

Searching for light Dark Matter with the **CRESST** Experiment

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On behalf of the CRESST
Collaboration



The CRESST Collaboration

Cryogenic Rare Event Search with Superconducting Thermometers



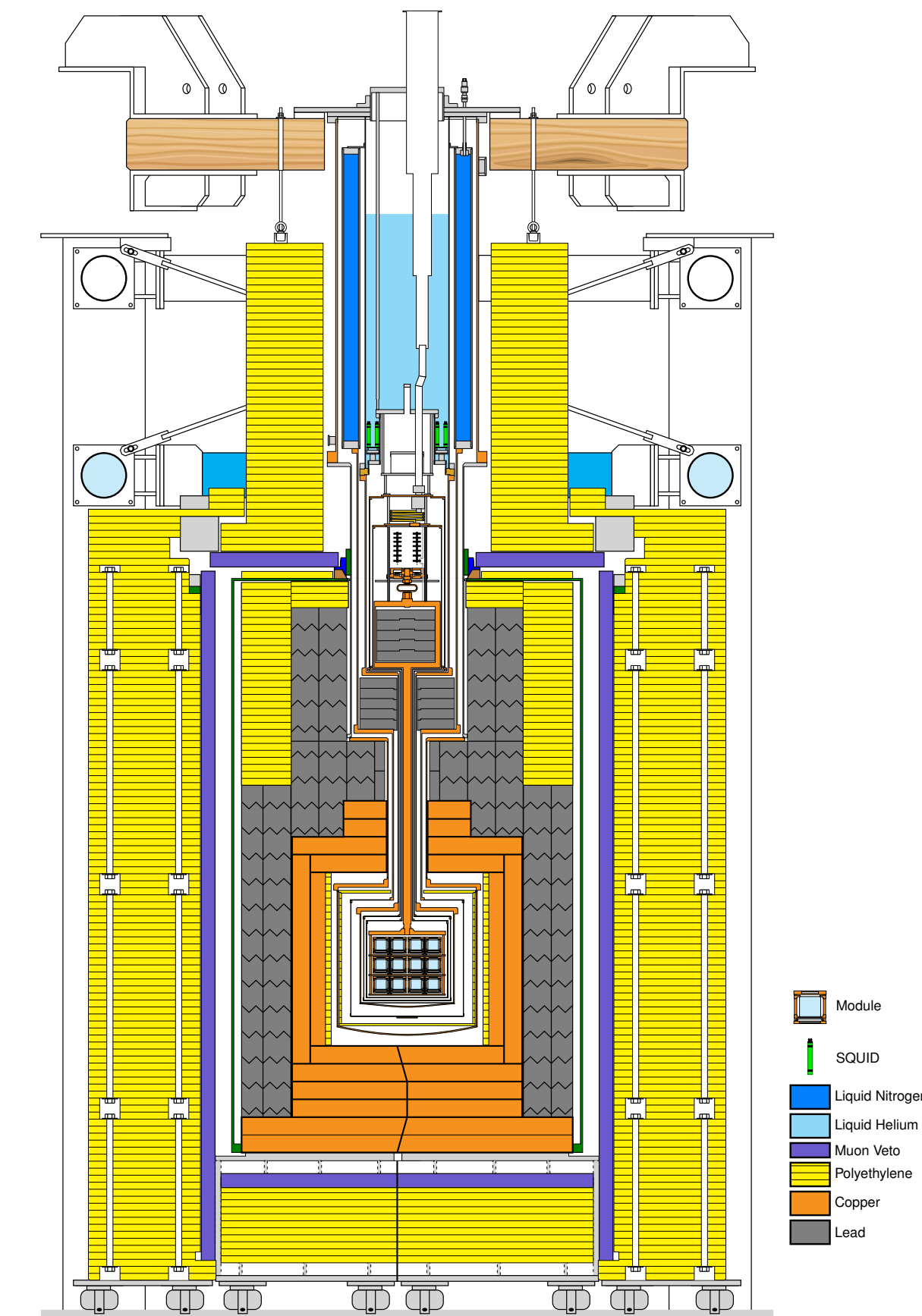
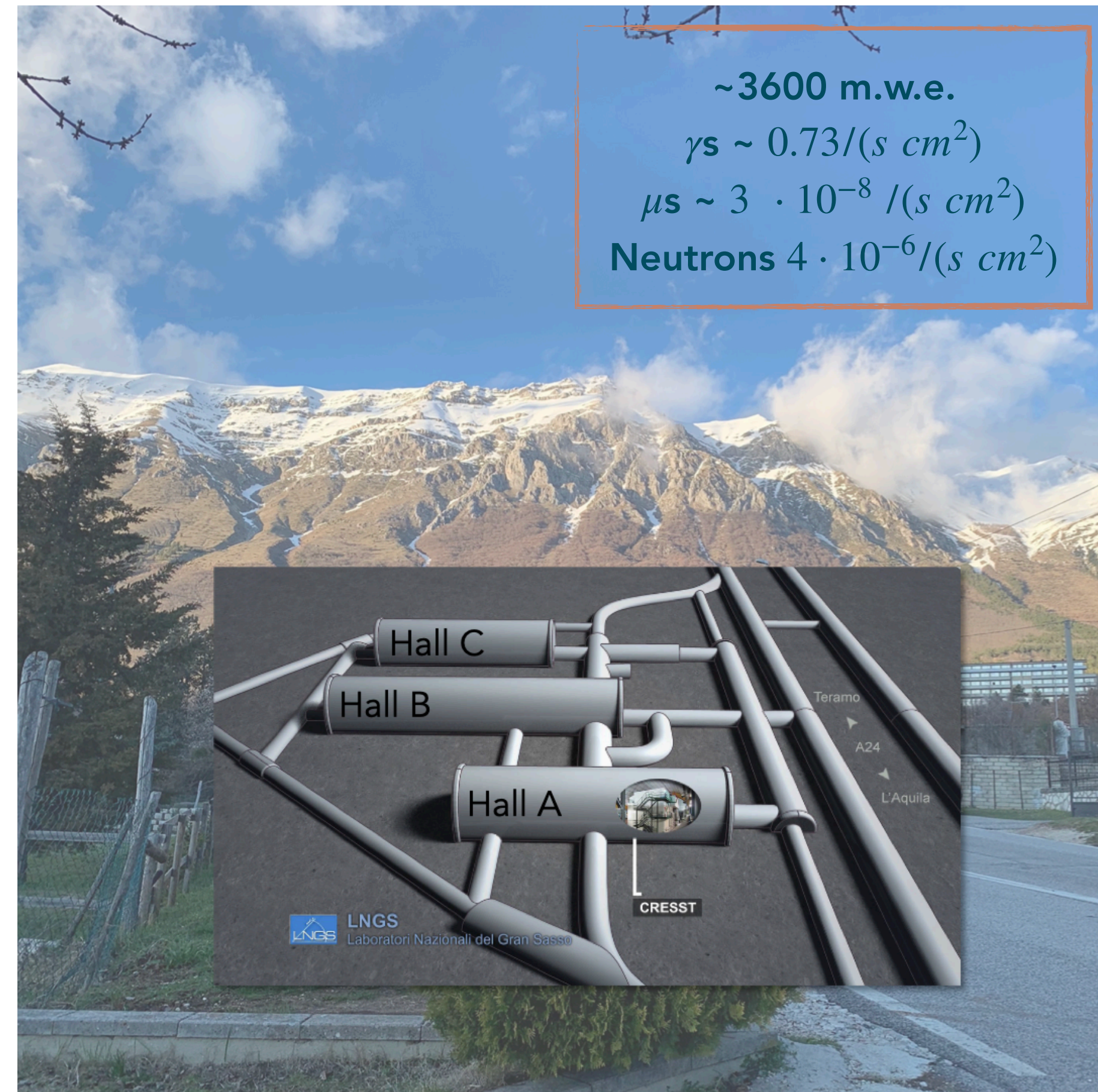
~60 people from 10 different institutes

The CRESST Experiment



Cryogenic Rare Event Search with Superconducting Thermometers

- CRESST aims at directly detecting dark matter particles via their scattering off target nuclei in cryogenic detectors operated at ~ 15 mK
- Situated at the Laboratori Nazionali del Gran Sasso

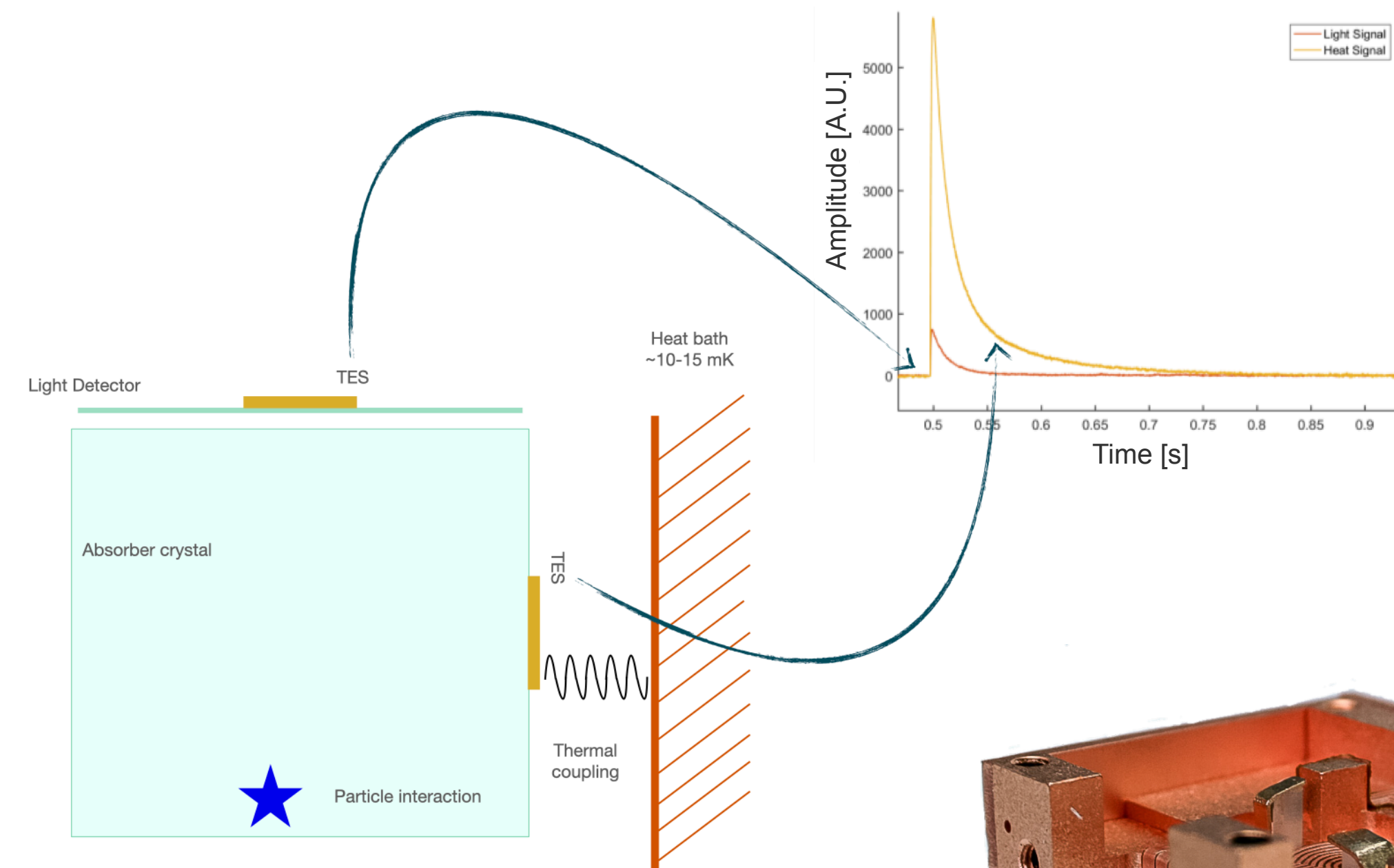


Multiple passive shielding layers

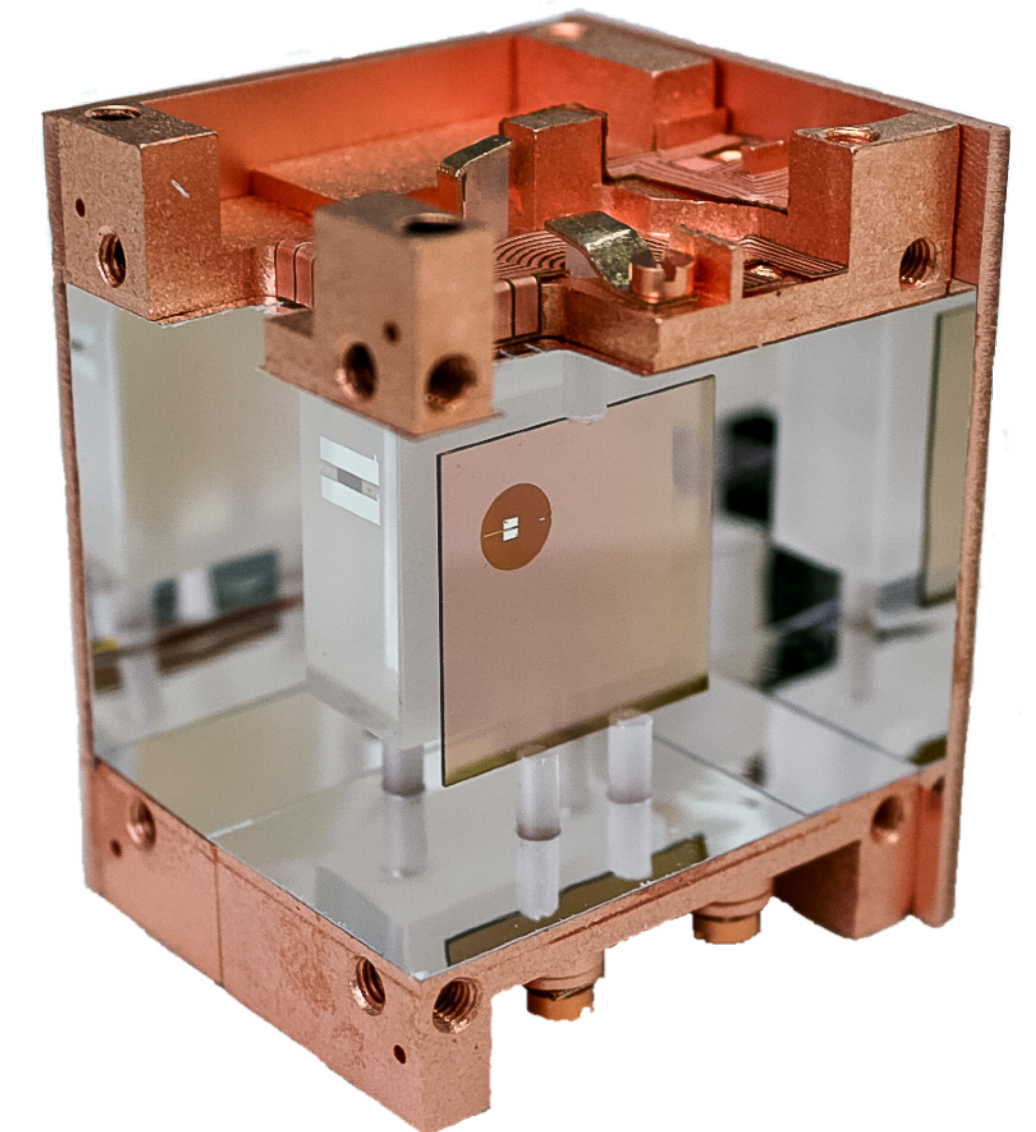
Detector Modules

Cryogenic Rare Event Search with Superconducting Thermometers

- Main target crystals of different materials
- Operated as cryogenic calorimeters
- Separate cryogenic light detector to detect the scintillation signal
 - Phonon signal (>90%): precise measurement of the deposited energy, independently of the type of particle
 - Light signal (few %): depends on the particle and on the type of recoil



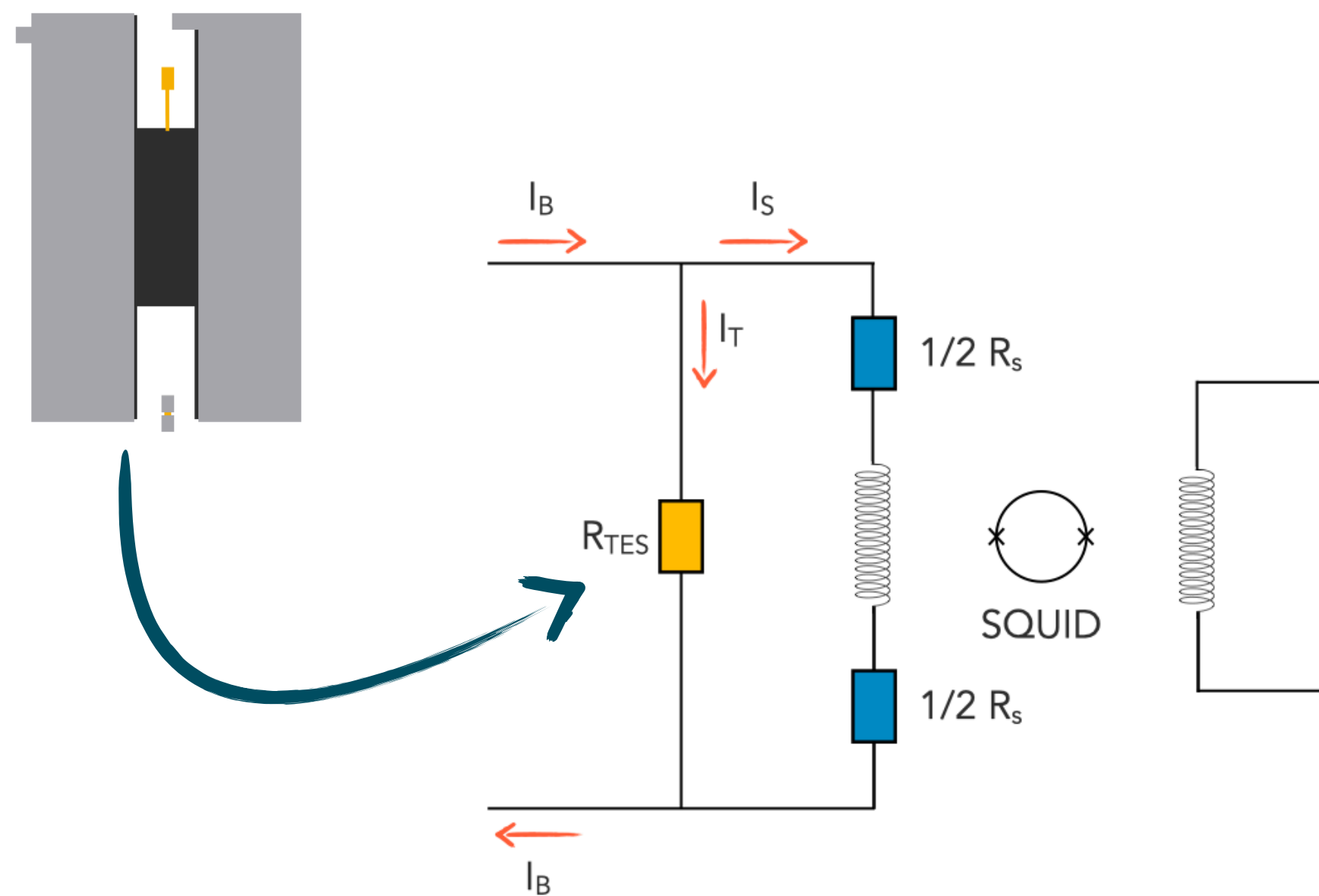
CRESST-III detectors are optimised for low mass (< few GeV) DM searches



Transition Edge Sensors

Cryogenic Rare Event Search with Superconducting Thermometers

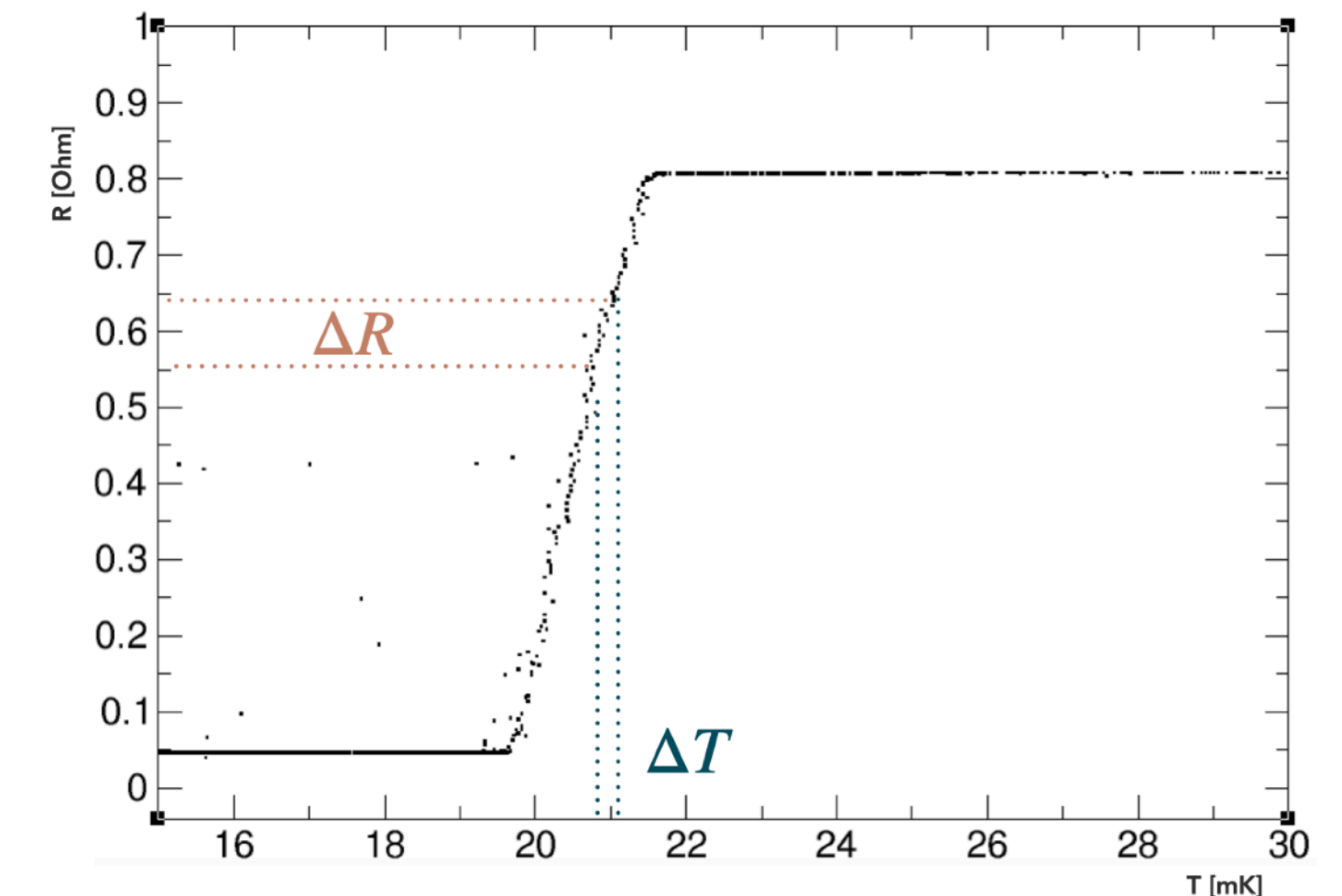
- Tungsten thin films operated in their superconducting transitions
- Energy deposits measured as variations in the sensor's temperature
- $\Delta T \sim \Delta E/C$ $\rightarrow$ Low temperatures $\rightarrow$ Low heat capacity $\rightarrow$ High sensitivity



Energy Deposition $\sim keV$

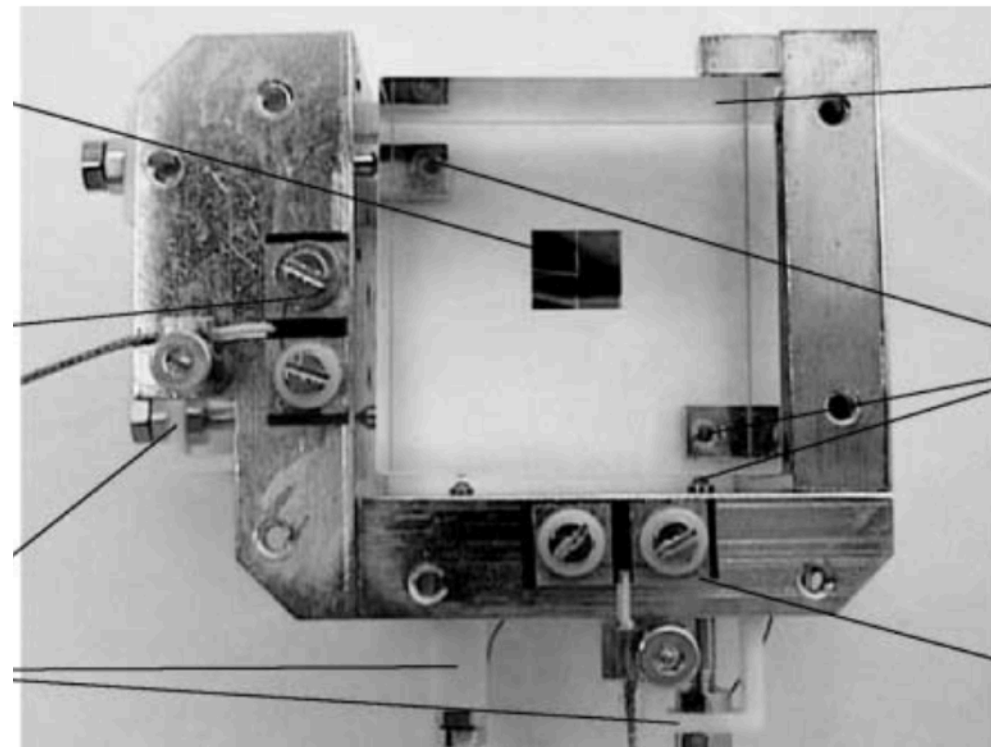
Temperature Rise $\sim \mu K$

Resistance change $\sim m\Omega$



The CRESST Evolution

Cryogenic Rare Event Search with Superconducting Thermometers



2002

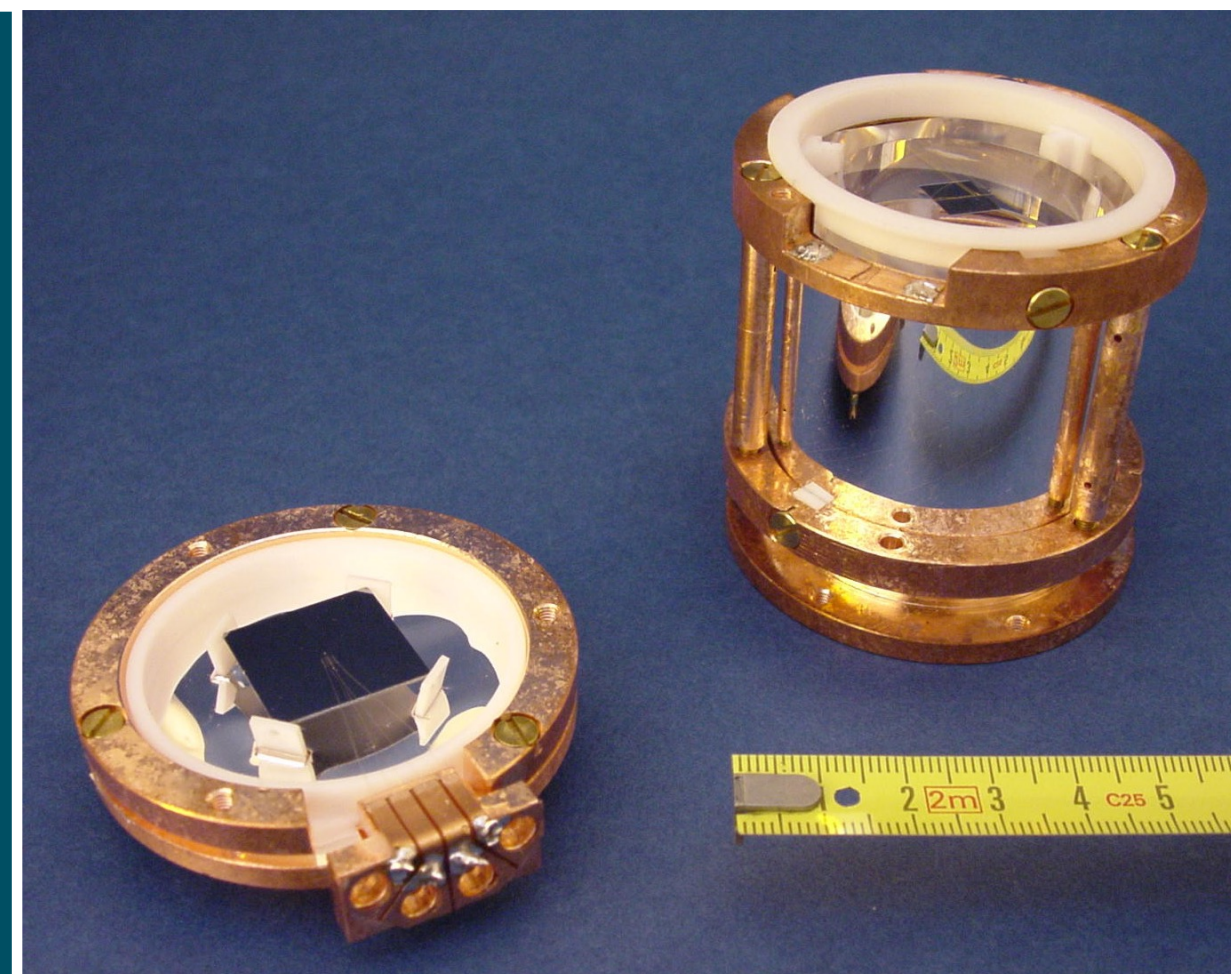
Sapphire

$m = 262 \text{ g}$

$E_{\text{th}} = 600 \text{ eV}$

DOI:10.1016/S0927-6505(02)00111-1

CRESST-I

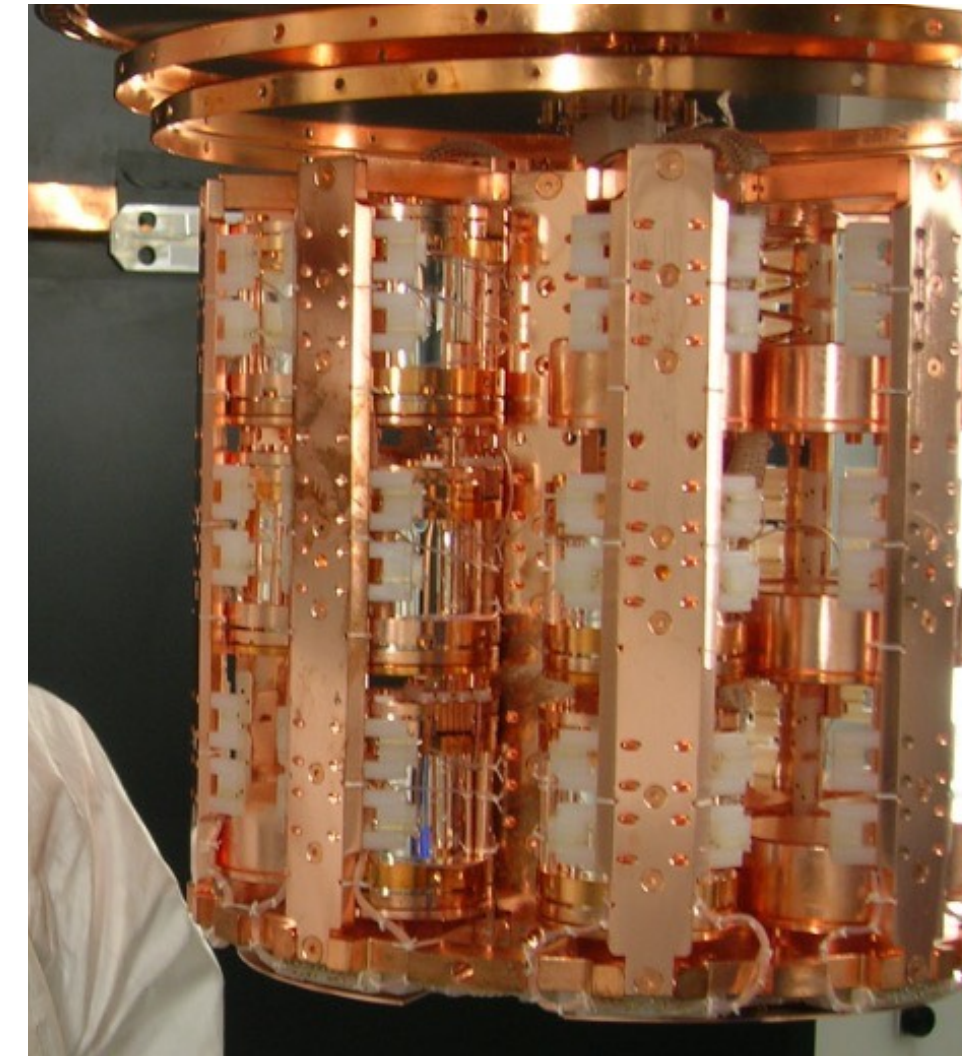


2005

CaWO_4

$m = 300 \text{ g}$

$E_{\text{th}} = 5 \text{ keV}$



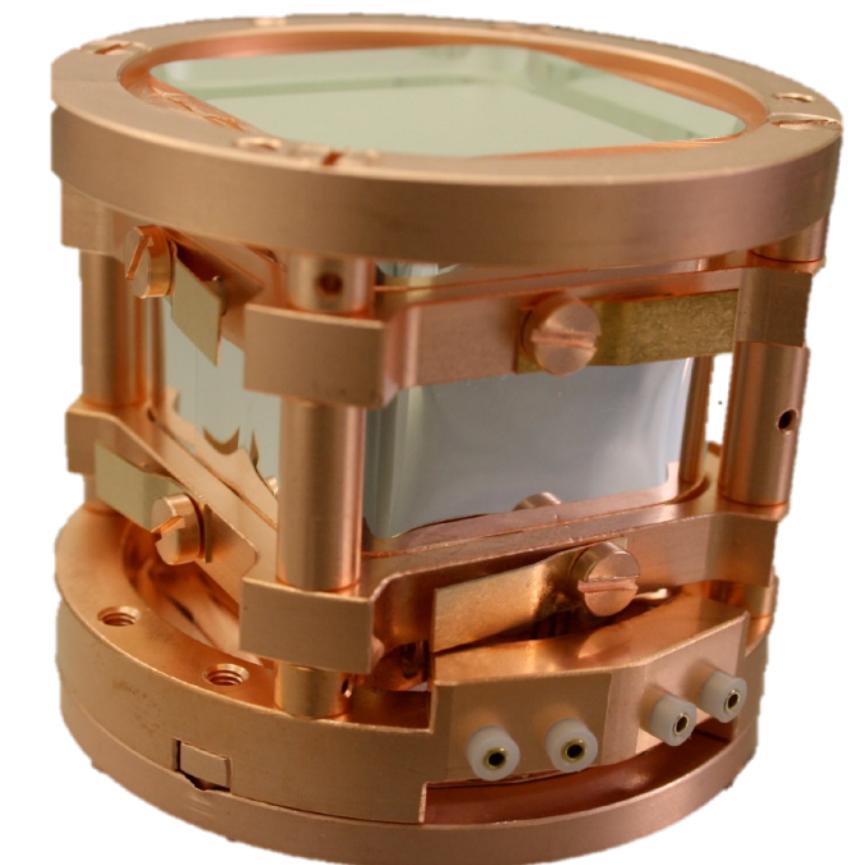
2012

CaWO_4 (8 det.)

$m = 300 \text{ g}$

$E_{\text{th}} = 10 \text{ keV}$

DOI:10.1140/epjc/s10052-012-1971-8



2014

CaWO_4 (TUM40)

$m = 249 \text{ g}$

$E_{\text{th}} = 600 \text{ eV}$

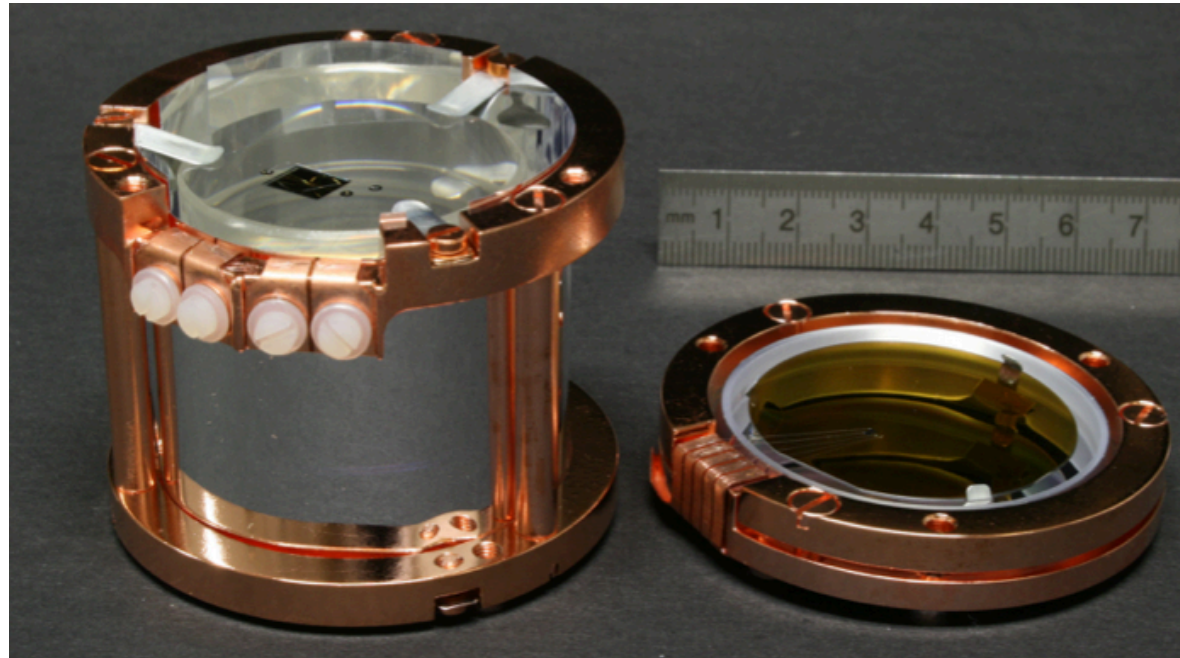
DOI:10.1140/epjc/s10052-014-3184-9

Analysis thresholds:
actual threshold $\sim 2 \text{ keV}$

CRESST-II

The CRESST Evolution

Cryogenic Rare Event Search with Superconducting Thermometers



2016

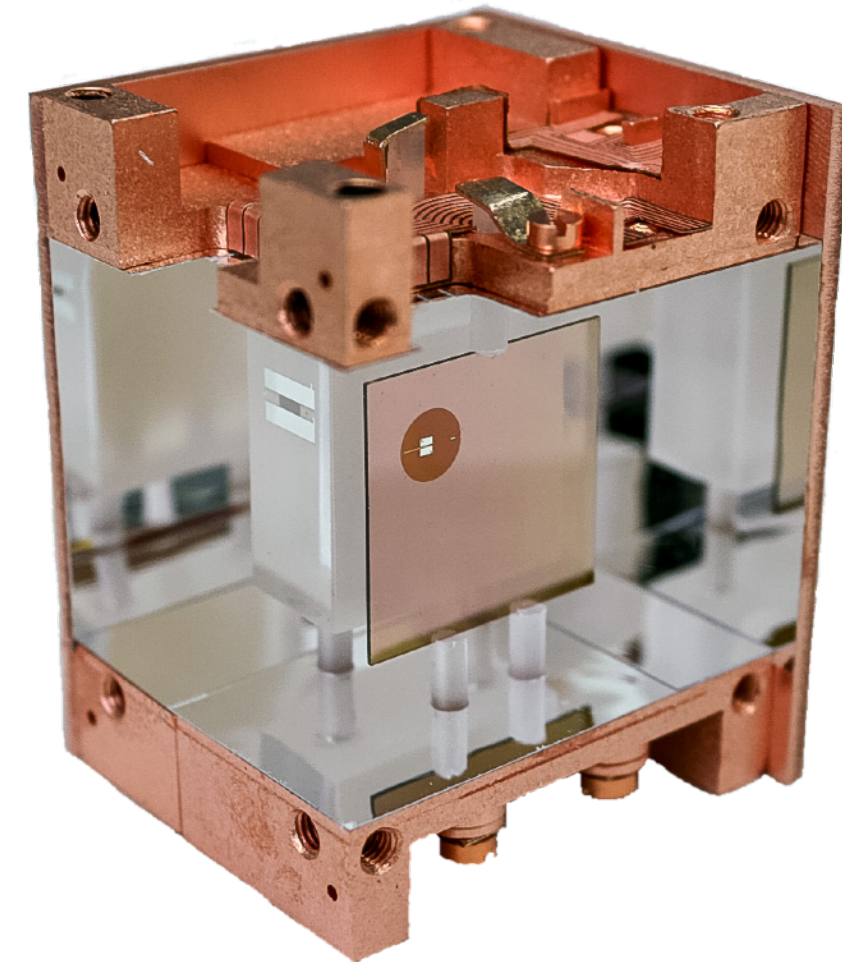
CaWO₄ (Lise)

$m = 300 \text{ g}$

$E_{\text{th}} = 307 \text{ eV}$

DOI10.1140/epjc/s10052-016-3877-3

CRESST-II



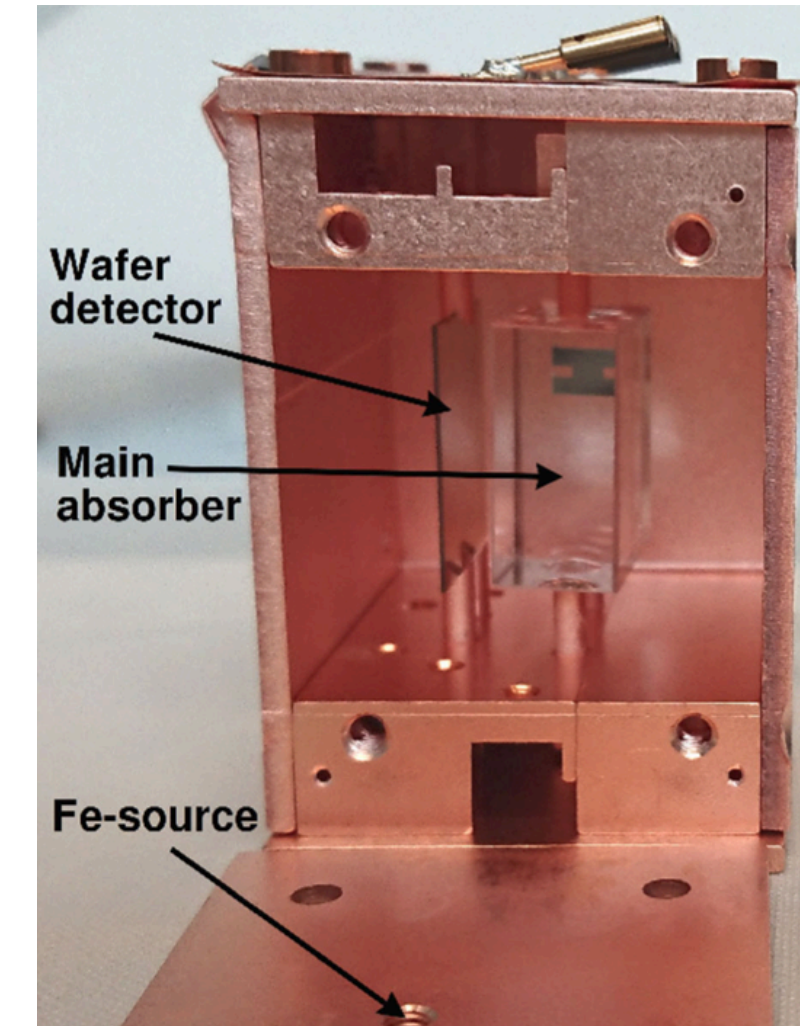
2019

CaWO₄ (Det.A)

$m = 24 \text{ g}$

$E_{\text{th}} = 30.1 \text{ eV}$

DOI:10.1103/PhysRevD.100.102002



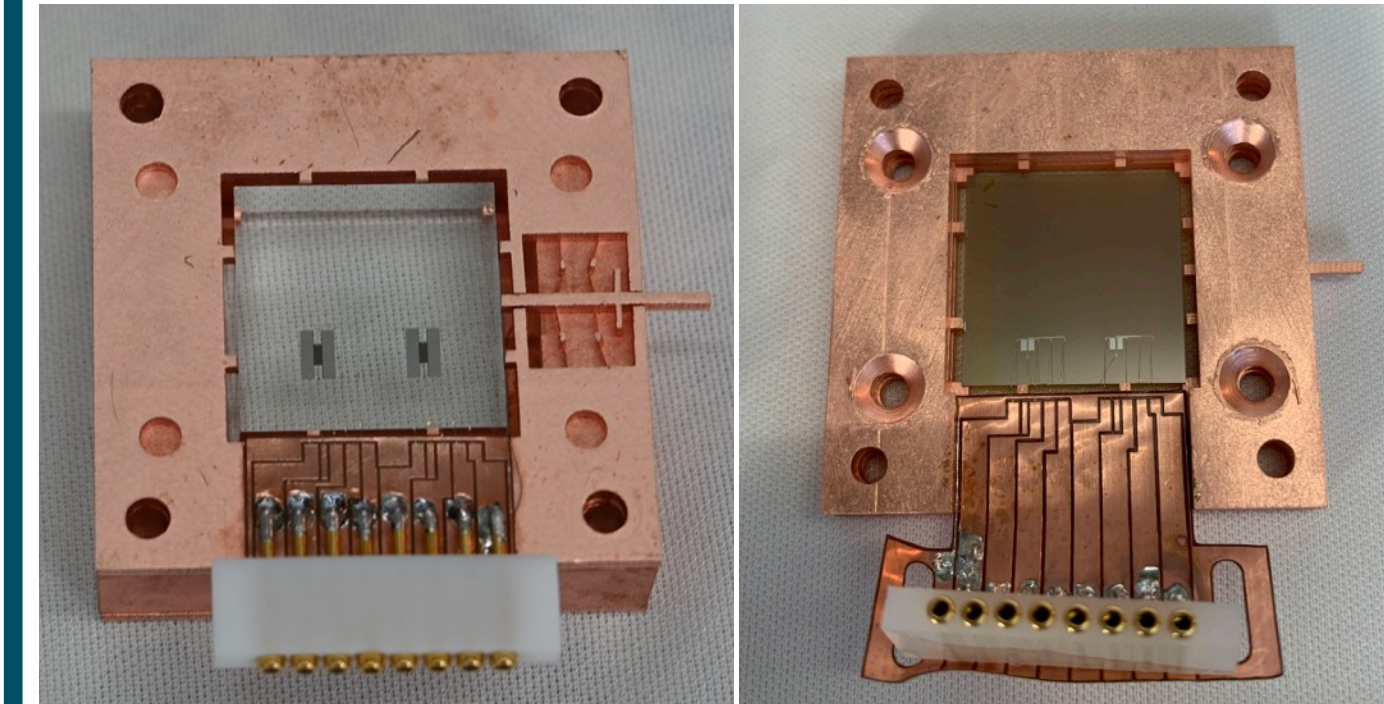
2024

SOS-wafer

$m = 0.6 \text{ g}$

$E_{\text{th}} = 6.7 \text{ eV}$

DOI: 10.1103/PhysRevD.110.083038



Upcoming

DoubleTES

$m = 24 \text{ g} / 0.6 \text{ g}$

$E_{\text{th}} \sim 35 \text{ eV} / \sim 6 \text{ eV}$

First evidence of LEE

CRESST-III

CRESST-III: First Results

Cryogenic Rare Event Search with Superconducting Thermometers

Spin independent limit with Detector A

Crystal: 23.6 g CaWO_4

Data Taking period: Oct. 2016 - Jan. 2018

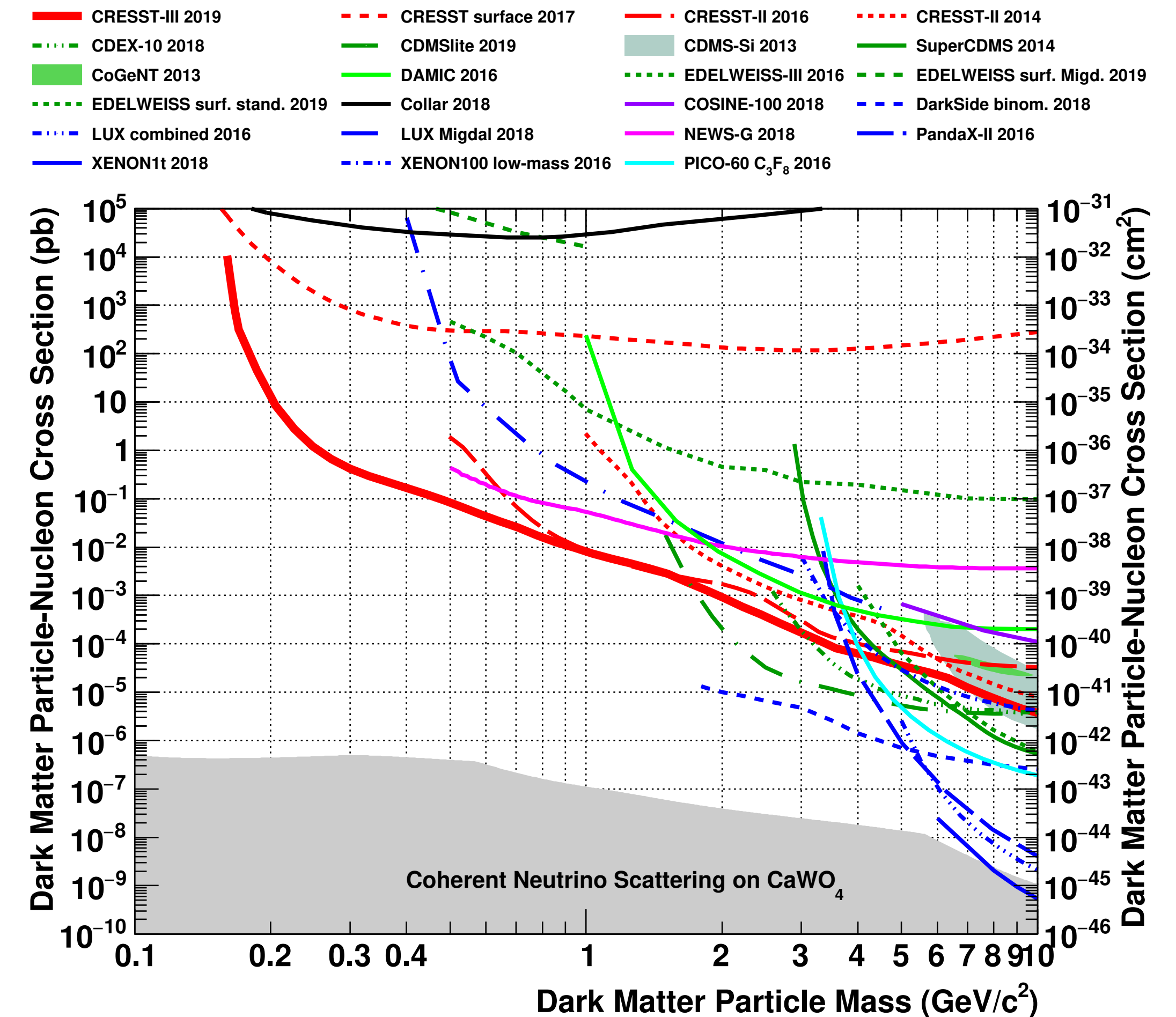
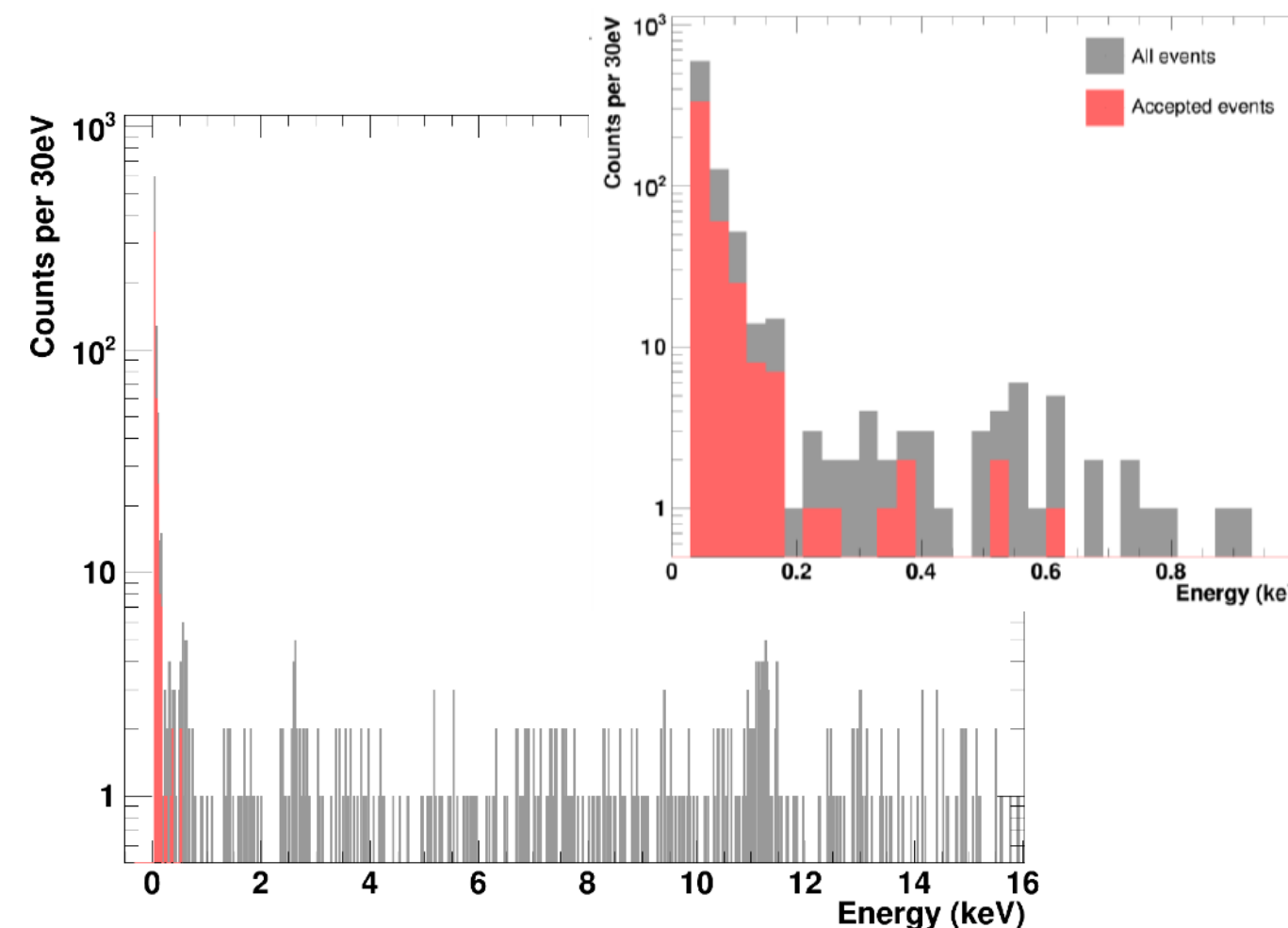
Exposure: 5.698 kg·days

Baseline Resolution: 4.6 eV

Nuclear recoil threshold: 30.1 eV

First Observation of a Low Energy Excess (LEE):

- Rise of particle-like events at energies below 200 eV
- Observed in multiple detector modules



CRESST-III: First Results



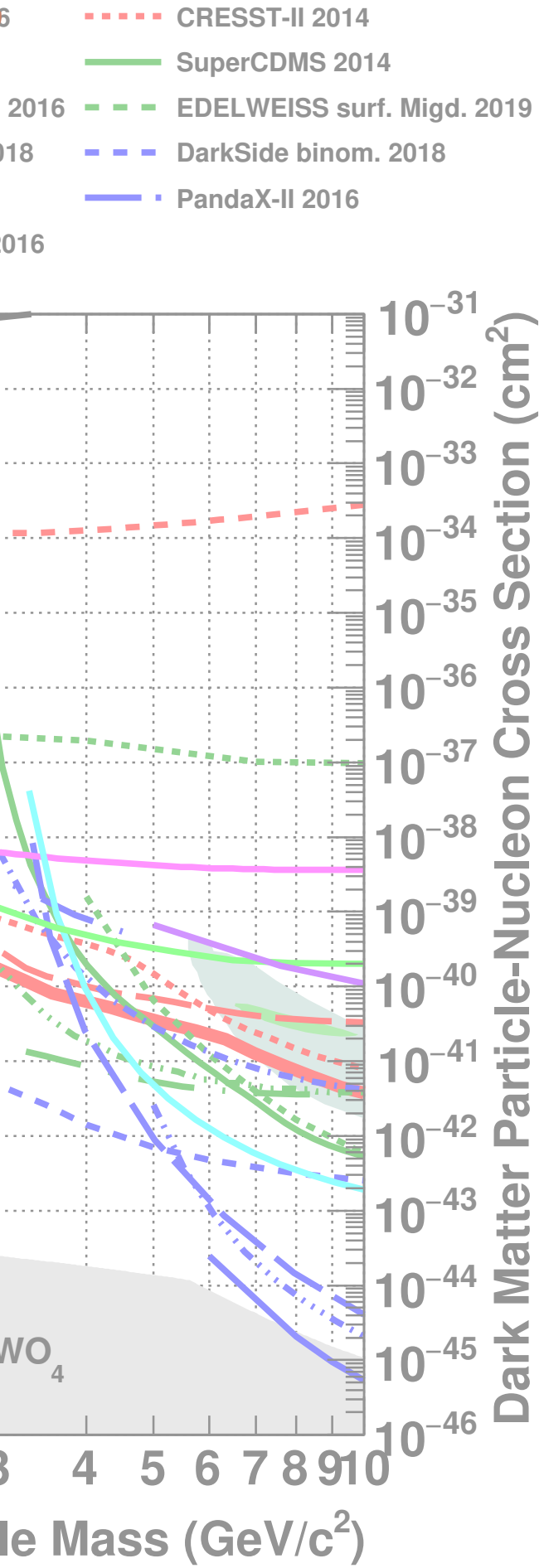
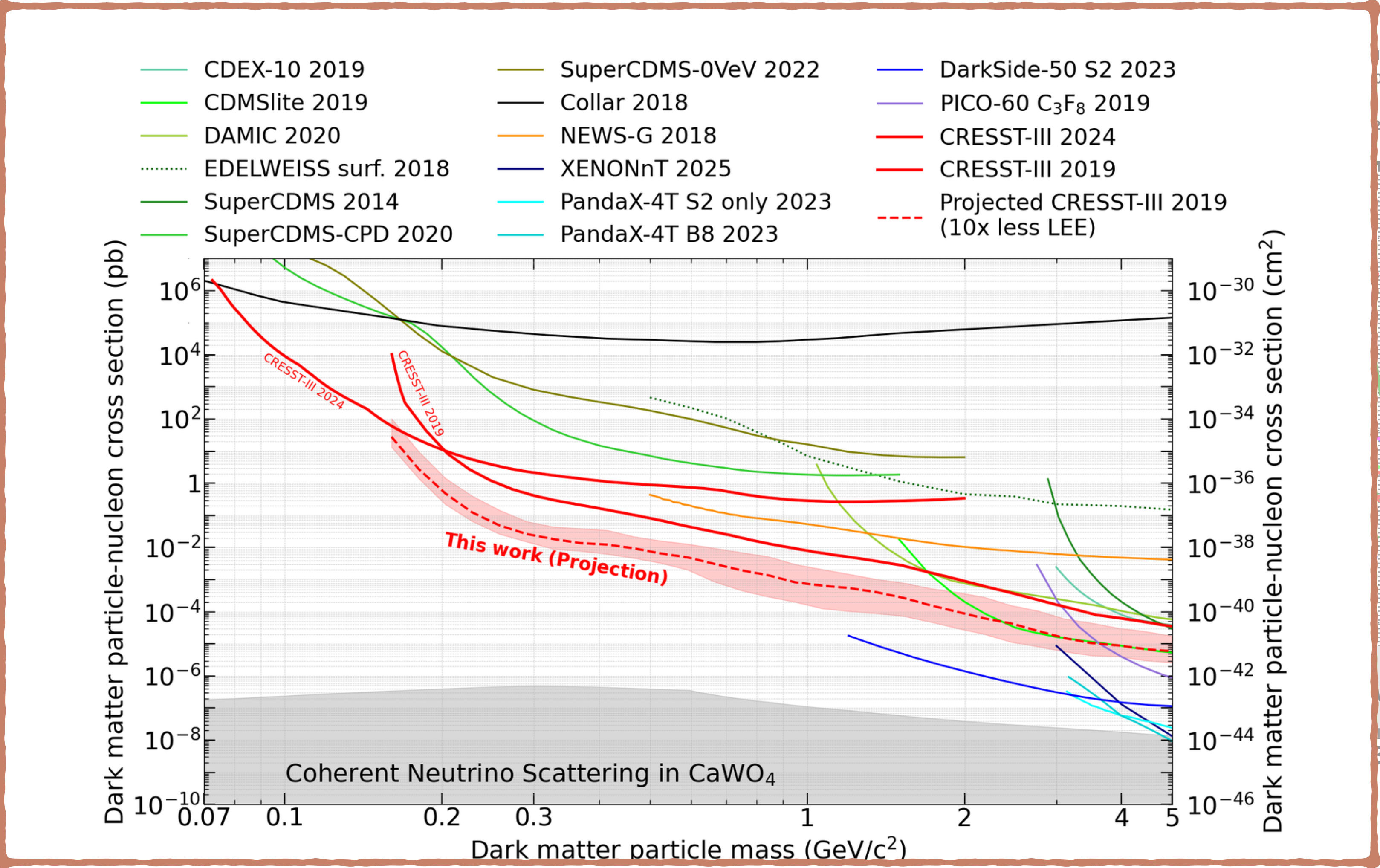
Cryogenic Rare Event Search with Superconducting Thermometers

Spin independent limit with Detector A - **projections with reduced LEE**

Crystal: 2
Data Taki
Exposure
Baseline
Nuclear r

First Observati

- Rise of particle events at ener below 200 eV
- Observed in n detector mod



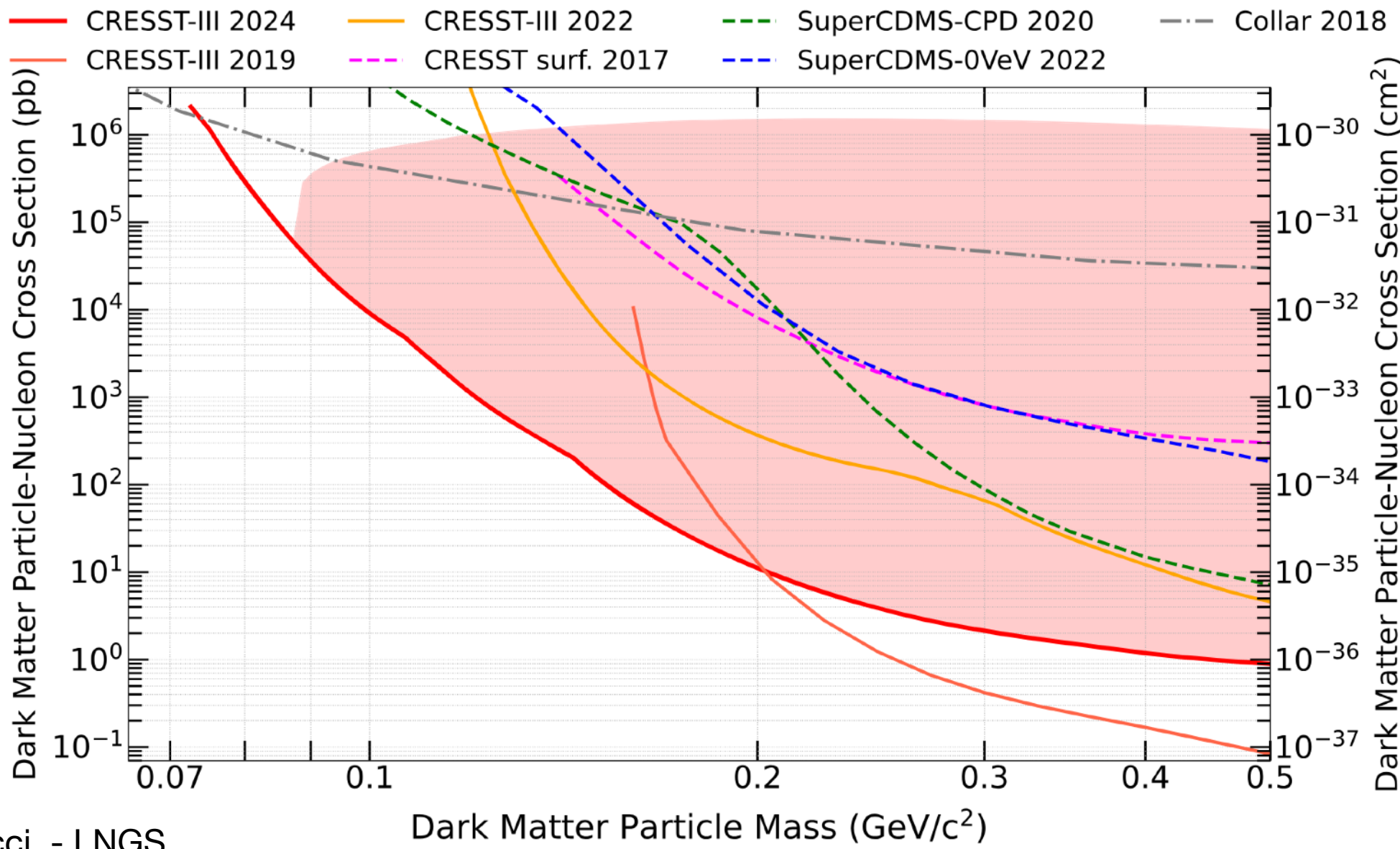
CRESST-III: Dark Matter Results

Cryogenic Rare Event Search with Superconducting Thermometers

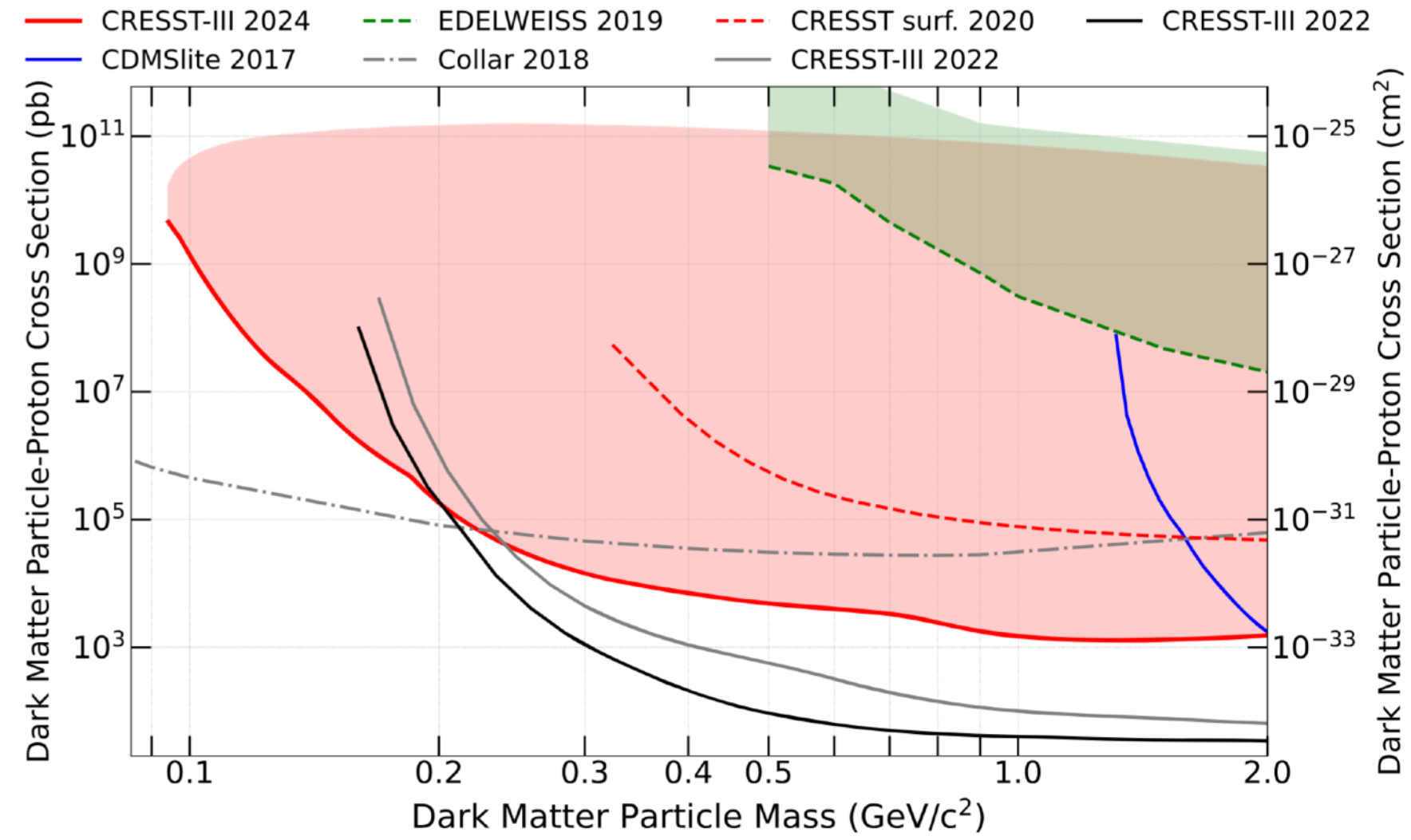
Dark matter limit using light detector as main absorber

Crystal: 0.6 g Al_2O_3
Data Taking period: Nov. 2020 - Aug. 2021
Exposure: 138 g·days
Baseline Resolution: 1.0 eV
Nuclear recoil threshold: 6.7eV

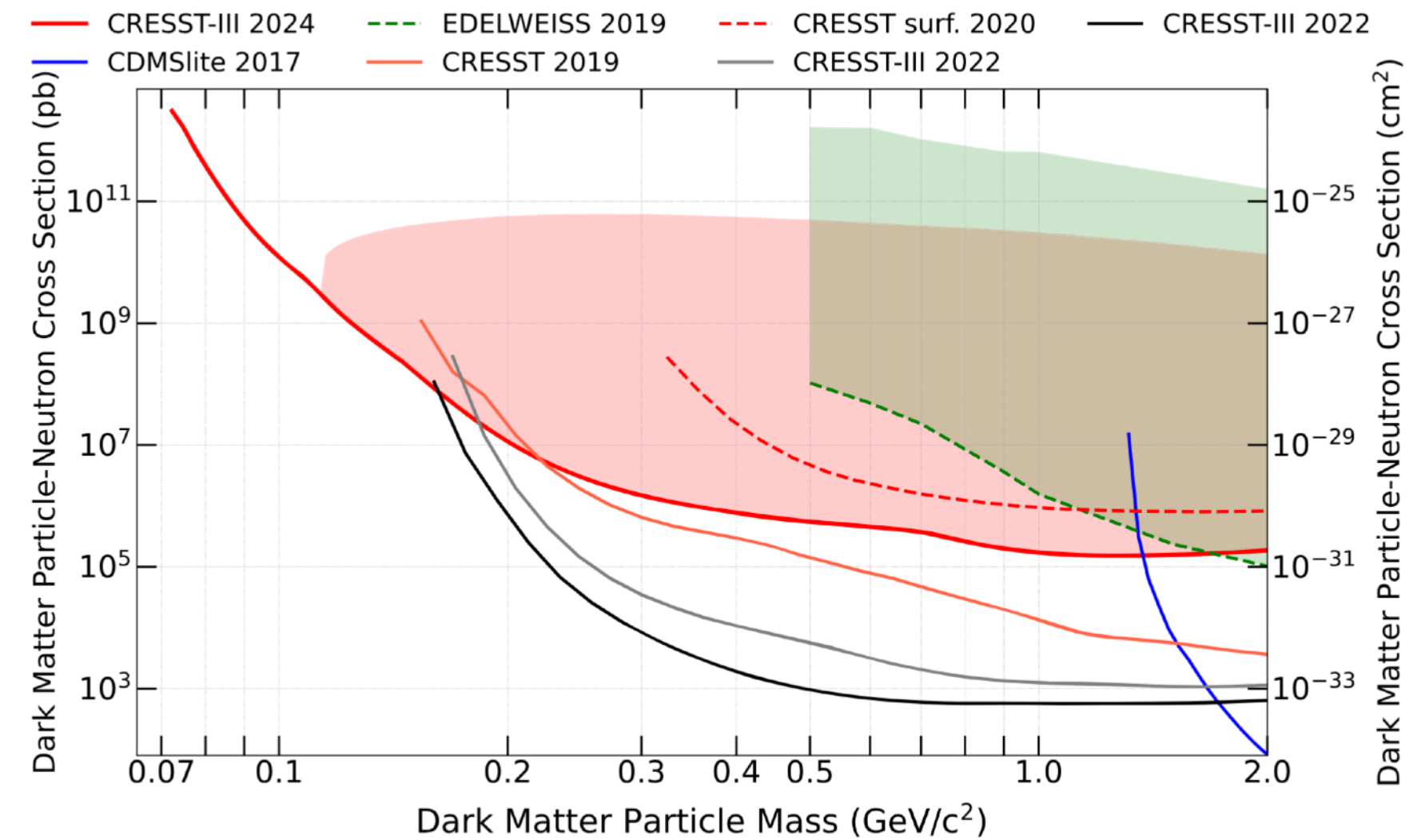
Spin Independent



Spin Dependent - Proton



Spin Dependent - Neutron

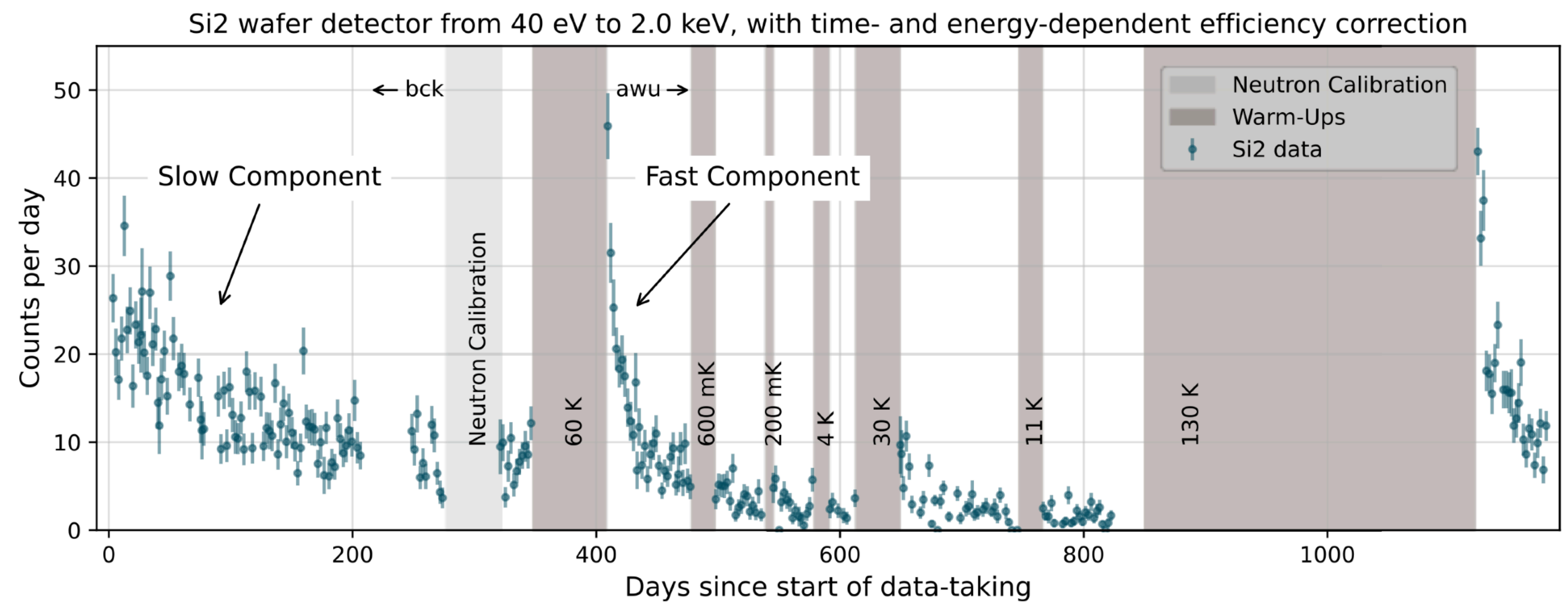


The Low Energy Excess

Cryogenic Rare Event Search with Superconducting Thermometers

- It appears in solid-state cryogenic detectors
- Different in different detector modules
- Decays over time and can be repopulated with thermal cycles
- Different parts of the CRESST detector modules investigated as possible origin

Check out J. Dohm's poster
"Low Energy Excess Studies in the CRESST Experiment"



The origin is still unclear

A new generation of detectors is needed to reach a better understanding of this signal

The doubleTES

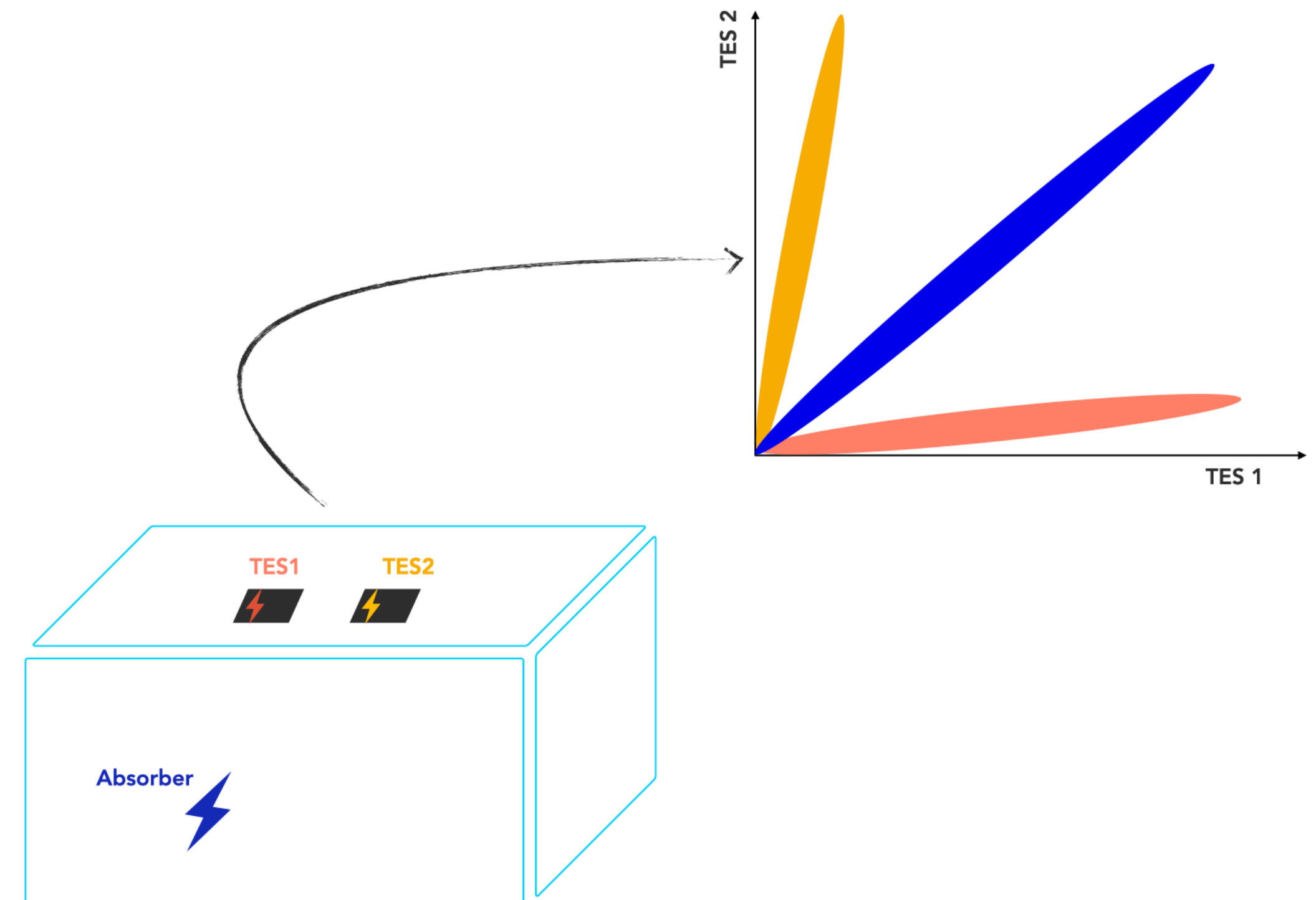
Cryogenic Rare Event Search with Superconducting Thermometers

- Idea: Instrument the absorber with two TES
 - If the signal is originated in the absorber the two TES will show the same response
 - If the signal is originated in or close to the sensor, the two response signals will be different
- Several tests of doubleTES modules performed above ground yielded promising results

[10.1140/epjc/s10052-024-13282-8](https://arxiv.org/abs/10.1140/epjc/s10052-024-13282-8)

Adoption of doubleTES detector modules for the CRESST measurement campaign

Check out D. Valdenaire's poster "DoubleTES detector"

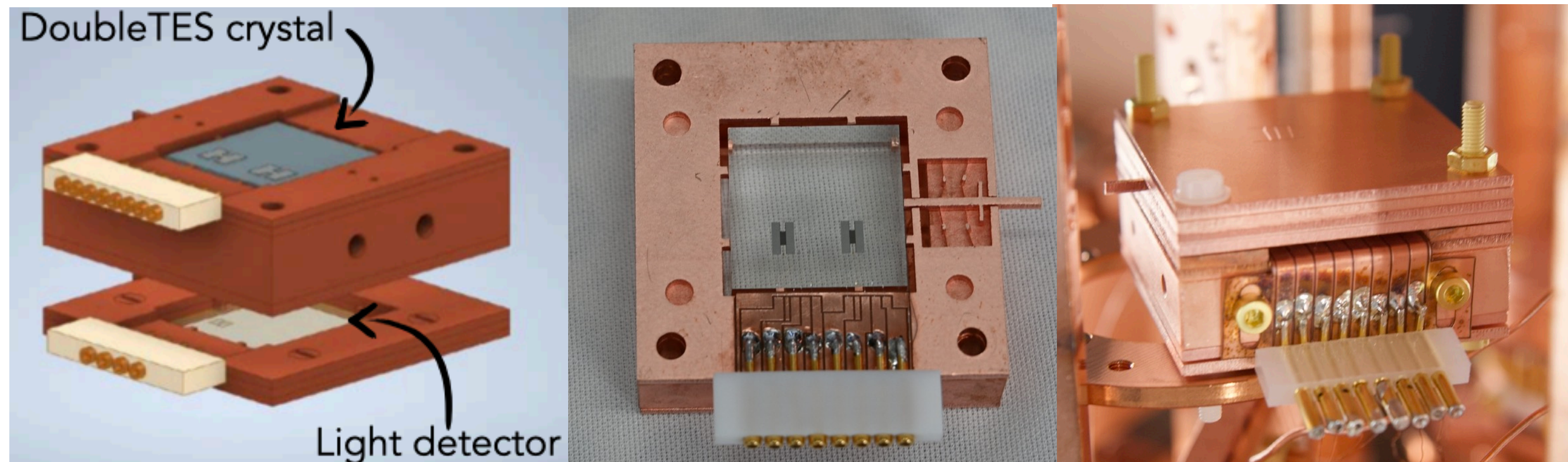
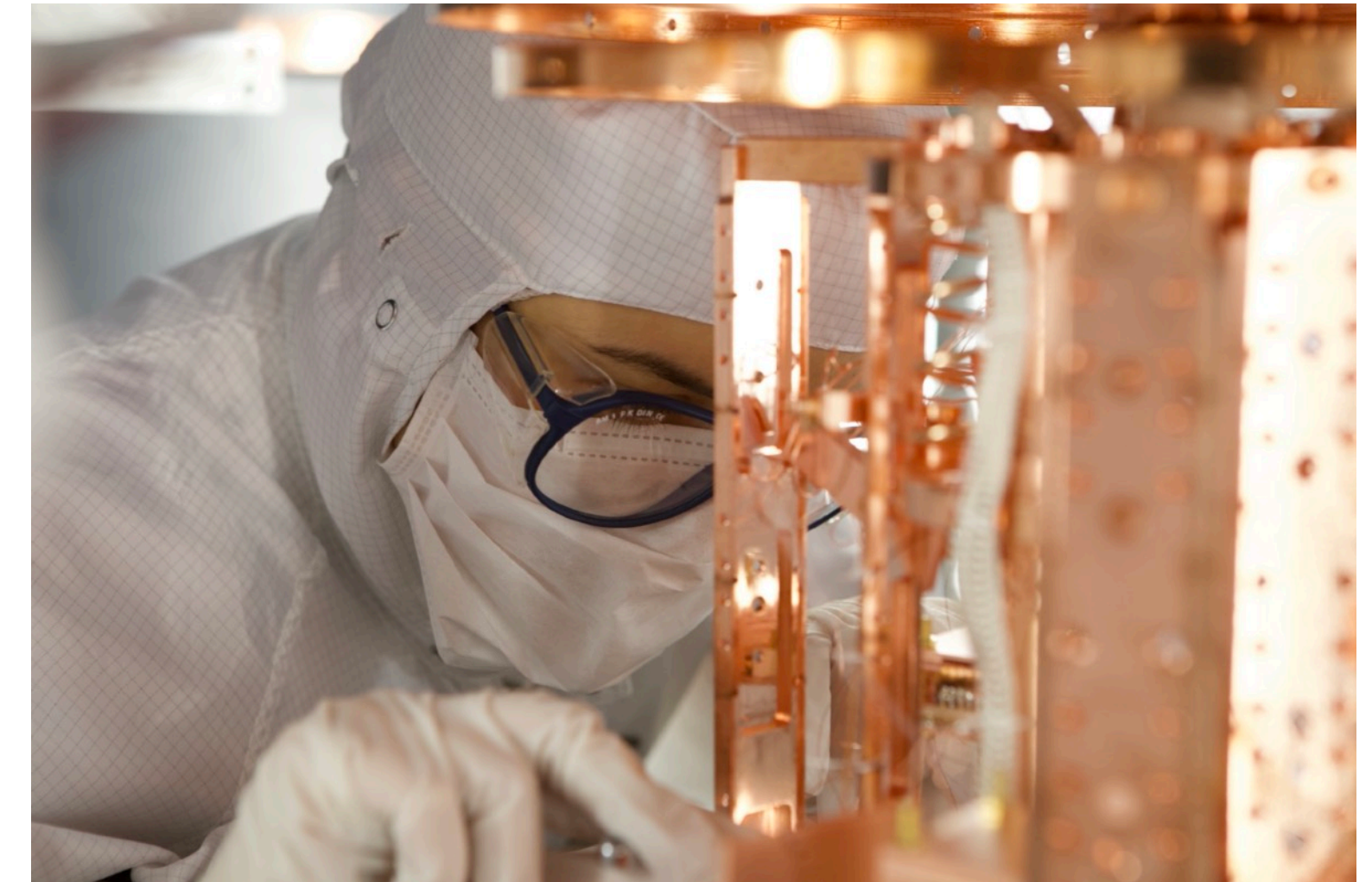


10.1007/s10909-024-03154-6

Run37: Detector Modules

Cryogenic Rare Event Search with Superconducting Thermometers

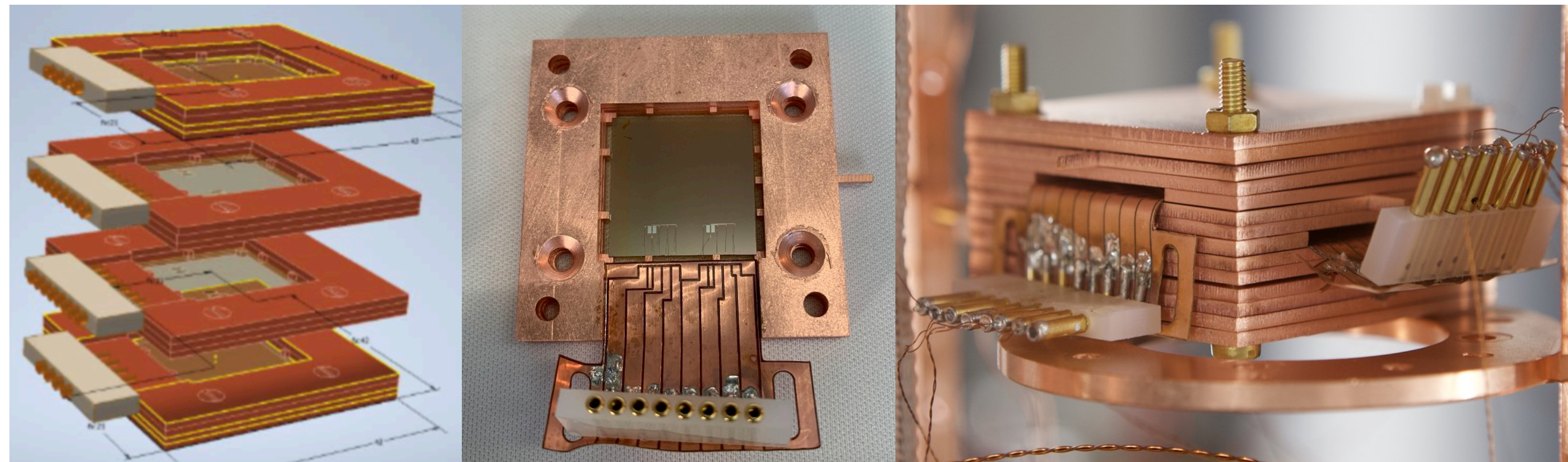
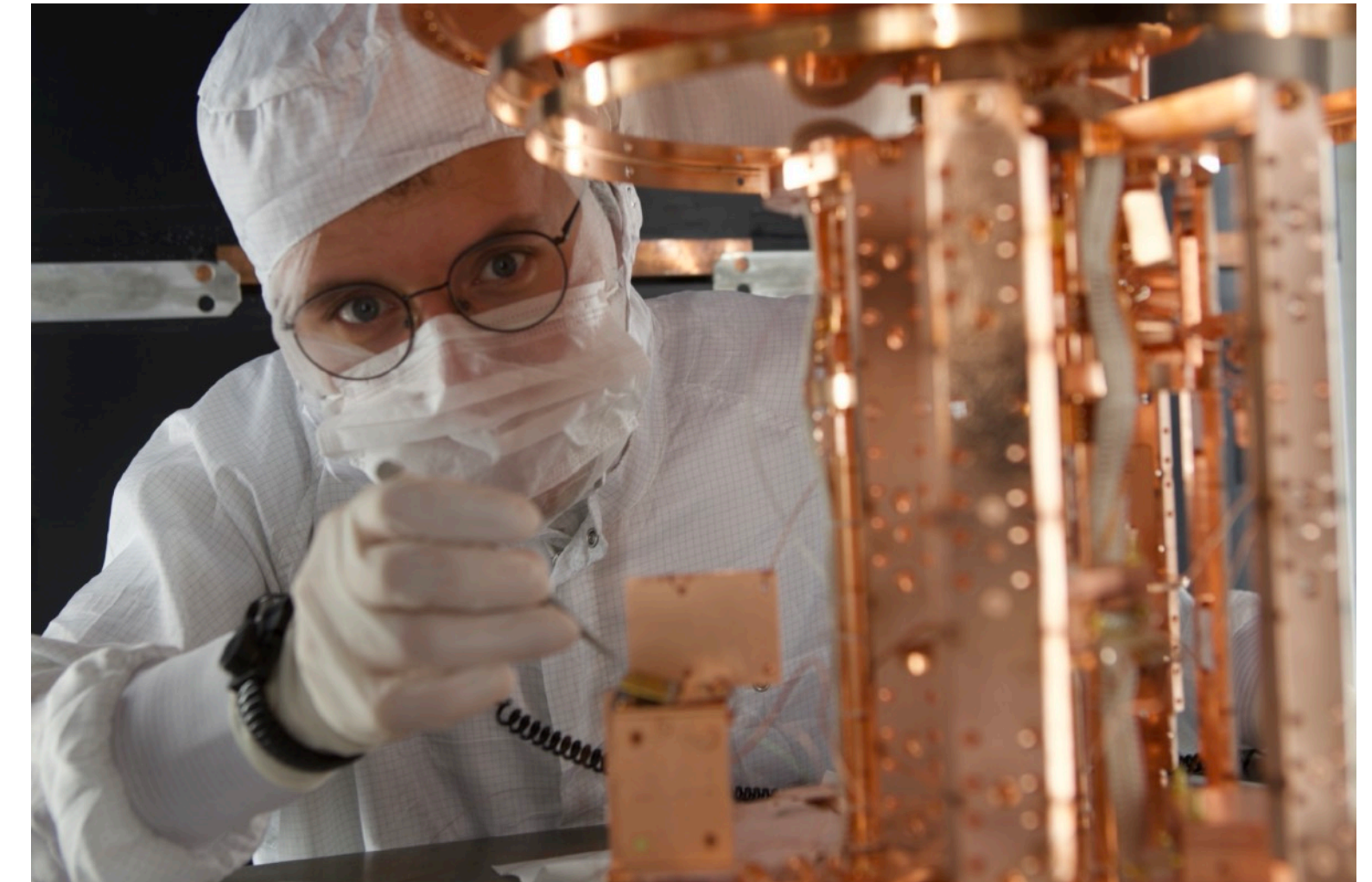
- In-depth study of the LEE with new detector designs
- 5 doubleTES modules:
 - doubleTES target crystal of ~ 24 g of CaWO_4
 - Gravity-assisted holding scheme for stress minimisation
 - Combined with light detectors for particle discrimination



Run37: Detector Modules

Cryogenic Rare Event Search with Superconducting Thermometers

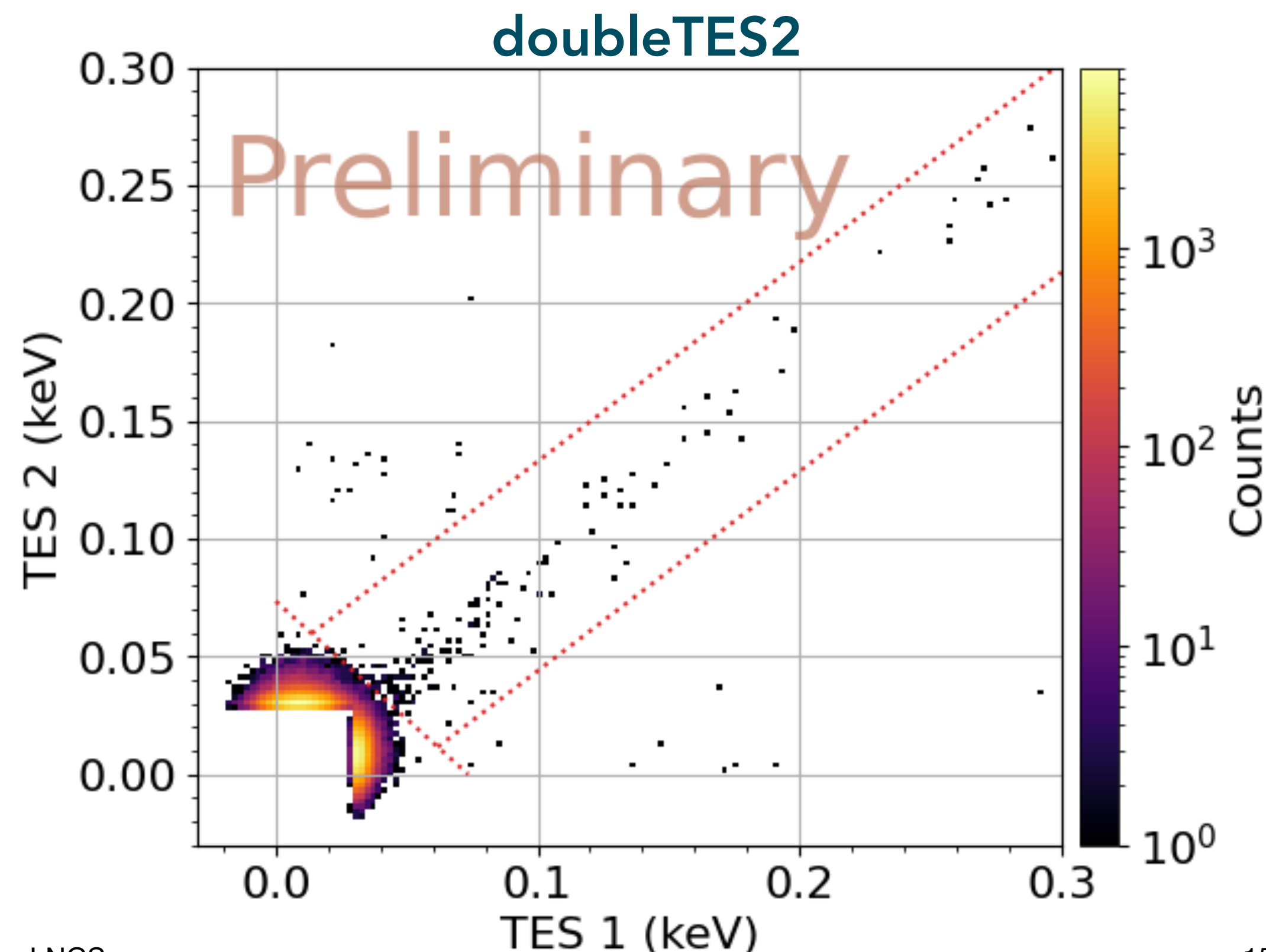
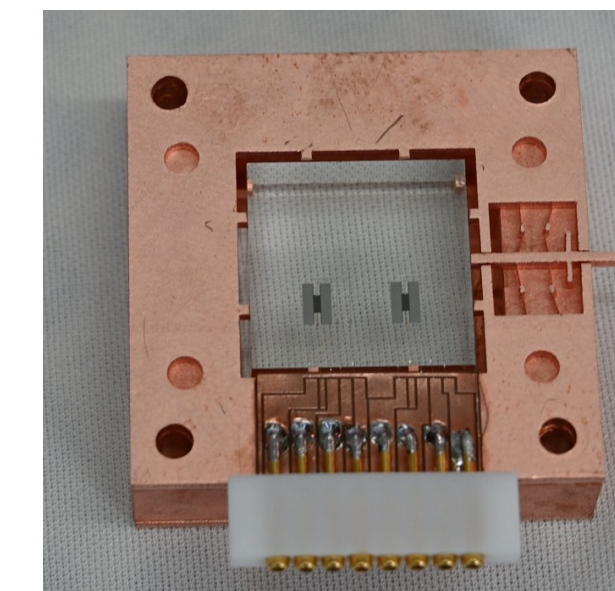
- In-depth study of the LEE with new detector designs
- 1 doubleTES wafer stack module:
 - 4 doubleTES target crystals of ~ 0.6 g of silicon-on-sapphire
 - Gravity-assisted holding scheme for stress minimisation
 - Full surface coverage of inner crystals



Run37: Results

Cryogenic Rare Event Search with Superconducting Thermometers

- CaWO_4 doubleTES modules reach thresholds of ~ 35 eV
- The doubleTES design shows two different LEE components: a shared and a singleTES component



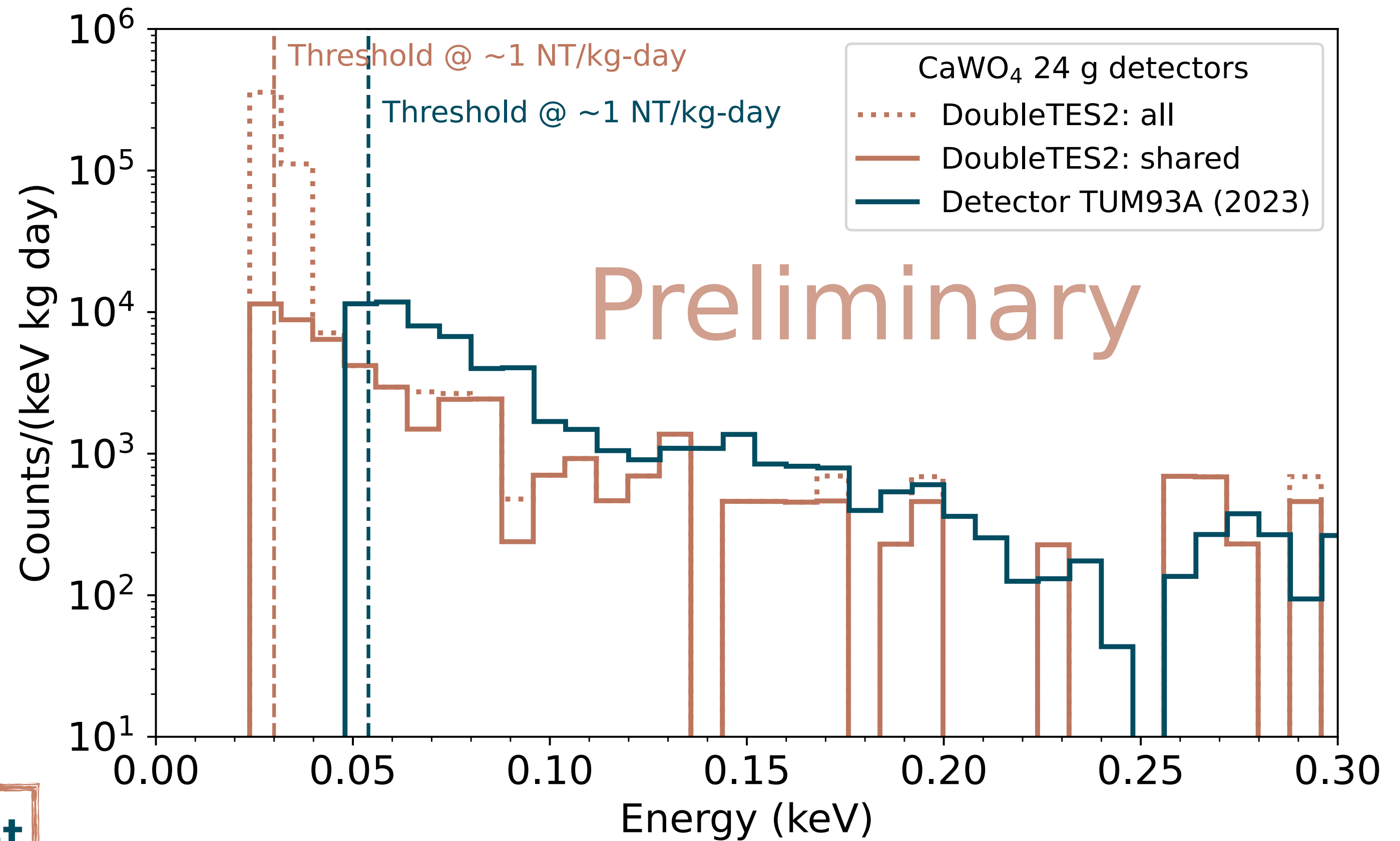
#	Baseline resolution TES1	Baseline resolution TES2
doubleTES 2	~ 7 eV	~ 7 eV
doubleTES 5	~ 8 eV	~ 7 eV

Run37: Results

Cryogenic Rare Event Search with Superconducting Thermometers

- The doubleTES design allows for lowering the threshold of the detectors
- Comparable baseline resolutions yield very different thresholds
 - Most of the noise is uncorrelated
- Open possibility to explore a broader region of the parameter space for low mass dark matter

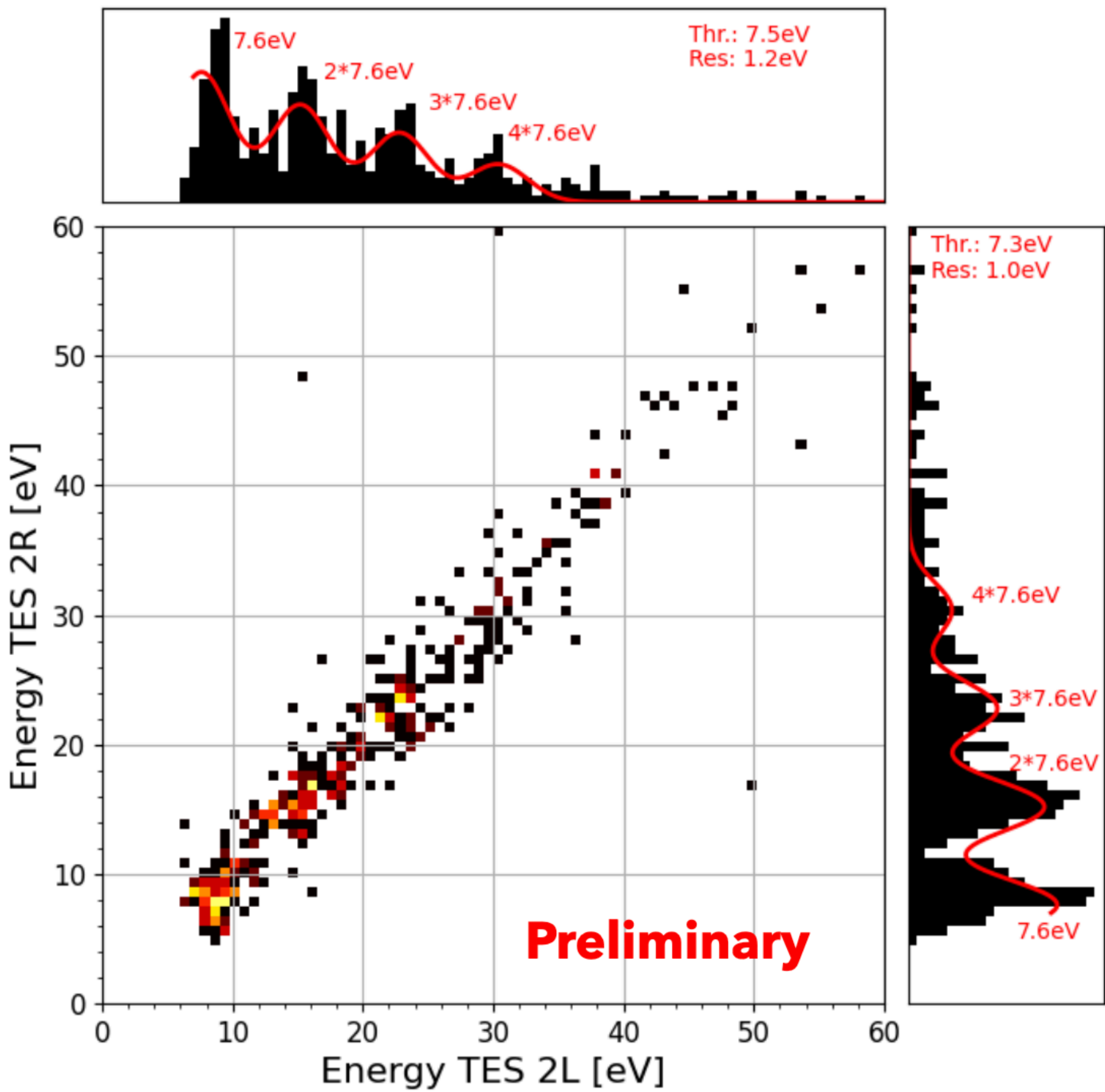
Strong motivation to collect blind data set and perform a dark matter analysis



Run37: Results

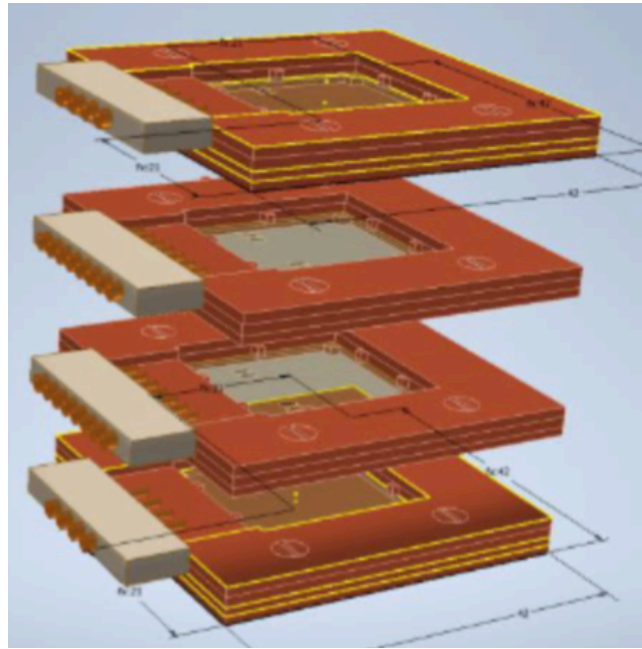
Cryogenic Rare Event Search with Superconducting Thermometers

- Wafer doubleTES detectors have very low thresholds and very good energy resolution



- 8 fully working TESs
- ^{55}Fe calibration sources
- Optimised to search for light dark matter
- Low thresholds allow for observing single photons from vacuum ultraviolet (VUV) luminescence from nearby wafer
- Already observed in CRESST

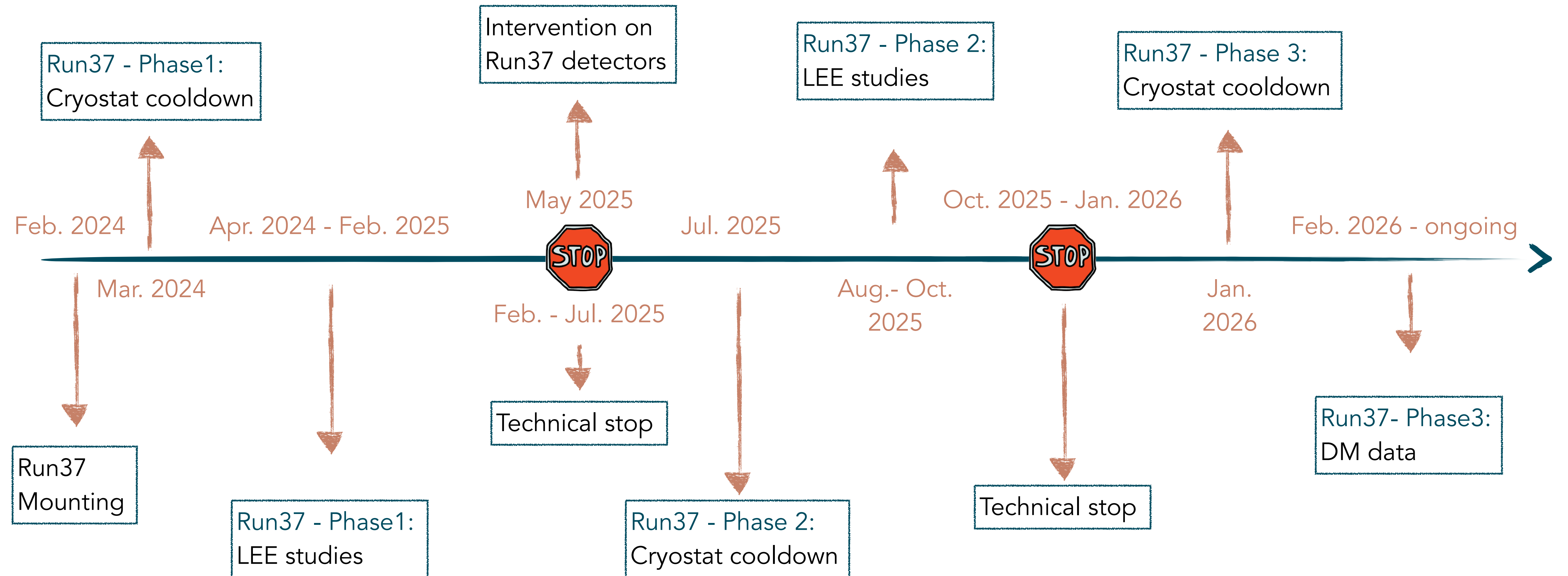
Phys. Rev. D 110, 083038



#	Baseline resolution TES1	Baseline resolution TES2
1	1.4 eV	1.1 eV
2	1.2 eV	1.0 eV
3	1.7 eV	1.5 eV
4	1.4 eV	3.9 eV

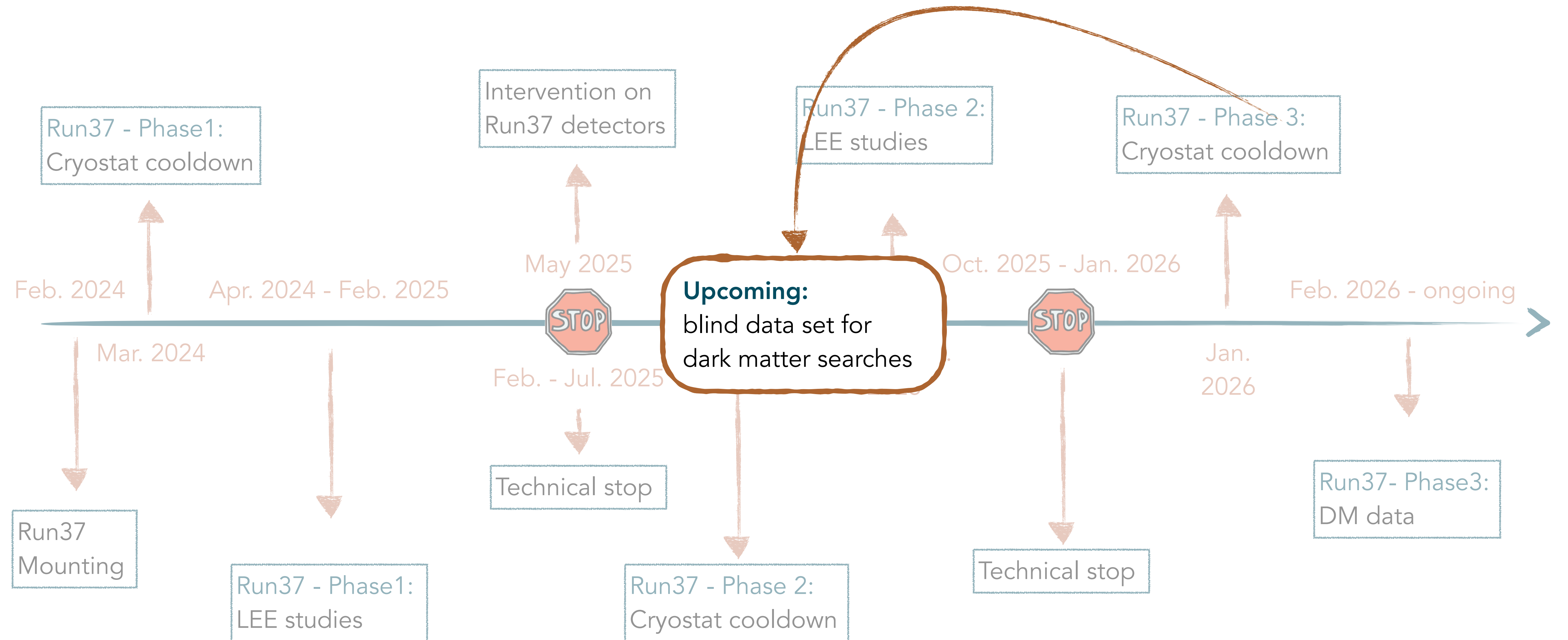
Run37: Timeline

Cryogenic Rare Event Search with Superconducting Thermometers



Run37: Timeline

Cryogenic Rare Event Search with Superconducting Thermometers



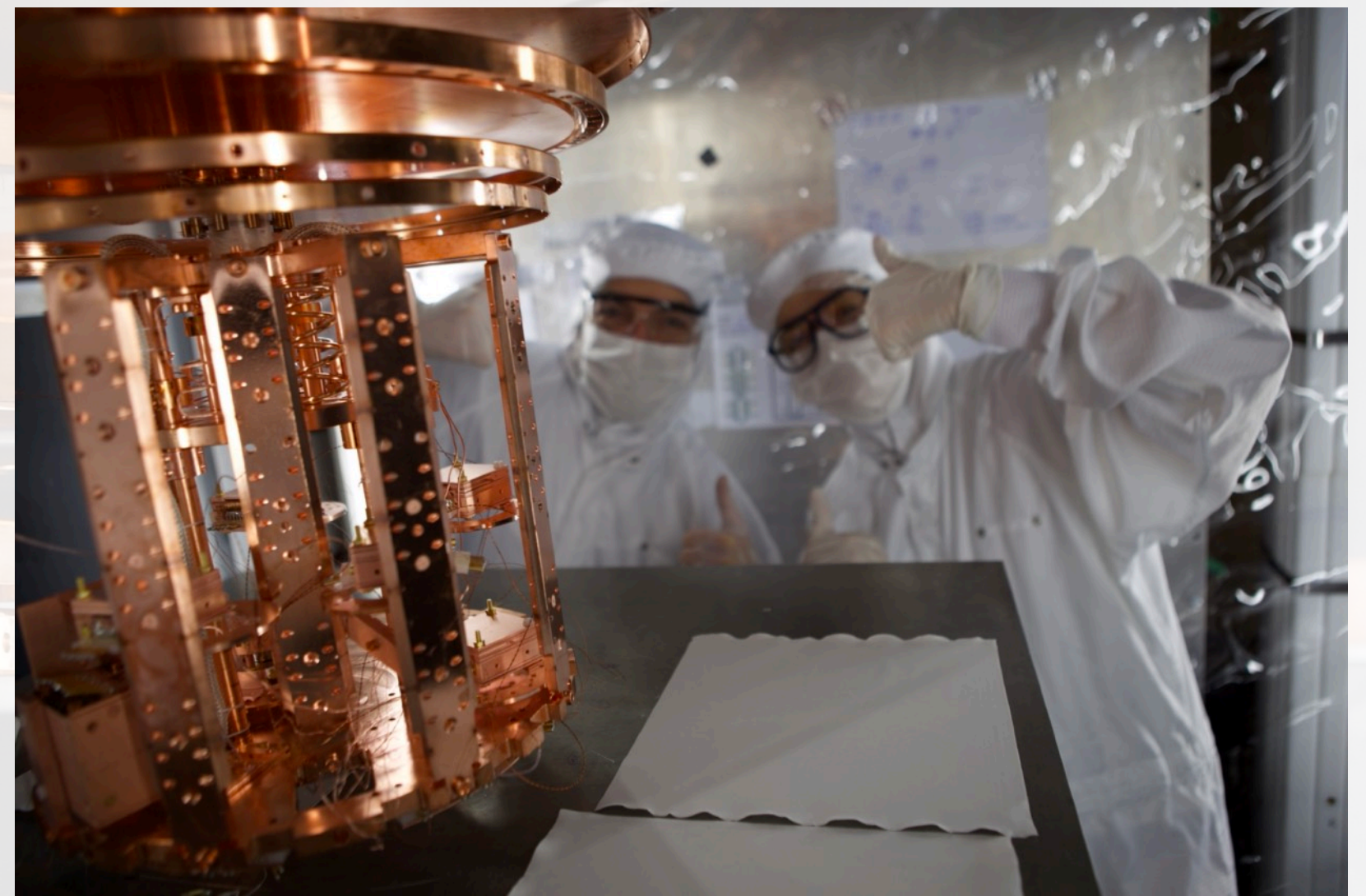
Summary and Outlook

Cryogenic Rare Event Search with Superconducting Thermometers

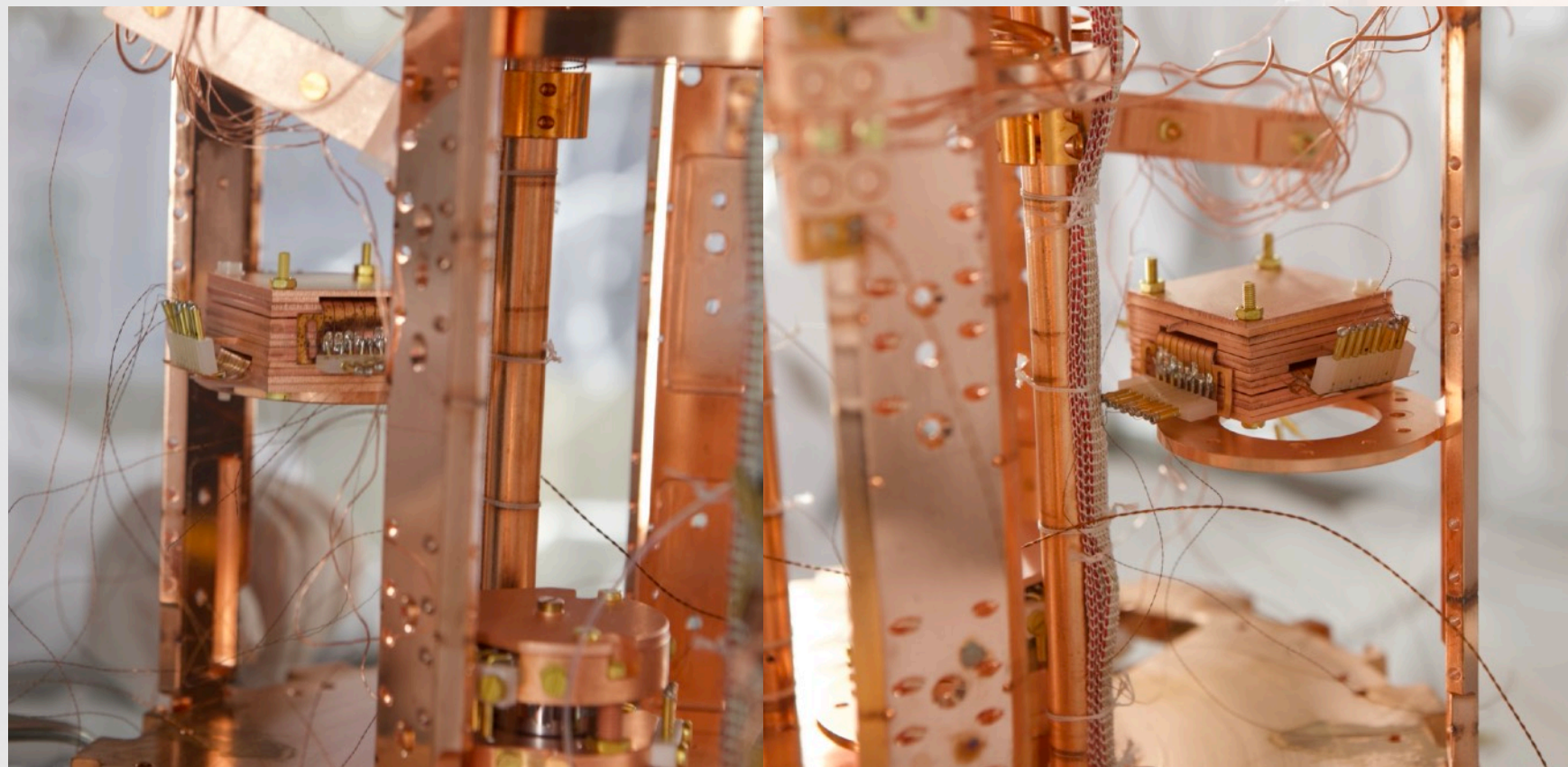
- CRESST energy thresholds allow for deep exploration of light DM mass region below 1 GeV/c²
- The capability to adapt the technology to **multiple target crystals** allows the investigation of both spin-dependent and spin-independent interactions
- DoubleTES detectors operated in the CRESST cryostat show different components of the LEE and allow for a **relevant reduction** of the detectors' energy threshold
- Dark matter run started in February 2026



Stay tuned for DM results!



Thank you for your attention



Backup Slides



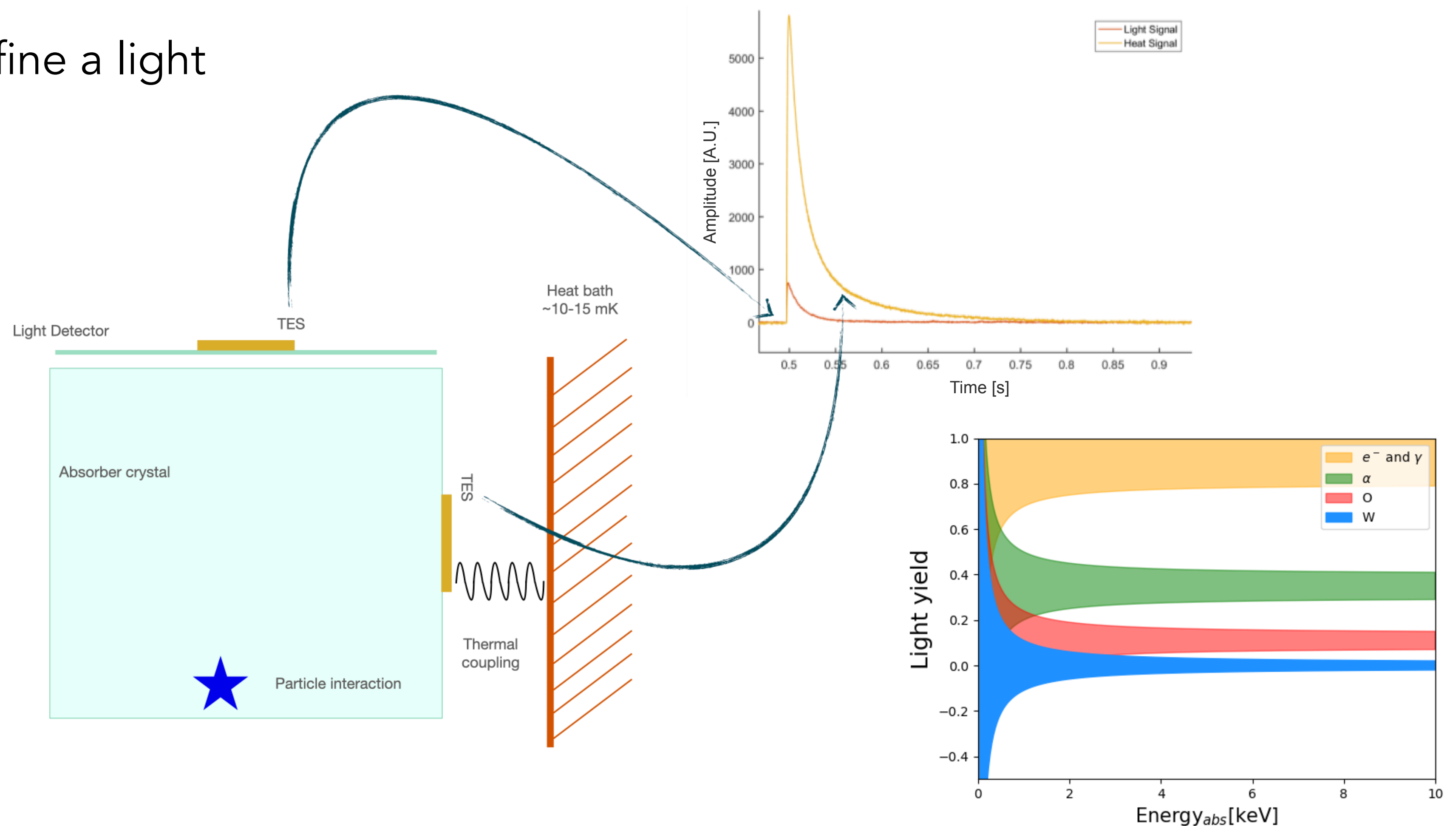
Particle Discrimination

Cryogenic Rare Event Search with Superconducting Thermometers

- Dual readout allows to define a light yield (LY)

- $$LY = \frac{\text{Light signal}}{\text{Phonon signal}}$$

- LY enables separation of potential signal events (**nuclear recoils**) from the dominant radioactive background (**electron recoils**)



CRESST-III: New Calibration Methods



Cryogenic Rare Event Search with Superconducting Thermometers

New calibration technique for low nuclear recoil energy in $CaWO_4$ and Al_2O_3 through (n, γ) reactions

CRAB Collaboration 2021 JINST 16 P07032

$CaWO_4$

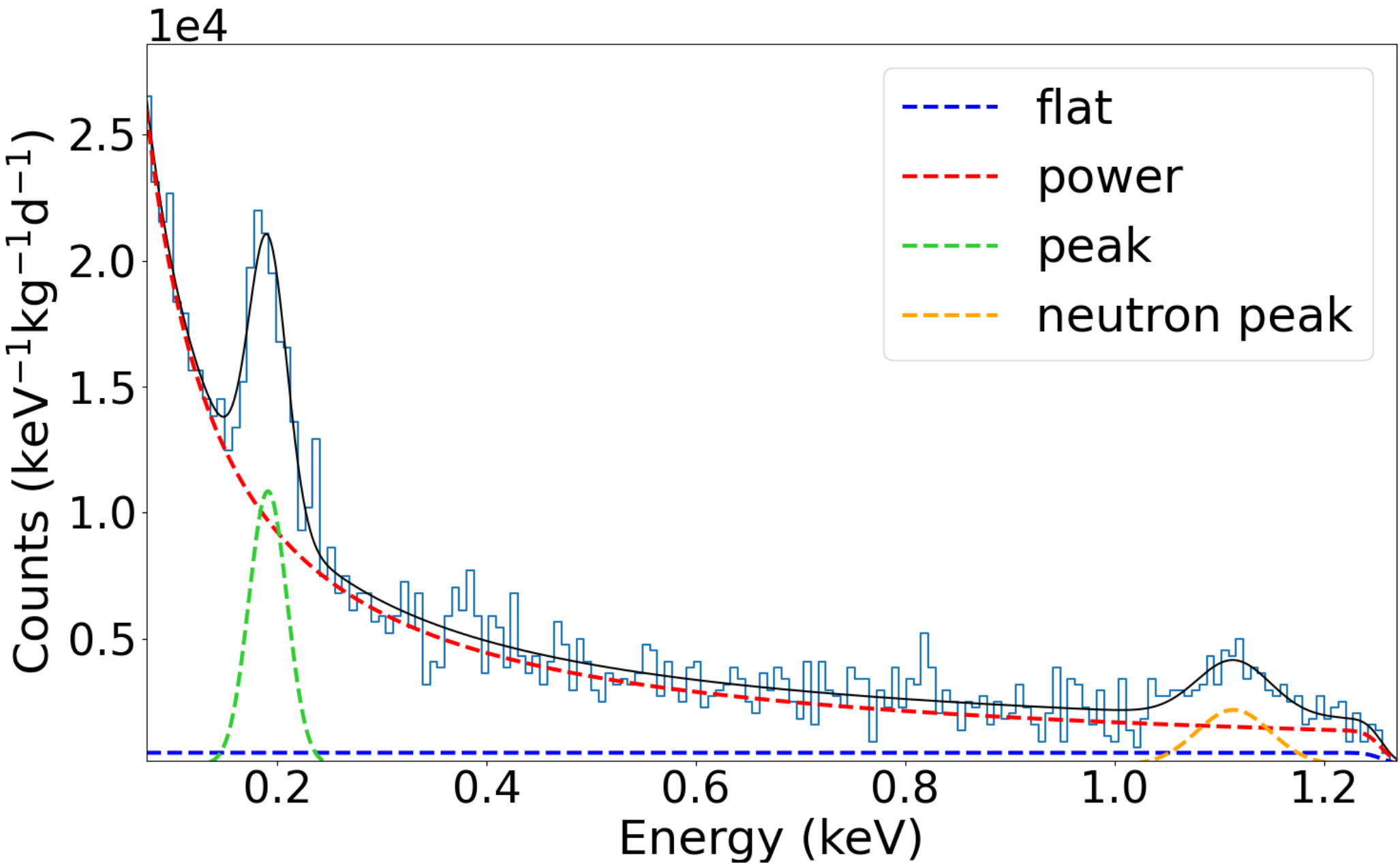
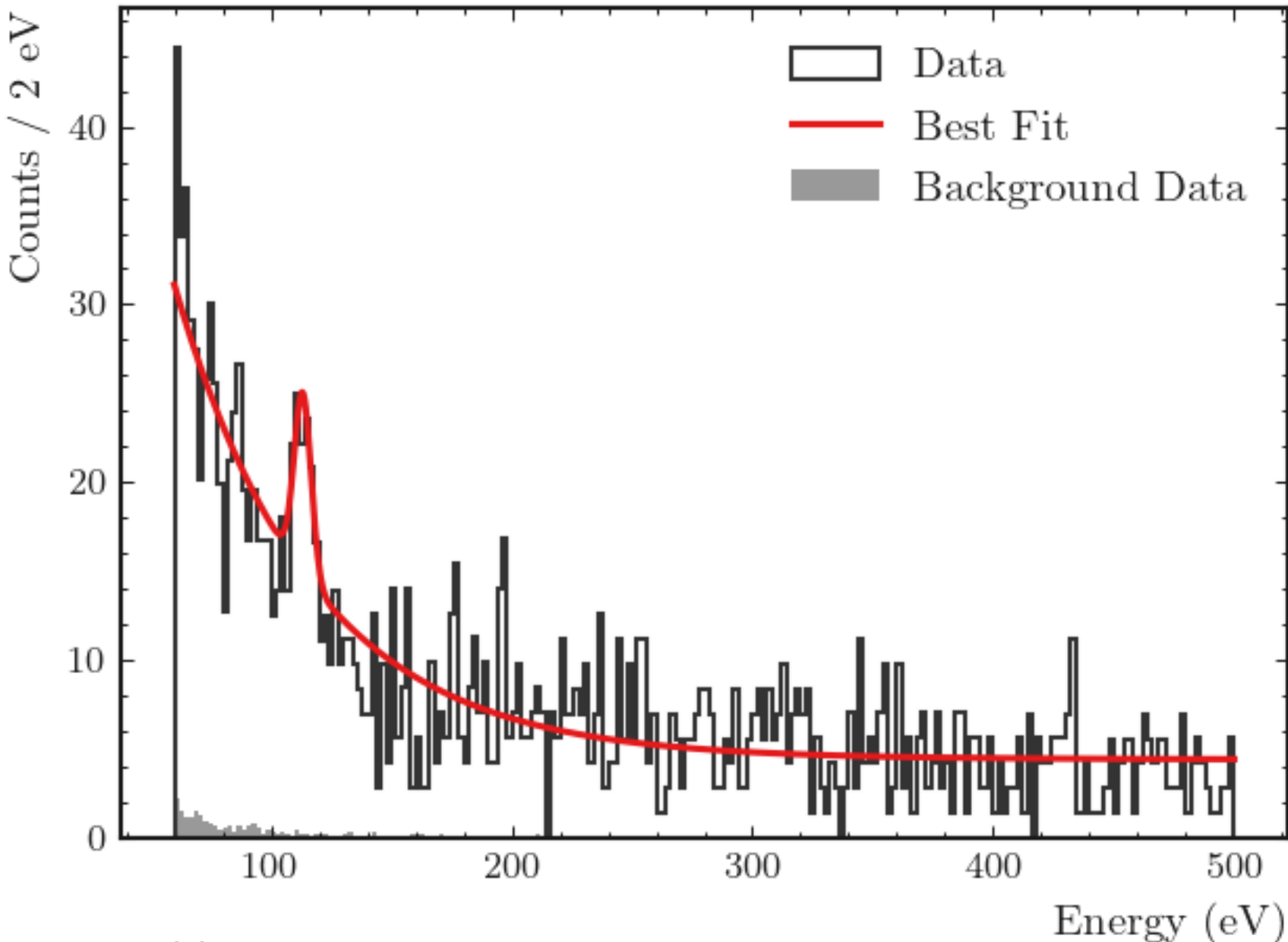
$^{182}W(n, \gamma) ^{183}W$

De-excitation γ of 6.1 MeV
and W nuclear recoil of 112 eV

Al_2O_3

$^{27}Al(n, \gamma) ^{28}Al$

De-excitation γ of 7.7 MeV
and Al nuclear recoil of 1144 eV



PhysRevD.108.022005

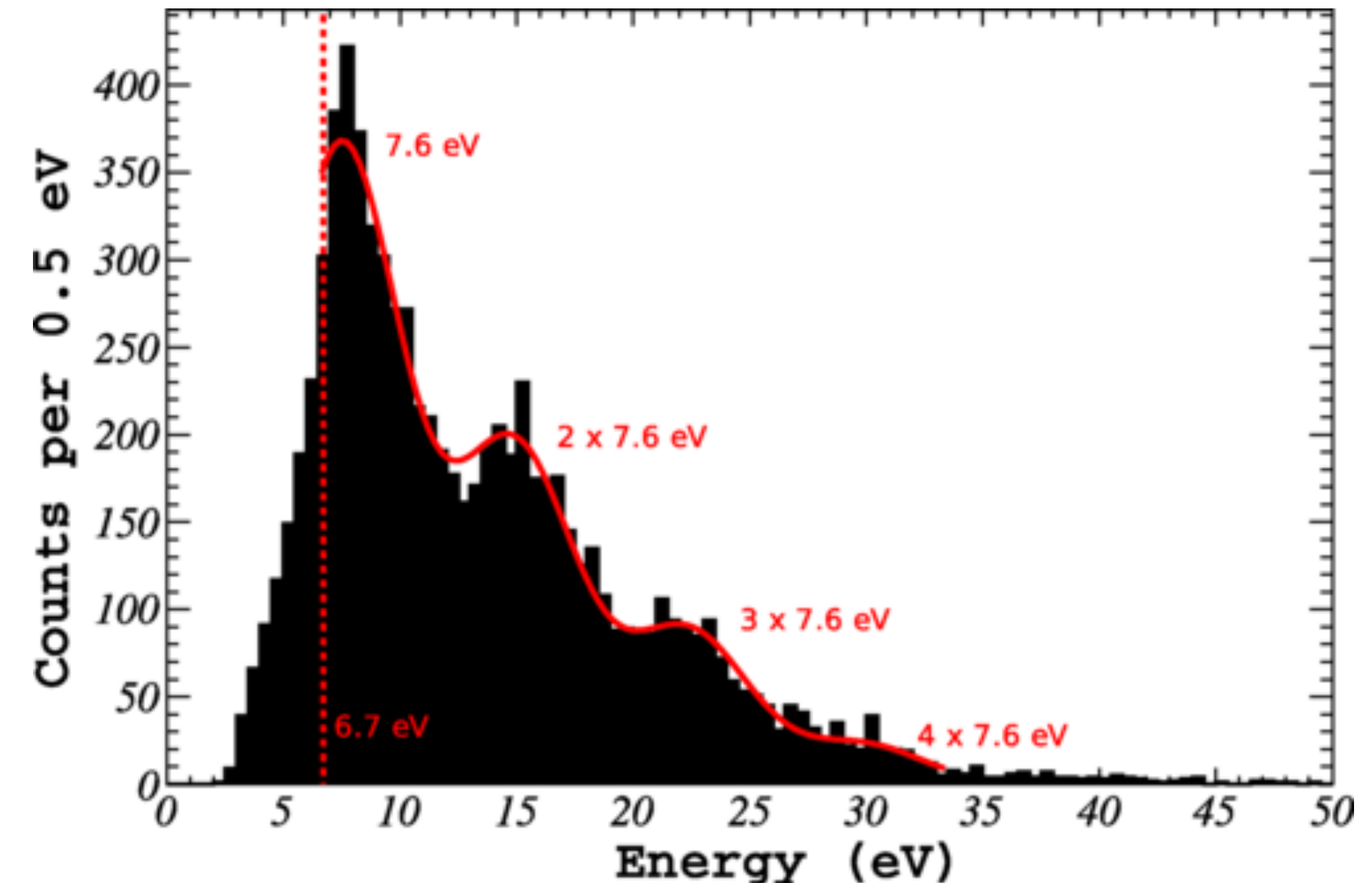
PhysRevD.108.022005

CRESST-III: New Calibration Methods



Cryogenic Rare Event Search with Superconducting Thermometers

- Ultra-pure sapphire crystals emit luminescence at 7.6 eV via radiative decay of excitons
- High energy deposition → multiplication of electronic excitations → creation of multiple luminescence photons
- Process is fast → various photons detected as a single event with multiple of single photon energy
- Validation of calibration performed with ^{55}Fe source (5.9 and 6.5 keV) down to threshold
- First measurement of single photons in CRESST

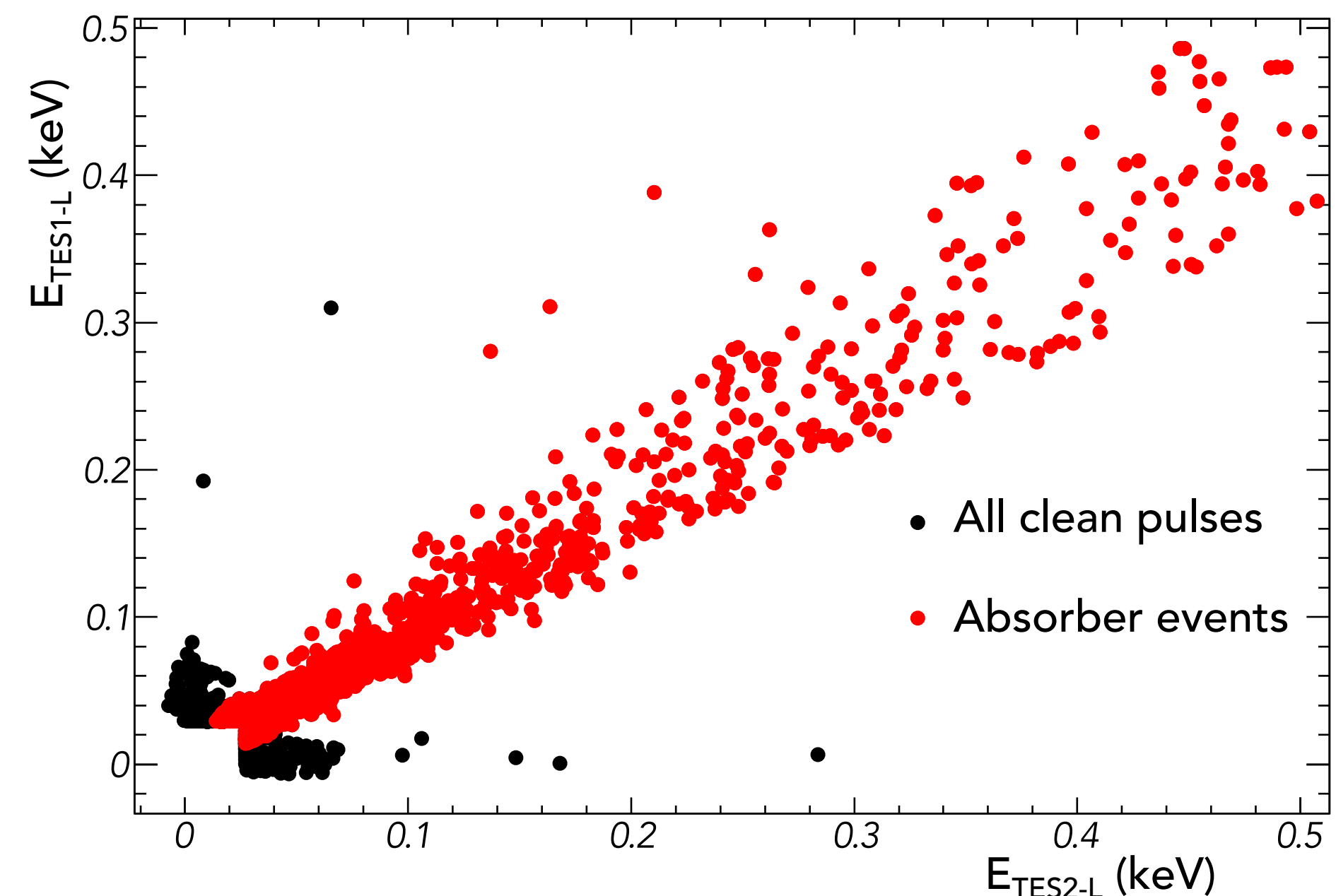
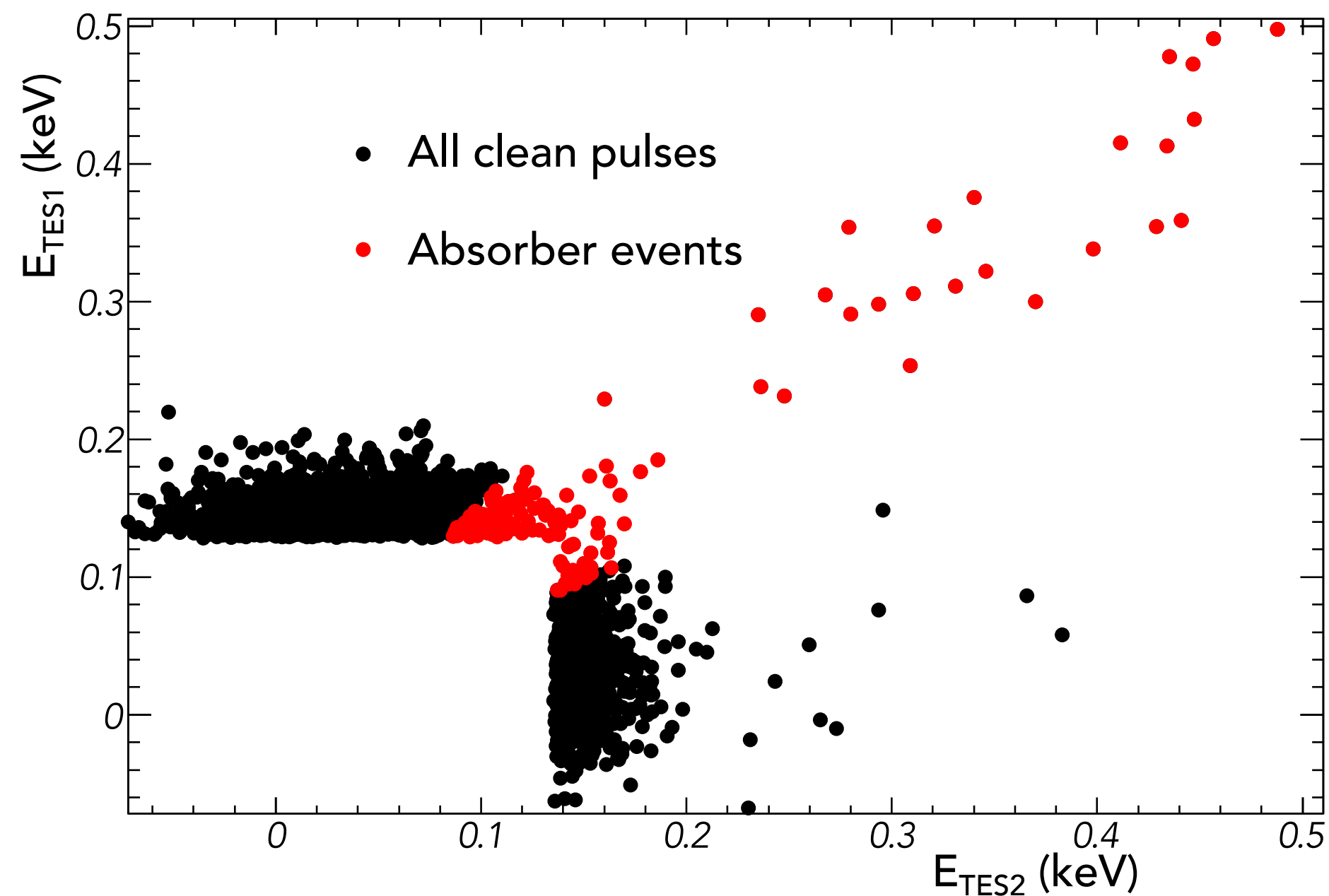


Phys. Rev. D 110, 083038

LEE Investigation: The DoubleTES

Cryogenic Rare Event Search with Superconducting Thermometers

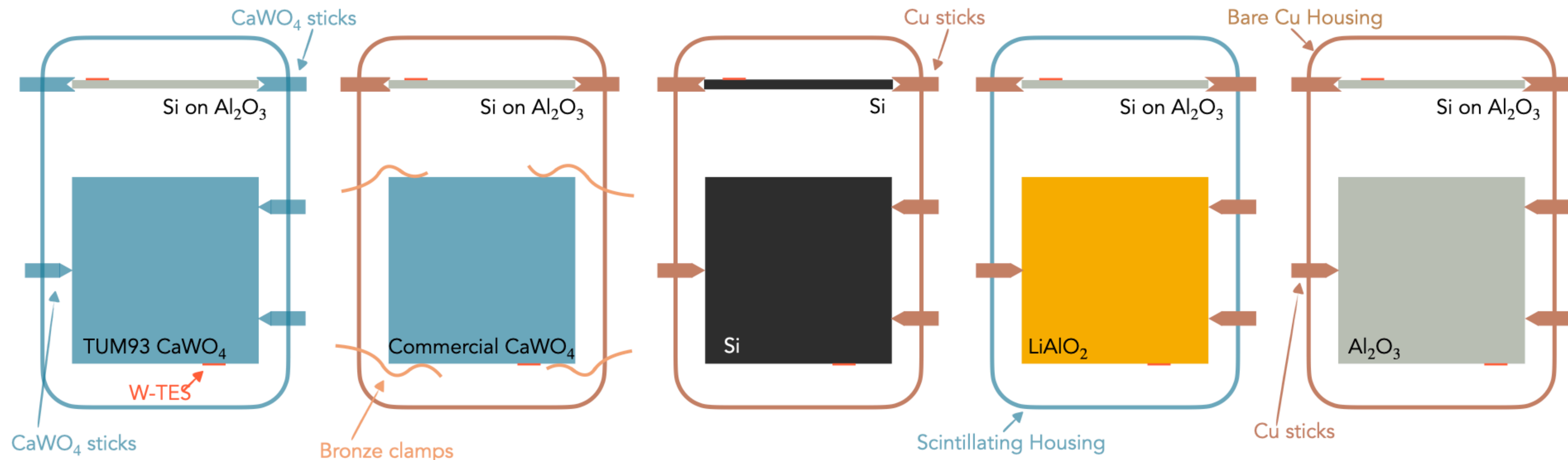
- Several tests of doubleTES modules performed above ground
- SingleTES events are one of the LEE components observed
- Similar observations reported by TESSERACT and by Nucleus



LEE Investigation

Cryogenic Rare Event Search with Superconducting Thermometers

- Understanding & mitigating LEE fundamental to improve CRESST DM sensitivity
- Several modifications to CRESST-III design to investigate different hypotheses on the LEE origin:
 - Material dependence
 - Internal stress
 - Stress induced by holder
 - Scintillation light
 - Detector geometry



Cryogenic Rare Event Search with Superconducting Thermometers

- Understanding & mitigating LEE fundamental to improve CRESST DM sensitivity
- Several modifications to CRESST-III design to investigate different hypotheses on the LEE origin:

Different target materials tested

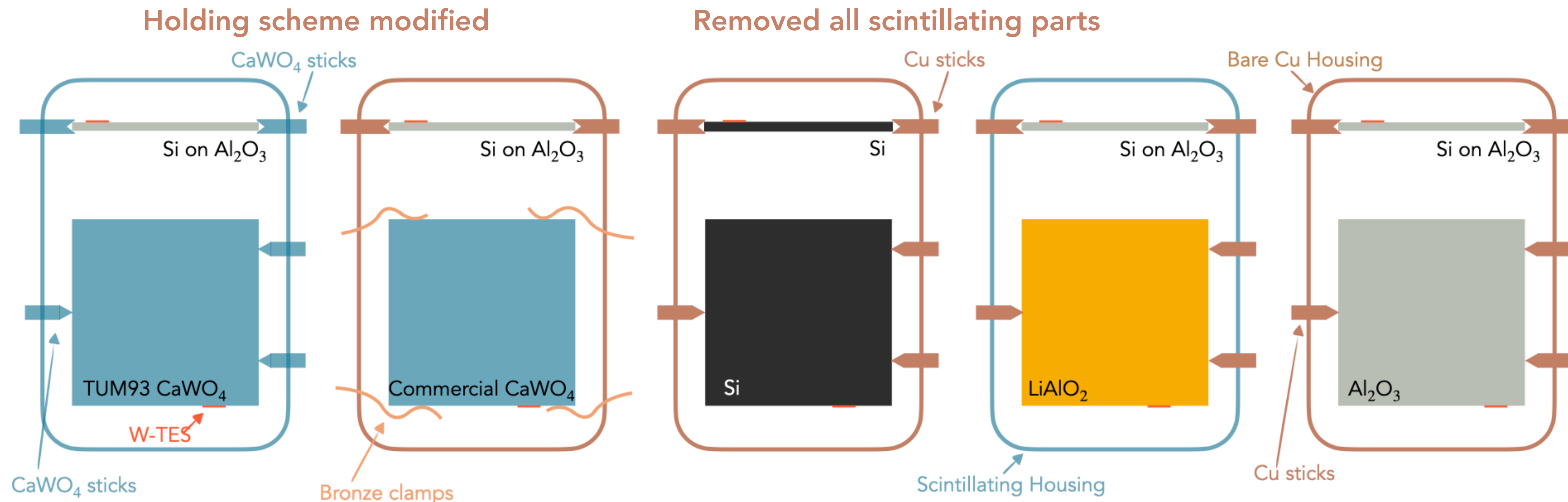
- ▶ Material dependence
- ▶ Stress induced by holder

Tested slow grown crystals

- ▶ Internal stress
- ▶ Scintillation light

LD analysed as target crystals

- ▶ Detector geometry



Cryogenic Rare Event Search with Superconducting Thermometers

- Understanding & mitigating LEE fundamental to improve CRESST DM sensitivity
- Several modifications to CRESST-III design to investigate different hypotheses on the LEE origin:

Different target materials tested

- Material dependence
- Stress induced by holder

Tested slow grown crystals

- Internal stress
- Scintillation light

LD analysed as target crystals

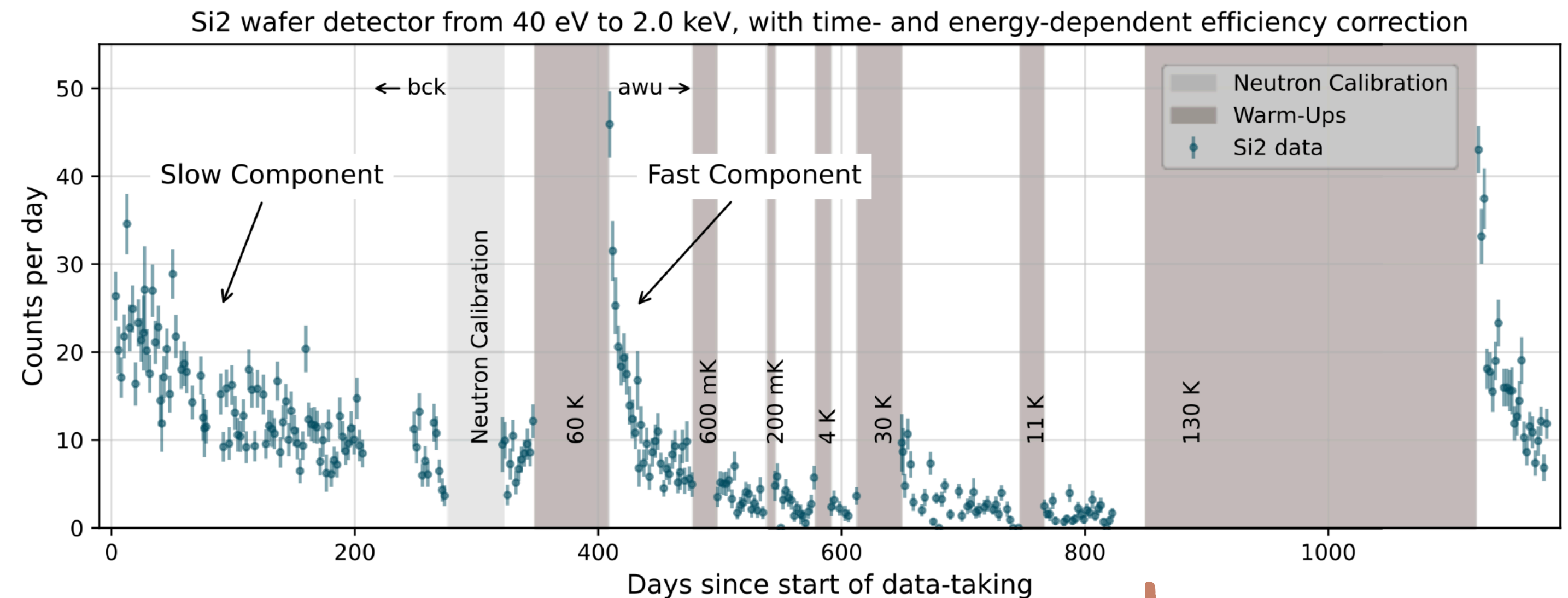
- Detector geometry



LEE Investigation

Cryogenic Rare Event Search with Superconducting Thermometers

- Rise of particle events at energies below 200 eV
 - ▶ It is present in all absorber materials with different holding schemes
 - ▶ The LEE decays with time
 - ▶ The LEE can be repopulated with thermal cycles
 - ▶ Diversity of the decay times observed and behaviour after thermal cycles puts tension on a possible interpretation as radioactive background
 - ▶ No significant increase of the LEE rate after the neutron calibration

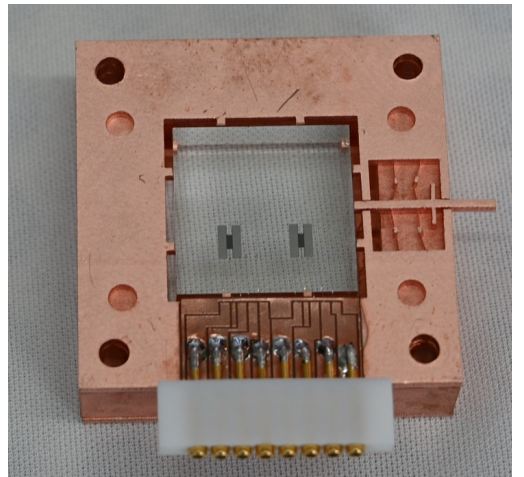
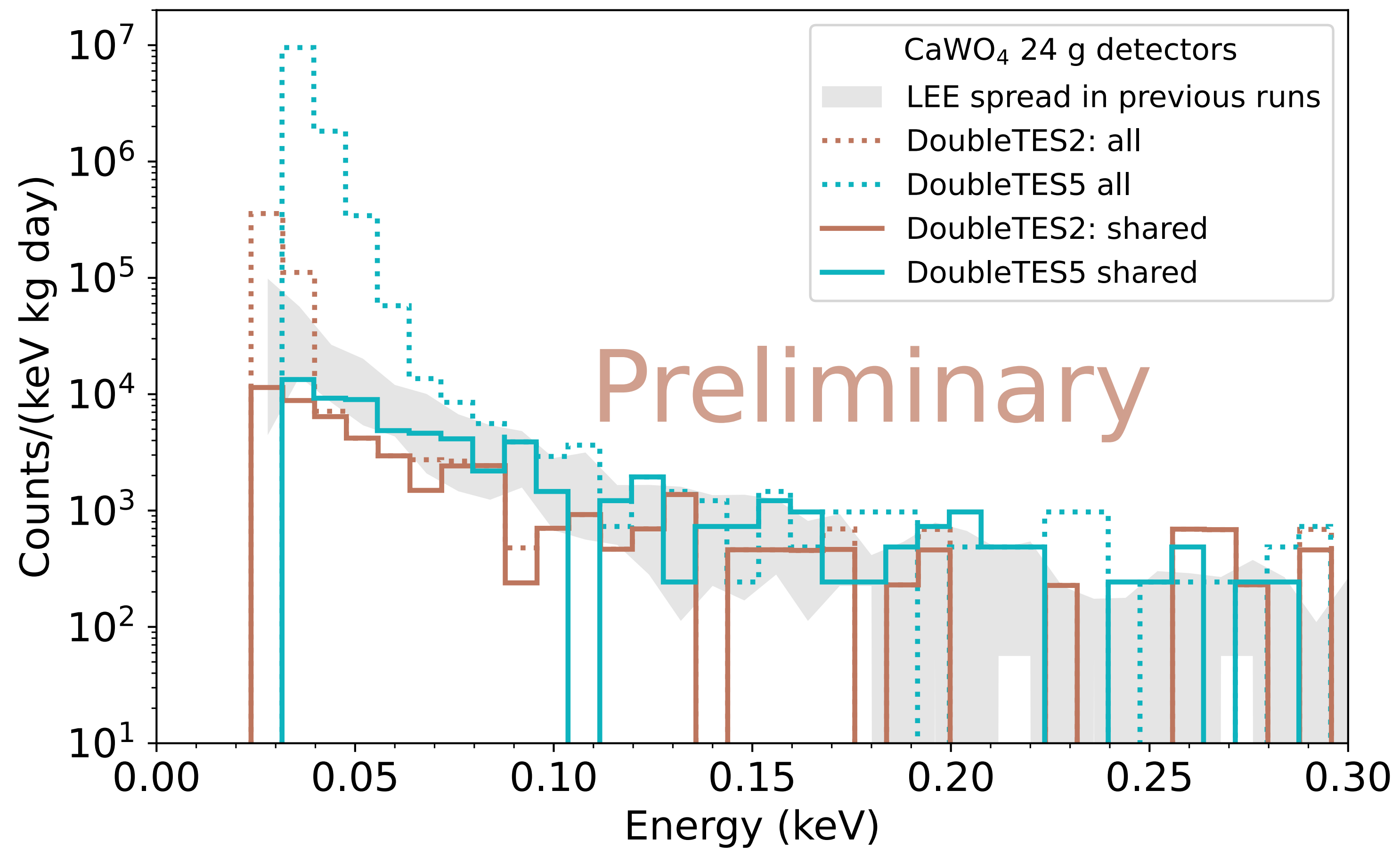


The origin is still unclear

A new generation of detectors is needed to reach a better understanding of this signal

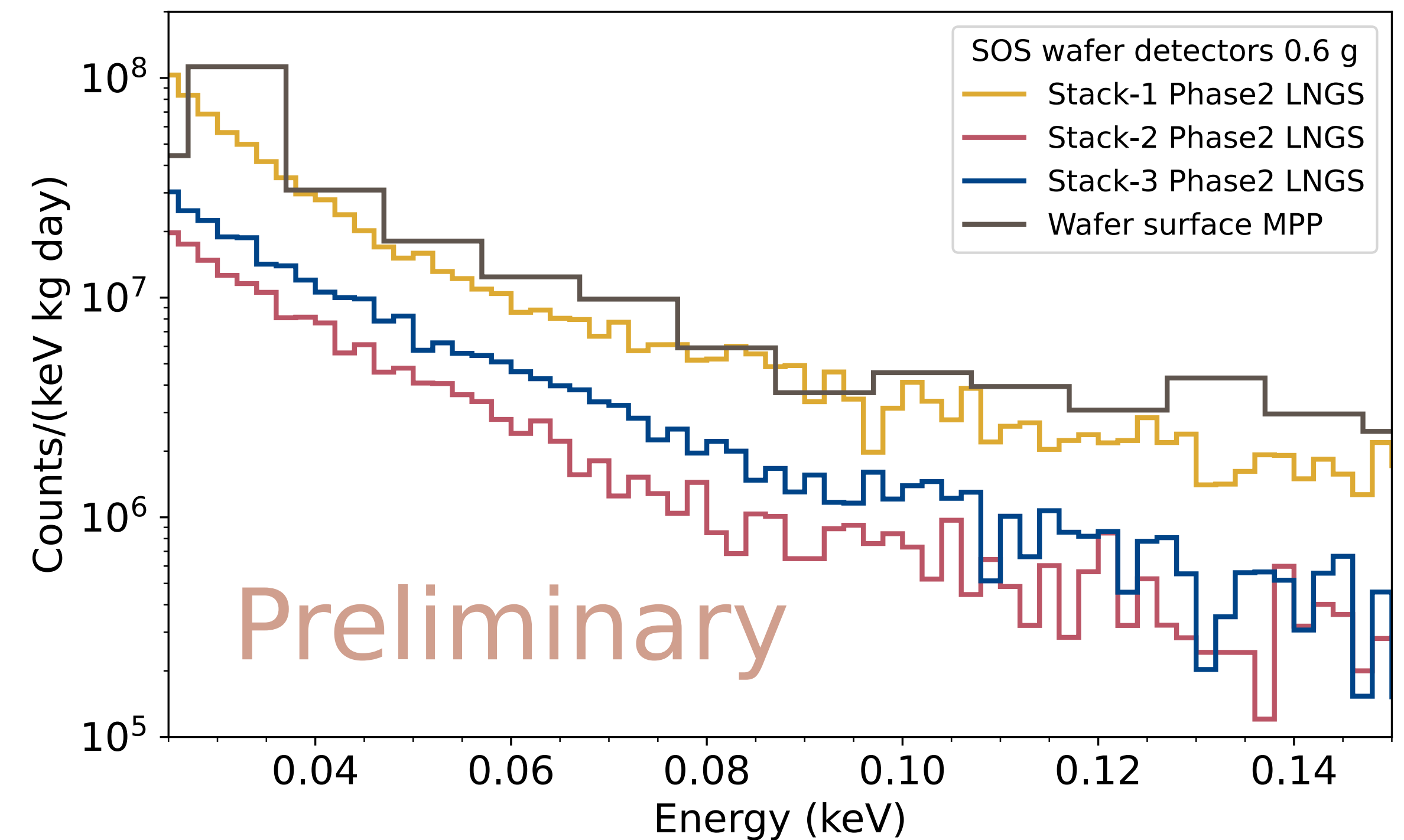
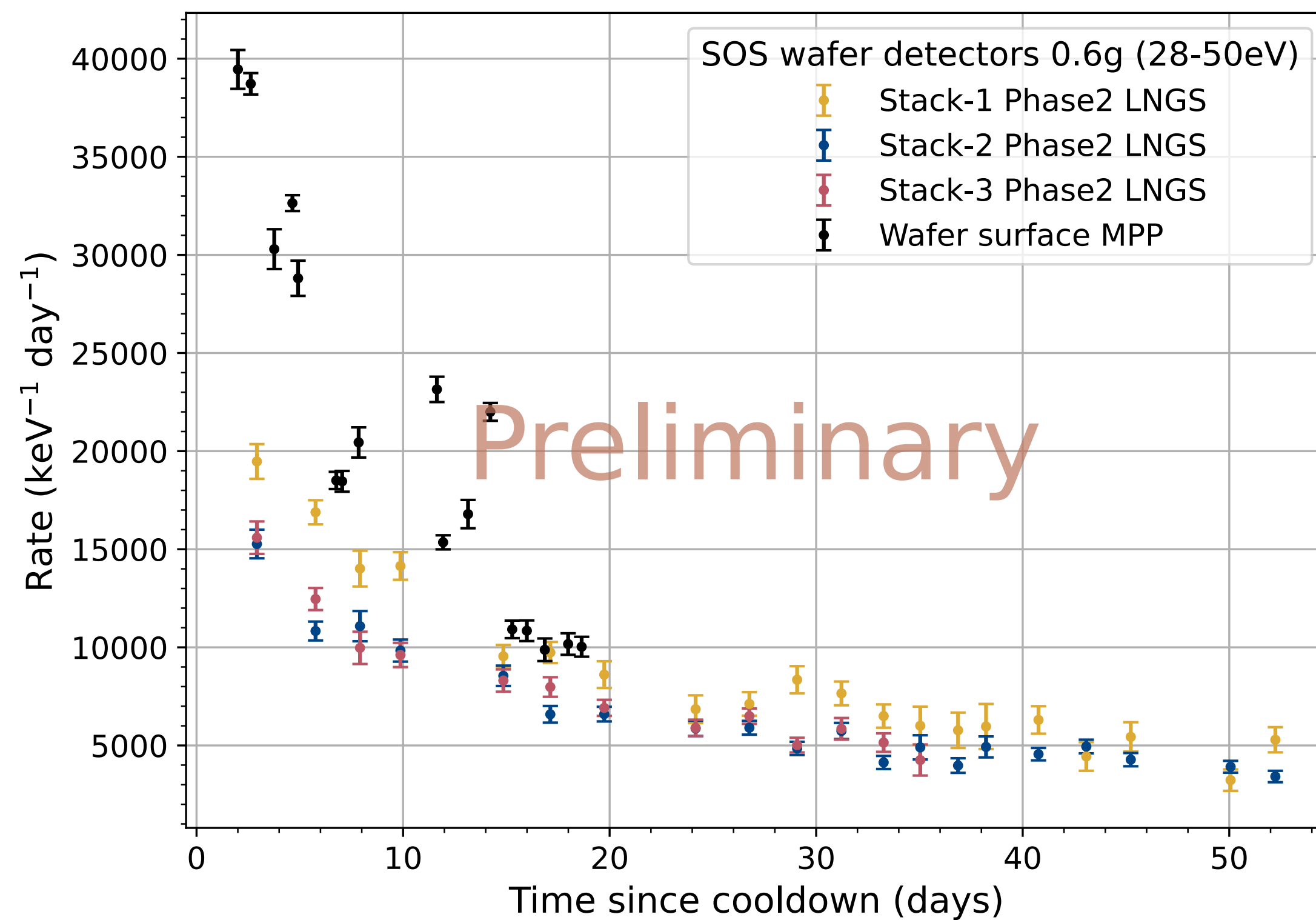
LEE Comparison

Cryogenic Rare Event Search with Superconducting Thermometers



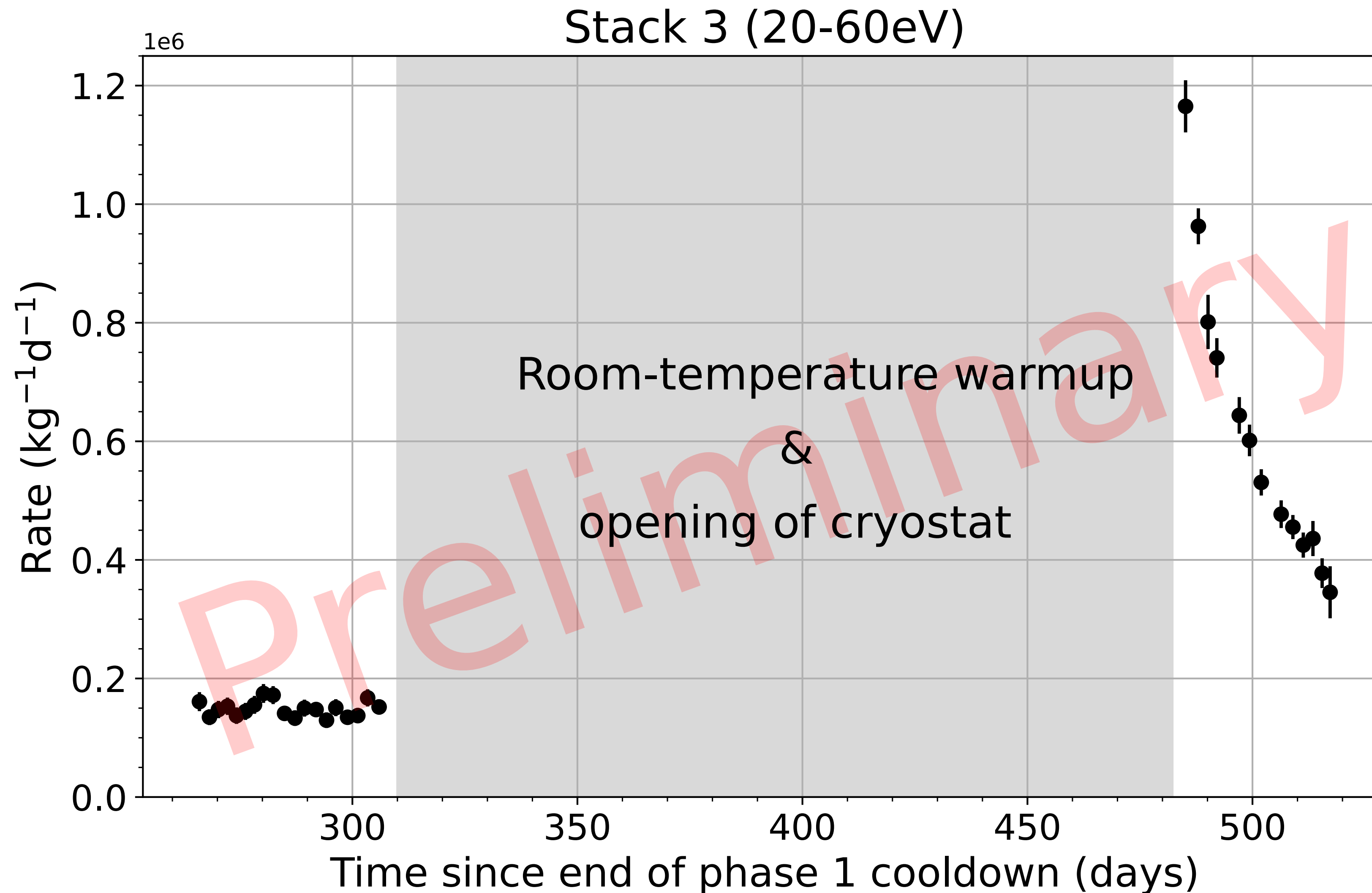
LEE Comparison

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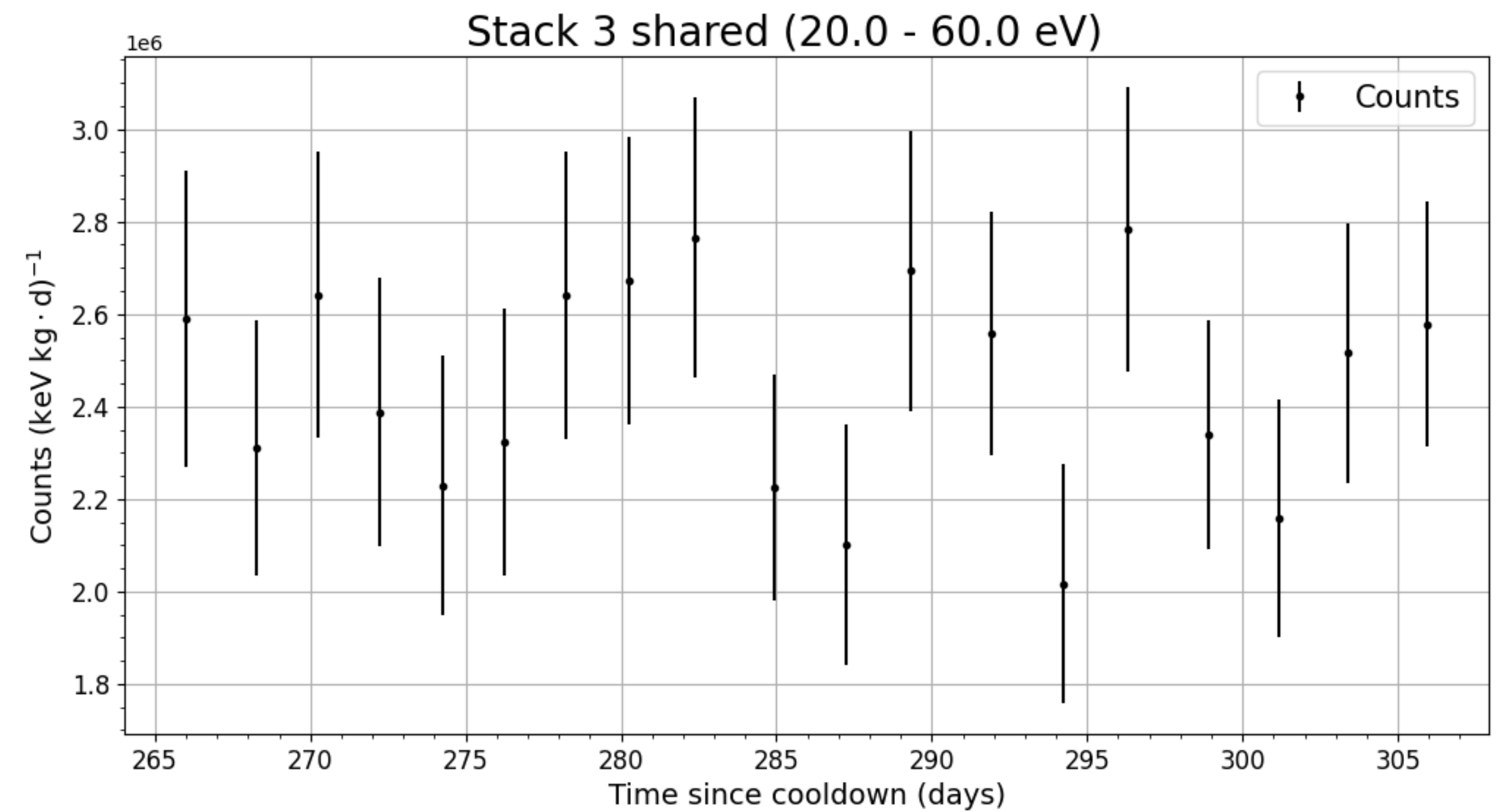
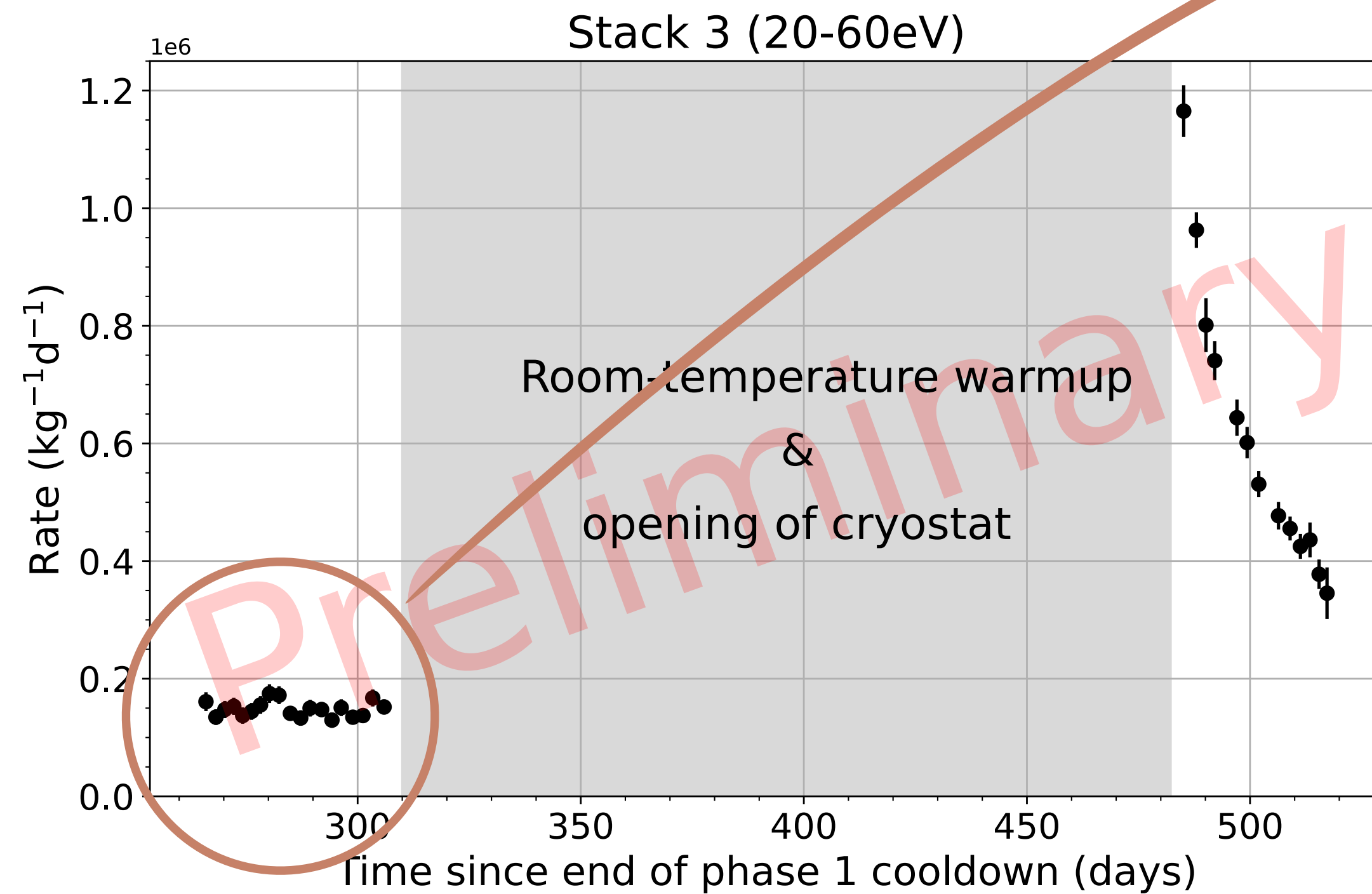
LEE time decay

Cryogenic Rare Event Search with Superconducting Thermometers



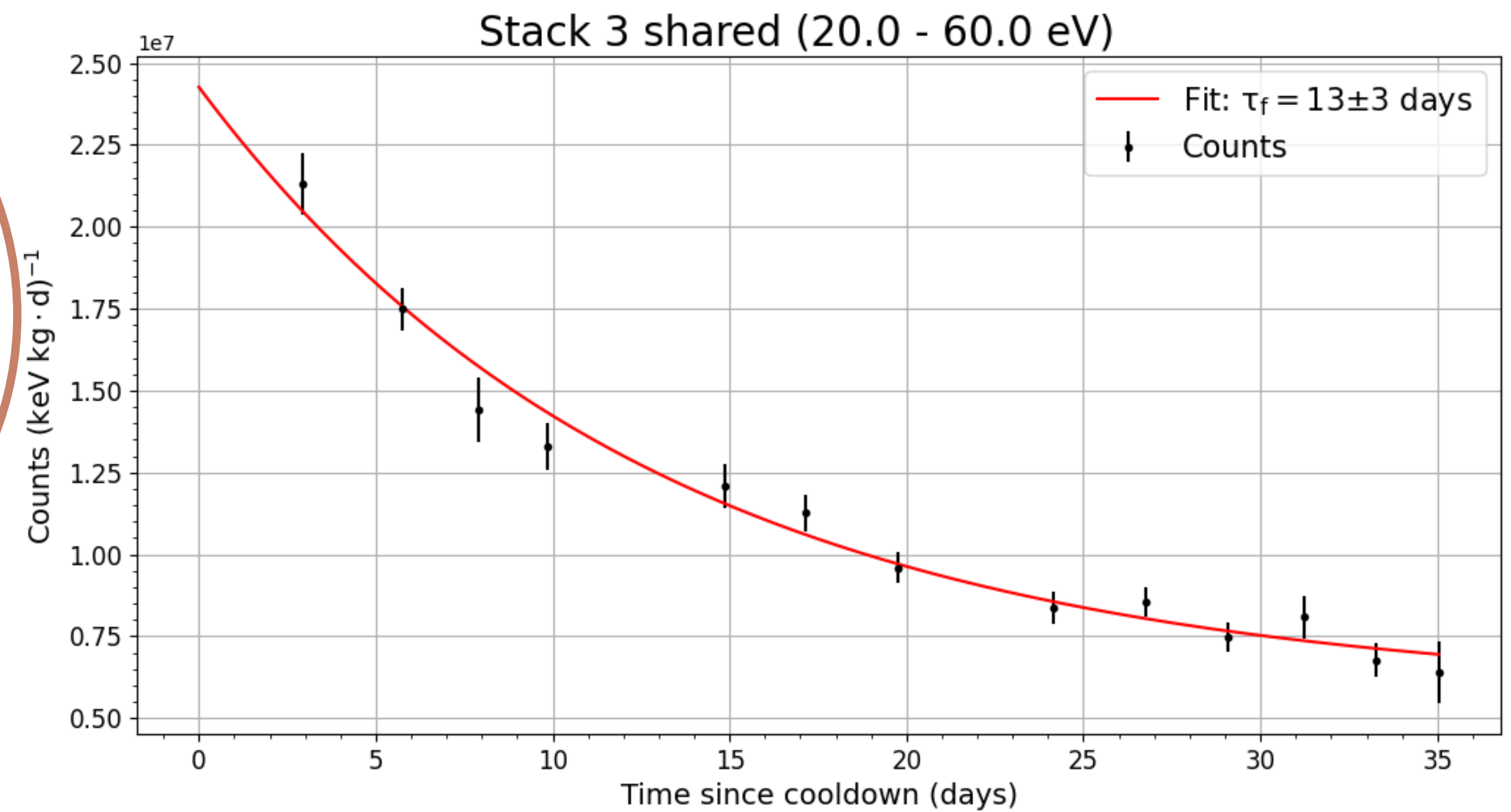
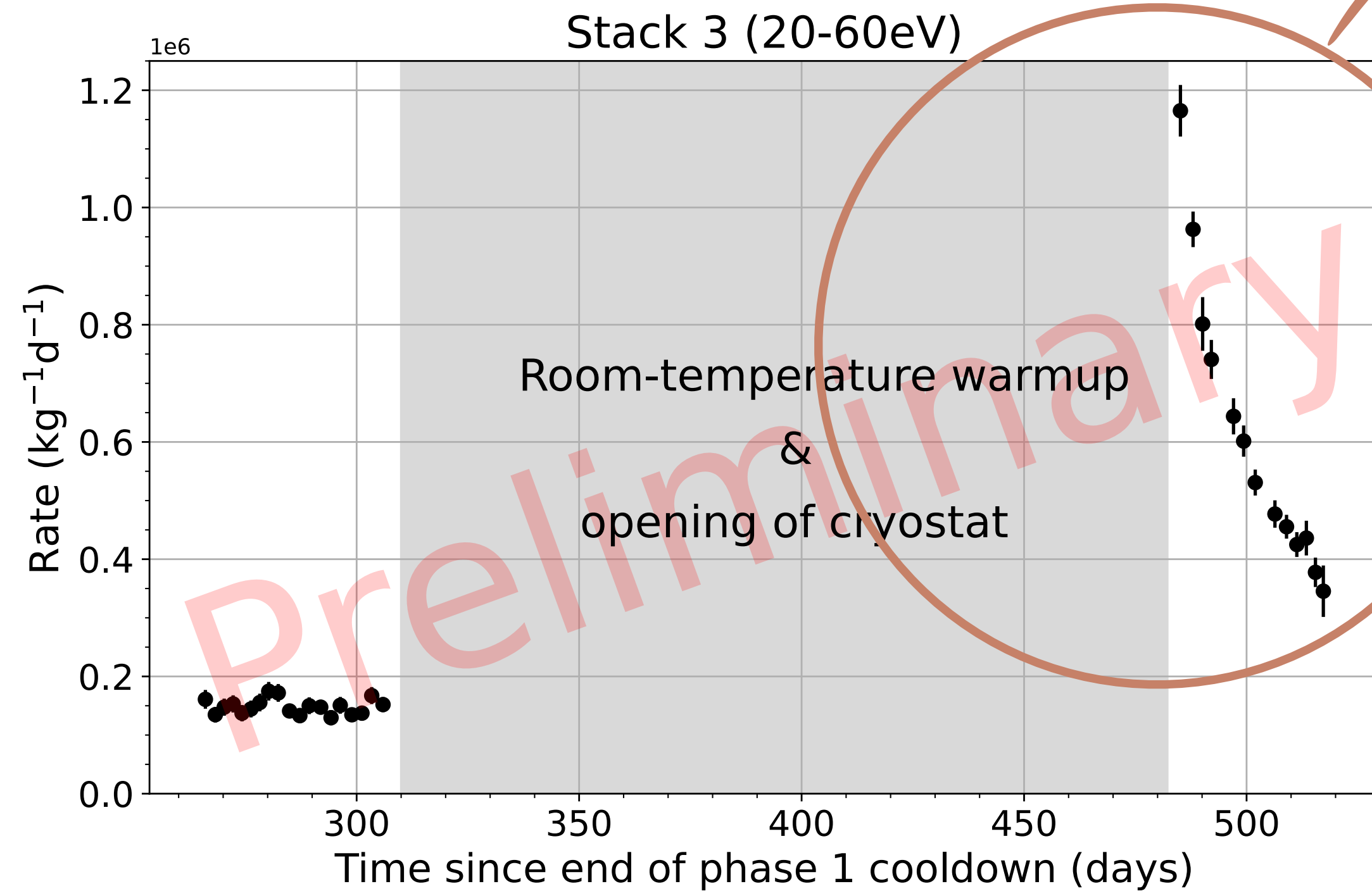
LEE time decay

Cryogenic Rare Event Search with Superconducting Thermometers



LEE time decay

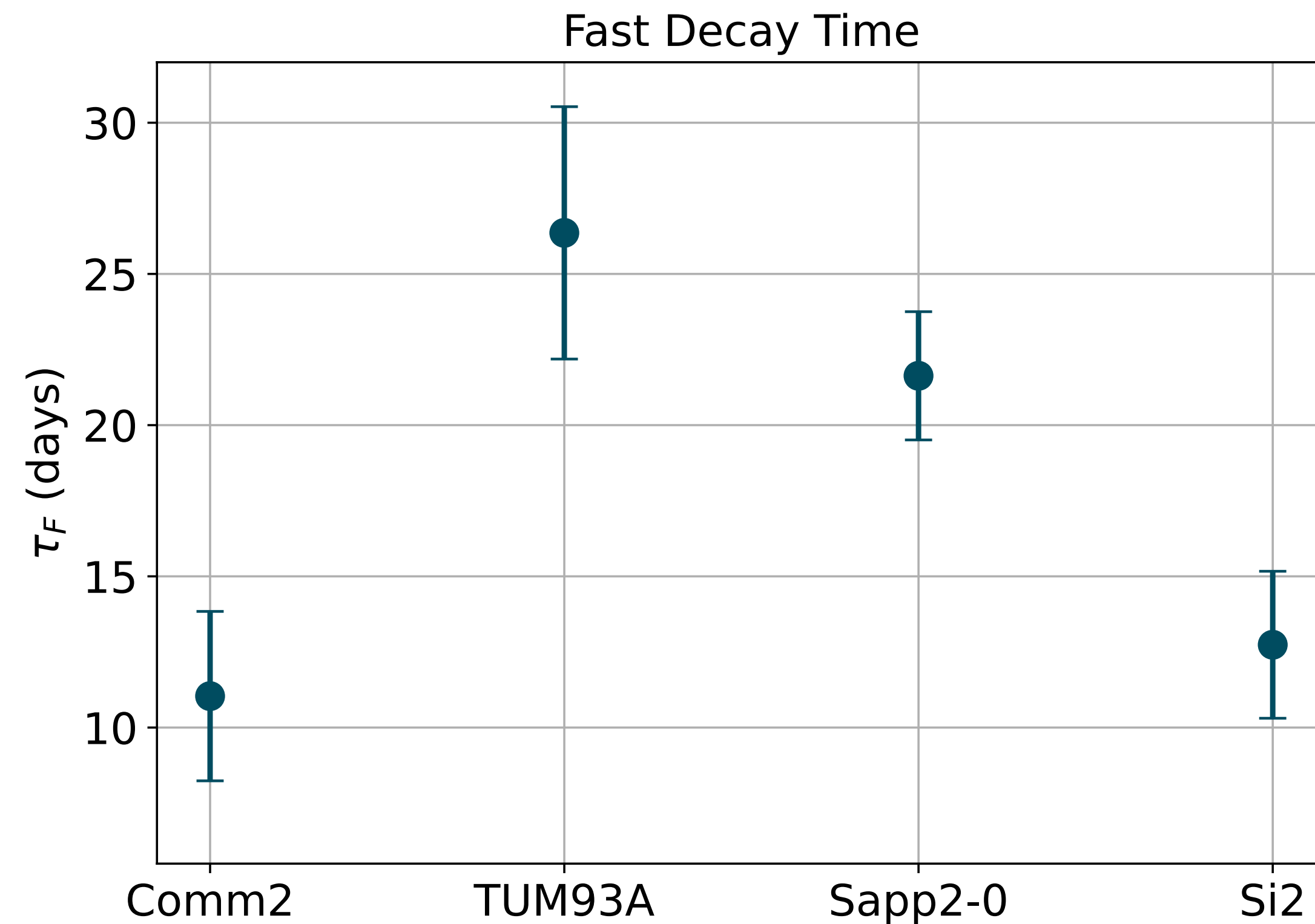
Cryogenic Rare Event Search with Superconducting Thermometers



LEE time decay

Cryogenic Rare Event Search with Superconducting Thermometers

Run36



Run37

