Alps 2024
April 1-6

Direct Dark Matter search with the CRESST-III experiment

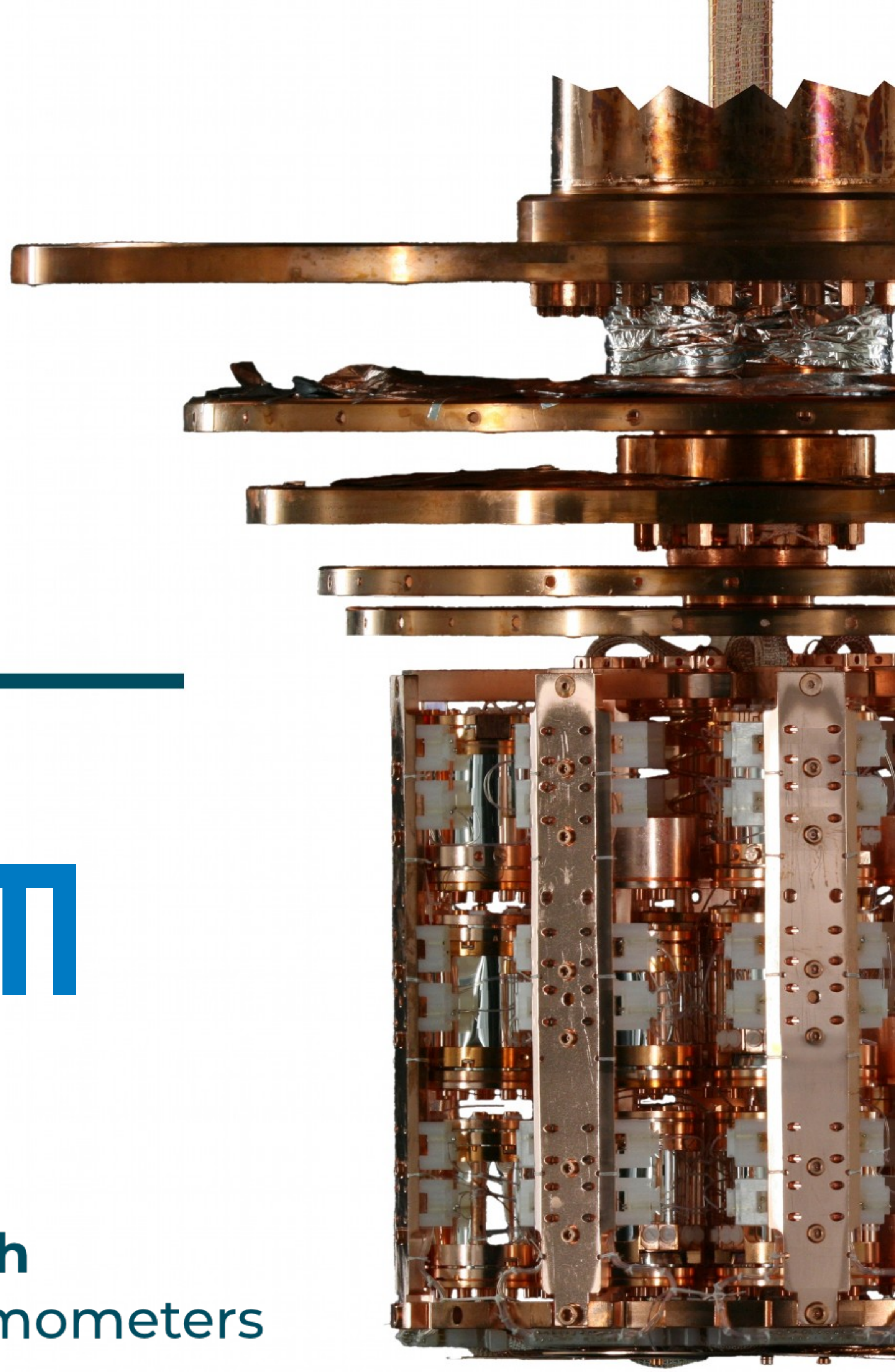
Status and prospects

Alpine Particle Physics Symposium: Dark Matter

Johannes Rothe | Technical University of Munich
johannes.rothe@tum.de
On behalf of the CRESST Collaboration

TUM

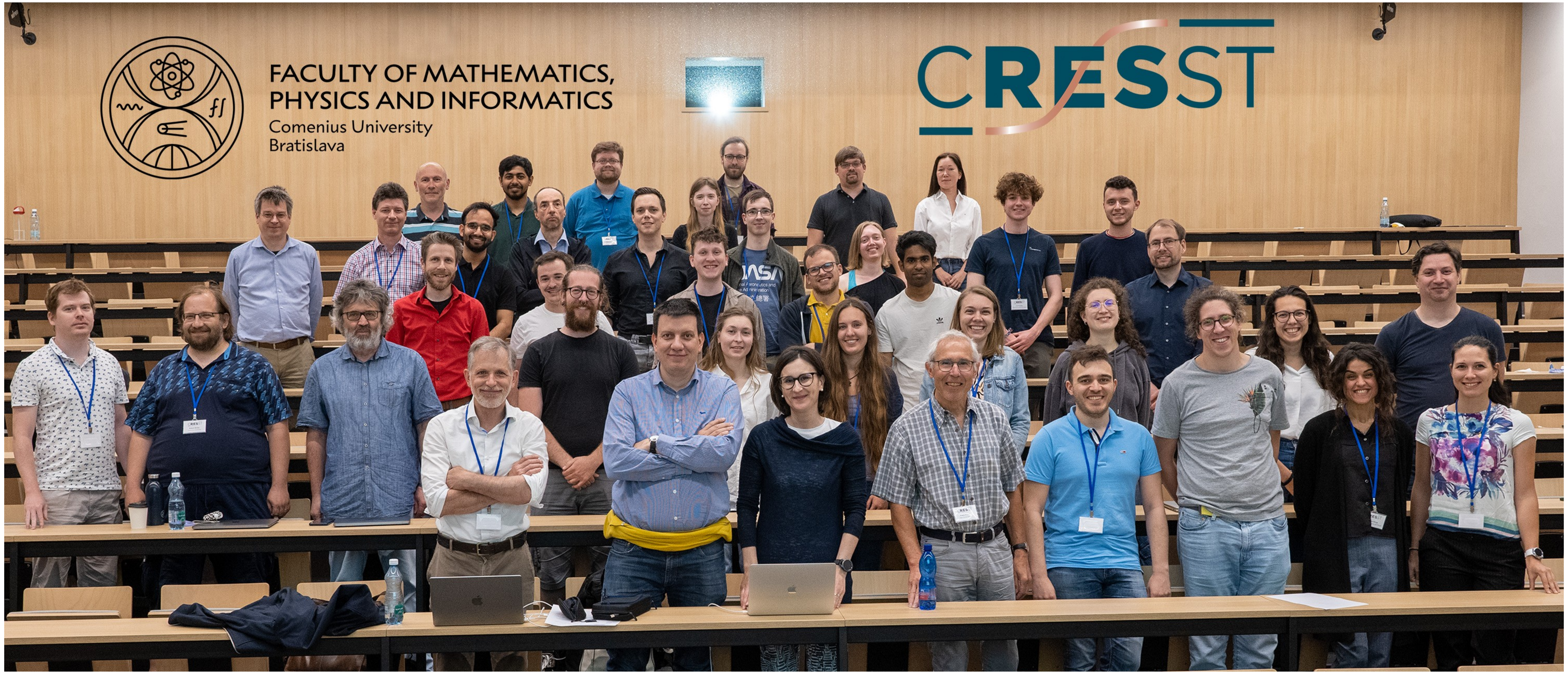
CRESST
Cryogenic **Rare Event Search** with Superconducting Thermometers



https://cresst-experiment.org

CRESST collaboration

~60 people from 8 institutions from 5 countries in Europe

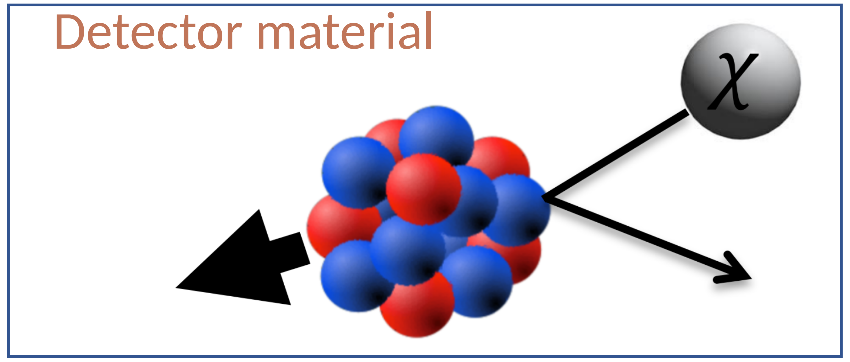


June 2023, CRESST collaboration meeting in Bratislava

TUM
MAX PLANCK INSTITUTE FOR PHYSICS
TU WIEN
HEPHY INSTITUTE OF HIGH ENERGY PHYSICS
COMENIUS UNIVERSITY BRATISLAVA
INFN LNGS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Gran Sasso
EBERHARD KARLS UNIVERSITÄT TÜBINGEN
UNIVERSITY OF OXFORD

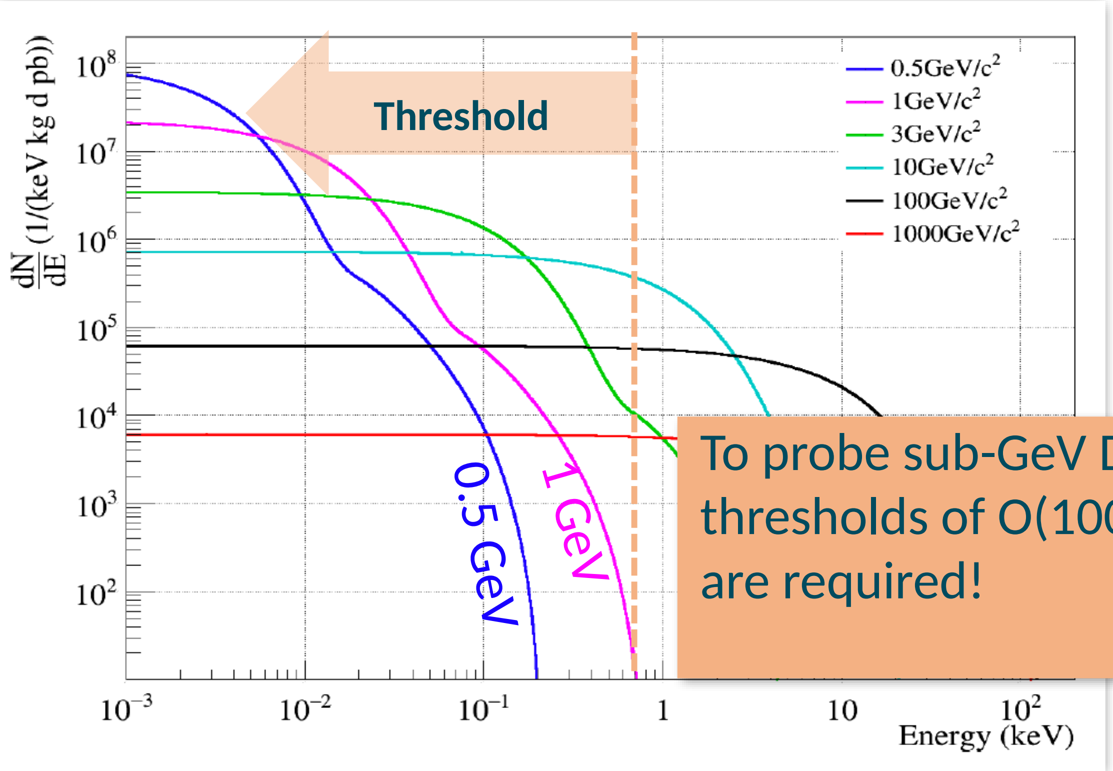
The CRESST experiment searches for sub-GeV DM particles.

Interaction:



Signal: nuclear recoil energy

Expected differential energy spectrum in CaWO4



F. Reindl (2016),PhD Thesis: http://mediatum.ub.tum.de/?id=1294132

To probe sub-GeV DM, energy thresholds of O(100 eV) and lower are required!

The CRESST experiment searches for sub-GeV DM particles.

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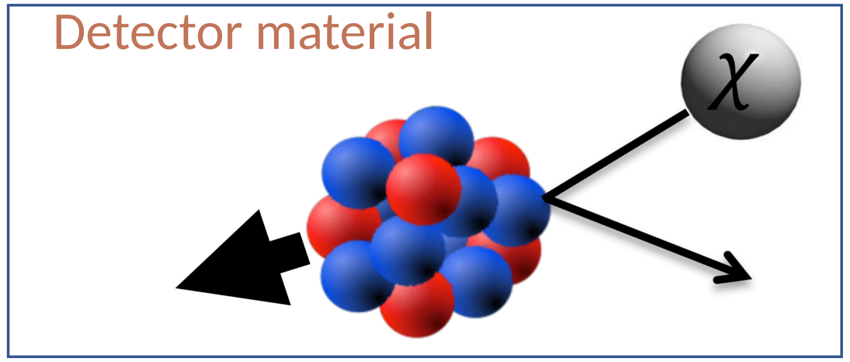

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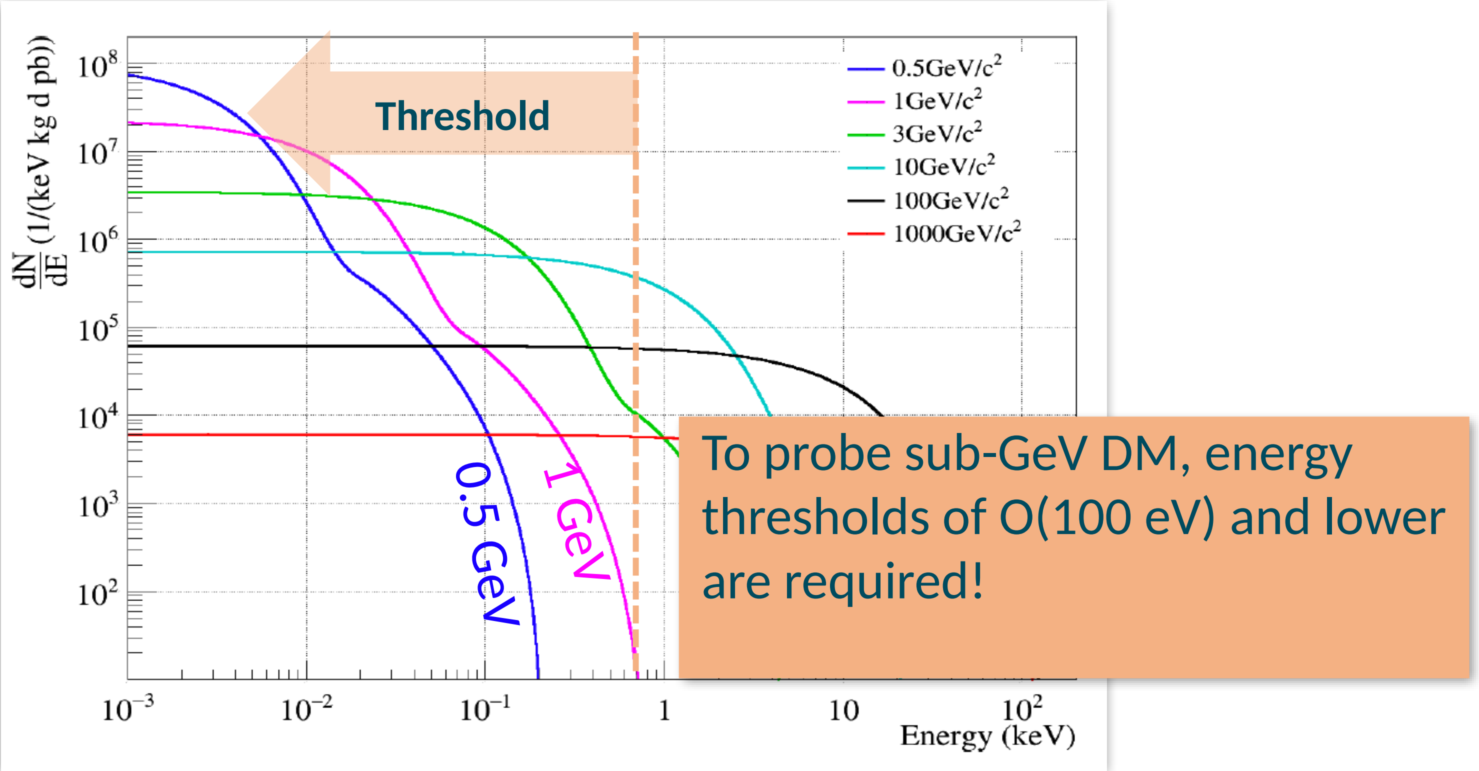
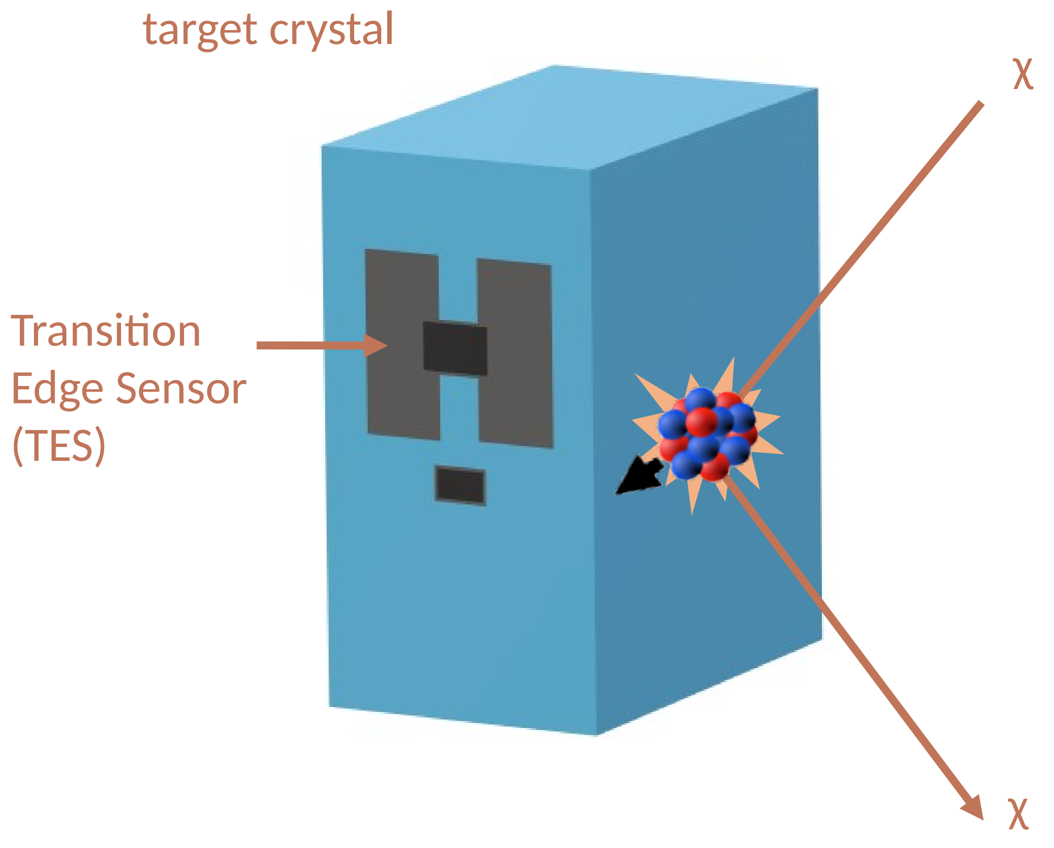


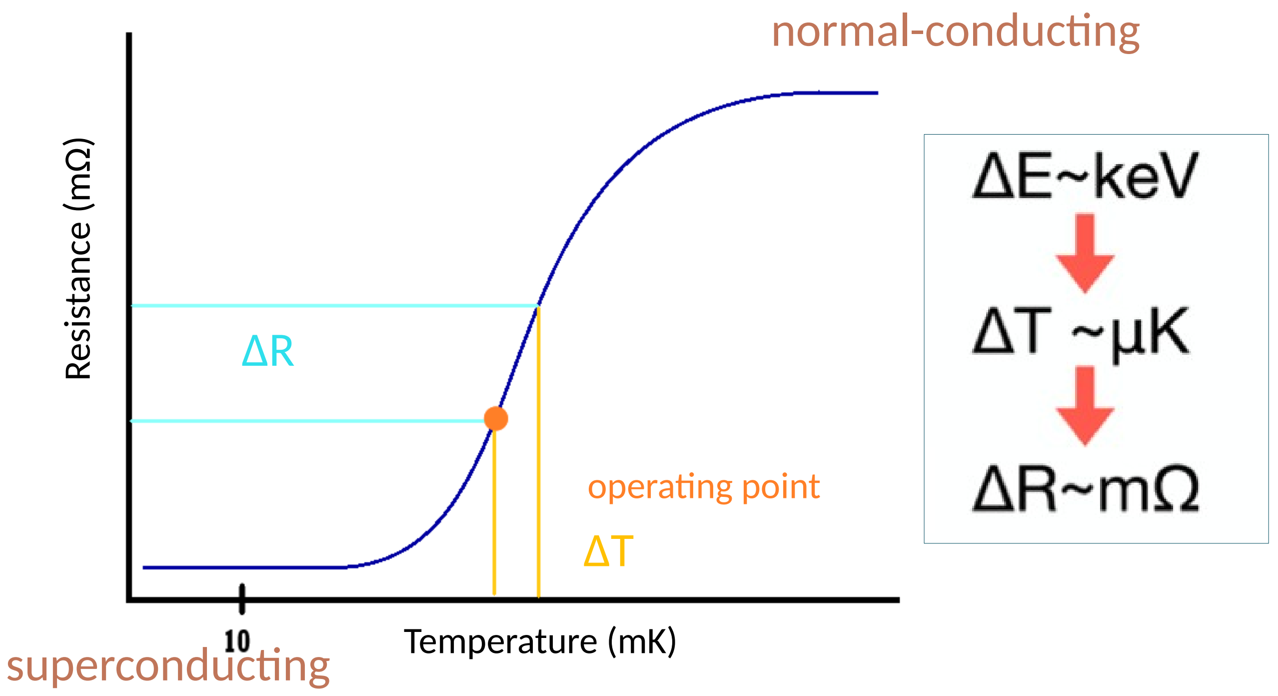
Detector:



Target: various crystal materials ($CaWO_4$, Al_2O_3, $LiAlO_2$, Si)

F. Reindl (2016),PhD Thesis: http://mediatum.ub.tum.de/?id=1294132

Small energy deposition in the crystal leads to a measurable TES resistance change.



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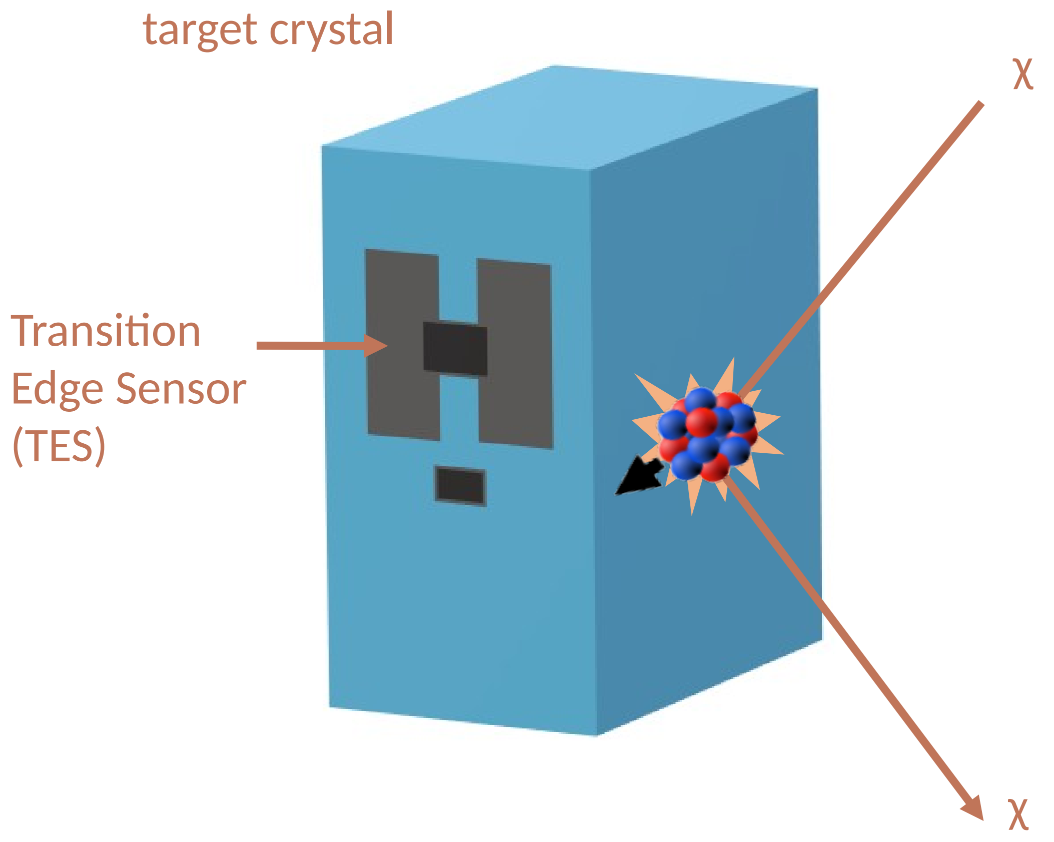

Target: various crystal materials ($CaWO_4$, Al_2O_3, $LiAlO_2$, Si)
Sensor: W-TES at 15 mK

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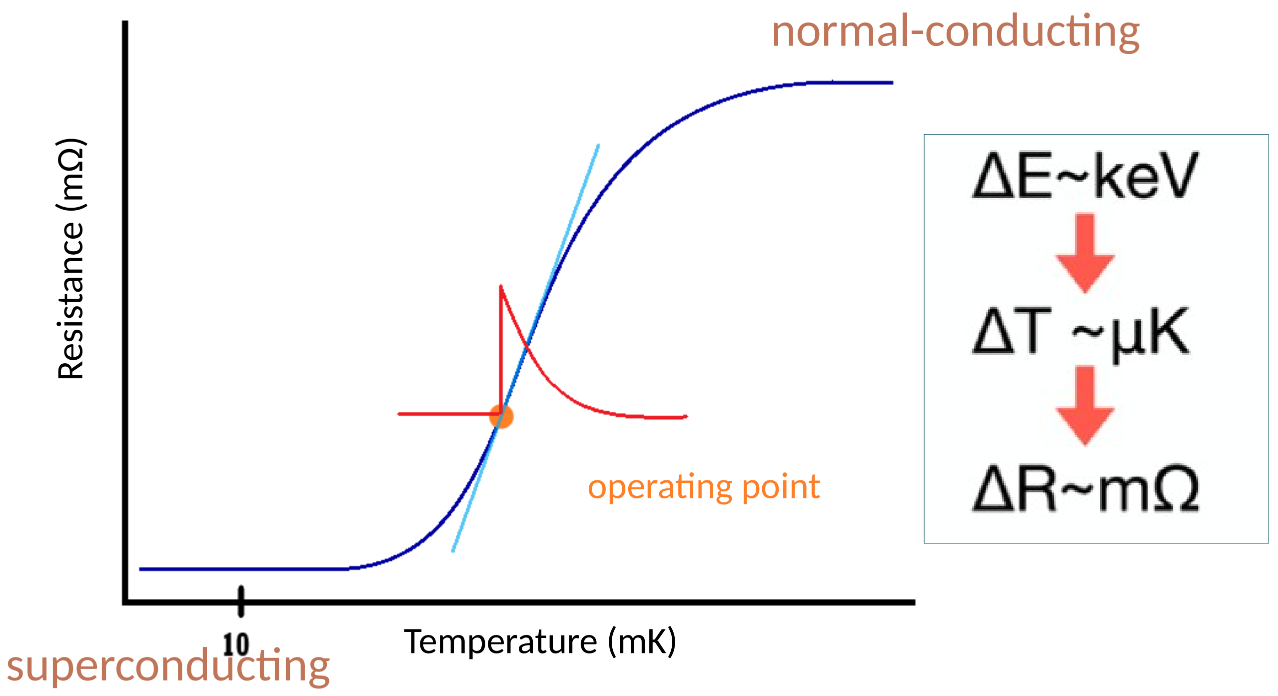

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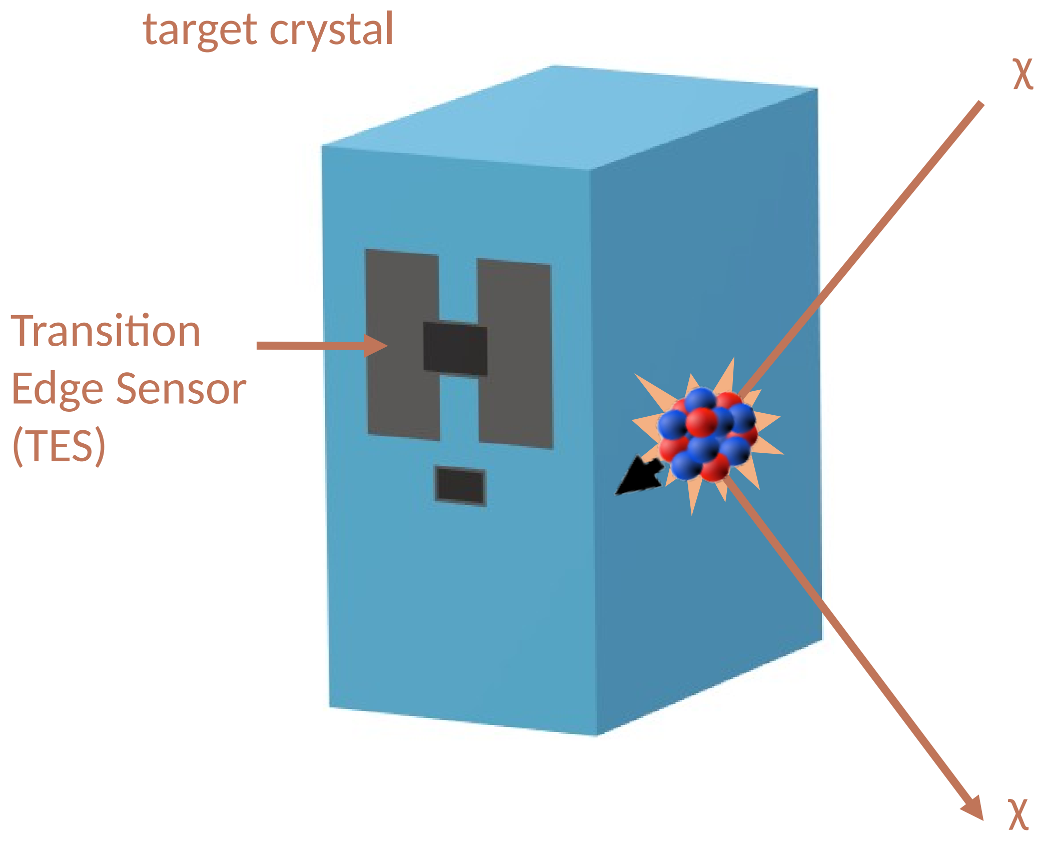
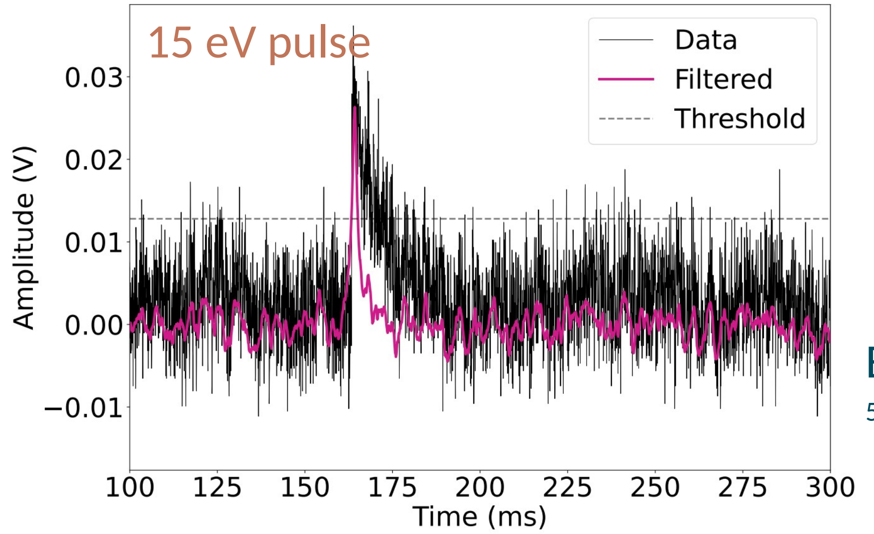




Pulse height is a measure of energy deposition.

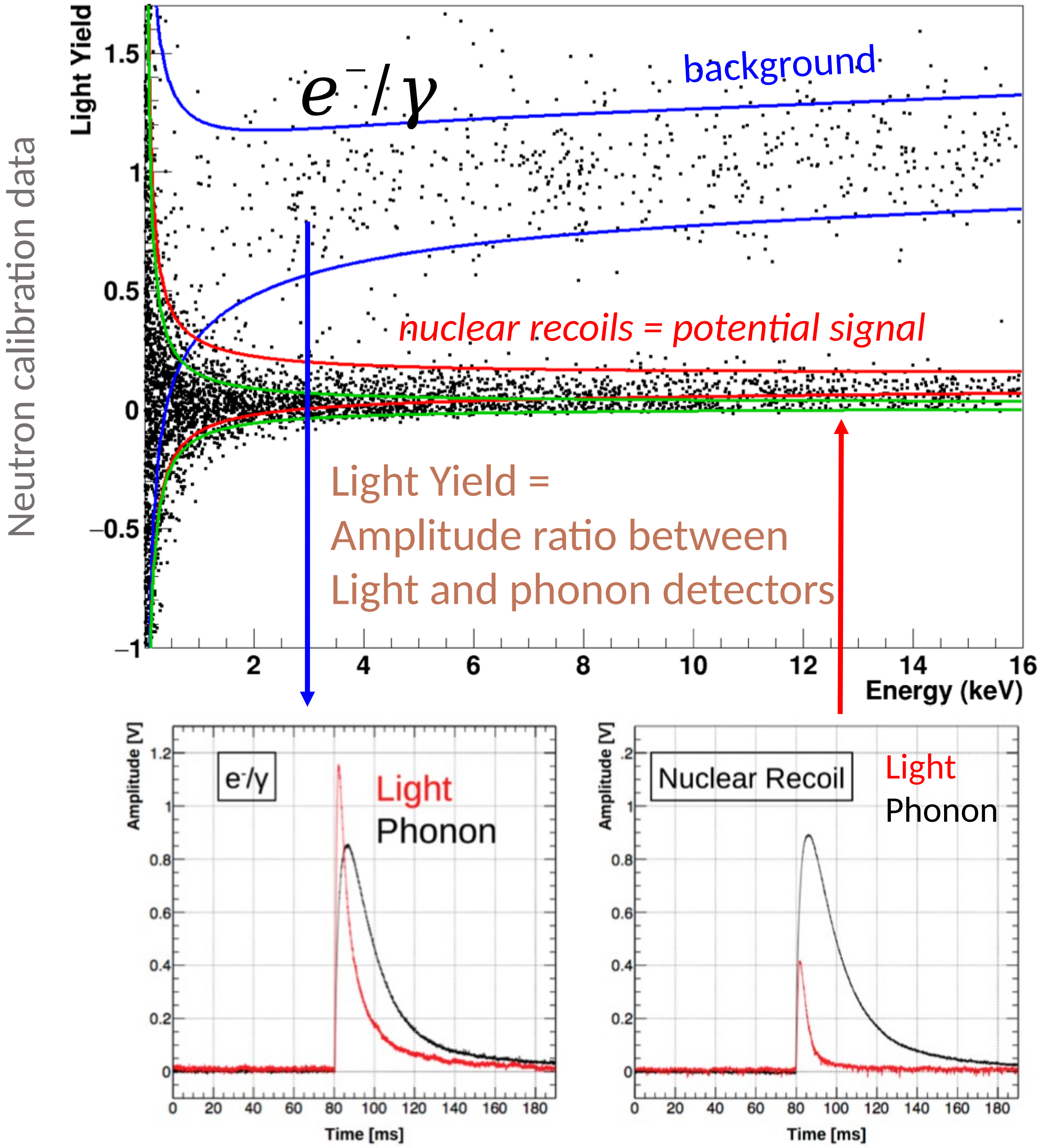
Energy calibration with X-rays from a ^{55}Fe source@6 keV

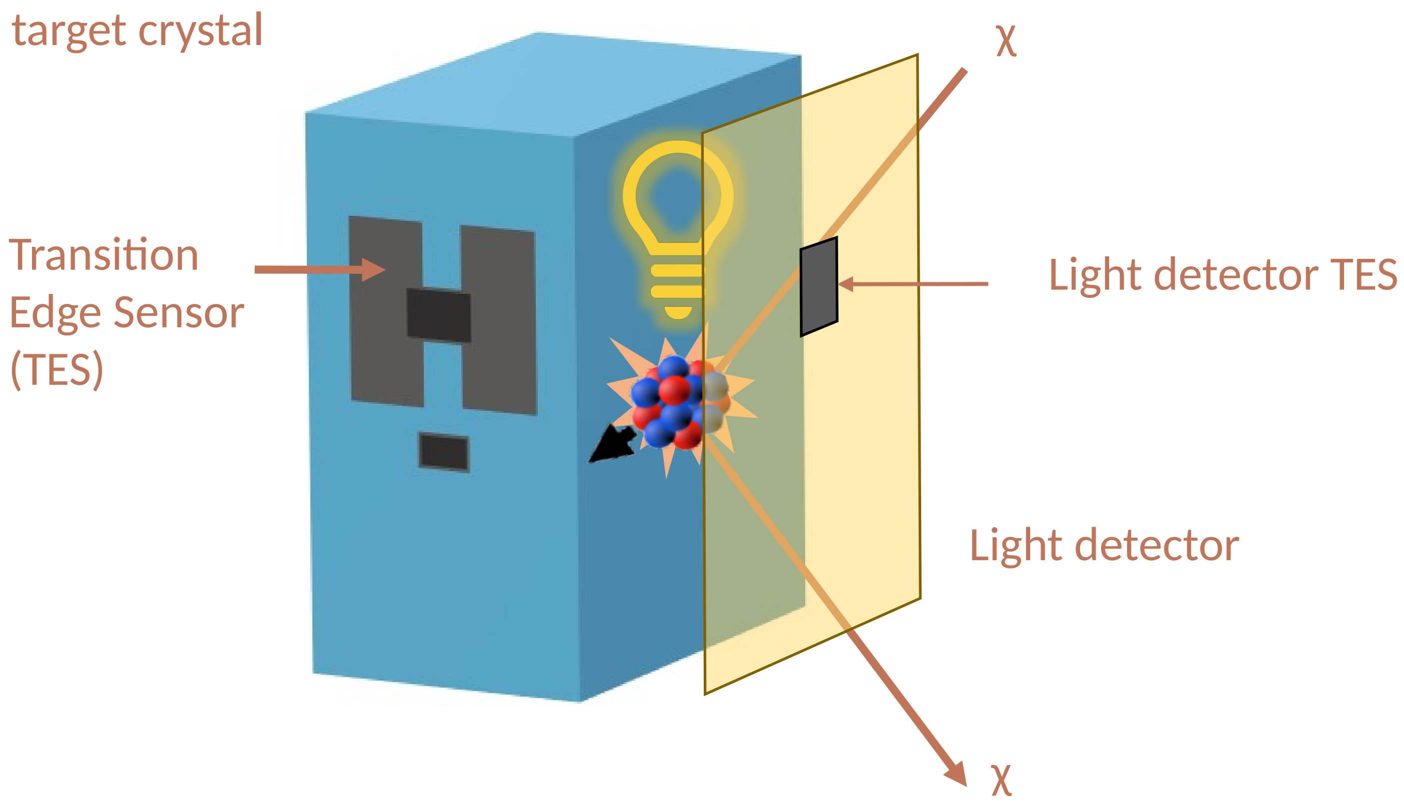
Target: various crystal materials ($CaWO_4$, Al_2O_3, $LiAlO_2$, Si)

Sensor: W-TES at 15 mK

Energy threshold of O(10 eV)

Additional light signal allows to discriminate electron and nuclear recoils to reduce background signal.





For scintillating target materials (e.g.$CaWO_4$), a small part of the deposited energy is released as ***light.***

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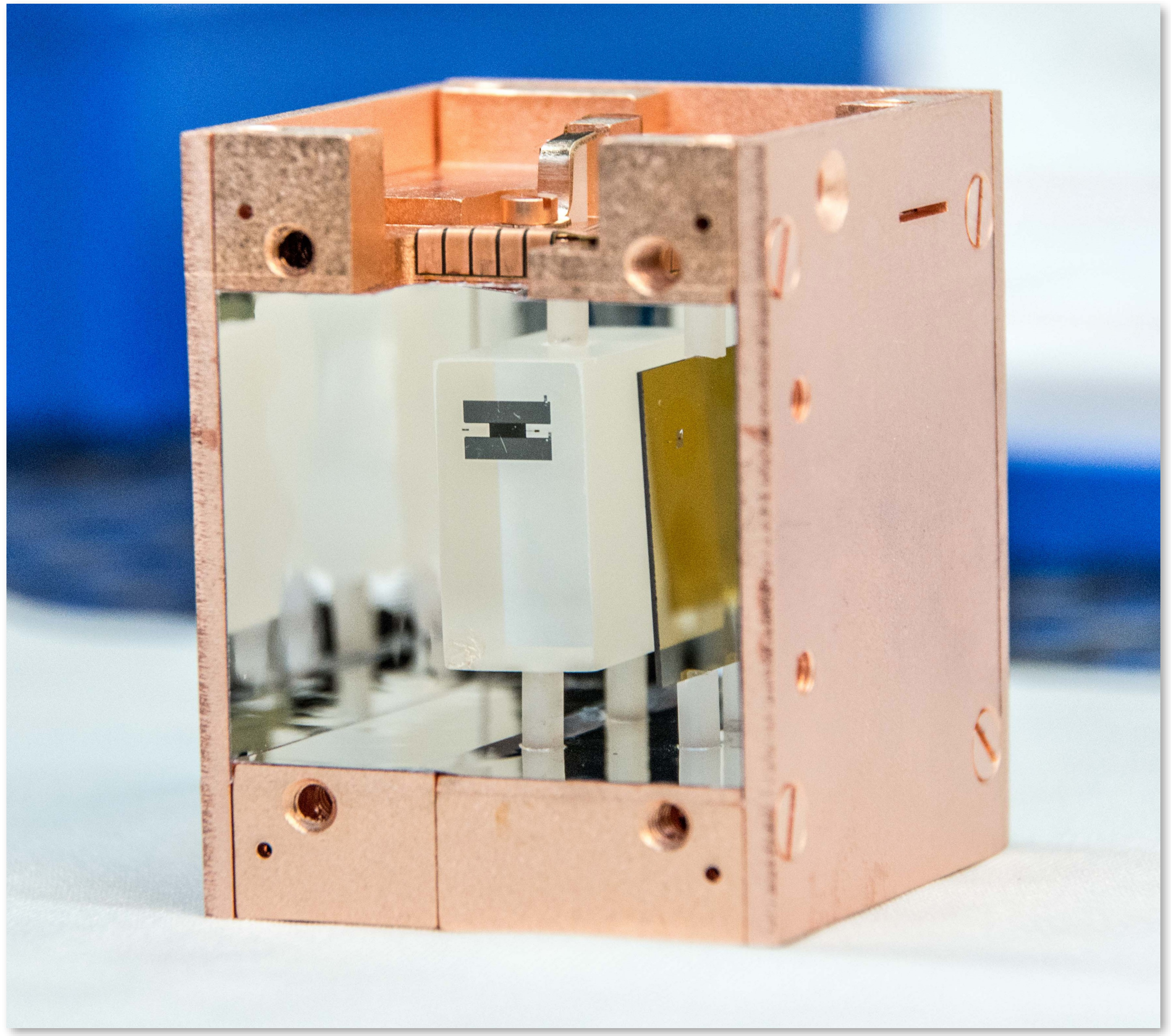
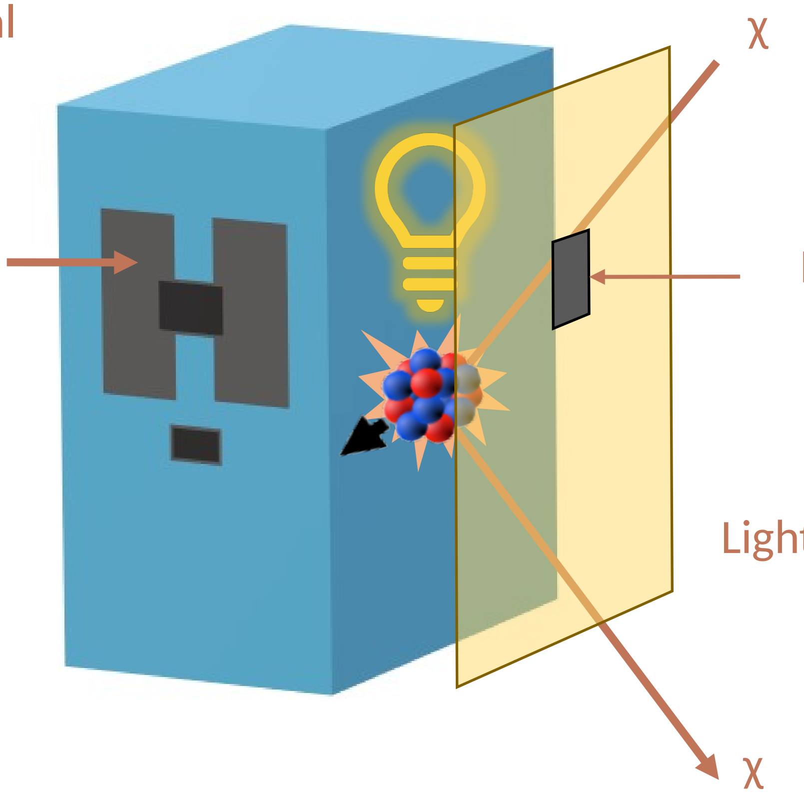
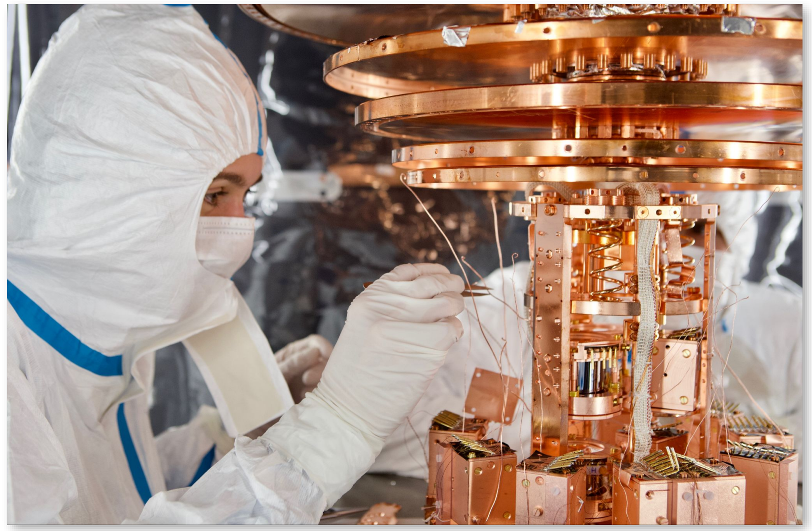
CRESST-III detector module

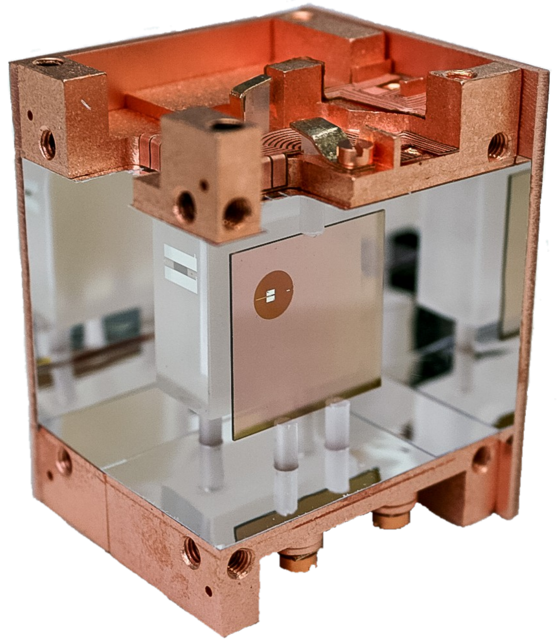




For scintillating target materials (e.g.$CaWO_4$), a small part of the deposited energy is released as ***light.***

The CRESST experiment is located in the deep underground laboratory LNGS in Italy that provides excellent shielding against cosmic radiation.

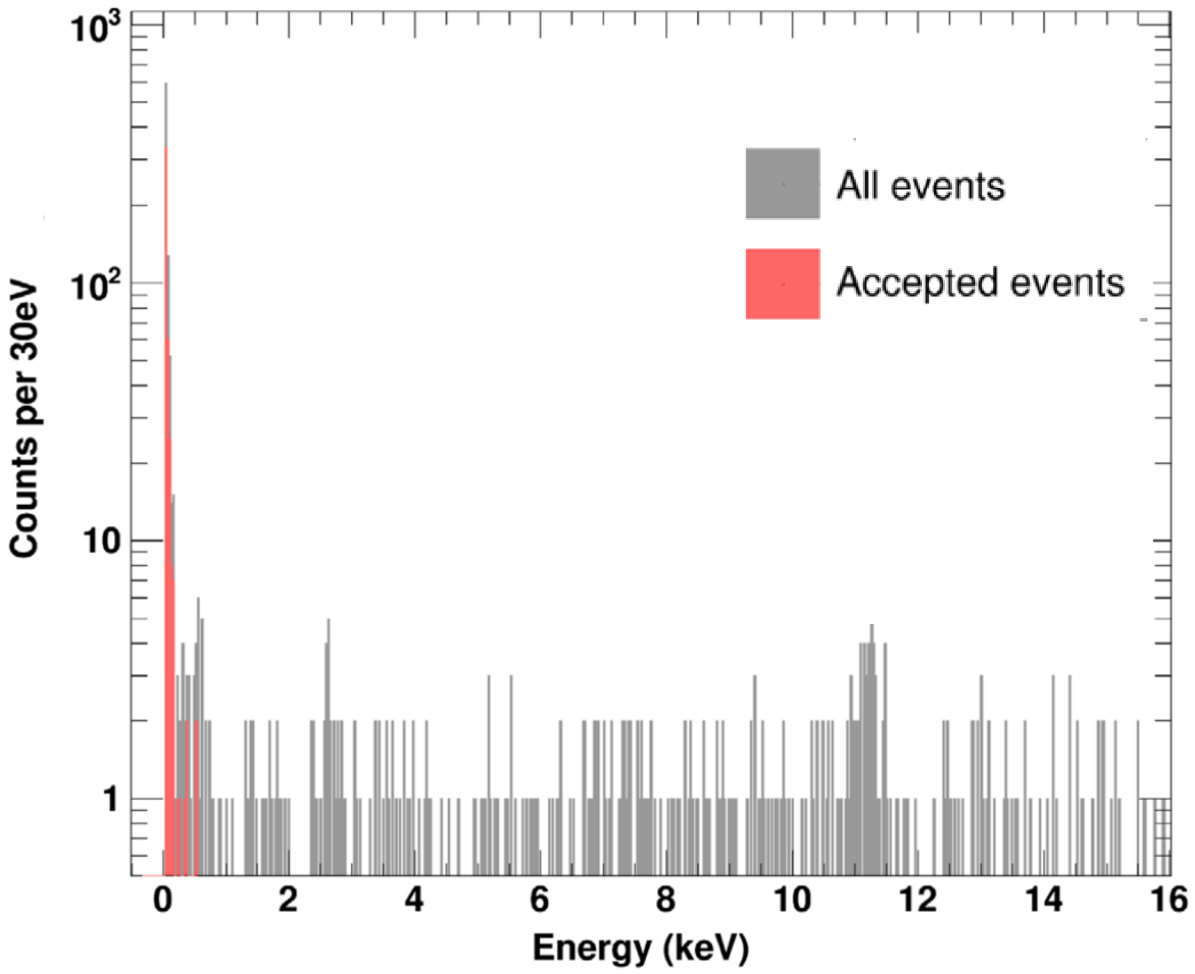


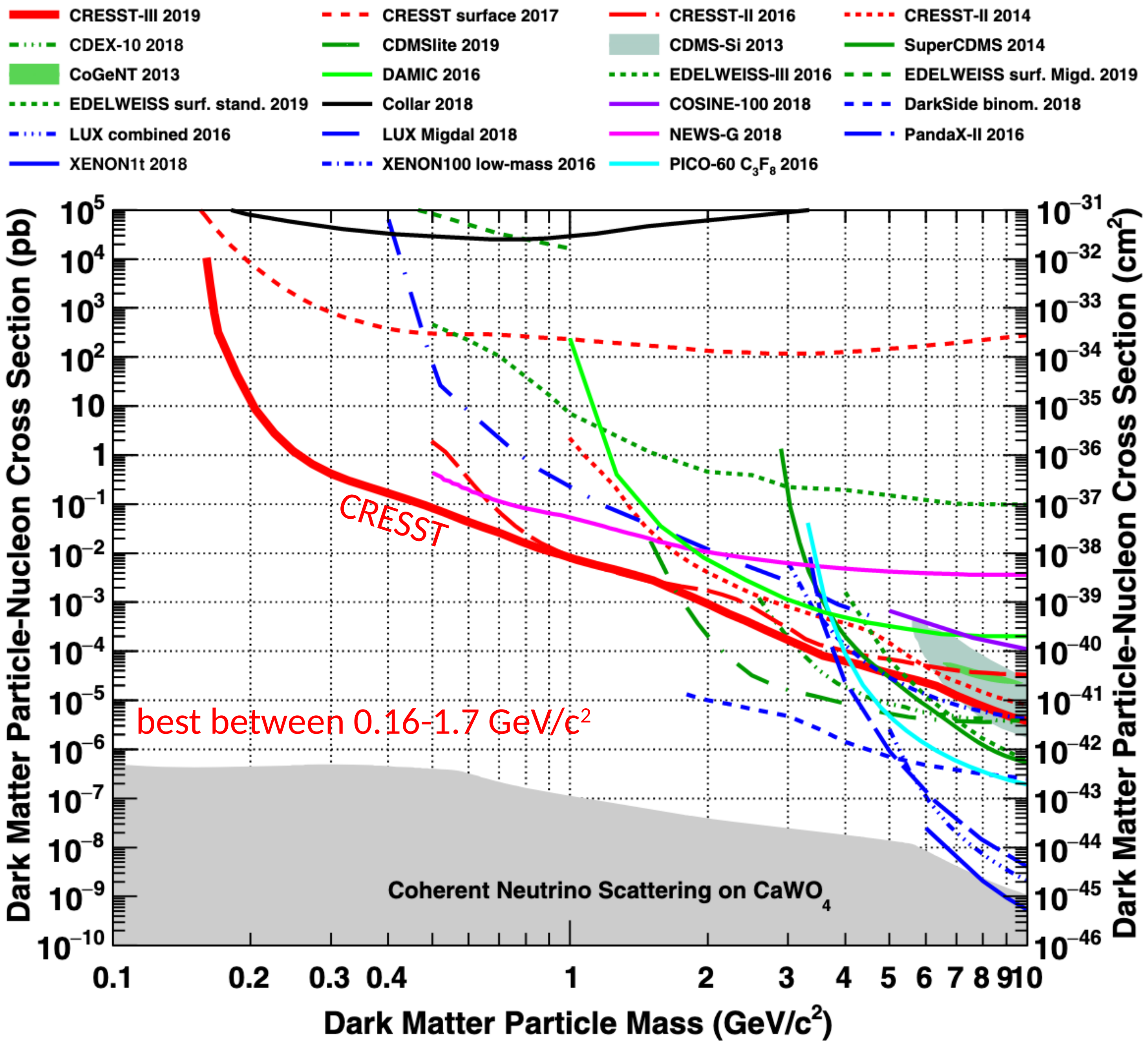


First results from CRESST-III (2019): leading limit for sub-GeV DM with a **30 eV** energy threshold detector.

Detector A: 23.6 g CaWO4
Data-taking period: Oct 2016 – Jan 2018

Exposure: 5.698 kg · days
Energy threshold: **30.1 eV**





Phys. Rev. D 100, 102002 (2019) / arXiv:1904.00498

Sharply rising energy spectrum below 200 eV - **low energy excess (LEE)** - is observed in CRESST-III detectors and limits the sensitivity to sub-GeV DM.

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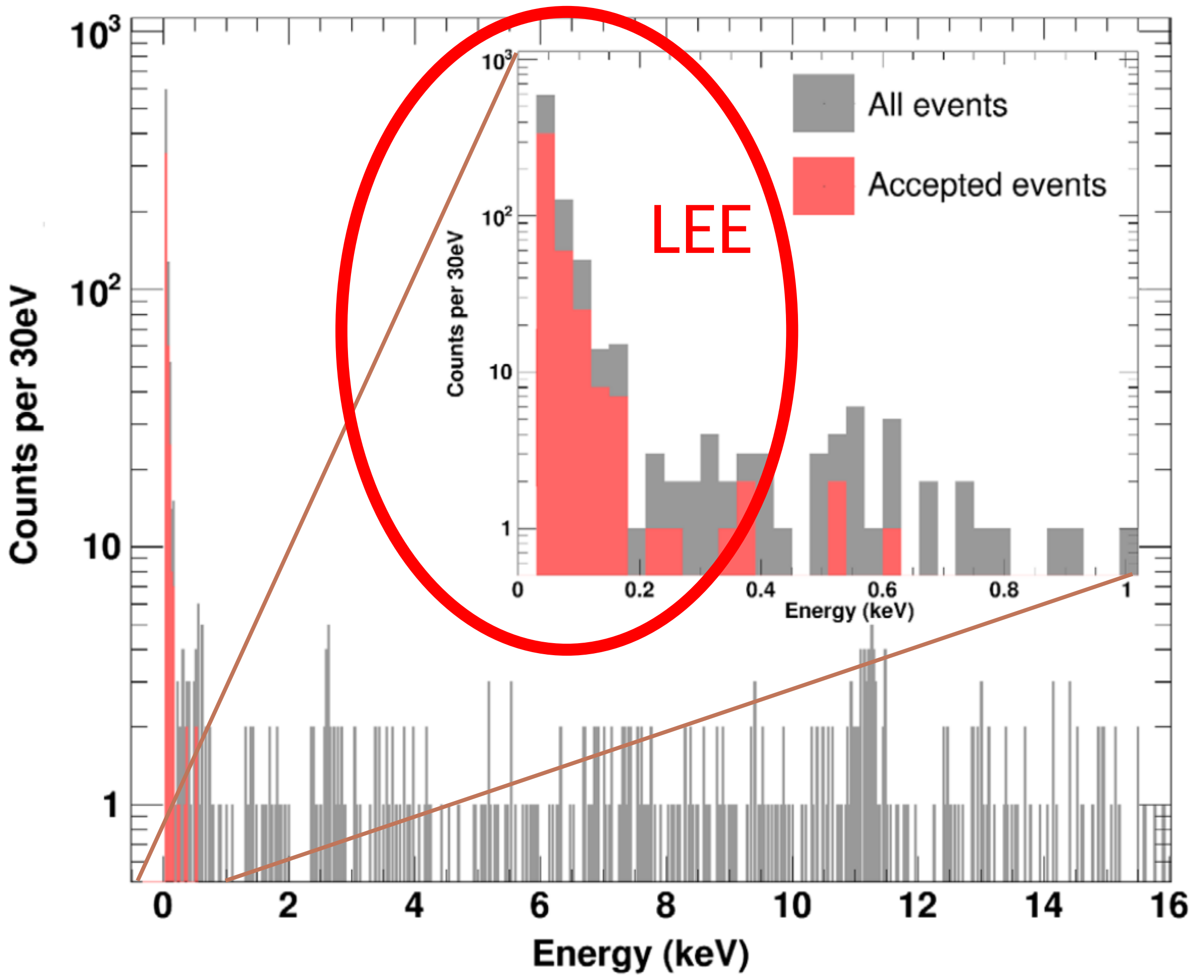

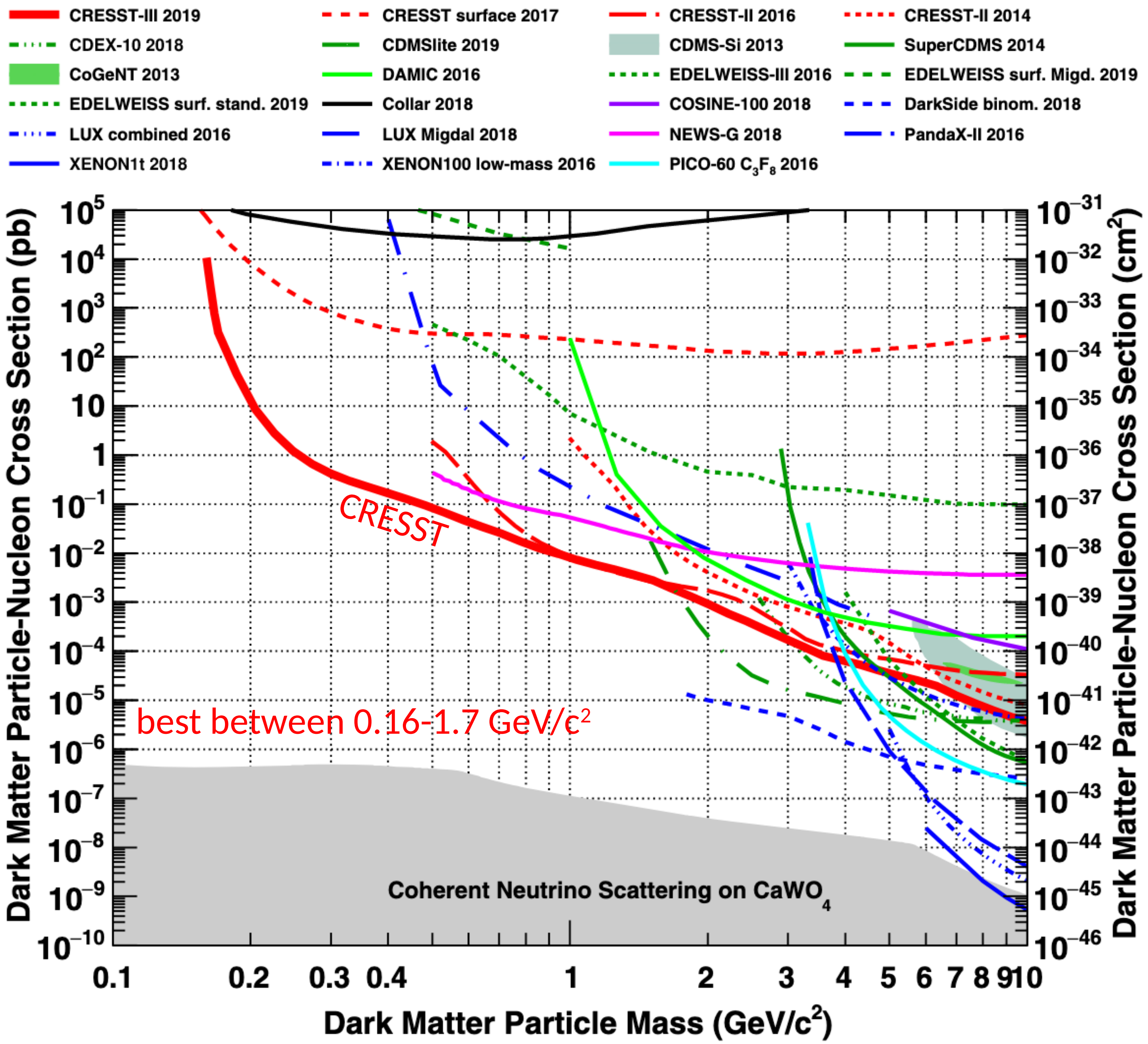

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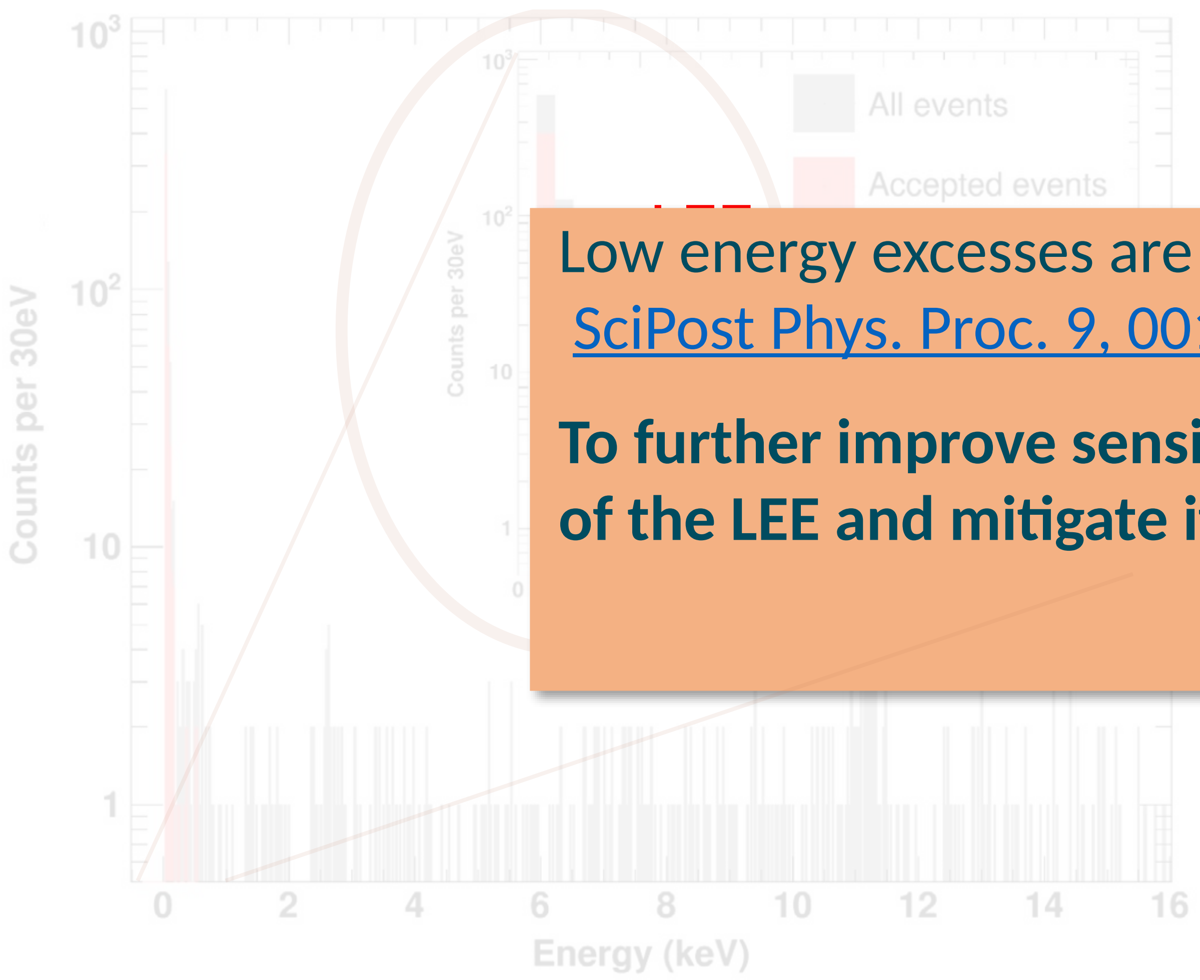
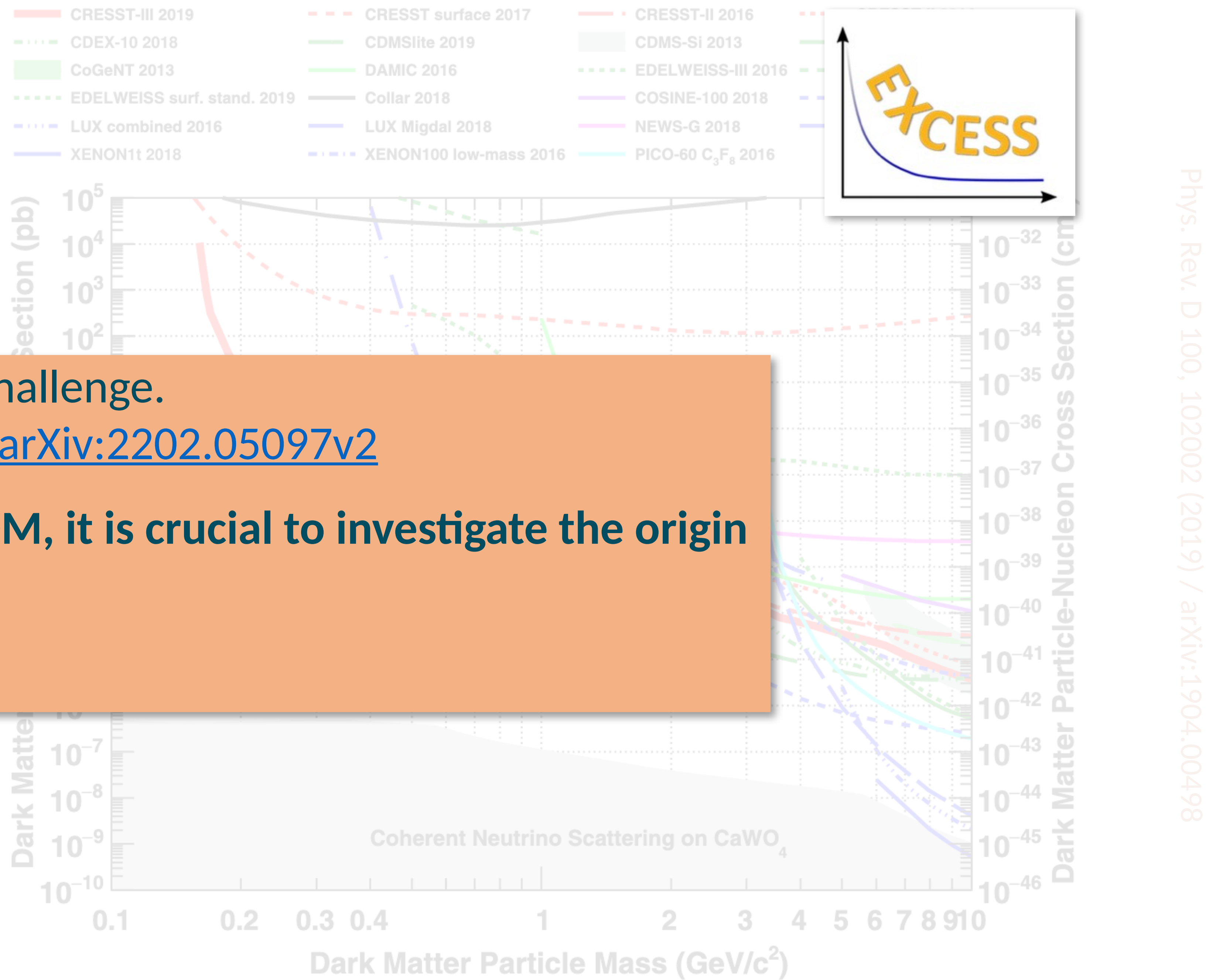


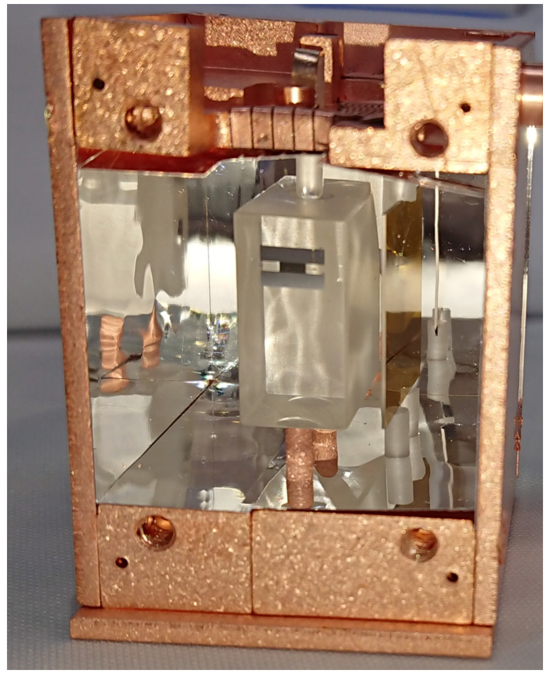


Low energy excesses are a global challenge.
[SciPost Phys. Proc. 9, 001 (2022)] / [arXiv:2202.05097v2]

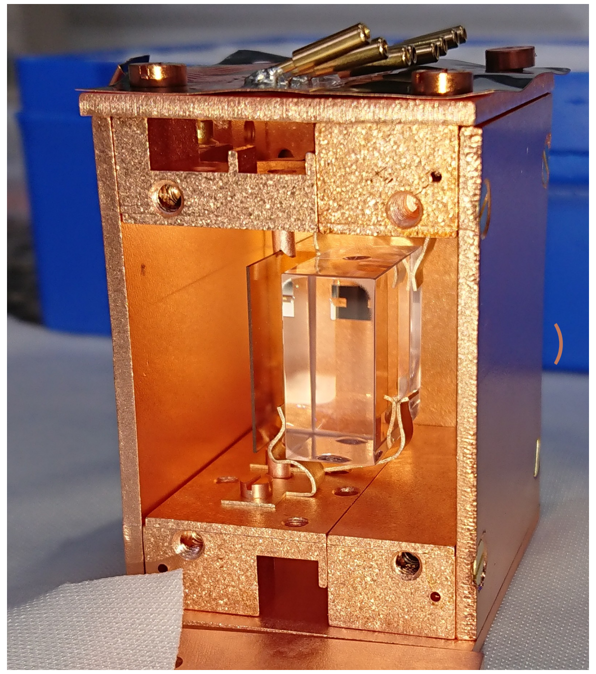
To further improve sensitivity to DM, it is crucial to investigate the origin of the LEE and mitigate its effects!

Multiple design modifications were applied in the most-recent data-taking campaign to test ideas about the LEE origin.

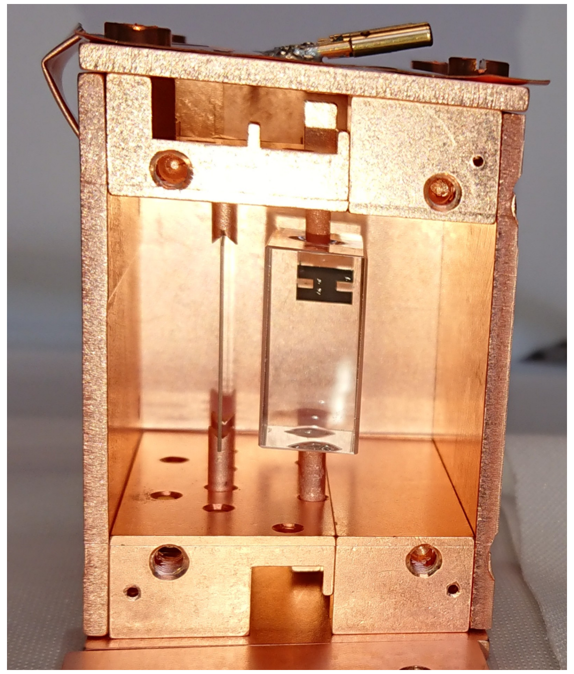
SciPost Phys. Proc. 12, 013 (2023) / arXiv:2207.09375



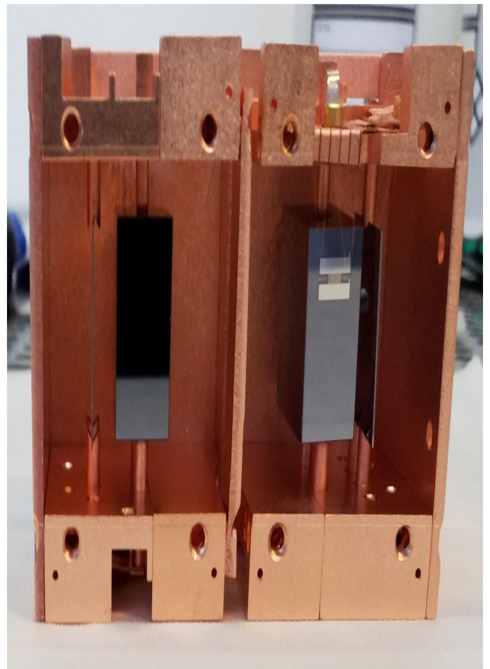
$CaWO_4$ grown at TUM



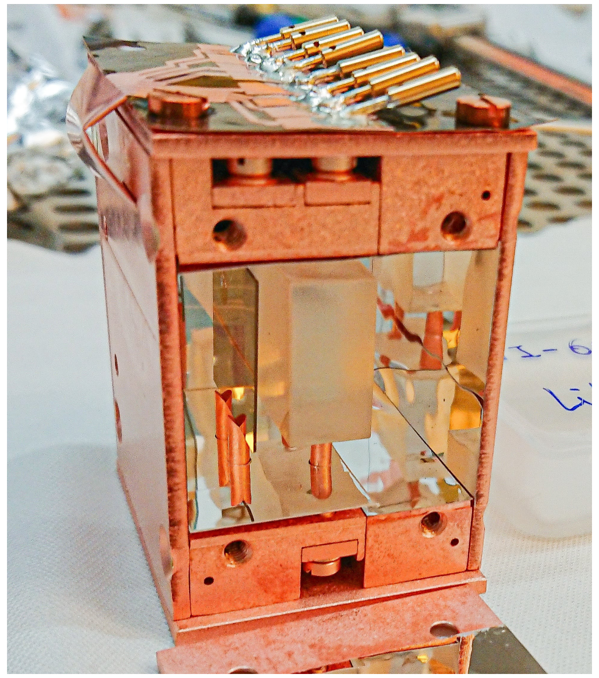
Commercially grown $CaWO_4$



Al_2O_3



Si



$LiAlO_2$

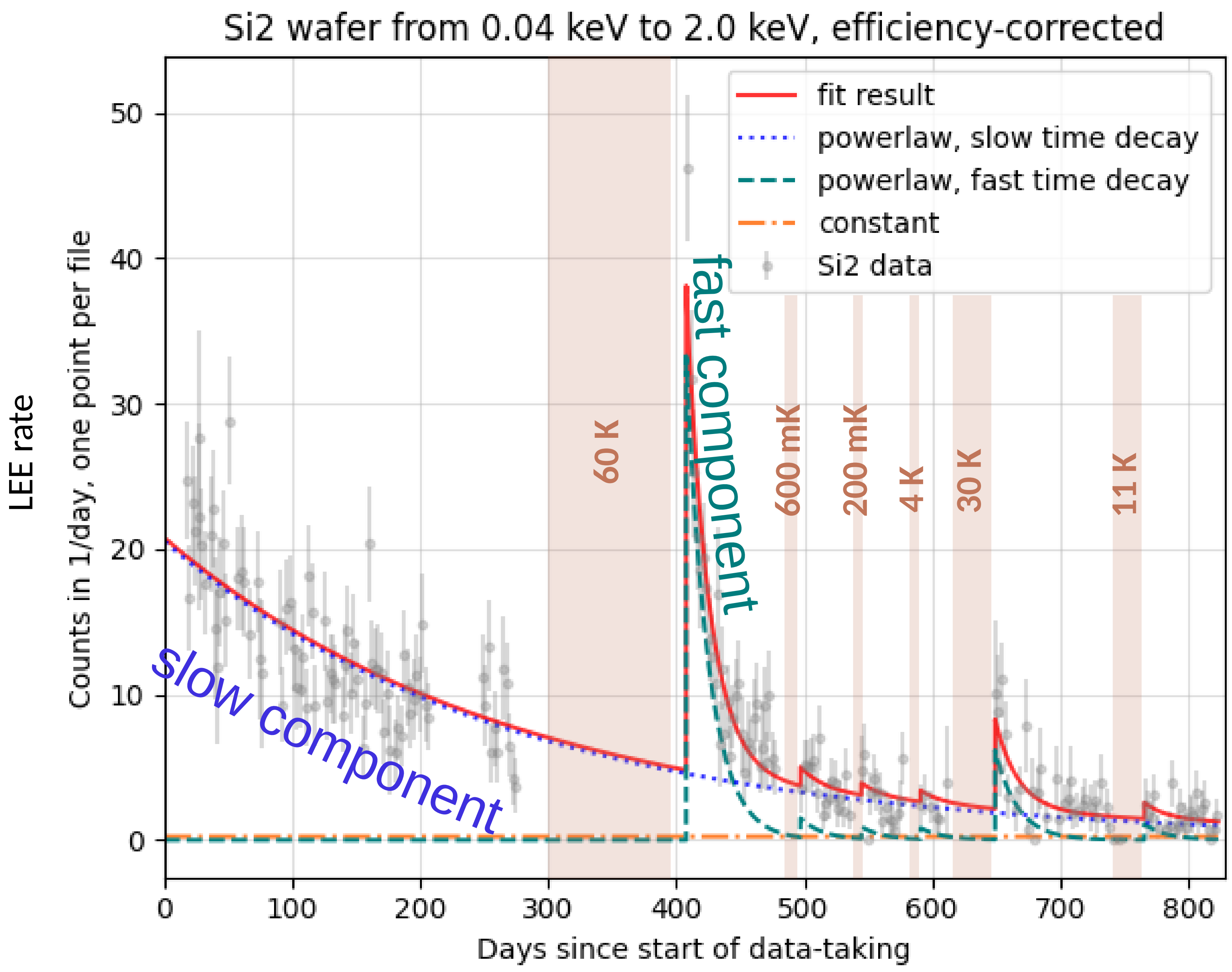
Recent measurement campaign started in November 2020 and was completed in February 2024.

- Various target materials: $CaWO_4$, Al_2O_3, $LiAlO_2$, Si
- Different holding structures (sticks, clamps)
- Remove scintillating parts (foil, sticks, scintillating crystals)

All thresholds are at O(10 eV)

LEE is observed in all detectors

LEE rate is decaying with time.
Excess rate increases after warming up the cryostat to O(10K).

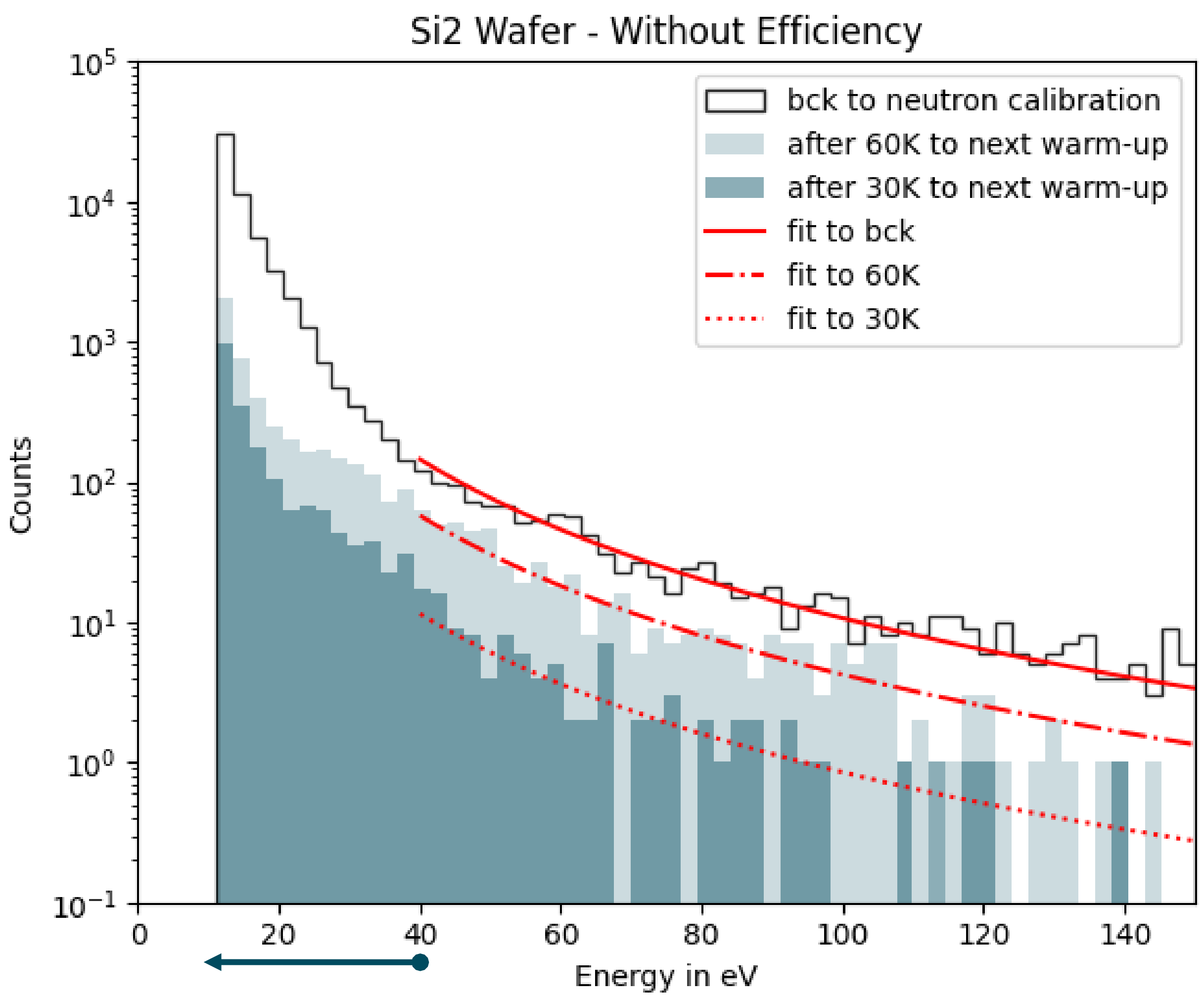


1. Continuous decaying trend since the start of the data taking O(100 days)
→ **slow component**

2. An additional component of about 15 days appears after warming up to O(10K)
→ **fast component**

Rate increase after warm-ups excludes external and internal radioactivity as well as DM as a major origin of the LEE.

For all detectors, **spectral shape above 40 eV**:
- is well described by a single power law
- has two time components.



Extension of the model is needed at lower energies <40 eV.

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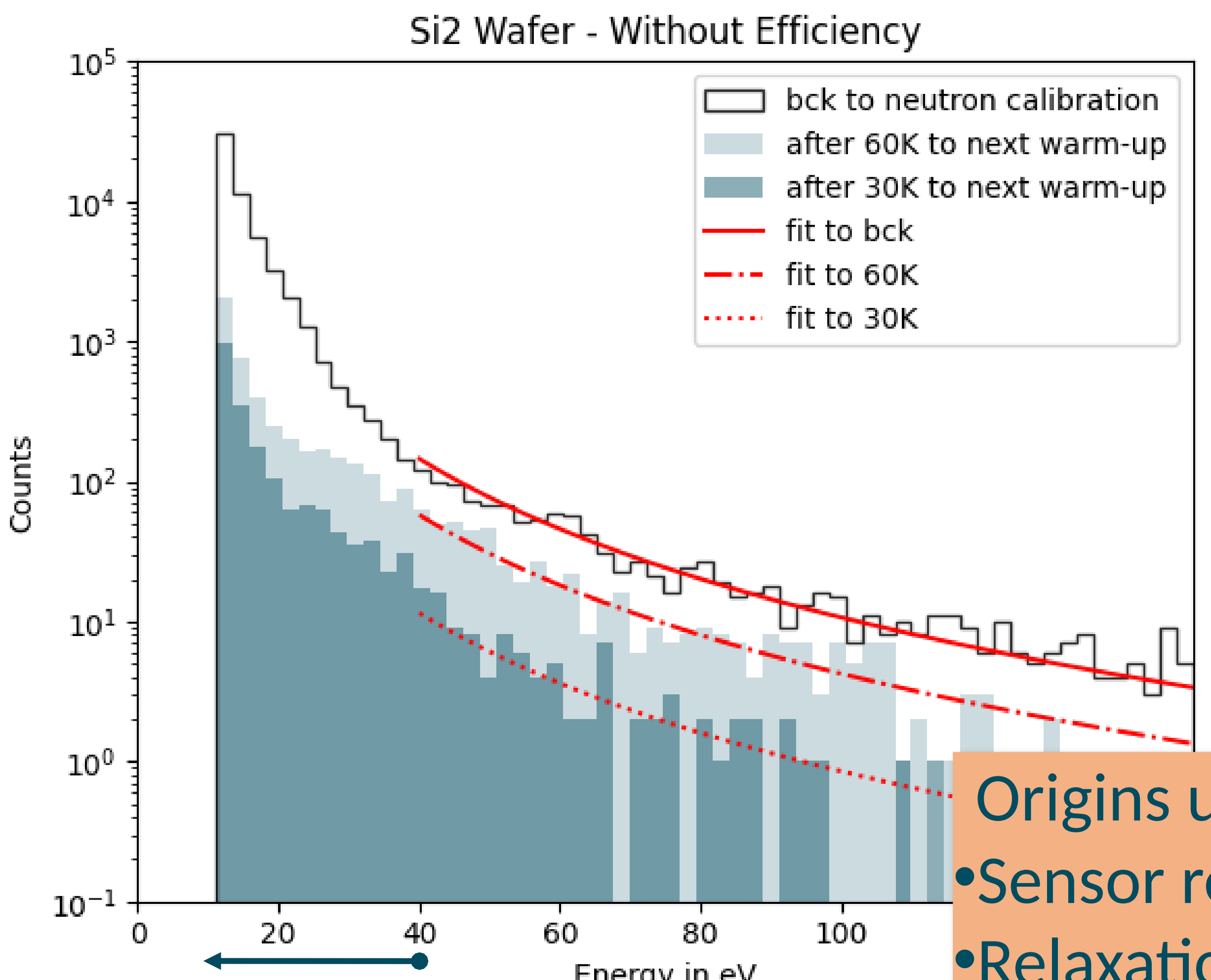
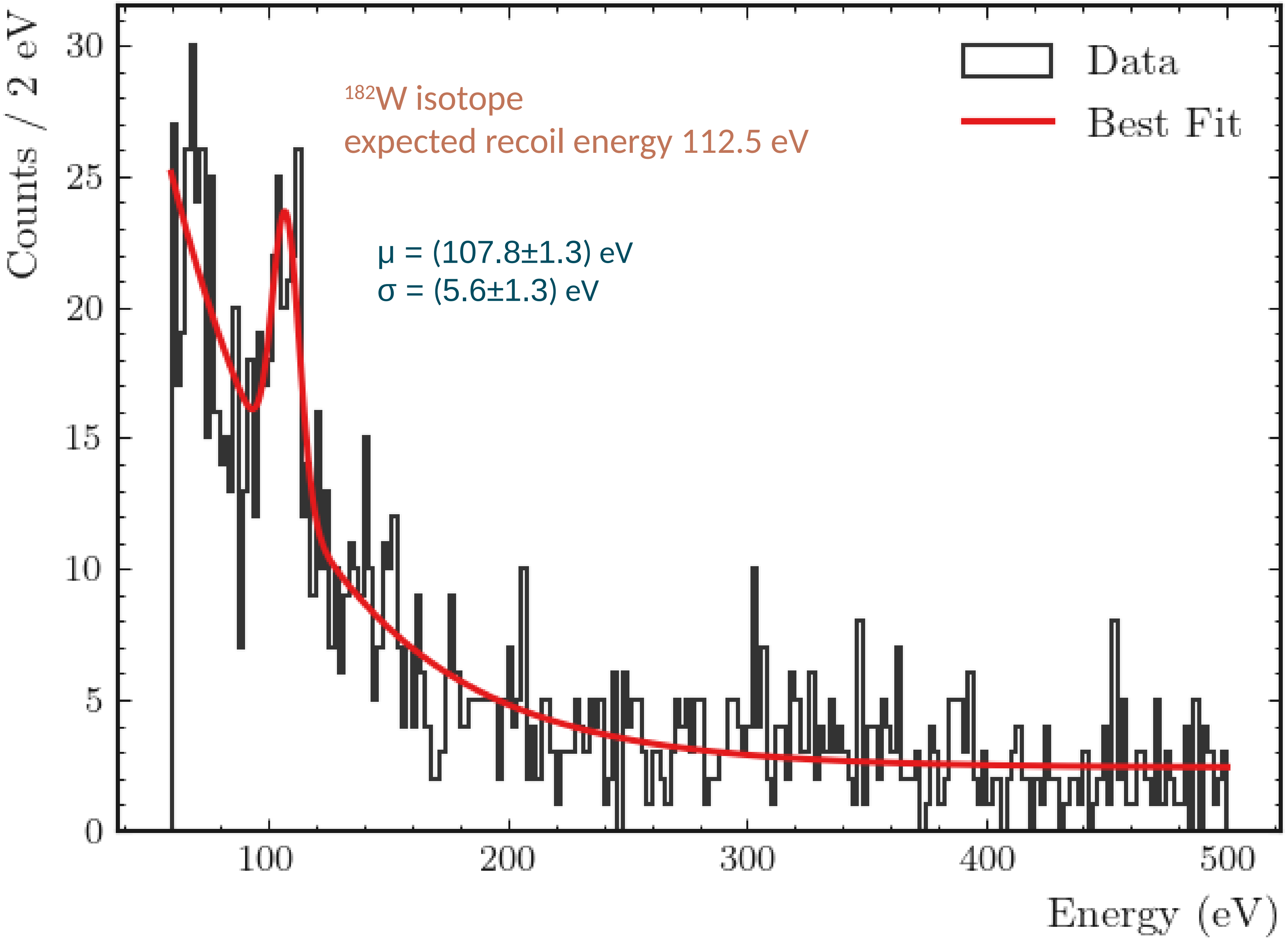


Extension of the model is needed at lower energies <40 eV.

Origins under investigation:
- Sensor related events
- Relaxation of holding-induced stress
- Intrinsic crystal effects

Observation of a mono-energetic nuclear recoil peak at **112 eV** in three CRESST-III $CaWO_4$ detectors -> **new calibration technique**

Neutron calibration data (AmBe source)



Thermal neutron capture

→ de-excitation with a single γ

→ mono-energetic nuclear recoil

Proposed as a low-energy calibration method for cryogenic detectors (CRAB collaboration).

L. Thulliez *et al* 2021 *JINST* 16 P07032 /

Observation of the nuclear recoil peaks around the predicted value in multiple detectors

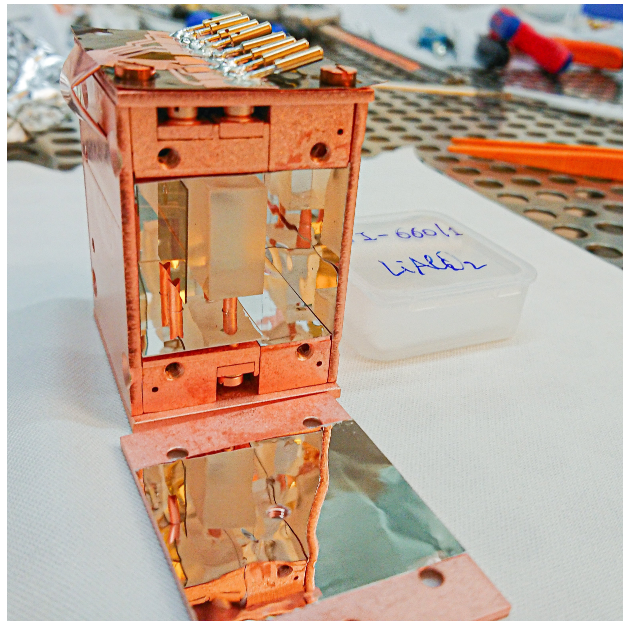
1. confirms CRESST energy calibration approach,
2. provides a potential for **precise energy calibration for nuclear recoils at 100 eV scale**.

Phys. Rev. D **108**, 022005 / arXiv:2303.15315

DM results with different target materials

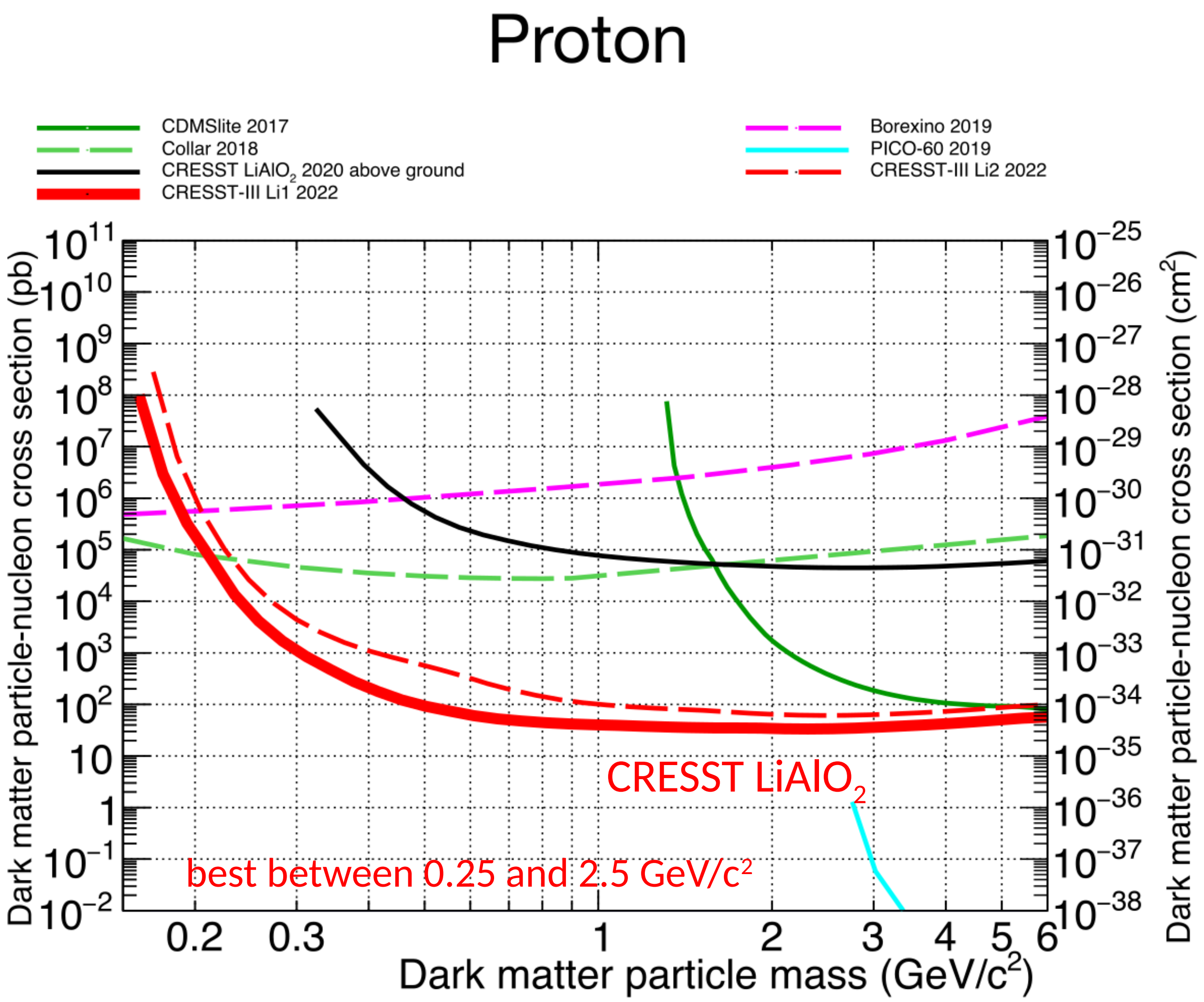
Well performing $LiAlO_2$ detector allowed to greatly improve the limits for **spin-dependent** DM-nucleon interactions.

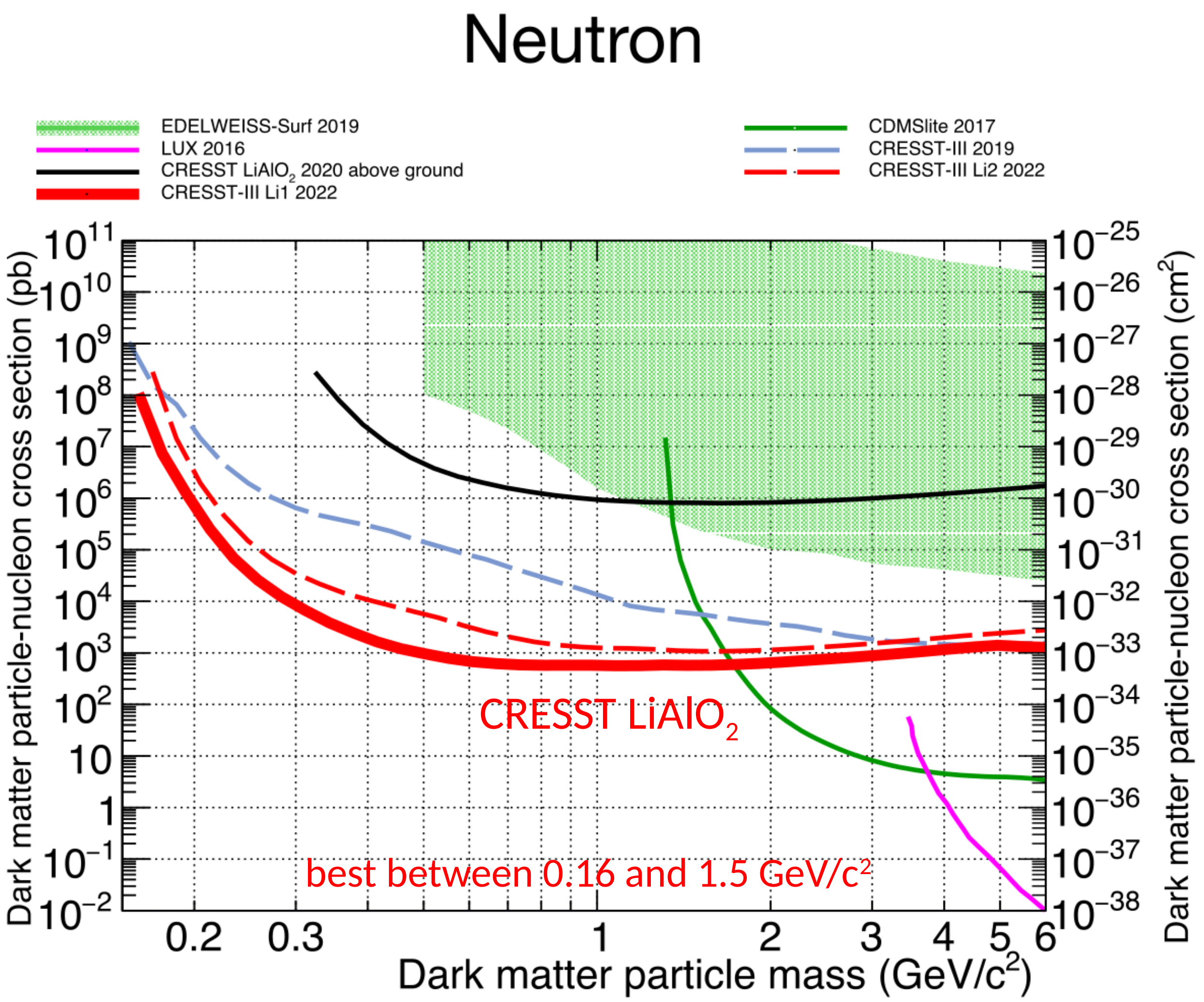
Phys. Rev. D 106, 092008 / arXiv:2207.07640



Li1 detector: 10.5 g LiAlO2
Data-taking period: Feb 2021 – Aug 2021

Exposure: 1.161 kg · days
Energy threshold: 83.6 eV





CRESST technique allows to use various target materials to test different interaction channels!

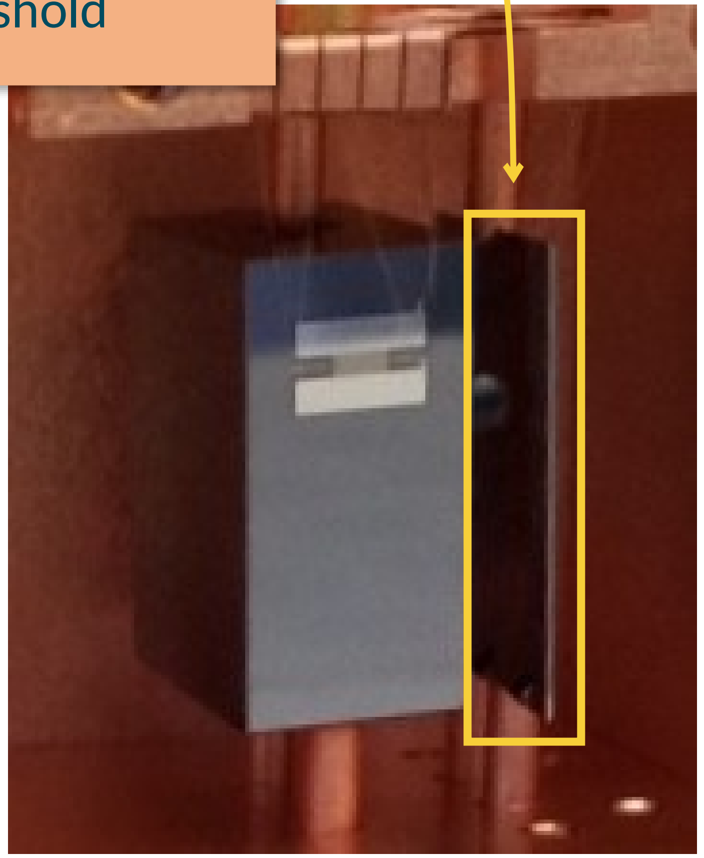
Si wafer detector: energy threshold of **10 eV** extends sensitivity to DM particles with the mass down to **115 MeV/c²**.

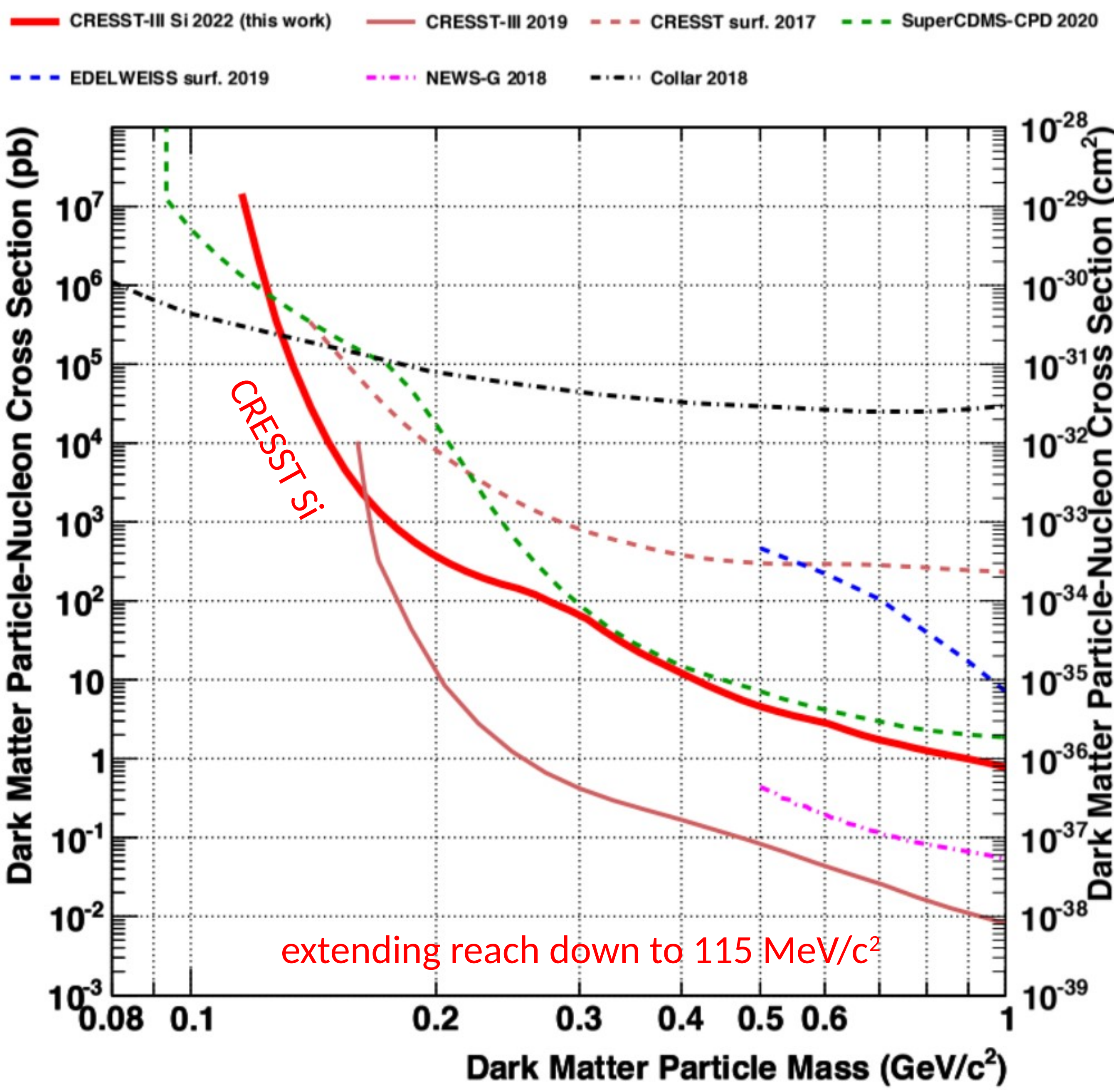
Si wafer detector: 0.35 g
Data-taking period: Nov 2020 – Aug 2021

Exposure: 55.06 g · days
Energy threshold: **10.0 eV**

Thin wafer detector is a target
Bulky detector is a veto to remove coincidence events.

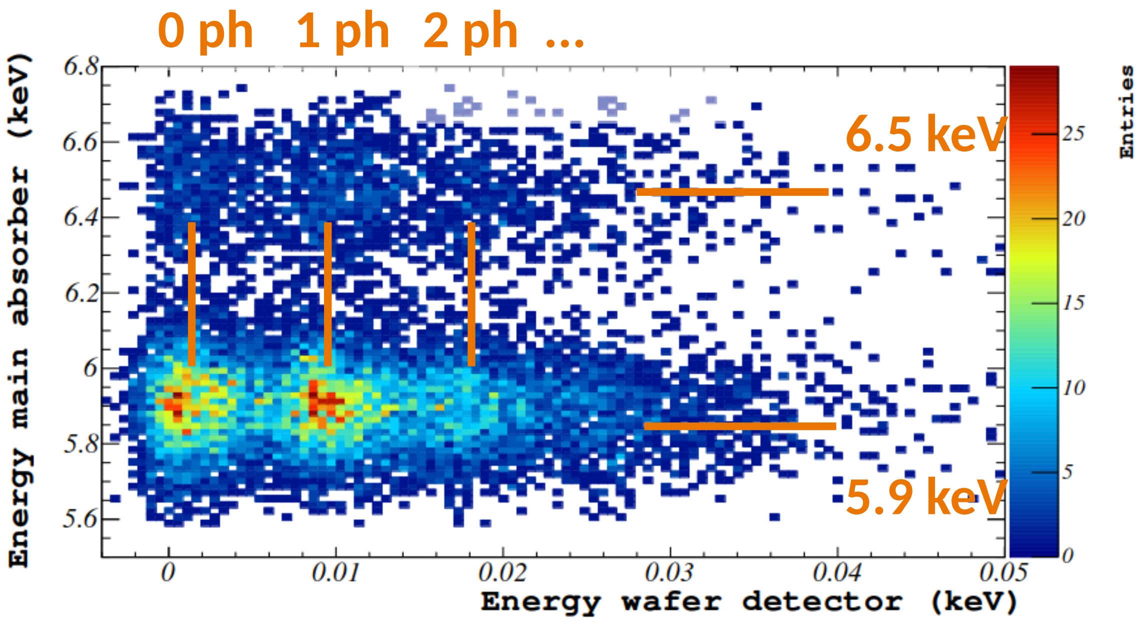
10.0±0.2 eV energy threshold





Phys. Rev. D **107**, 122003 / arXiv:2212.12513

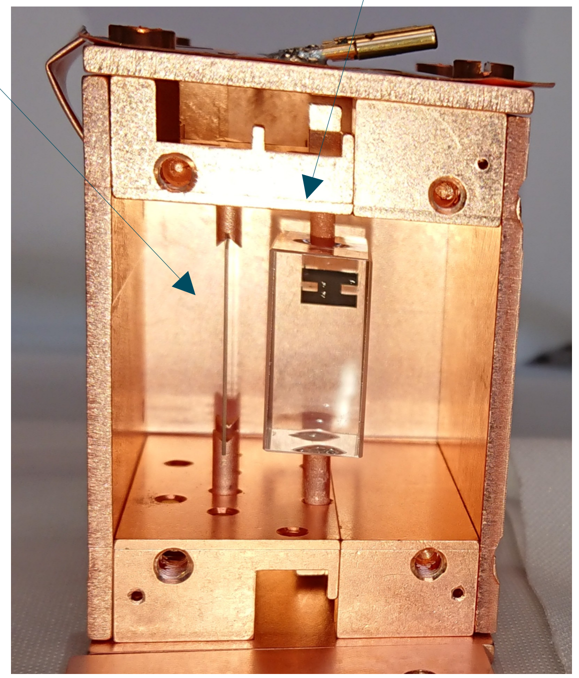
Silicon-on-sapphire wafer detector achieves an **energy threshold < 10 eV and reaches sensitivity to DM mass < 100 MeV/c²**.



^{55}Fe event in Al_2O_3 bulky crystal

→ luminescence emission at 7.6 eV

→ single photon detection in wafer detector

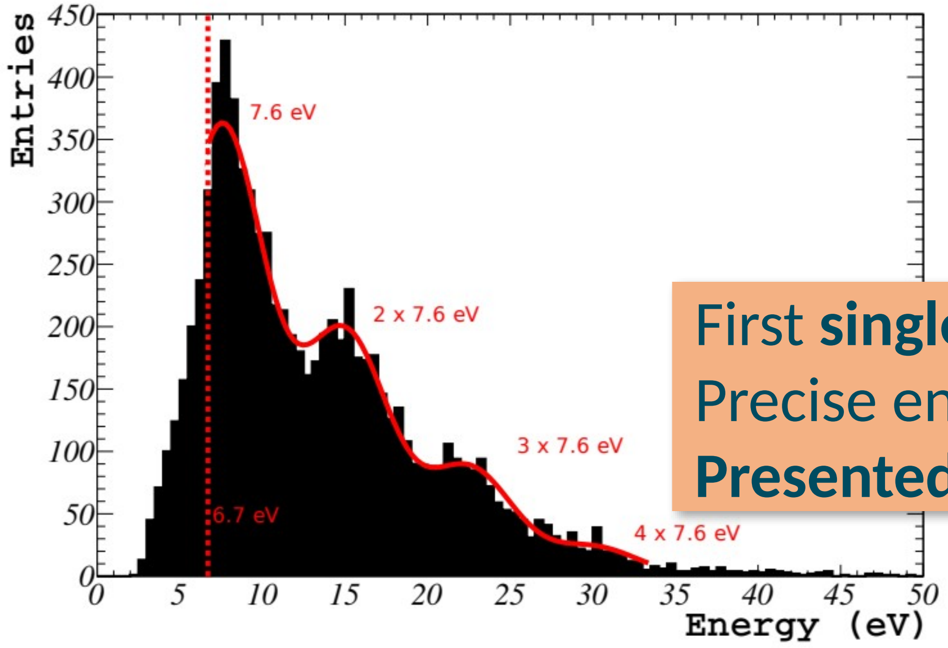


Al_2O_3 wafer detector: 0.6 g

Data-taking period: Nov 2020 – Aug 2021

Exposure: 0.14 kg · days

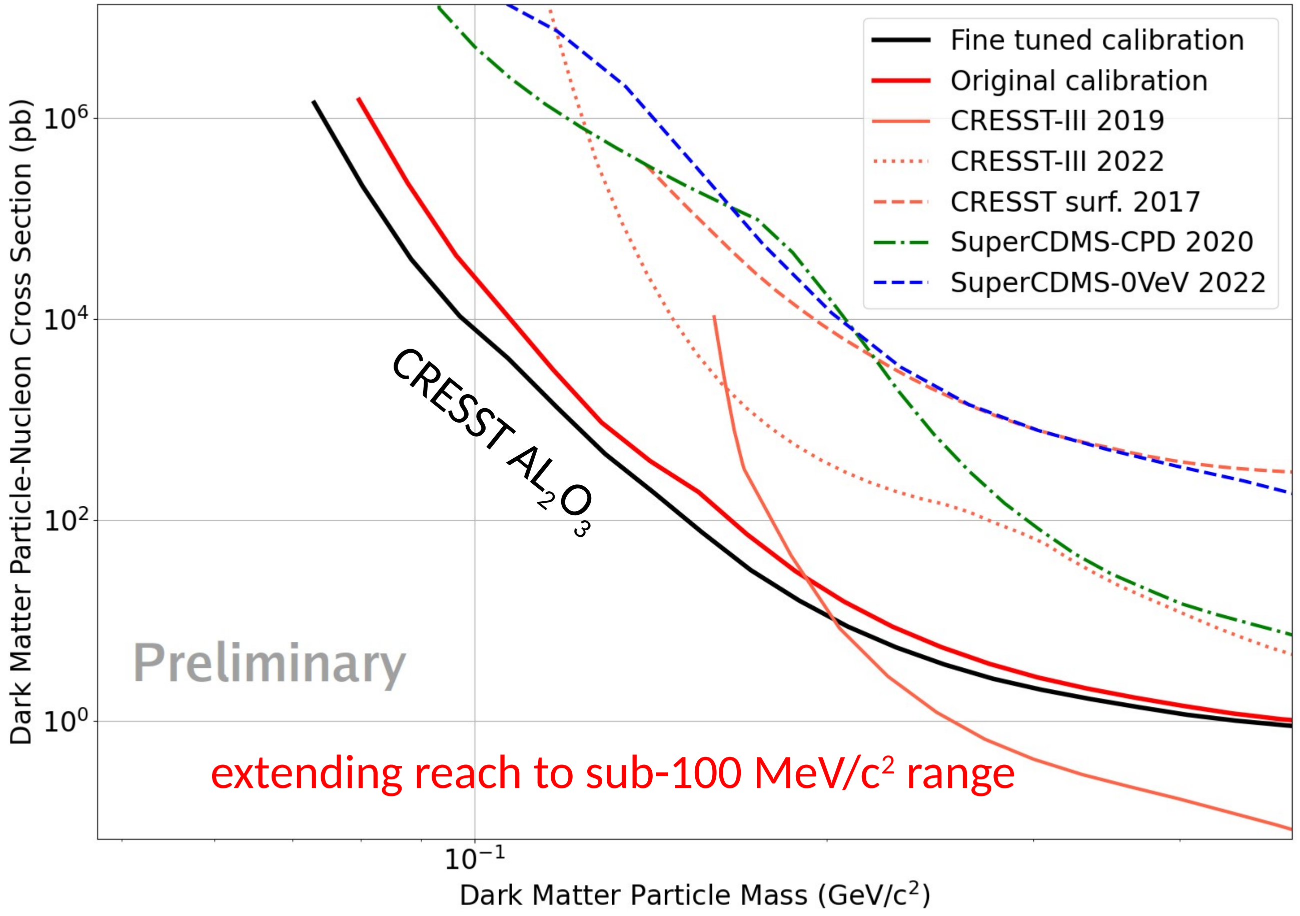
Energy threshold: **6.7 eV**



First **single photons** observation in CRESST!

Precise energy calibration **at eV-scale!**

Presented at TAUP23 by Dominik Fuchs



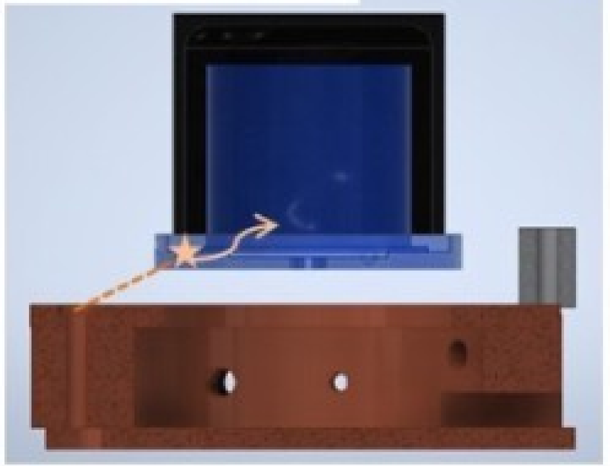
Future: New CRESST detectors

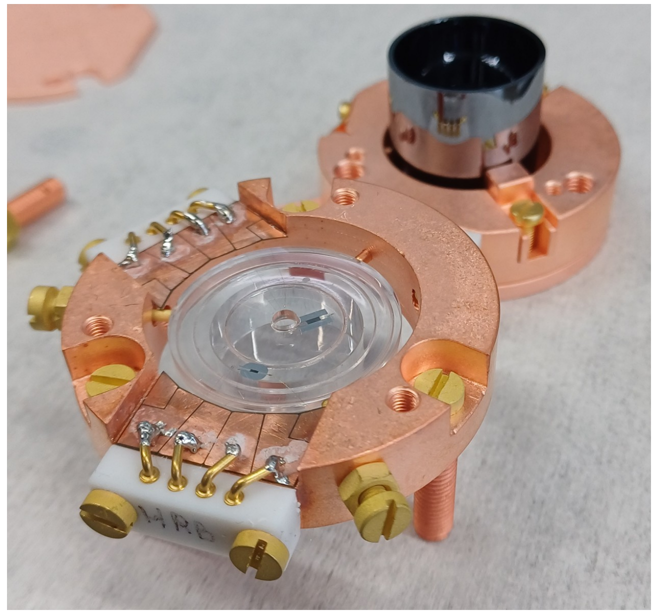
Detectors with new module designs to study the LEE origin are installed at LNGS since February 2024. Taking new data since last week!

Holding structures

instrumented holder: target crystal only touches other cryodetectors
4 pi veto: target crystal surrounded by silicon beaker

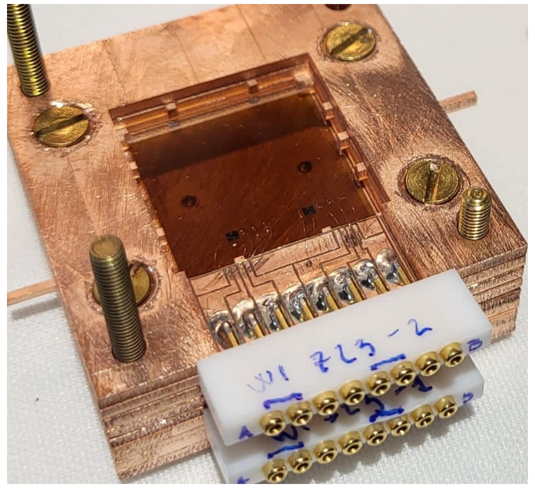
→discriminate external events and events transmitted through the holding structure



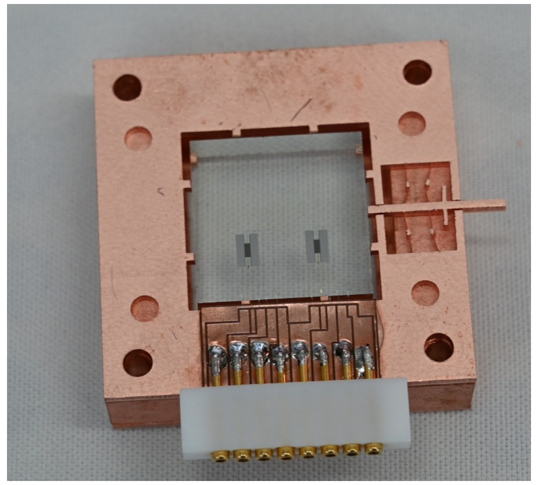


Double TES read-out

→ discriminate events in the absorber from events in the TES films or material interfaces
→ stress-free holding scheme:
reduced thermal stress on target crystals



4cm² silicon-on-sapphire



4cm³ $CaWO_4$

Talk by **Francesca Pucci** at EXCESS23@TAUP
https://indico.cern.ch/event/1213348/contributions/5411386/

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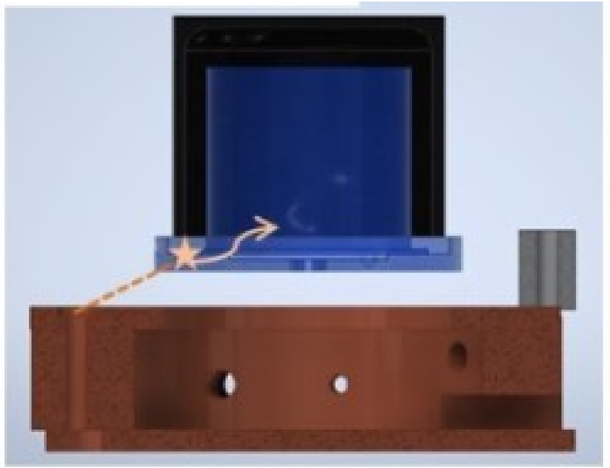

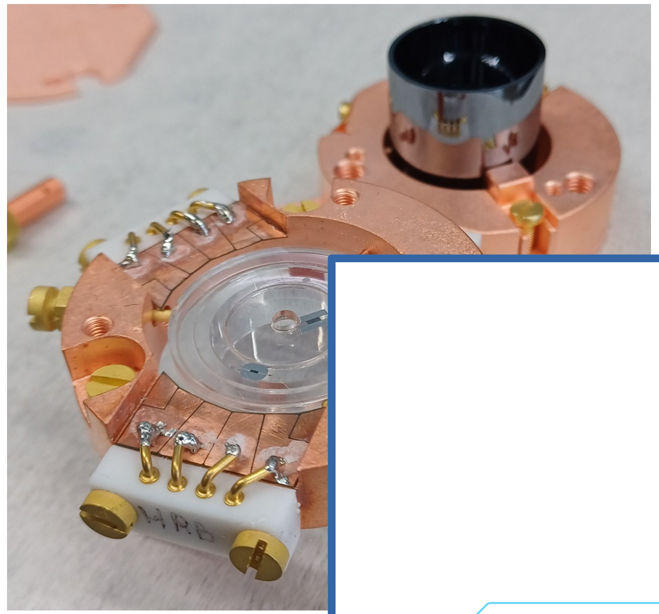

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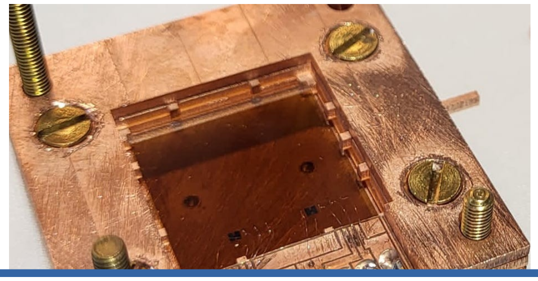

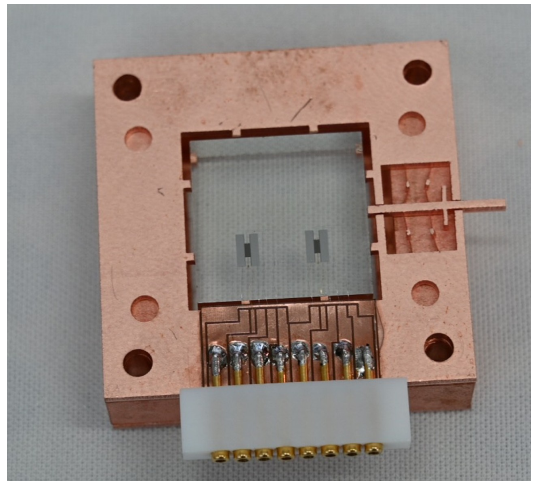

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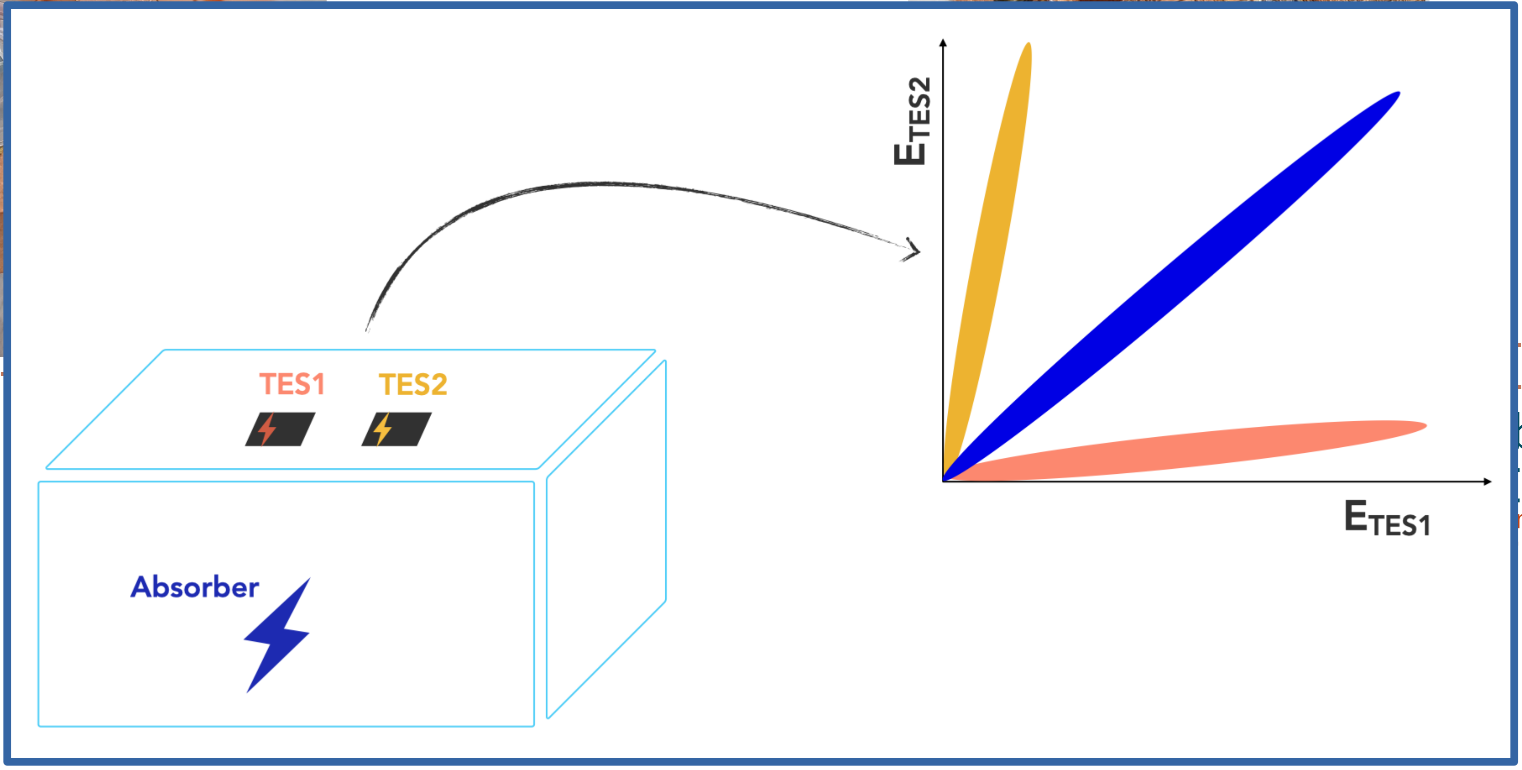

…by **Francesca Pucci** at …SS23@TAUP
…ndico.cern.ch/event/1213348/contributions/5411386/

Above-ground measurements with double-TES detectors show potential to explore LEE physics

Al_2O_3 double-TES

0.75g crystal operated at TUM (NUCLEUS R&D setup)
thresholds of 31 eV & 34 eV (5σ)

Flat trigger efficiency of 76% above 40eV

Clearly resolves multiple event distributions at low energy

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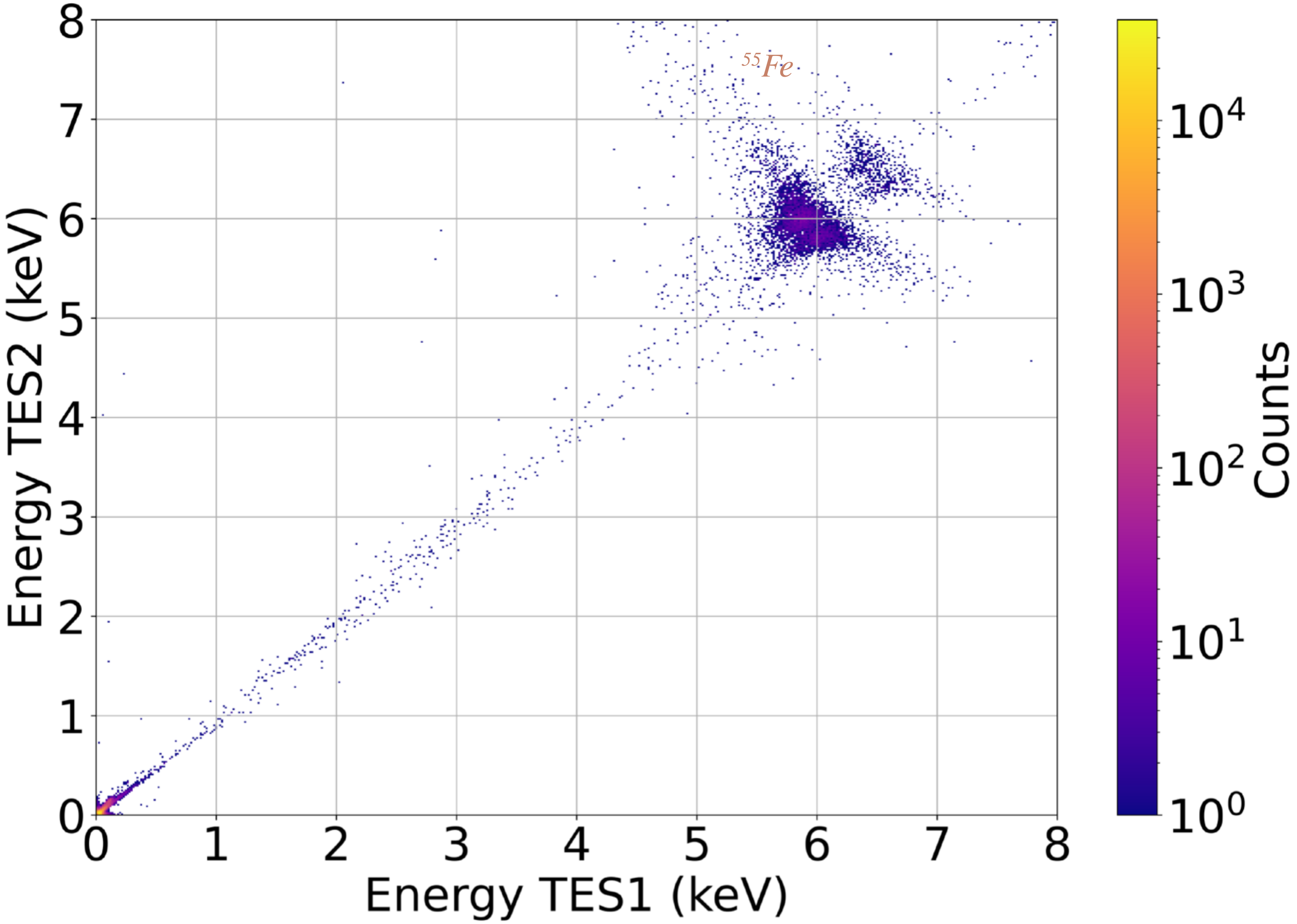

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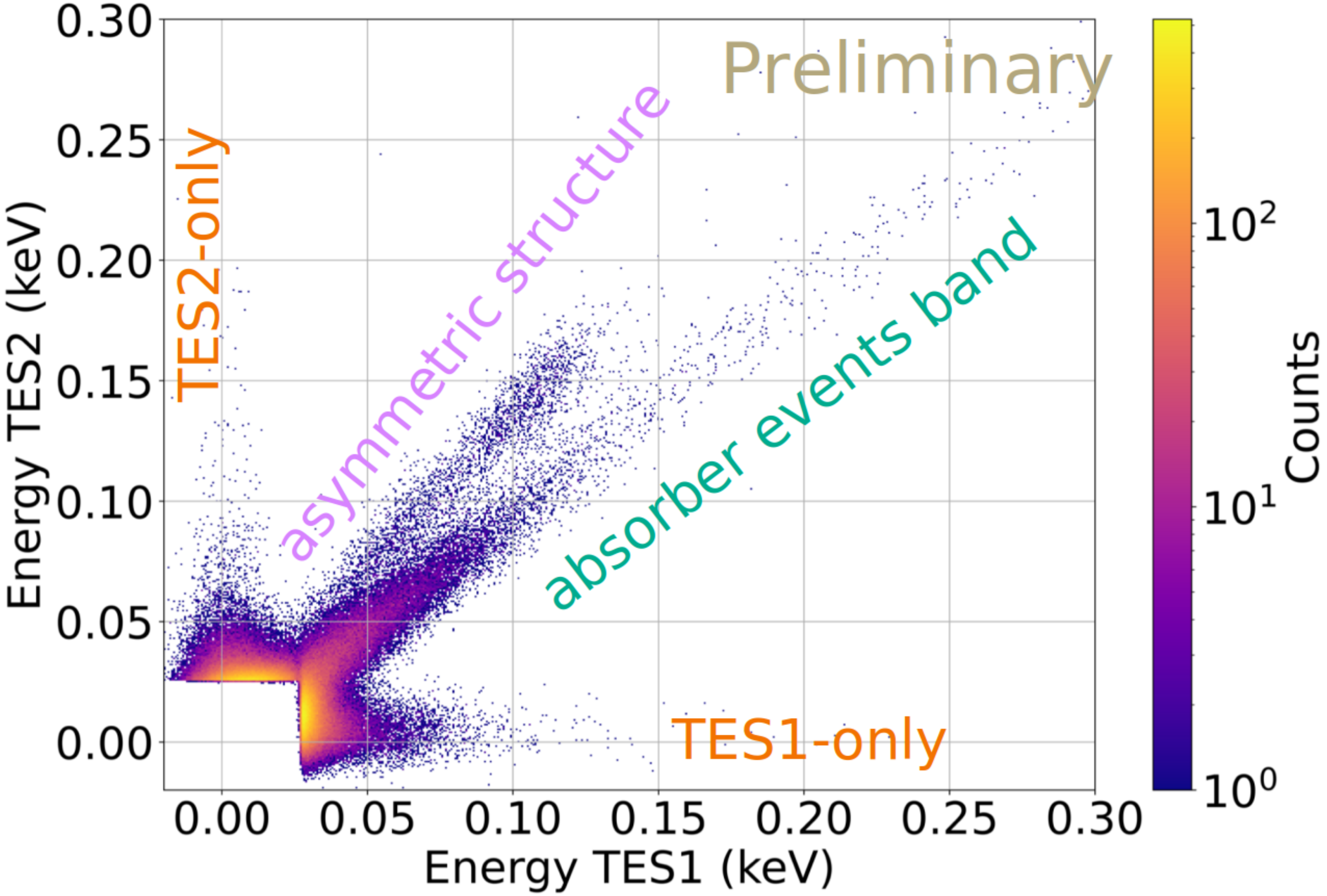
Flat trigger efficiency of 76% above 40eV

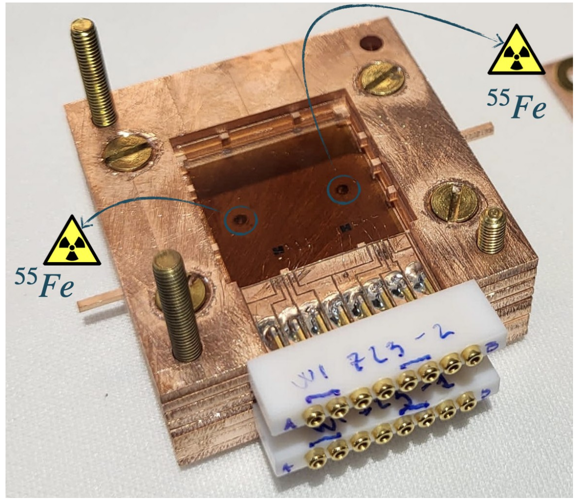
Clearly resolves multiple event distributions at low energy



Talk by **Francesca Pucci** at EXCESS23@TAUP
https://indico.cern.ch/event/1213348/contributions/5411386/

Above-ground measurements with double-TES detectors show potential to explore LEE physics

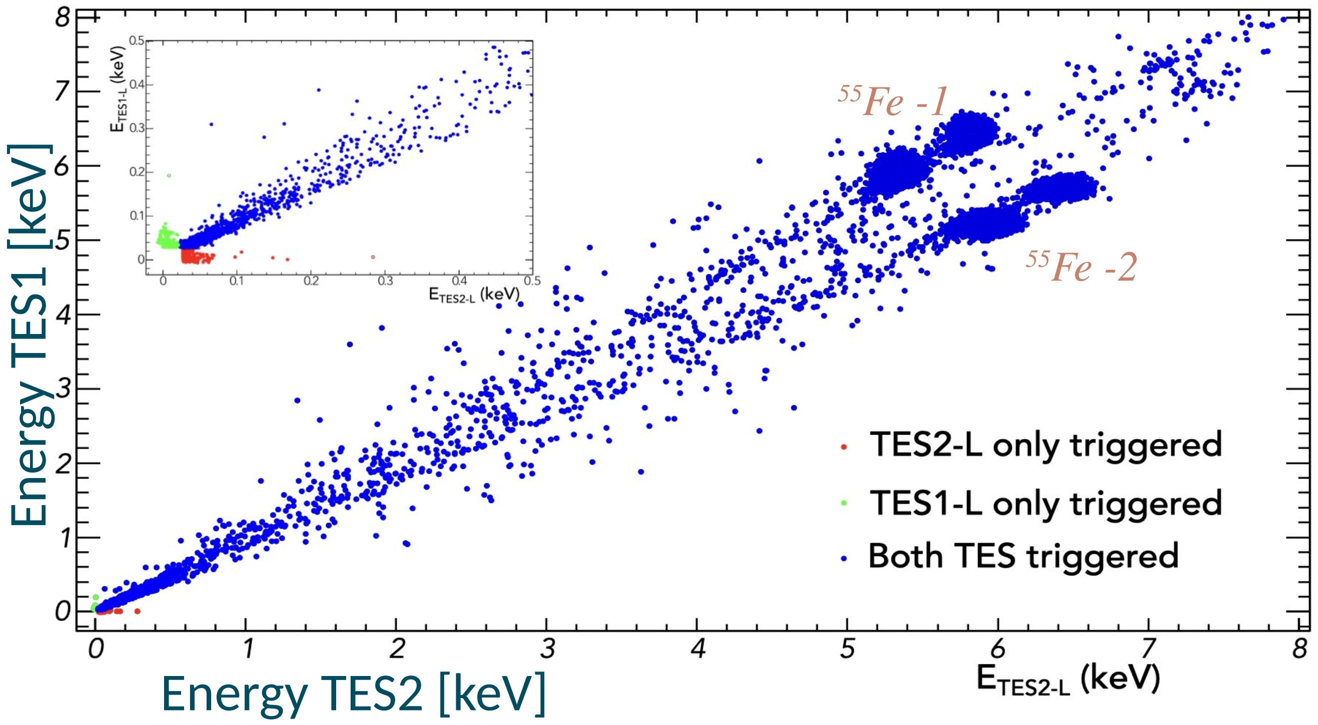
Silicon-on-sapphire double-TES



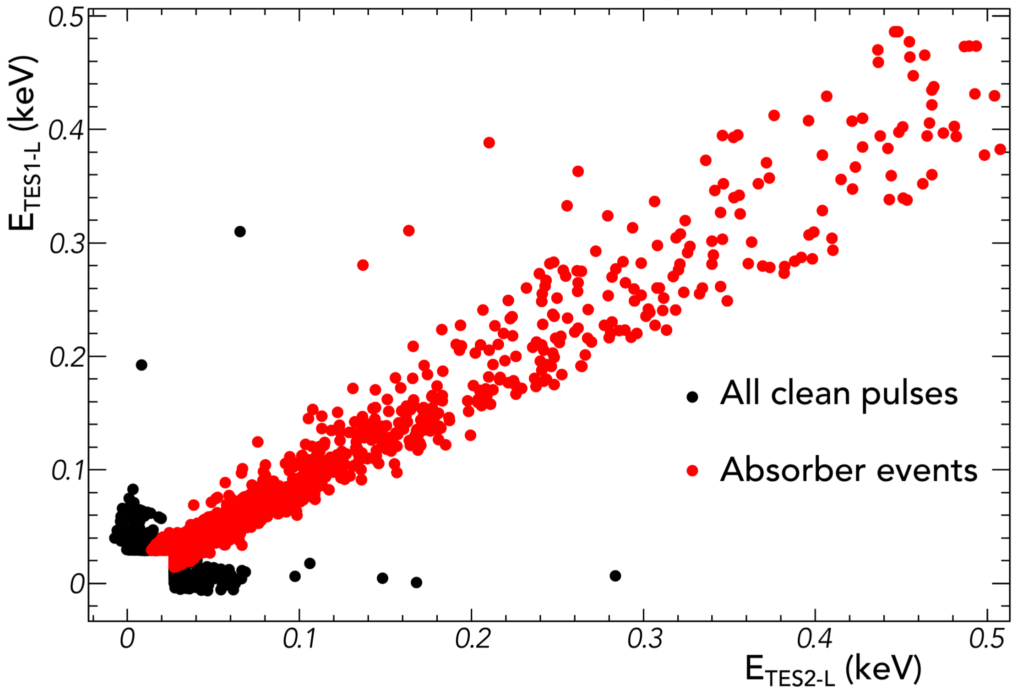
- 20x20x0.4mm³ wafer
- operated above ground at MPP
- thresholds of 27 eV & 20.5 eV (5σ)
- two 55Fe sources reveal mild position-dependence

At low energy:
band of coincident events
+ distributions of single-TES events

→ low-background operation at LNGS started!



Zoom into low-energy region



published on arXiv today: 2404.02607

Above-ground measurements with double-TES detectors show potential to explore LEE physics

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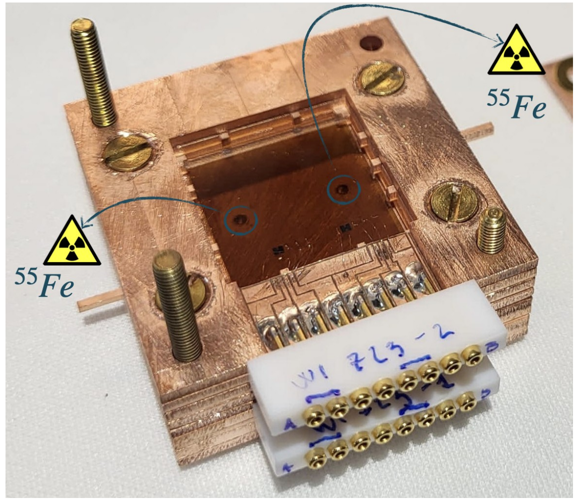

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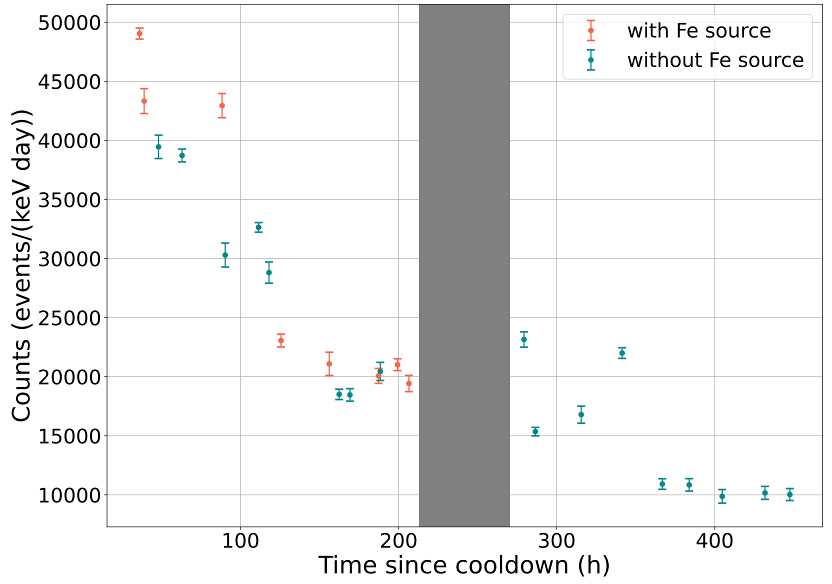
Time dependence:

Single-TES events: constant rate

Coincident band: decay ~10 days



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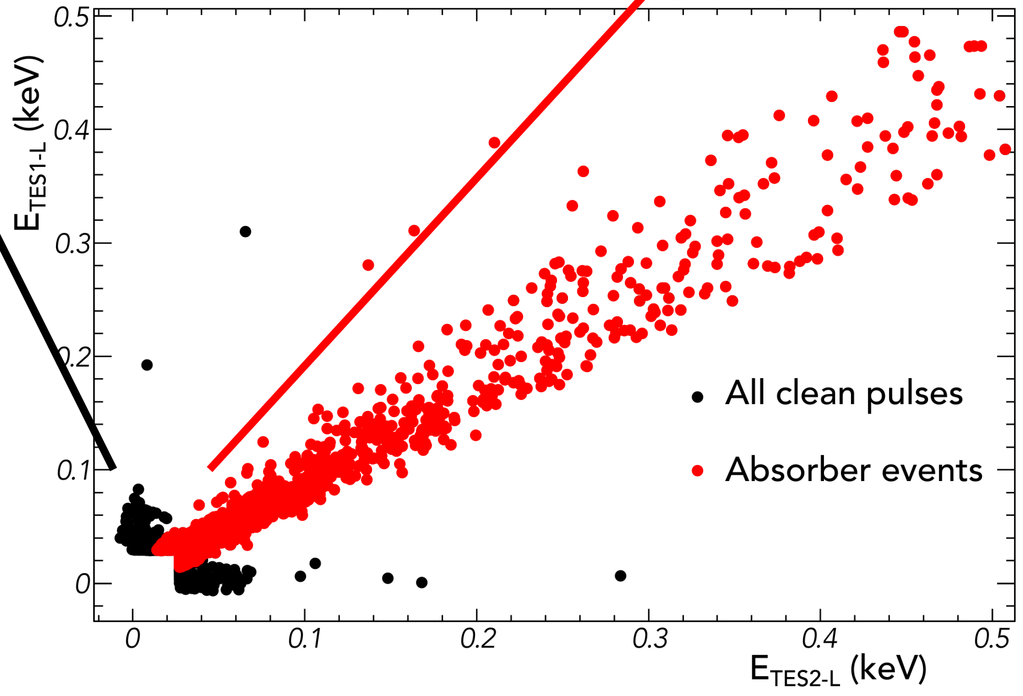

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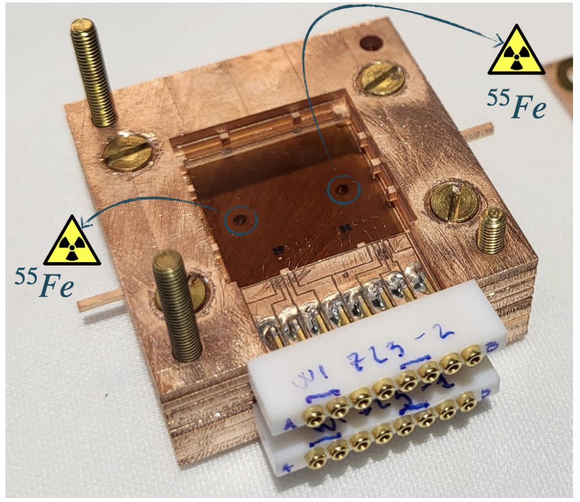

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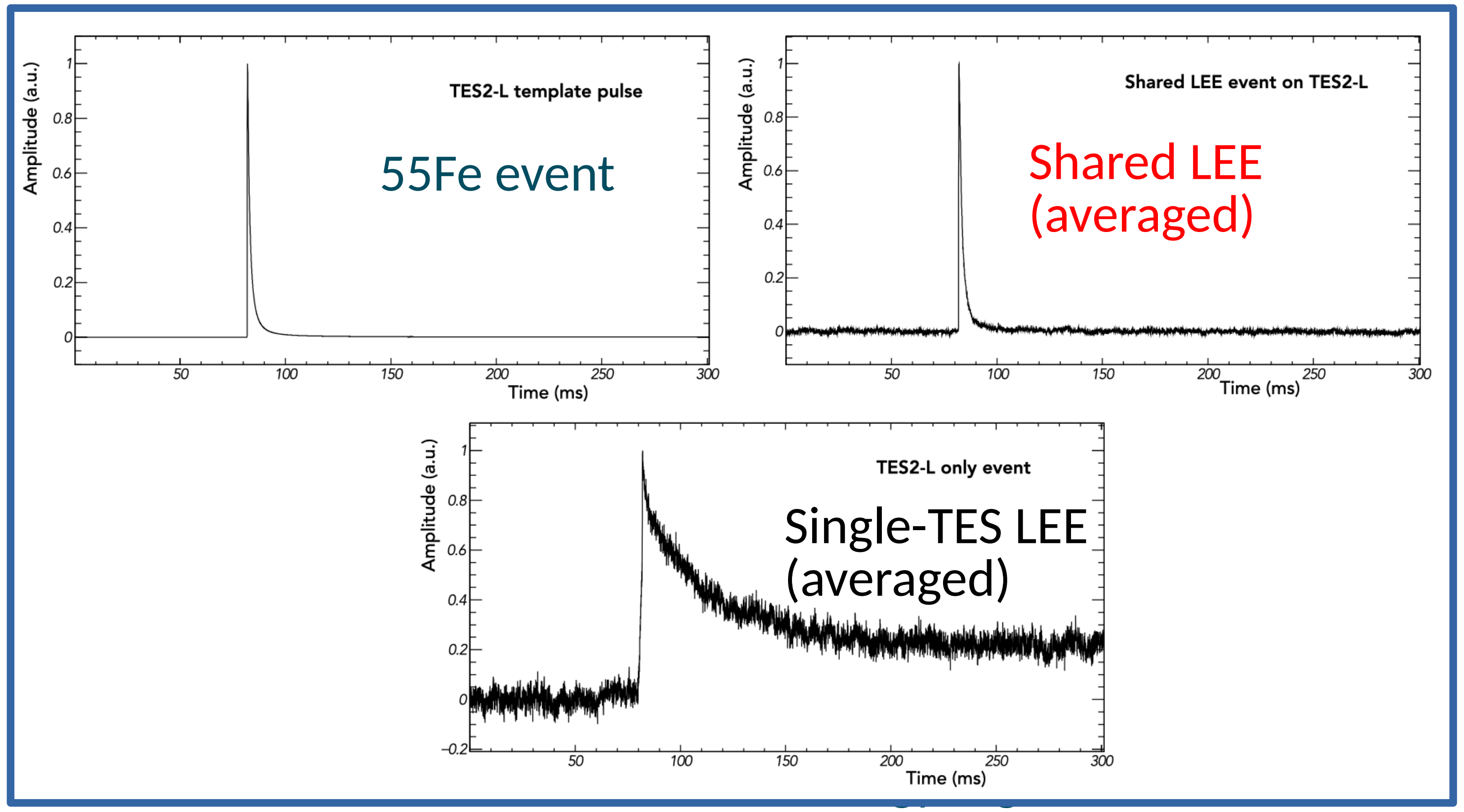
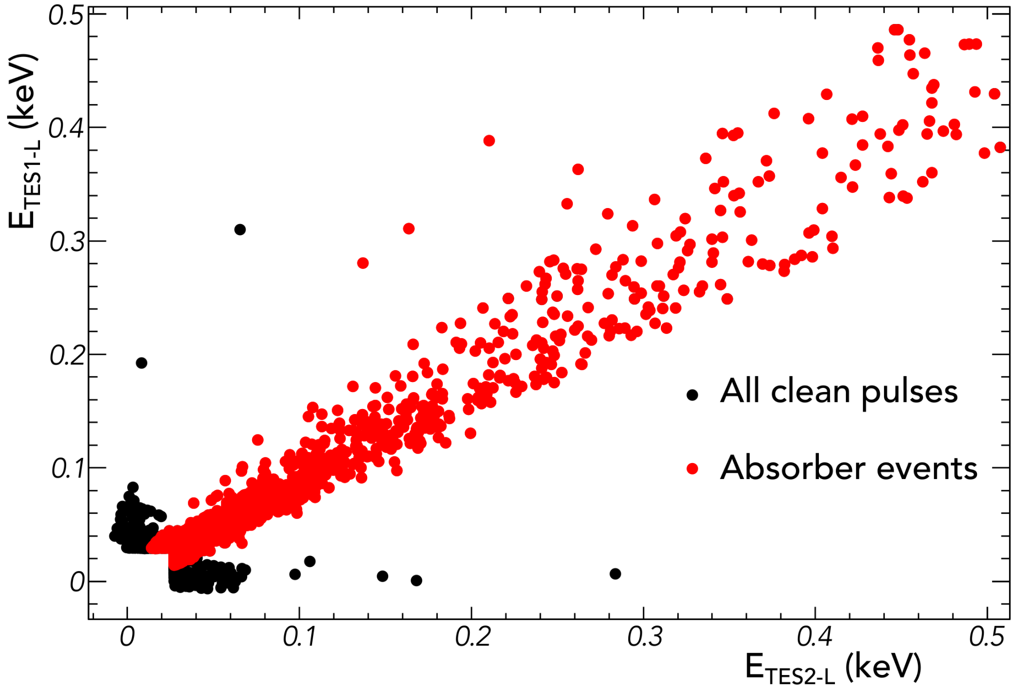
Pulse shapes:





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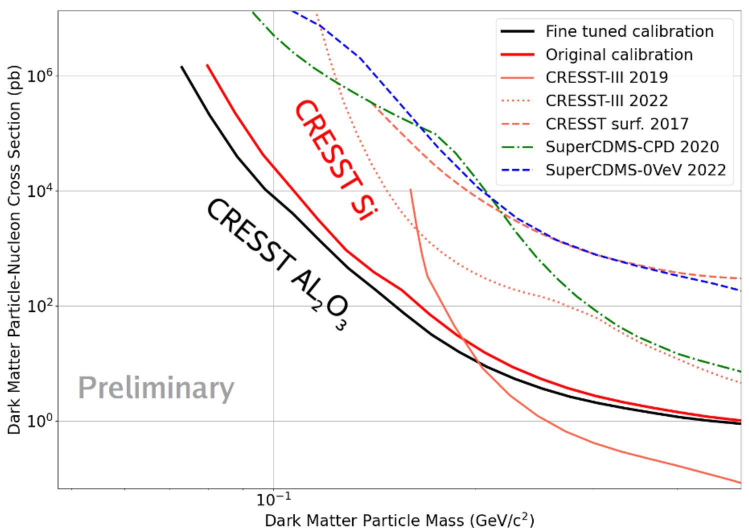
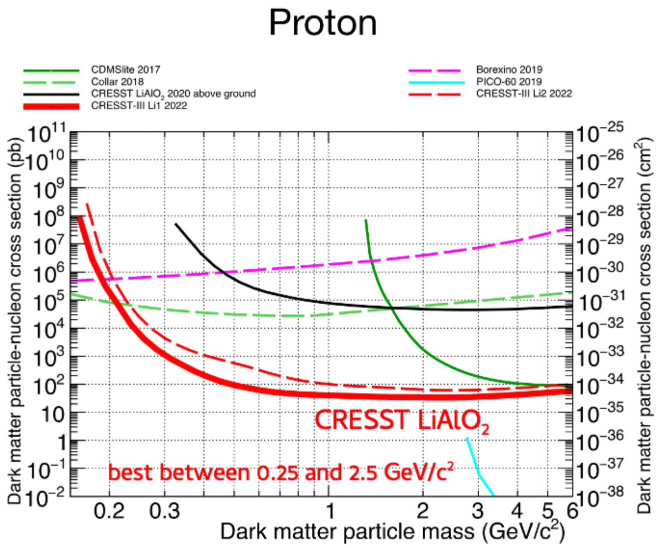
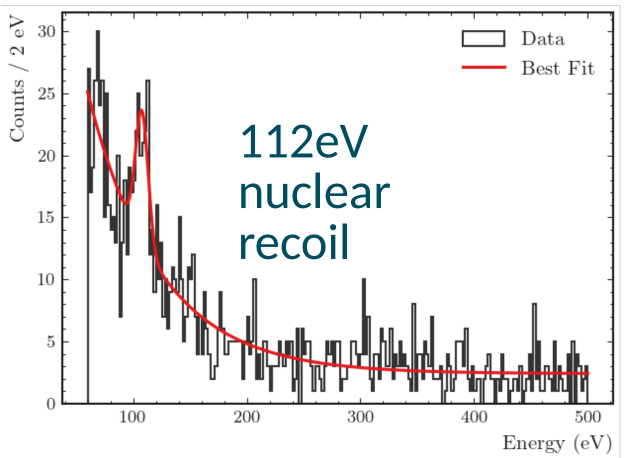
Conclusions & Outlook

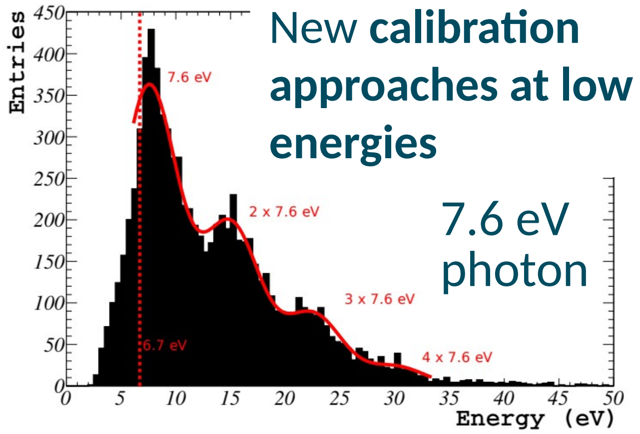


Reach to DM masses <100 MeV/c² with low threshold detectors

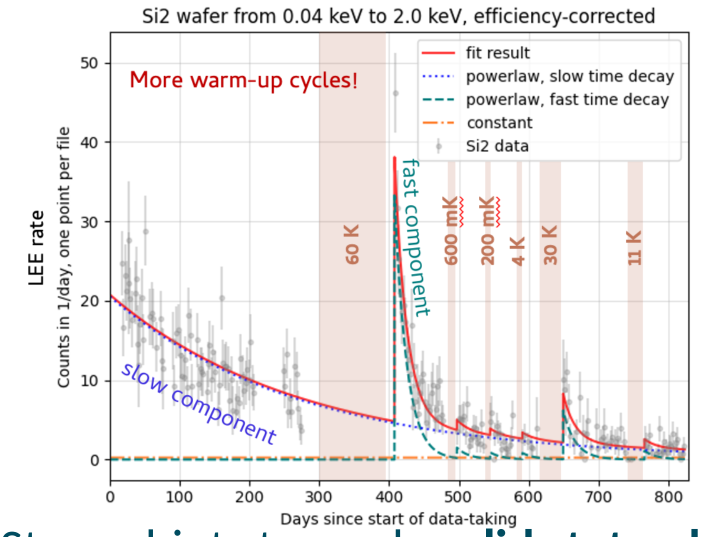


Improved limits for **spin-dependent interactions with** $LiAlO_2$ target.



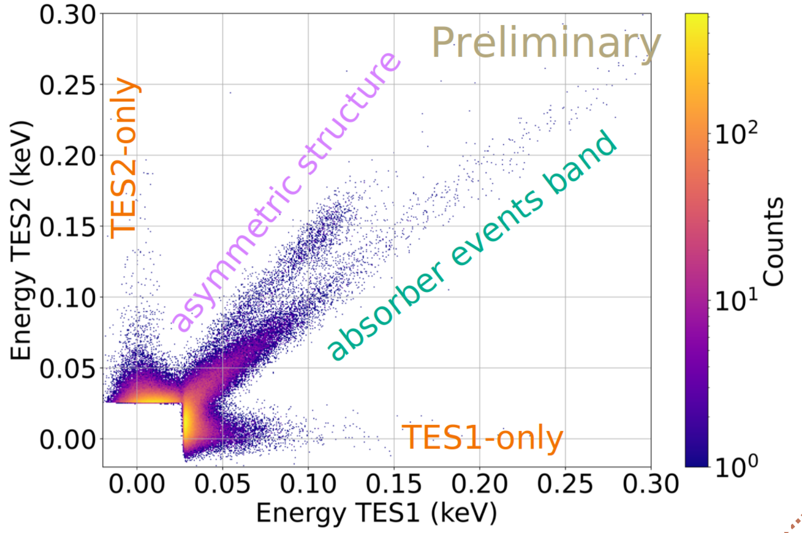


New **calibration approaches at low energies**



Strong hints towards **solid state physics effects playing a major role for low energy excess.**

Multiple LEE origins under study with above-ground data



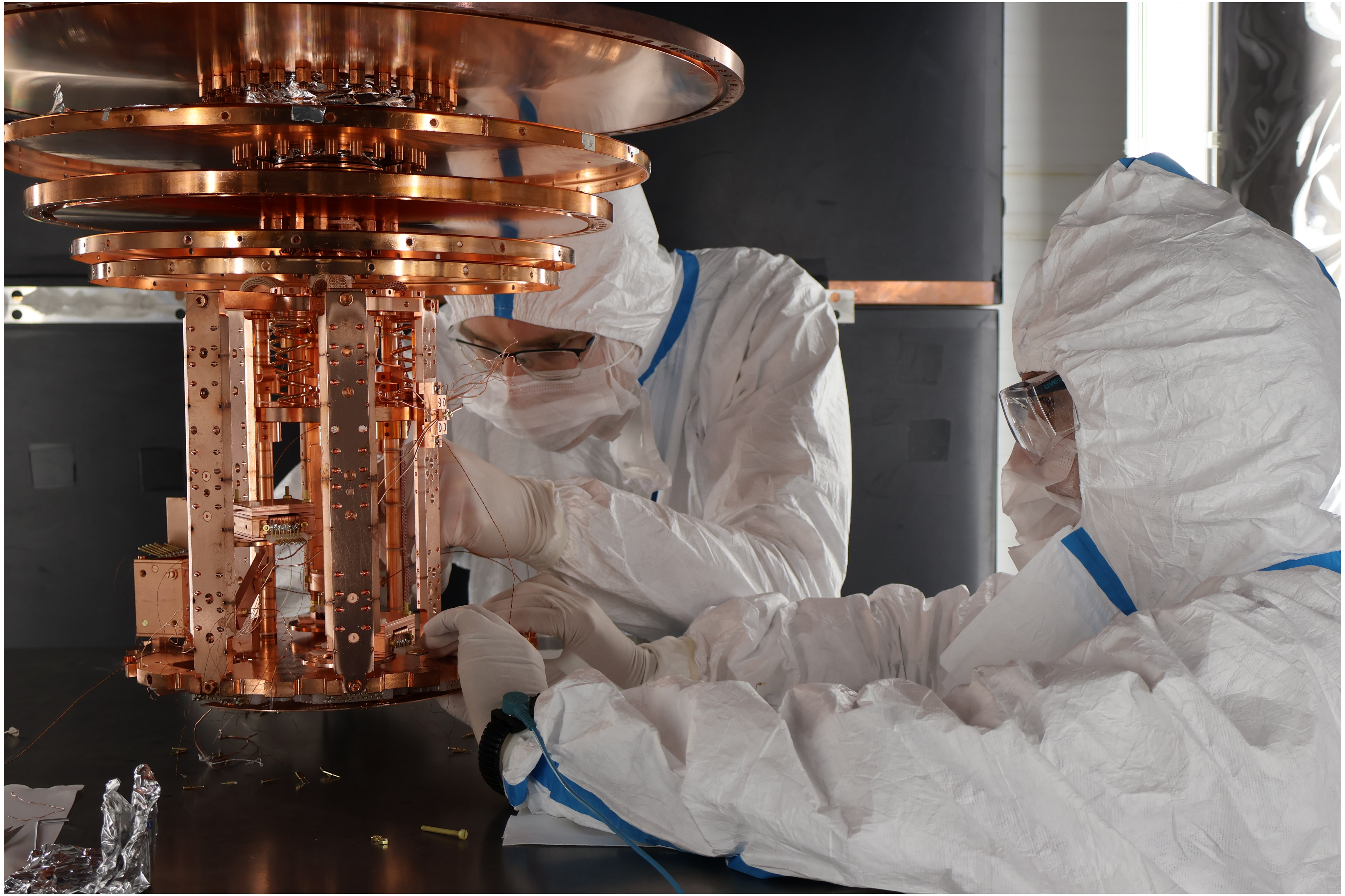
New data taking at LNGS started!

Novel detector module designs to study sensor-related events and the impact of the stress from holders

A **major CRESST setup upgrade** to 288 read-out channels is in preparation:

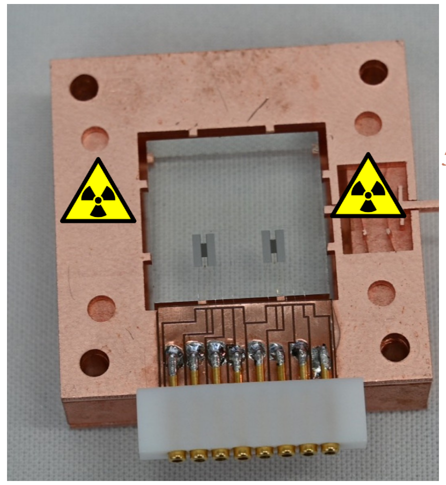
- SQUIDs and wiring are already produced
- new DAQ and bias electronics are designed
- goal: installation at LNGS in 2024

Thank you for your attention!



Above-ground measurements with double-TES detectors show potential to explore LEE physics

$CaWO_4$ double-TES

^{55}Fe  ^{55}Fe

24g crystal operated at MPP
thresholds of 137 eV & 148 eV (5σ)
2x 55Fe sources reveal mild position-dependence

At low energy:
band of coincident events
+ distributions of single-TES events

Resolution limited by high rate above-ground
→ low-threshold operation at LNGS starting soon

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