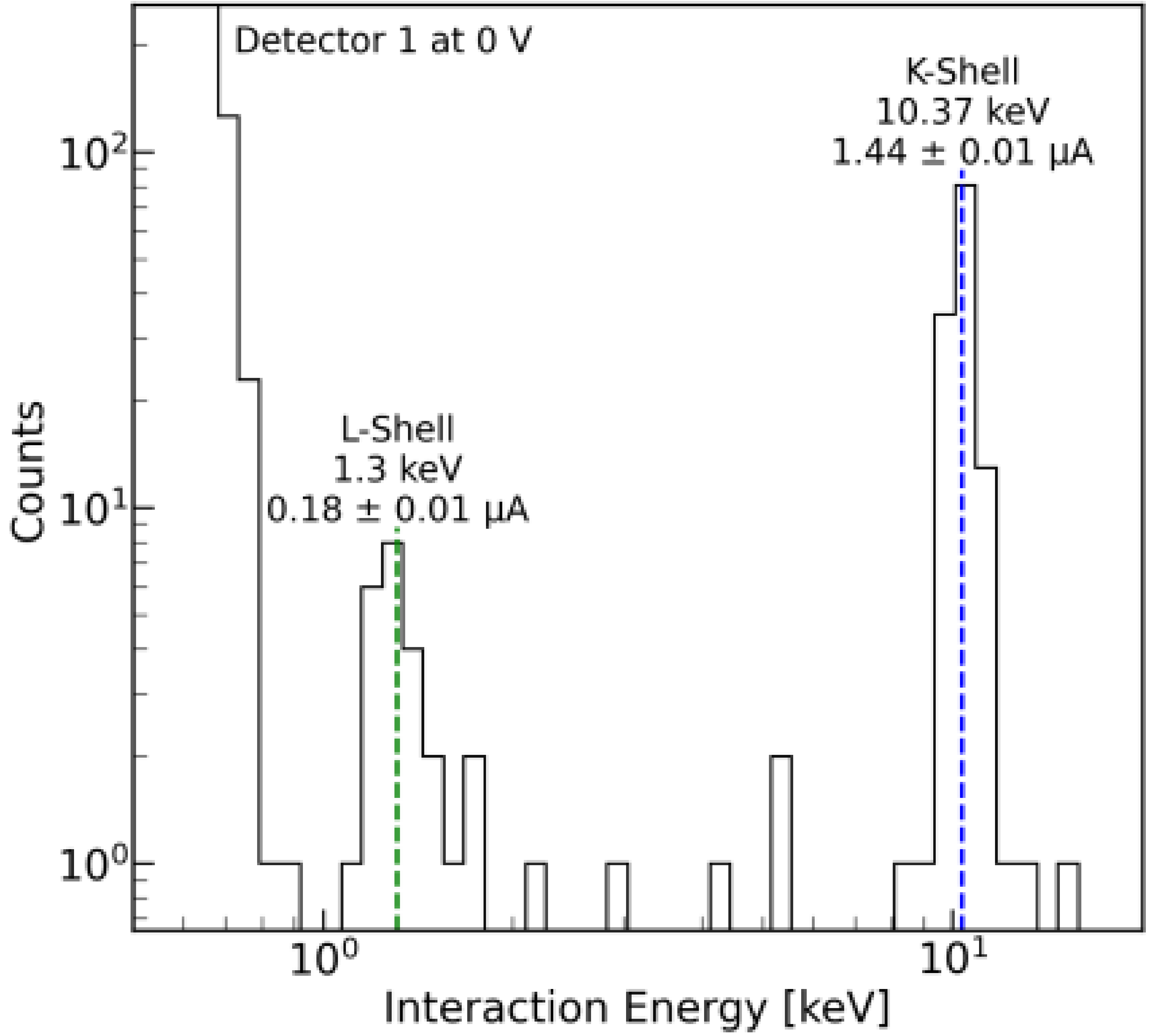


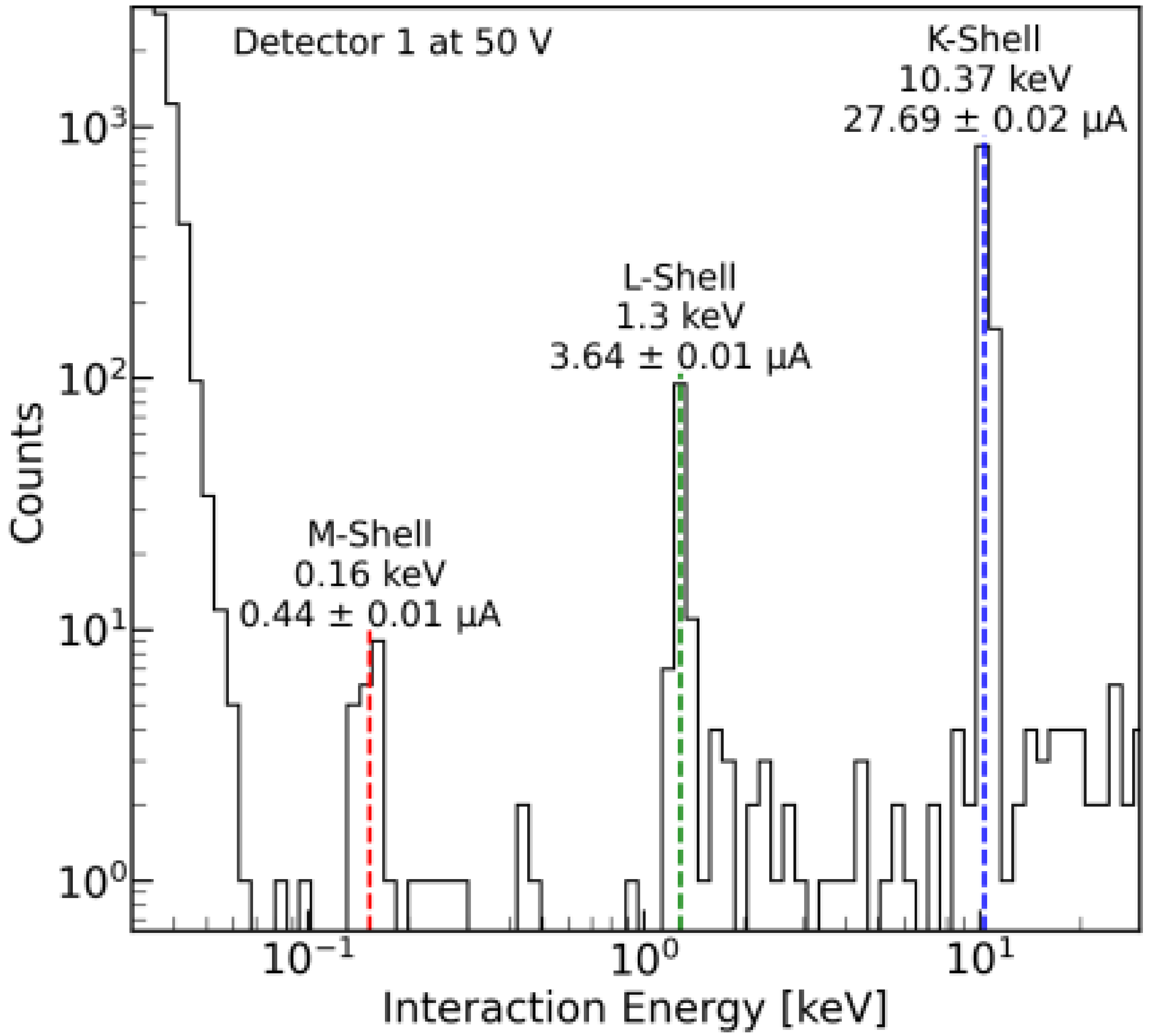
- Cryogenic Underground TEsting Facility
- One full SuperCDMS HV tower (6 detectors) was placed into CUTE and operated for ~6 months
- Allowed for detector characterization
- Email: cute_ proposals @ snolab. ca



Ge Detector Calibration I

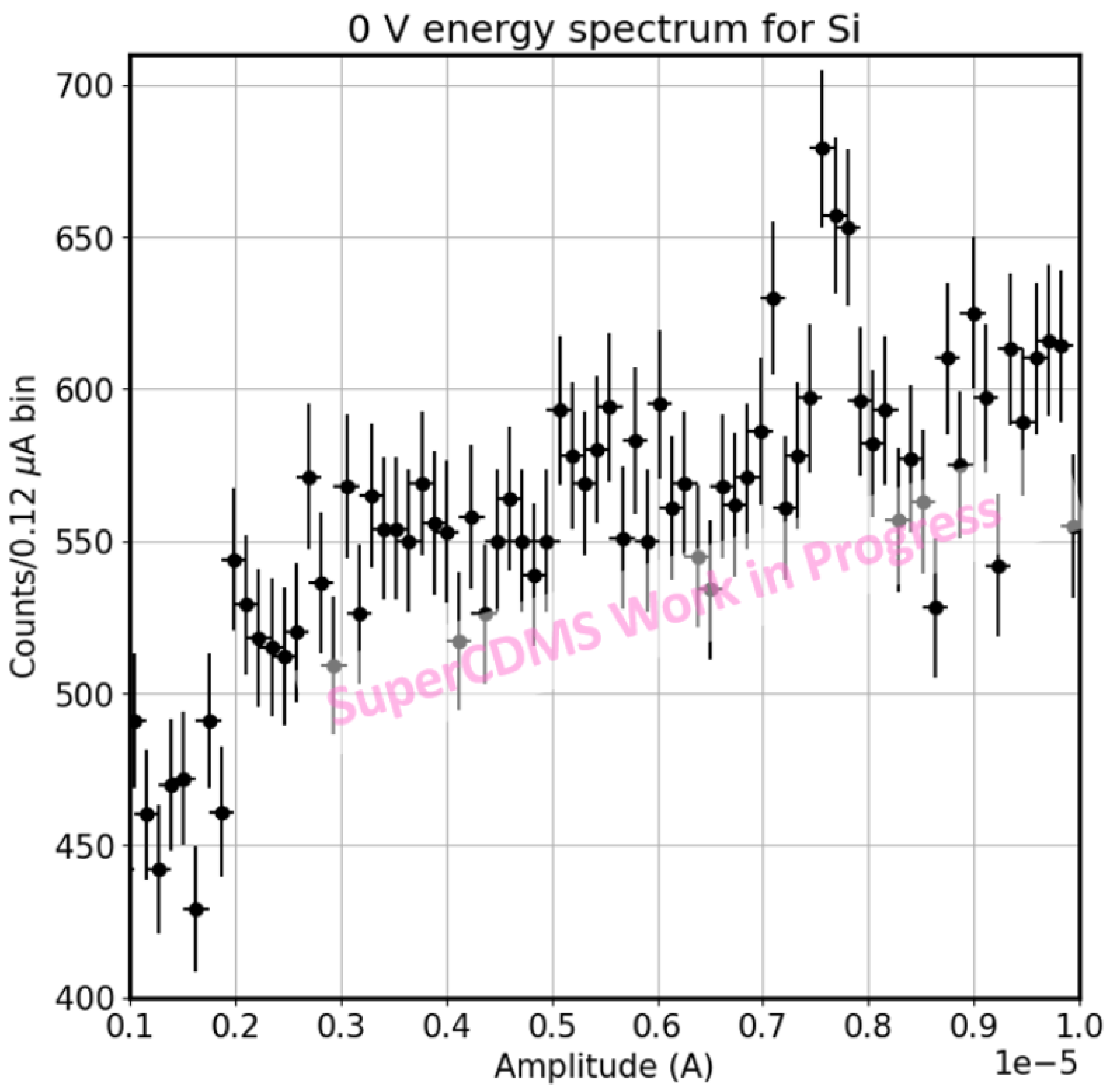
https://arxiv.org/abs/2606.26391



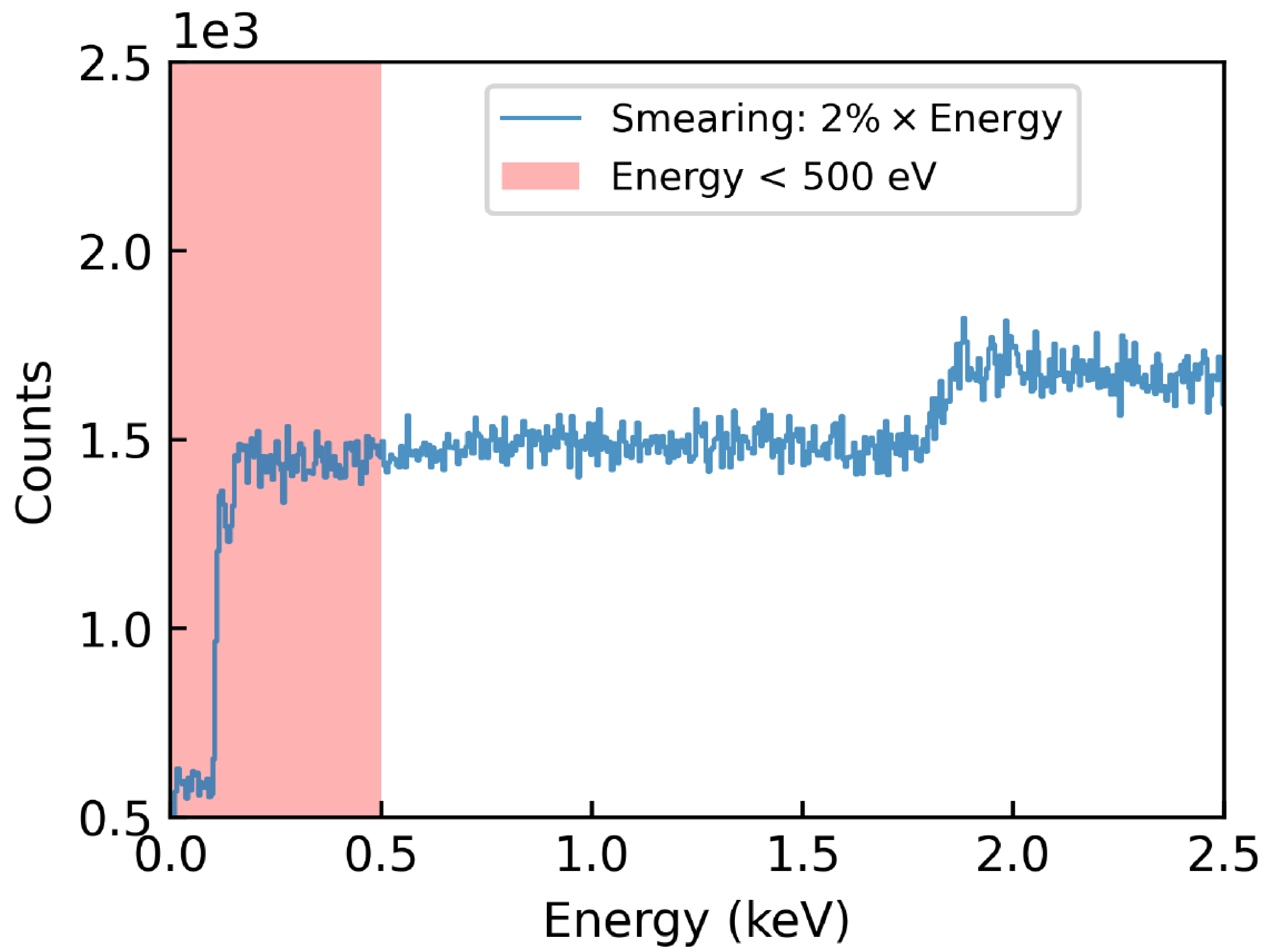


- Cf-252 neutron capture on Ge-70 -> leads to EC of Ge-71
- **Z1:** 89.2 ± 0.7 eV, **Z3:** 80.2 ± 1.0 eV, **Z6:** 167 ± 14.0

Si Detector Calibration



- Compton scattering will produce visible "steps" at K, L and M shell energy levels
- K-Shell: 1.8 keV
- Cu fluorescence peak ~8.1 keV



https://arxiv.org/abs/2508.02402

R&D: RAMPS/LUCE, LMO

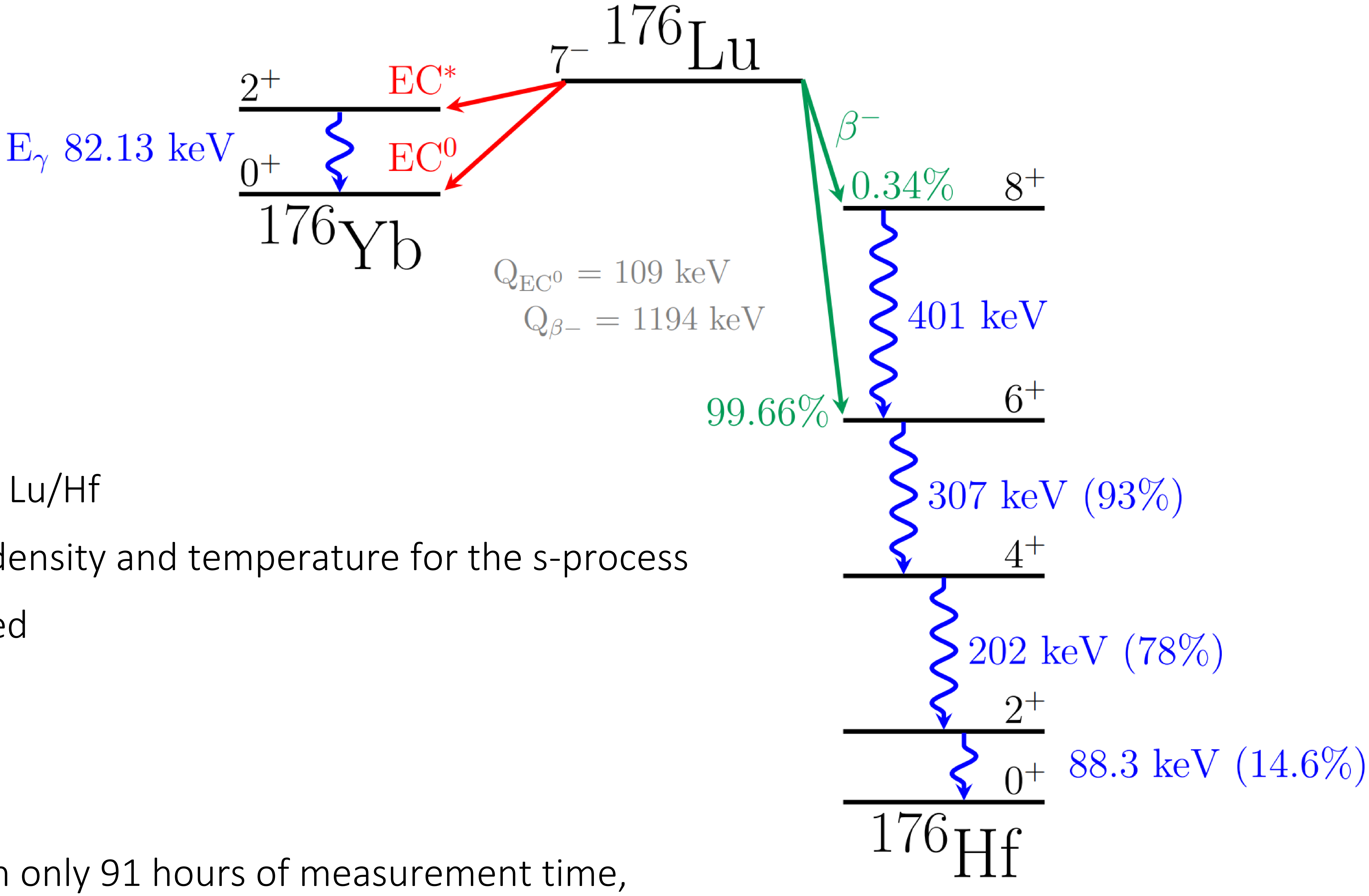
SNOLAB

AMPS

(RadioActive isotope Measurement Program at SNOLAB)

- GOAL: Perform novel, precision or standardization measurement of long-lived (highly forbidden) isotopes using or enhancing existing equipment at SNOLAB

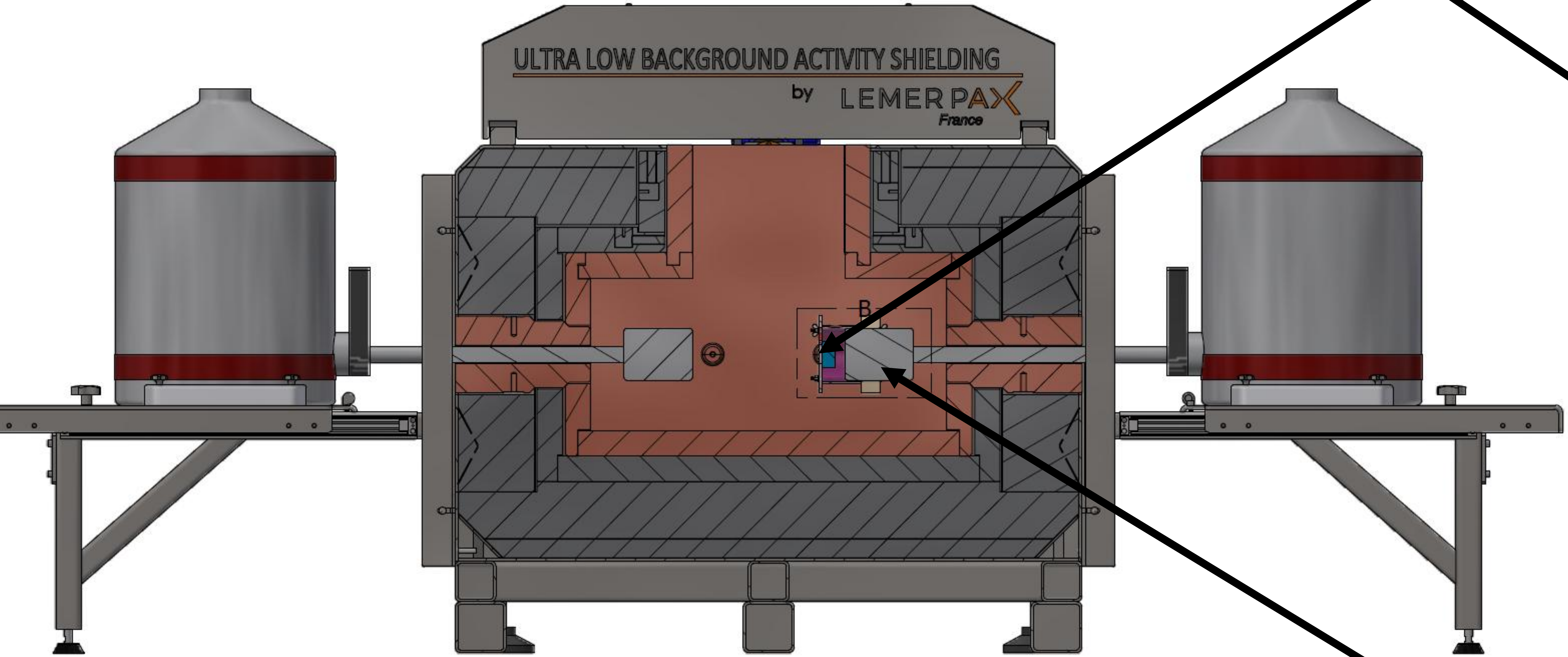
Measurement of EC ^{176}Lu

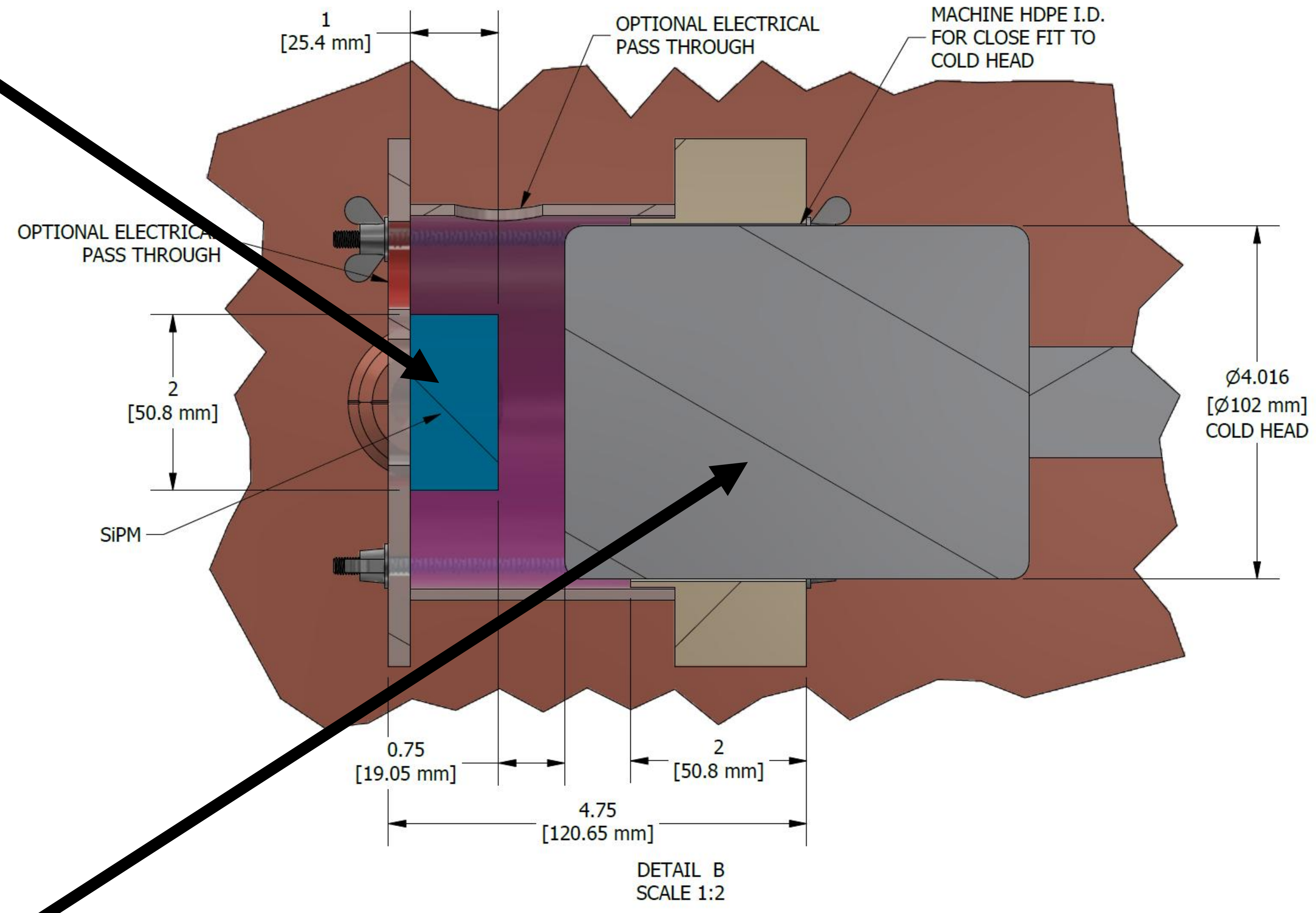


- Useful for understanding nuclear theory:
- ^{176}Lu: Used to date meteorites and minerals Lu/Hf
- ^{176}Lu can provide estimates of the neutron density and temperature for the s-process
- EC* has never been experimentally measured
- Only predicted
  - 2^+: $10^{19} - 10^{21}$ yrs
  - 0^+: $10^{25} - 10^{27}$ yrs
- Current half-life limit ($>10^{14}$ yrs) was set with only 91 hours of measurement time, background limited due to not being underground

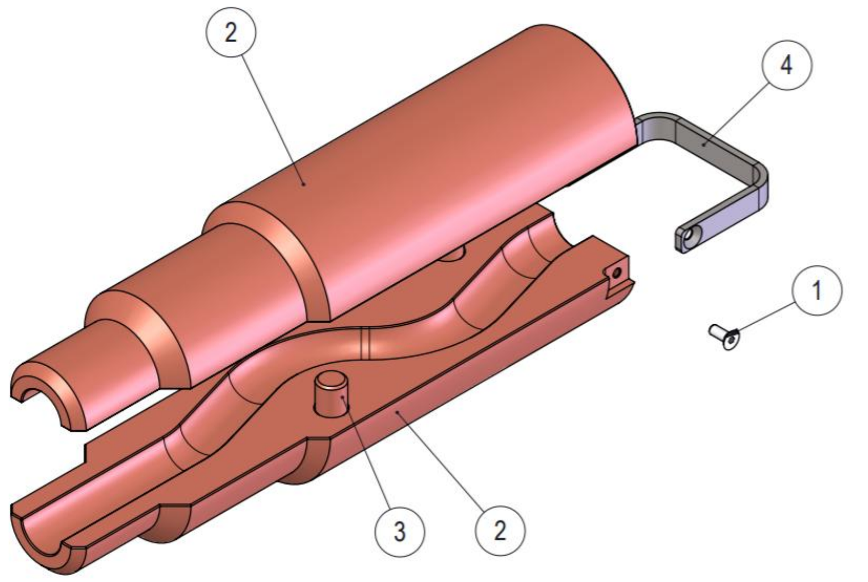
RAMPS: Experimental Setup

SiPM (CNL)





HPGe + Shielding (Health Canada)

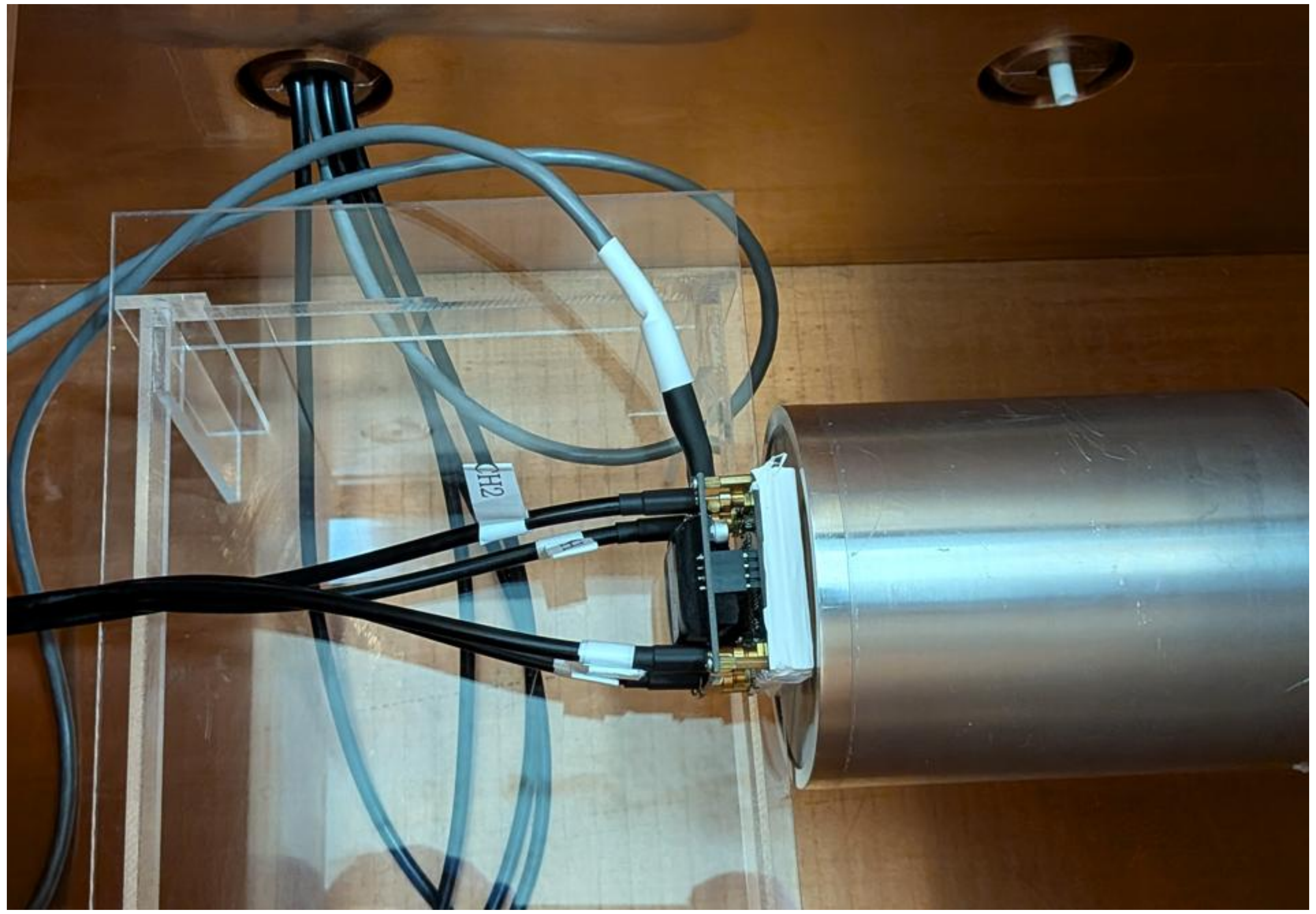


DC Voltage Supply → SiPM → CAEN DT2751 Digitizer

HV Supply → HPGe → CAEN DT2751 Digitizer

CAEN DT2751 Digitizer → PC

RAMPS: Science Run 1 (March 9th-13th)



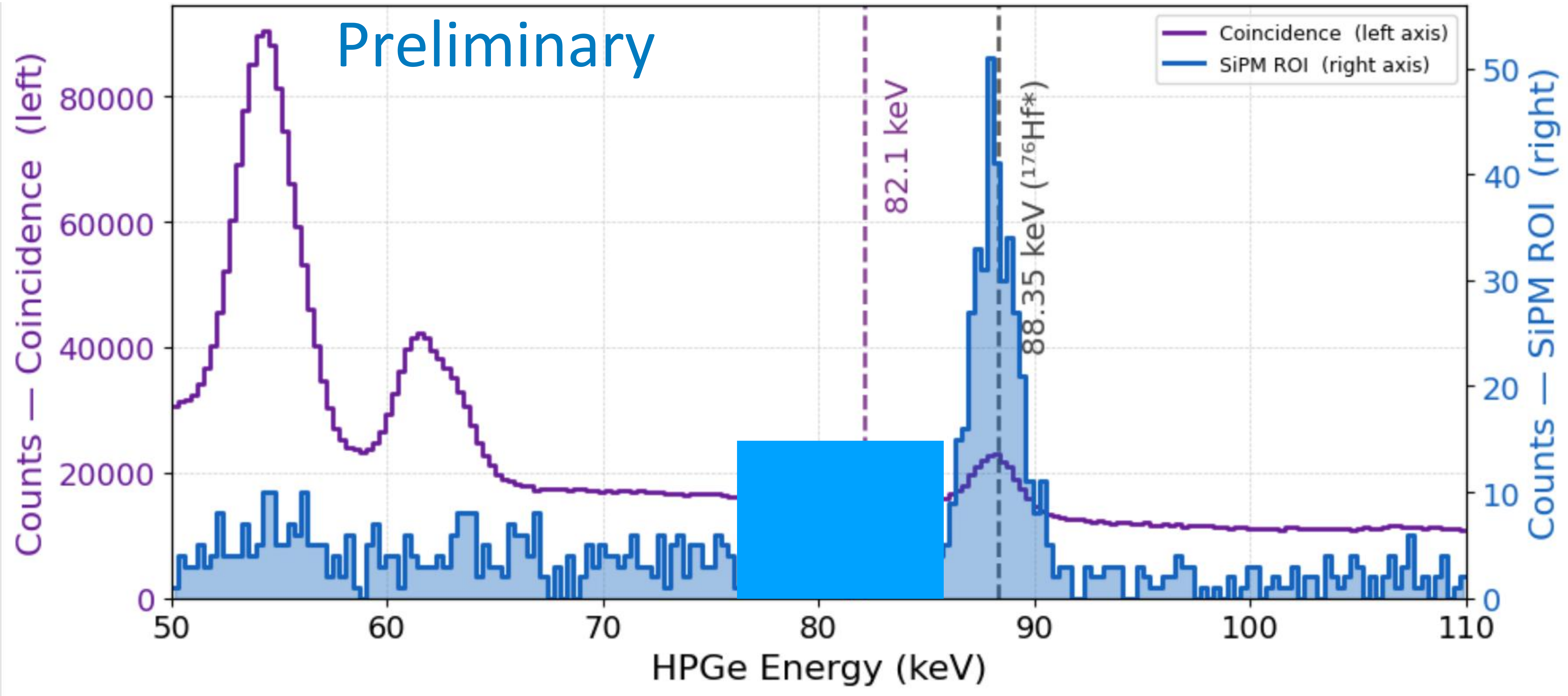
Experimental Setup

First Pulses!

- Over 20 TB of data taken!
- Over 30 hours of science data
- More than 12 hours of calibration data: ^{133}Ba, ^{152}Eu and ^{22}Na

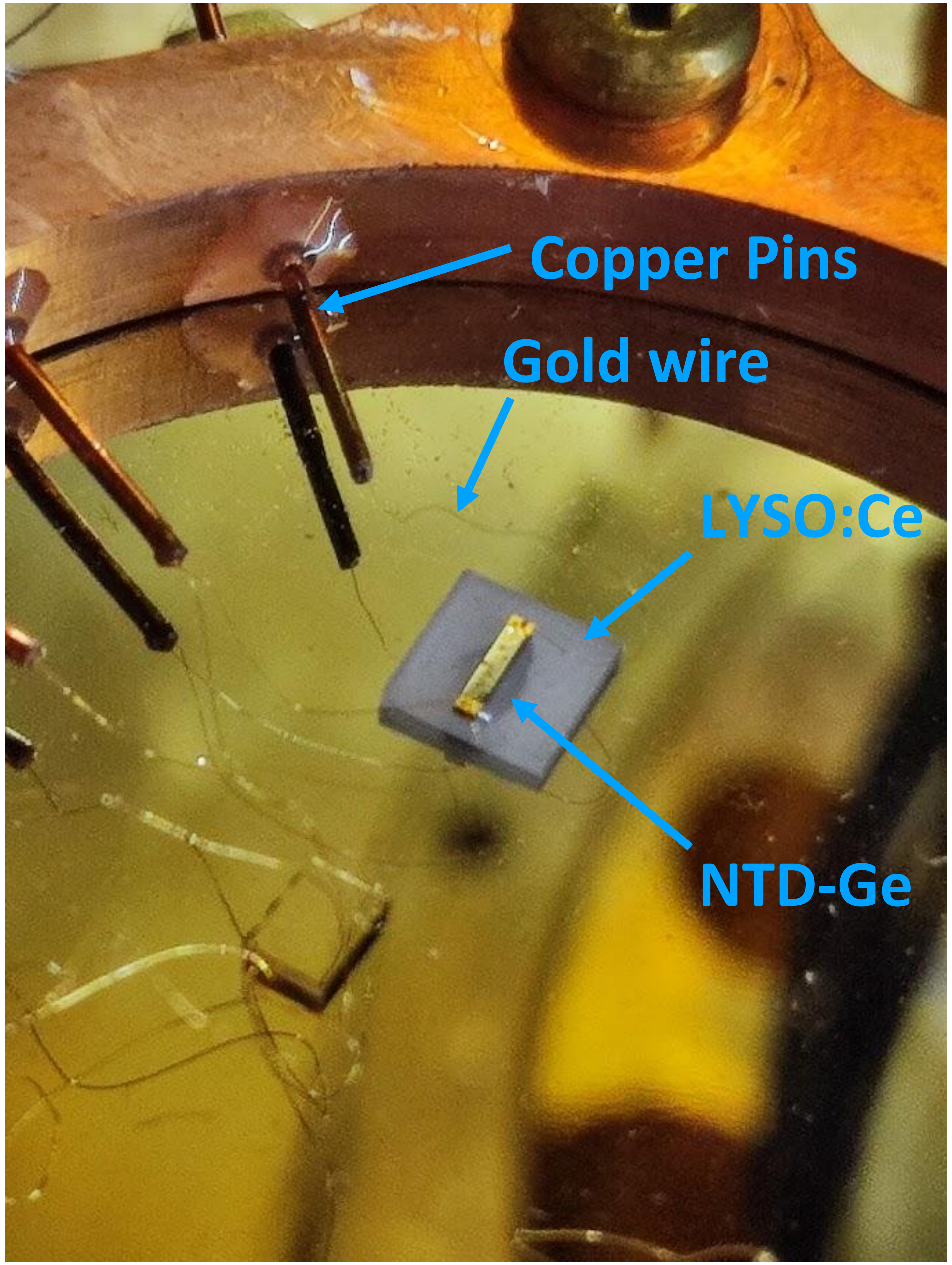
RAMPS: Science Run 1 (March 9th-13th) - Preliminary

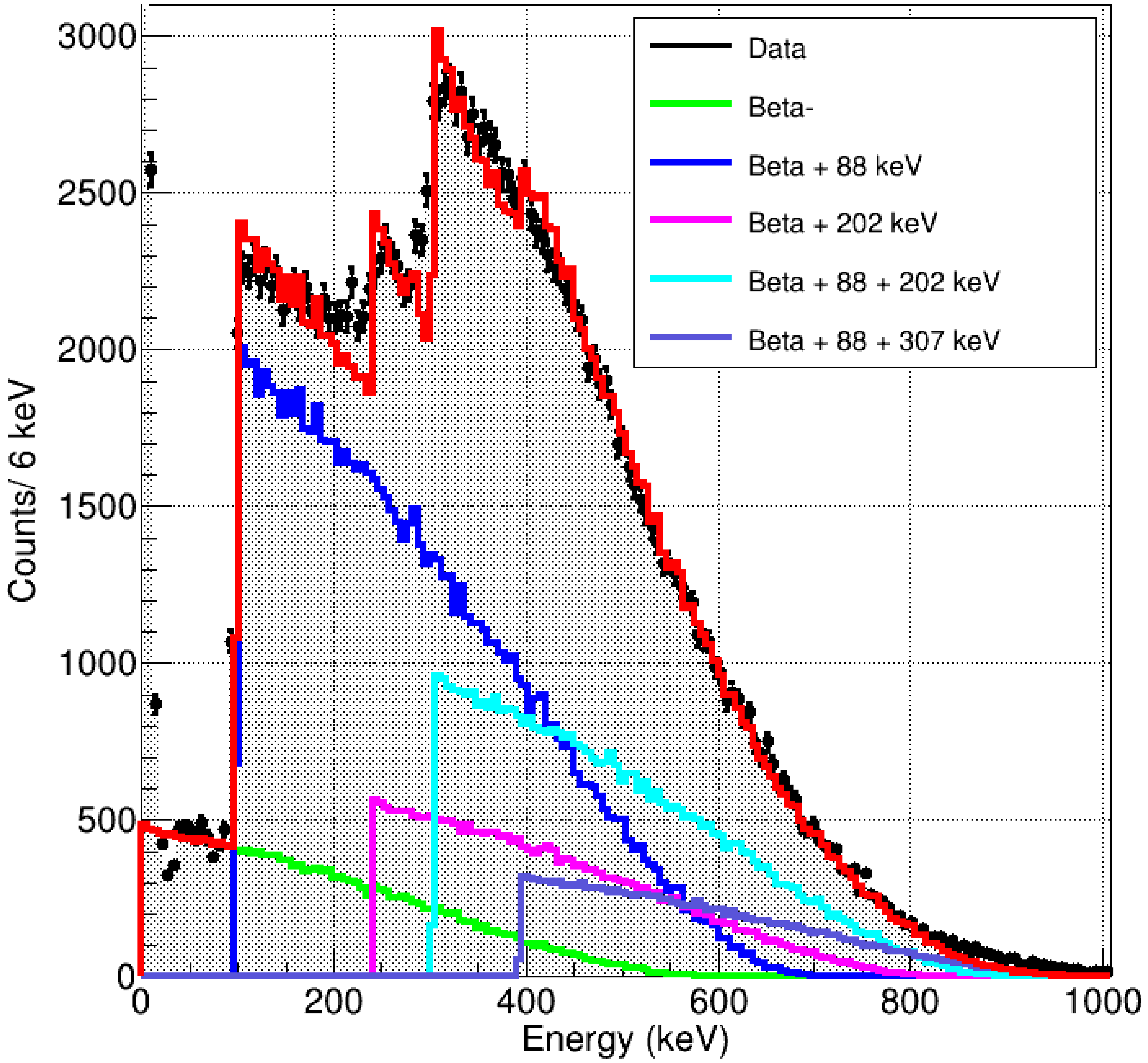
SNOLAB

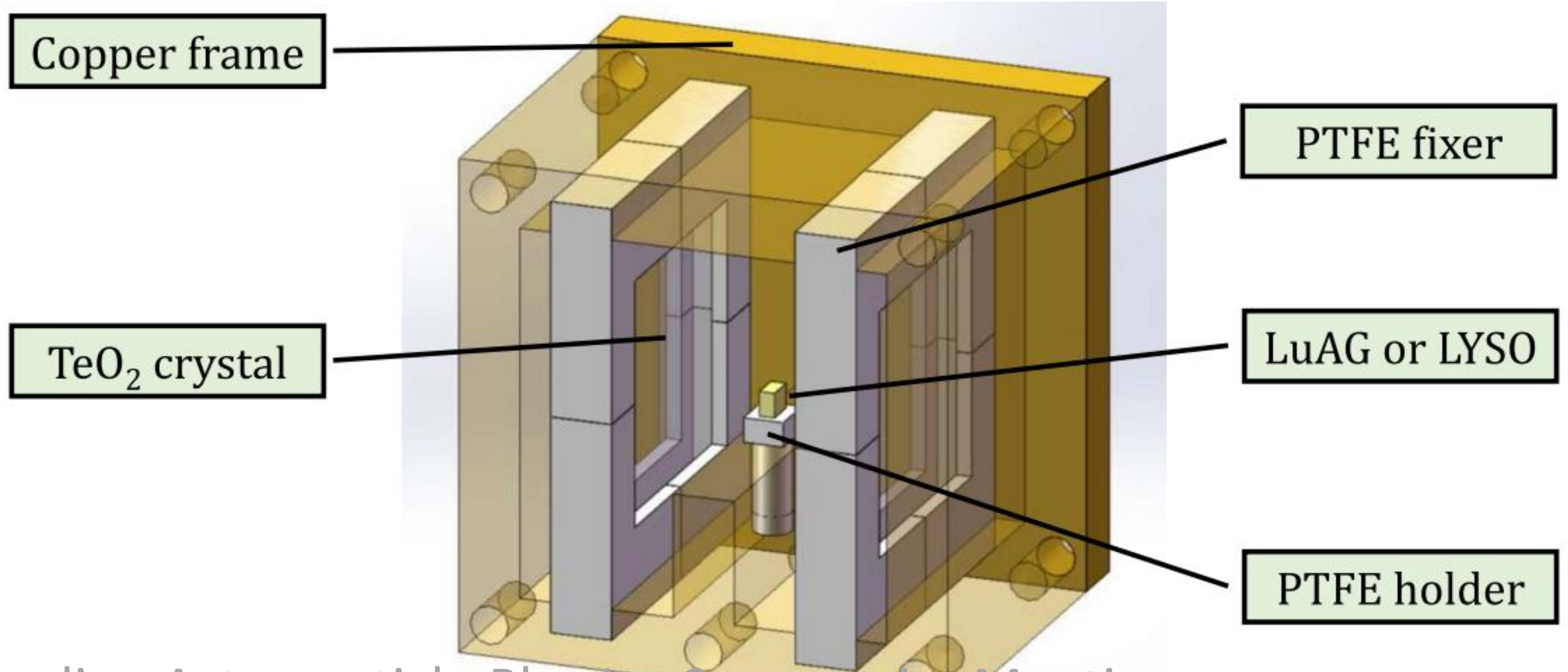


- Over 3 orders of magnitude reduction in β^- background
- Analysis and calibration is ongoing.
- Applying for NSERC alliance grant (contact me if this interests you!)

LUCE: LUtetium Scintillation Experiment

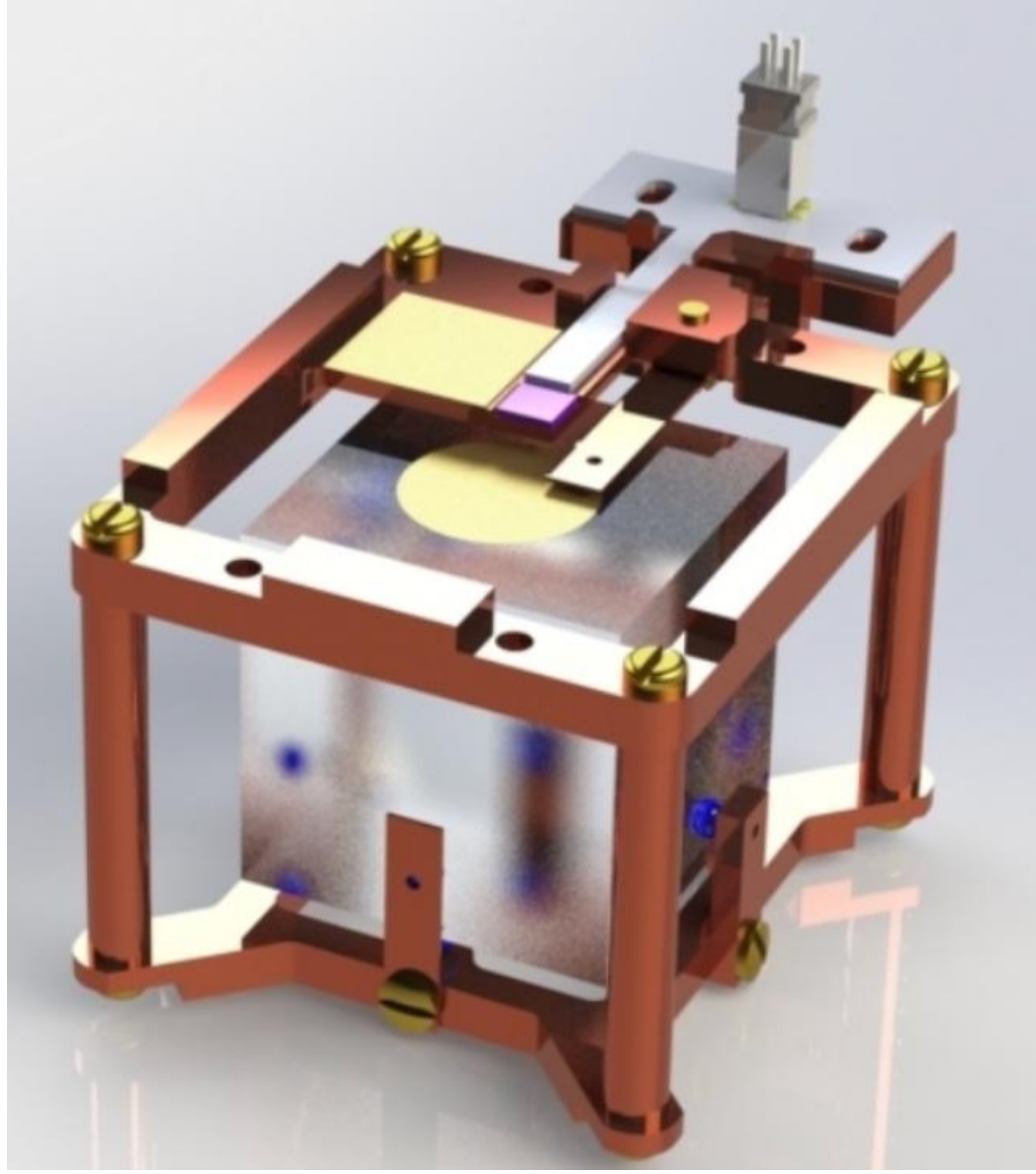
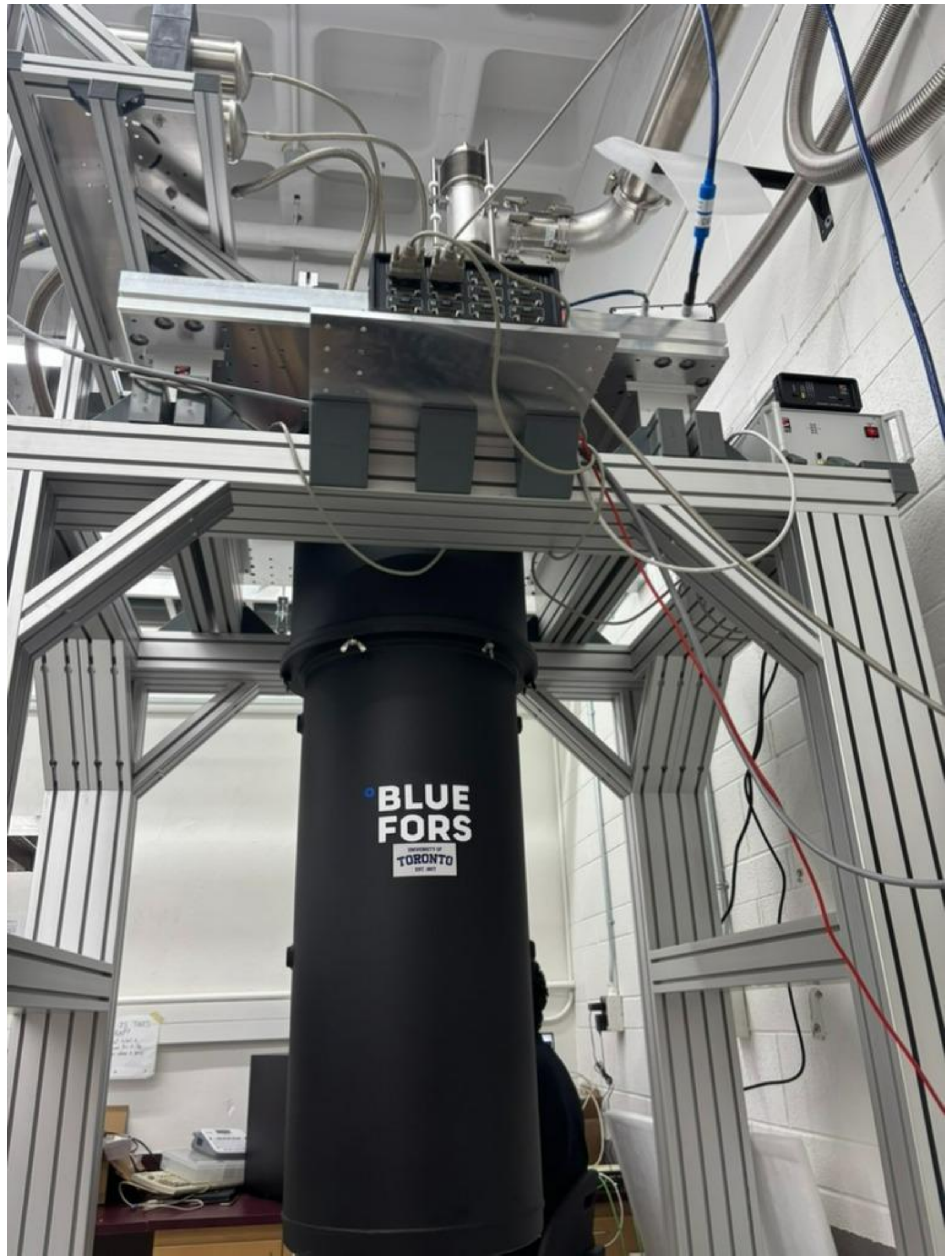


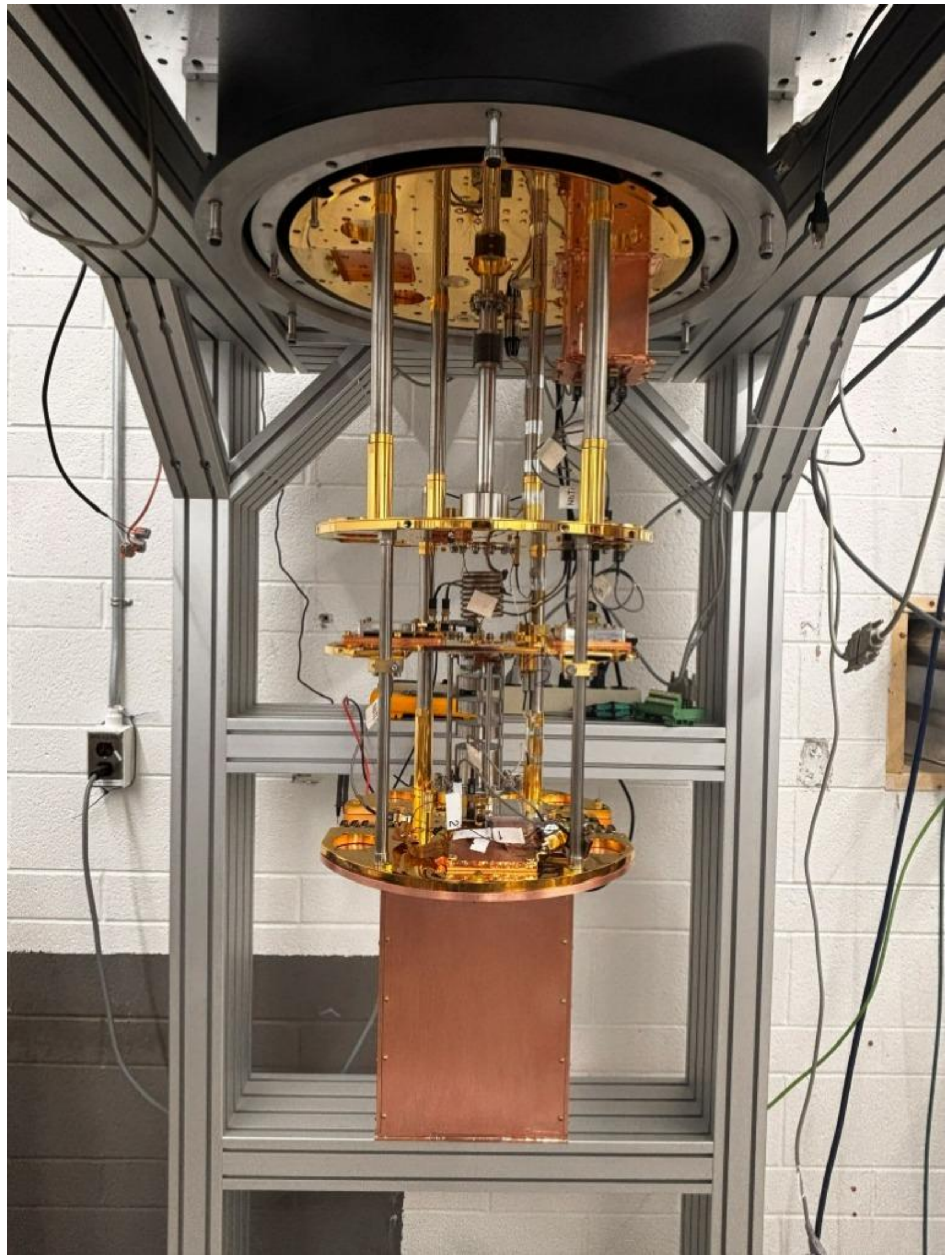




- A 4x4x1 mm LYSO:Ce (0.11g) was operated as a calorimeter at the Ieti facility, underground at the Laboratori Nazionali del Gran Sasso
- Demonstrated the first operation of a LYSO crystal as a cryogenic calorimeter
- Threshold = 20 keV

TES based cryogenic Li_2MoO_4



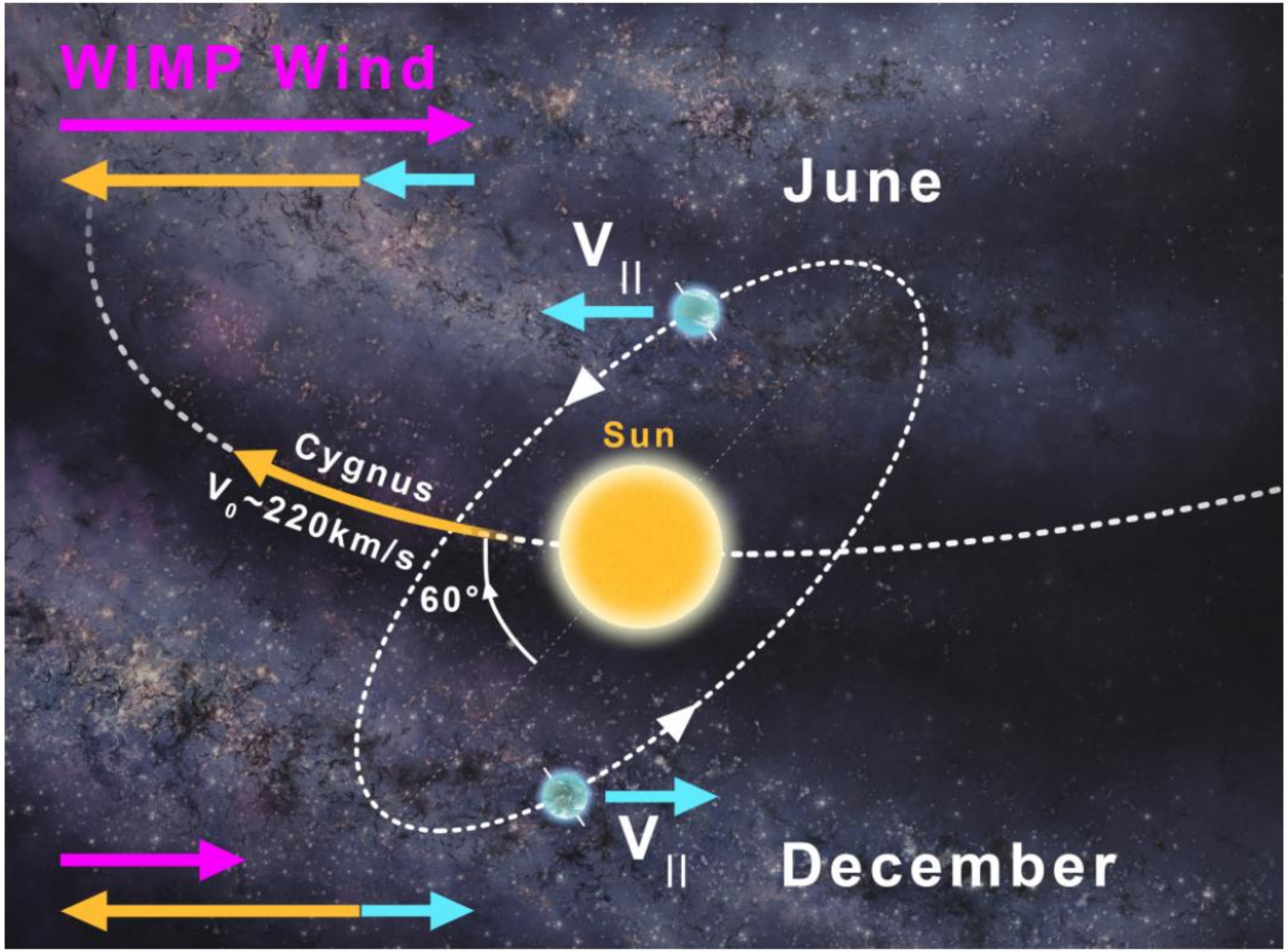
- The COSINUS experiment uses a very similar design
- Current testing is ongoing at University of Toronto (talk to Ziqing Hong), with the <u>goal of running a module in CUTE</u>
- https://arxiv.org/pdf/2406.02025

Conclusion

- KDK: Measured ^{40}K to try and interpret DAMA/LIBRA
  - KDK+
- COSINUS: Uses cryogenic calorimeters to test DAMA/LIBRA
- SuperCDMS: Uses cryogenic calorimeters to search for low-mass dark matter
  - Commissioning data started!
- R&D:RAMPS/LUCE SNOLAB program to measure rare nuclear decays
  - LMO TES design for neutrinoless-double beta decay experiments

Extra Slides

Annual Modulation



https://iopscience.iop.org/article/10.1088/1361-6471/ab8e93/meta

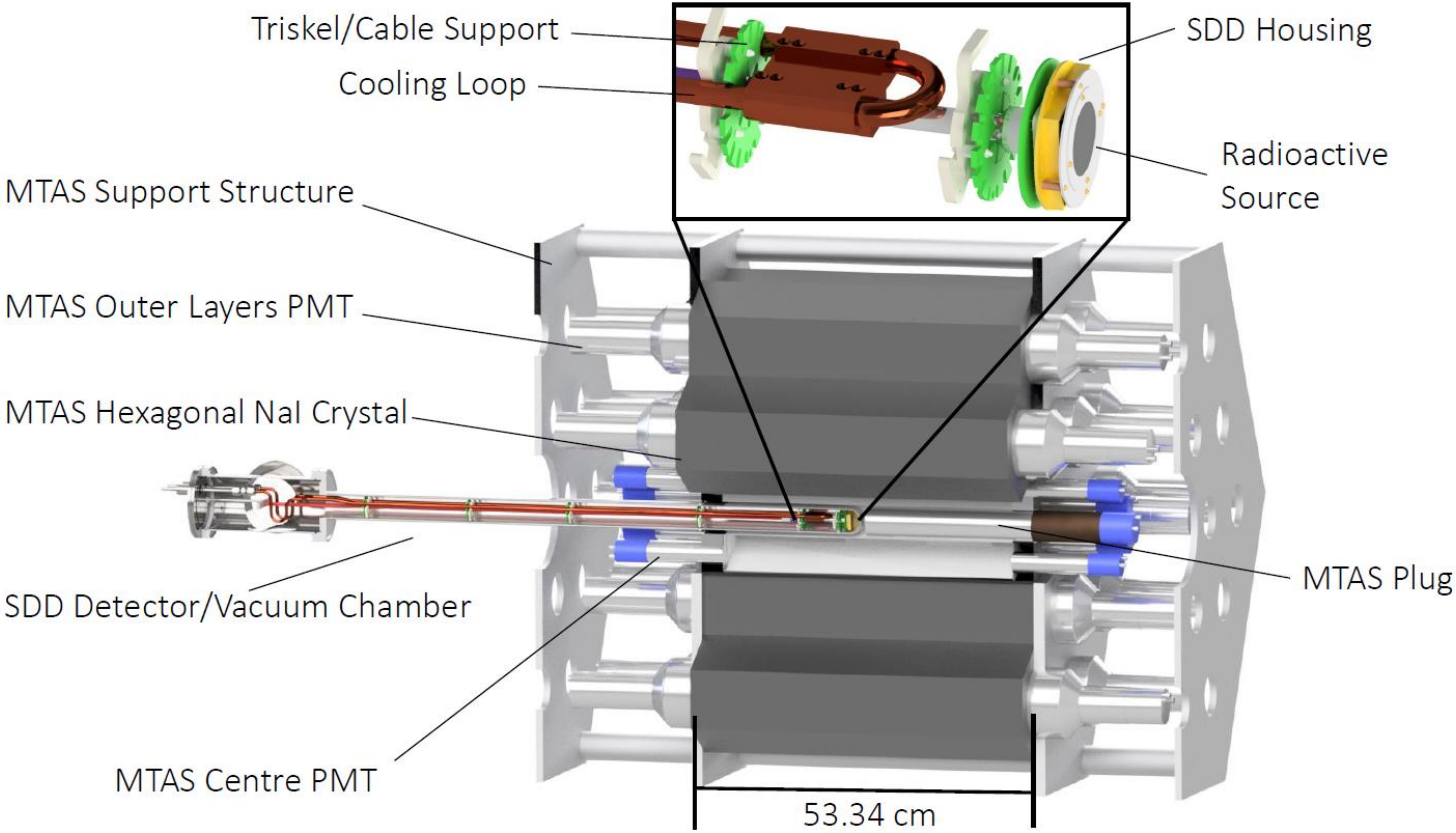
- The sun moves through the galactic dark matter halo
- The earth rotates around the sun
- Induces a change in the dark matter flux throughout the year
- The DAMA collaboration has detected a peculiar annual modulation signal since 1997
- Unique and detectable signal for dark matter
  - Period of one year
  - Peaks around June 2nd
  - Signal expected in low energy region (O(keV))

DAMA/LIBRA

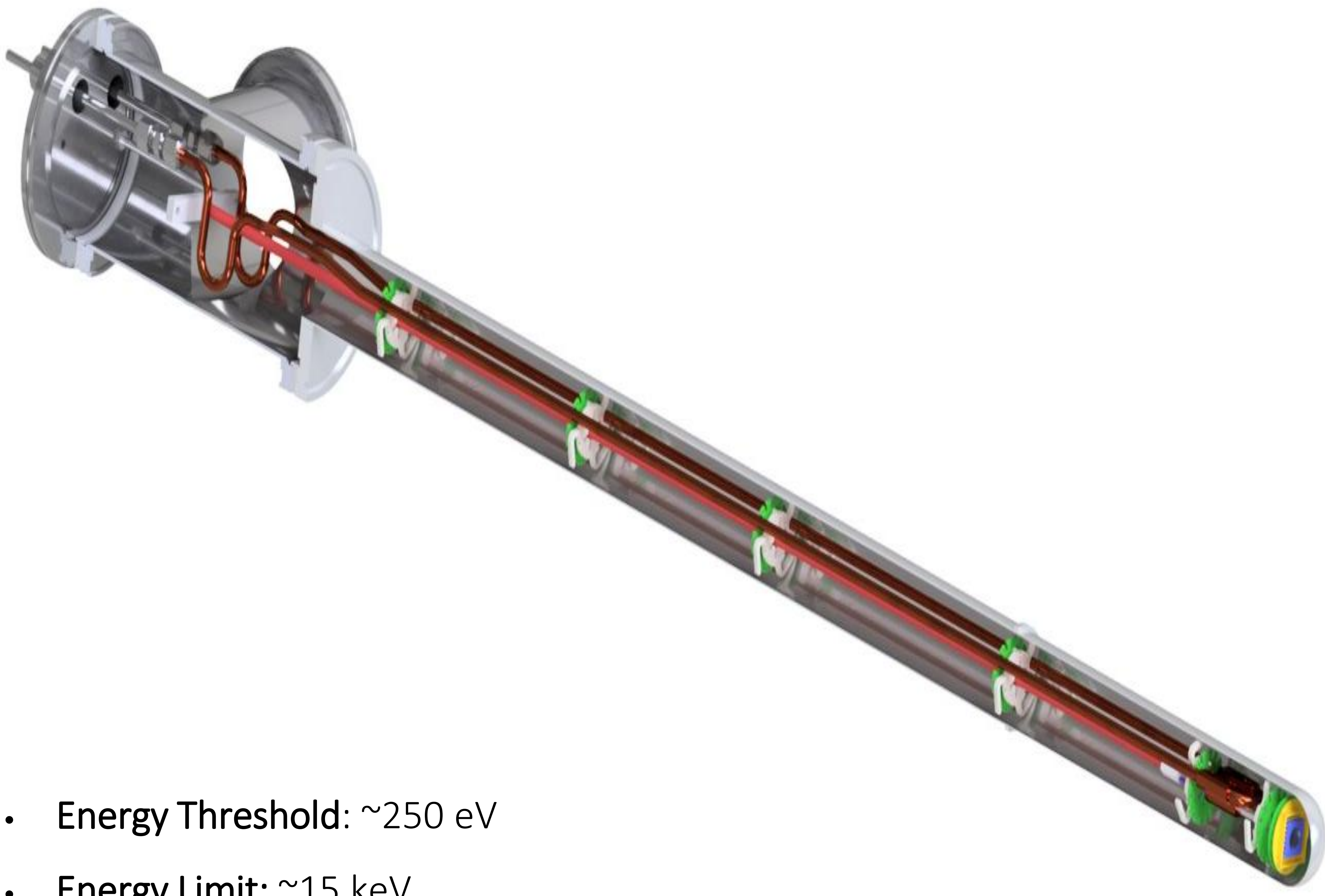
https://indico.cern.ch/event/1188759/contributions/5230561/attachments/2622519/4534672/belli_DM2023_web.pdf

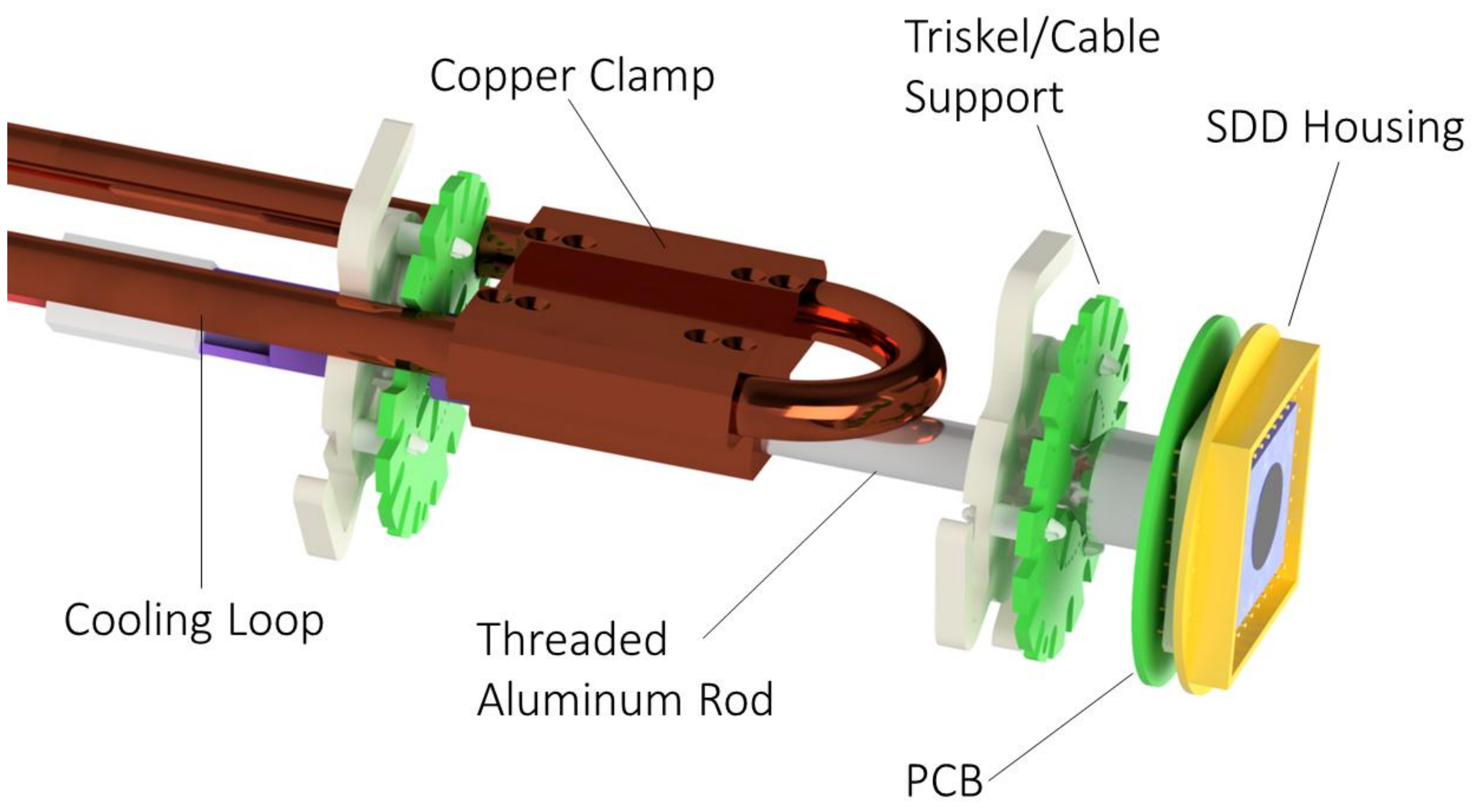
- The DAMA collaboration has detected a peculiar annual modulation signal since 1997
- Signal is consistent with WIMP dark matter halo predictions (0.75 keV threshold shown)
  - Statistics: >13σ
  - Period: 0.999 +/- 0.001
  - Phase: 25th May +/- 5 days
  - Non-dark matter explanation: No

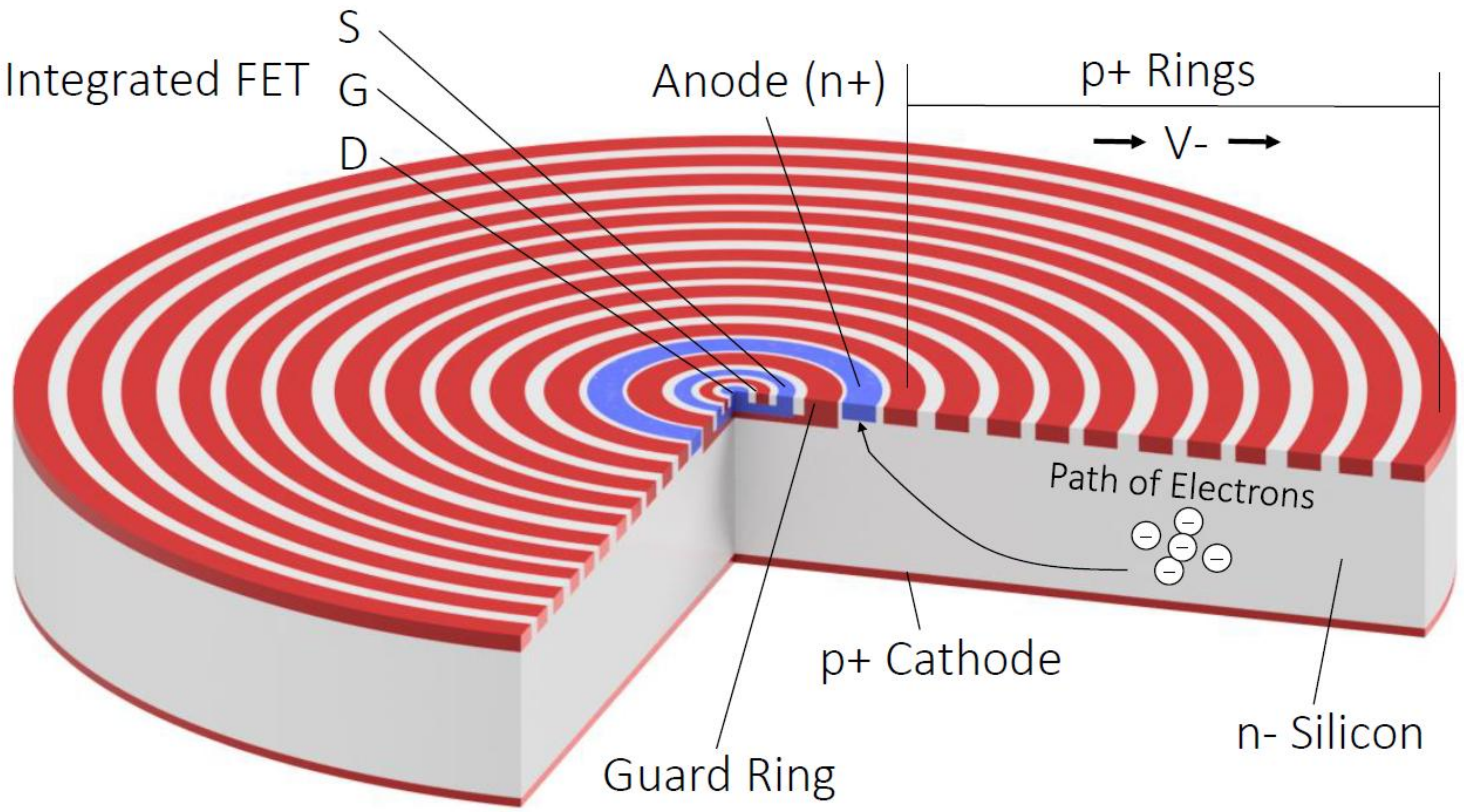
KDK Experimental Setup



SDD – Silicon Drift Detector

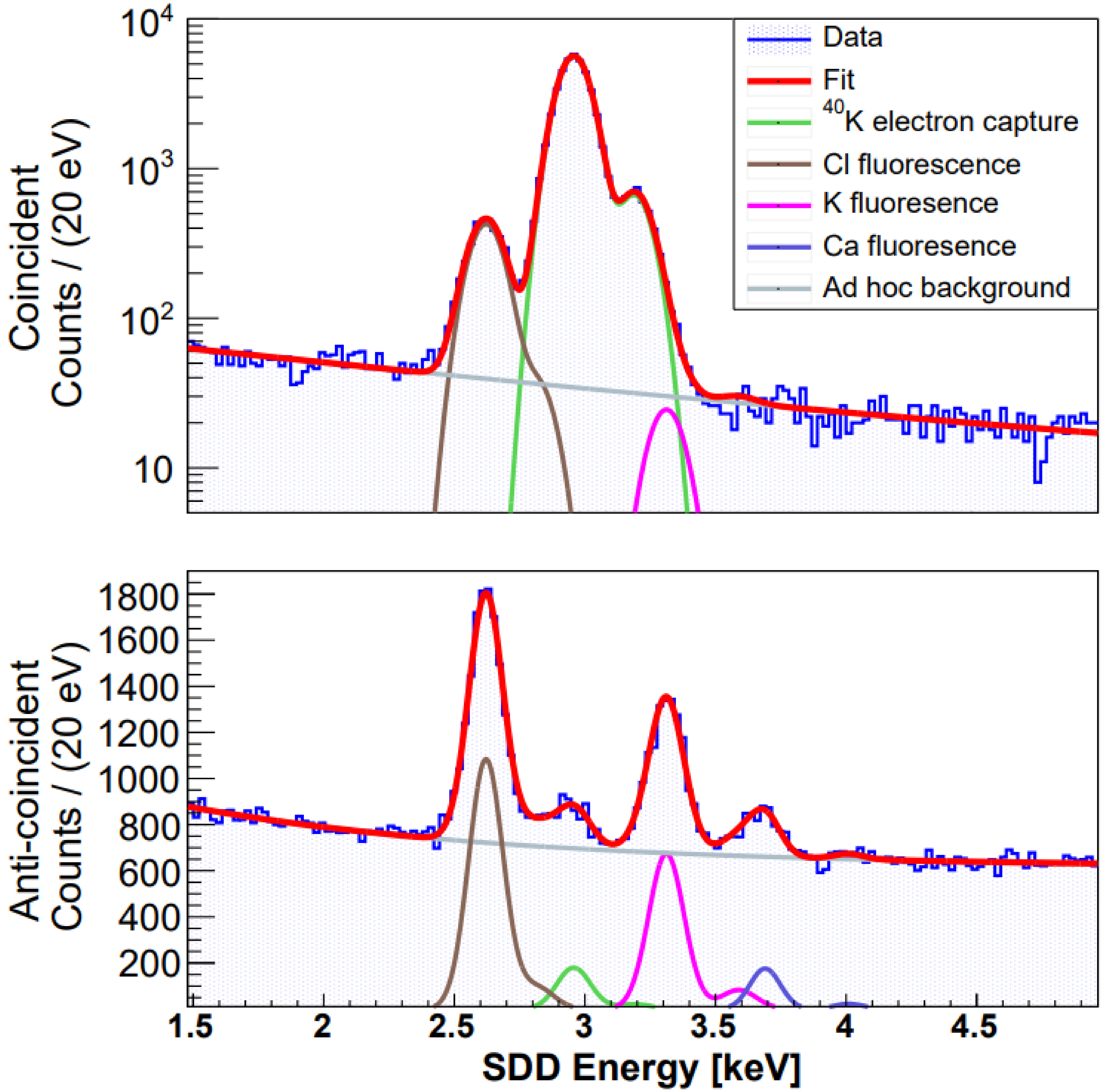


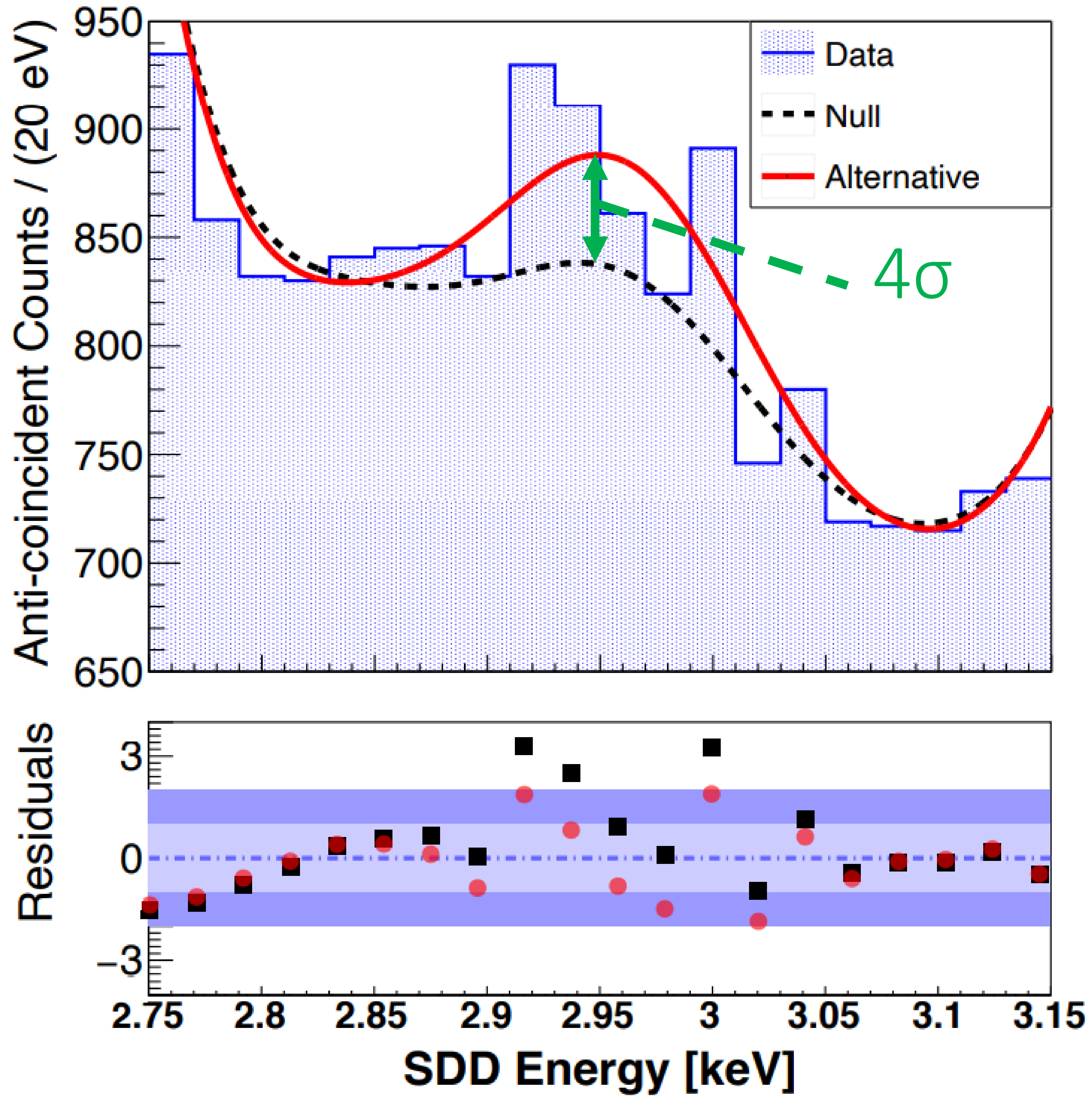




- **Energy Threshold**: ~250 eV
- **Energy Limit:** ~15 keV
- **FWHM:** ~170 eV @ 6keV

KDK Results





$$\rho = \frac{BR_{EC}}{BR_{EC*}} = 0.0095 \pm 0.0022 \pm 0.0010$$

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VIEWPOINT

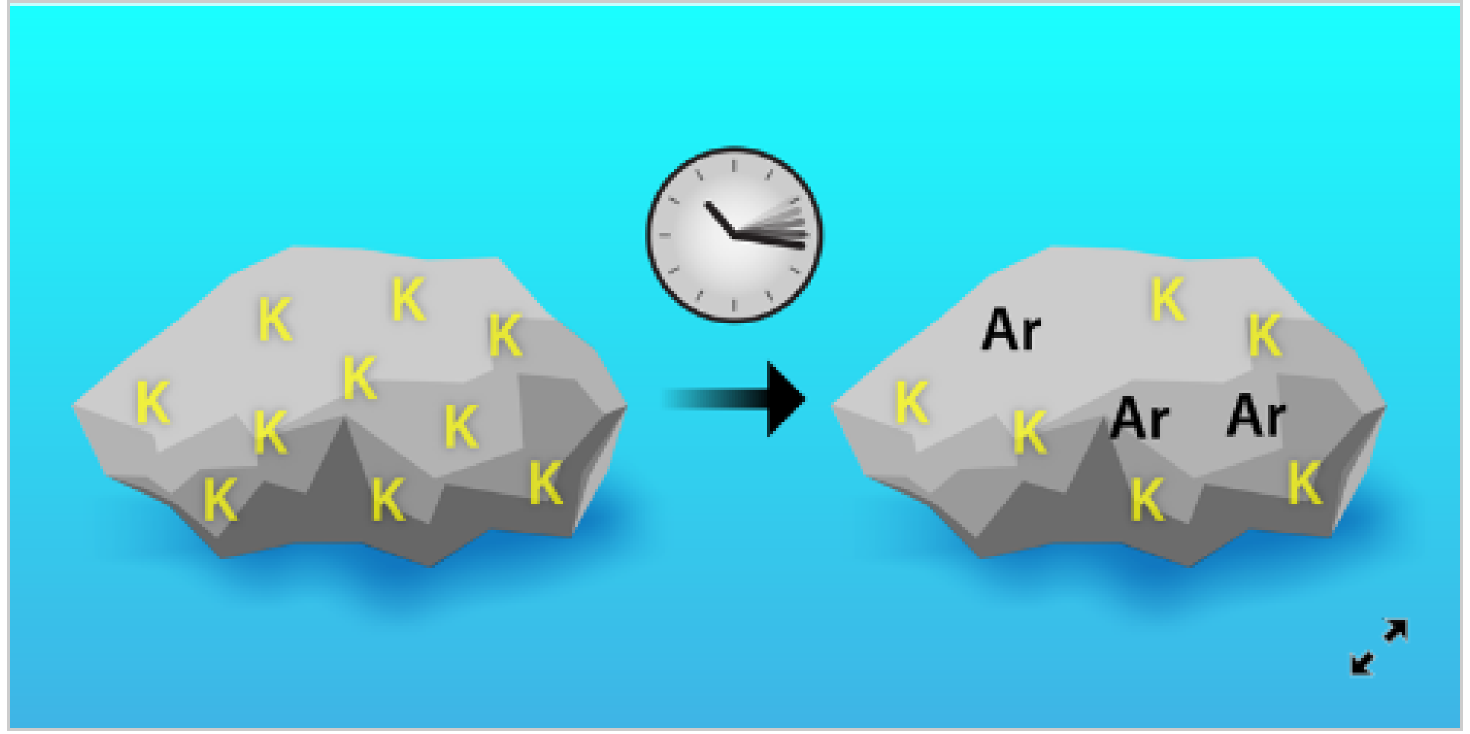
PDF Version

Measuring Decays with Rock Dating Implications

Stephen Ellis Cox
Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, US

July 31, 2023 • *Physics* 16, 131

Researchers revisit a neglected decay mode with implications for fundamental physics and for dating some of the oldest rocks on Earth and in the Solar System.



APS/Alan Stonebraker

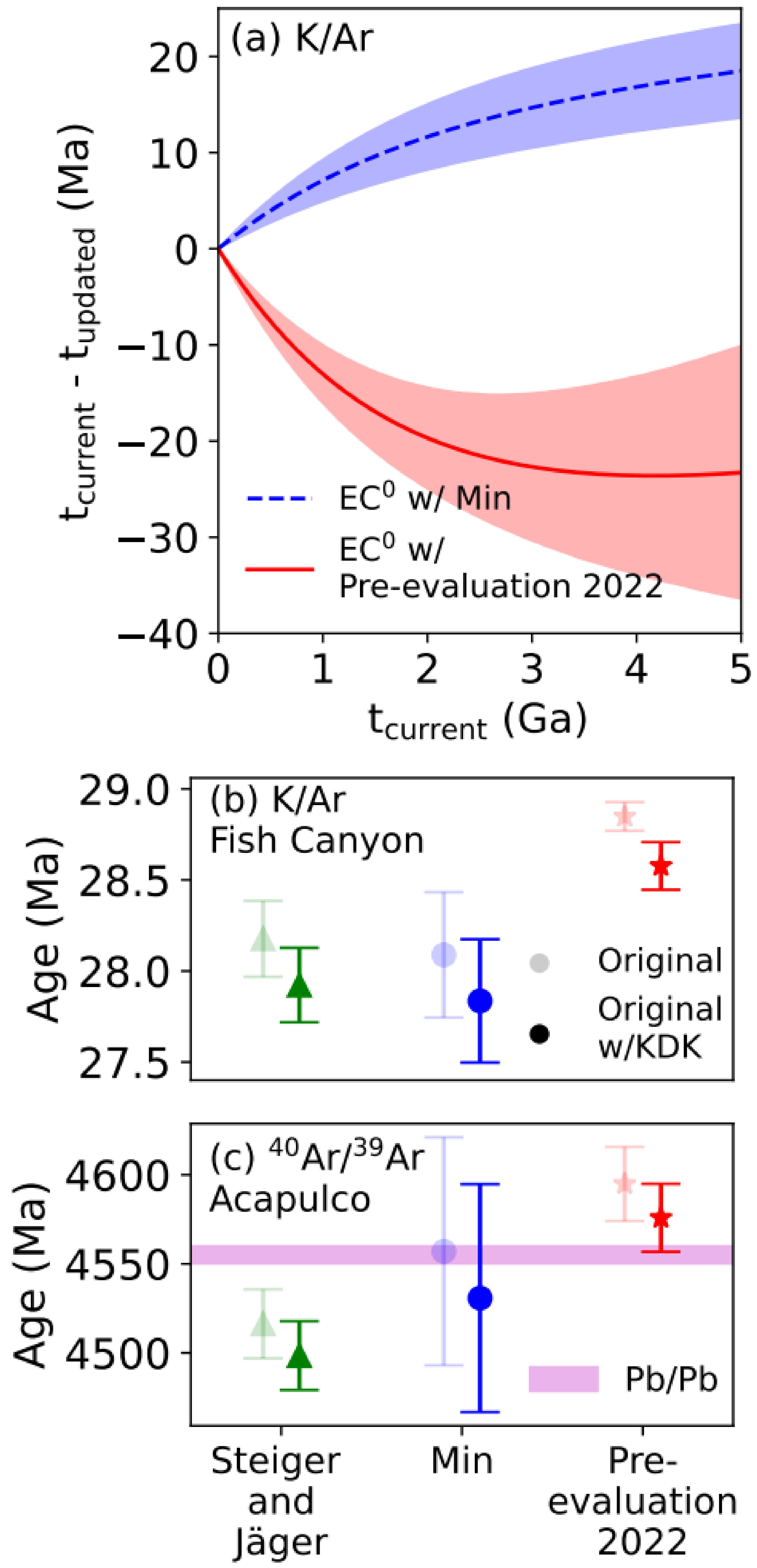
Figure 1: As a rock forms, it traps a set of potassium-40 within the solid. Decays of this isotope produce argon-40. By measuring the amount of argon-40 relative to that of potassium-40, geologists can date the rock.

Rare ^{40}K Decay with Implications for Fundamental Physics and Geochronology
M. Stukel *et al.* (KDK Collaboration)
Phys. Rev. Lett. 131, 052503 (2023)
Published July 31, 2023
Read PDF

Evidence for ground-state electron capture of ^{40}K
L. Hariasz *et al.* (KDK Collaboration)
Phys. Rev. C 108, 014327 (2023)
Published July 31, 2023
Read PDF

Recent Articles

How Metal Meteorites Magnetize
For a metal meteorite to retain a magnetic field, its parent asteroid may need a cold rubble core to help drive an internal dynamo.



Link: https://physics.aps.org/articles/v16/131

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Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

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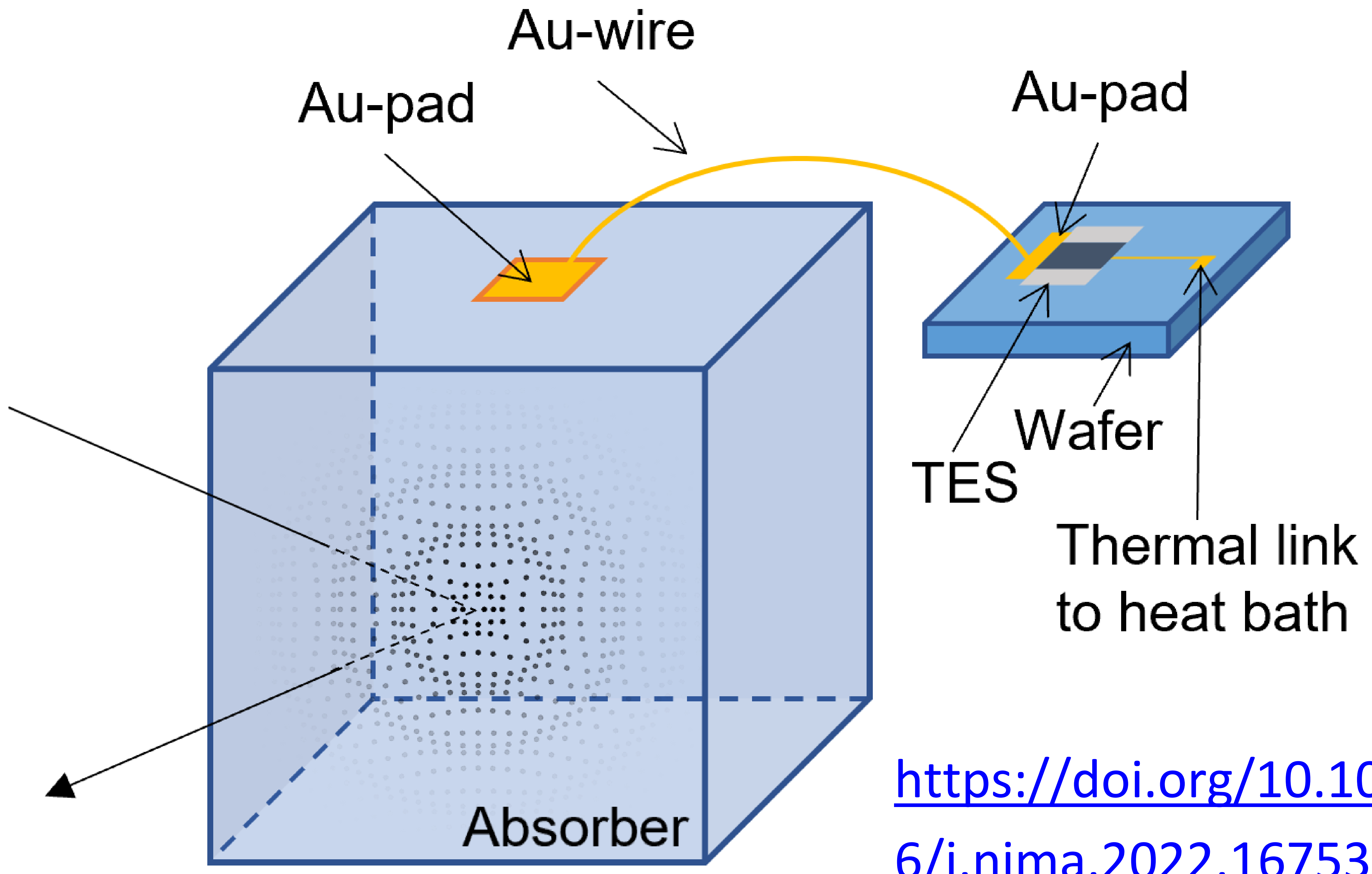
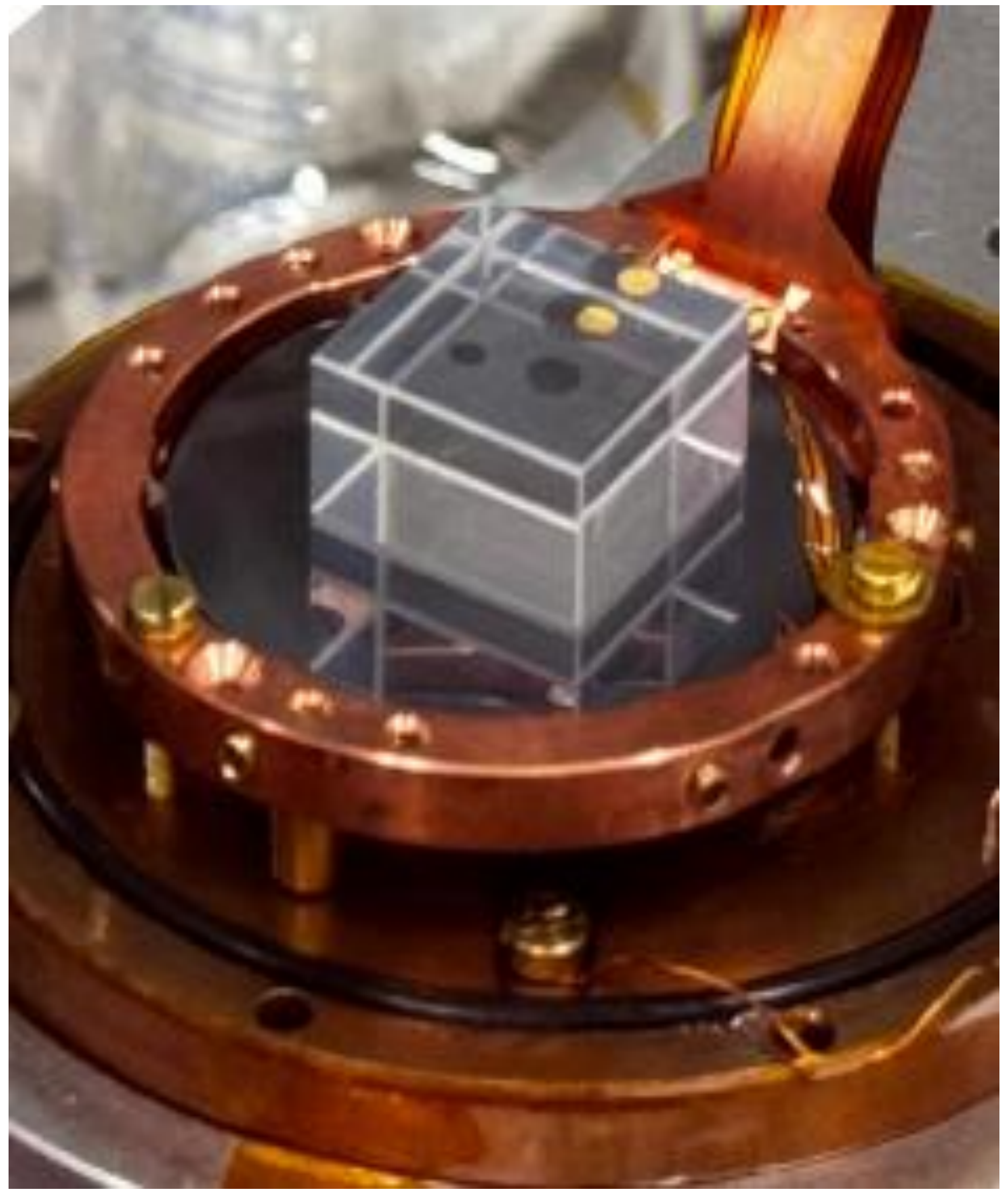
GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

NaI – remoTES design

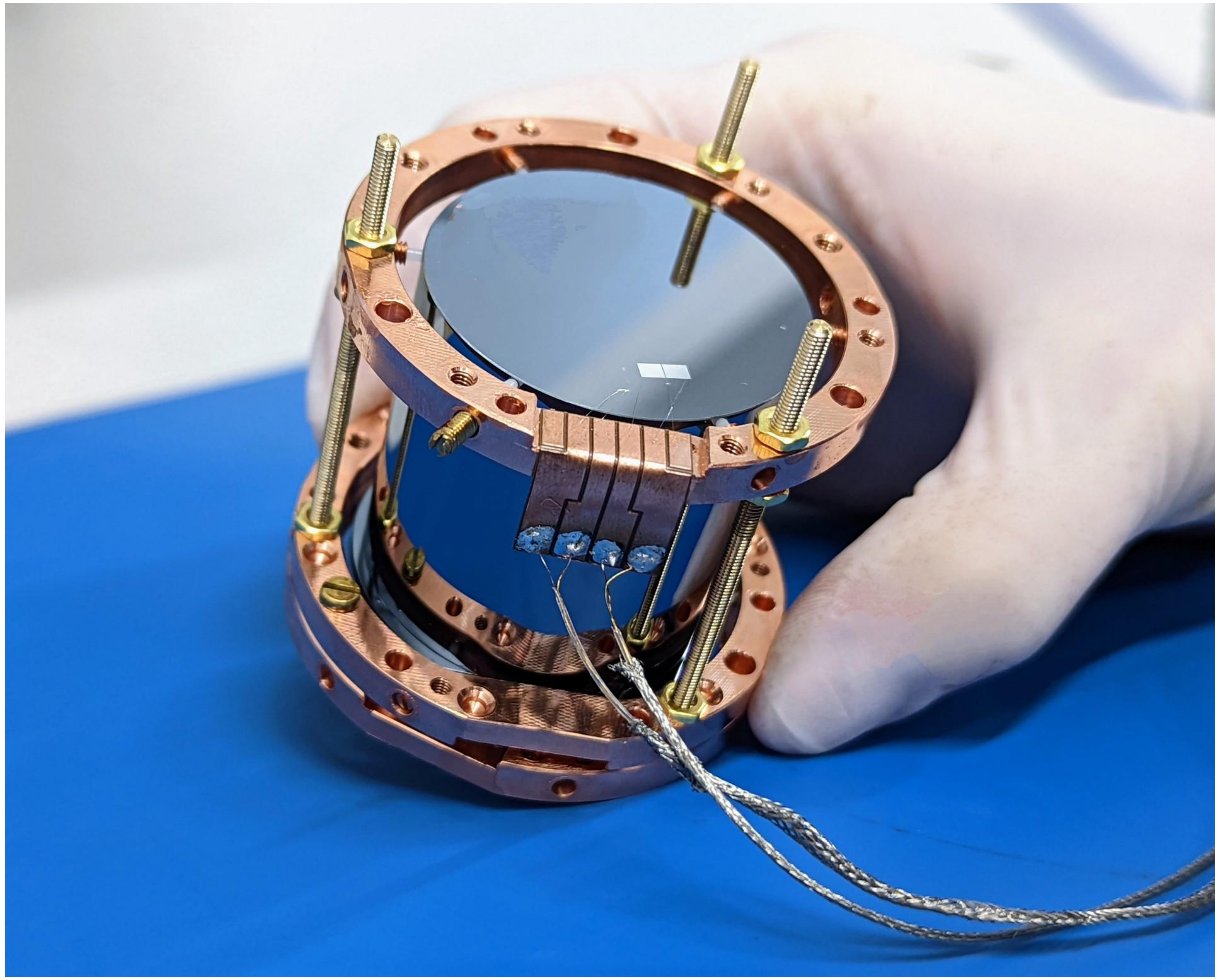


https://doi.org/10.1016/j.nima.2022.167532



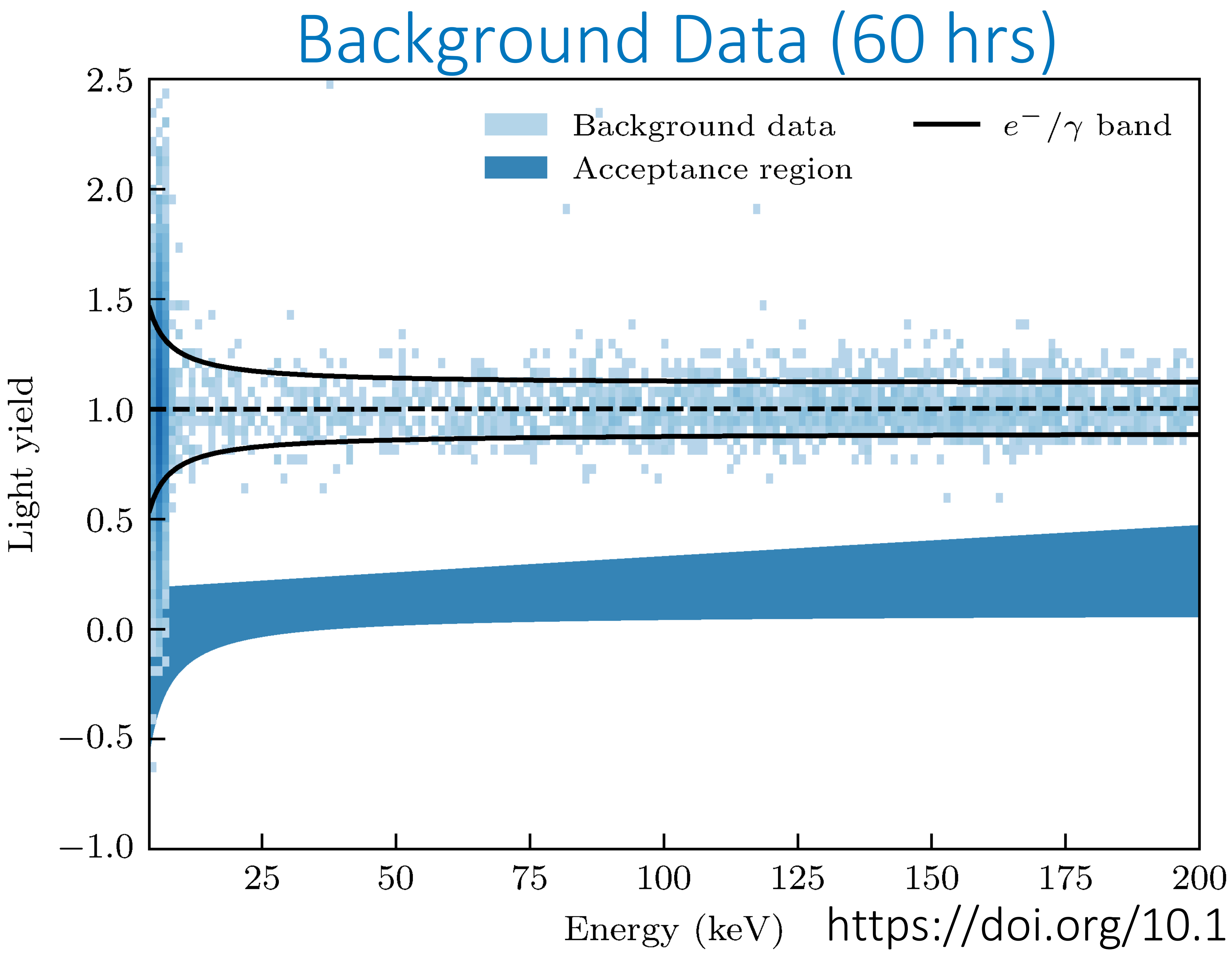
- Implement remoTES design
  - NaI is hygroscopic (no contact with humid air)
  - Very soft and low melting point (easy to damage when handling)
  - Not suited for traditional thin film deposition
- Separate wafer that holds the TES: Wafer: Al_2O_3

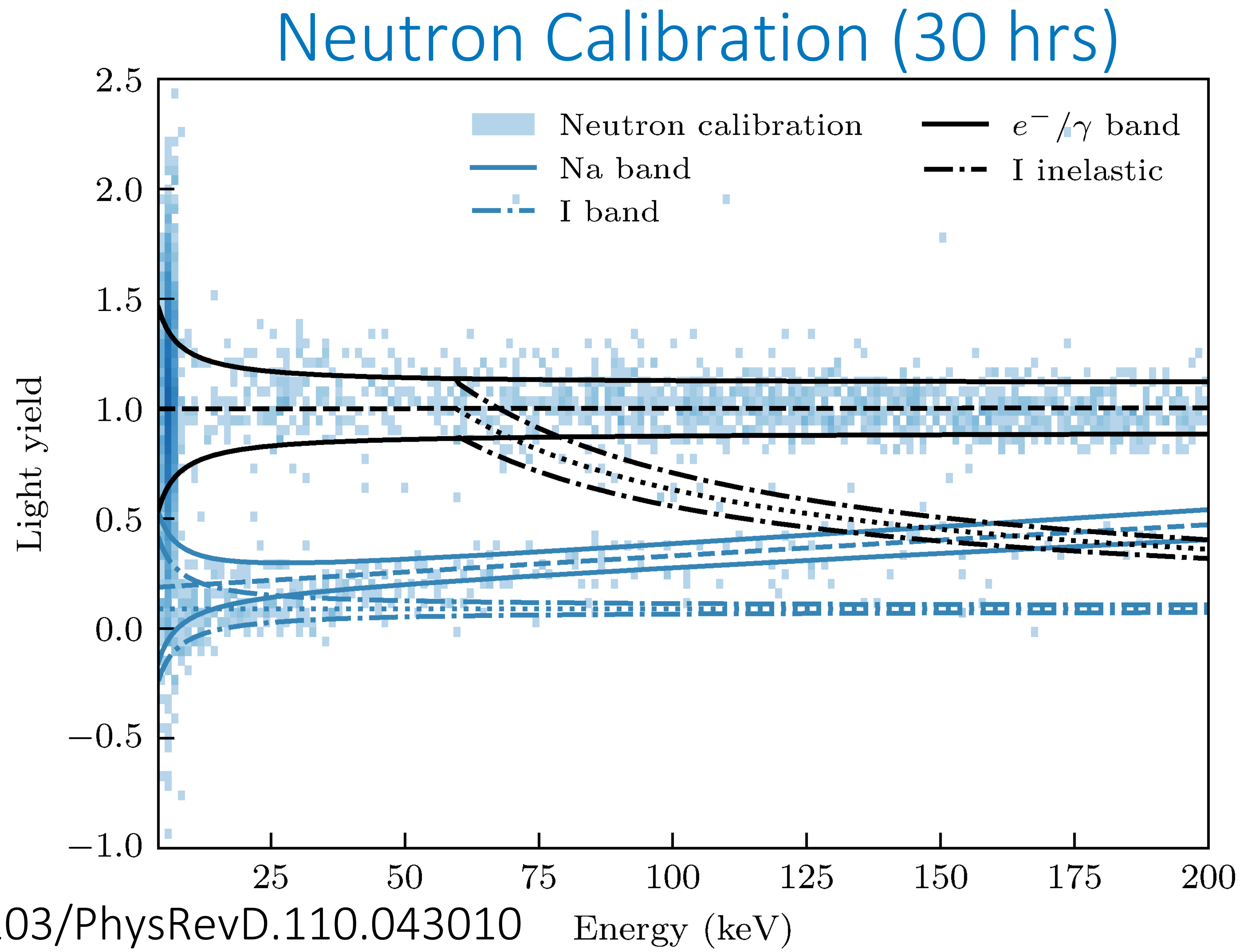
NaI – Light Detector



- Scintillation light is detected by a surrounding silicon beaker
  - 1mm thick, 40mm in diameter
- 4π coverage to maximize light collection
- TES is evaporated directly onto the silicon
- Resolution: <10 eV

COSINUS – Particle Discrimination II

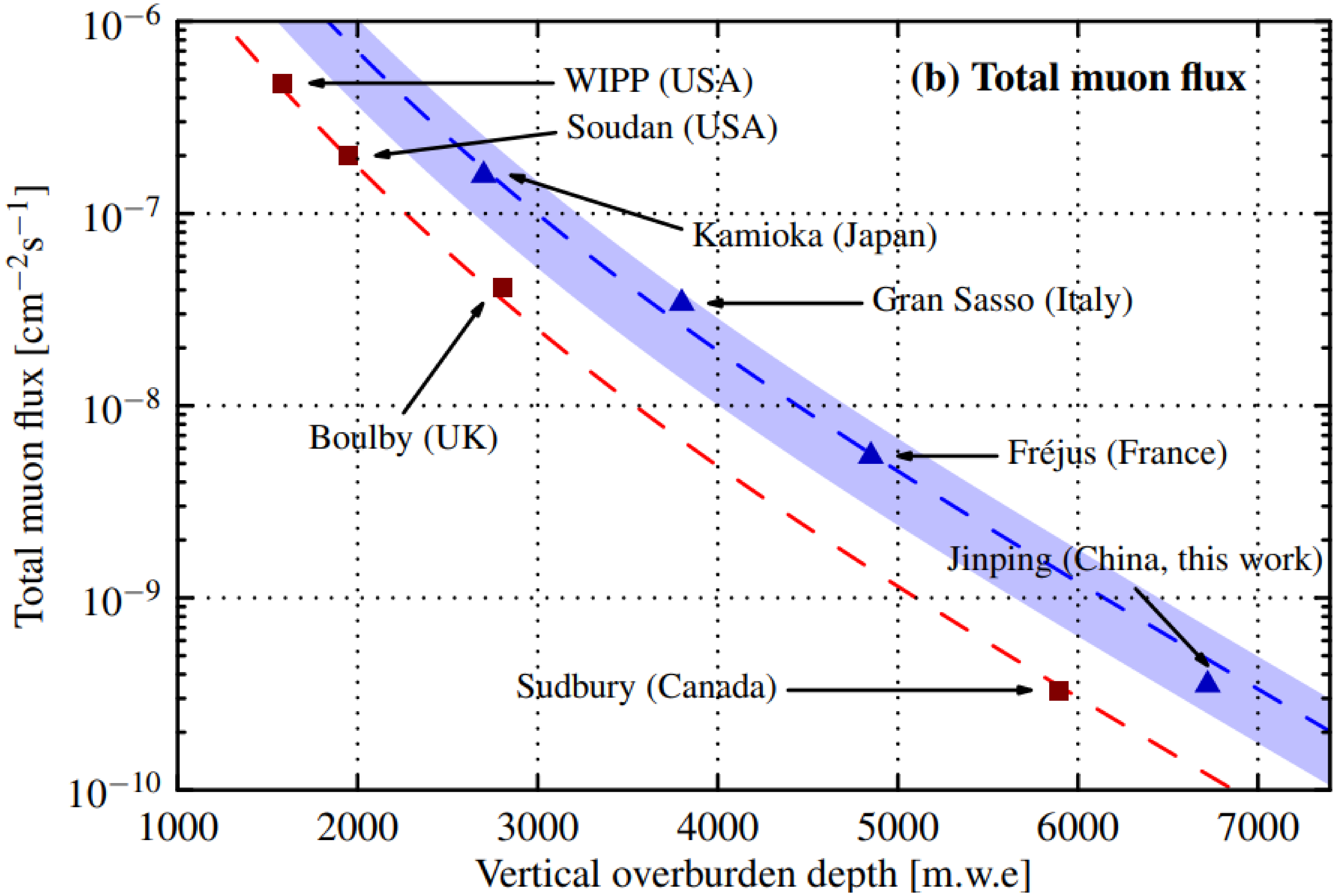




https://doi.org/10.1103/PhysRevD.110.043010

- December 2021: Demonstrated the first particle discrimination in NaI at a surface setup
- June 2022: Measurement was carried out using a CRESST test facility at the Gran Sasso National Laboratory (underground)
- NaI phonon baseline resolution: 440 eV_{nr}
- Neutron band is clearly visible, <u>proof of particle discrimination in NaI</u>

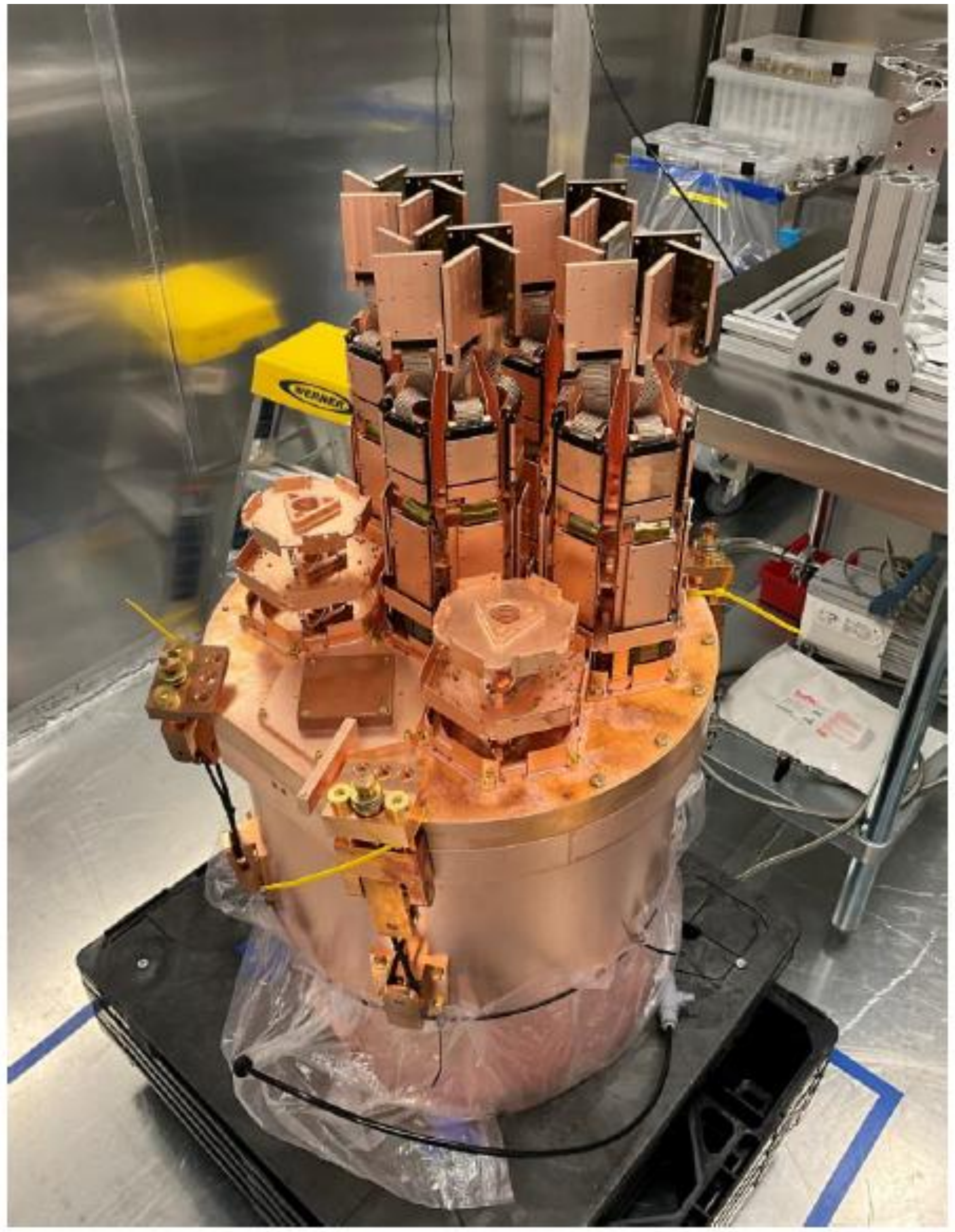
Advantage at SNOLAB



https://arxiv.org/pdf/2007.15925.pdf

- One of the lowest muon flux in the world
- Class-2000 clean-room
- <2000 particle >0.5µm in diameter per cubic feet

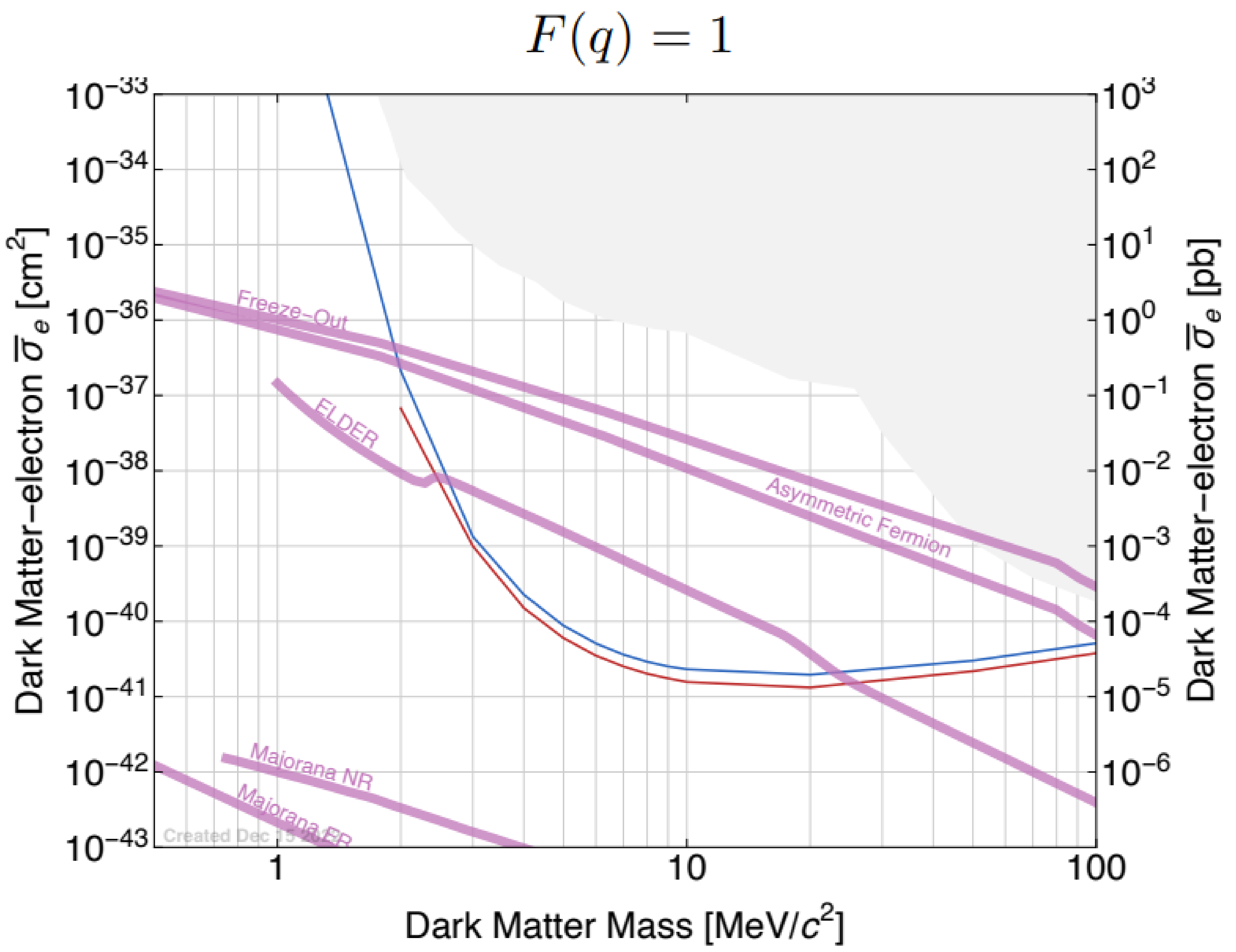
The building process

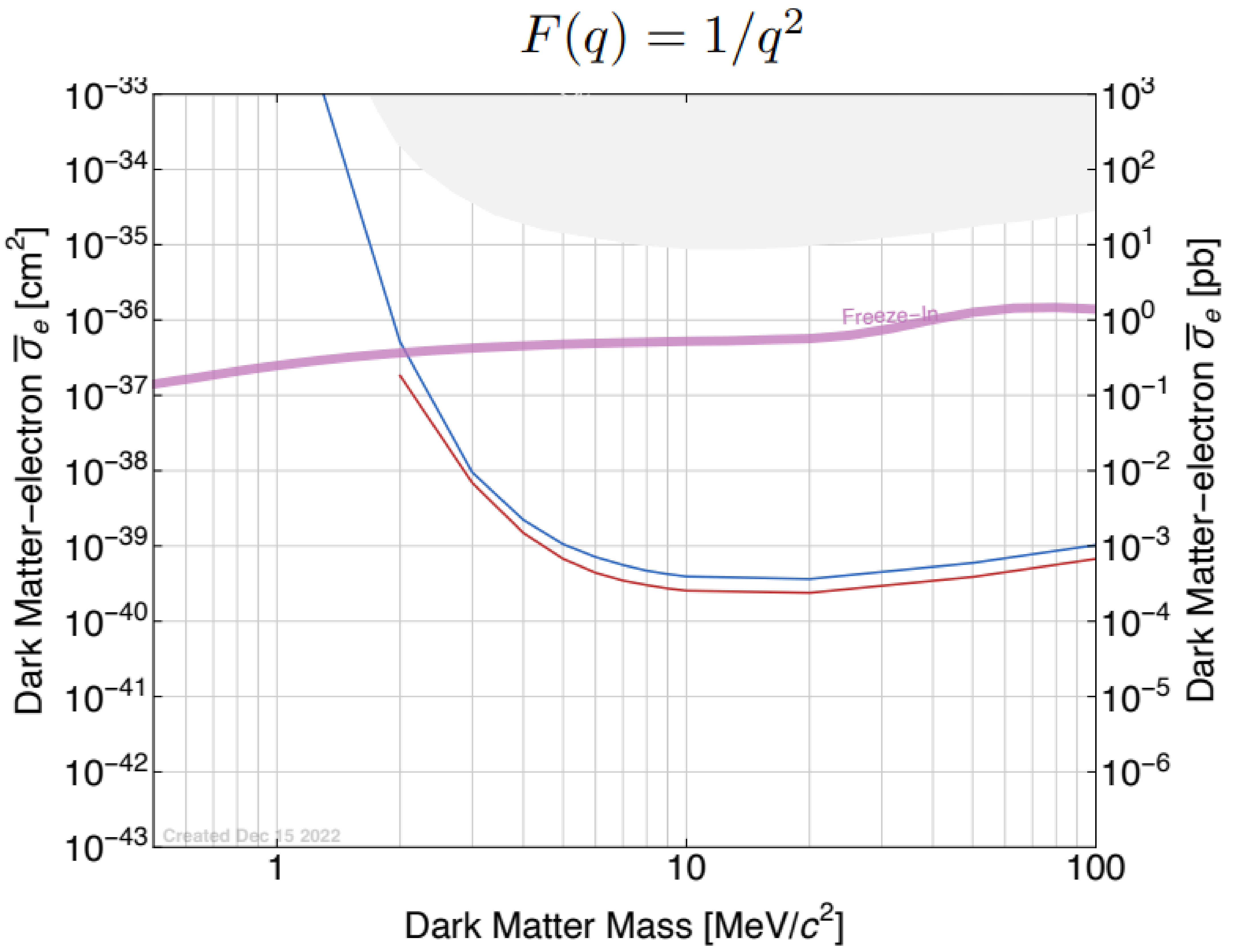


The building process

DM-electron scattering sensitivity

- SuperCDMS can probe electron scattering from photon coupled light DM (O(MeV)). Si = blue, Ge = Red

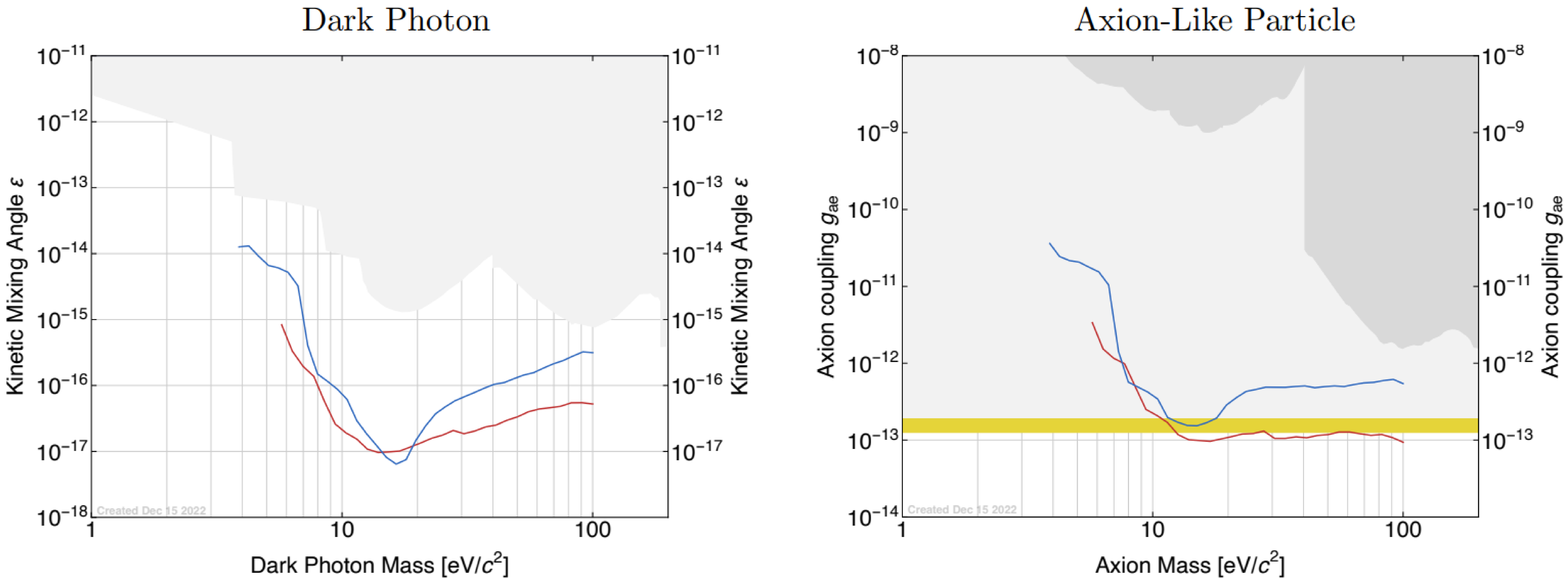




https://doi.org/10.48550/arXiv.2203.08463

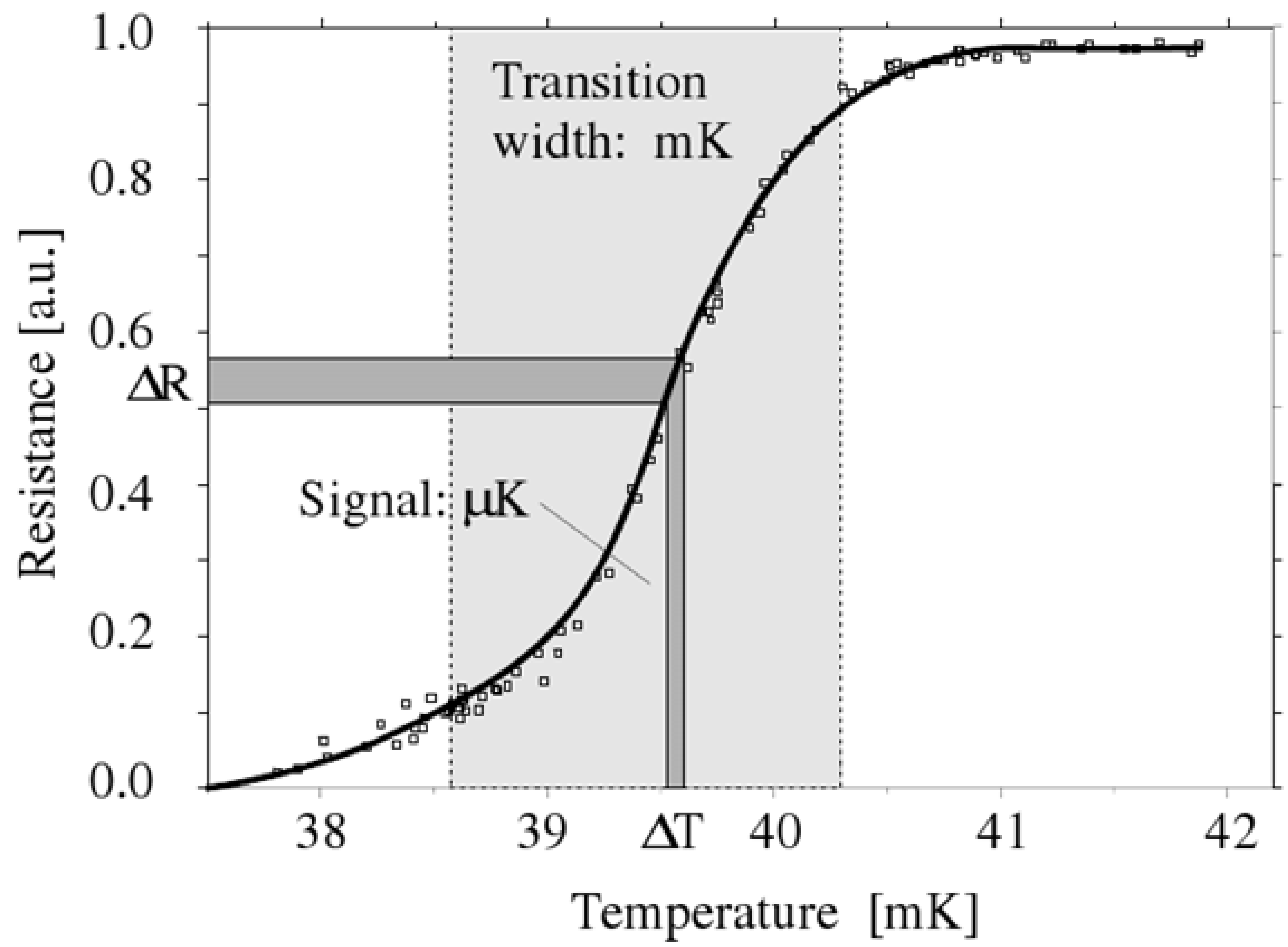
Absorption Sensitivity

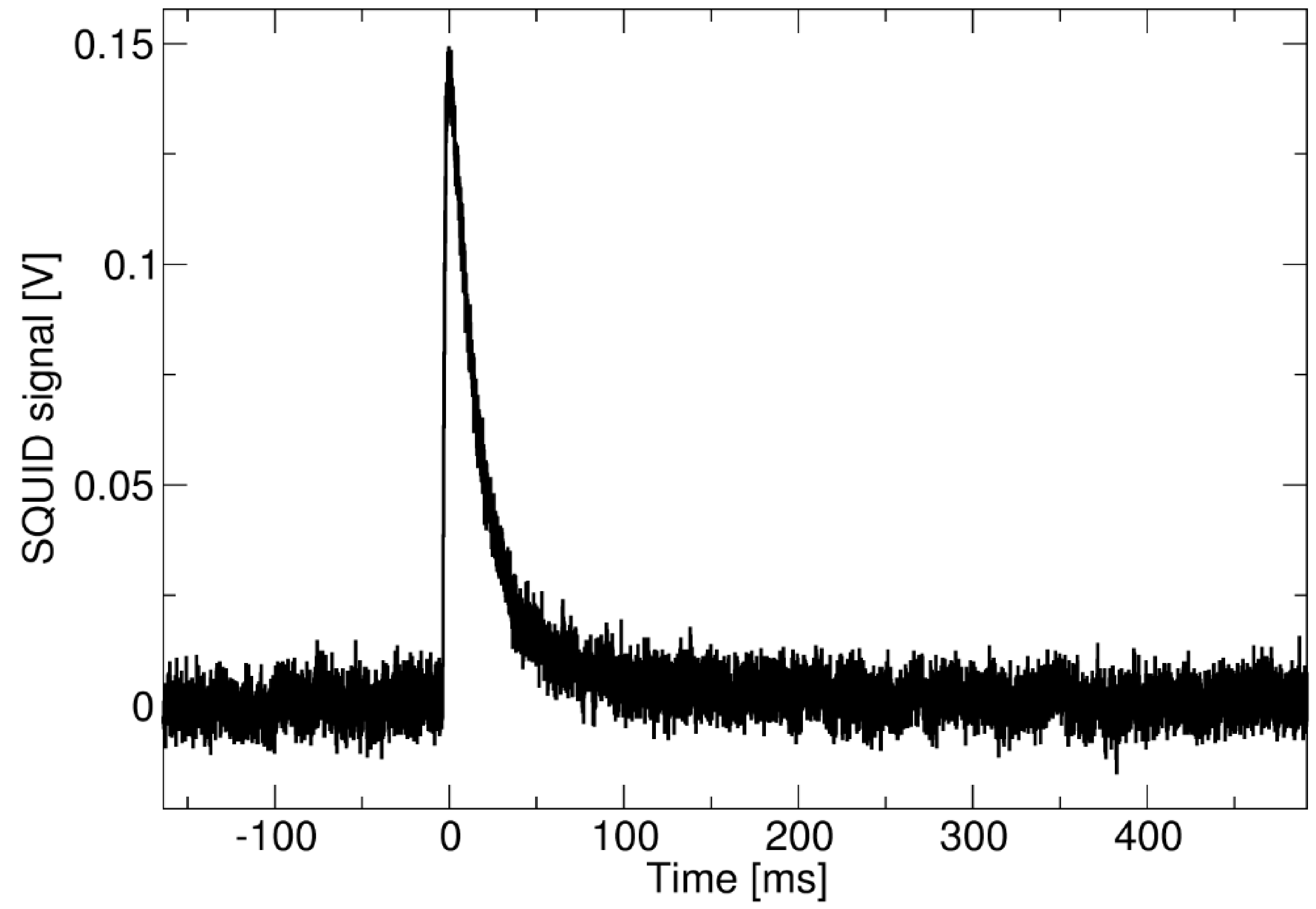
- SuperCDMS can probe even further by looking for dark photon (O(eV)) absorption (peak) or axion-like particle absorption (O(eV)). Si = blue Ge = Red



https://doi.org/10.48550/arXiv.2203.08463

Transition Edge Sensors (TES)

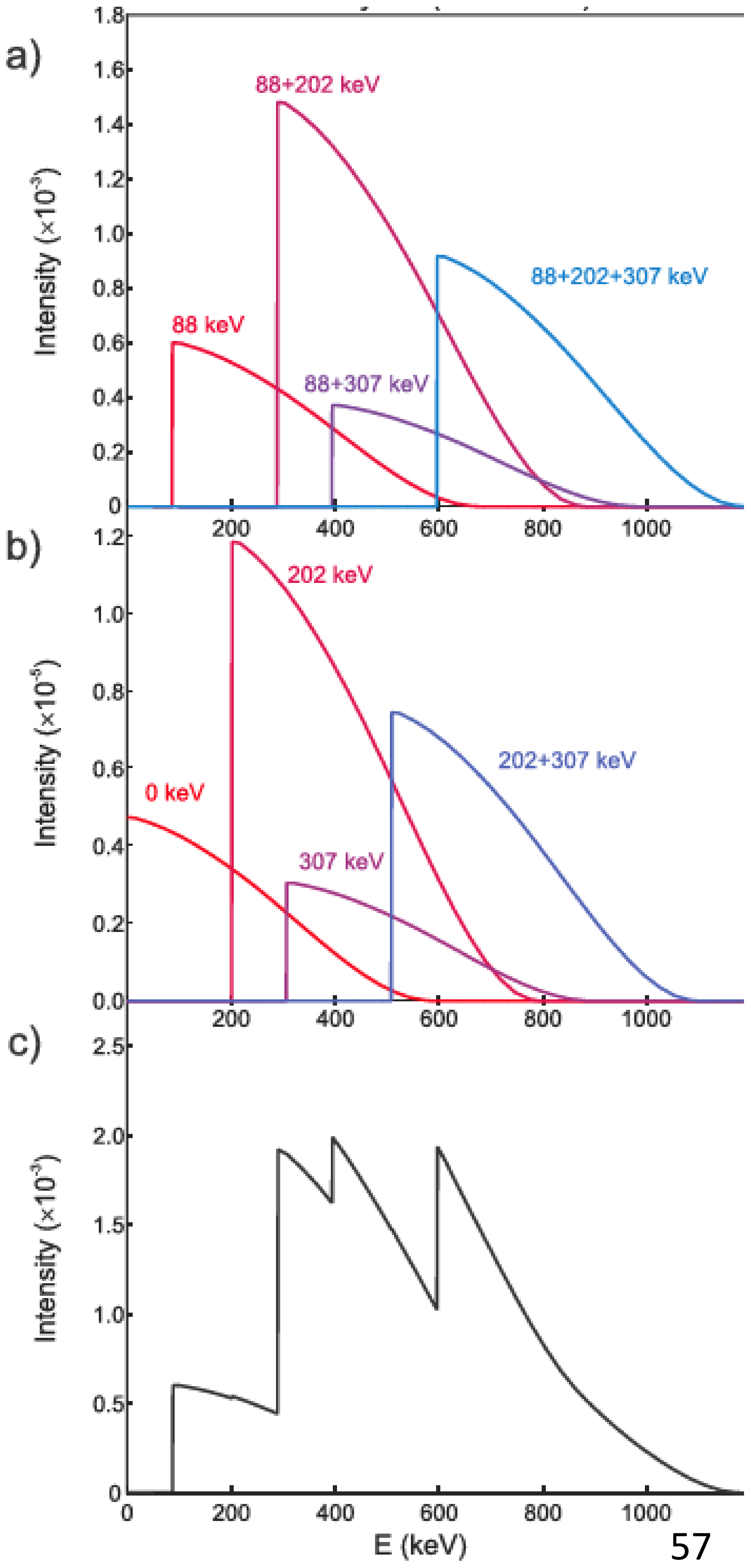




- Deposition of energy → Lattice vibrations (**Phonons)** → Change of temperature → Change in resistance → Signal
- Critical temperature reduced from 90 mk (Soudan) to 40 mk.
- TES are widely used in the field of rare event searches

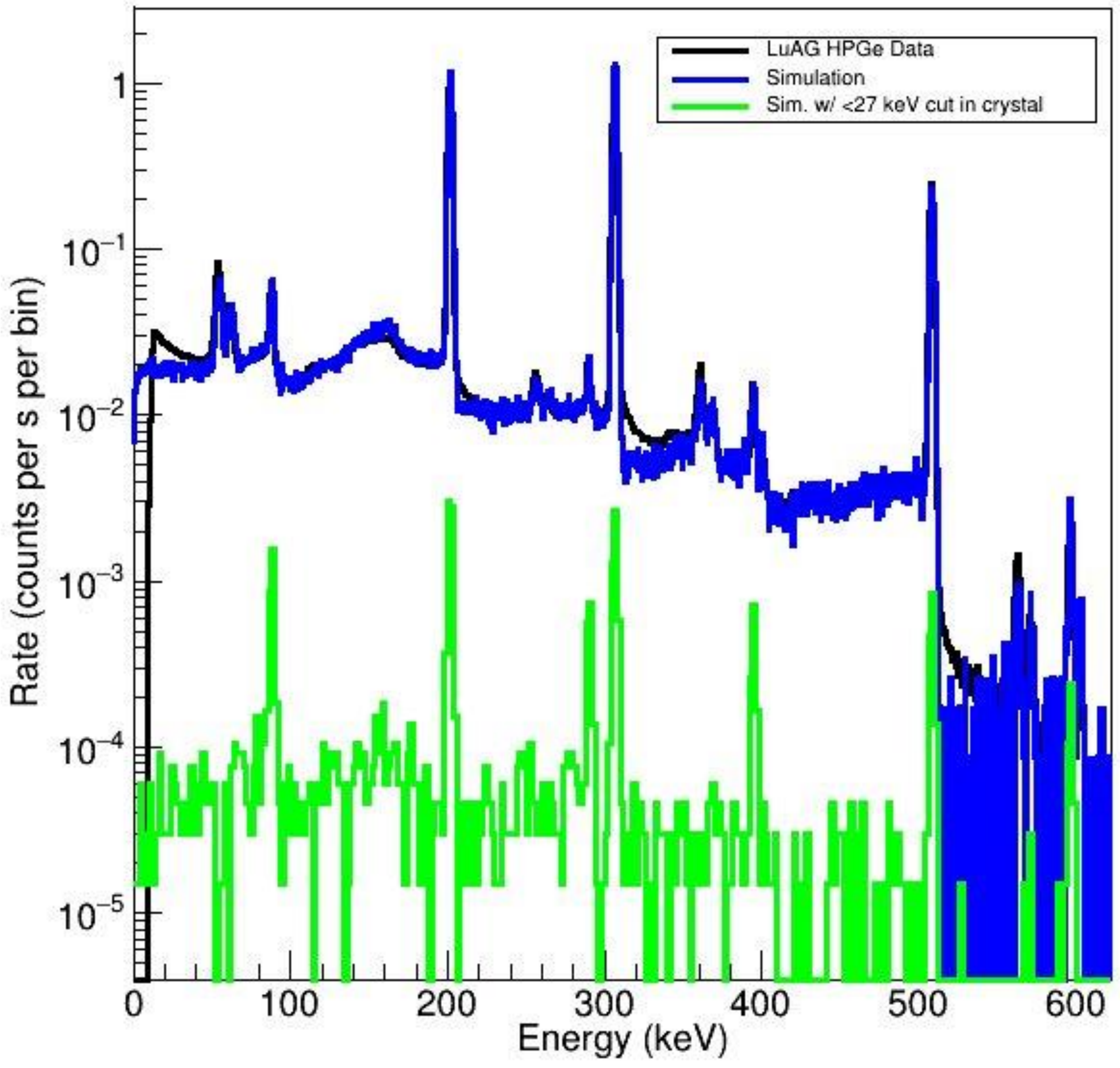
Understanding the Spectrum of ^{176}Lu

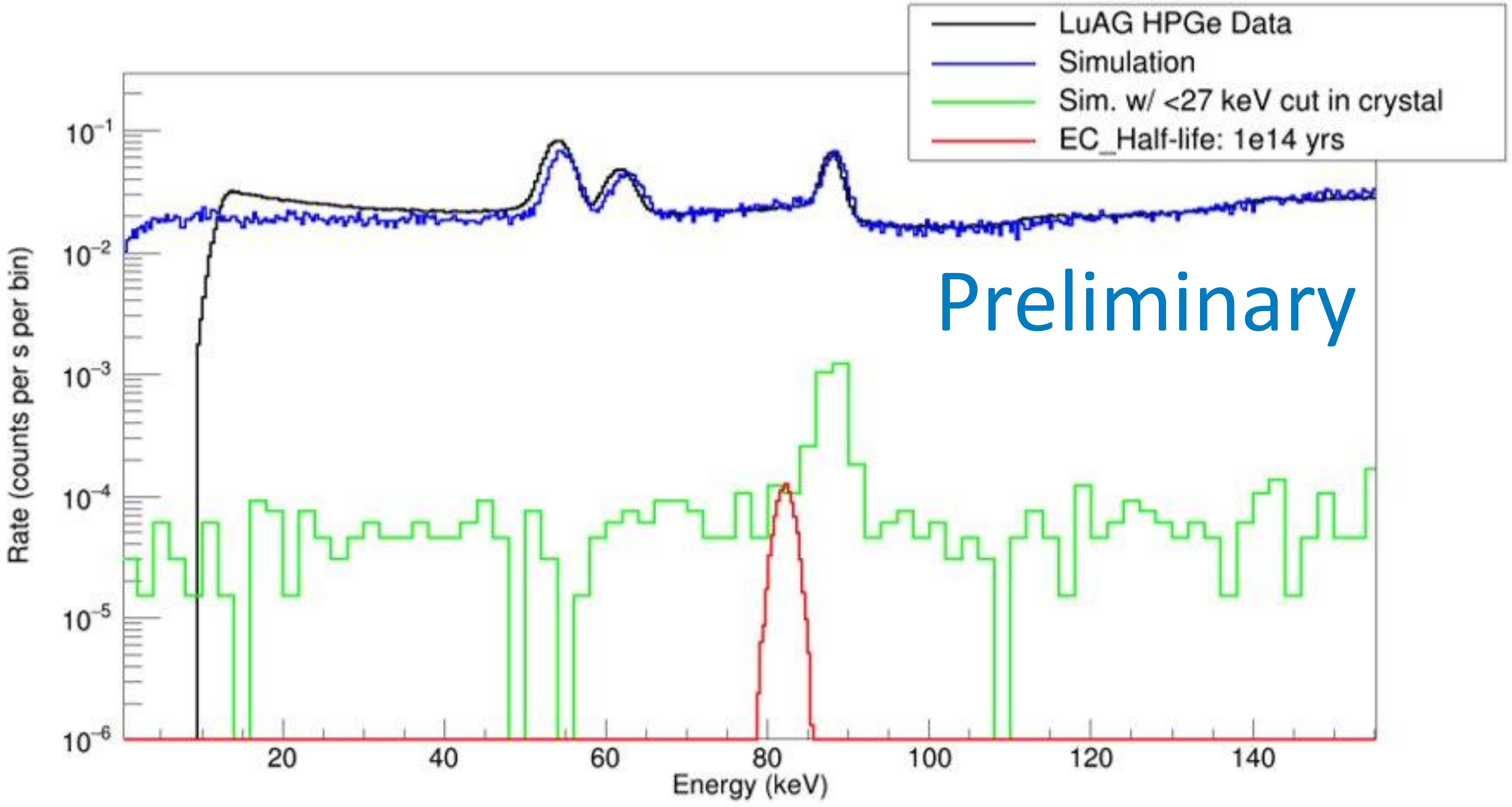
- If measured on a pure HPGe primary background is β^- decay.
  - Significantly limits the sensitivity
- Need a way to remove it!
- Lucky!!!!
  - EC Q-value = 109 keV
  - With gamma at 82 keV means only 27 keV available for the electron capture
  - K-shell capture is not possible!
- Coincidence technique: <u>**SiPM + HPGe**</u>



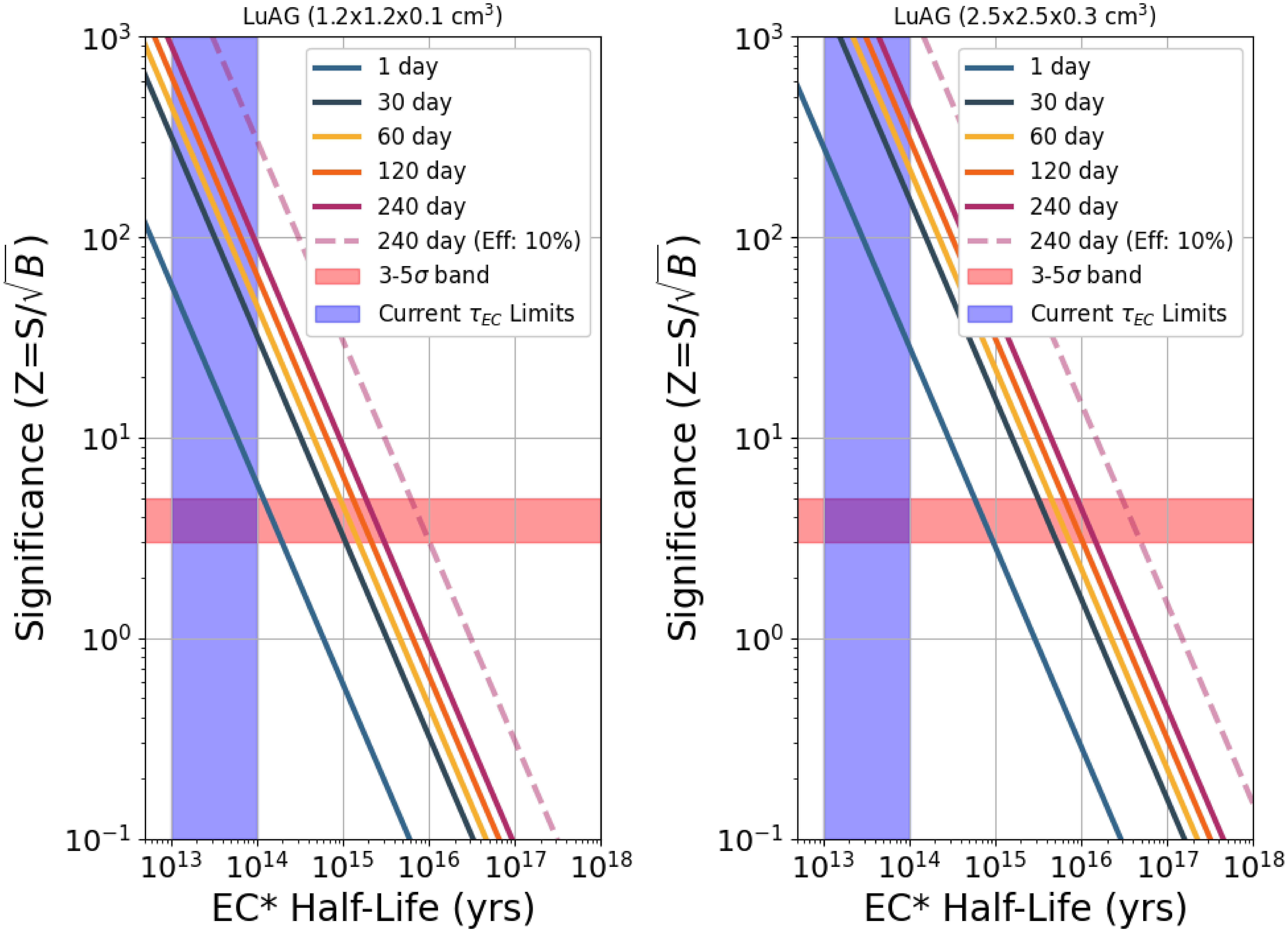
Experimental Design

RAMPS: Experimental Technique



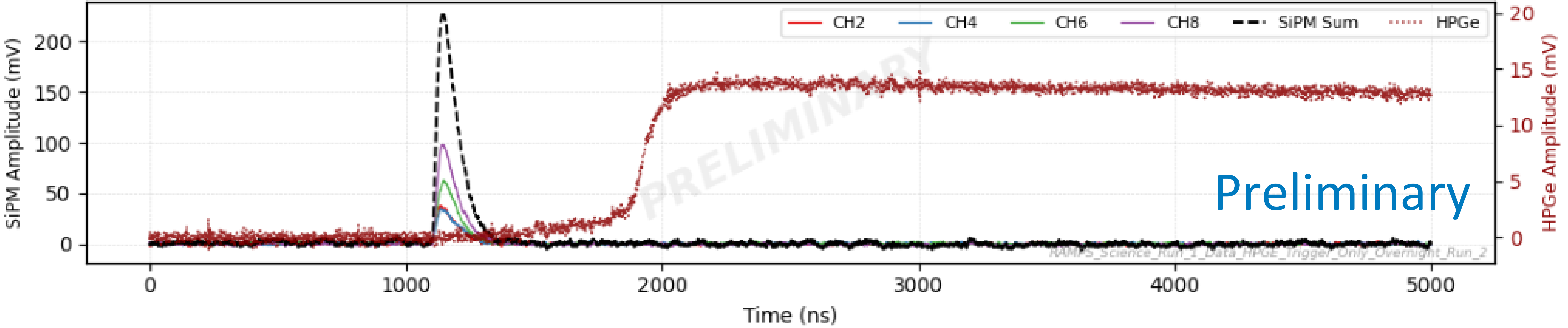


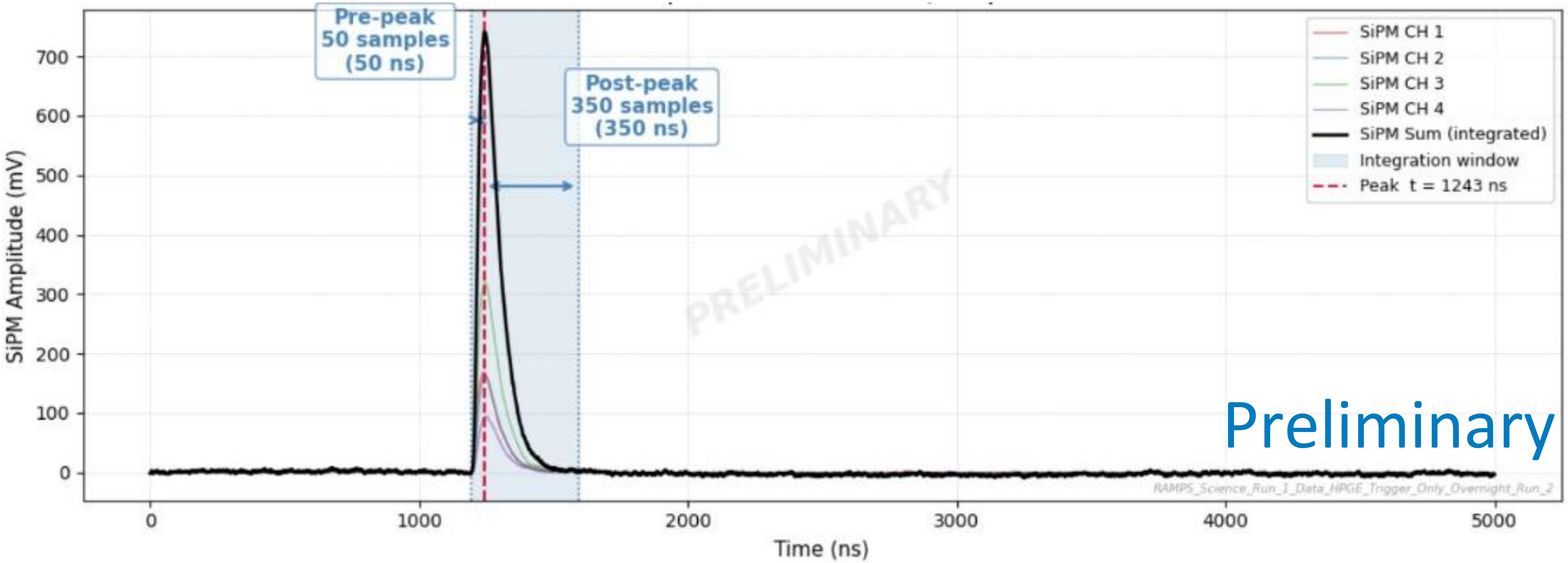
- An energy cut of <27 keV in the SiPM channel will reduce the β- events by >99%
- HPGe has the resolution to separate 82 keV vs. 88 keV



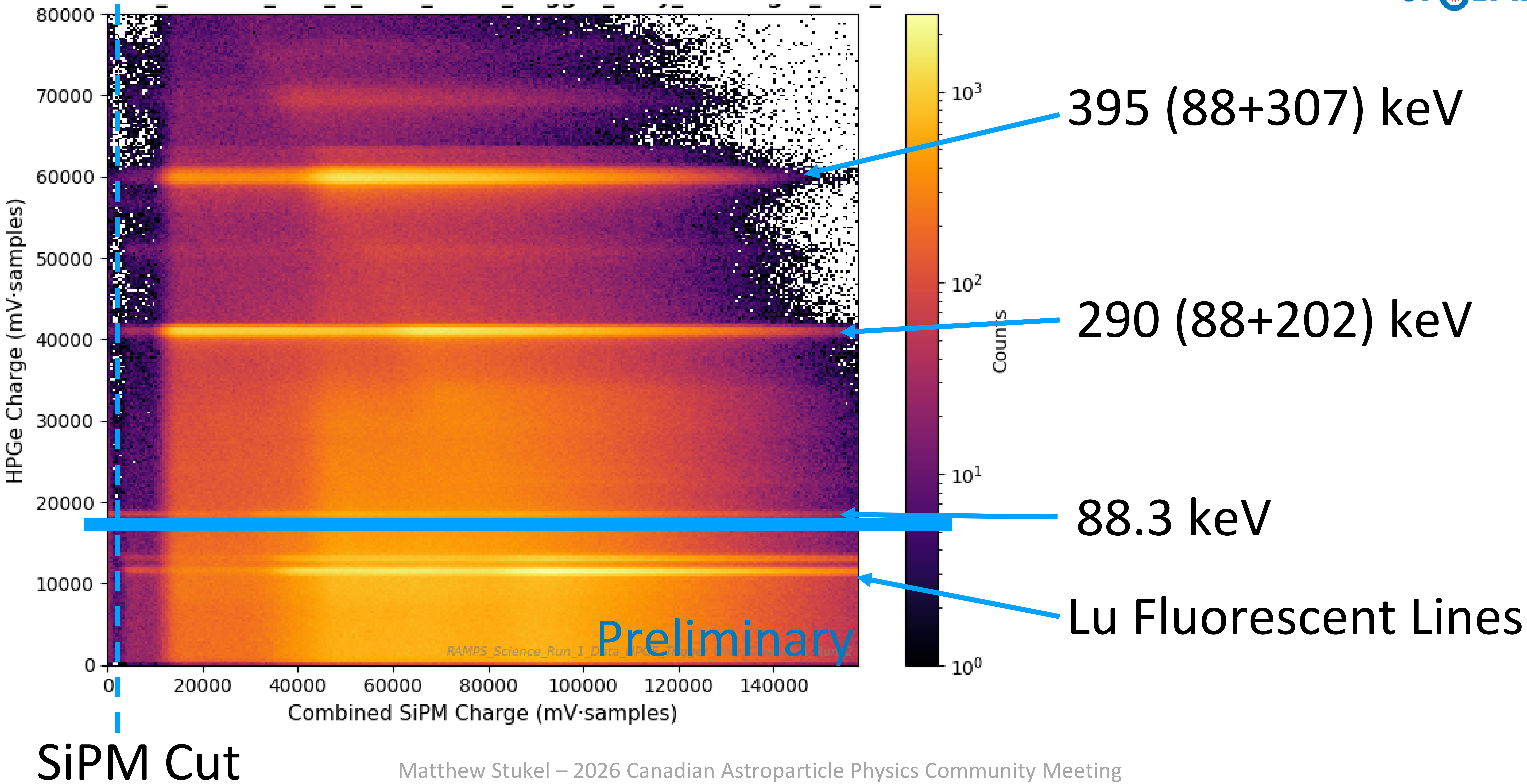
- Meet current limits with a single day of runtime
- Potentially surpass by 2 orders of magnitude
- Actual crystal was 5x5x0.5 cm^3

RAMPS Science Run 1: First Pulses

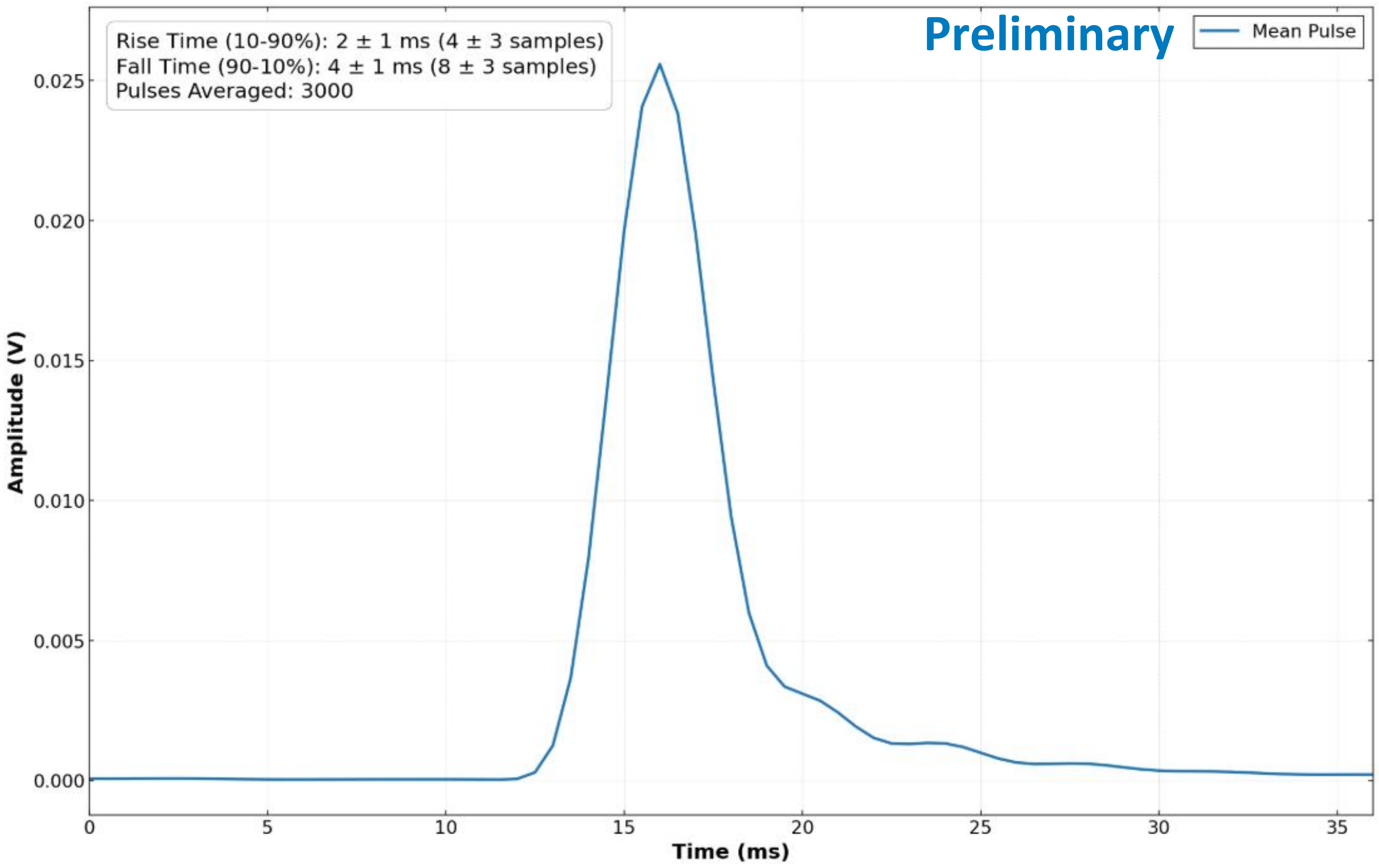




RAMPS Science Run 1: Coincidence Spectrum

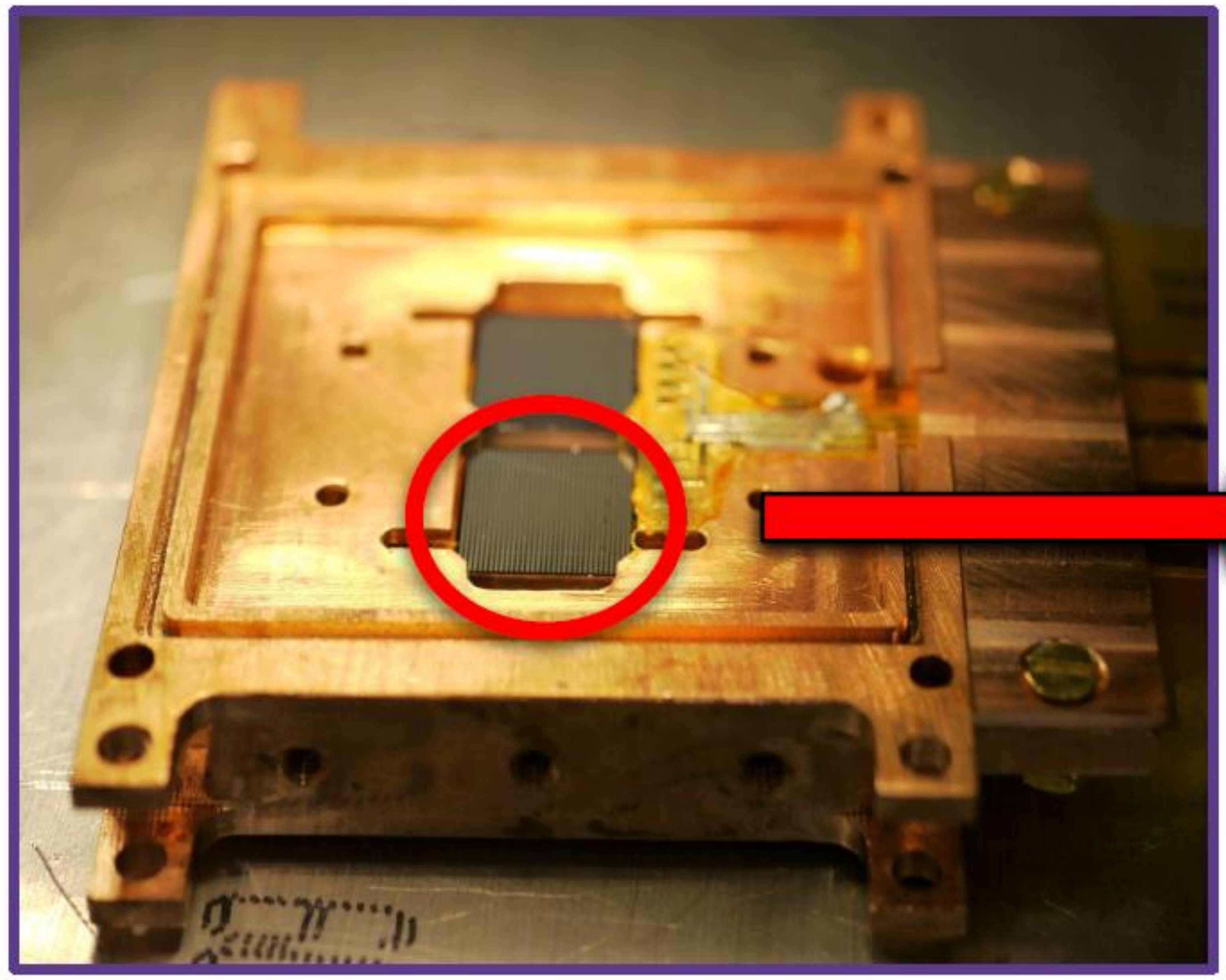


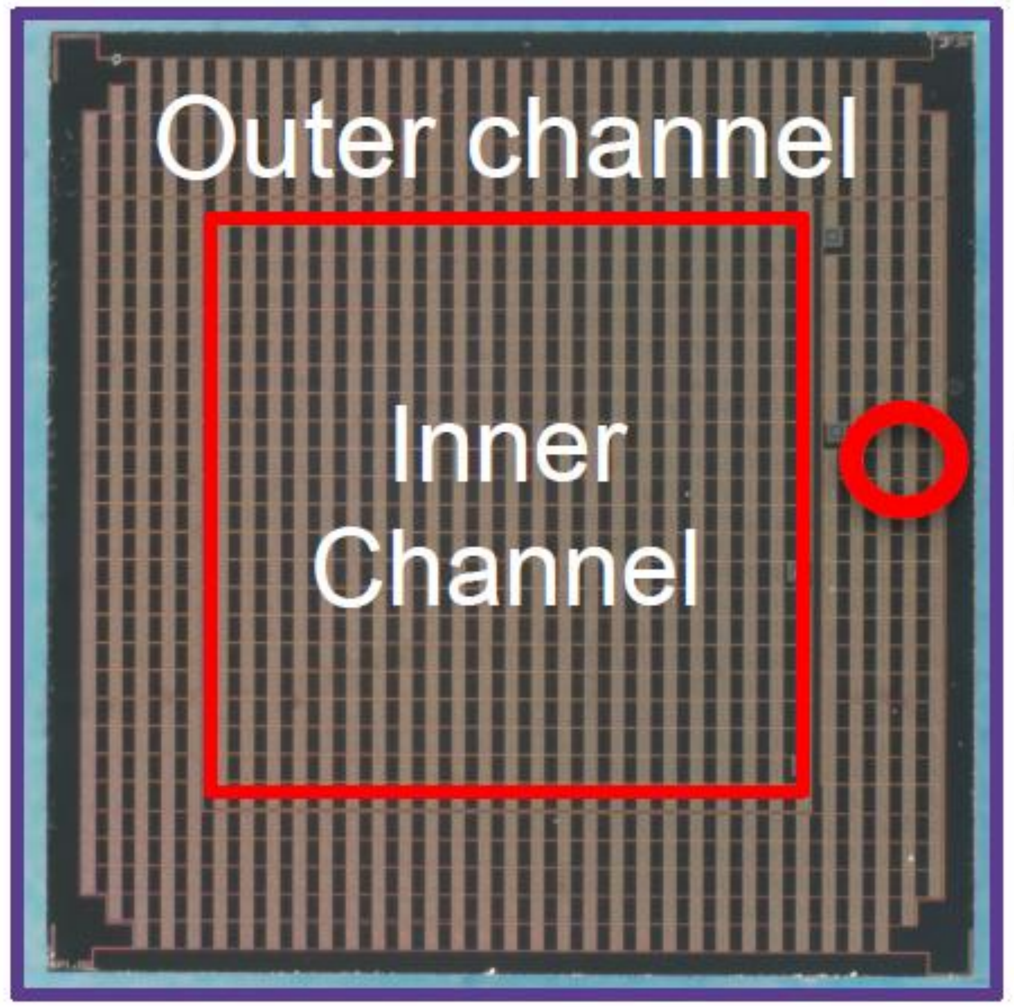
LYSO Cryogenic Calorimeter Results

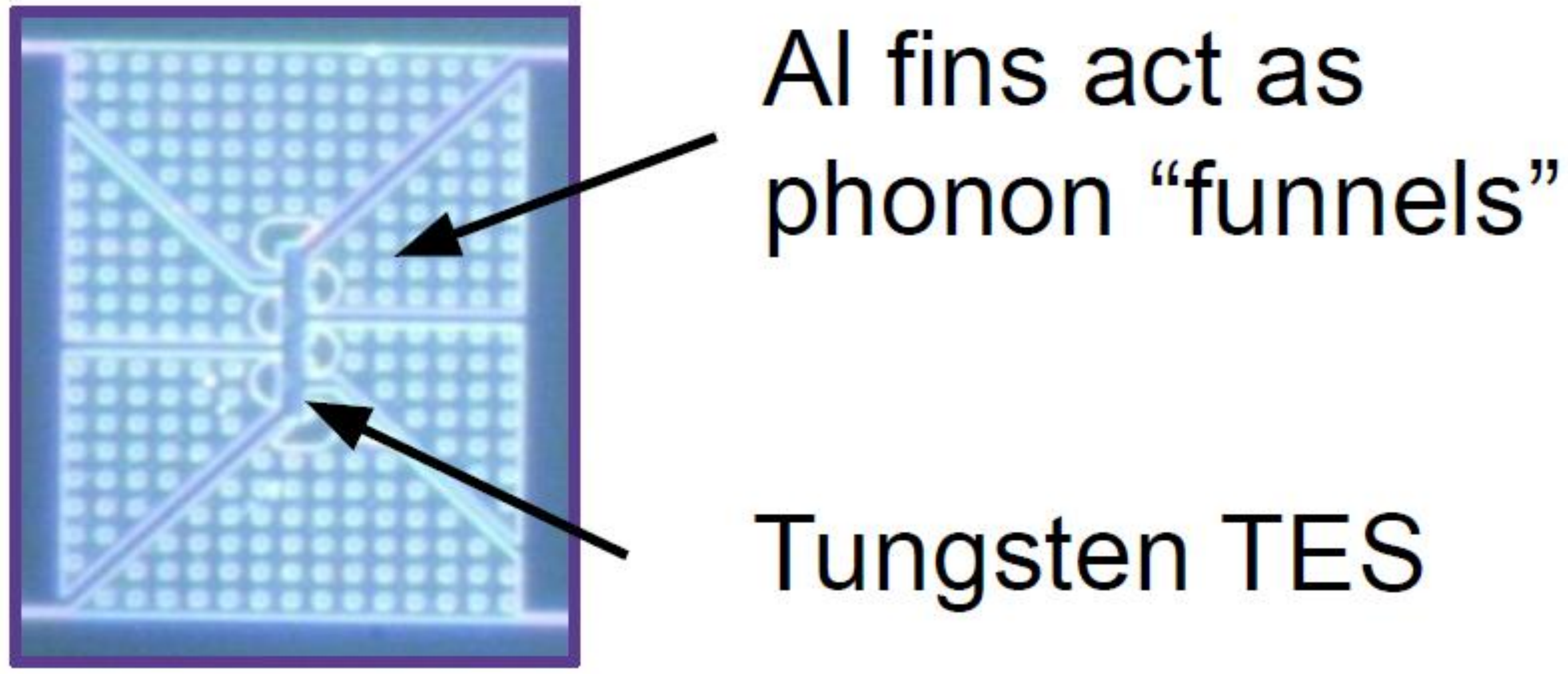


- Data was processed through electronics positioned at room temperature [6]
- The readout electronics consist of low-noise DC coupled front-end boards operated at room temperature and high-resolution digitizers
- Data was digitized in “continuous” mode, and a matrix profile trigger was used
- Sampling frequency was 2 kHz
- Rise Time (10-90%): 2 ms
- Fall Time (10-90%): 4 ms

SuperCDMS- HVeV Program

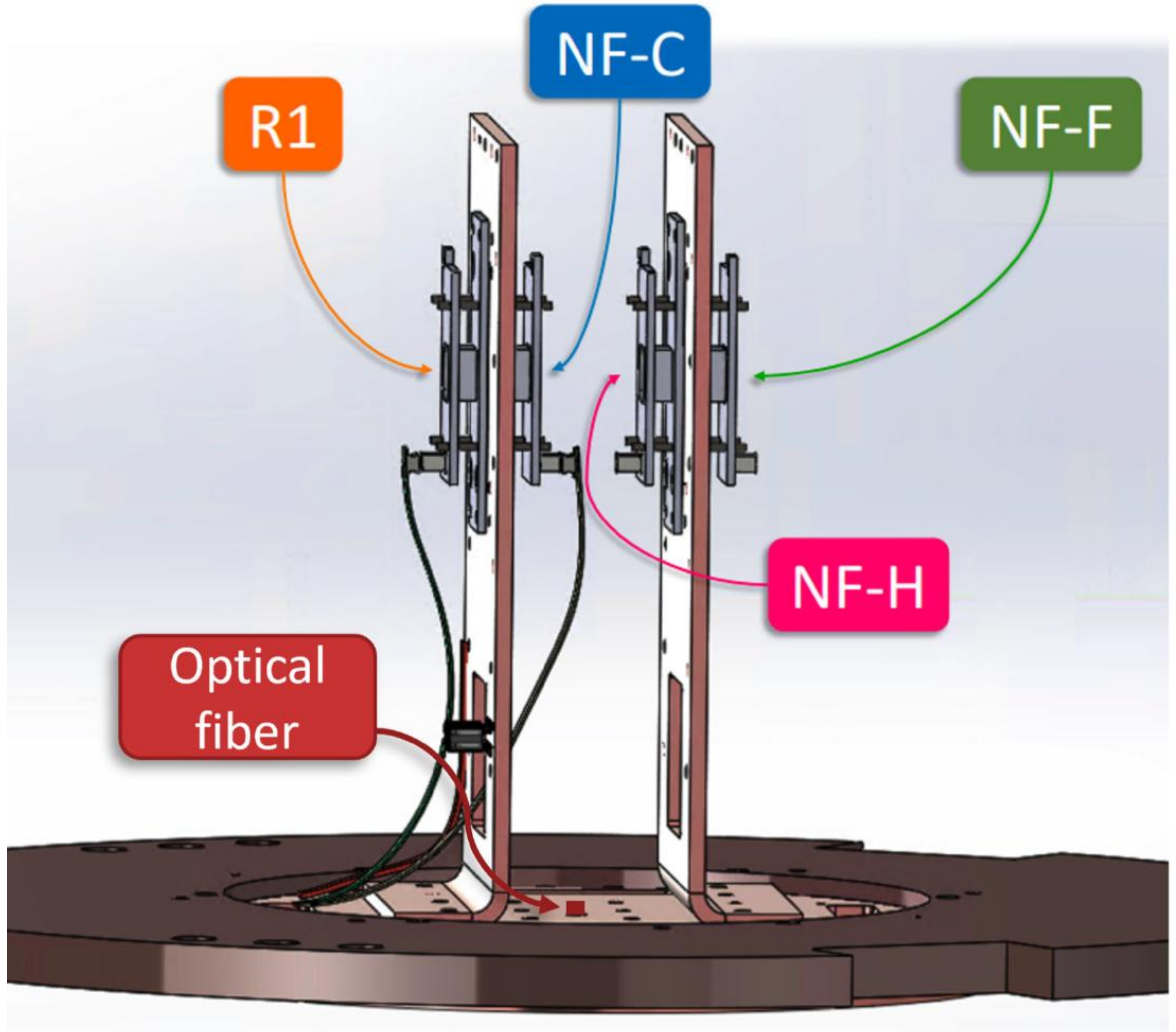


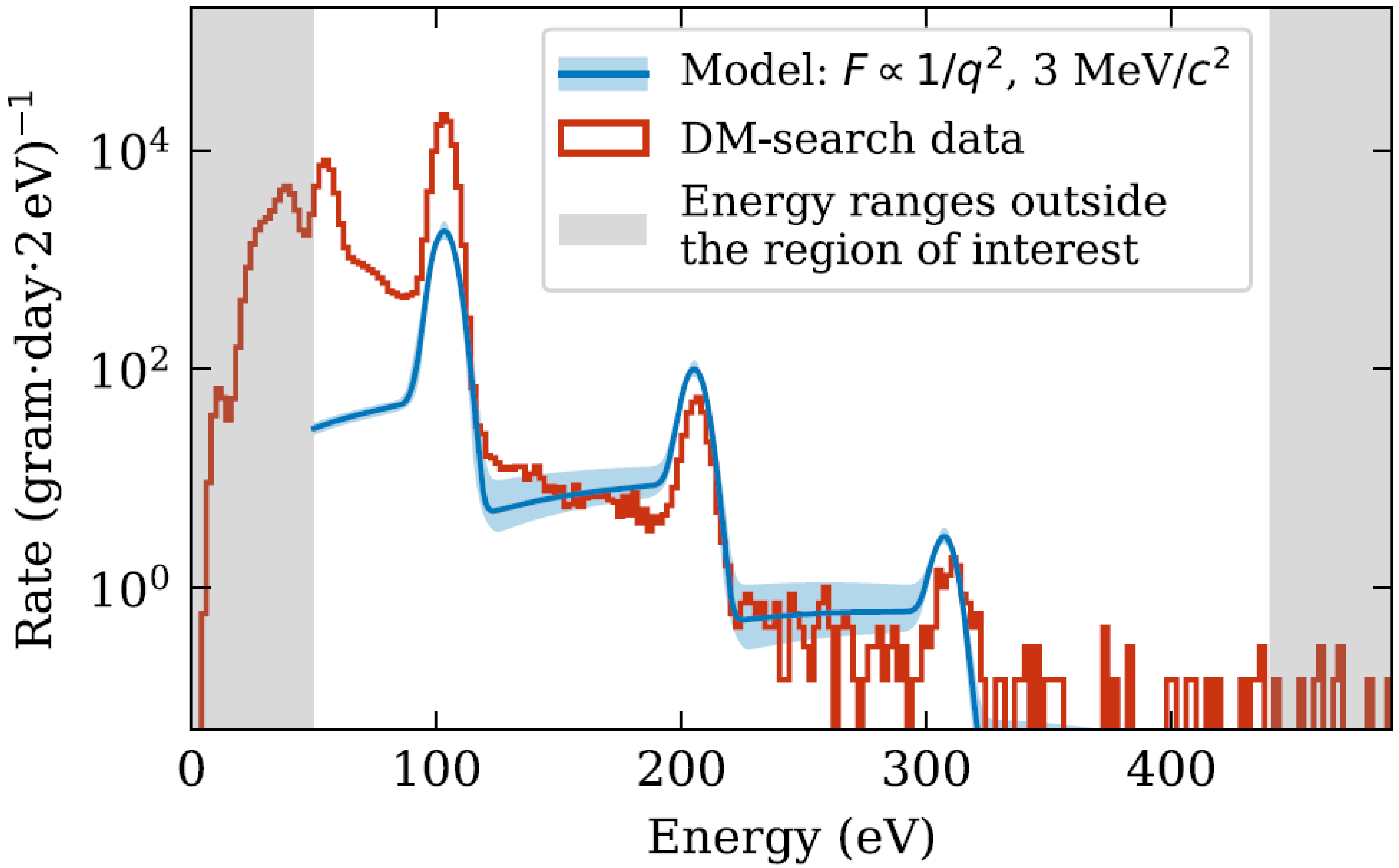




- Gram-scale detectors aimed at achieving eV energy resolution
- Si: 10x10x4 mm^3
- Two channels (inner and outer), similar technology to SuperCDMS detectors
- Background studies, Low-mass dark matter searches

HVeV Run-3

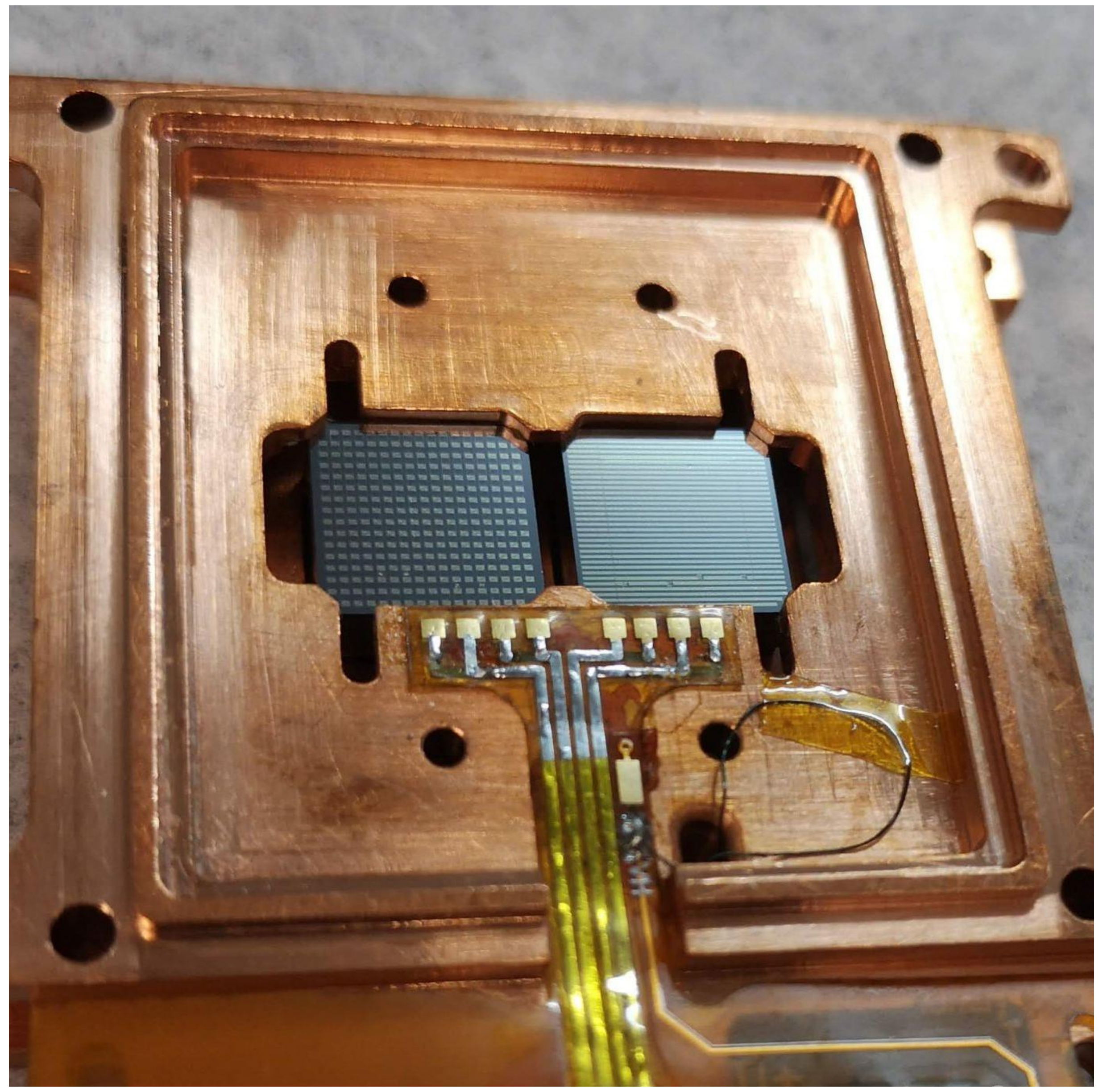


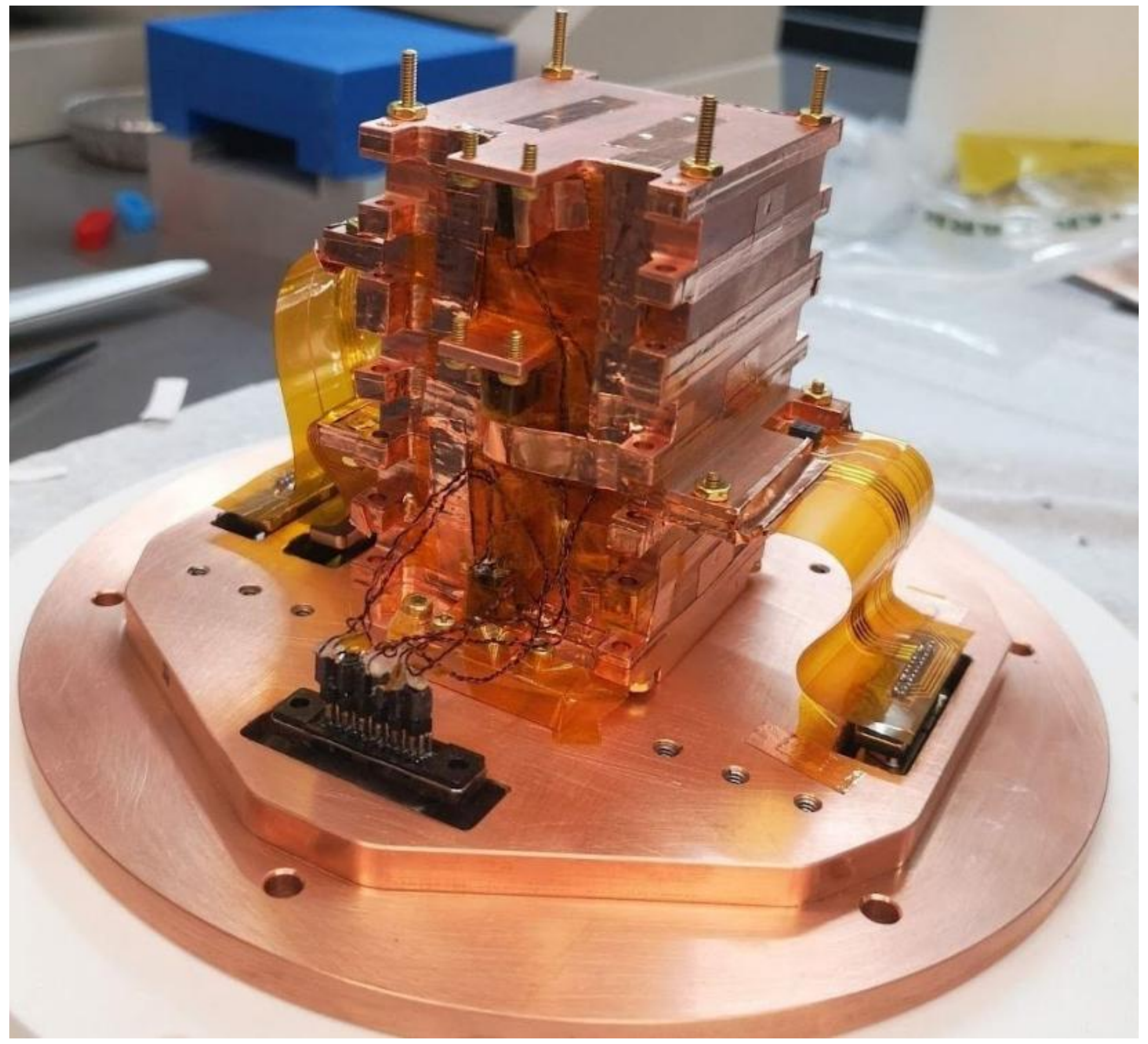


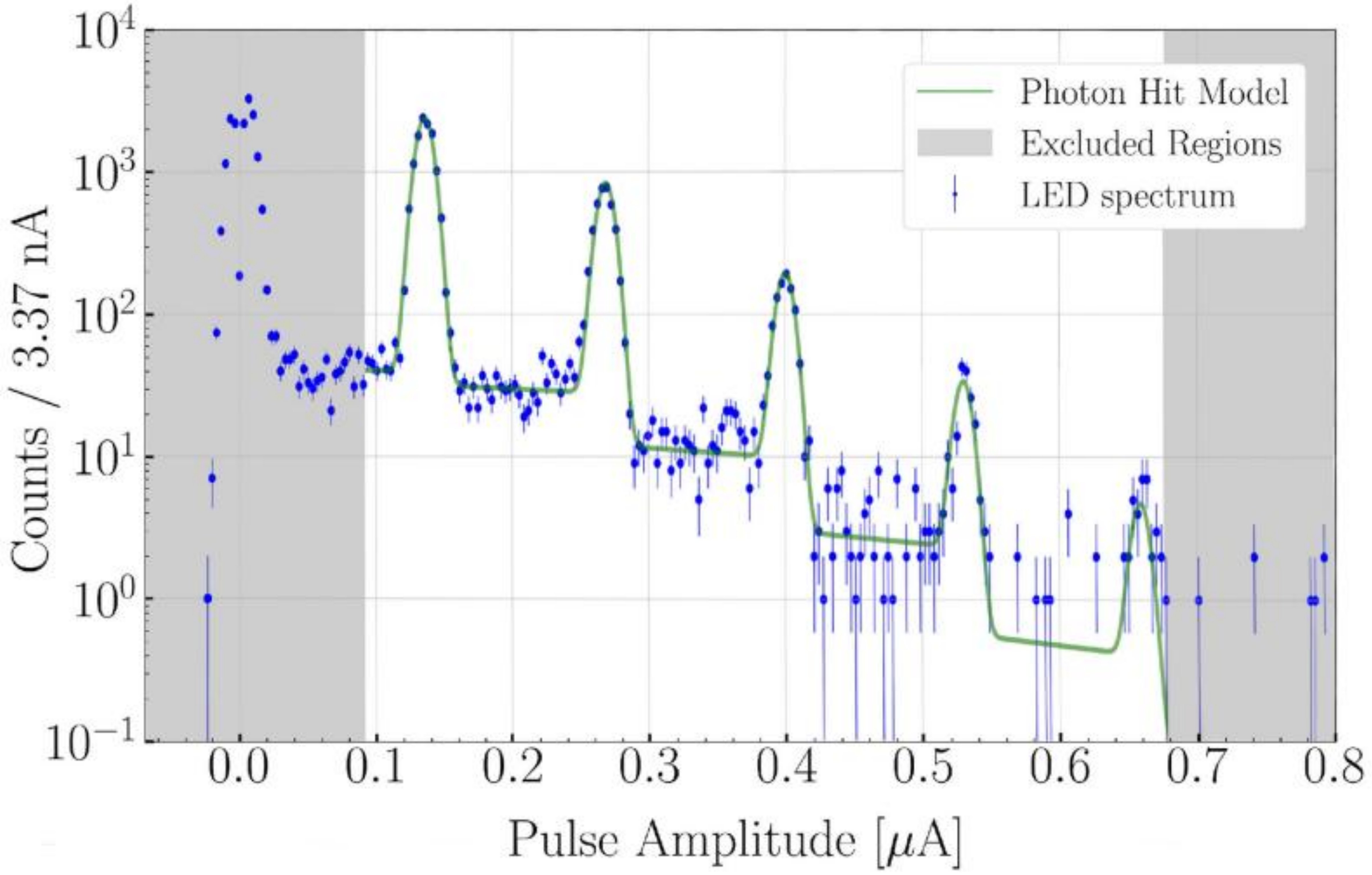
- First underground Dark Matter search using the NEXUS facility
- Achieved a 3.03 eV baseline resolution, w/ 100 V applied
- Optical fiber allows for detector calibration
- Burst events present in data due to luminescence of the PCB

https://doi.org/10.1103/PhysRevD.111.012006

HVeV Run-4

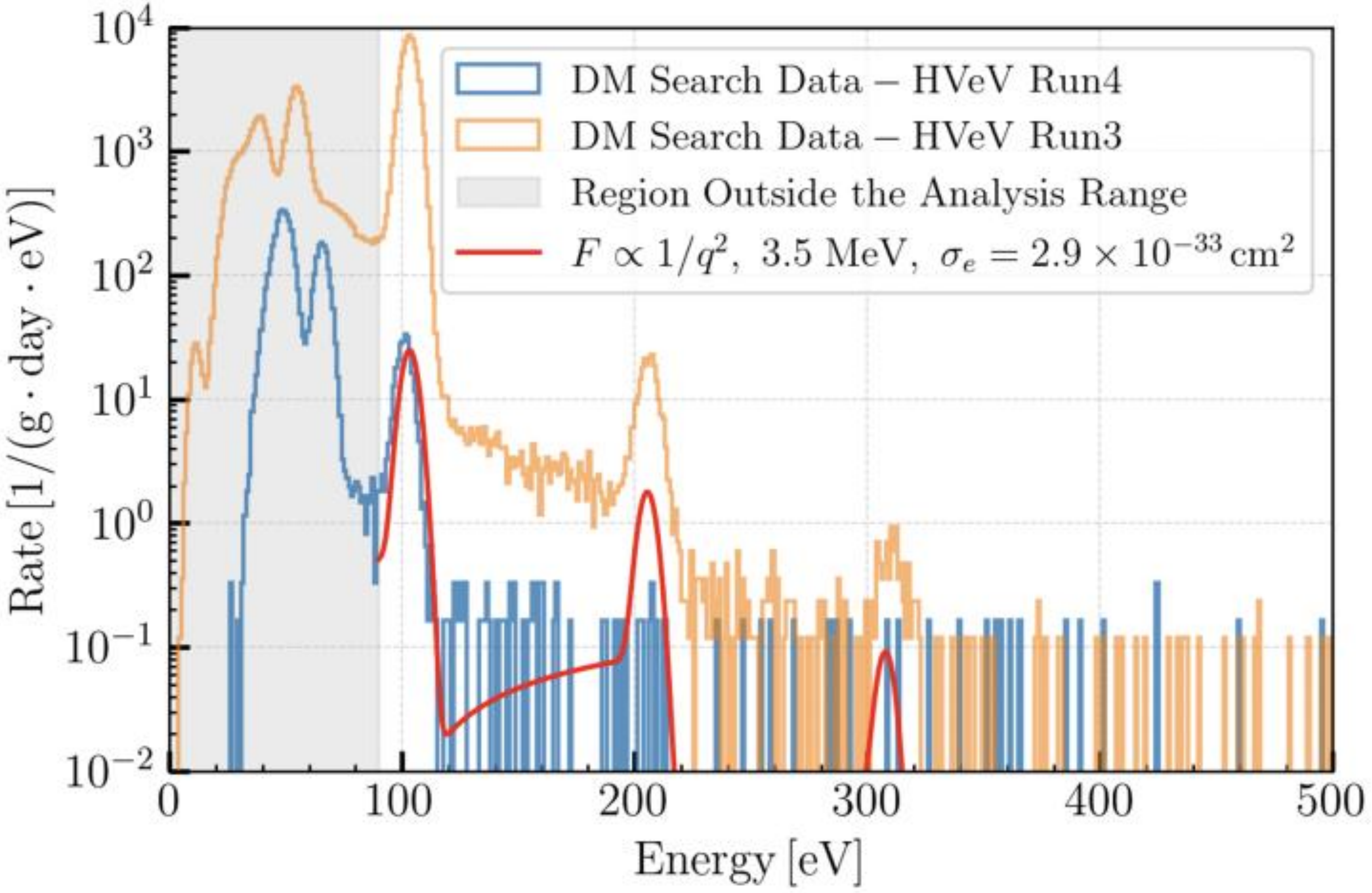






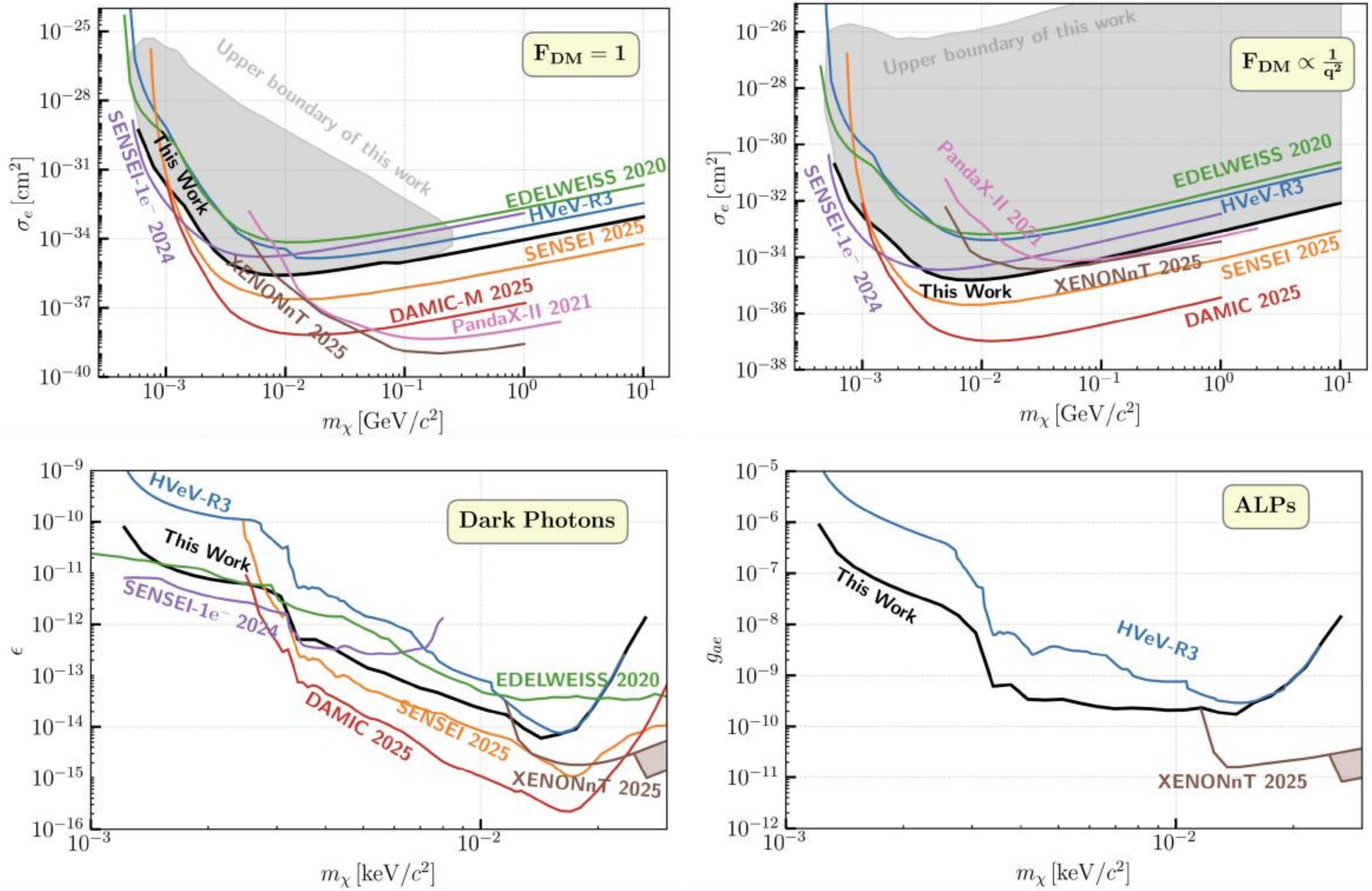
- Improved light-tight copper housing with individual LED for each detector
- Baseline Resolution: 3.2 +/- 0.1 eV
- https://doi.org/10.1103/5lnp-6mng

HVeV Run-4: Comparison

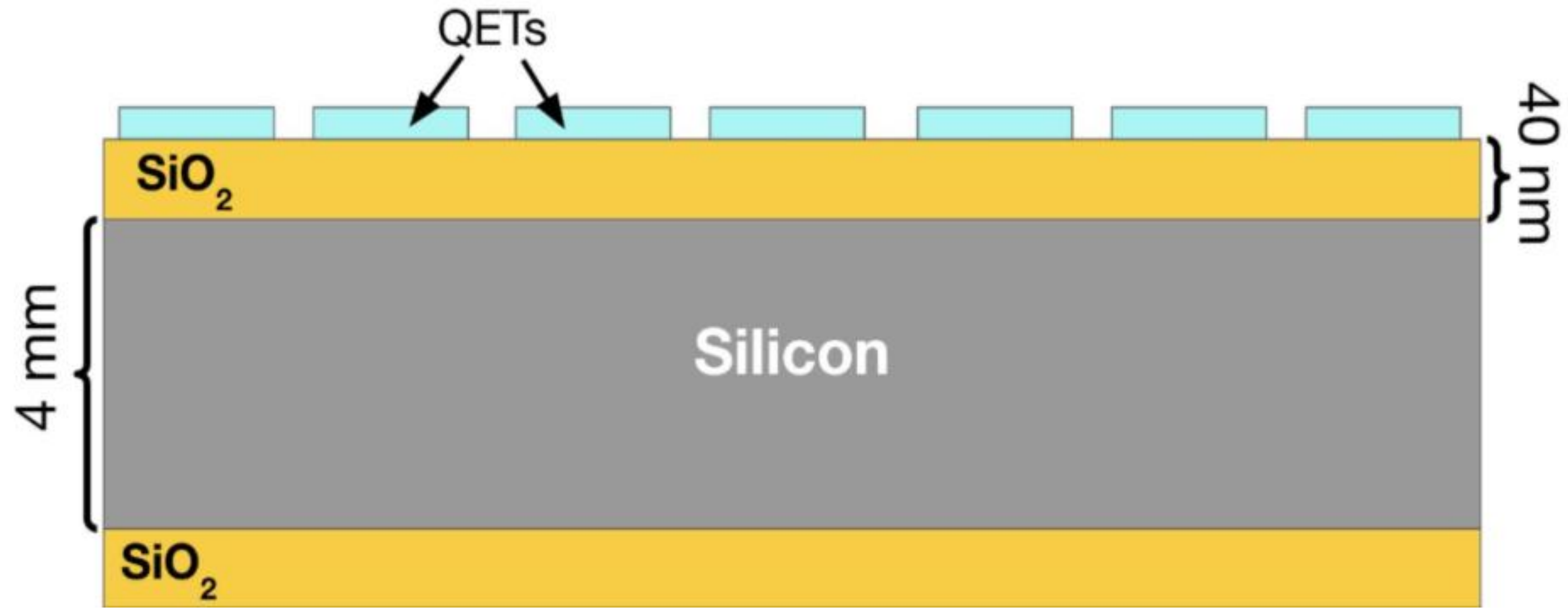


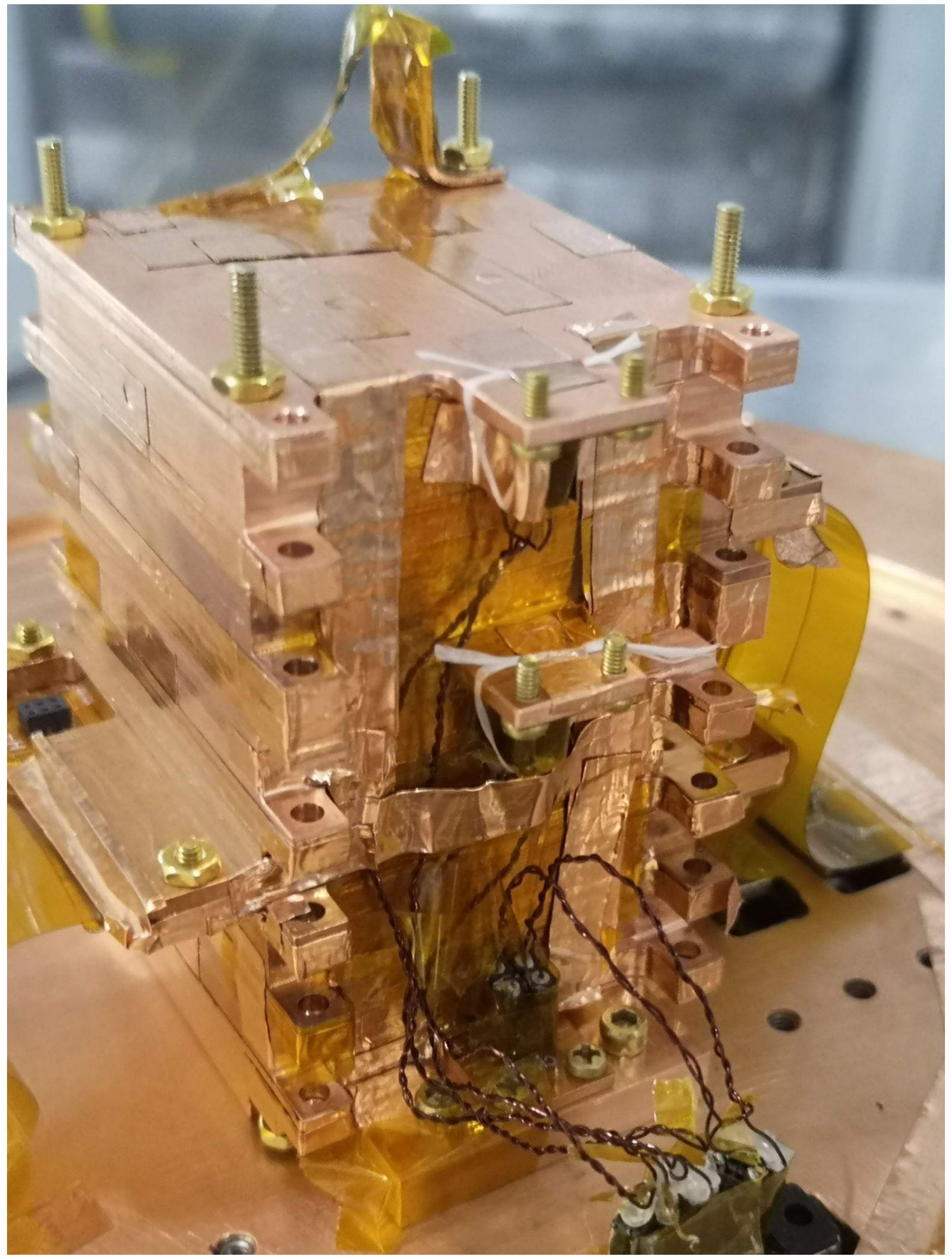
Significant improvement in the background energy spectrum at the 2 and 3 eh level

HVeV Run-4: Results



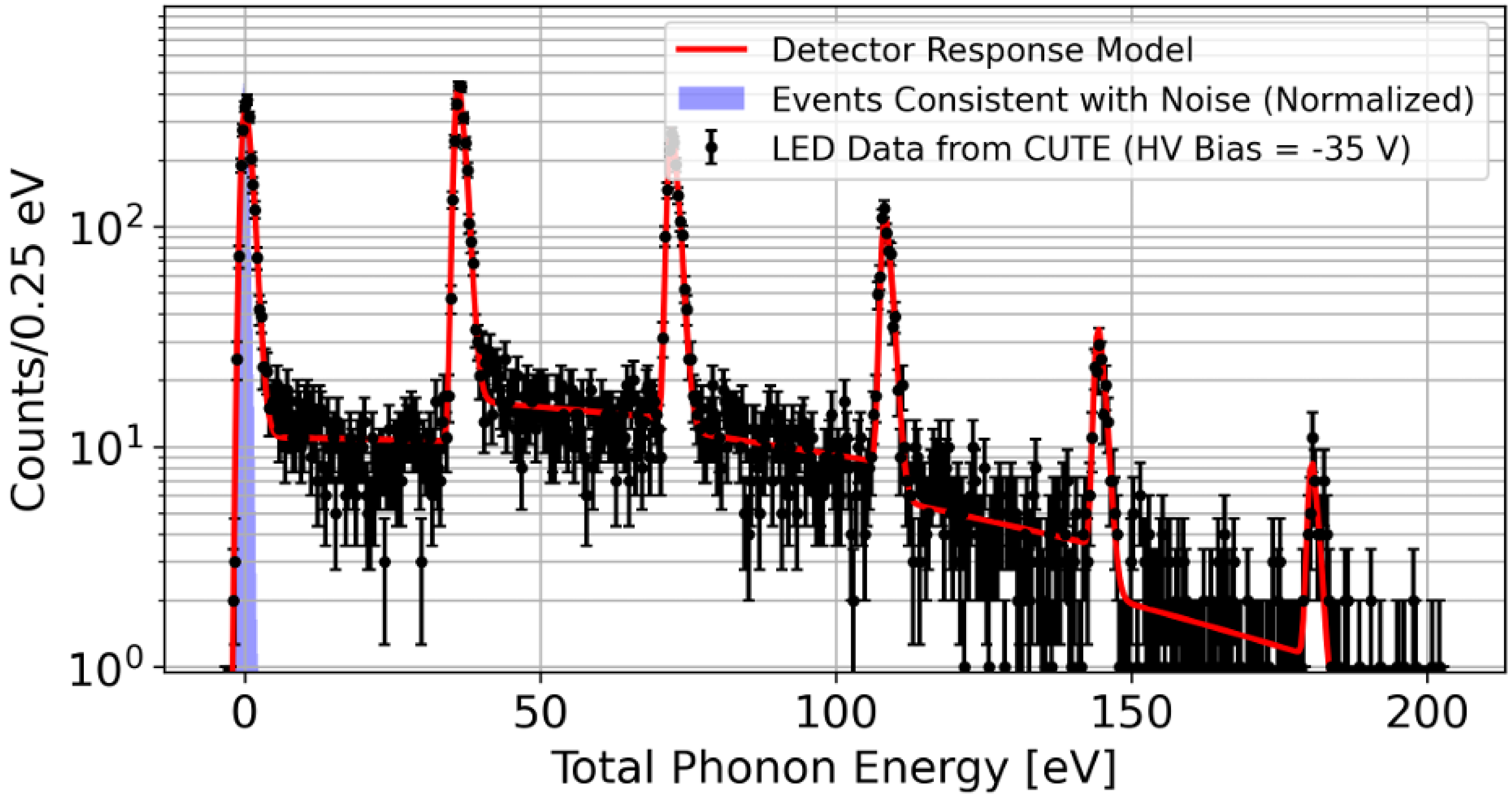
HVeV-Run 5





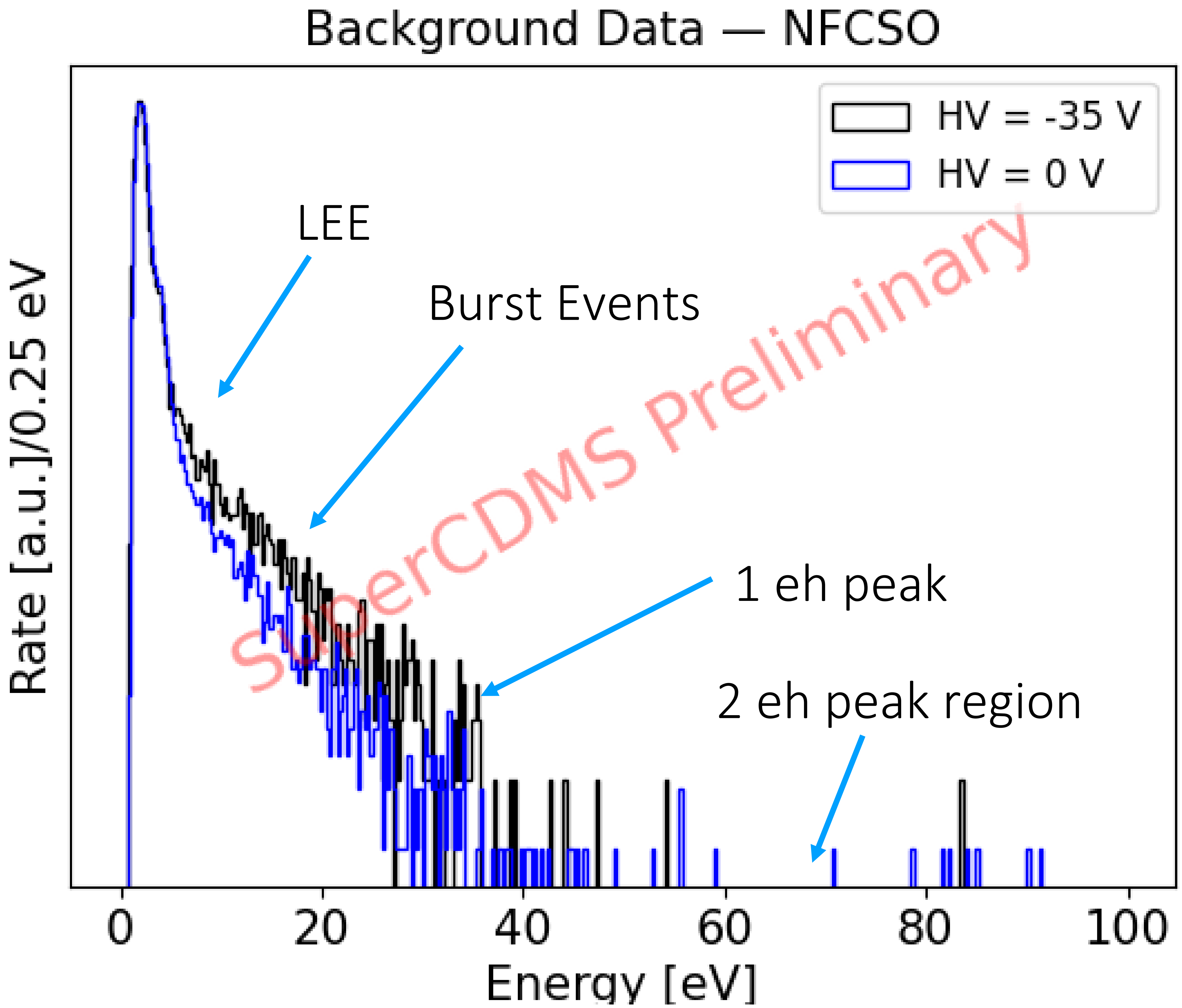
- Ran 6, 1g Si detectors capable of reaching 1 eV threshold at the CUTE facility
- Two new detectors with lower T_c (60 -> 45 mK) and SiO_2 layer to reduce leakage from QETs
- Detector tower was put into CUTE at the end of March, 2024 and ran until the end of September

HVeV – Run 5 Results



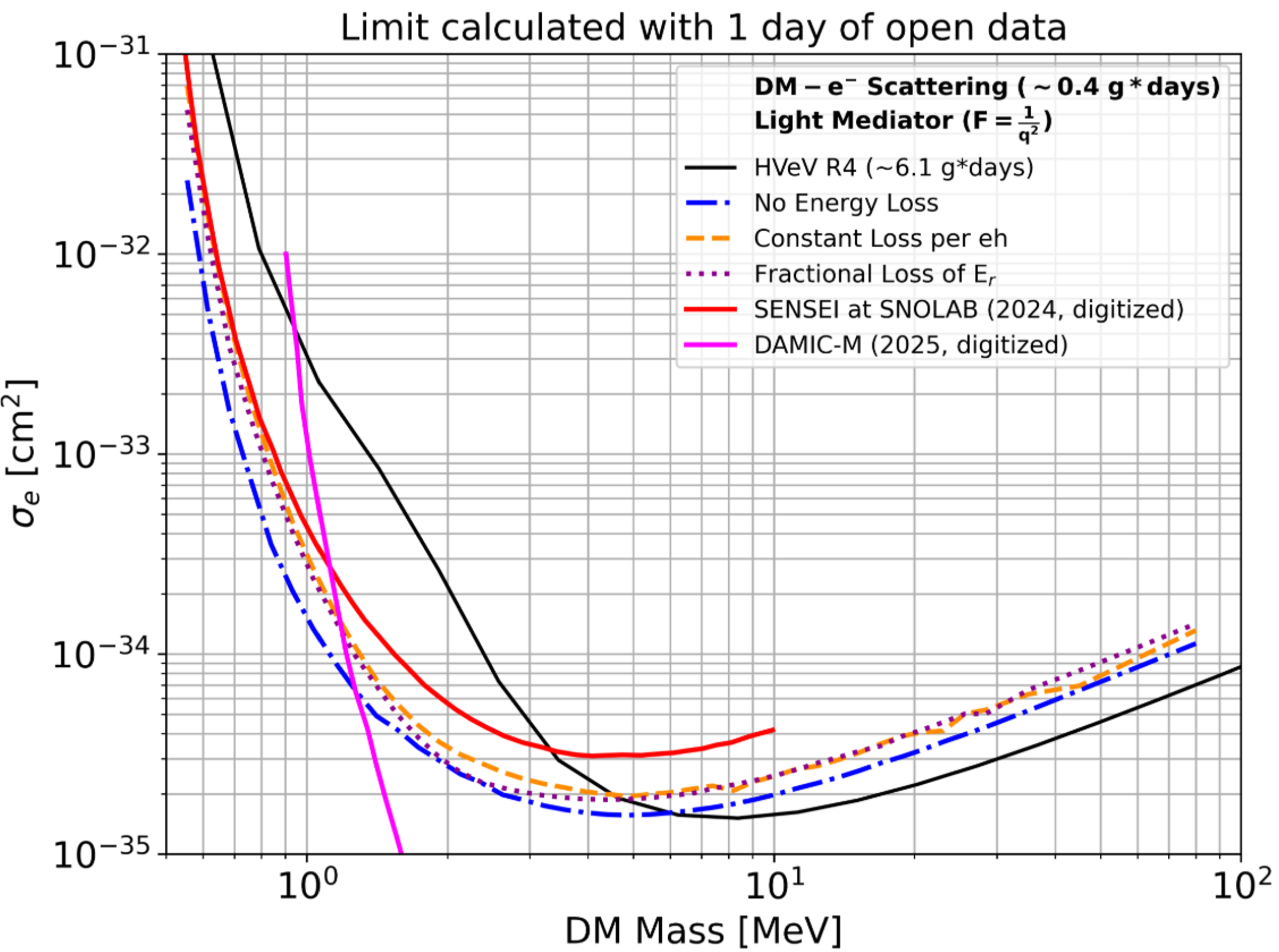
- HVeV achieved a baseline resolution 589 meV ± 4 meV
- Calibrated with 2 eV photons
- https://doi.org/10.48550/arXiv.2601.16307

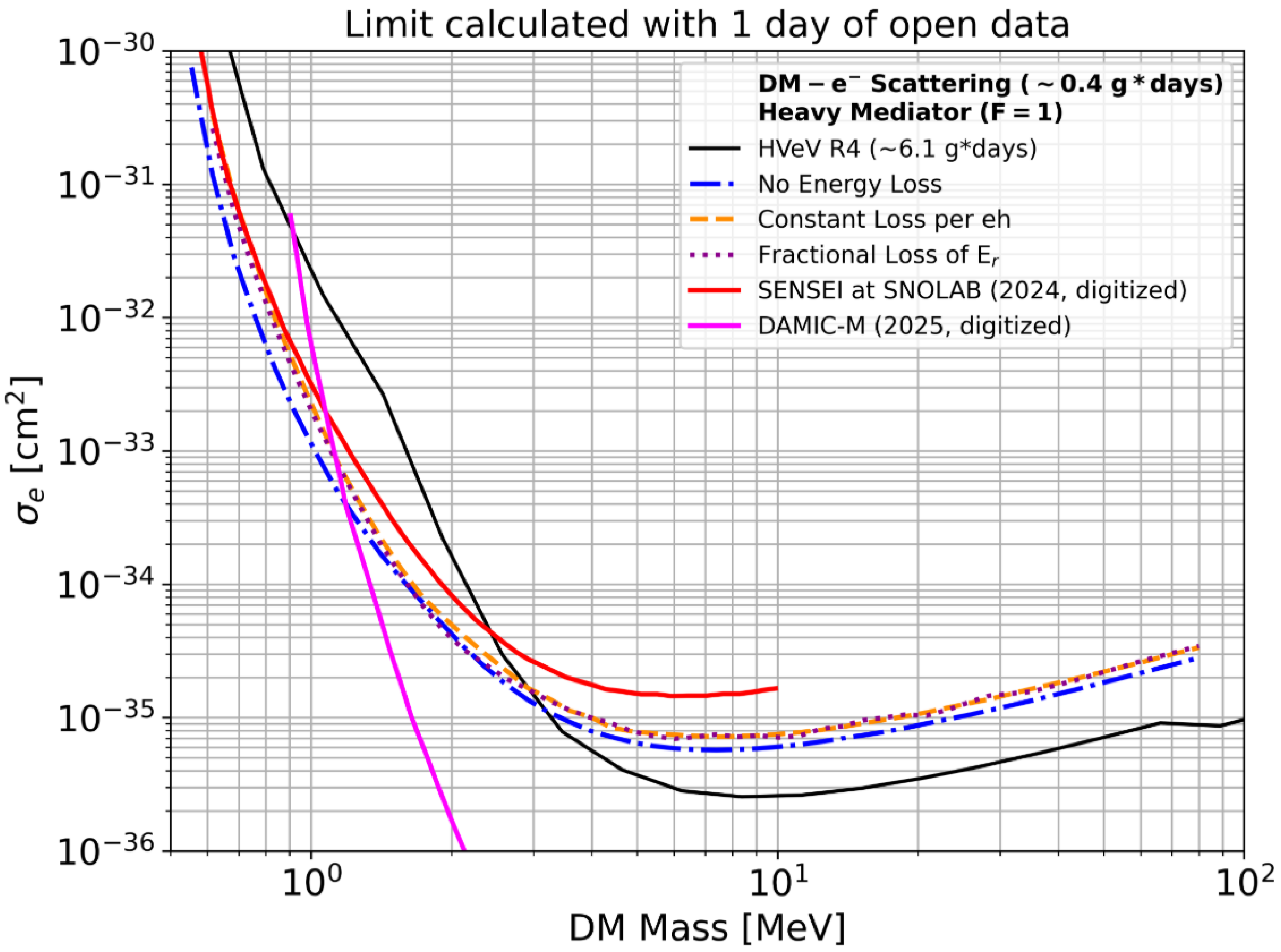
HVeV – Run 5 Results



- Reduced 1eh rate compared to Run 3 and 4
- Took DM search data (-35V for 10 days of exposure)
- 1 day of data is unblinded. Full data will be shown very soon!

HVeV – Dark Matter Search





- <u>World leading below 1.2 MeV</u>
- Surface trapped events (eh recombine) don’t yield NTL. Leads to lose of energy (0.9 eV per photon)
- Further unblinding would expect a facto of 10 improvement at higher energies

Neganov-Trofimov-Luke Amplification

Total phonon energy

$$E_t = E_r + \overbrace{(N_{eh} \cdot e \cdot V_b)}^{\text{Luke phonon energy}}$$

Primary recoil energy

Bias Voltage

- Both prompt phonons from the recoil and secondary phonons from the amplification are athermal:
- eh : is around 3 eV in Si and Ge
- Since a phonon must have enough energy to break a cooper pair (340 ueV, thermal phonons, 1 ueV) only athermal phonons are collected

Background Model

1610.00006

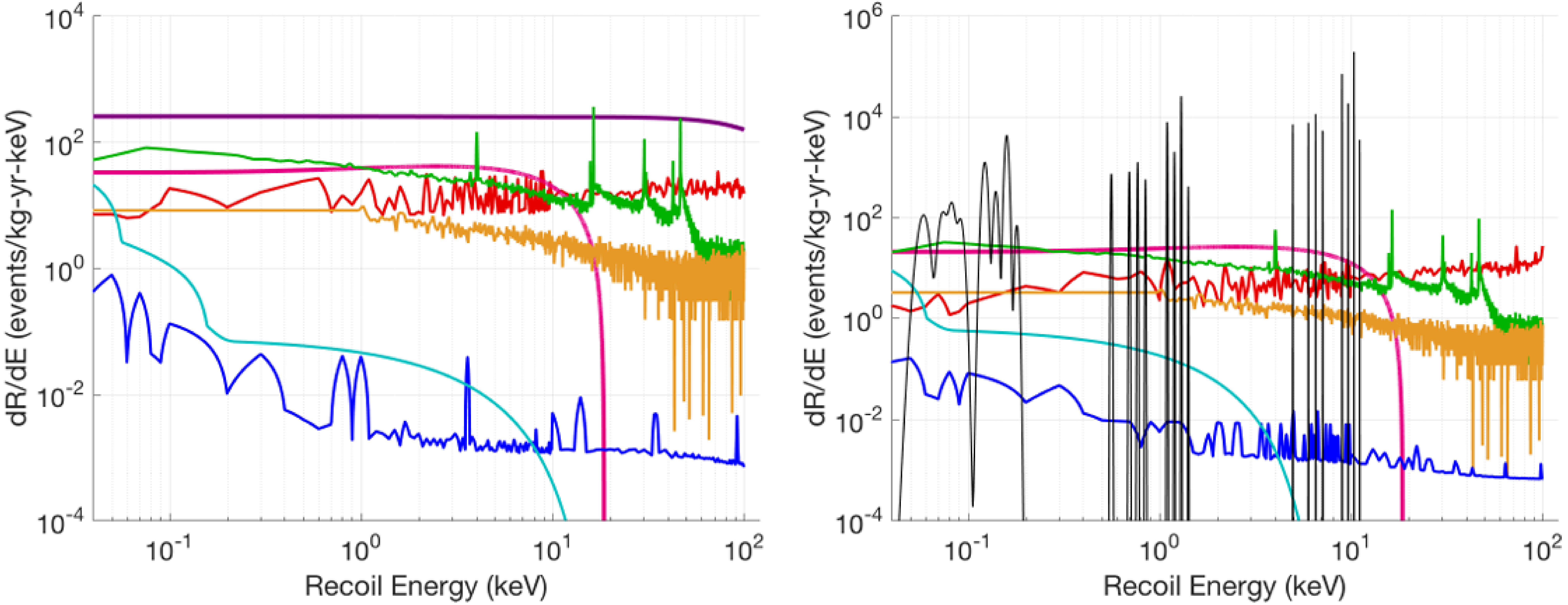
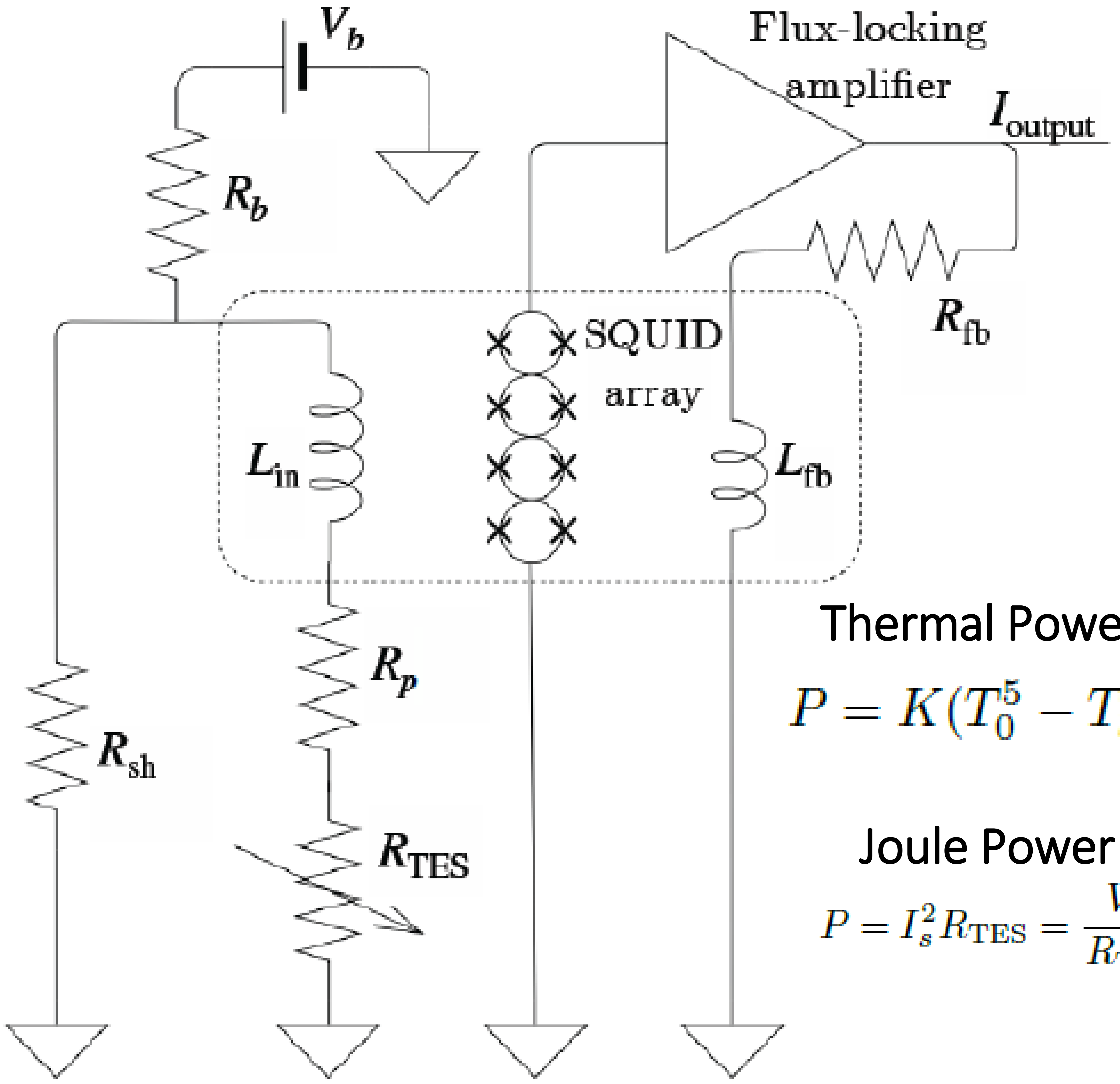


FIG. 4. Raw background spectra of single scatter interactions in a Si (left) and Ge (right) detector obtained from the Monte Carlo simulation. The spectra are broken out by components and shown as a function of recoil energy (ER or NR depending on the interaction). ^{3}H (pink) and ^{32}Si (purple) are the largest individual contributors to the backgrounds in the Ge and Si detectors, respectively. The Ge activation lines (black) are shown convolved with a 10 eV r.m.s. resolution (σ_{Ph} for the Ge HV detectors) to allow them to be clearly displayed in this figure. The remaining components are Compton scatters from gamma-rays (red), surface betas (green), surface ^{206}Pb recoils (orange), neutrons (blue) and coherent elastic neutrino-nucleus scattering (cyan). Note that the neutron spectrum (blue) has some spurious structure from the limited simulation statistics in the cavern component of the neutron background (*cf.* Table V).

TES SQUID Circuit and Thermal Feedback System



Thermal Power

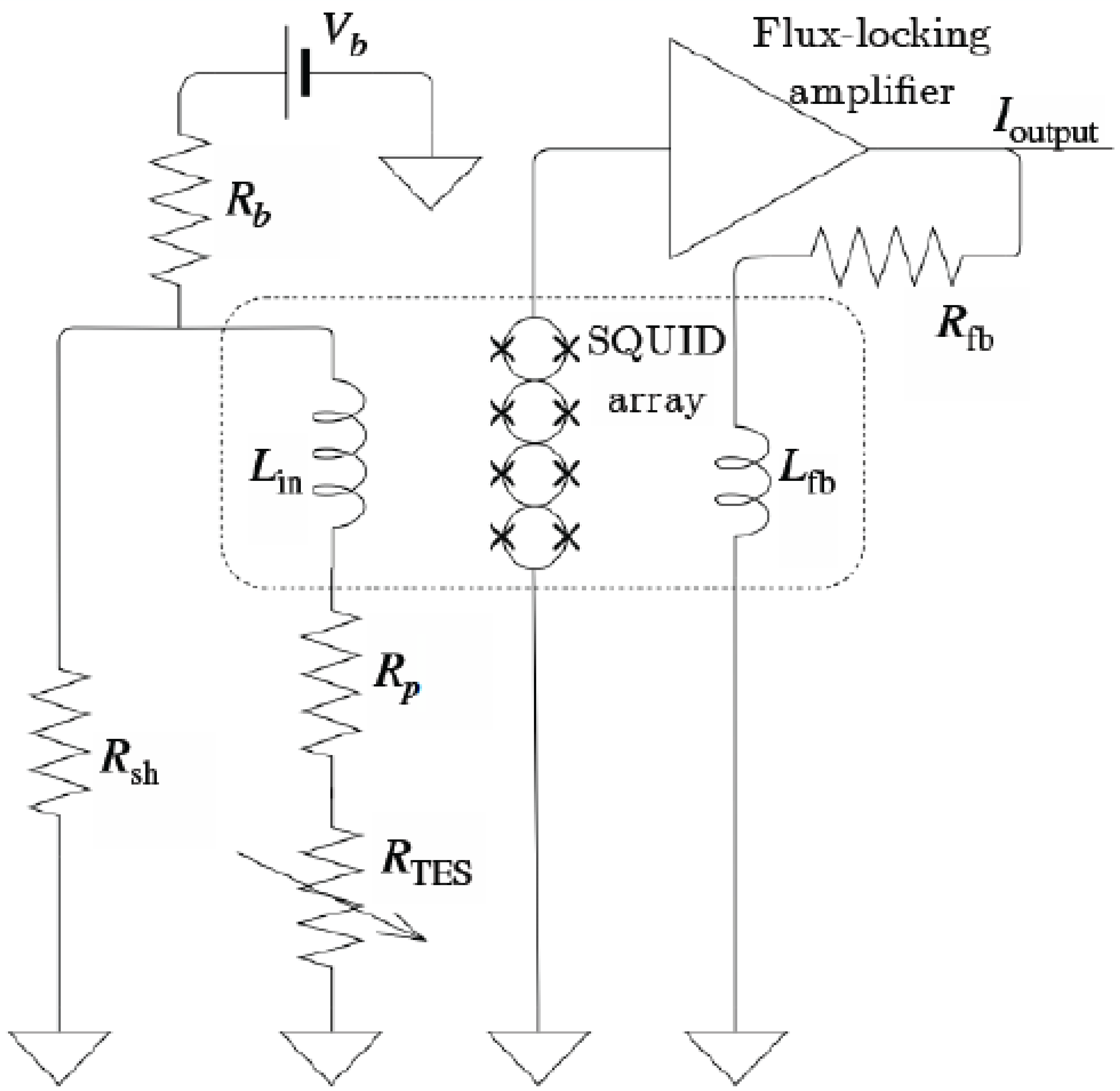
$$P = K(T_0^5 - T_b^5),$$

Joule Power

$$P = I_s^2 R_{\text{TES}} = \frac{V_b^2}{R_{\text{TES}}},$$

- Resistance changes in the TES are converted to a measurement signal using superconducting quantum interference devices (SQUIDs).
- **Electrothermal Feedback**
- An array of TESs are held at a temperature **T0** (near Tc) providing a voltage bias **Vb** with a bias resistance **Rb** that keeps a constant current **Is** through the TESs.
- The shunt resistor **Rsh** in the TES-SQUID circuit ensures that the voltage across the TESs remains relatively constant.
- Thermal power and Joule power are usually equal
- As the resistance of the TESs increases, the Joule power decreases and becomes less than the thermal power loss. The thermal power then allows the TES to return to TC

TES SQUID Circuit and Thermal Feedback System

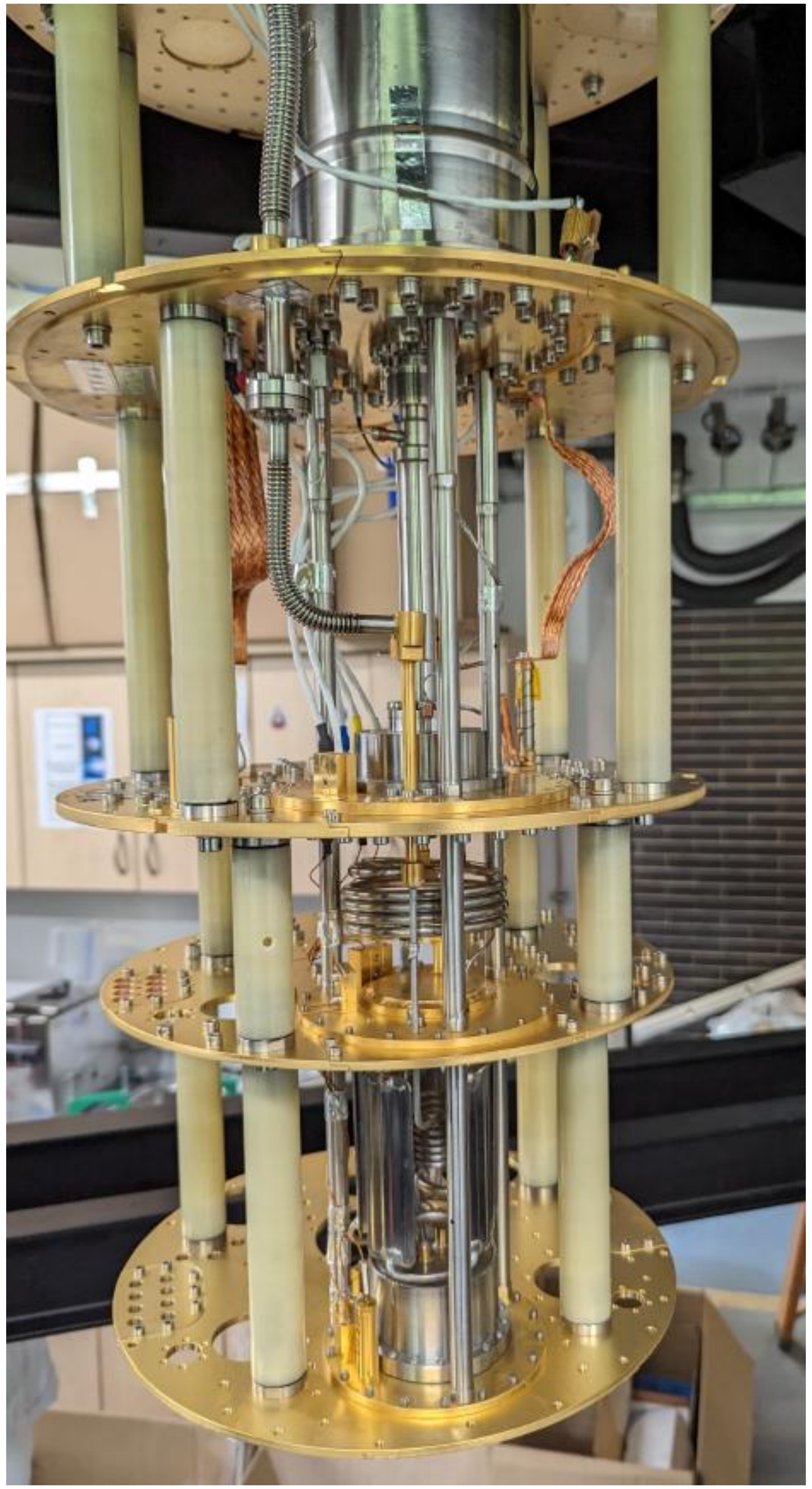


The array of TESs are also in series with a coil that has an input inductance Lin.
The SQUIDs are connected to a flux-locking amplifier which serves multiple purposes, one of which is to provide a bias current through the SQUIDs to lock them at some point on the periodic voltage-magnetic flux curve.
The magnetic flux from Lin induces a voltage across each of the SQUIDs, and the total voltage across the SQUID array is amplified by the flux-locking amplifier.
A feedback voltage Vfb is provided to supply a current through a feedback resistor Rfb and an additional coil that provides a feedback inductance Lfb to the array of SQUIDs.
The purpose of this feedback inductance is to continuously counteract the magnetic flux through the SQUIDs supplied by Lin by supplying an opposing magnetic flux. Through a negative-feedback loop gain circuit, Vfb provides the voltage required to keep the net magnetic flux through the SQUIDs, and thus VSQ, constant at all times

- The actual signal taken as a measurement is Vfb recorded over time and later digitized and converted to current through the TESs.

Refrigeration Terminology (Dry Fridge)

- Dilution Refrigerators are able to change the temperature over 4 orders of magnitude
- The sound!!!!!



Pulse Tube First Stage (60 K)

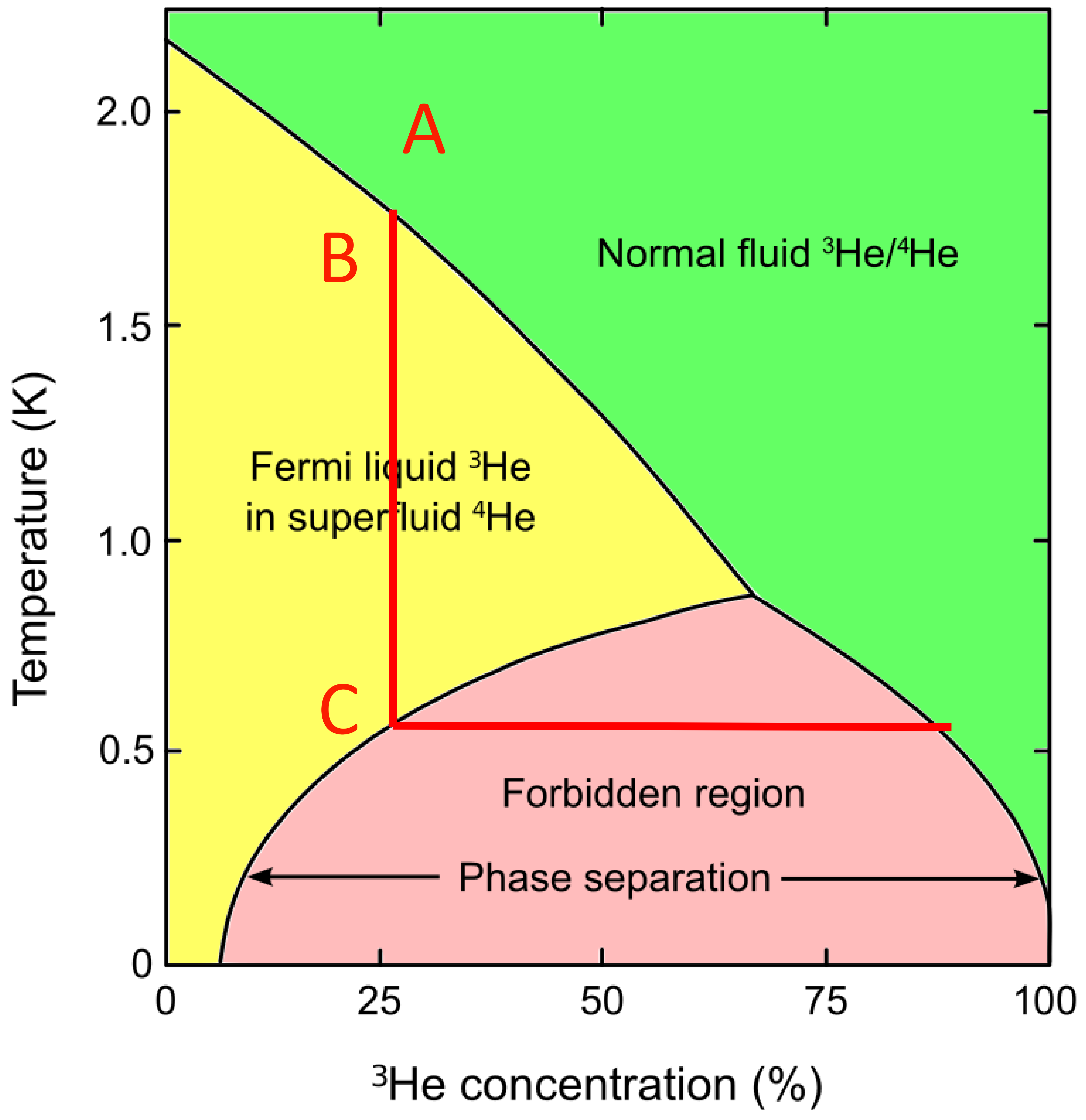
Pulse Tube Second Stage (4 K)

Still Plate (1 K)

Cold Plate (100 mK)

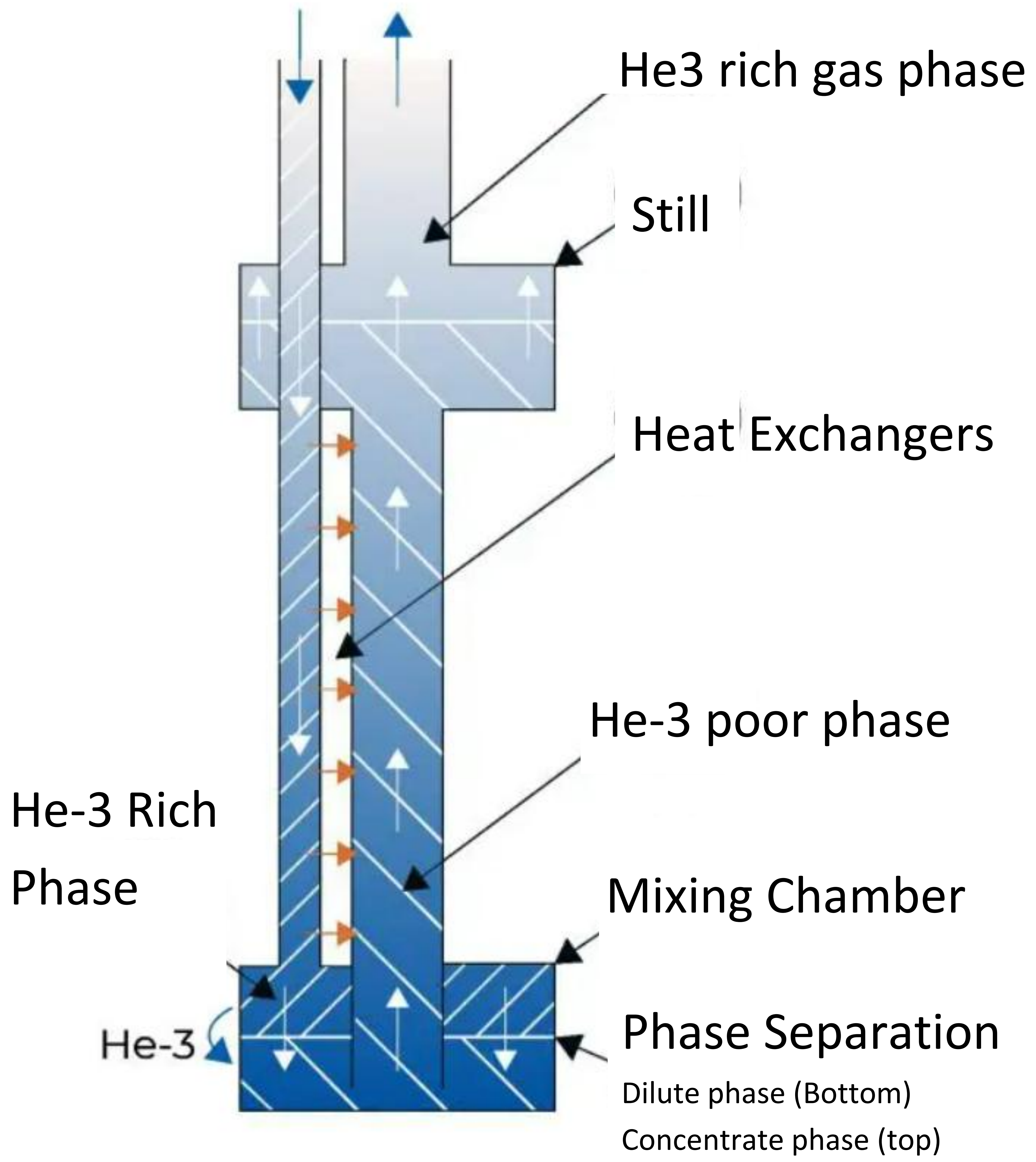
Mixing Chamber Plate (10 mK)

How to reach mK: Dilution Technique?



- Dilution refrigeration utilizes the properties of ^{3}He-^{4}He mixtures to achieve mK cooling
- ^{4}He obeys Bose statistics while ^{3}He obeys Fermi statistics.
- Mixing the two isotopes together is what allows mK temperature to be achieved
- A mix of He3/He4 starts at temperature A
- If the temperature is lowered below point B that mix is now a superfluid
- When lower then point C ^{3}He-^{4}He separate into dilute and concentrated phases.
- This happens in the mixing chamber
- Concentrated phase will "float" on-top of the dilute phase
- It takes energy to move ^{3}He from the dilute to concentrated phase which is taken from well isolated environment providing the cooling

How to reach mK?



1. He-3 enters the dilution unit pre-cooled by the pulse tube at around 3K
2. It proceeds to the mixing chamber and is cooled by the heat exchangers
3. In the mixing chamber the phase separation occurs
4. He3 is pumped out to the still causing He3 to move from the concentrated phase to the dilute phase. Which takes energy from the system, thus providing the cooling
5. The He3 that was pumped out provides the cooling for the incoming He3
6. In the still He3 is evaporated and the cycle begins again

HVeV – ALP and Dark Photon