Direct Dark Matter search with the CRESST-III experiment

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The CRESST collaboration

CRESST

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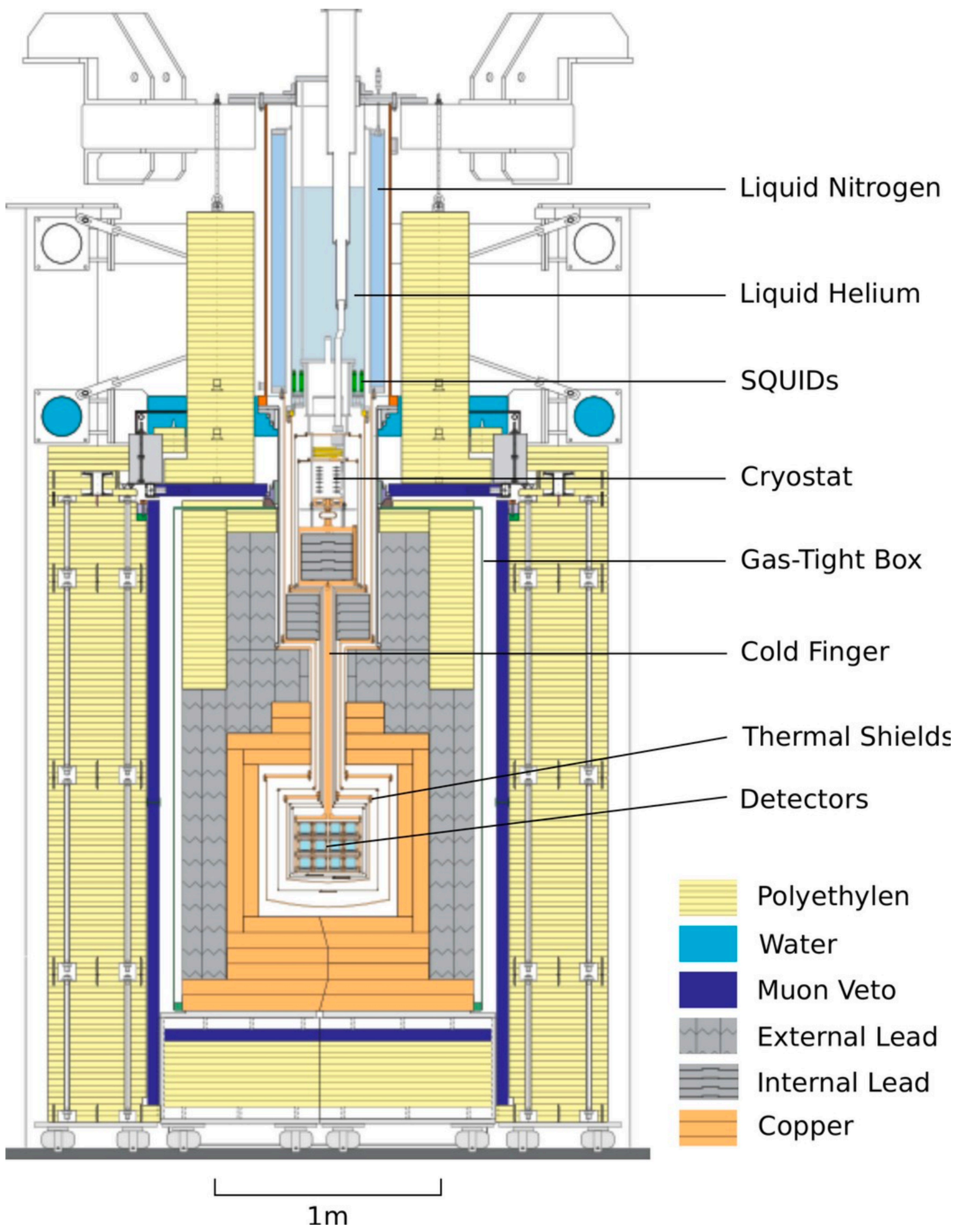
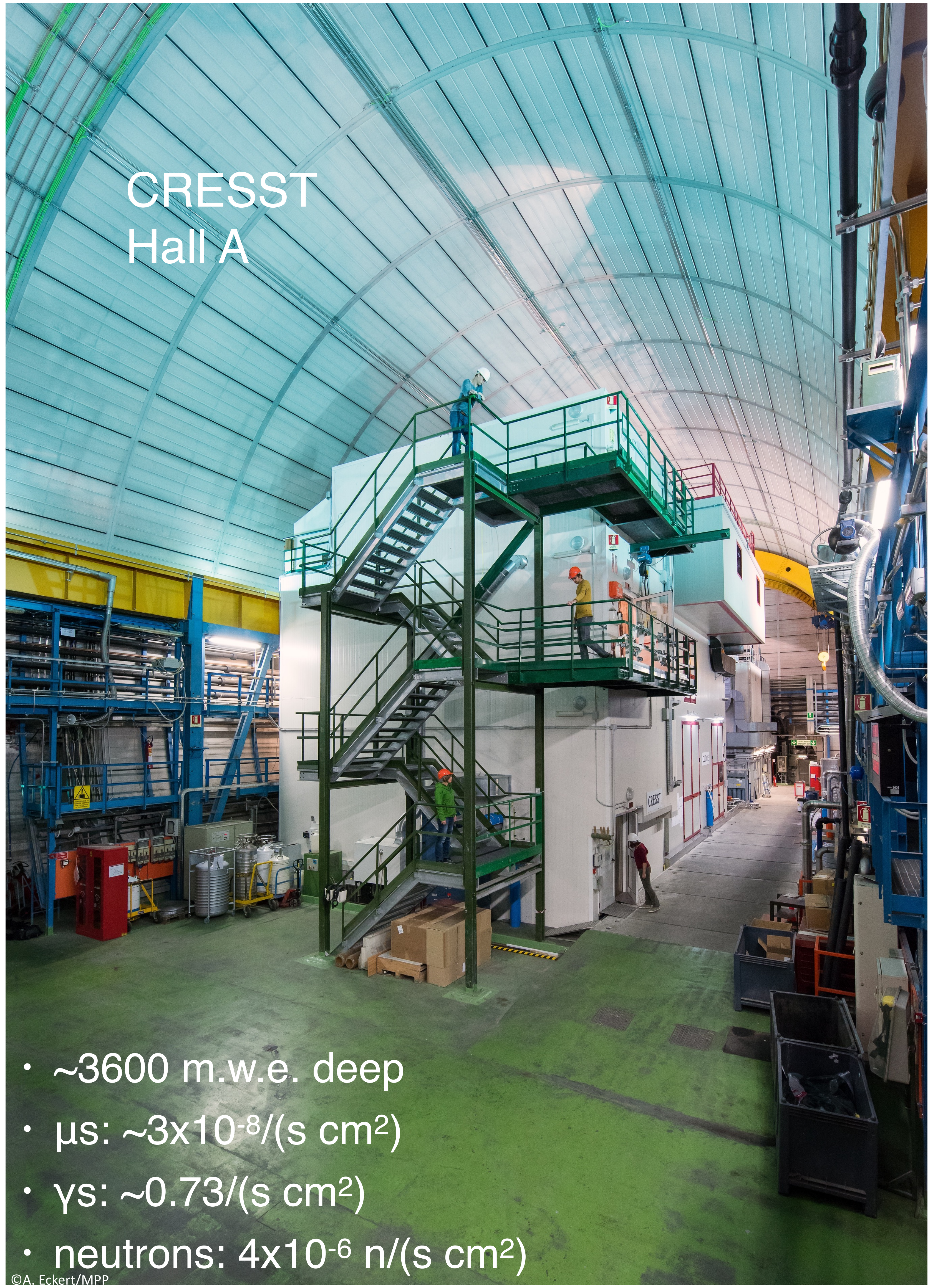
The CRESST experiment





- ~3600 m.w.e. deep
- µs: ~3x10^{-8}/(s cm^2)
- γs: ~0.73/(s cm^2)
- neutrons: 4x10^{-6} n/(s cm^2)

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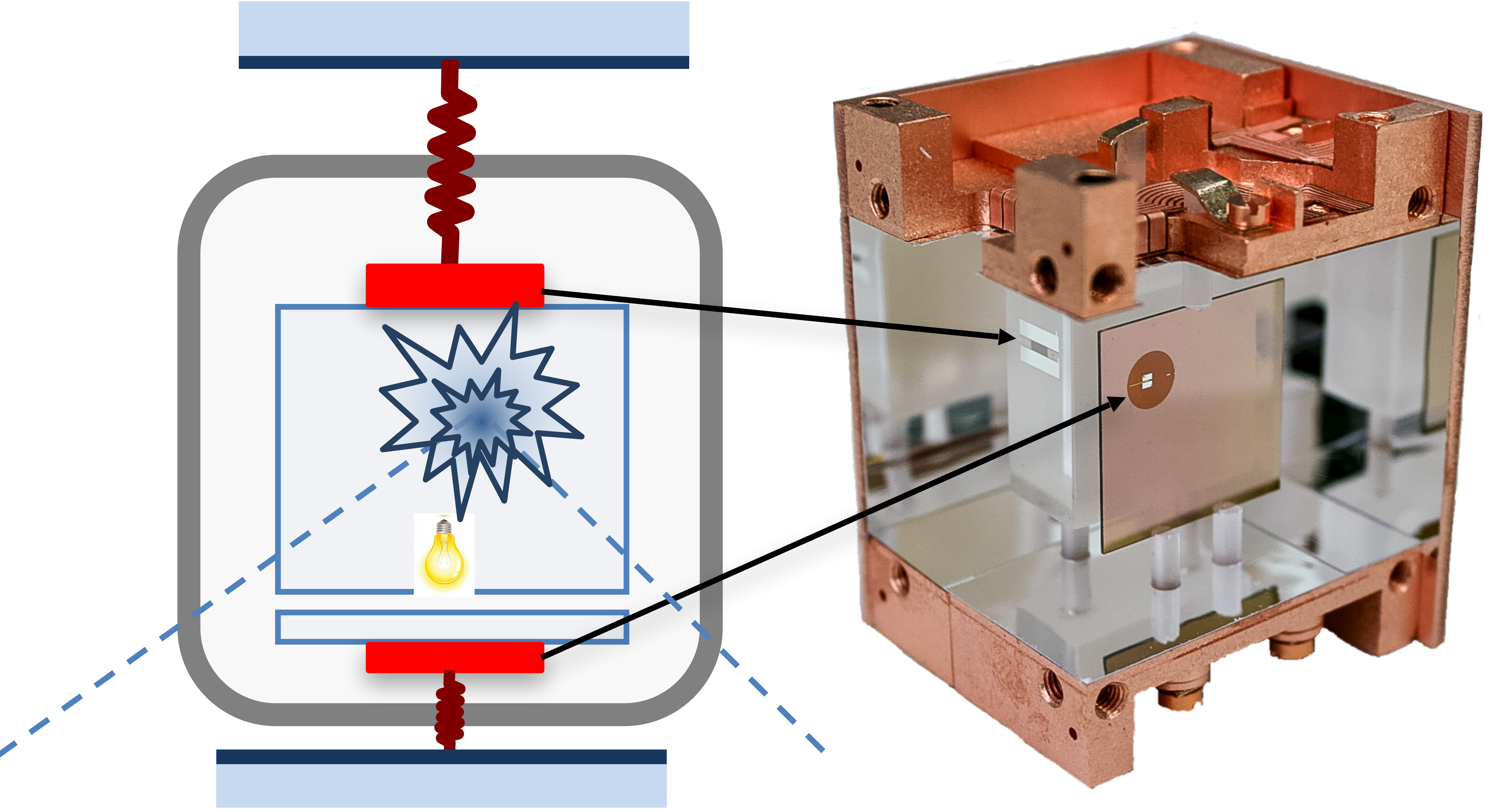
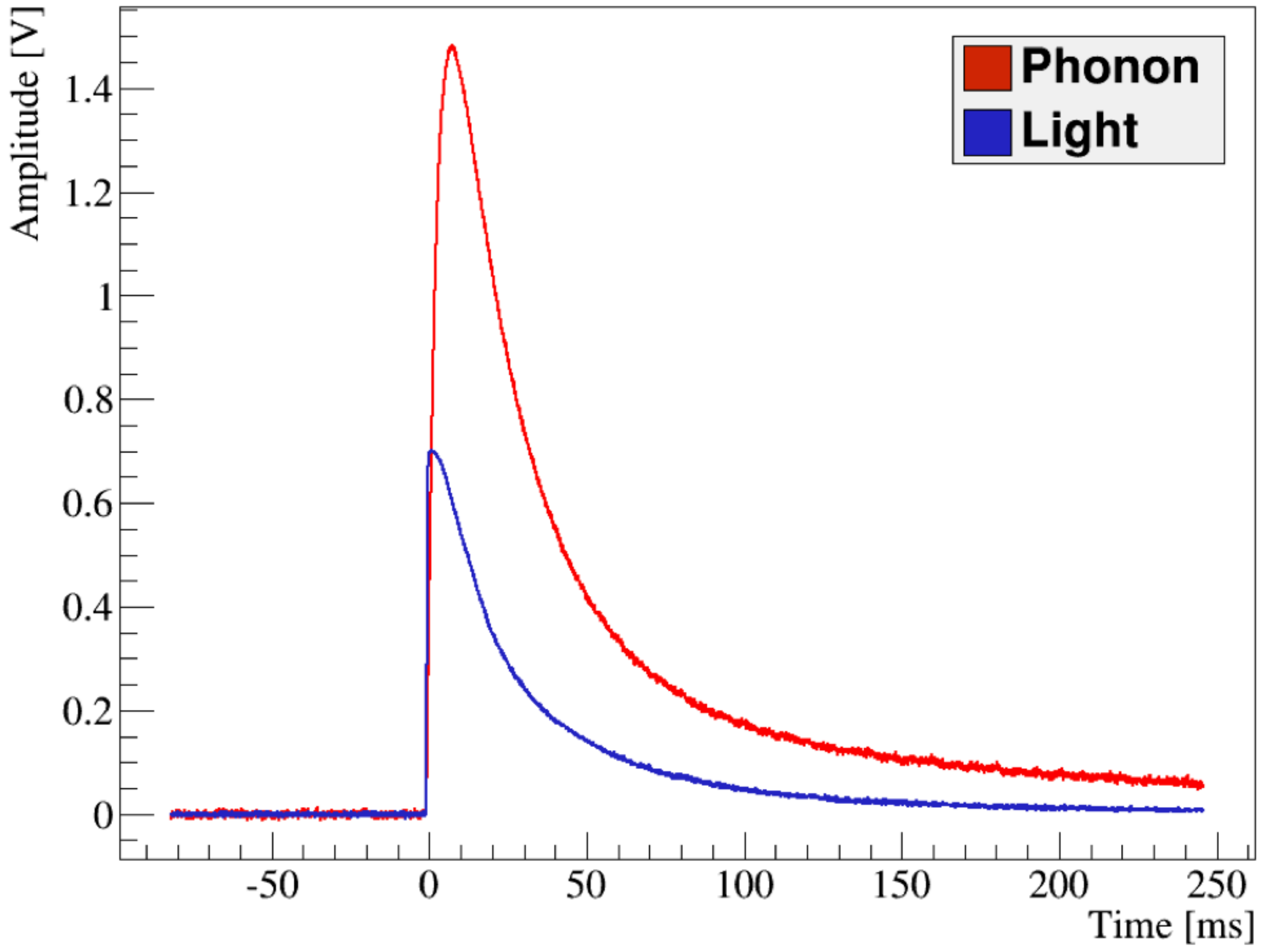
CRESST goal: direct detection of dark matter particles via their scattering off target nuclei in cryogenic detectors, operated at ~15 mK using Scintillating $CaWO_4$ crystals as target and Silicon on Sapphire (SOS) crystals as cryogenic light detector

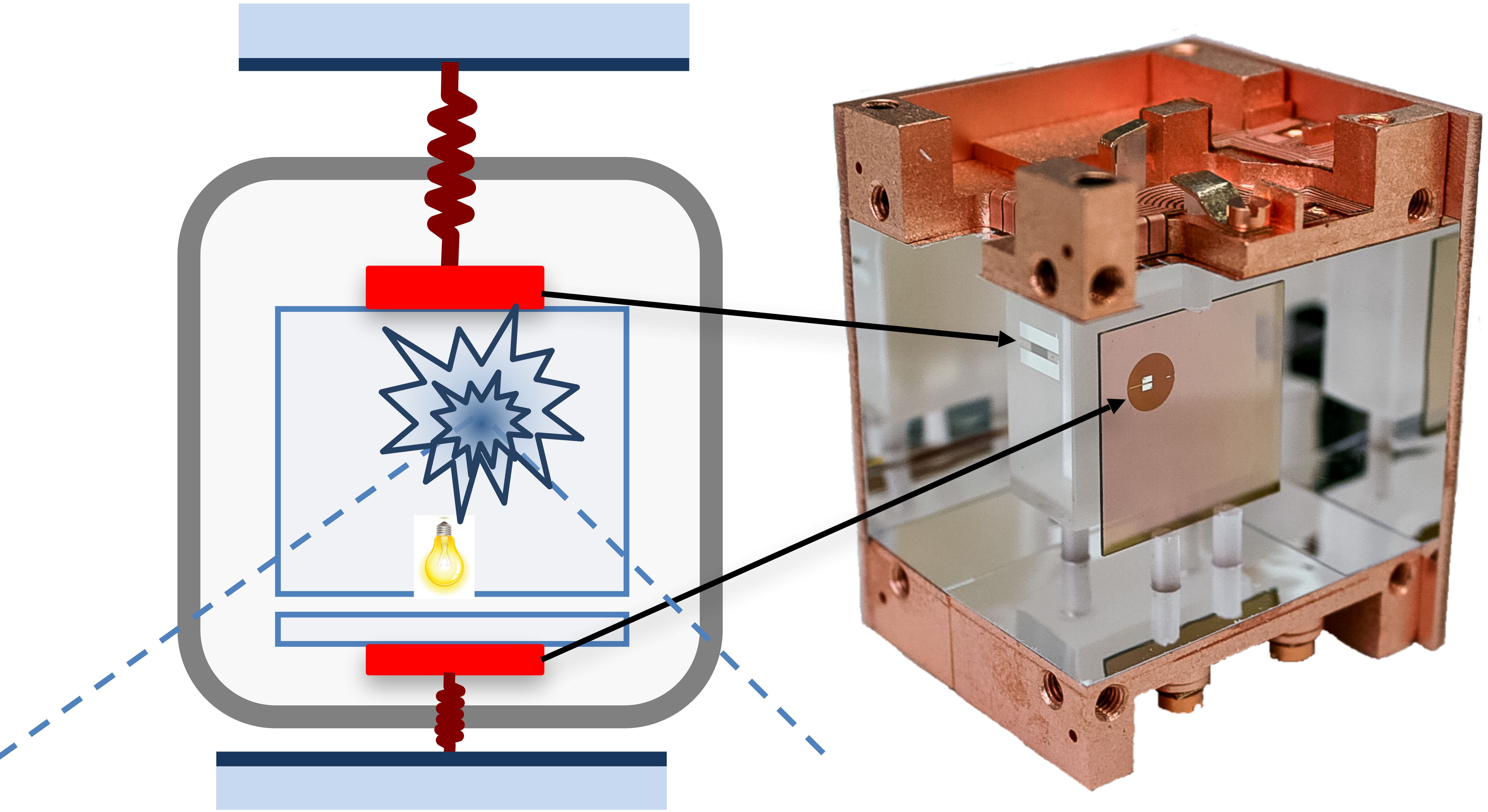
The CRESST detector module

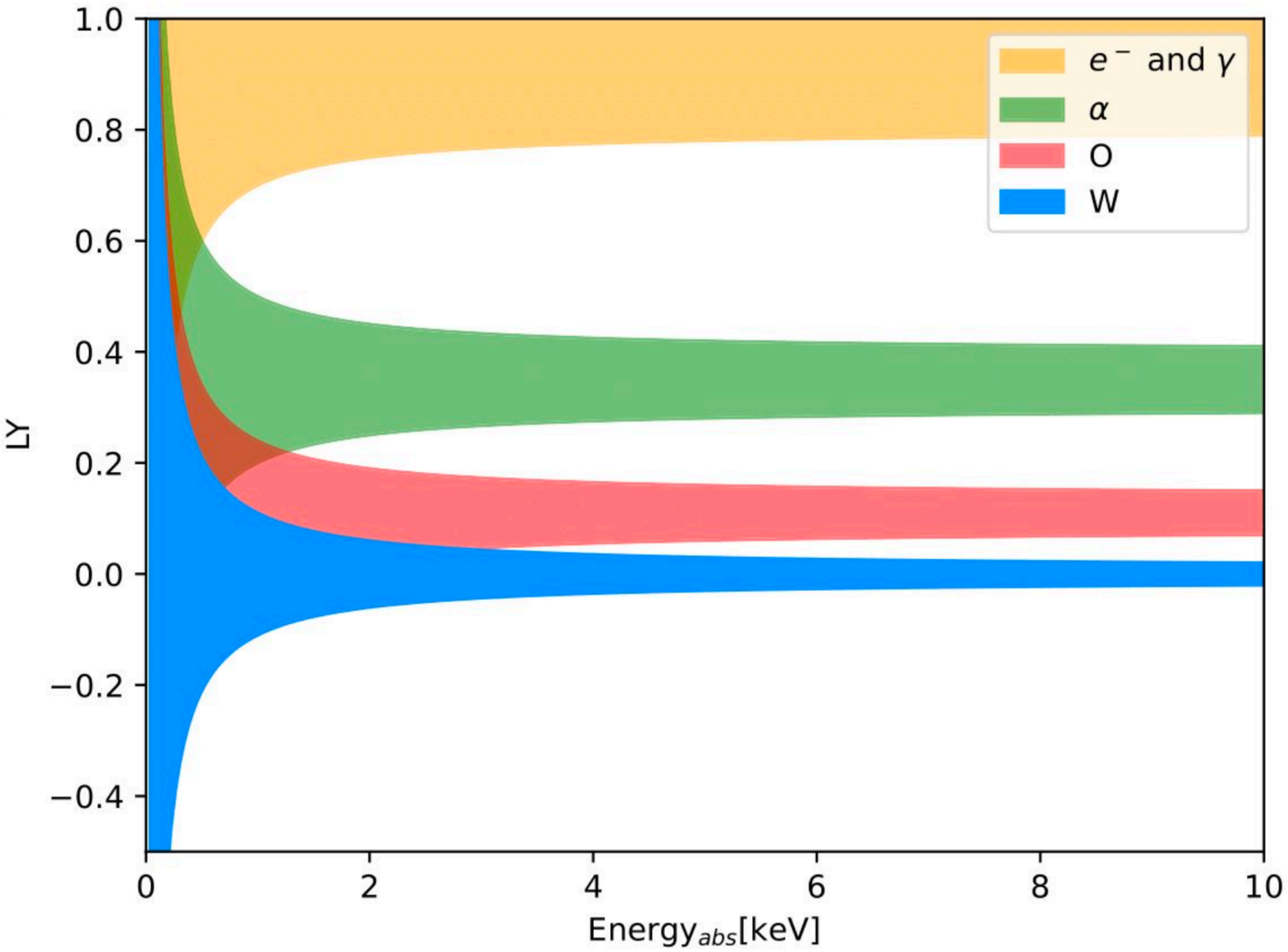




Simultaneous signals from the transition edge sensors (TESs)

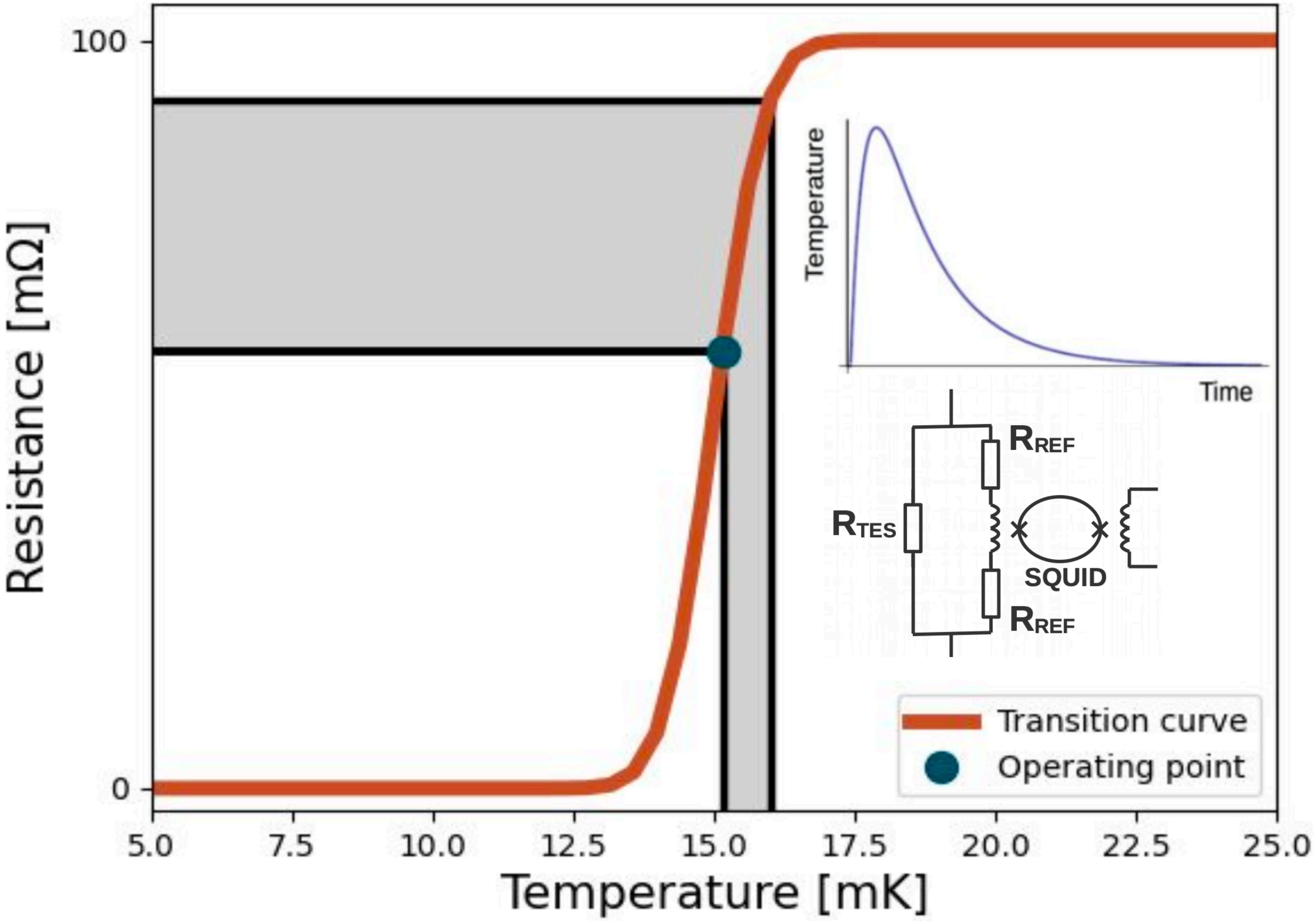
The CRESST detector module

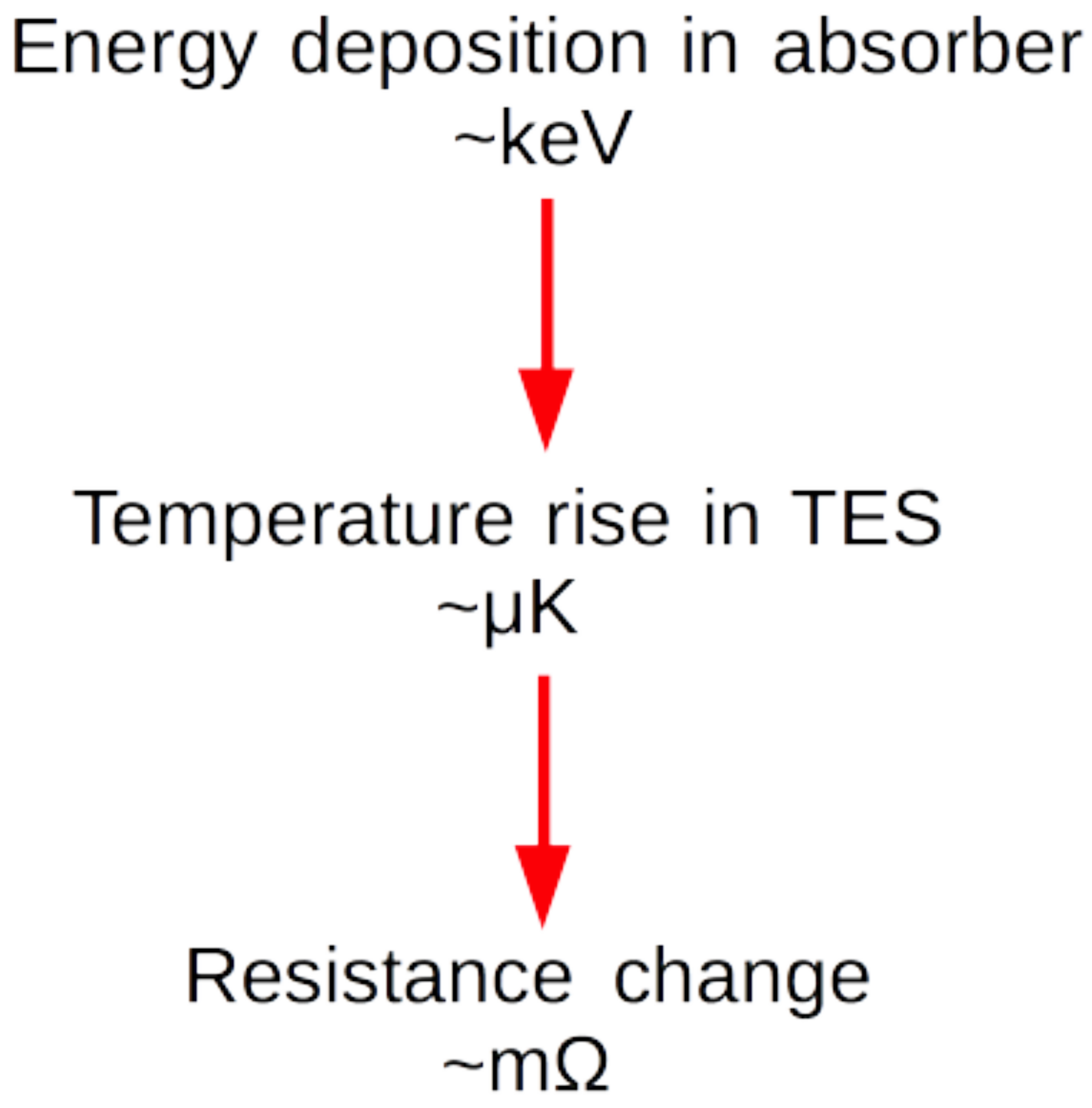




Discrimination between potential signal events (**nuclear recoils**) and dominant radioactive background (**electron recoils**)

Transition Edge Sensor





Energy deposition in absorber
~keV

Temperature rise in TES
~μK

Resistance change
~mΩ

- The sensor is operated at the transition between normal and superconducting phase
- Very small temperature variations can be read out through measurable changes in the resistance

DARK MATTER Results

Det A: 23.6 g, E_{th} = 30.1 eV

Analysis optimized for very low energies: 30.1eV → 16keV

Acceptance region fixed before unblinding

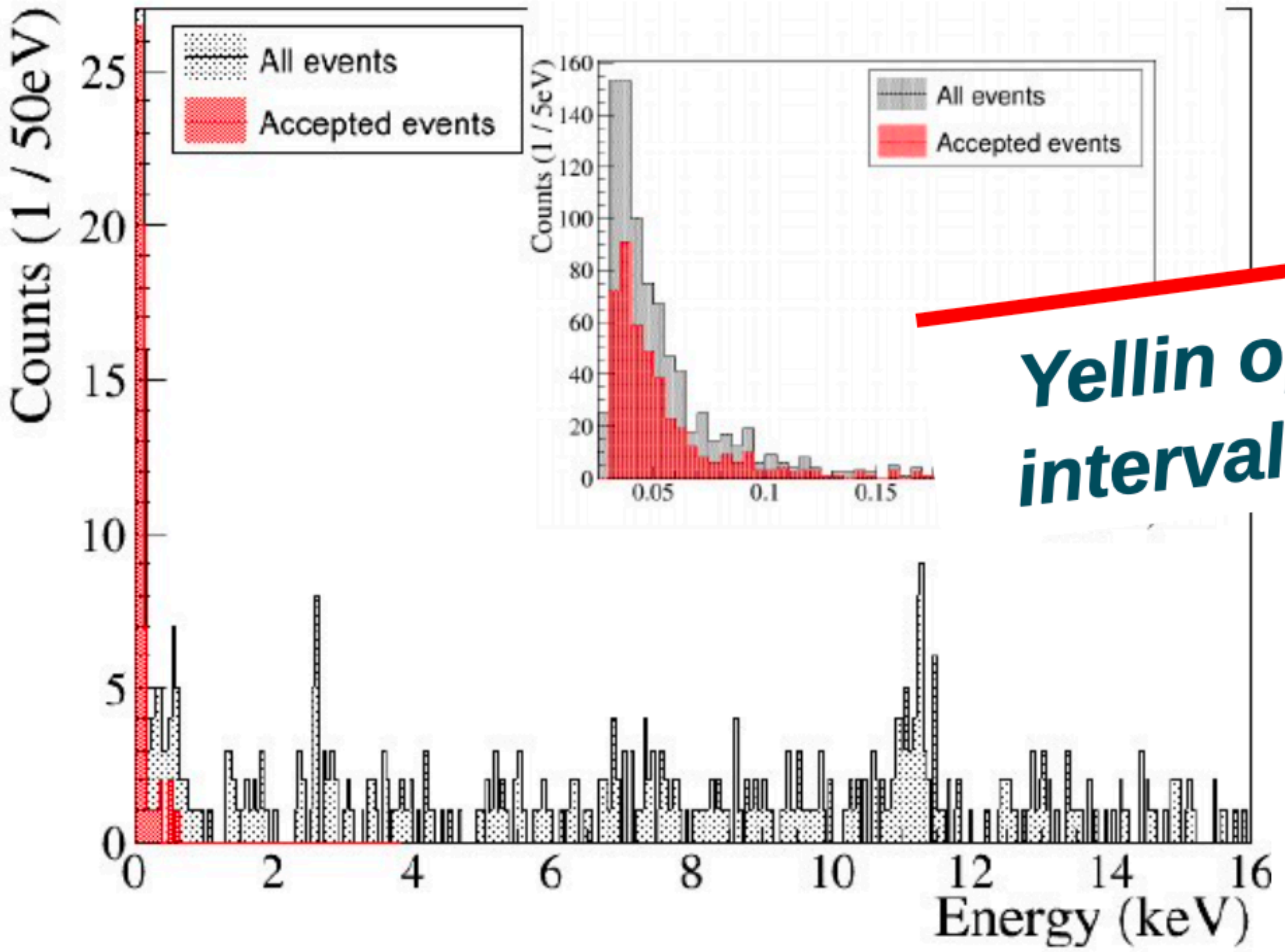
50 % O recoils below

99.5 % W recoils above

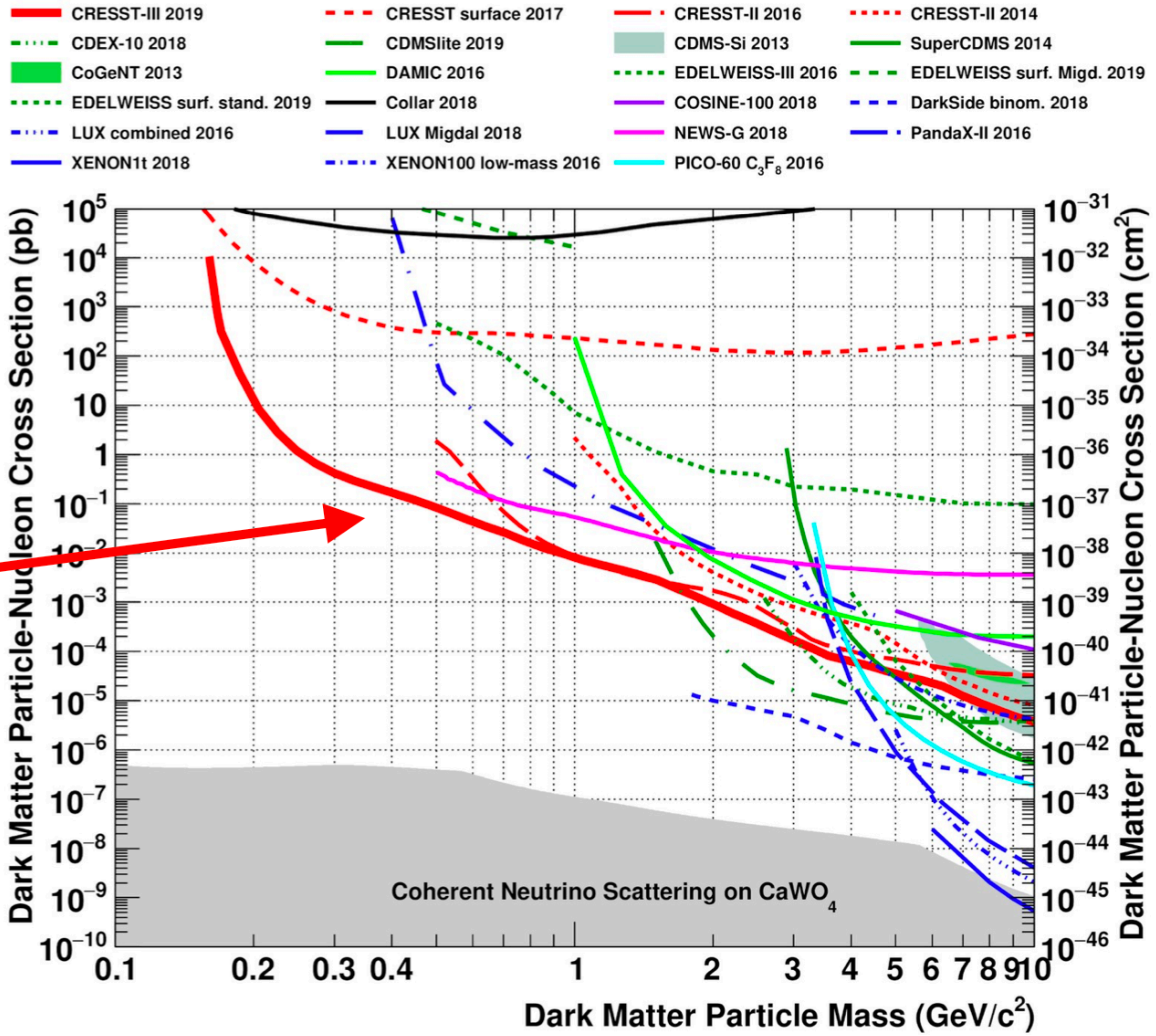
Dark Matter Results (I)

Detector A – 23.6 g $CaWO_4$

data taking period	Oct 2016 – Jan 2018
exposure	5.698 kg · days
baseline resolution	4.6 eV
nuclear recoil threshold	30.1 eV



Yellin optimum interval method

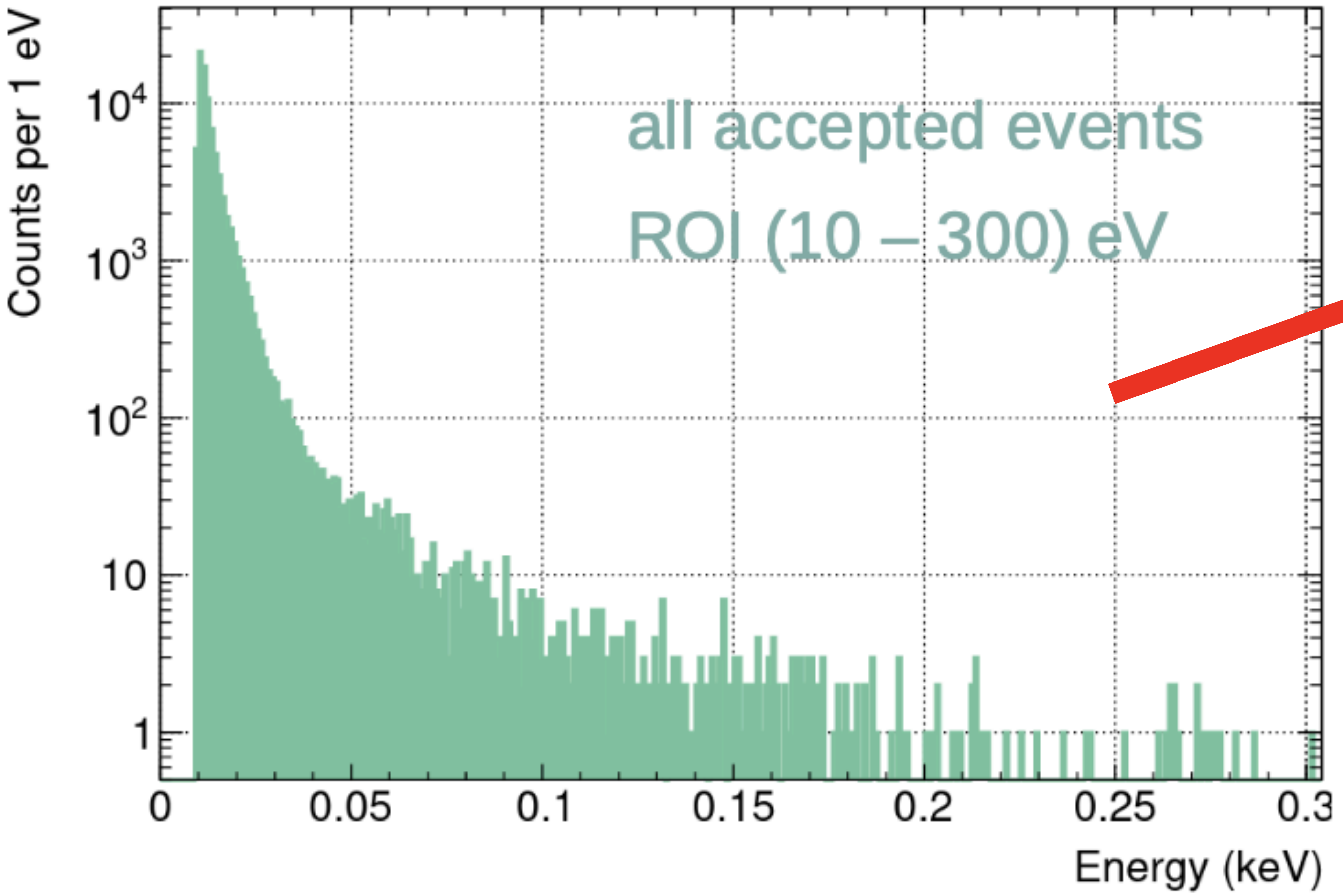


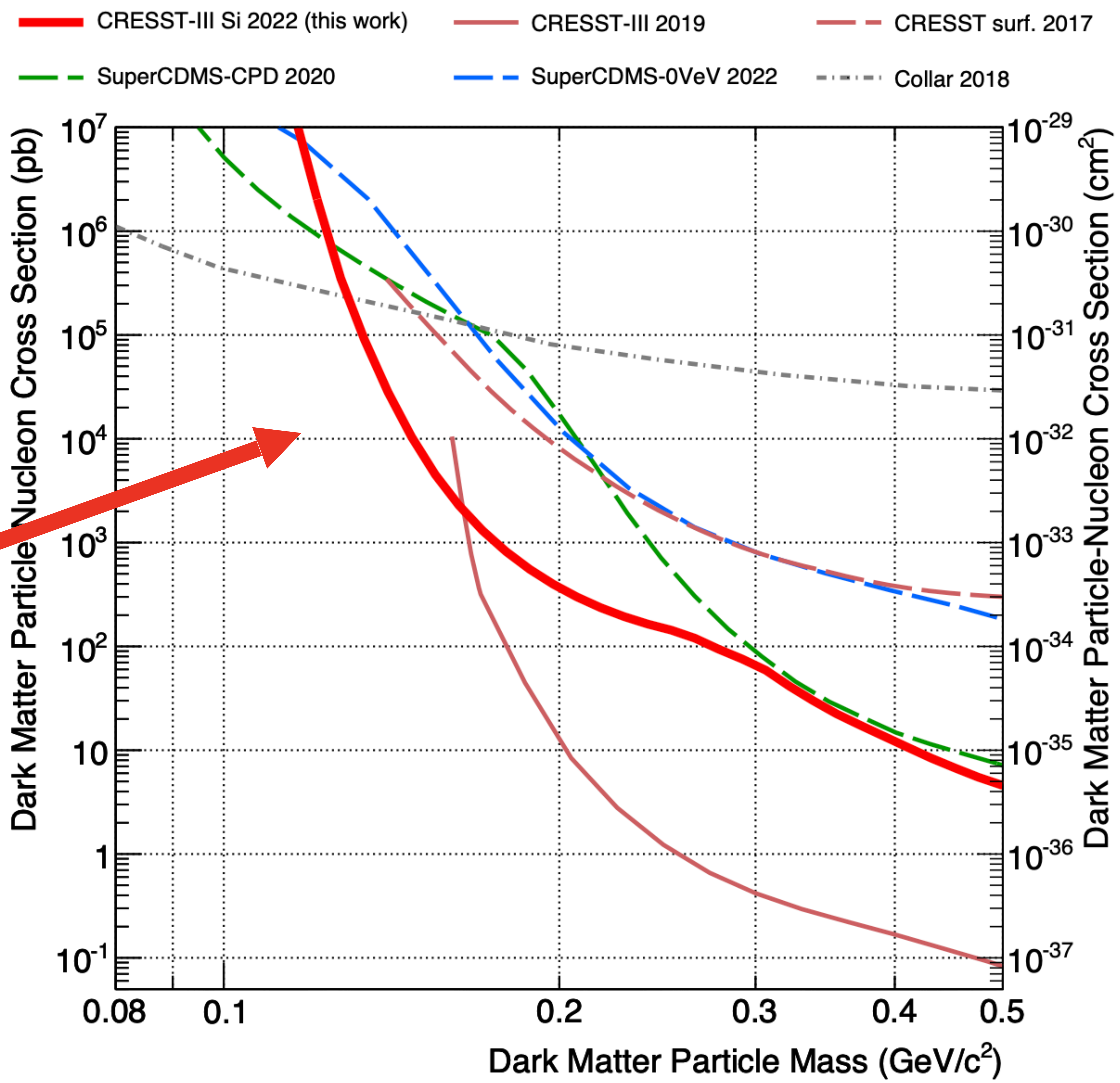
Phys. Rev. D 100, 102002 / arXiv:1904.00498

Dark Matter Results (II)

Si2 wafer detector – 0.35 g Si

data taking period	Nov 2020 – Aug 2021
exposure	55.06 g days
baseline resolution	1.36 eV
nuclear recoil threshold	10.0 eV

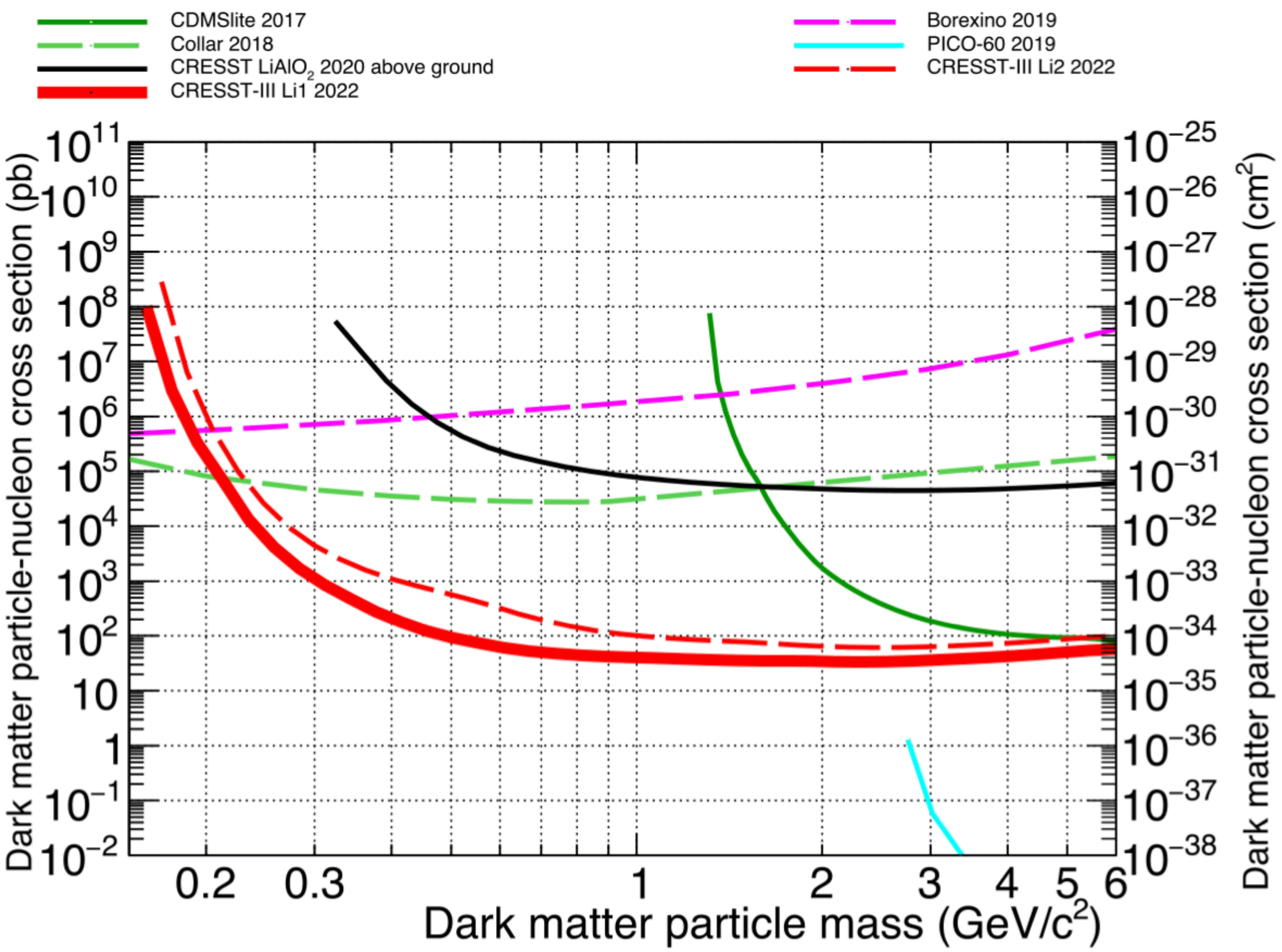




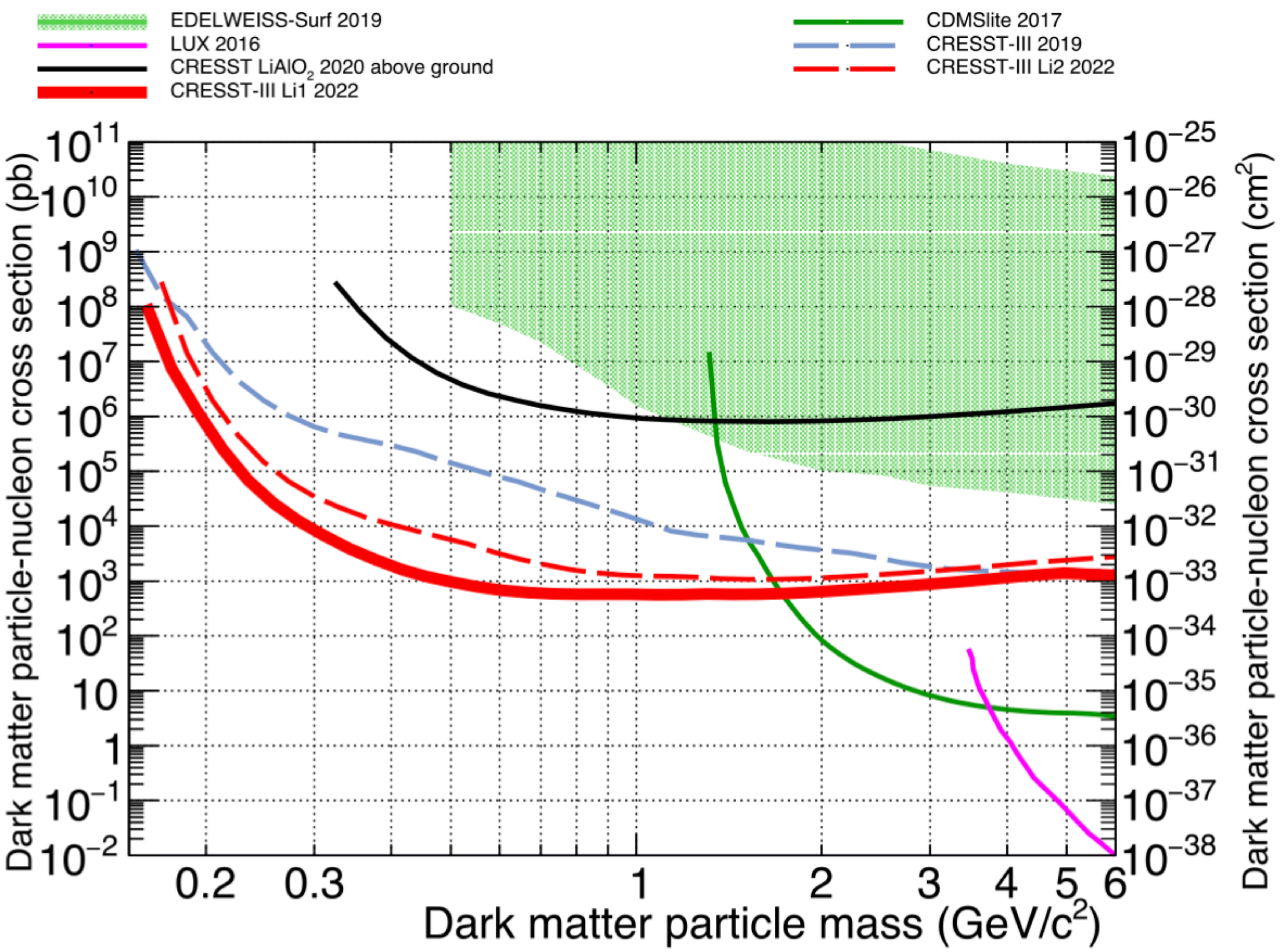
DOI10.1103/PhysRevD.107.122003

SD Limits with $LiAlO_2$ Detectors

Proton-only



Neutron-only



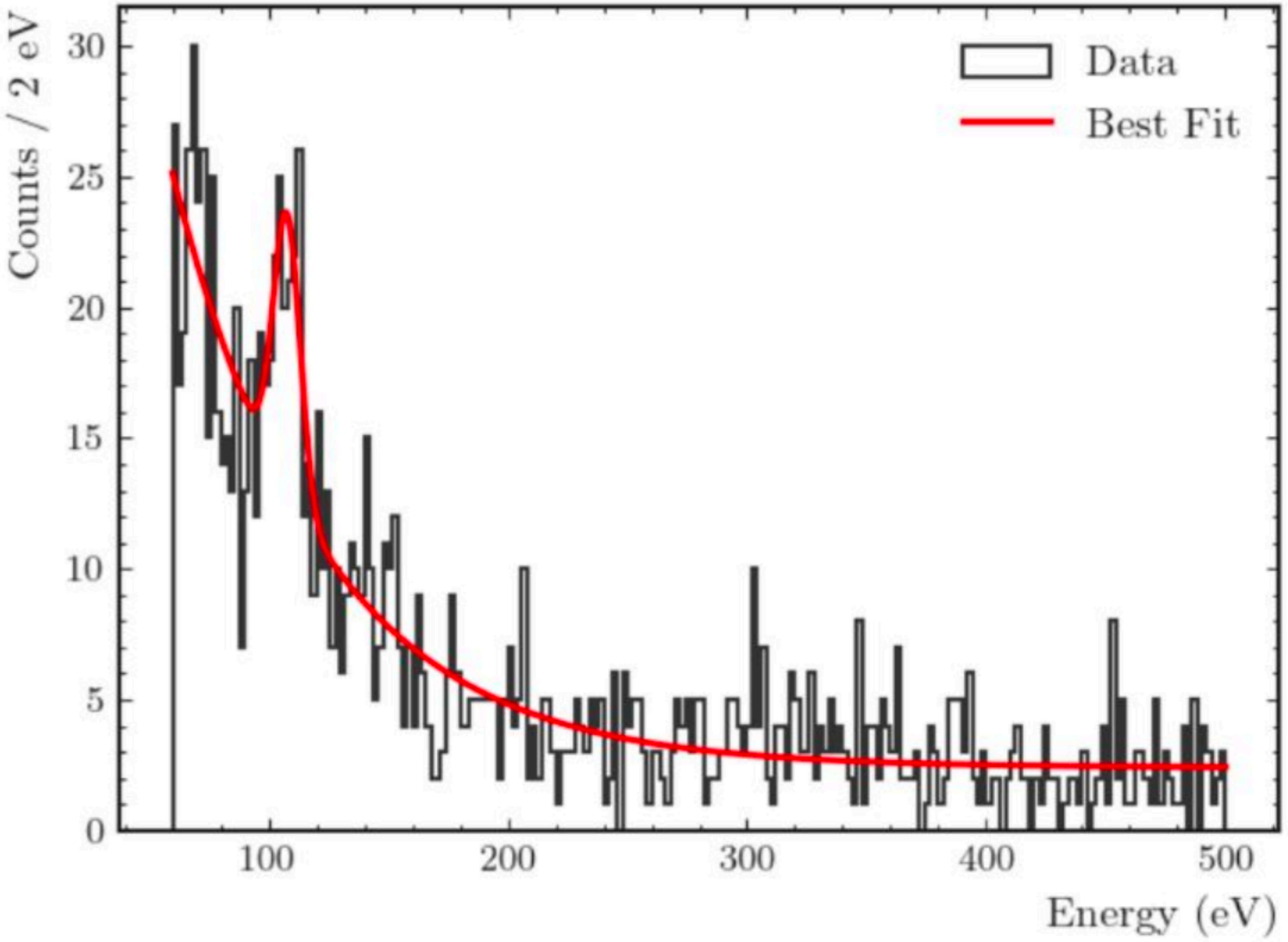
Phys. Rev. D 106, 092008 / arXiv:2207.07640

CRESST calibration with W recoil

Standard calibration → ^{55}Fe source with X-ray at 5.9 keV

New Technique:

CRAB collaboration
JINST 16 P07032



Phys. Rev. D 108, 022005

Energy calibration for nuclear recoil

^{182}W(n,γ)^{183}W

de-excitation with a single γ (6.1MeV)

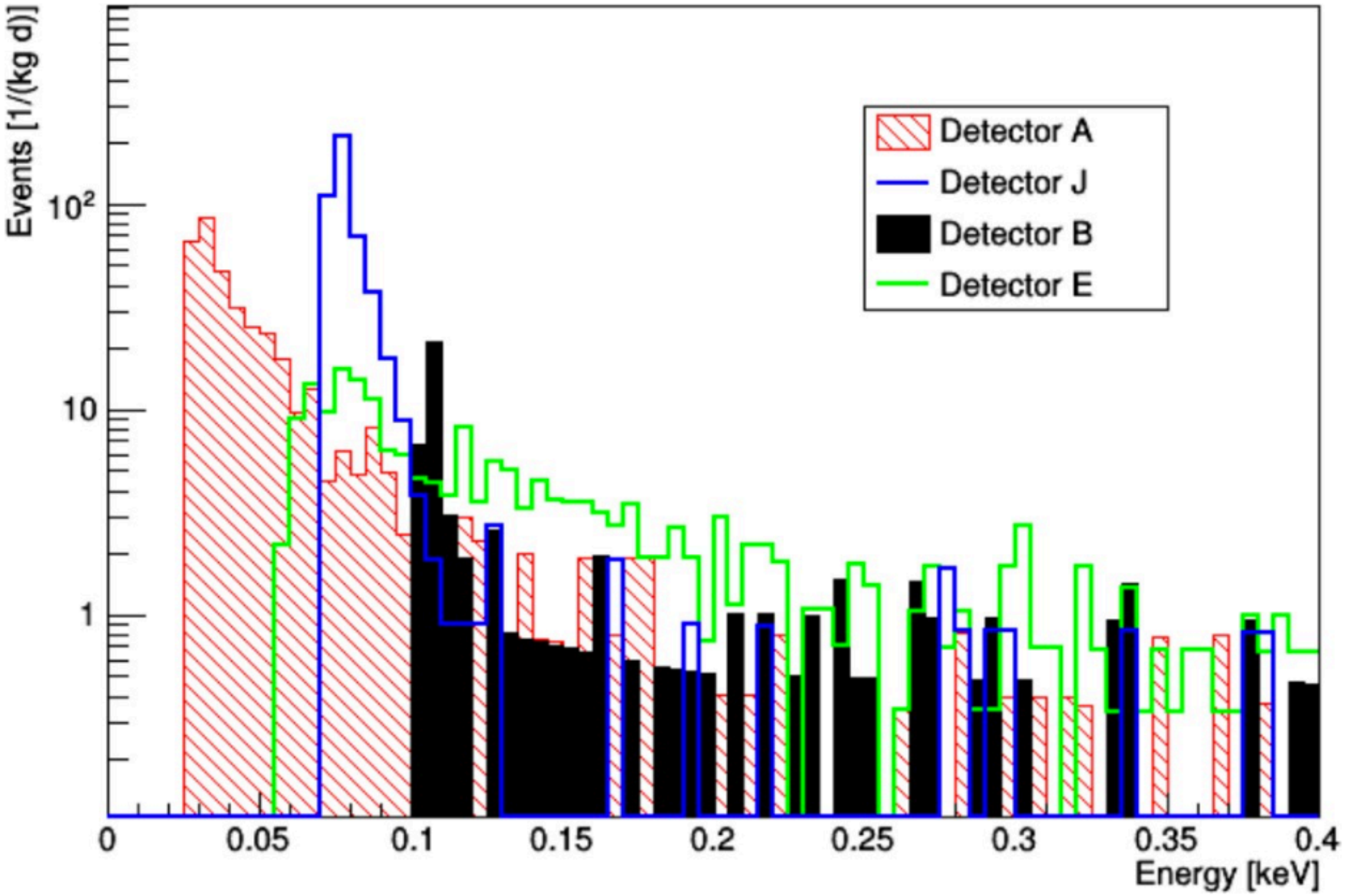
→ mono-energetic nuclear recoil 112.4eV

→ Confirms our energy calibration
→ Method can be used in the future

The Low Energy Excess (LEE)

First observations: 2016 – 2018

Overview of $CaWO_4$ Detectors



Phys. Rev. D 100, 102002 / arXiv:1904.00498

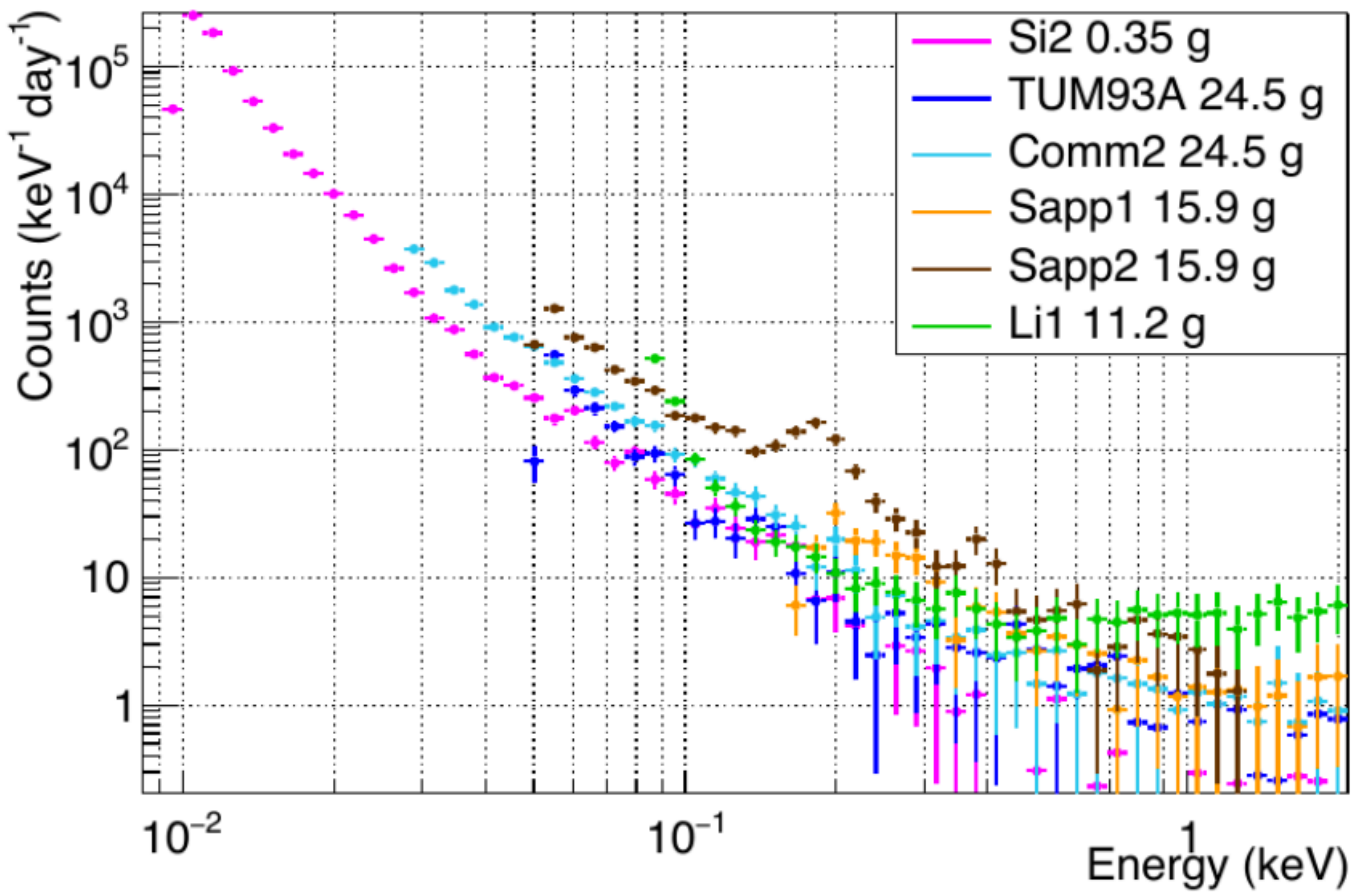
Unexplained event population at low energies

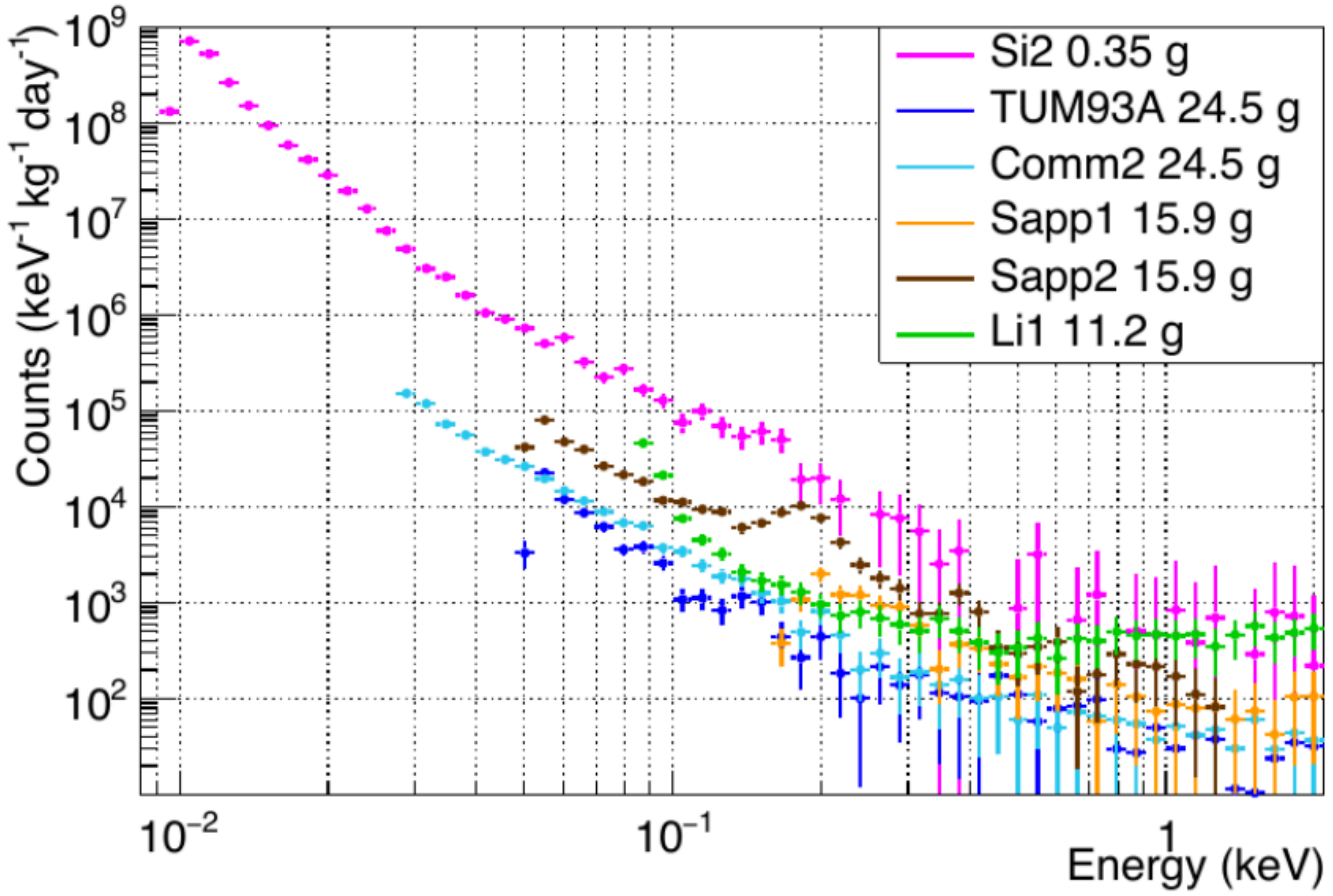
- high count rate
- steep rise in energy below ~200 eV
- different shape in different detectors

Detector	Threshold
Det-A	30.1 eV
Det-B	120 eV
Det-E	64.8 eV
Det-J	83.4 eV

Observations of LEE

LEE is observed in all CRESST detectors (independently from absorber material and geometry). Scaling the counting rate by volume (mass) does not improve the agreement between the different detectors.

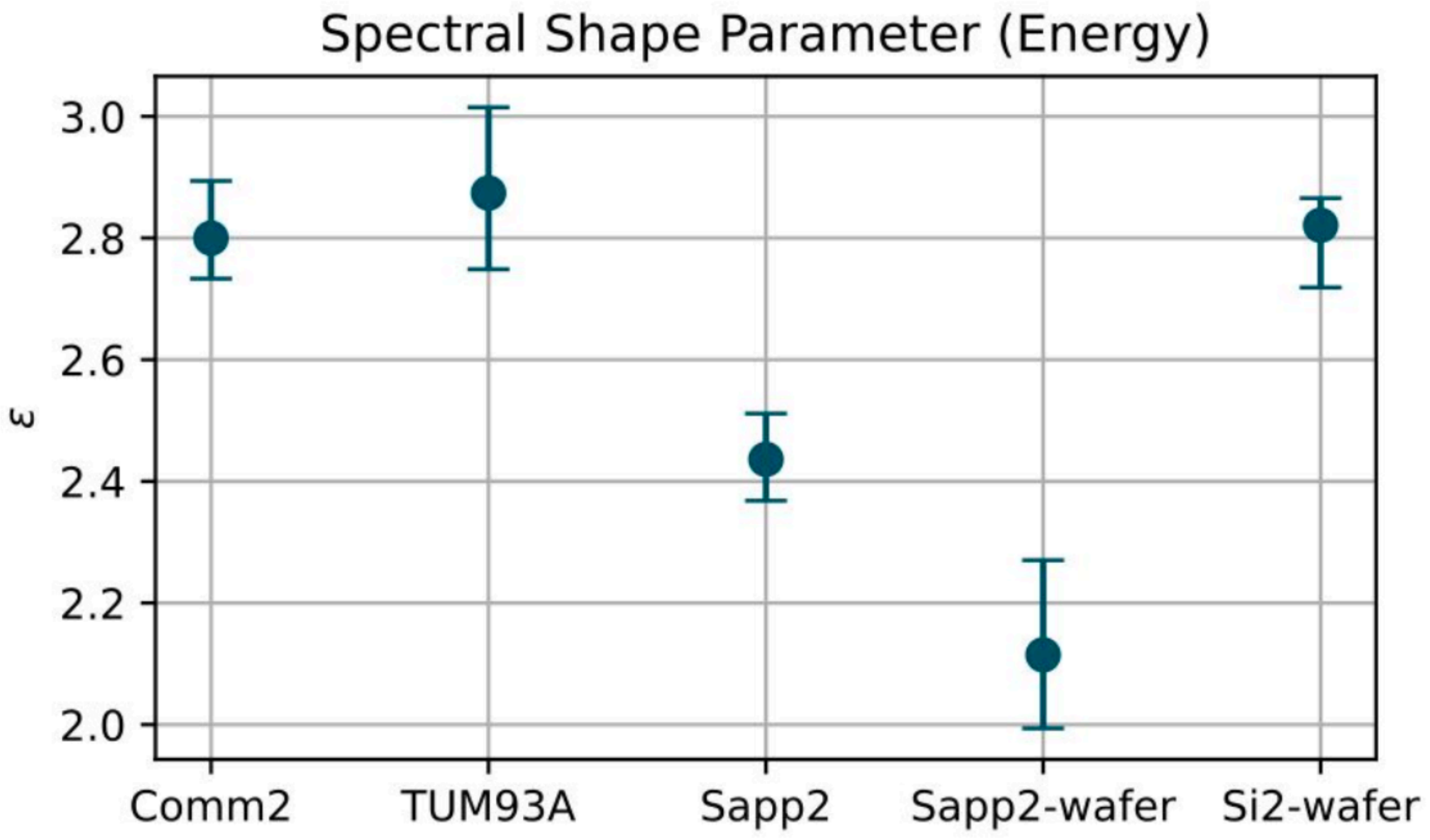




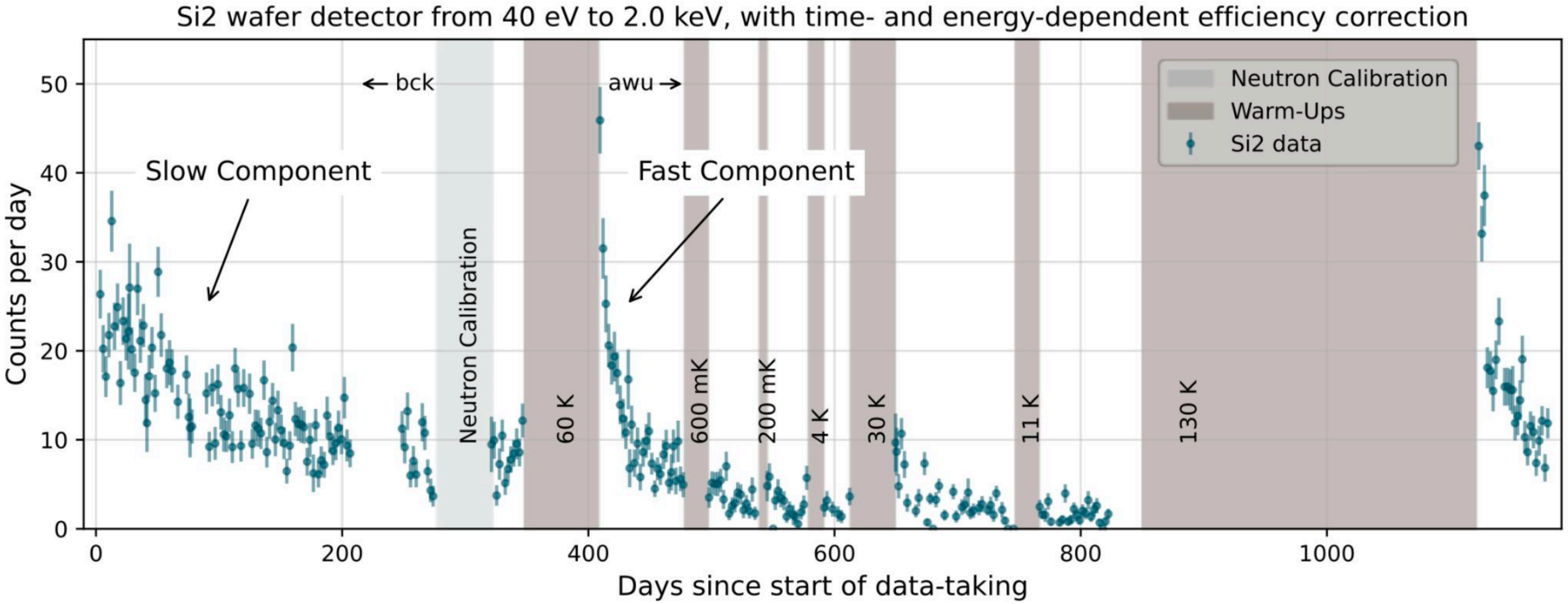
Normalized by mass

The spectral shape is well described by a power-law

$$\boxed{N(E,t) = C + E^{-\varepsilon}}$$

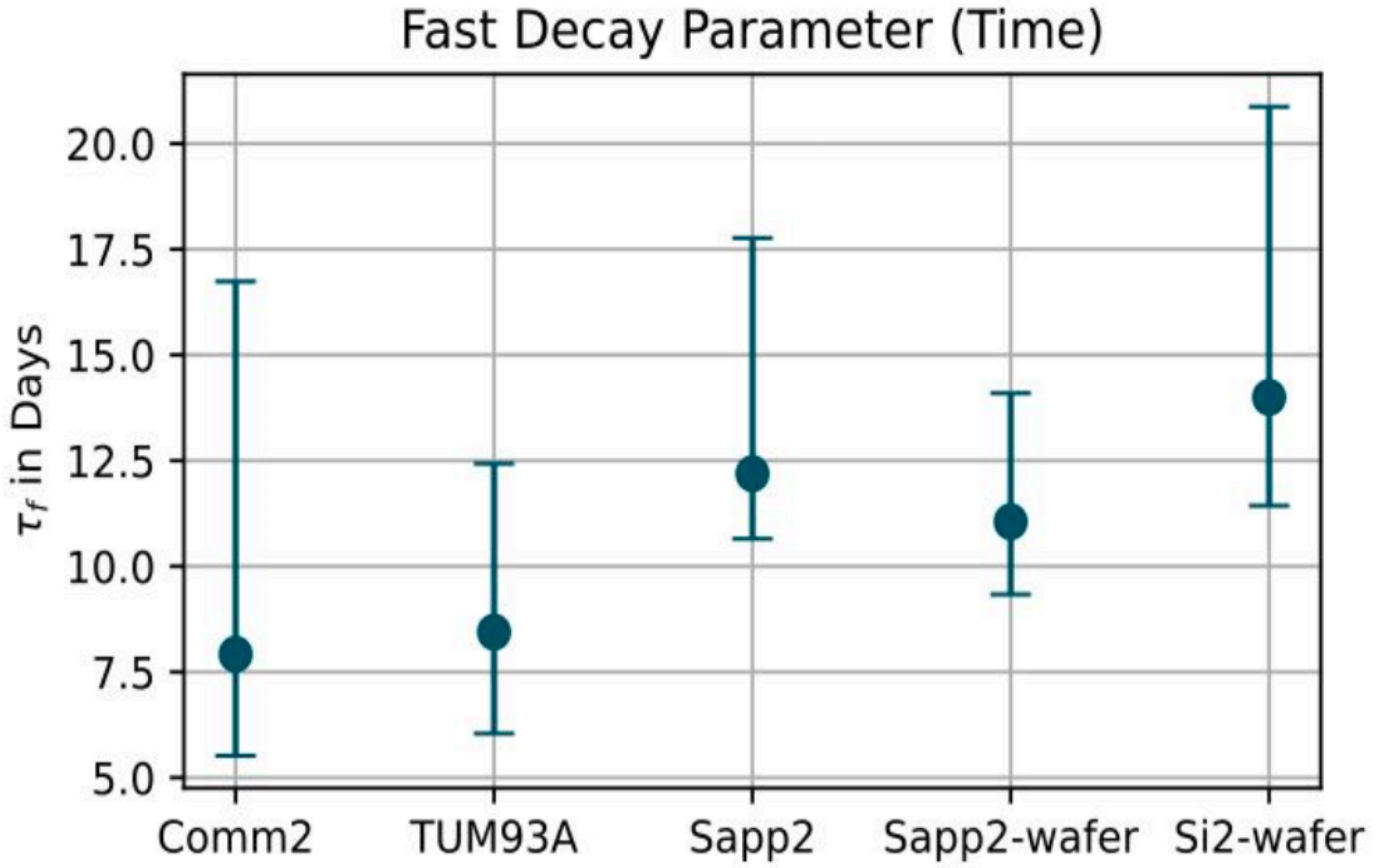


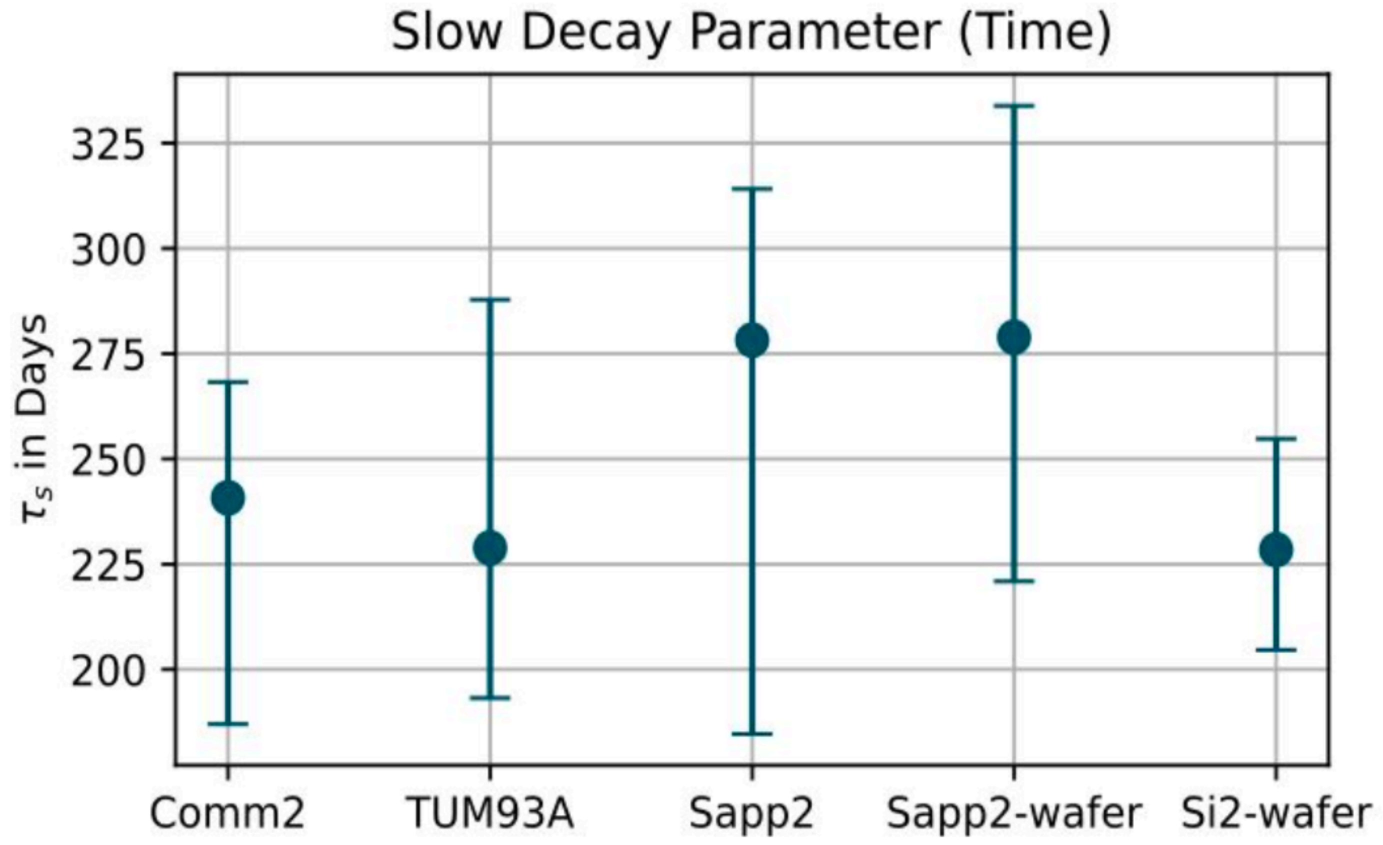
Time variation of LEE



Rate monitoring over time:

- Rate decays exponentially in time
- Reset of the rate after warm-up cycles
- Two decay constants
    - Fast decay ~ 10 days
    - Slow decay ~ 250 days





LEE rejection strategies

Related to target material?

Tested several materials

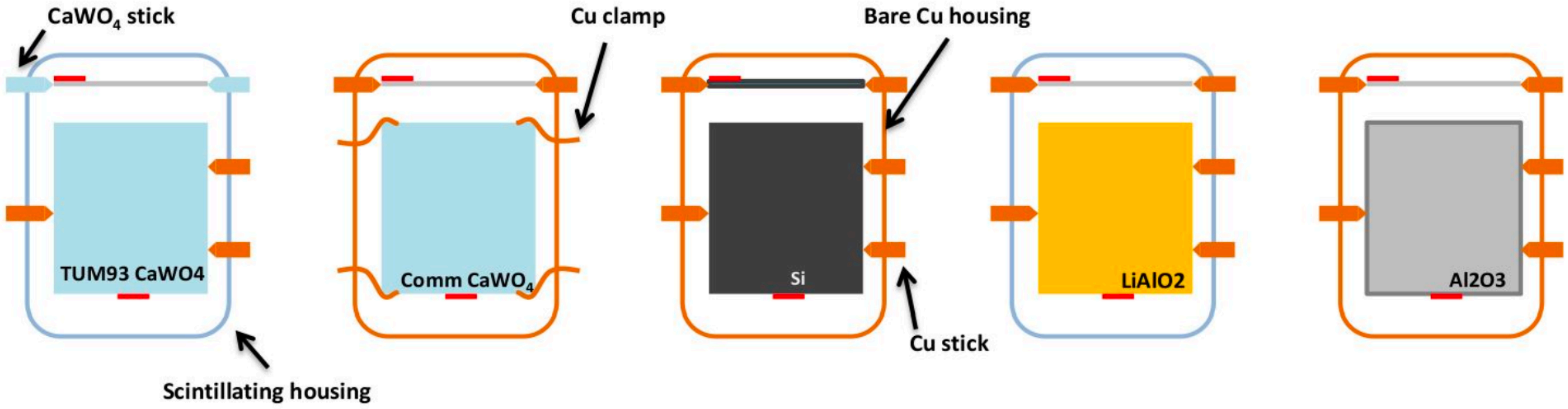
Depending on crystal growth parameters?

Tested slow grown crystal

Related to scintillating materials?

Removed scintillating materials

Dedicated modifications:



Adopted different holding mechanisms

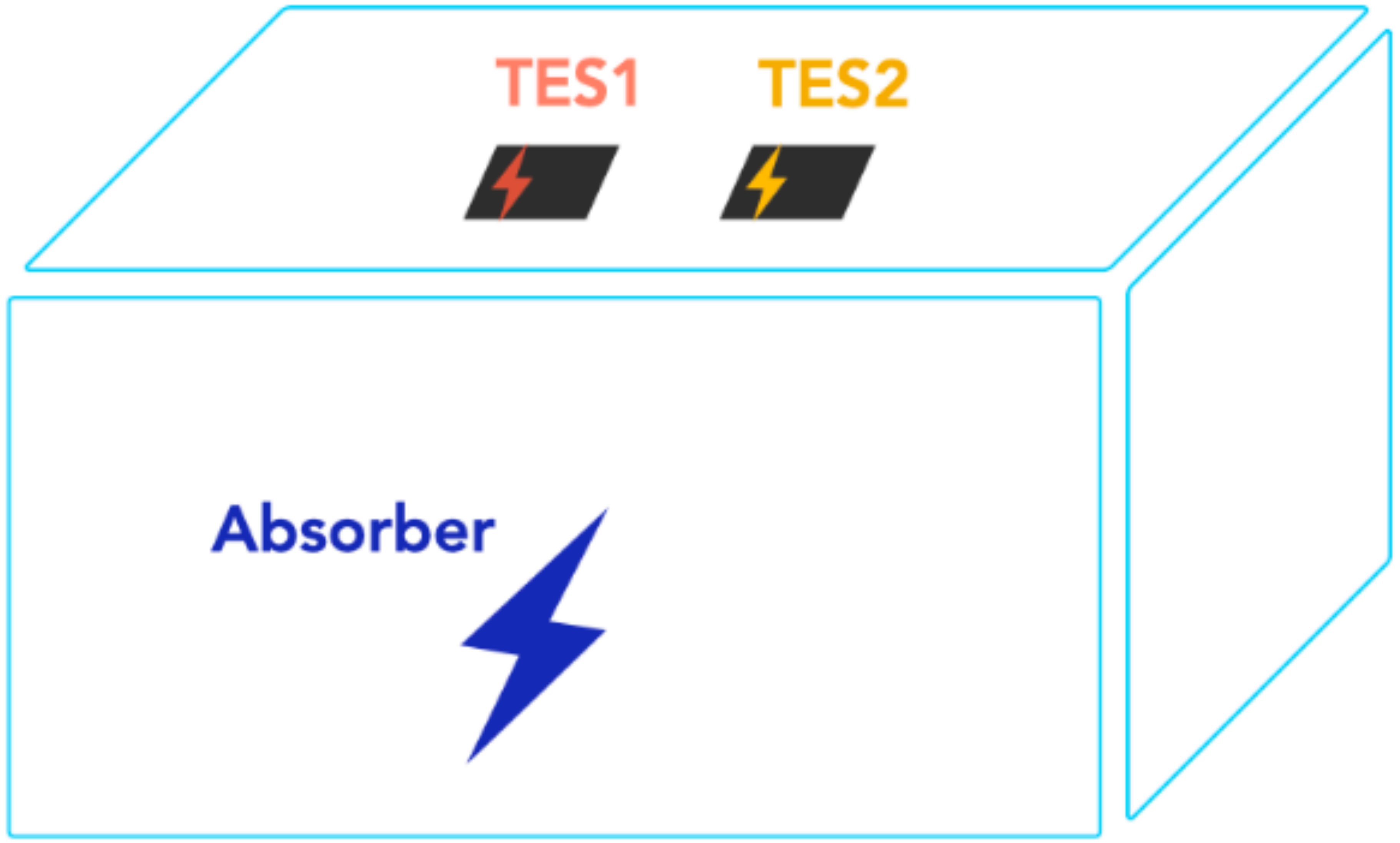
Caused by holder stress?

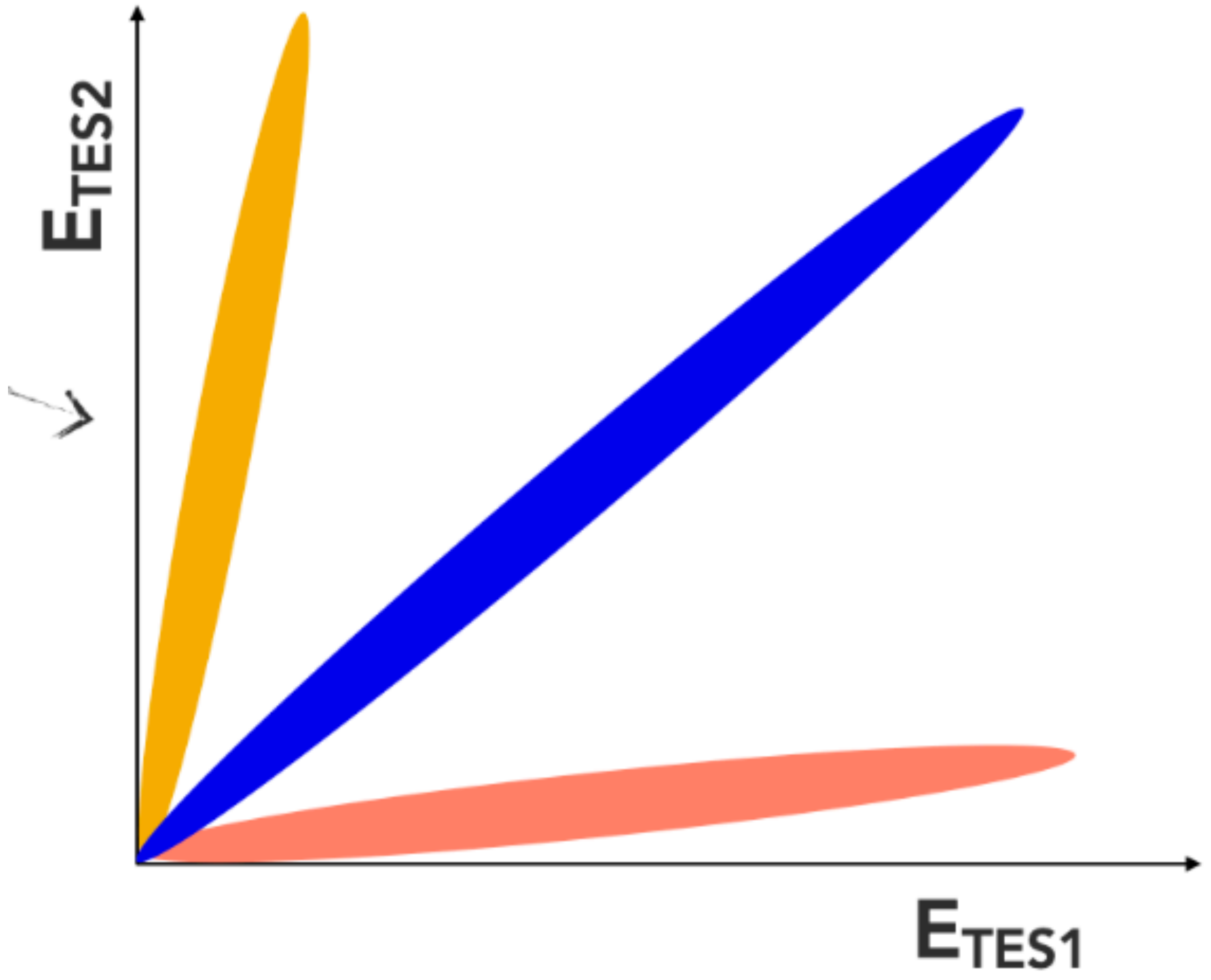
Analyzed LEE in a wafer detector

Depending on detector geometry?

Double TES

- Basic idea: instrument the absorber with 2 TES
- If the signal originates in the absorber the two TES are expected to show the same response.
- If the signal originates in or very close to one TES, the two response signals are expected to be different.

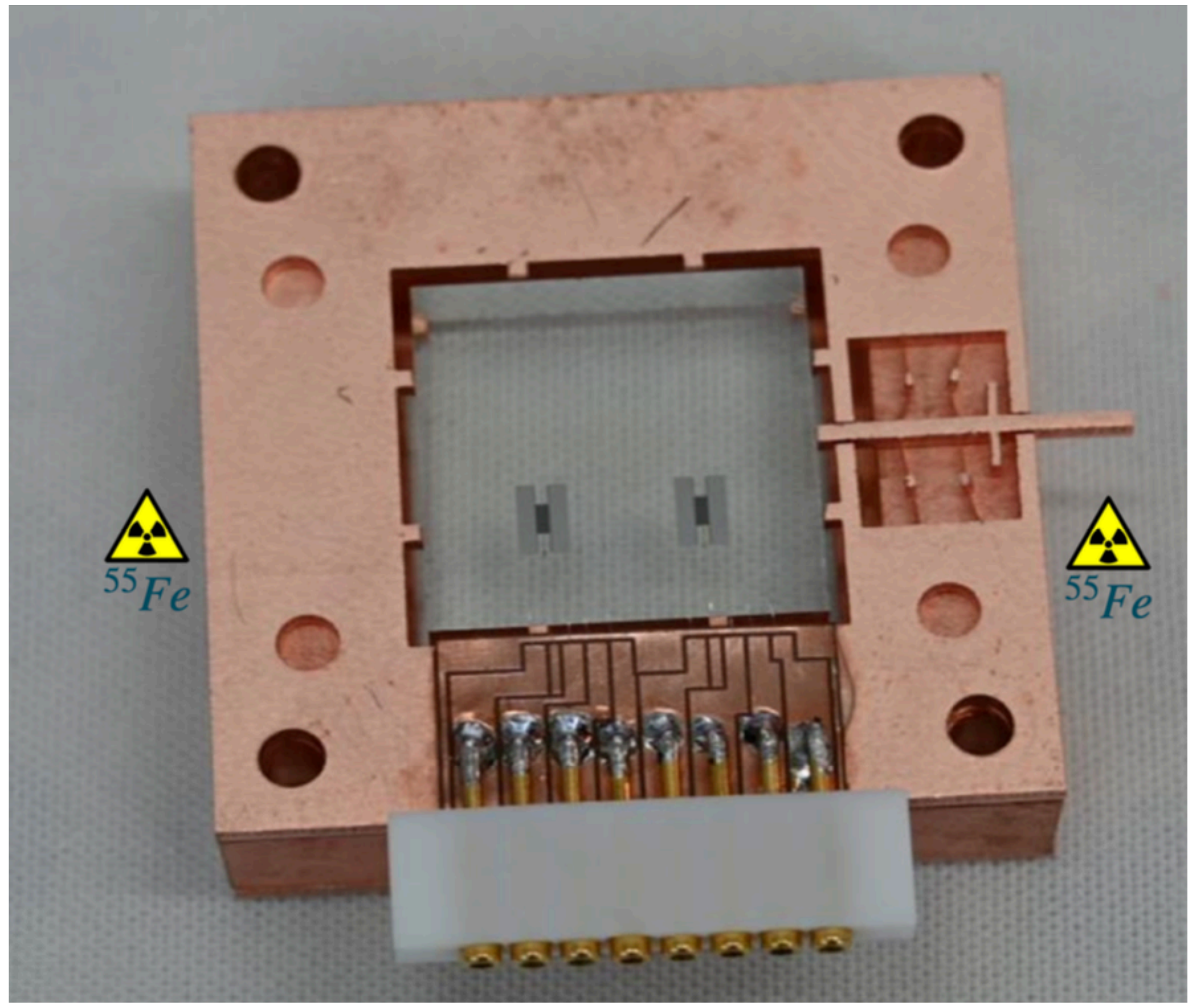


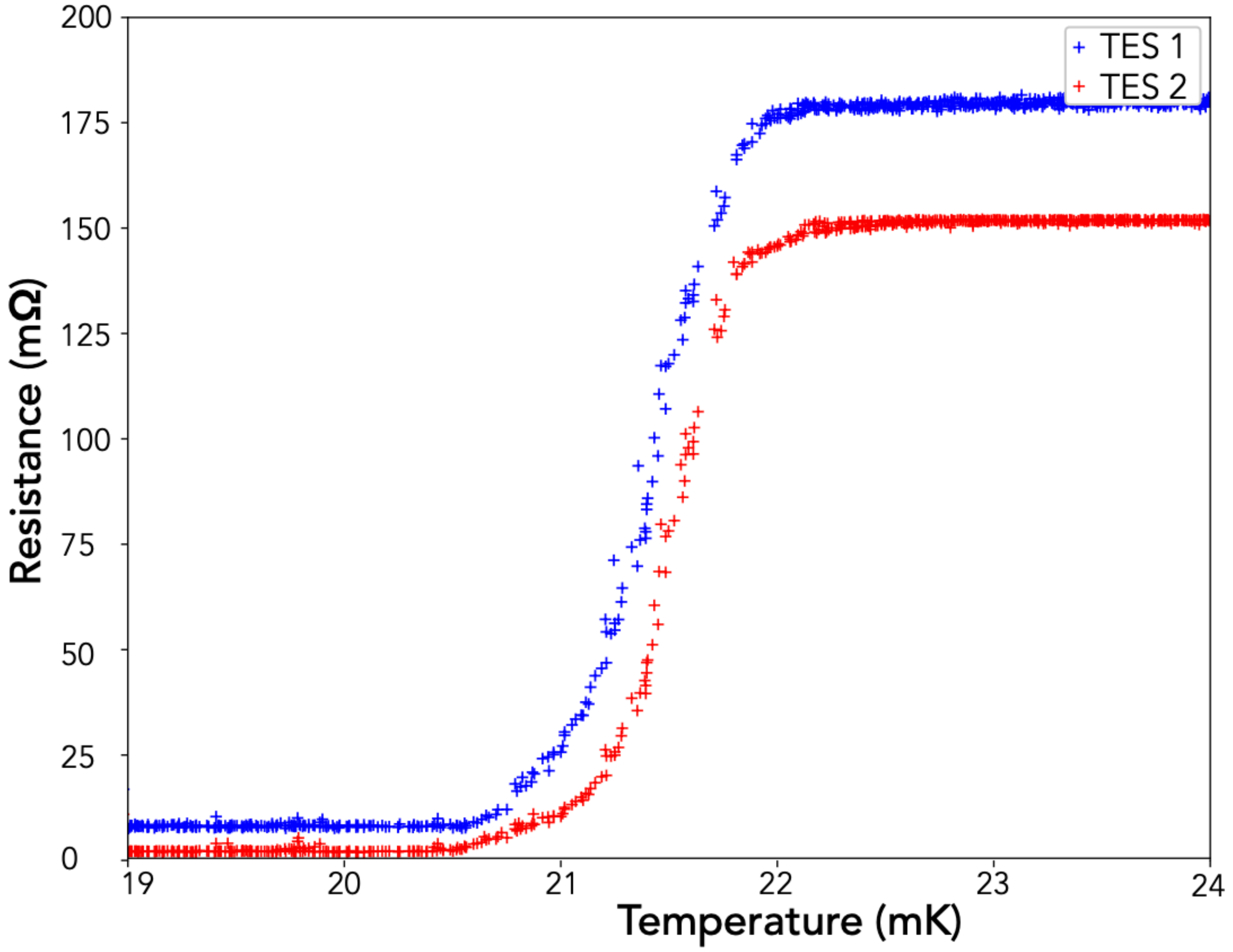


Double TES - Measurement

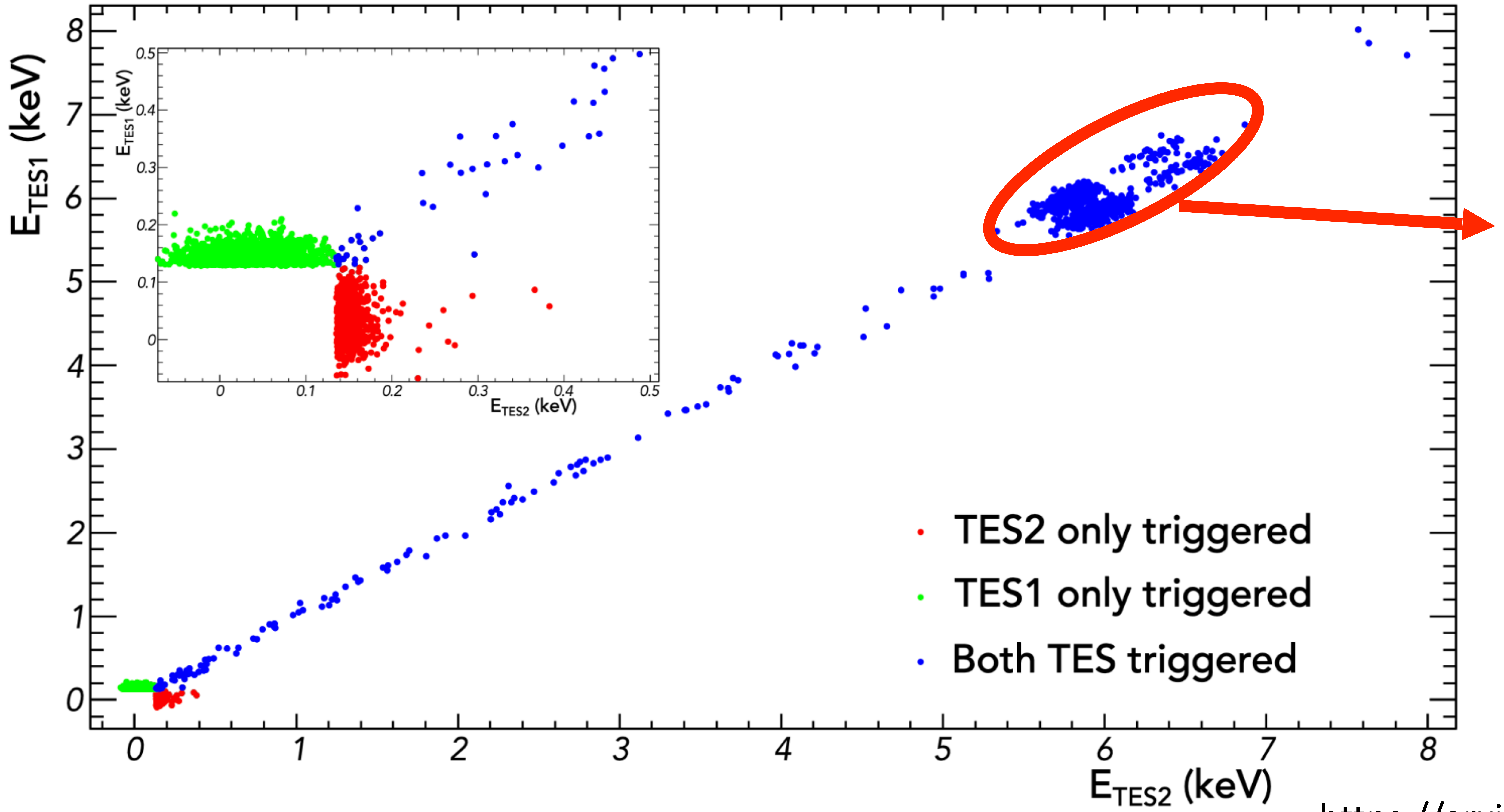
$CaWO_4$

- $20 \times 20 \times 10 mm^3$ crystal
- Two measurements in September and November 2022
- Above ground, wet cryostat
- Two independent heaters of independent stabilization
- Two 55Fe sources
- Two very reproducible transitions





Time variation of LEE ts (I)



^{55}Fe source:
little position
dependence effect

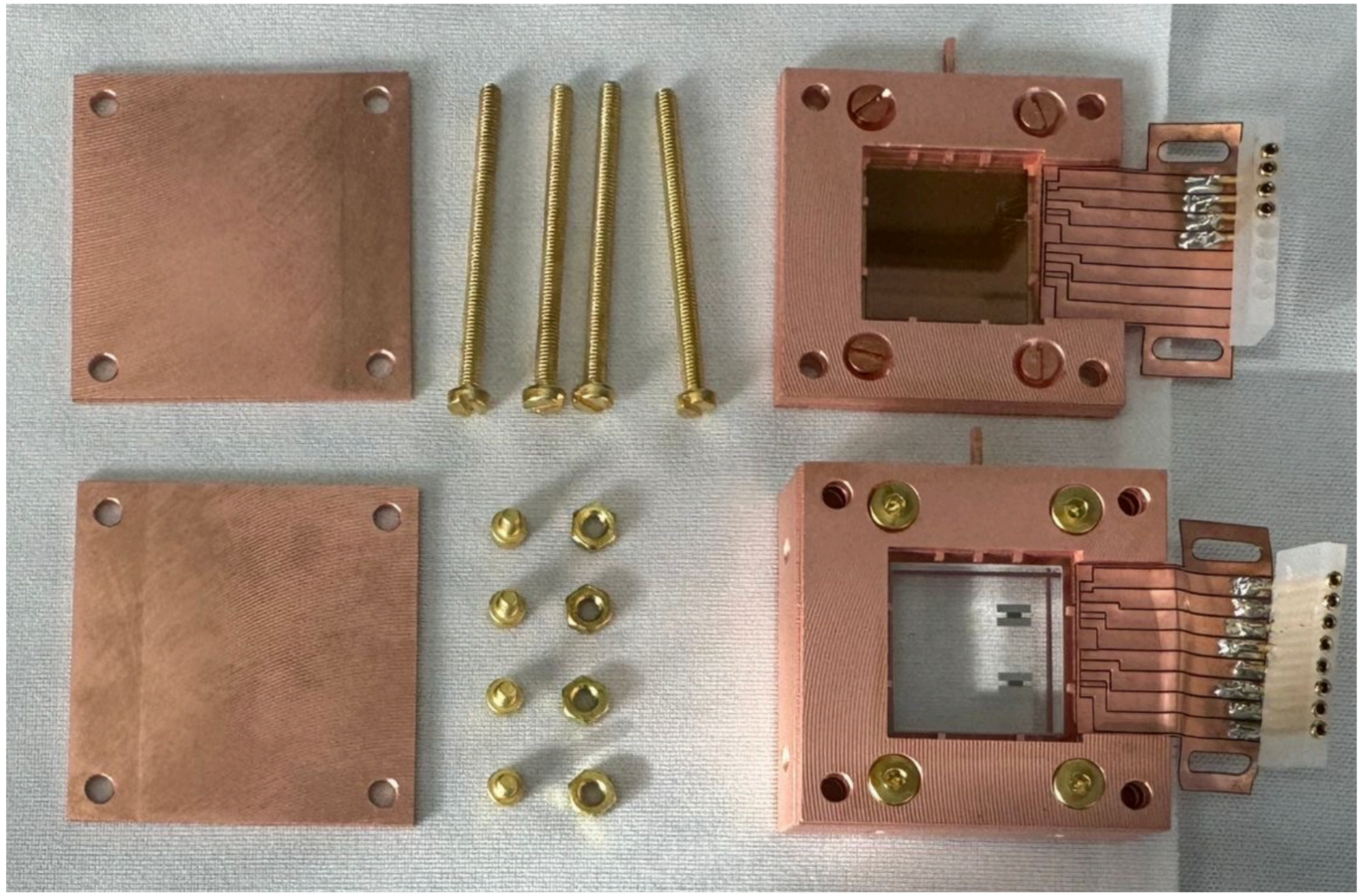
https://arxiv.org/abs/2404.02607

Double TES – Underground Test

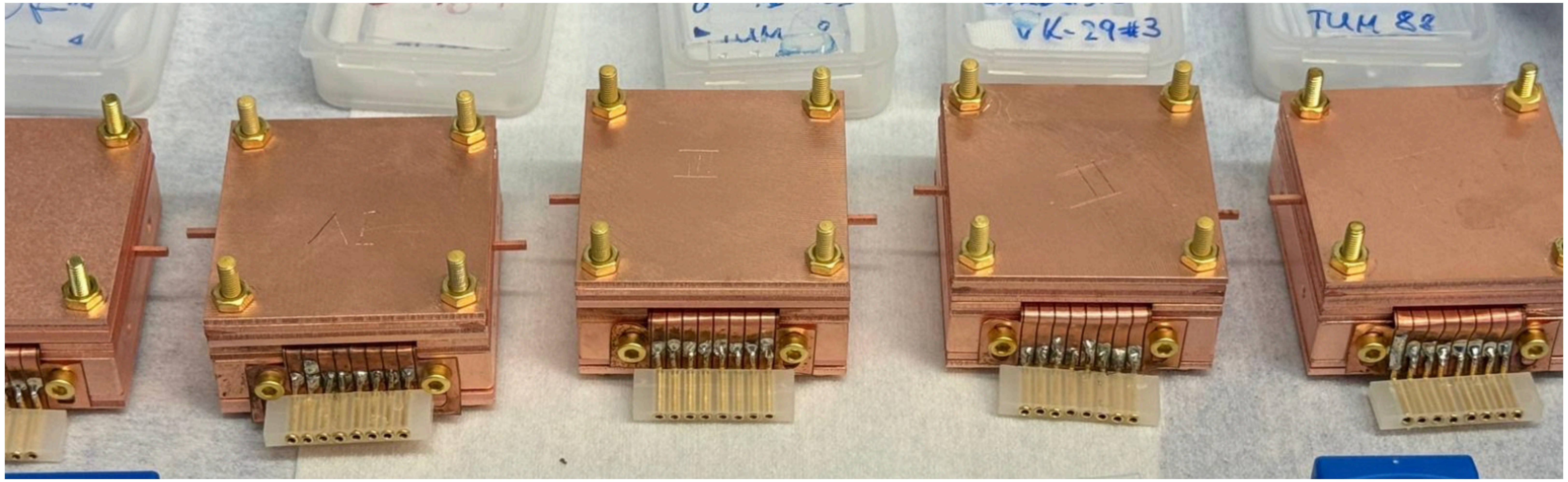
To explore the full potential of Double TES technology a Run in the CRESST cryostat was mandatory (low background + low noise).

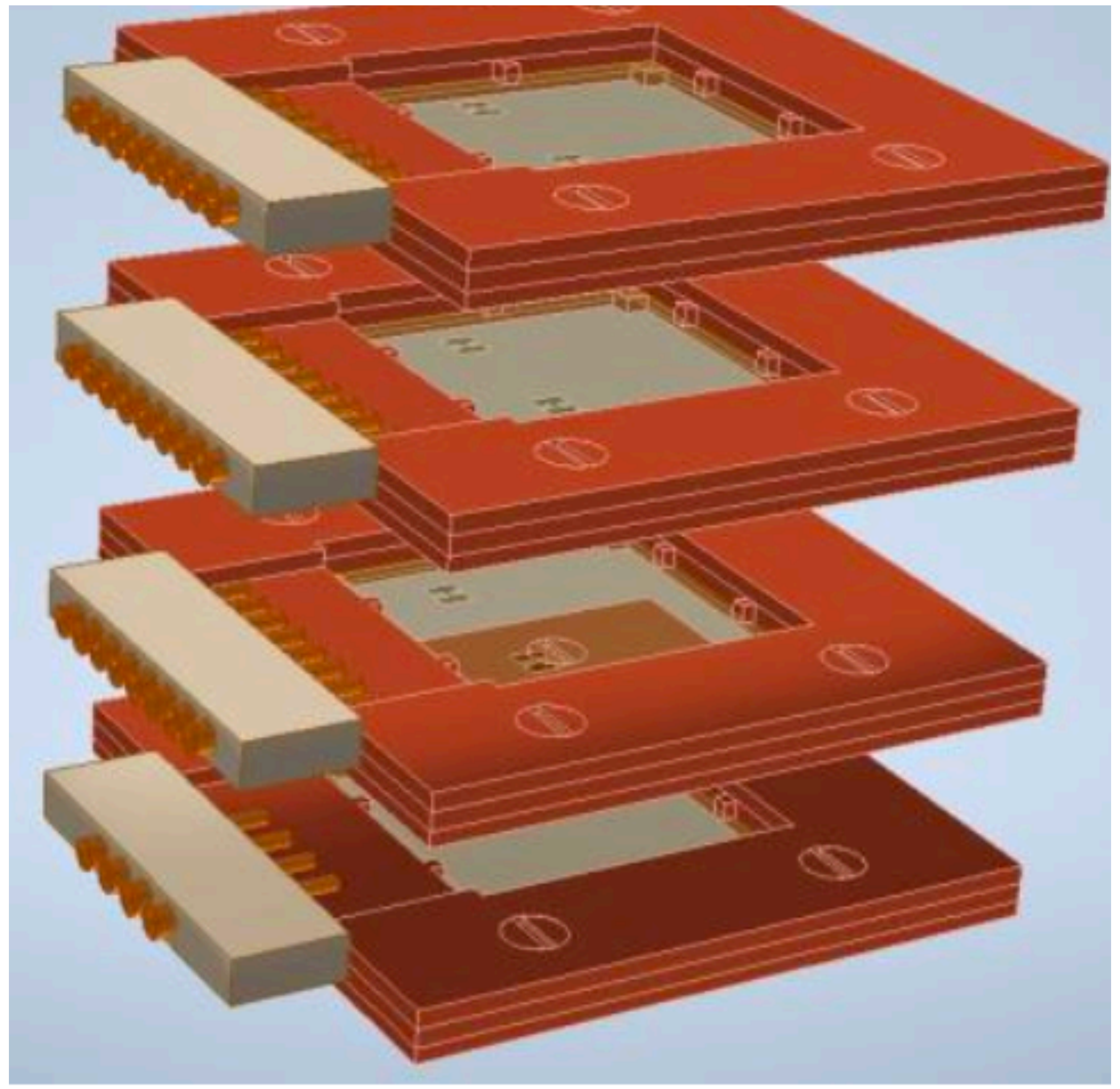
In February 2024, experimental Run37 detector modules have been installed in the CRESST cryostat:

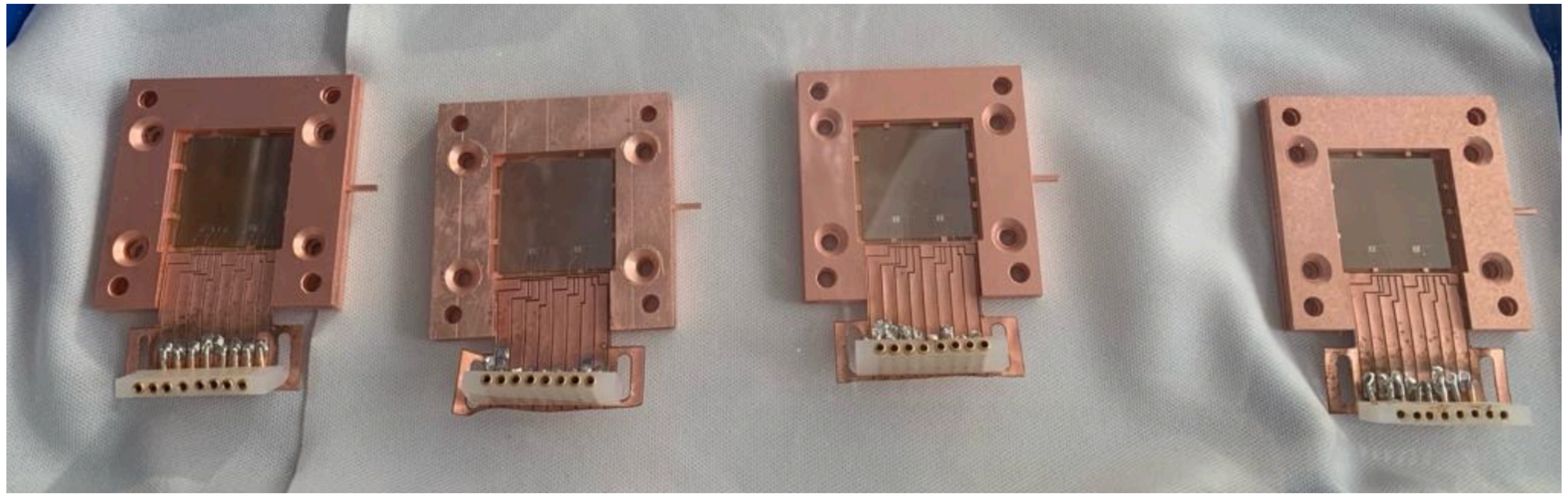
- 5 Double TES $CaWO_4$ modules
- A stack of 4 Double TES Al_2O_3 LD with double TES (with ^{55}Fe source)
- 1 Mini-Beaker module
- TUM93A $CaWO_4$ from Run36

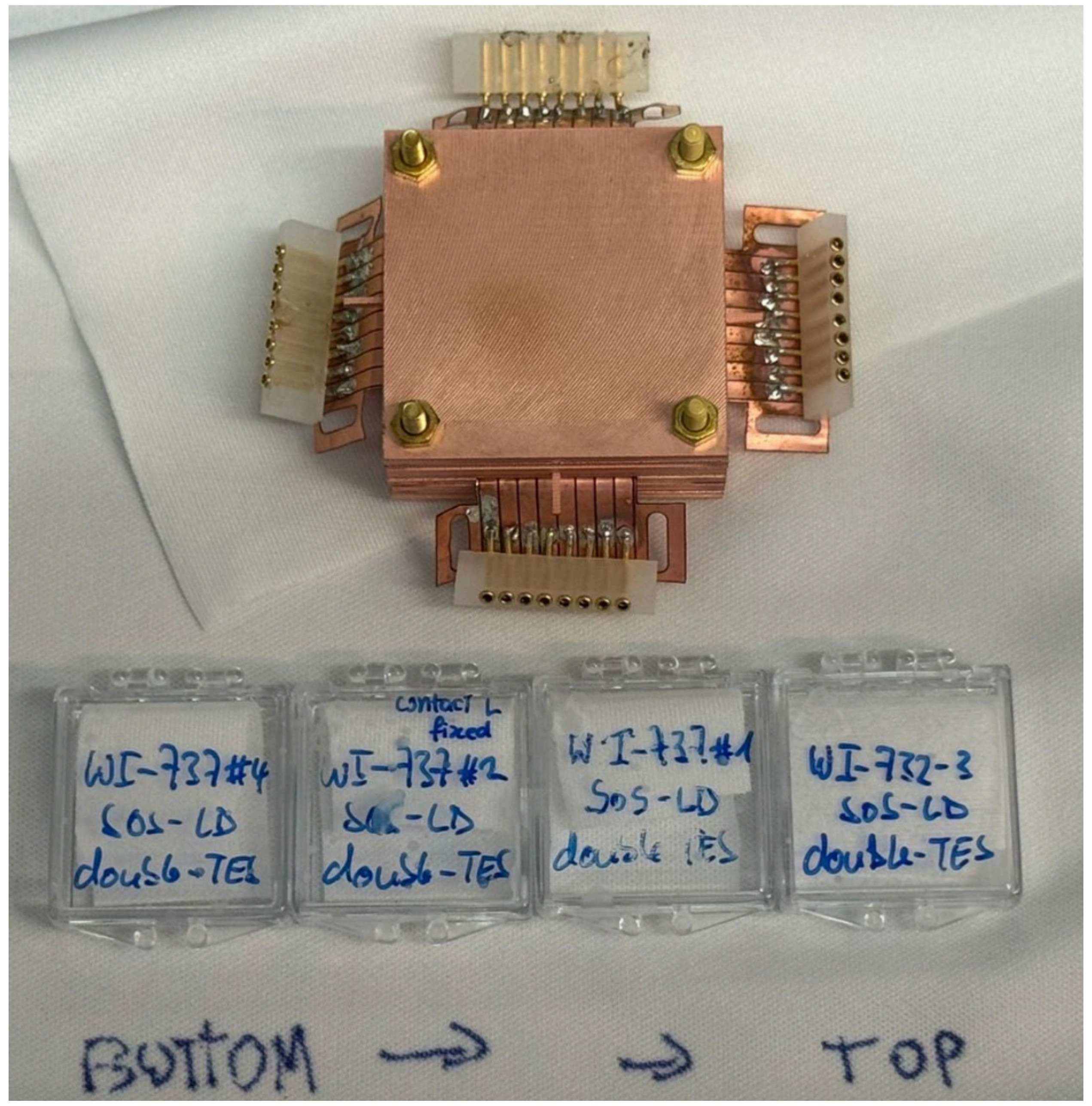


Double TES – Run 37









Double TES – Run 37

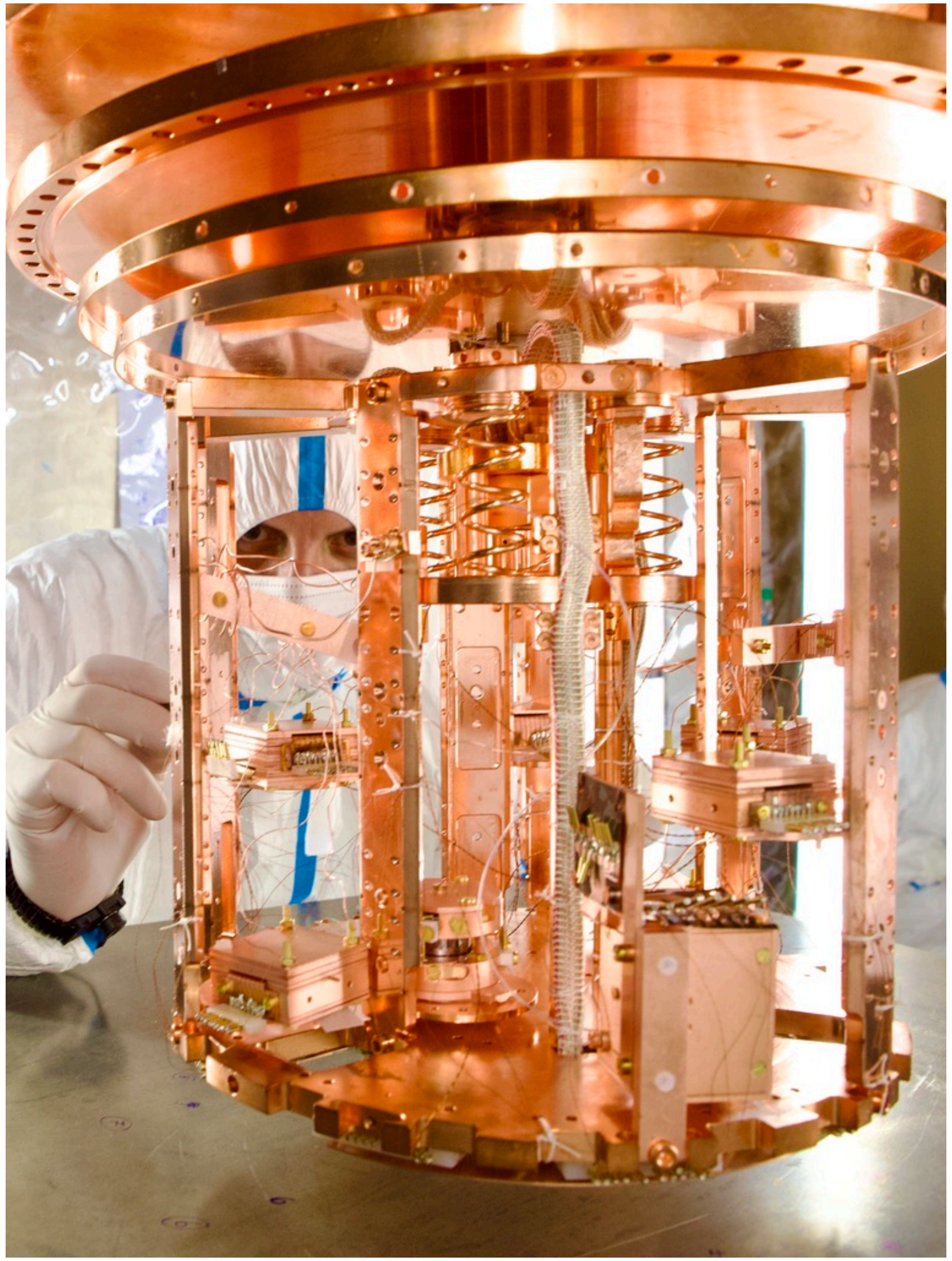
On March 23, 2024, the carousel reached operating temperature. TESs were operational and immediately set up to measure the LEE rate variation.

In July 2024 neutron-calibration (AmBe) was started (calibration via n radiative absorption for $CaWO_4$). Once the calibration is completed we will start the official Double TES campaign.

Stay tuned for upcoming results!

Conclusion

- CRESST energy thresholds O(10eV) represent the state of the art in the exploration of the light DM mass region
- Recent results in terms of E threshold are very promising for extending sensitivity in the ~100 MeV range for the DM mass and both SI (Si, $CaWO_4$) and SD ($LiAlO_2$, Al_2O_3) interactions
- Calibration from recoils induced by radiative capture of thermal neutrons allows calibration of $CaWO_4$ detectors without introducing contaminants in the CRESST setup
- CRESST collaboration is preparing to increase the number of channels to enhance exposure
- LEE comprehension and reduction represent a crucial step for the light DM community. Recent CRESST achievements with Double TES are promising to finally solve this puzzle. **Stay tuned for upcoming results!**



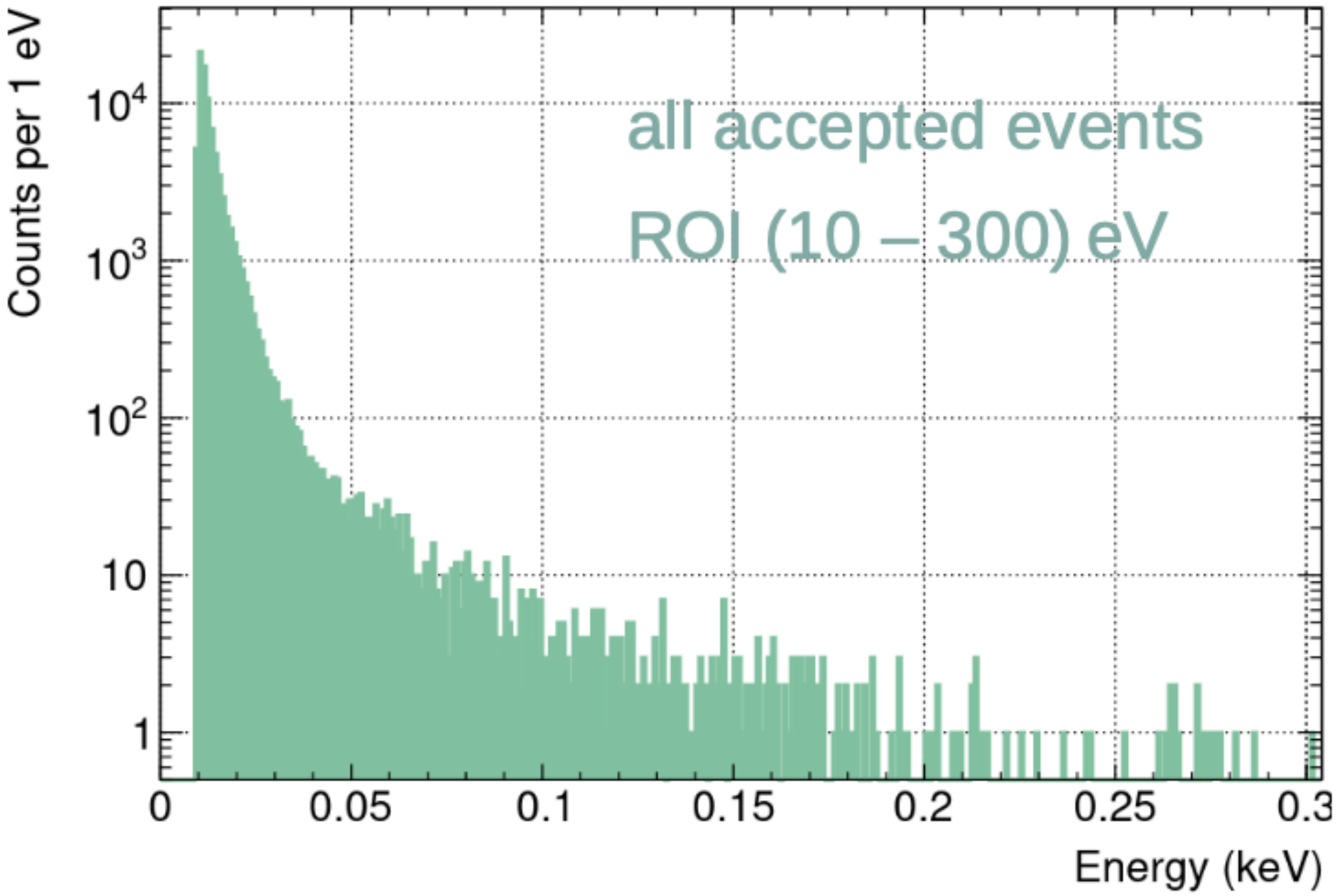
Backup slides

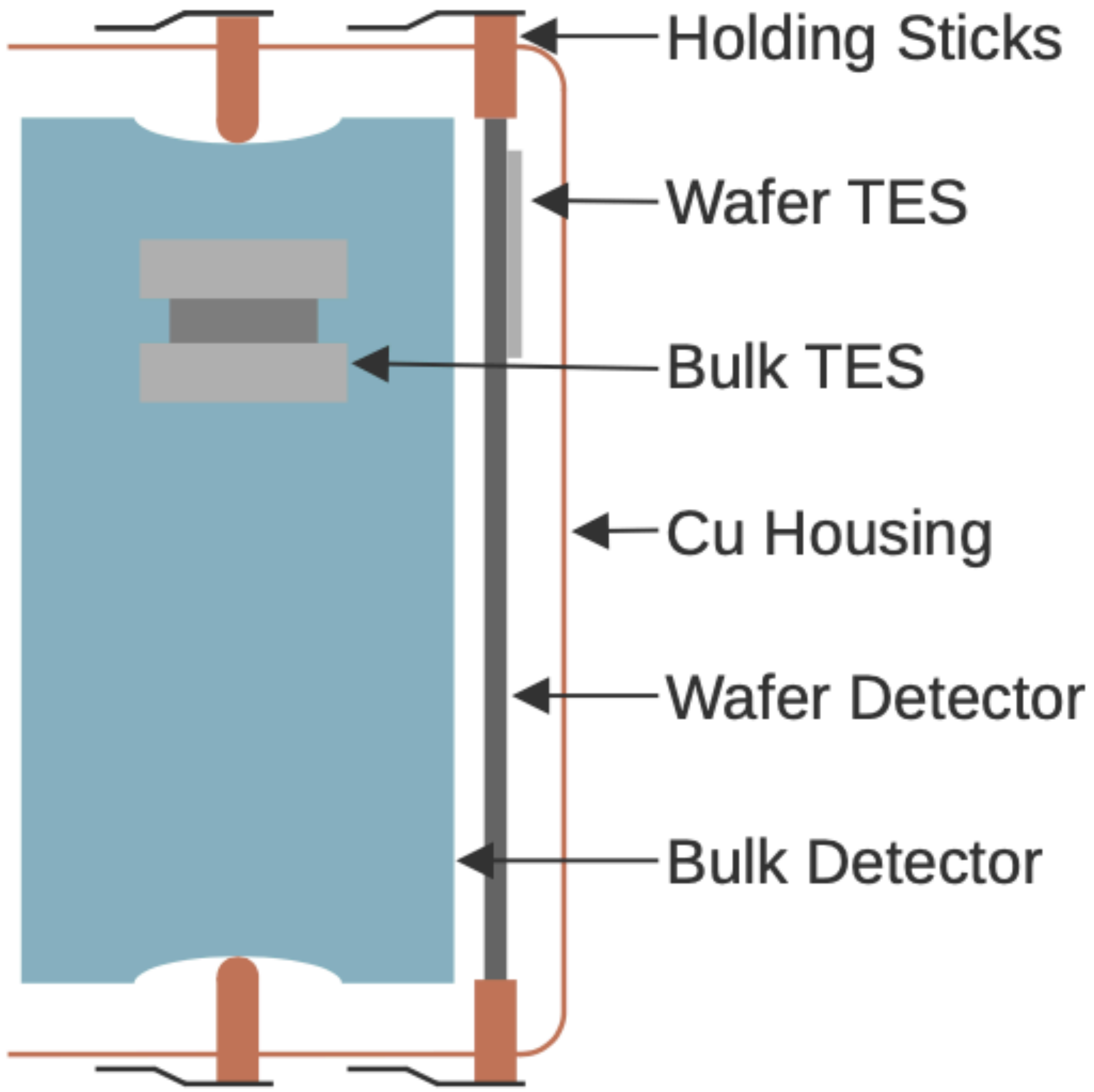
Results from a Si Wafer Detector

CRESST

Si2 wafer detector – 0.35 g Si

data taking period	Nov 2020 – Aug 2021
exposure	55.06 g days
baseline resolution	1.36 eV
nuclear recoil threshold	10.0 eV





Using thin wafer detector as target and bulky detector as veto detector.

https://arxiv.org/abs/2212.12513

Results from a Si Wafer Detector

Si2 wafer detector – 0.35 g Si

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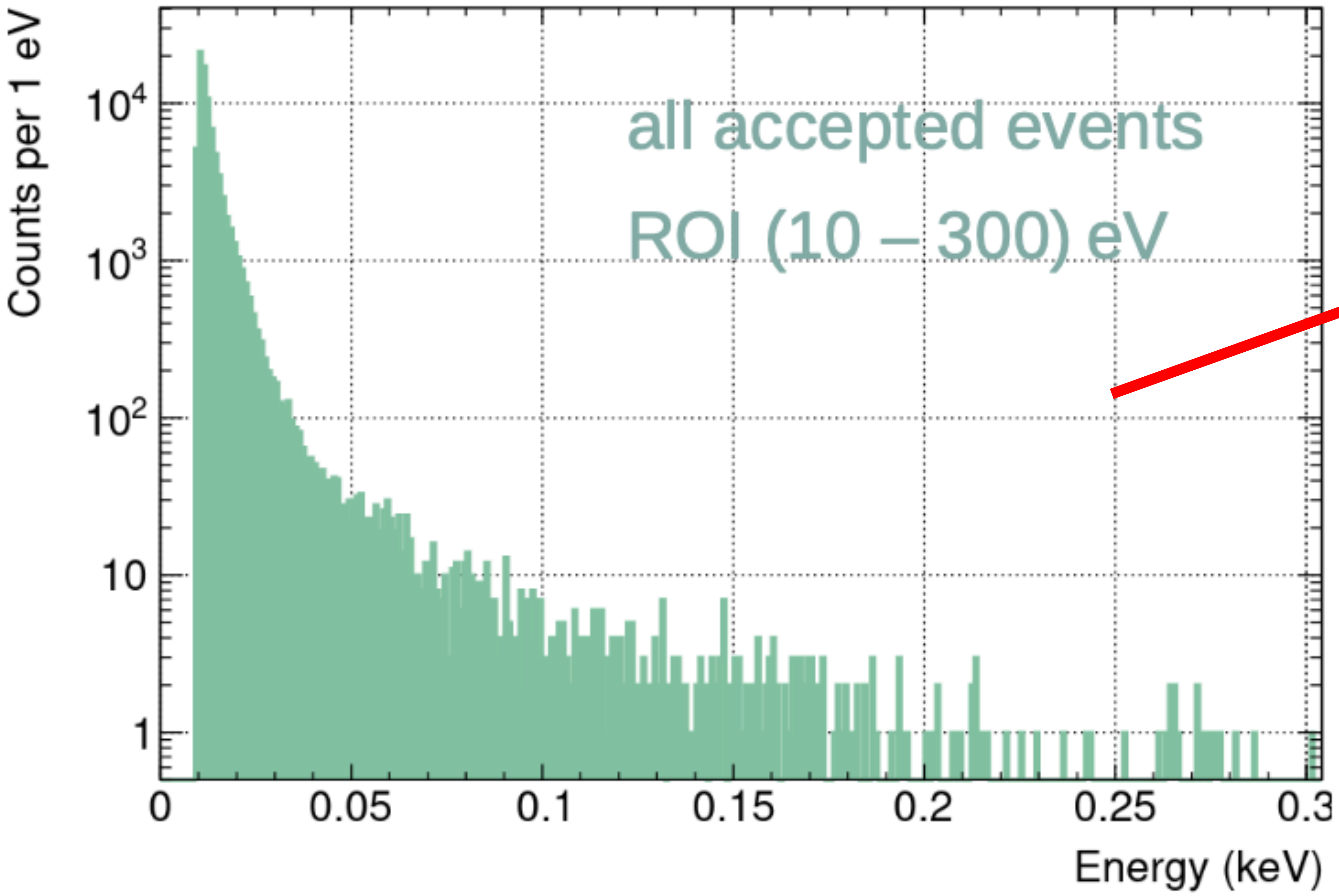
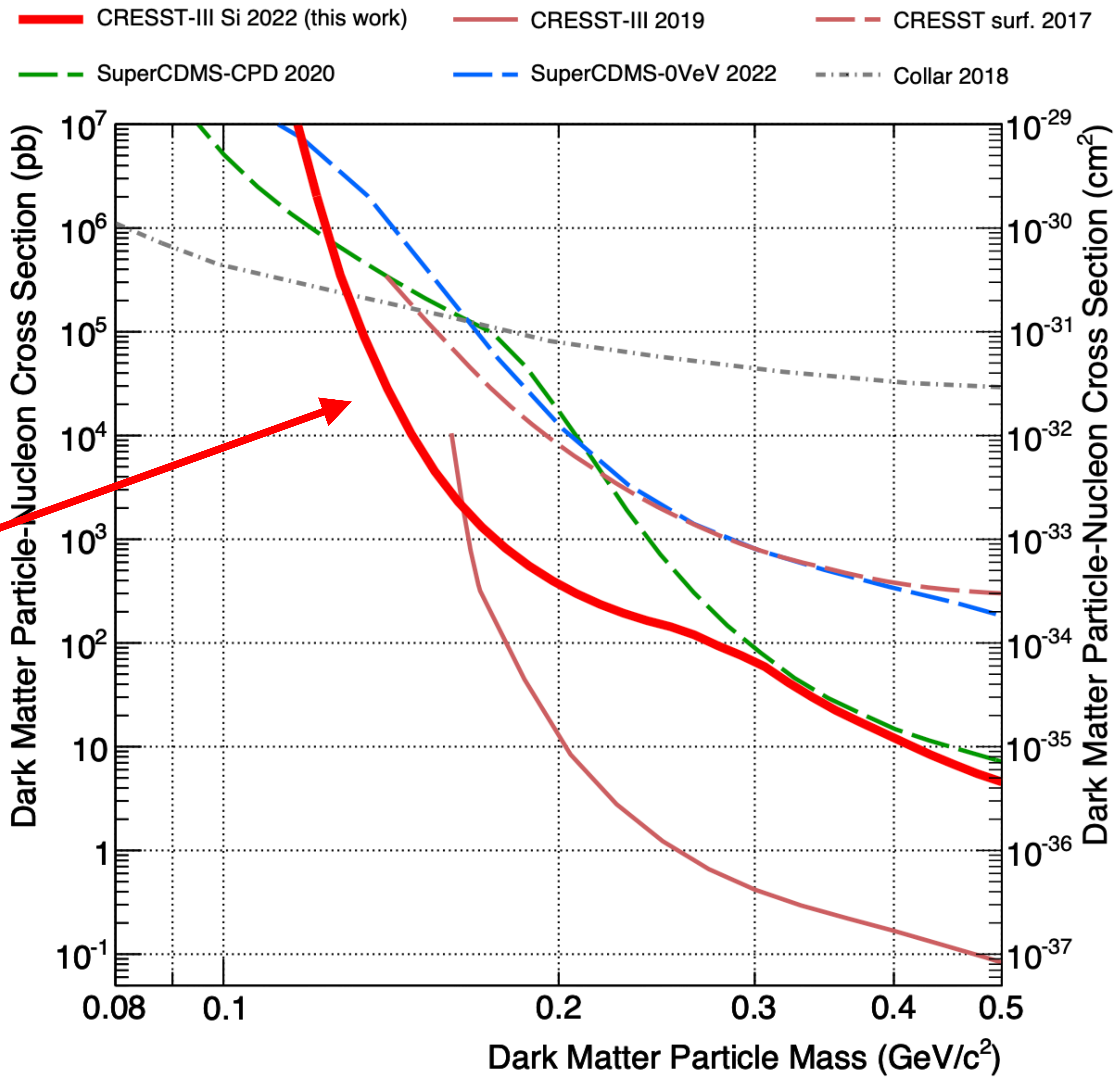
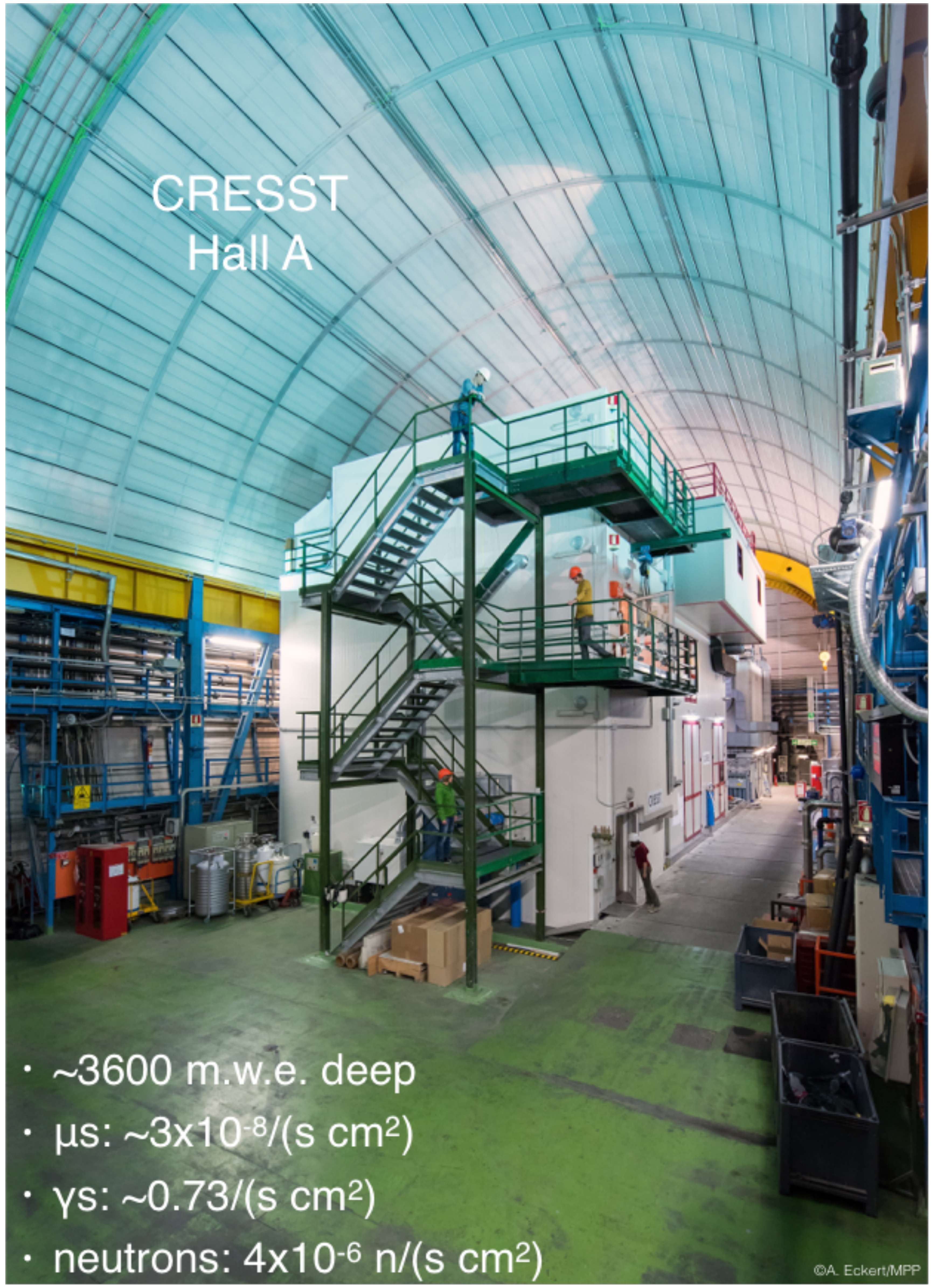
baseline resolution	1.36 eV
nuclear recoil threshold	10.0 eV





https://arxiv.org/abs/2212.12513

CRESST @LNGS



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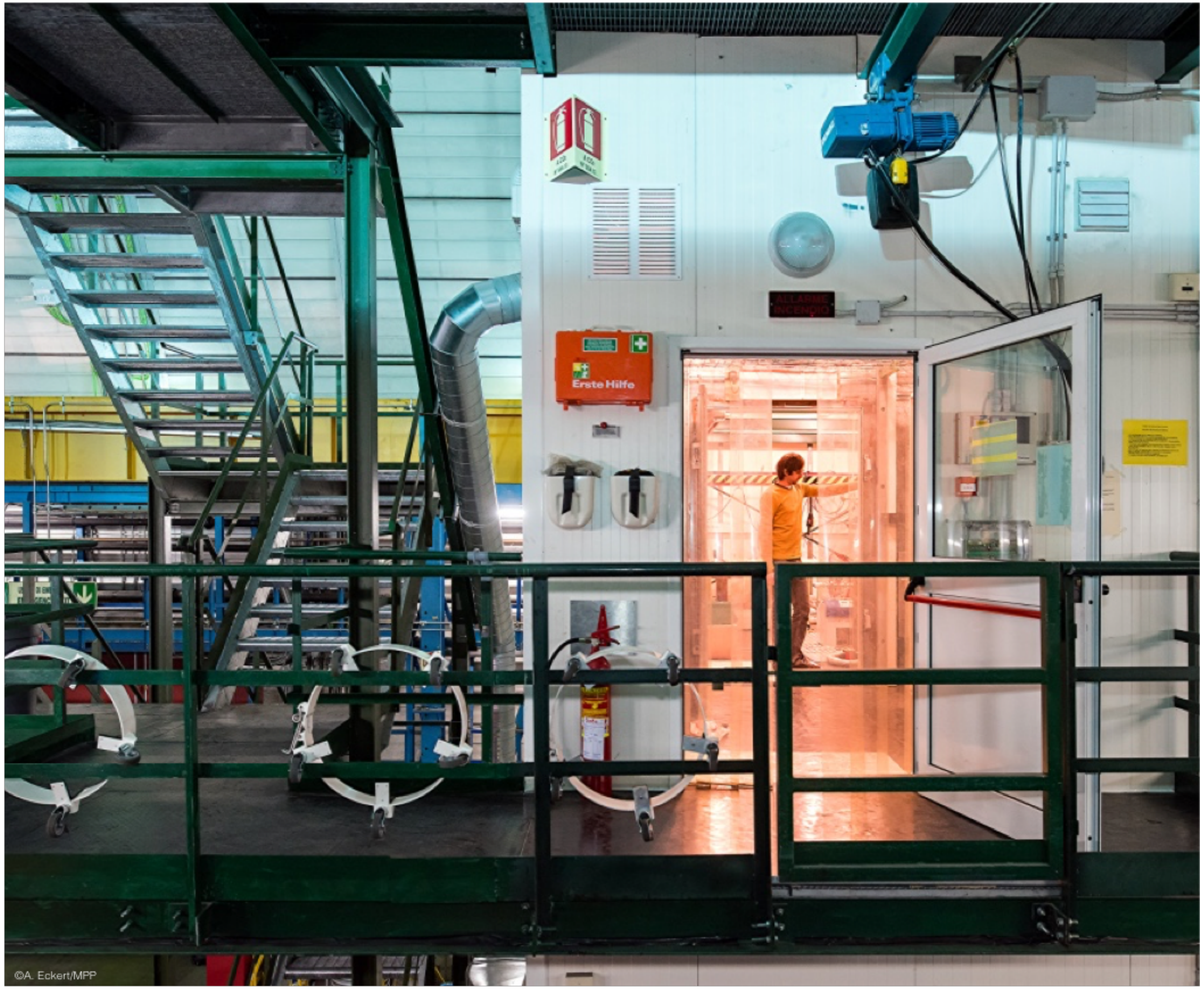

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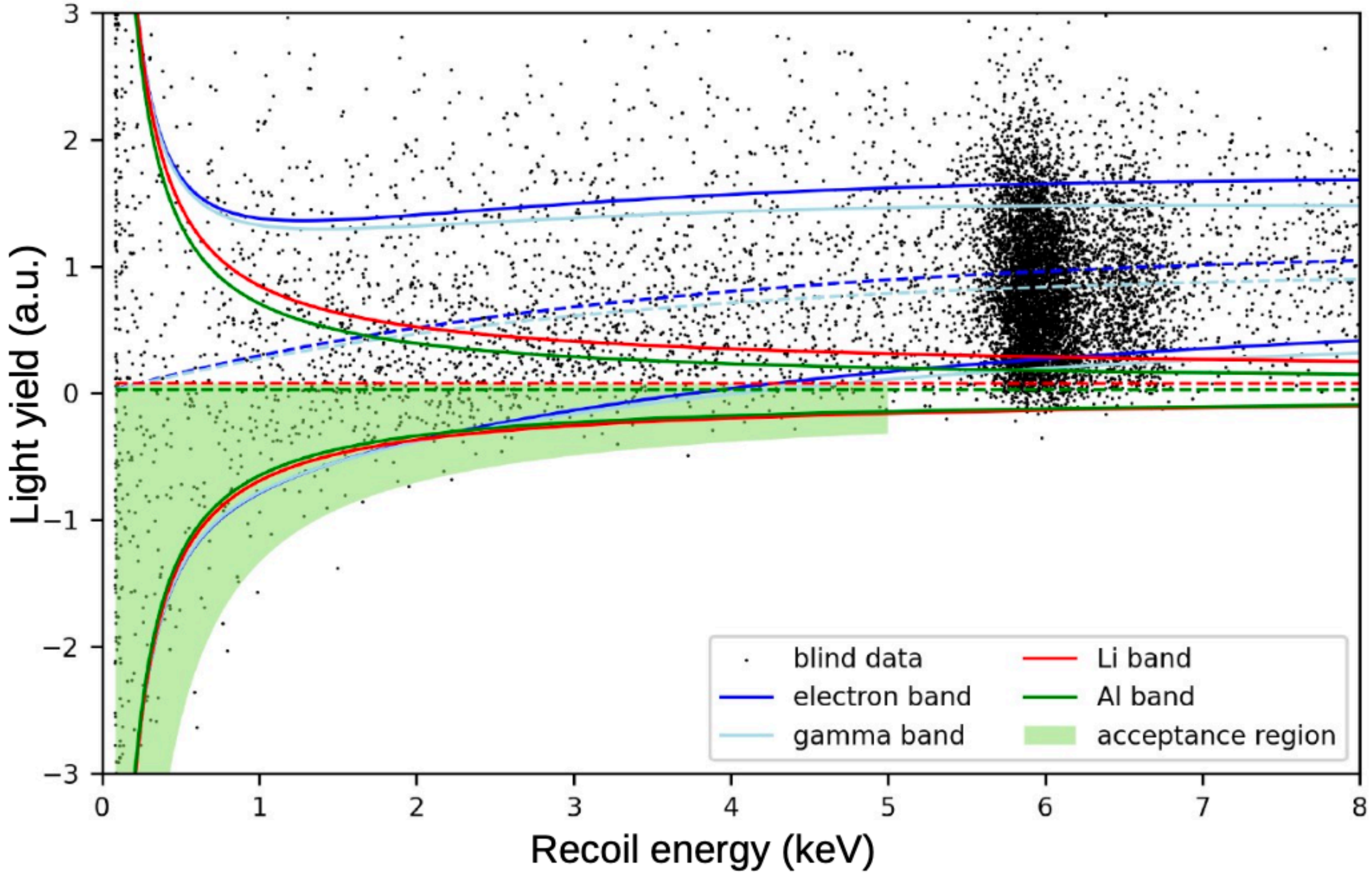
SD Limits with $LiAlO_2$ Detectors

Li1 detector – 11.2 g $LiAlO_2$

data taking period	Nov 2020 – Aug 2021
exposure	1.161 kg days
baseline resolution	12.8 eV
nuclear recoil threshold	83.6 eV

Isotopes sensitive to SD interactions:

Isotope	$\langle S_p \rangle$	$\langle S_n \rangle$
^{6}Li	0.472	0.472
^{7}Li	0.497	---
^{27}Al	0.343	0.0296



Phys. Rev. D 106, 092008 / arXiv:2207.07640

Title Text

	$LiAlO_2$	Al_2O_3
Mass	11.2 g	0.6 g
Data taking	Nov 20 -Aug 21	Nov 20 - Aug 21
Baseline resolution	12.8 eV	1.0 eV
Energy threshold	83.6 eV	6.7 eV

SD rate: $$\frac{dR}{dE} \sim \frac{(J+1)}{J}\langle S_{p/n}\rangle^2$$

Lithium aluminate

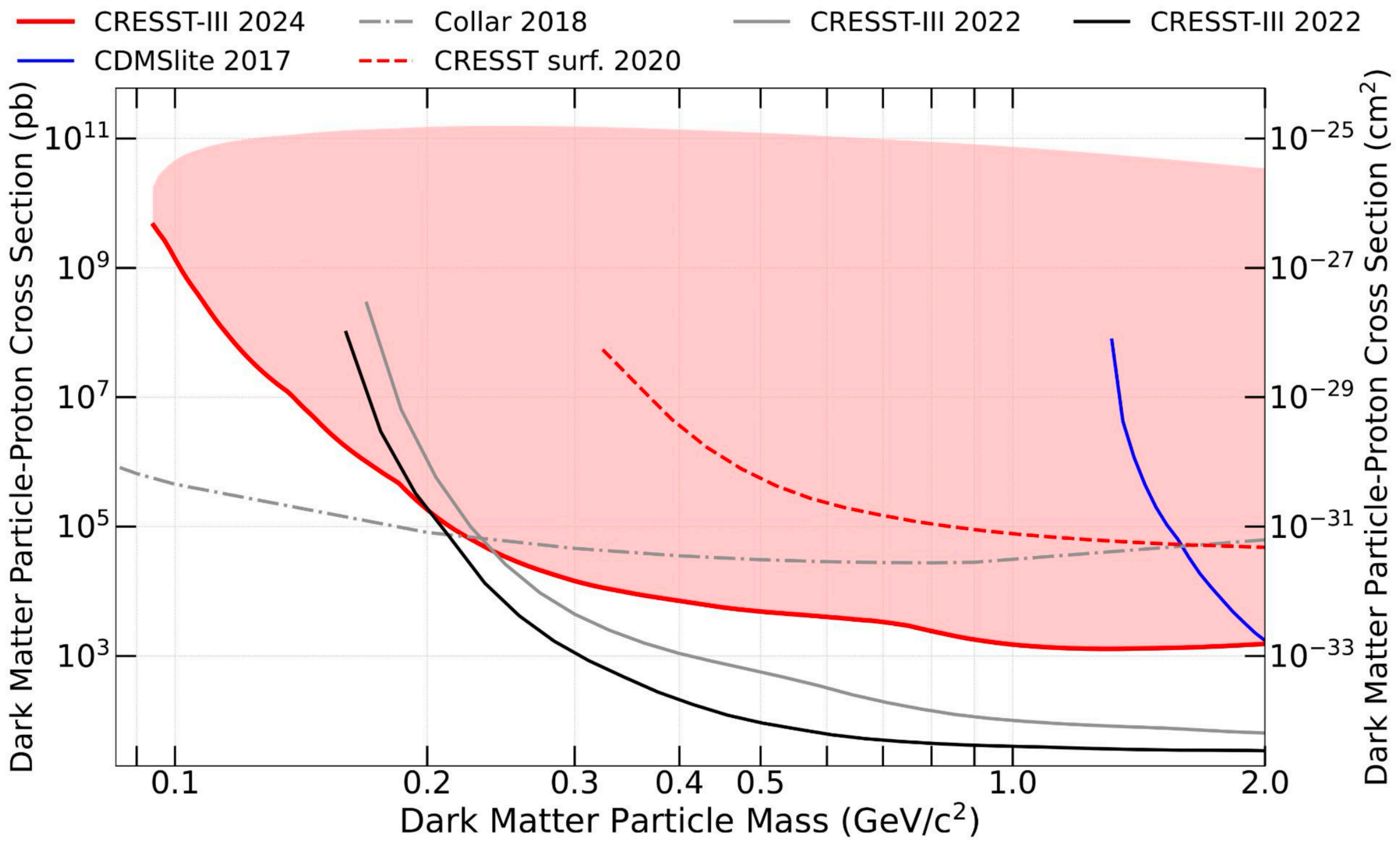
- Contains ^{6}Li, ^{7}Li, ^{27}Al
- High $\langle S_{p/n}\rangle$ values
  → high sensitivity

Sapphire

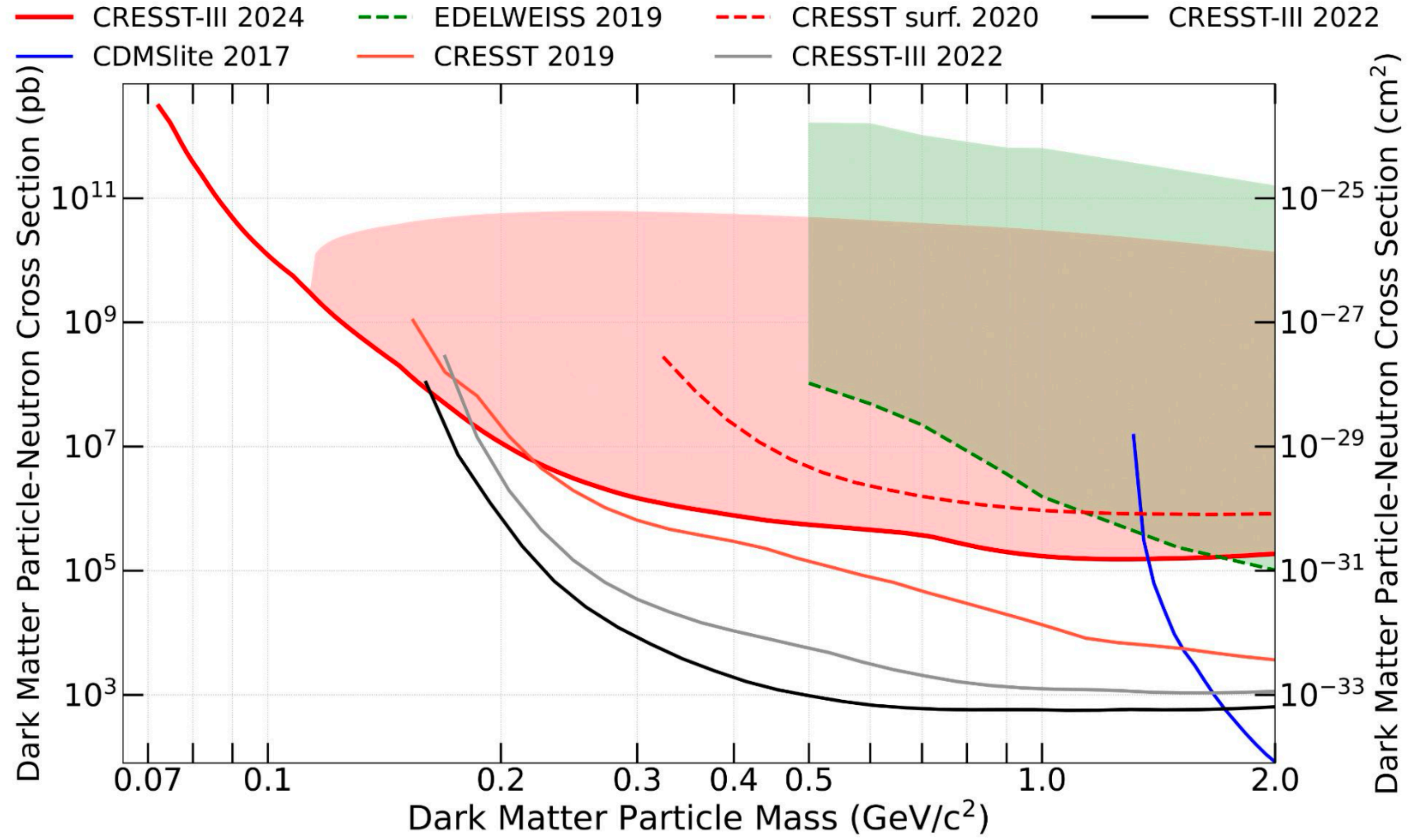
- Contains ^{27}Al
- Low energy threshold
  → sensitive to very low DM masses

Improved SD limits for both proton- and neutron-only case

proton-only



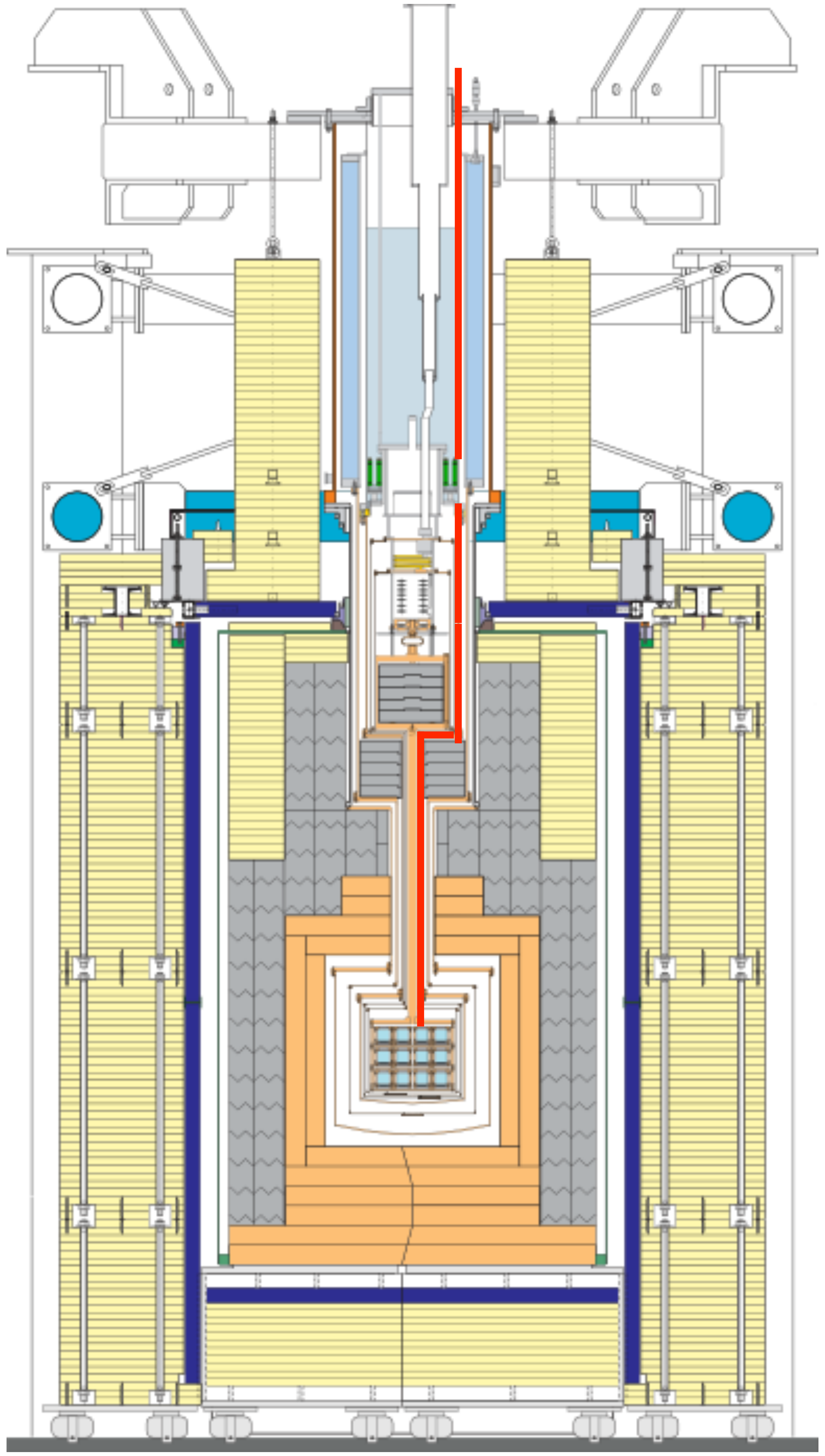
neutron-only

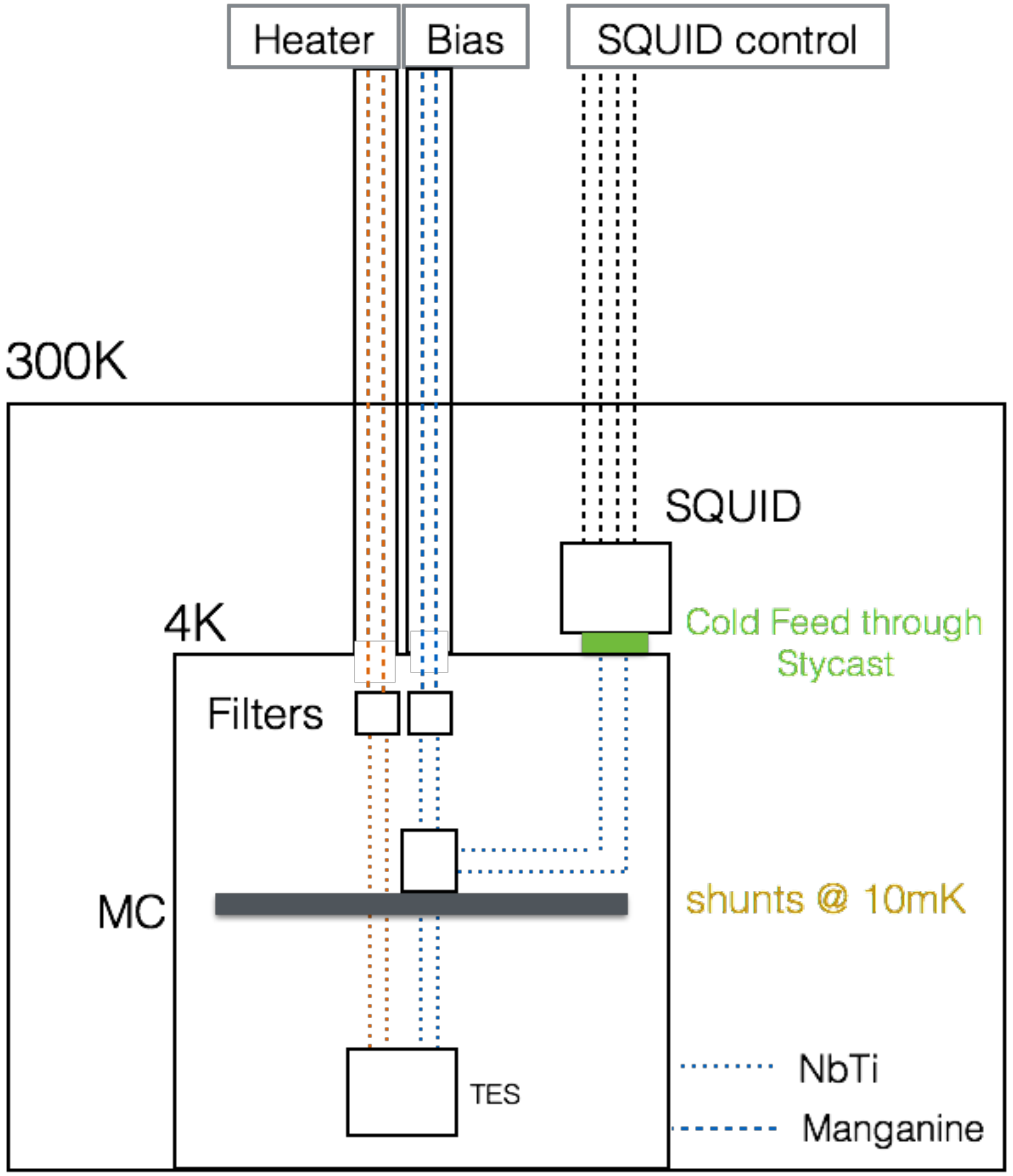


arXiv:2405.06527 | Phys. Rev. D 106, 092008

sapphire | lithium aluminate

CRESST upgrade





CRESST upgrade to 100 modules (288 readout channels) already in the procurement phase.
Cryogenic infrastructure will remain mostly the same while readout chain is upgraded.

Selection criteria

Objective

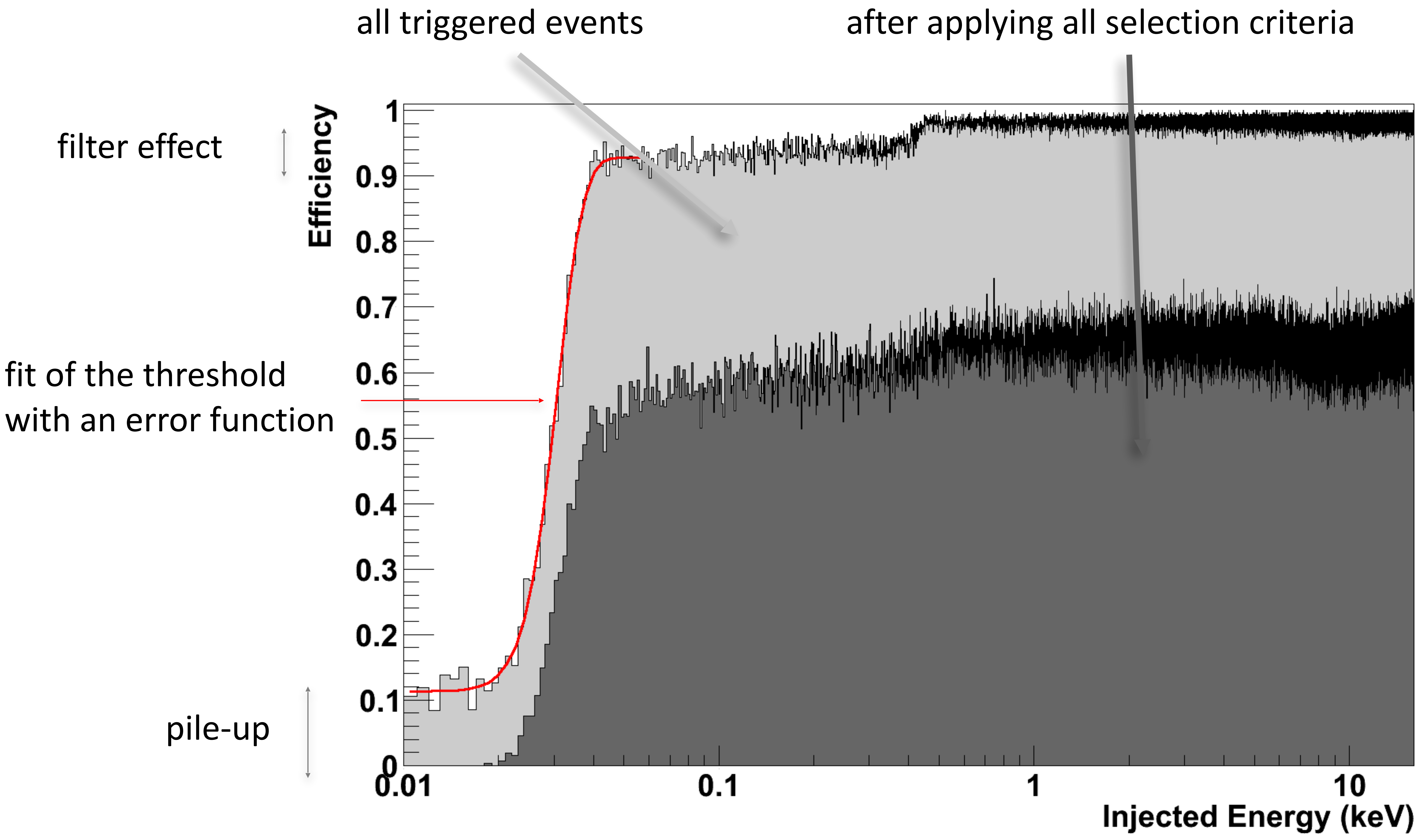
Keep only events where a correct determination of the amplitude (→energy) is guaranteed

Unbiased (blind) analysis

1. Design cuts on non-blind training set (≦20%, excluded from DM data set)
2. Apply without change to blind DM data set

Rate: noise conditions (14% of measuring time)
Stability: Detector(s) in operating point (3% of measuring time)
Data quality: Non-standard pulse shapes (e.g. i-Stick events and pileup)
Coincidences: with μ-veto (7.6% of measuring time), i-Sticks, other detector modules

EFFICIENCY/SIGNAL SURVIVAL PROBABILITY



Simulated by artificial pulses placed at random positions in the data stream

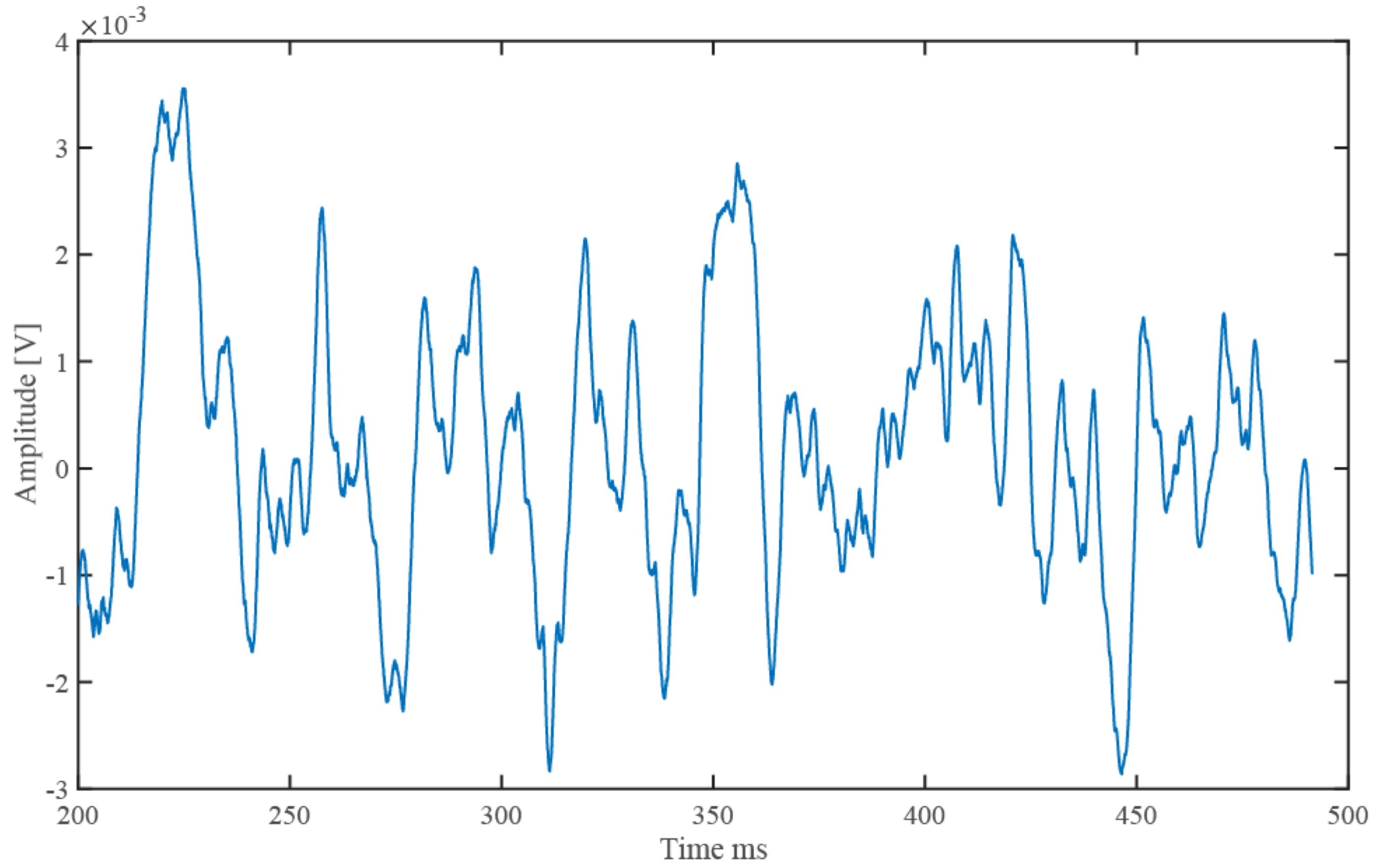
Includes trigger and cuts

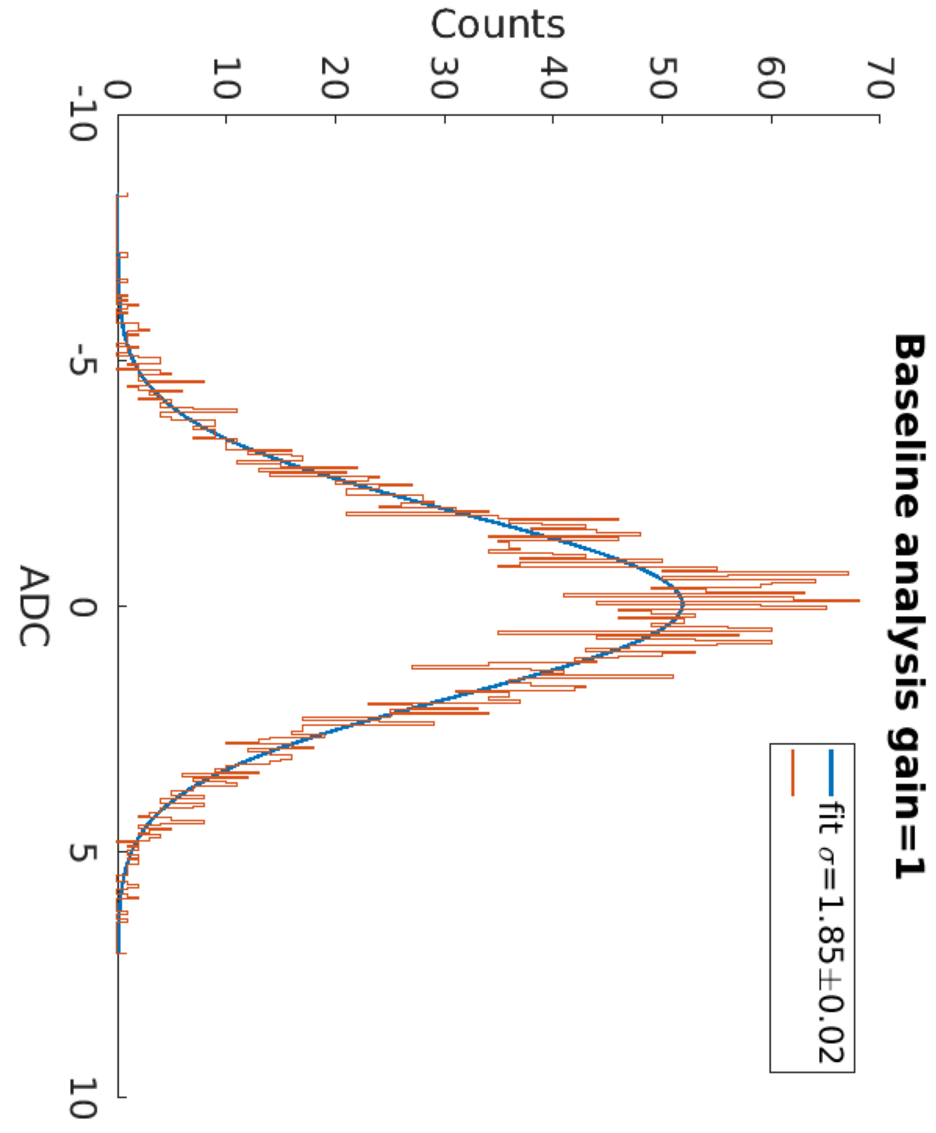
≳60% efficiency over broad energy range

OPTIMUM TRIGGER THRESHOLD

Optimum filter for threshold analysis

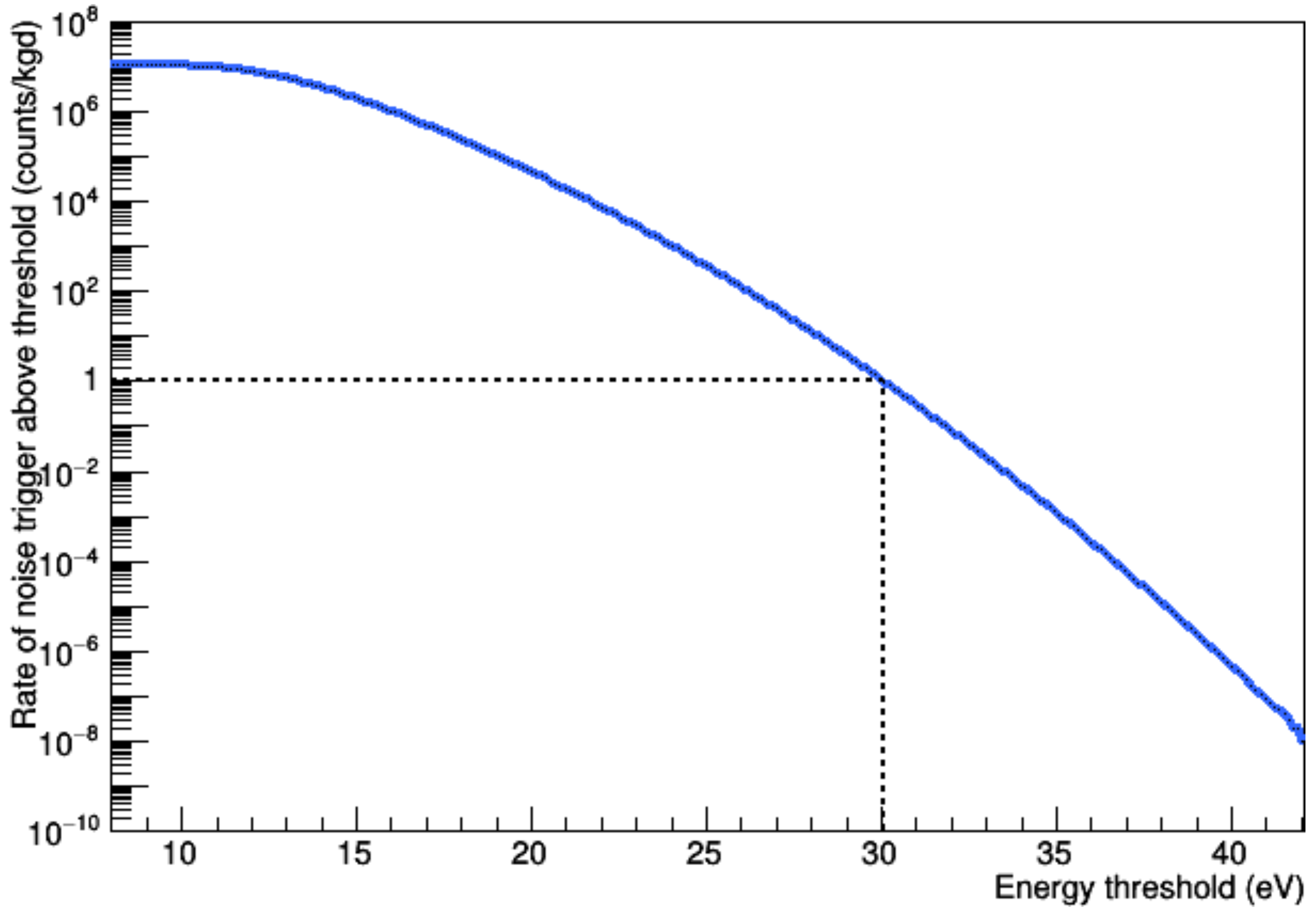
Empty base line trace





Histogram of a typical baseline trace

- Study the noise distribution after optimum filter in order to set the threshold
- Threshold optimised based on noise triggers in a given exposure



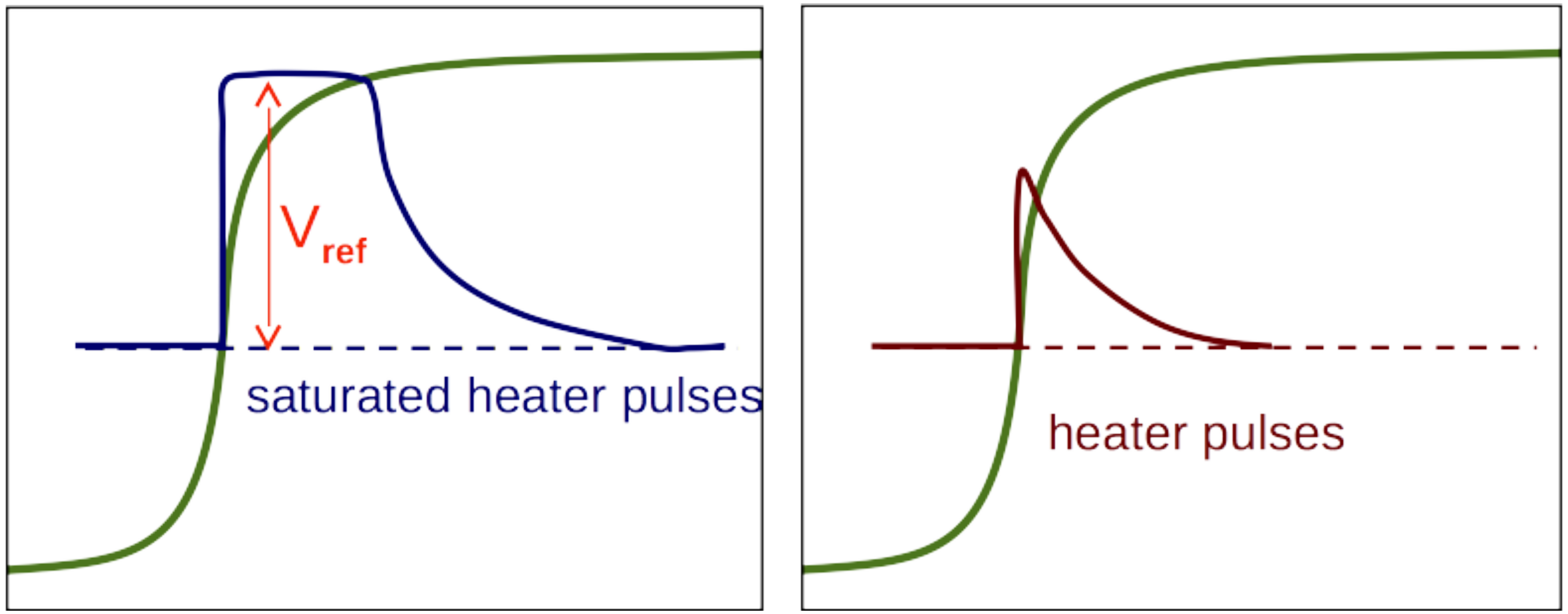
Analytical description of amplitude distribution in empty baselines

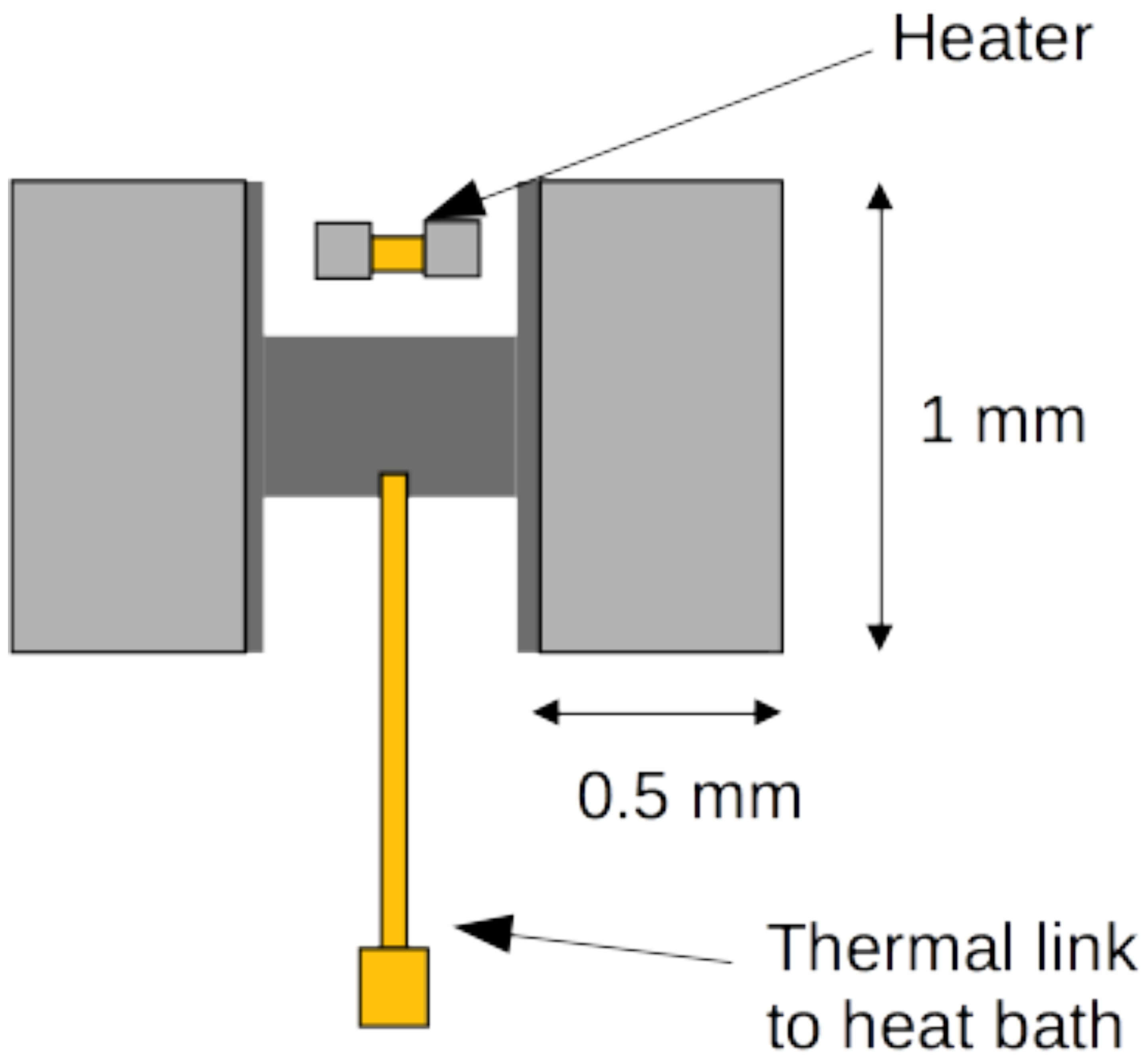
J Low Temp Phys (2019)
doi.org/10.1007/s10909-018-1948-6

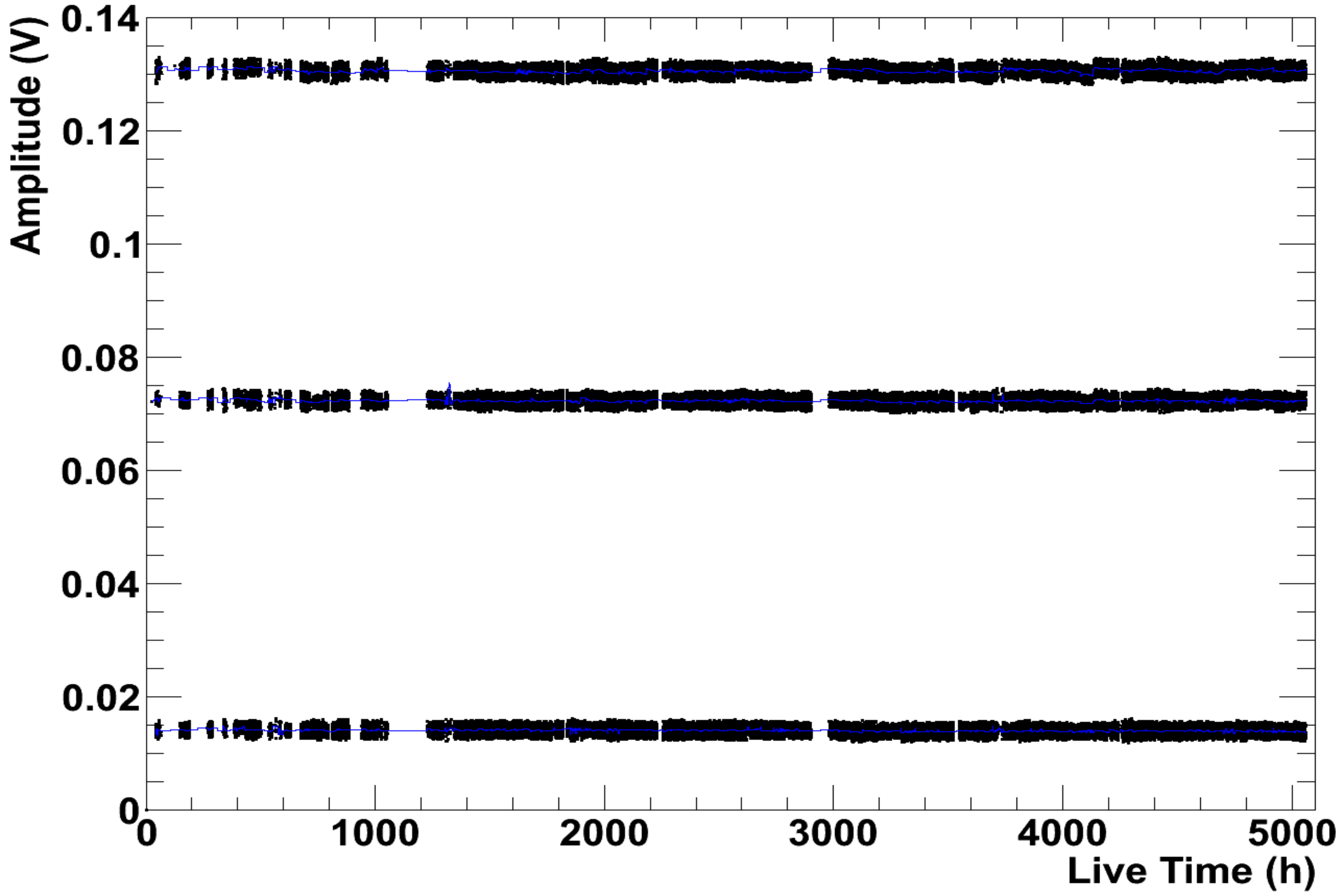
DETECTOR STABILITY

W-TES equipped with heaters

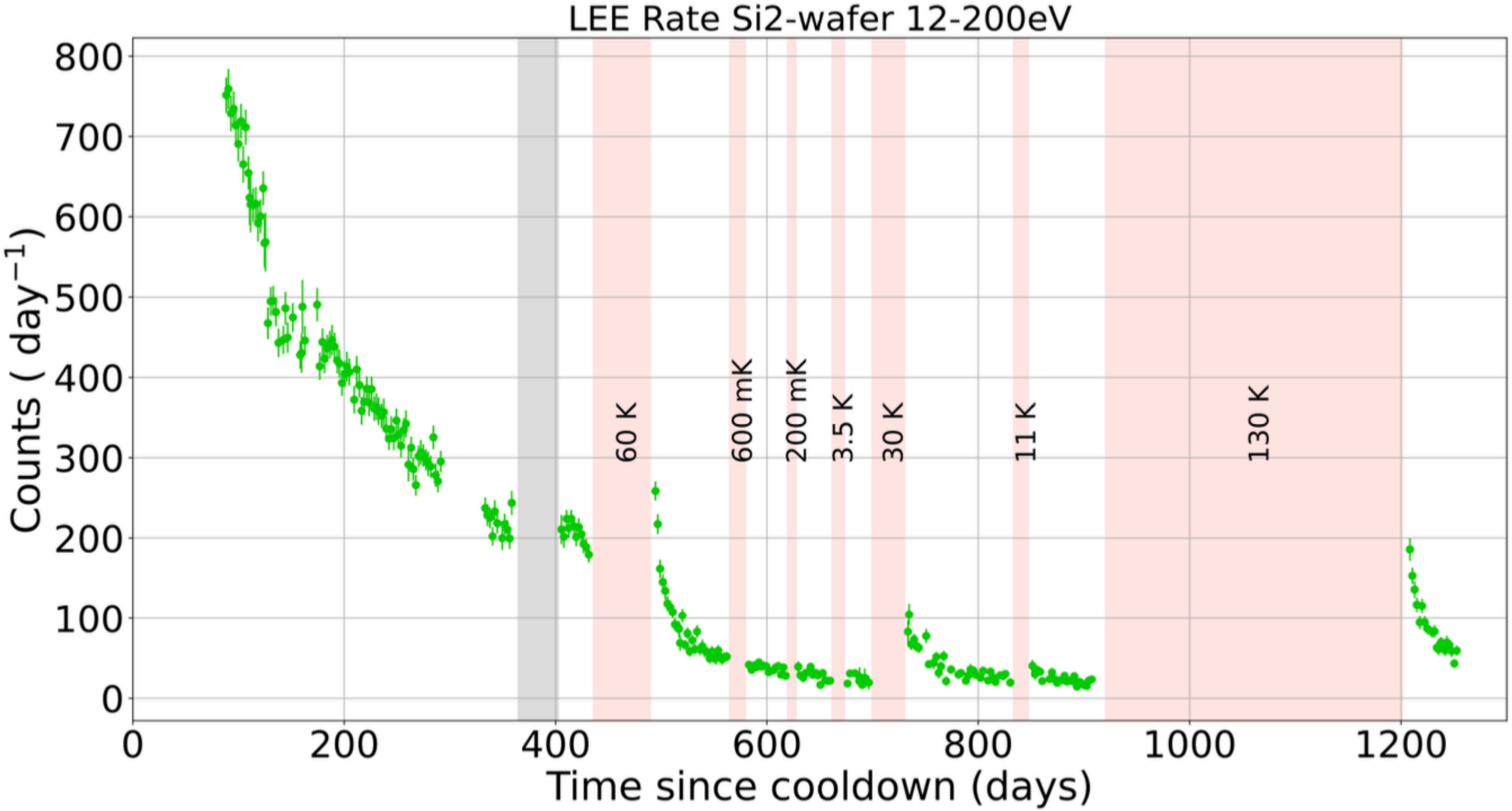
- Stabilization of detectors in the operating point
- Injection of heat pulses for calibration and determination of trigger threshold



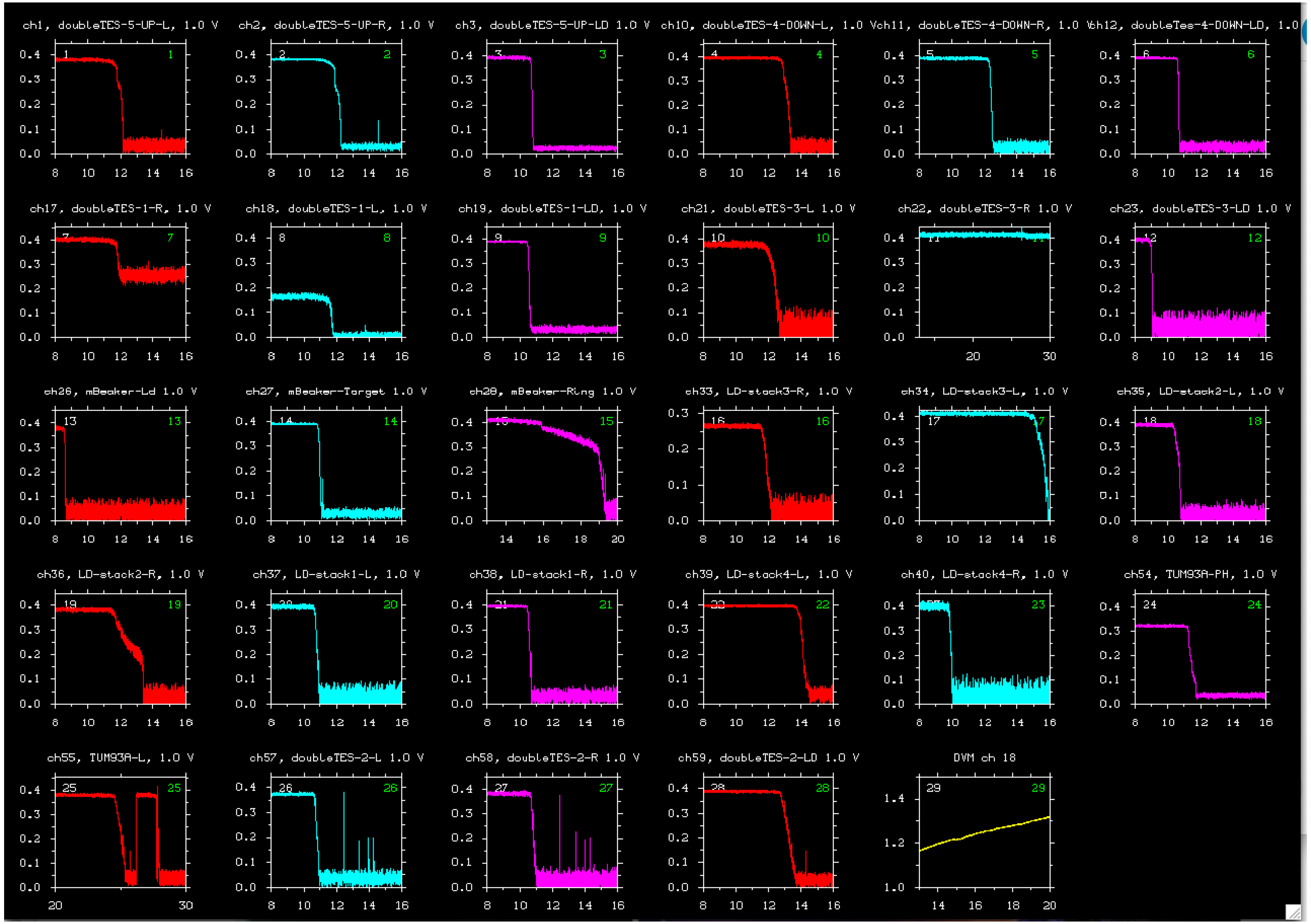




Time evolution of LEE



Double TES – Run 37



On March 23, 2024, the carousel reached operating temperature. TESs were operational and immediately set up to measure the LEE rate variation.

In July 2024 neutron-calibration (AmBe) was started (calibration via n radiative absorption for $CaWO_4$). Once the calibration is completed we will start the official Double TES campaign.

Stay tuned for upcoming results!