LX LNGS SC meeting

16 October 2023

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MAX-PLANCK-INSTITUT FÜR PHYSIK

CRESST report

The CRESST Collaboration

CRESST

UNIVERSITY OF OXFORD

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

TECHNISCHE UNIVERSITÄT MÜNCHEN

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

TU WIEN

HEPHY
INSTITUTE OF HIGH ENERGY PHYSICS

MAX PLANCK INSTITUTE FOR PHYSICS

UNIVERSITAS COMENIANA BRATISLAVENSIS · MCMXIX ·

The CRESST Experiment

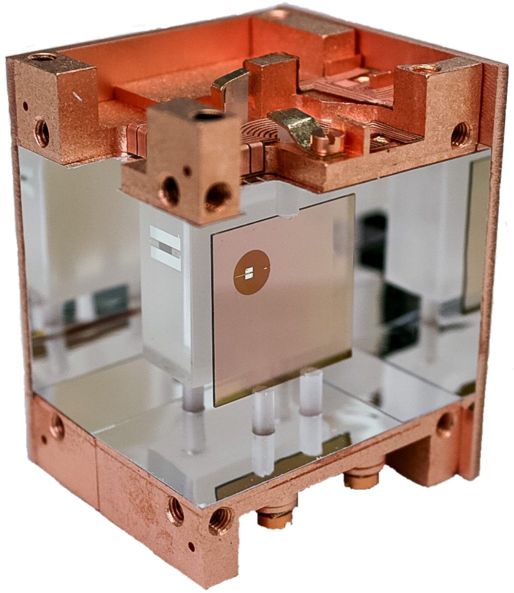
Cryogenic Rare Event Search with Superconducting Thermometers

Direct detection of dark matter particles via their scattering off target nuclei

Scintillating $CaWO_4$ crystals as target

Target crystals operated as **cryogenic calorimeters** (~15mK)

Separate **cryogenic light detector** to detect the scintillation light signal



Detector Module:
Simultaneous signals from the transition edge sensors (TESs) allow for background discrimination on an event-by-event base

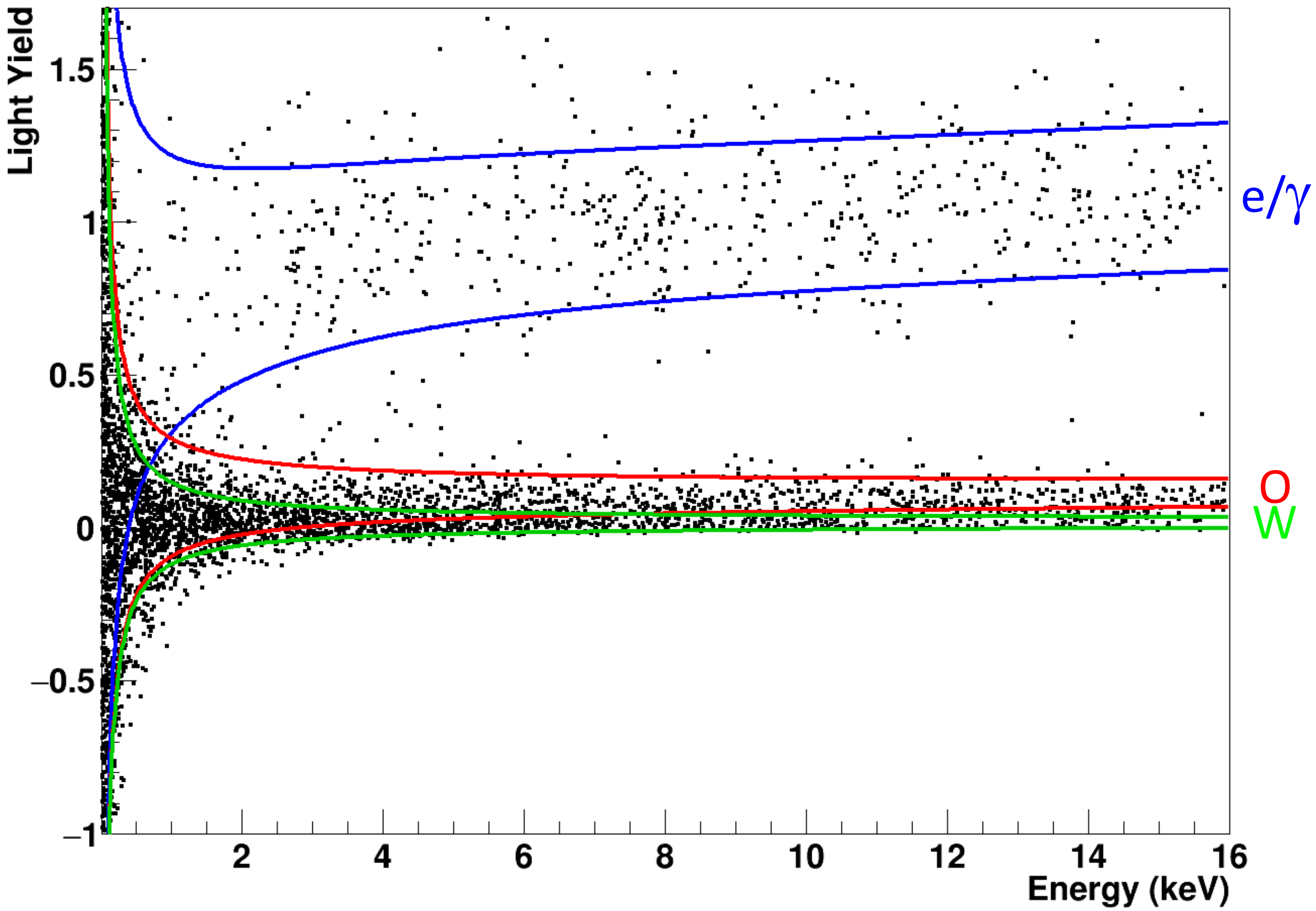
Event Discrimination

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

Characteristic of the event type

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

n-calibration data

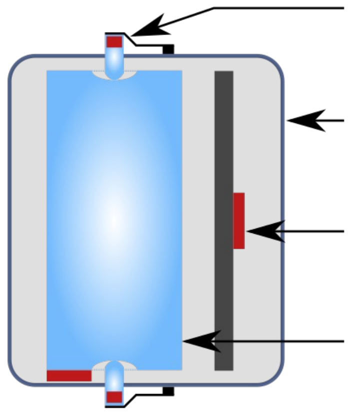


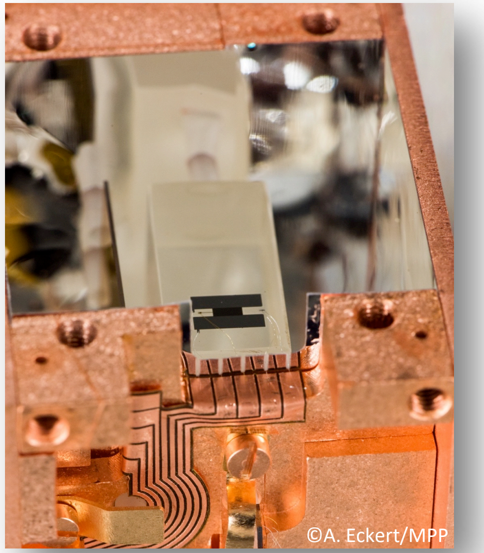
The CRESST-III Strategy

Detector layout optimised for low-mass dark matter

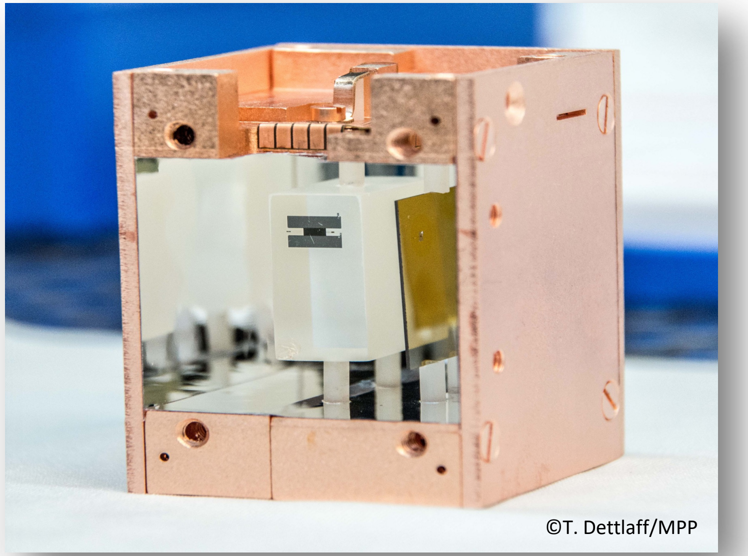
Radical reduction of dimension

- Cuboid crystals of (20×20×10)mm³ (≈**24g**)
- With self grown crystals **≈4 counts/(keV kg day)**
- Veto of surface-related background

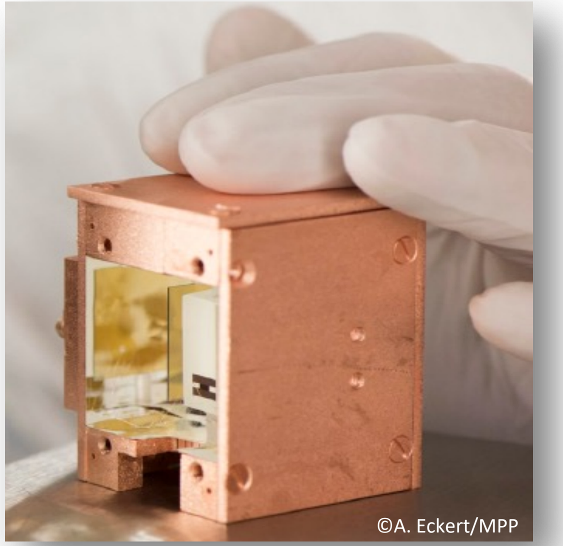




©A. Eckert/MPP



©T. Dettlaff/MPP



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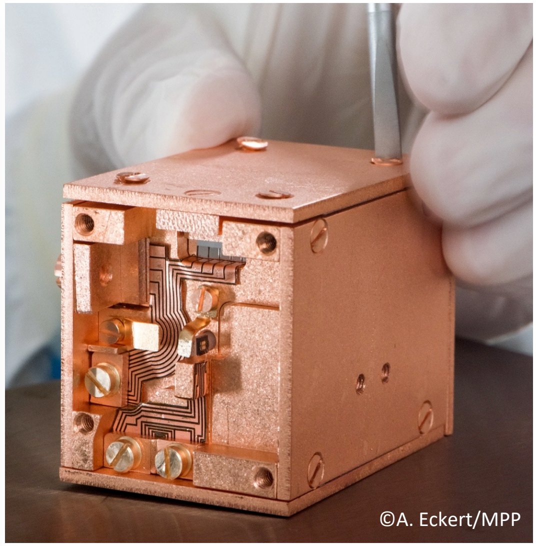

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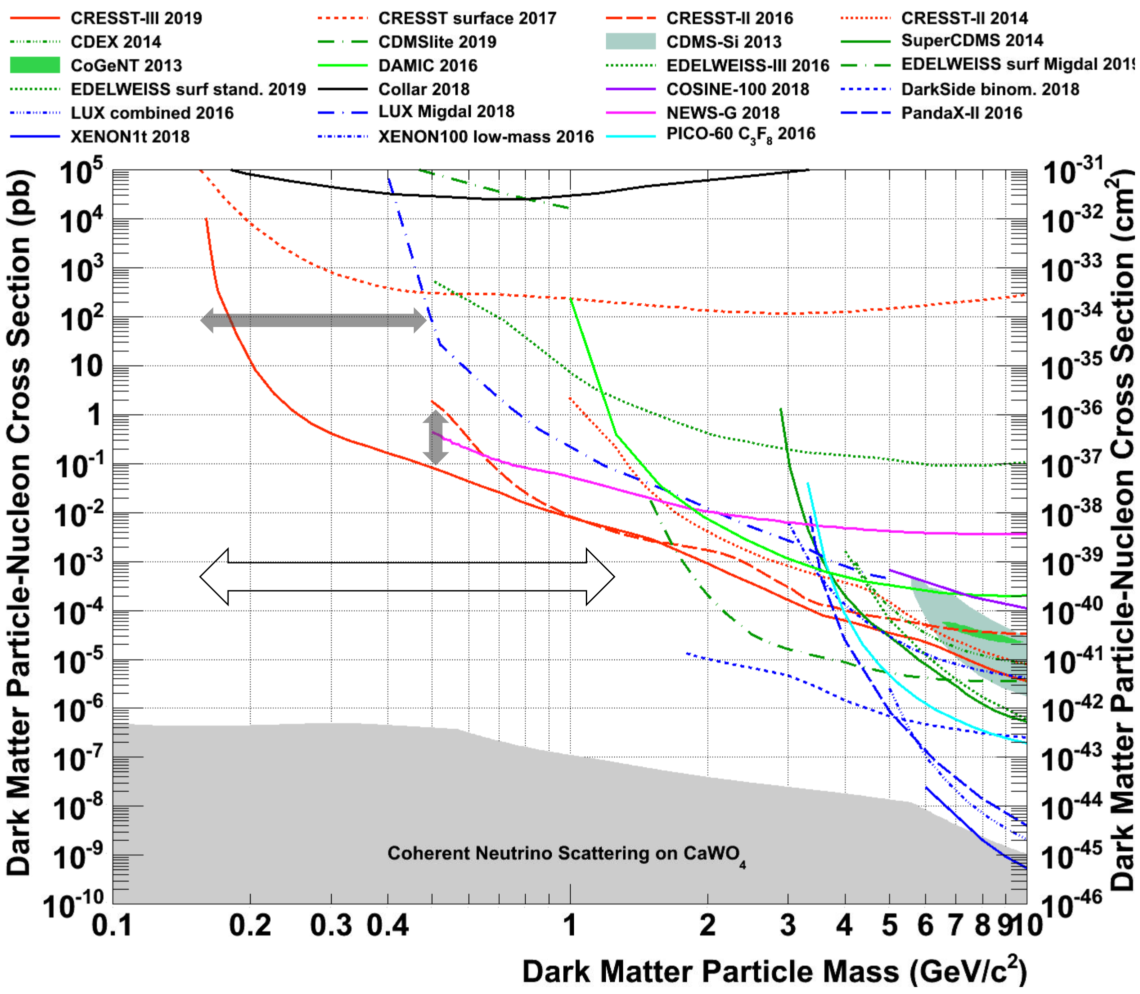
First Results

First results from the CRESST-III low-mass dark matter program
Phys. Rev. D 100, 102002 (2019)

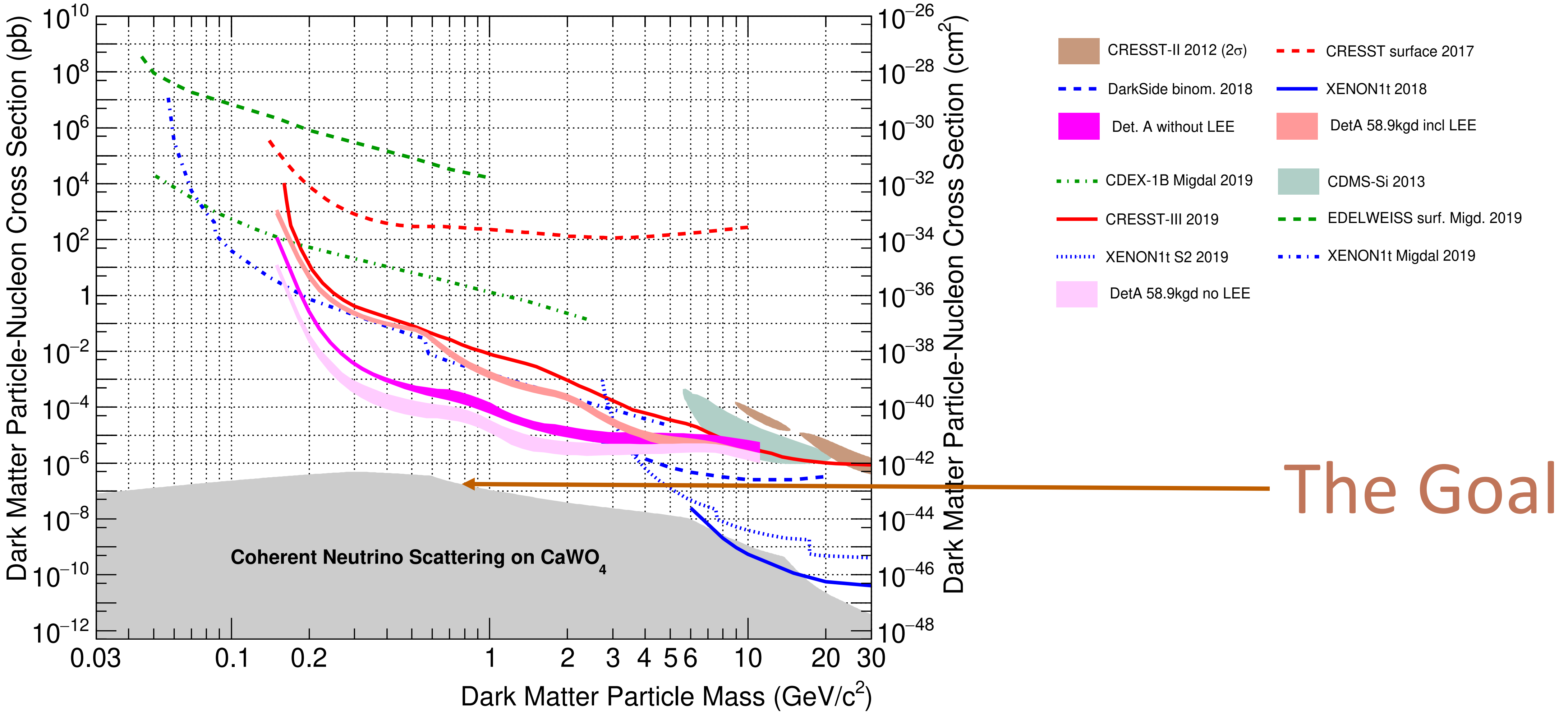
- Non-blind data (dynamically growing): 20% randomly selected
- Target crystal mass: 23.6g
- Gross exposure (before cuts): 5.689 kg days
- Nuclear recoil threshold: 30.1 eV

- More than one order of magnitude improvement at 0.5 GeV/c²
- Extended reach from 0.5GeV/c² to 0.16GeV/c²
- Unexpected rise of event rate < 200eV

Leading sensitivity
- Dark matter ☺
- Background ☹



Sensitivity projections

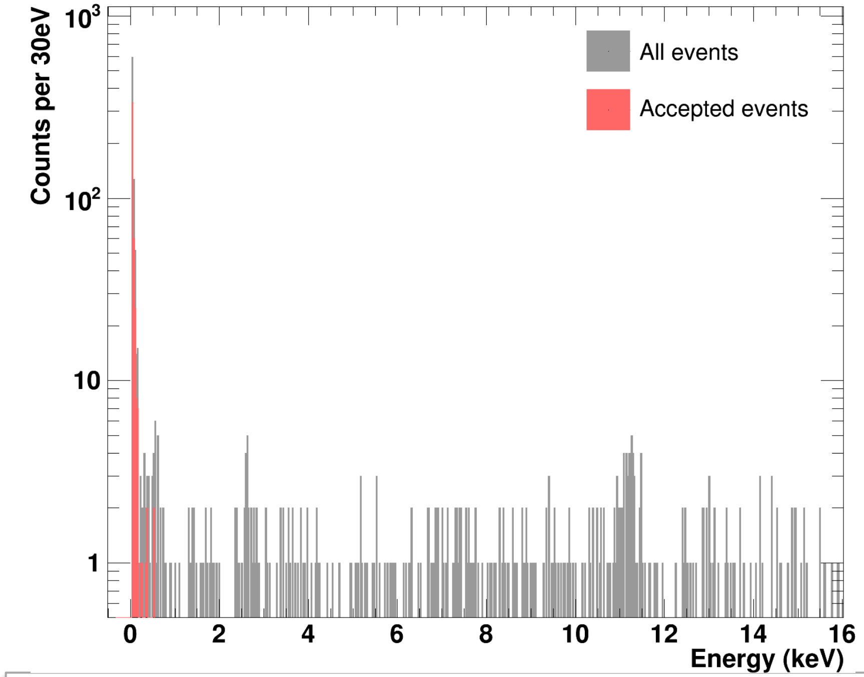


Short-Term Goals

a) Remove low-energy excess
b) Develop reliable calibration for nuclear recoils at eV energies
c) Increase number of read-out channels *

* Strategy subordinated to a)

The Event Rise



Present in different detectors, but spectral shape not compatible with one single common origin

To pinpoint its origin we prepared dedicated setups with hardware modifications to disentangle possible different contributions

- Crystal material
- Crystal surface
- Holding
- Facing surfaces
- ...

What happens below 100eV?
Cross checks with other low threshold experiments very interesting

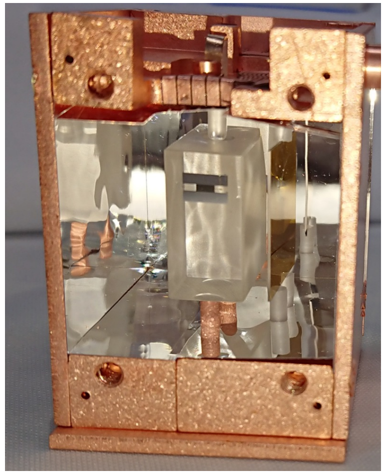
June 15 - 16, 2021
https://indico.cern.ch/event/1013203/

February 15-17, 2022
https://indico.scc.kit.edu/event/2575/

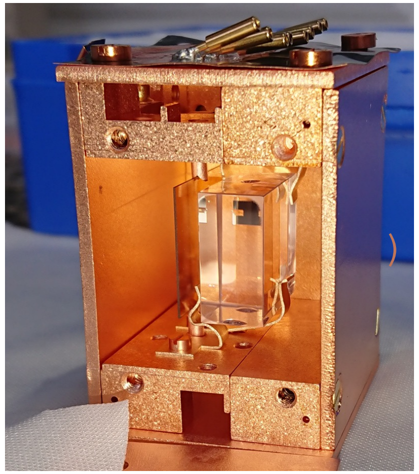
July 16, 2022
https://indico.cern.ch/event/1117540/

August 26, 2023
https://indico.cern.ch/event/1213348/

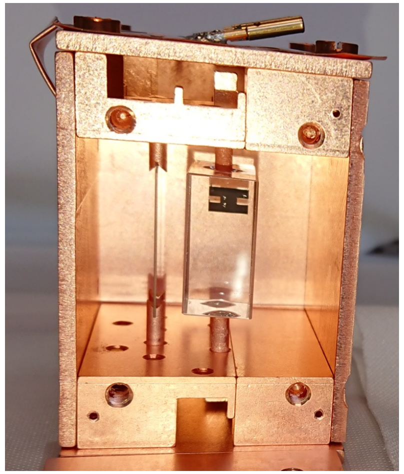
Current Measurement Campaign



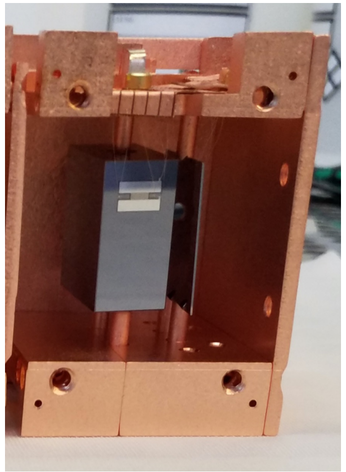
$CaWO_4$ grown at TUM



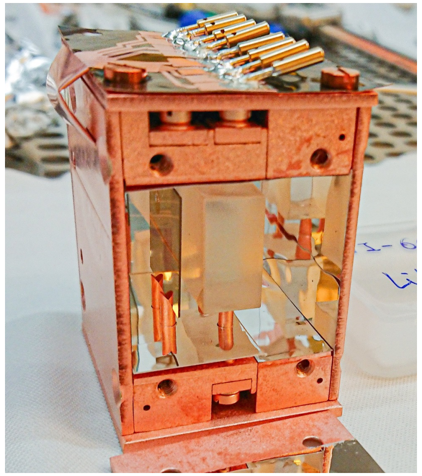
Commercially grown $CaWO_4$



Al_2O_3



Si



$LiAlO_2$

Dedicated modifications to probe LEE:

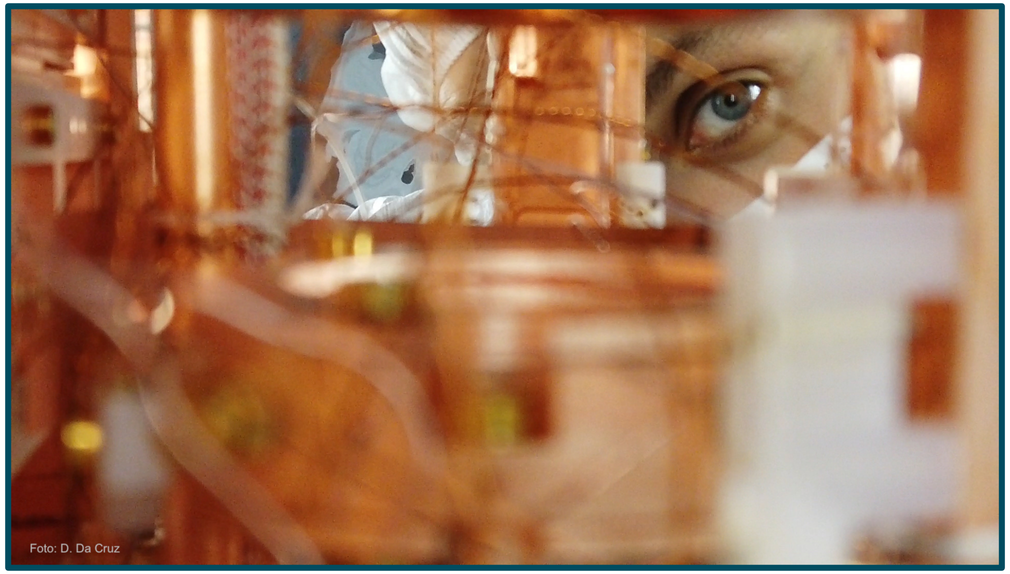
- different target materials
- change how crystals are held
- remove scintillating components

Routinely achieved thresholds < 100 eV

Name	Material	Holding	Foil	Mass	Threshold
Comm2	$CaWO_4$	bronze clamps	no	24.5 g	29 eV
TUM93A	$CaWO_4$	2 Cu + 1 $CaWO_4$	yes	24.5 g	54 eV
Sapp1	Al_2O_3	Cu sticks	no	15.9 g	157 eV
Sapp2	Al_2O_3	Cu sticks	yes	15.9 g	52 eV
Li1	$LiAlO_2$	Cu sticks	yes	11.2 g	84 eV
Si2	Si	Cu sticks	no	0.35 g	10 eV

Current Measurement Campaign

CRESST-III runs ongoing to look into the origin of the background



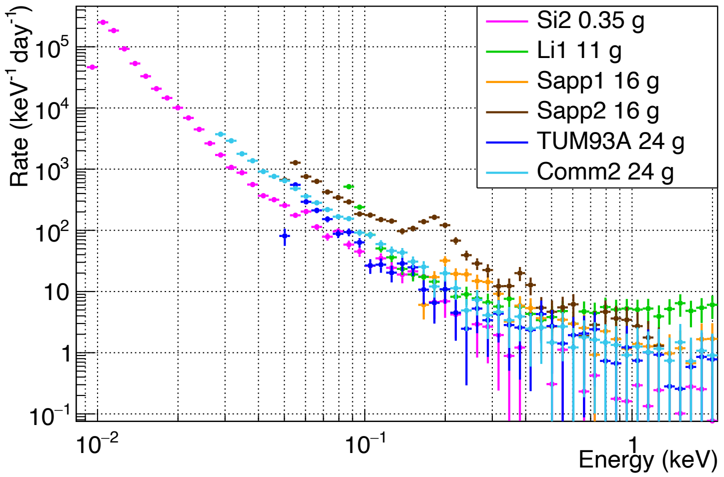
- Cryostat cold since summer 2020
- Dark matter data collection finished on August 6th, 2021
- Gamma and neutron calibrations were performed
- Data acquisition program to identify the Low Energy Excess (LEE) origin still ongoing

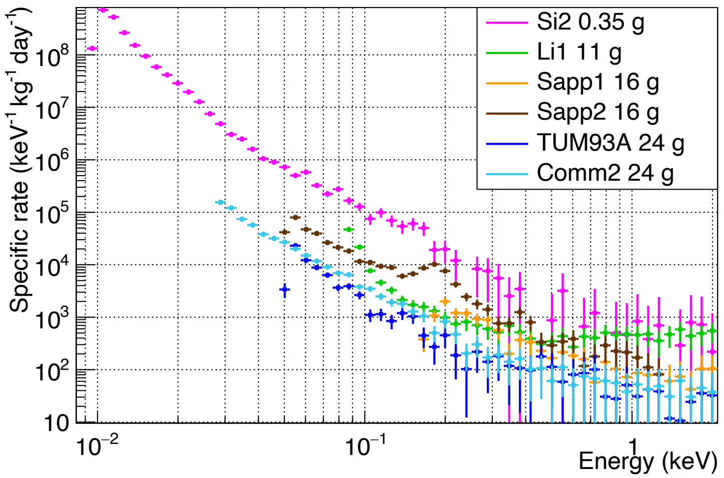
Observations on LEE

CRESST-III runs ongoing to investigate the origin of the background

From the first observation in 2019:

- Low energy excess seen with all absorber materials and with different holding schemes
- Low energy excess decays with time
- Low energy excess and its decay seem to be universal features, seen with all absorber materials and with different holding schemes
- Low energy excess does not scale with mass/volume of the absorber





arXiv:2207.09375 [astro-ph.CO]

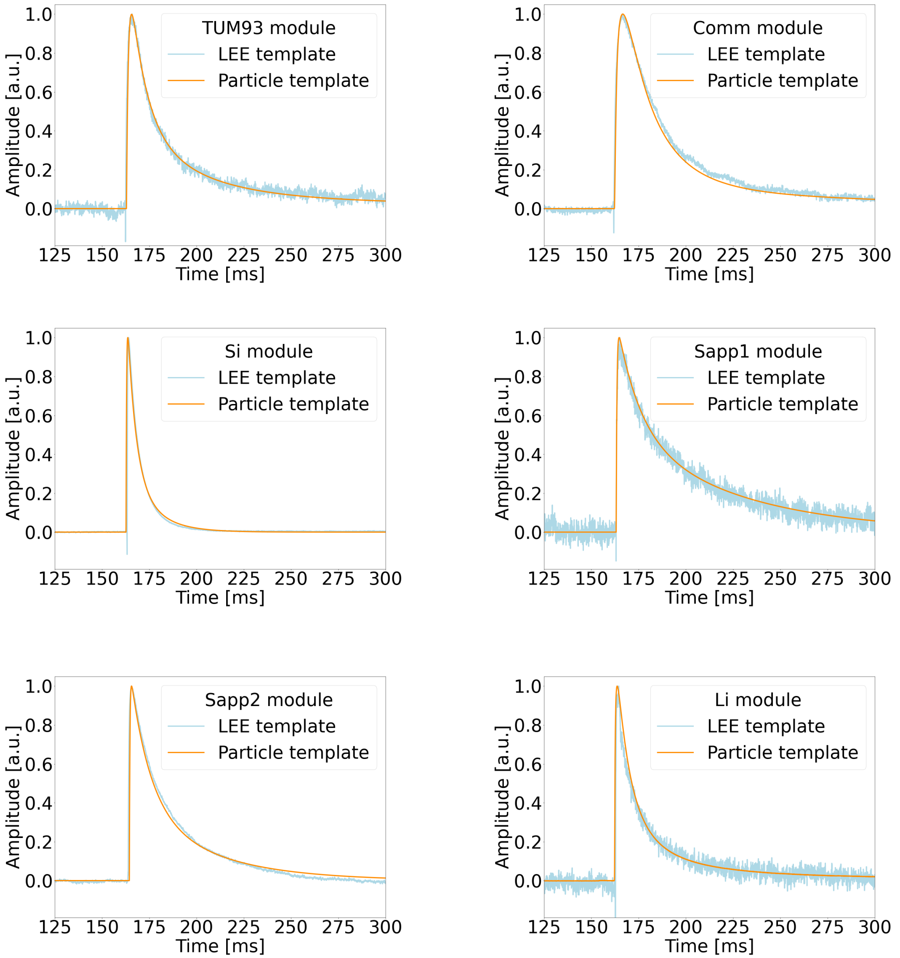
Observations on LEE

CRESST-III runs ongoing to investigate the origin of the background

arXiv:2207.09375 [astro-ph.CO]

From the first observation in 2019:

- Low energy excess events have the same pulse shape as particle events



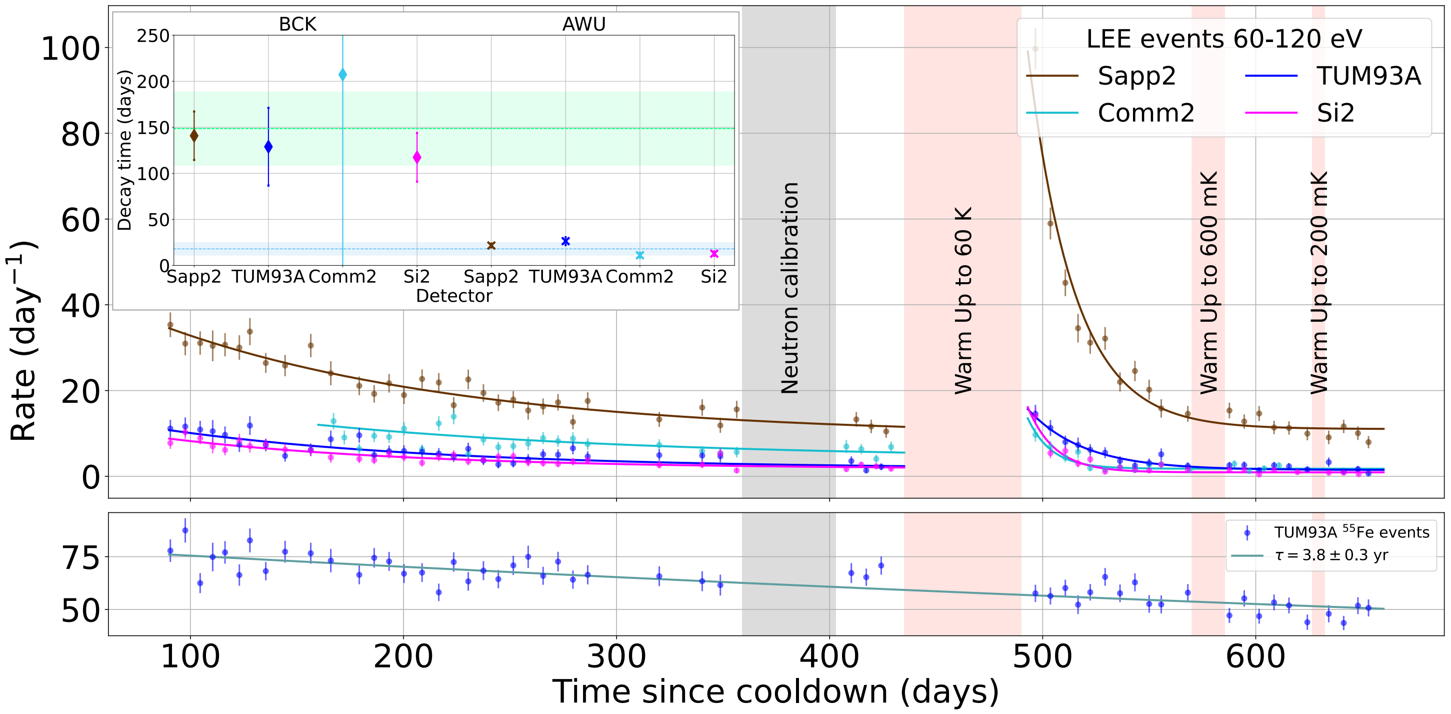
Observations on LEE

CRESST-III runs ongoing to investigate the origin of the background

From the first observation in 2019:

- Diversity of the decay times observed puts tension on a possible interpretation as due to radioactive background
- Time dependence of the rate in the peak of the ^{55}Fe calibration sources not-compatible with the decay of the excess
- Neutron calibration has no effect on the LEE count rate
- Low energy excess can be repopulated with thermal cycles

arXiv:2207.09375 [astro-ph.CO]



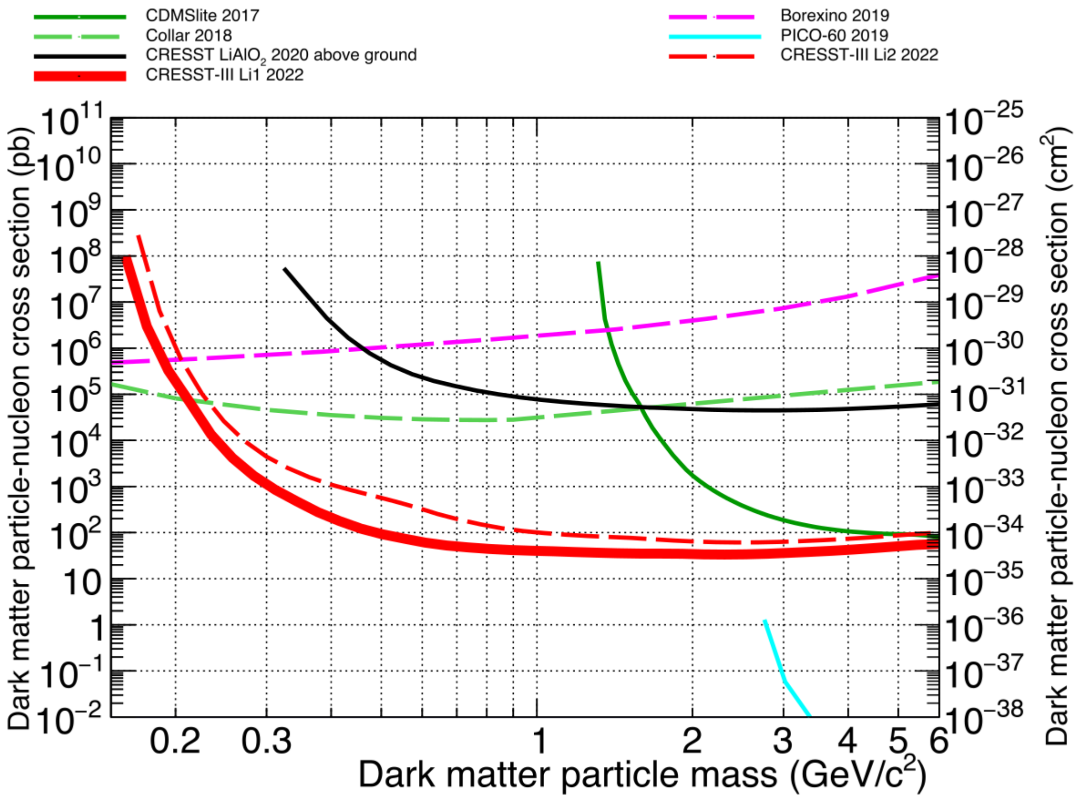
New Dark Matter Results

CRESST

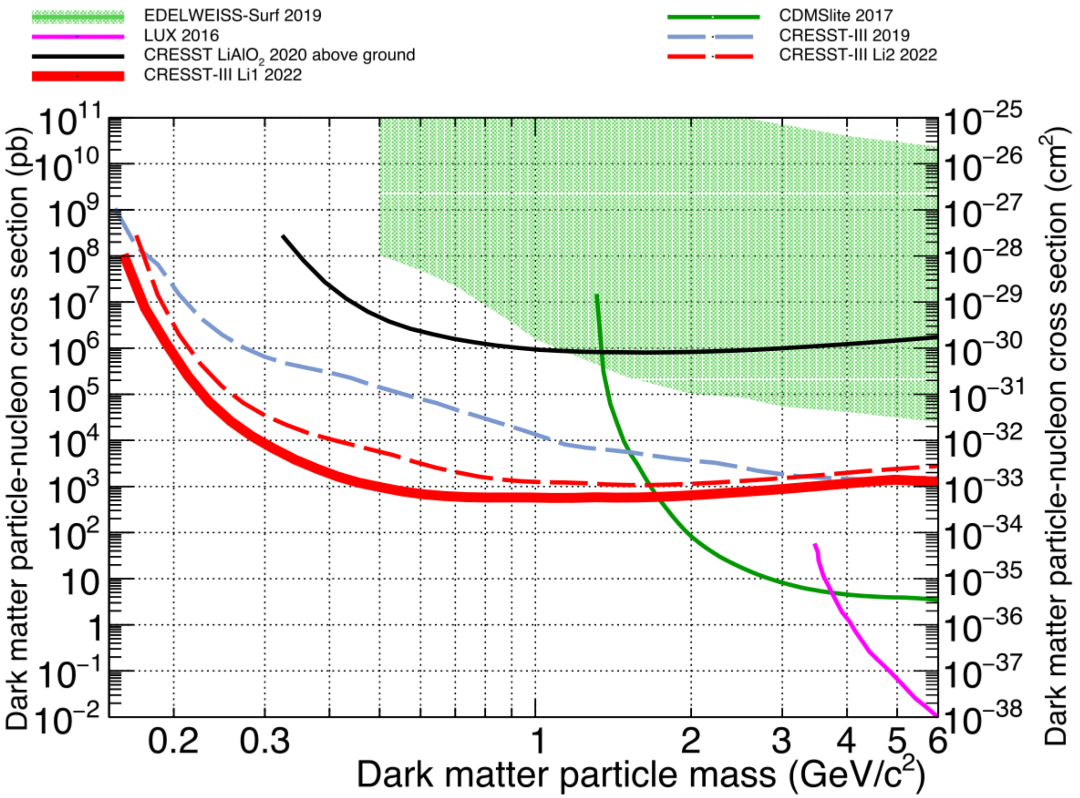
Spin dependent dark matter interactions with $LiAlO_2$ targets in CRESST-III

Phys. Rev. D 106, 092008
arXiv:2207.07640 [astro-ph.CO]

Proton



Neutron

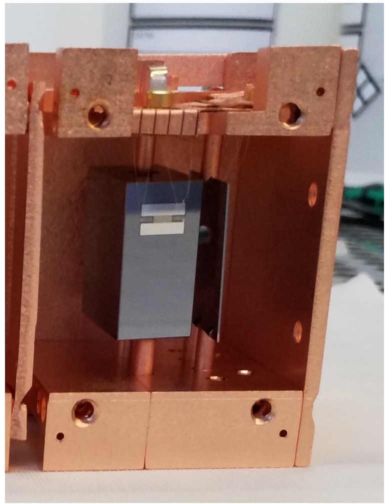


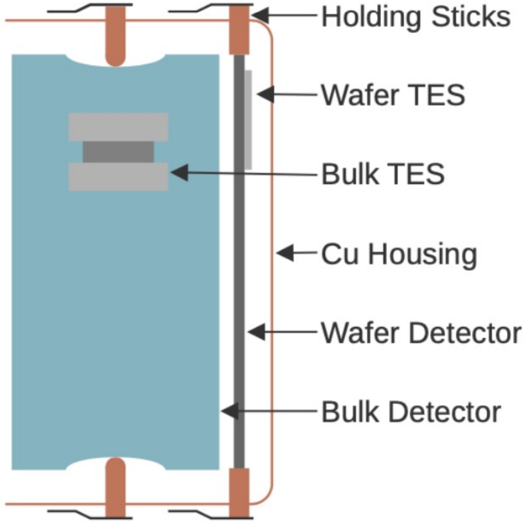
New Dark Matter Results

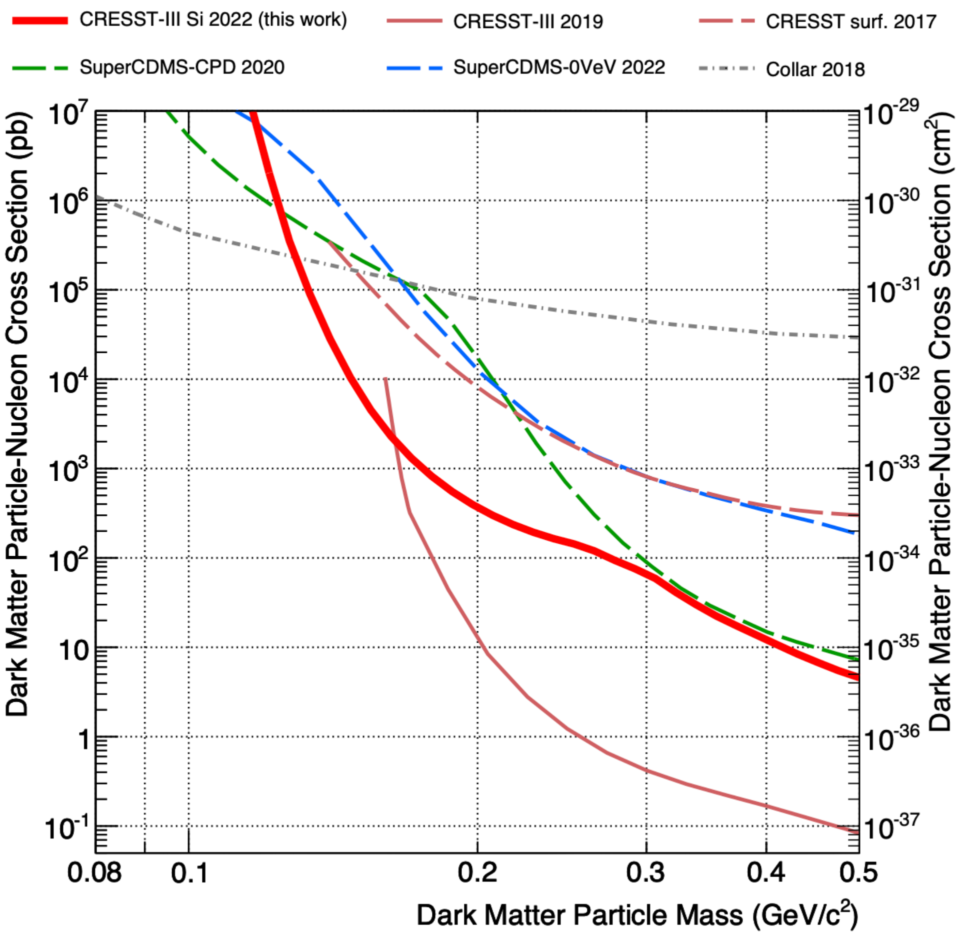
Results on sub-GeV dark matter from a 10eV threshold Si CRESST-III Detector

Accepted for publication: Phys. Rev. D
arXiv:2212.12513 **[astro-ph.CO]**

- 0.35 g Si cryogenic detector
- energy resolution σ_{BL} = (1.36±0.05)eV
- energy threshold E_{th} = (10.0 ± 0.2) eV_{nr}
- total exposure 55 g day







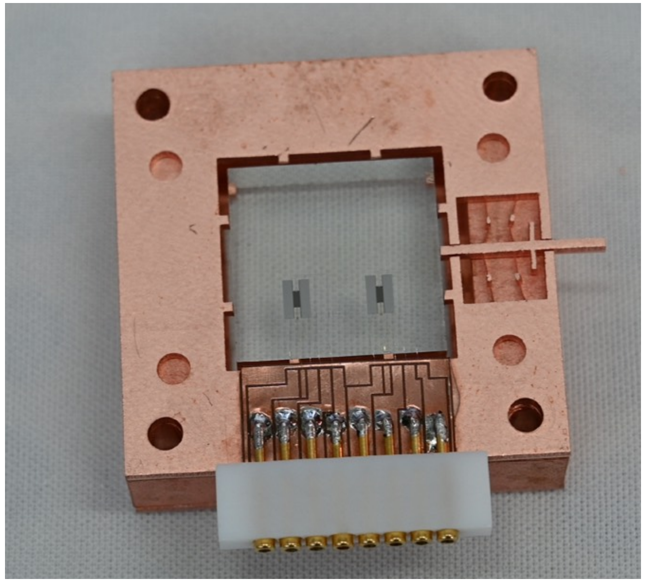
What Next?

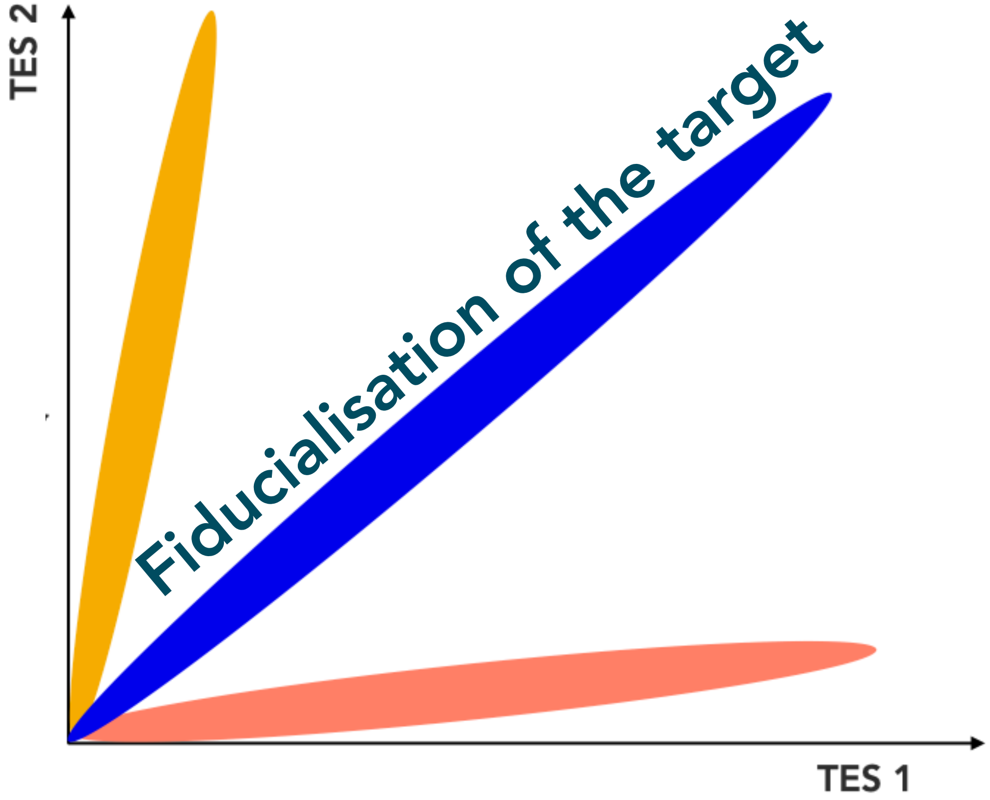
New Detector Design

Details presented at the EXCESS workshop

Hypothesis: LEE related to TES or TES/crystal interface

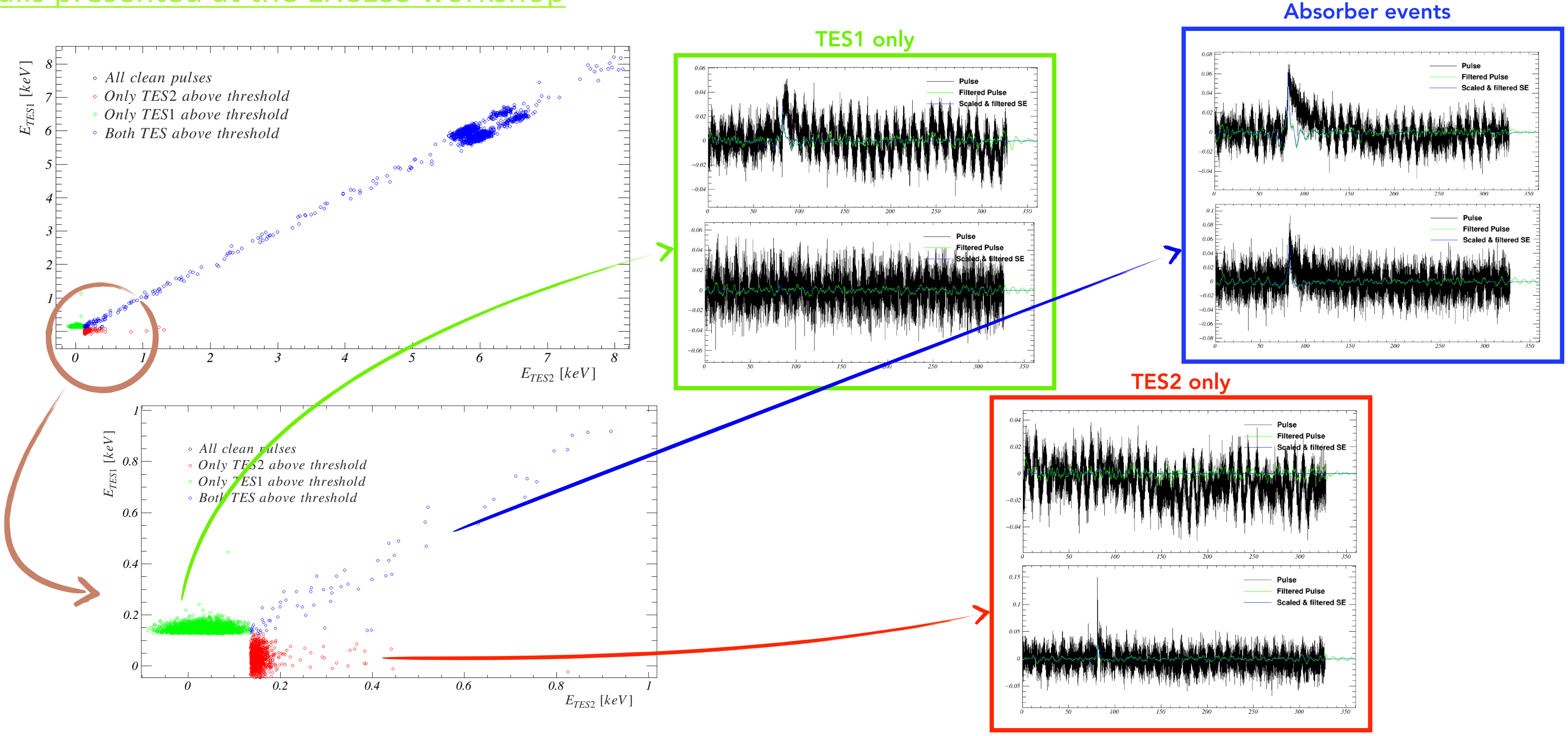
→ Instrument detectors with two sensors





New Detector Design

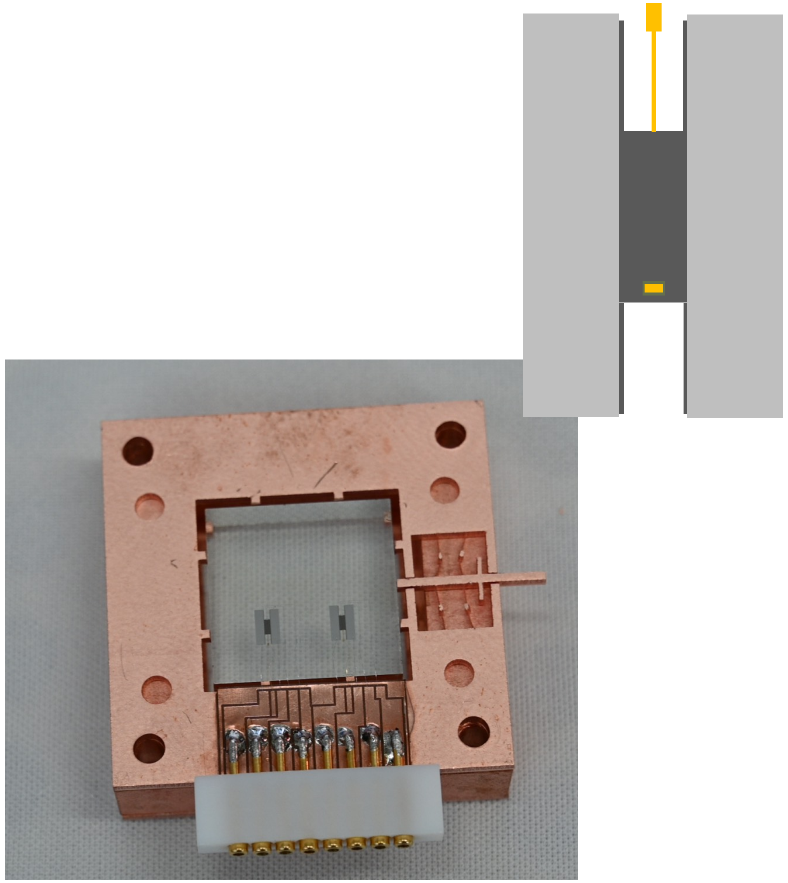
Details presented at the EXCESS workshop



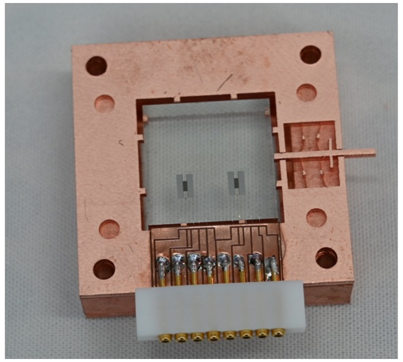
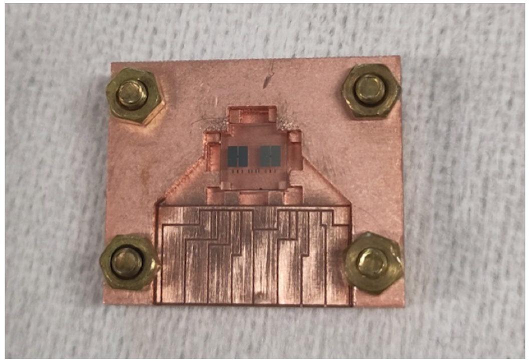
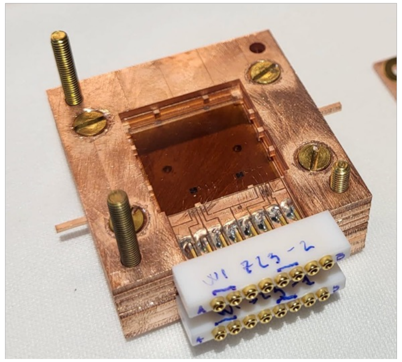
New Detector Design

Details presented at the EXCESS workshop

- High thresholds, $5\sigma_{BL}$ of 137 eV and 148 eV
- Above ground measurement
- Reduction of events at threshold
- Very promising performance and results
- Underground measurement campaign at the test facility of CRESST at LNGS foreseen soon
- DoubleTES modules will be measured in the next CRESST-III measurement run, foreseen to start early 2024



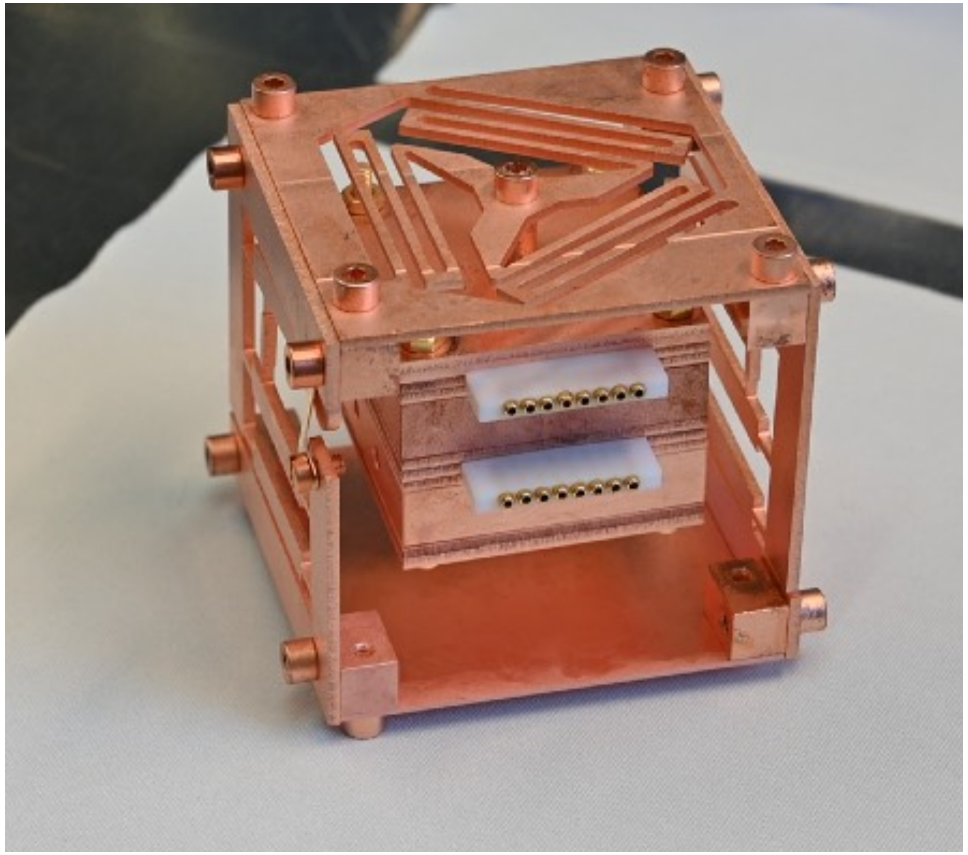
New Detector Design

$CaWO_4$	$Diamond$	$Silicon - on - sapphire$
Two measurements in September and November 2022	Measurement in April 2023	Two measurements in September and October (ongoing) 2023
Above ground, wet cryostat	Above ground, wet cryostat	Above ground, wet cryostat
Two insulated heaters for independent stabilisation	Two insulated heaters for independent stabilisation	Two insulated heaters for independent stabilisation
Gravity-assisted holding scheme	Gravity-assisted holding scheme	Gravity-assisted holding scheme
$20 \times 20 \times 10\ mm^3$	$7 \times 7 \times 2\ mm^3$	$20 \times 20 \times 0.4\ mm^3$
		

Conclusions (so far) from DoubleTES

- All of the tested double TES modules show evidence of energy deposits in single TES
- Single TES events are observed at threshold

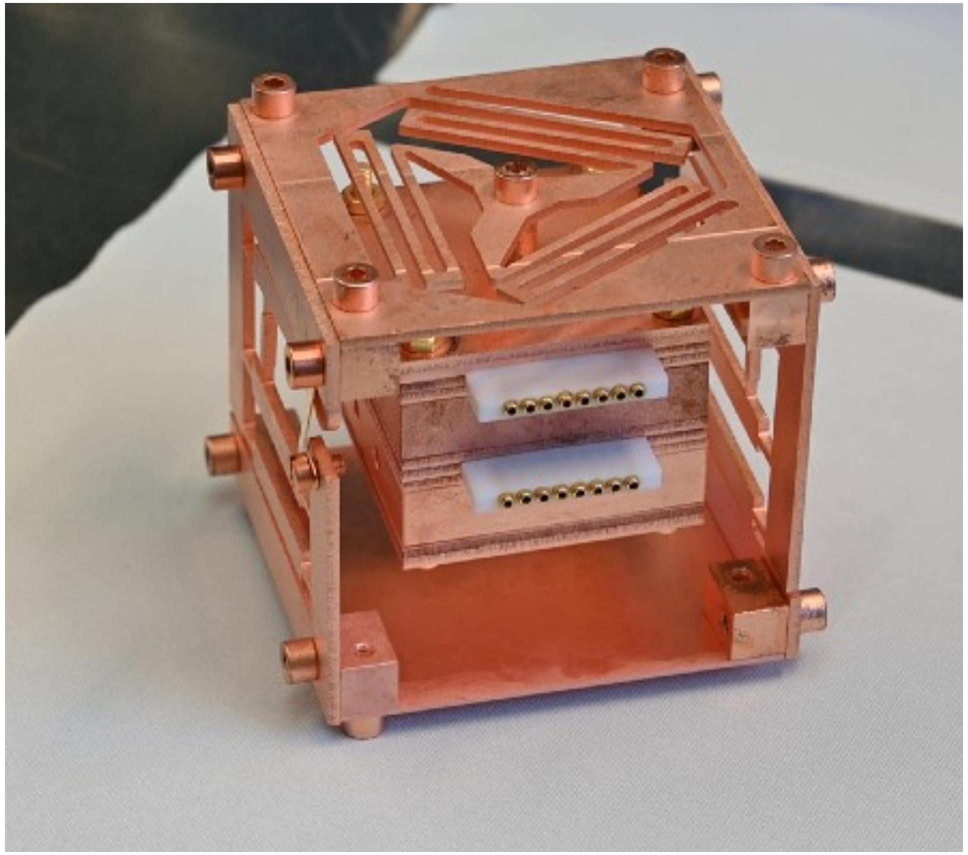
→ Low threshold measurements crucial to deepen our understanding



Next Experimental Run

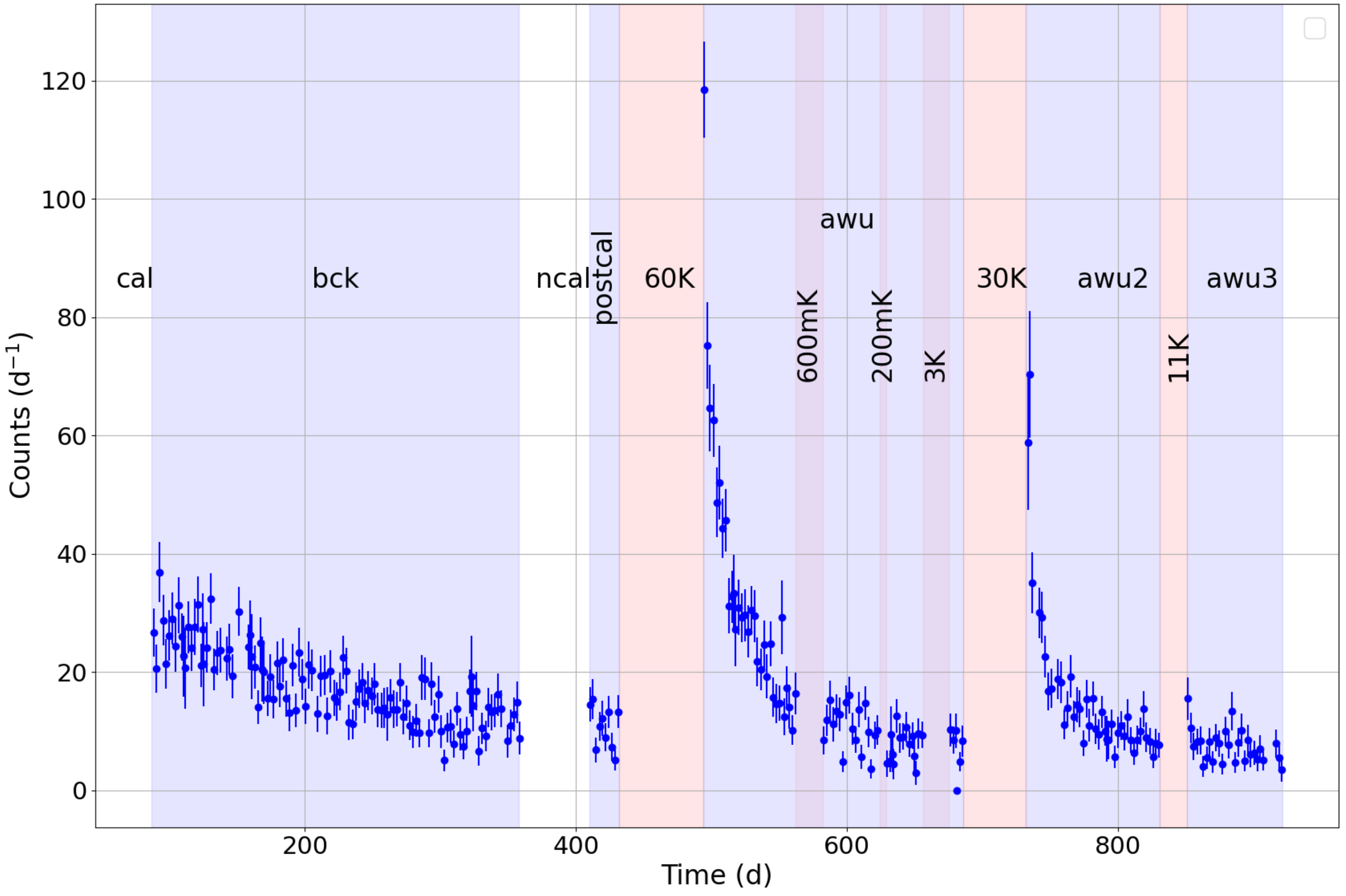
Current data taking ending in 2023

Next underground run starting early next year
- Up to 5 DoubleTES main crystals and light detectors
  - Ready to be installed at LNGS
- Short time needed to assess the presence/behaviour of the LEE
- No ^{55}Fe needed
  - n-capture for *O*(100eV) nuclear recoil calibration



Thank you for your attention!

Observations on LEE



First systematic studies of low energy excess

➔ one step closer to the solution

Observations on LEE

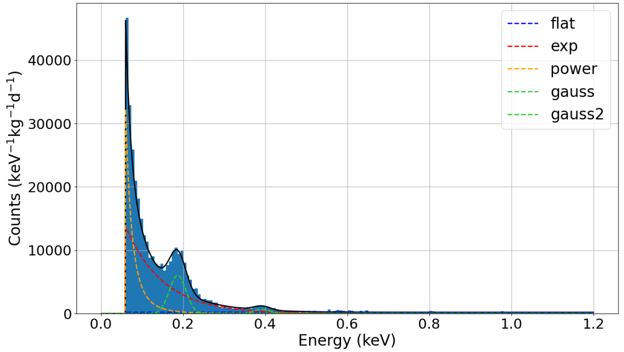
CRESST

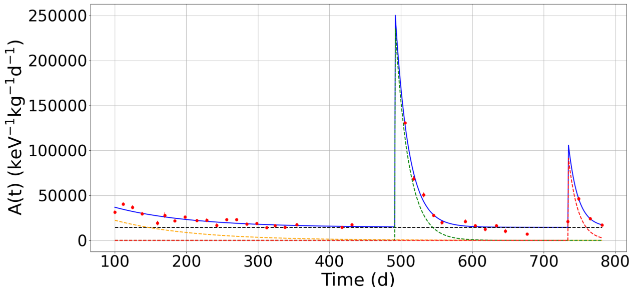
CRESST-III runs ongoing to investigate the origin of the background

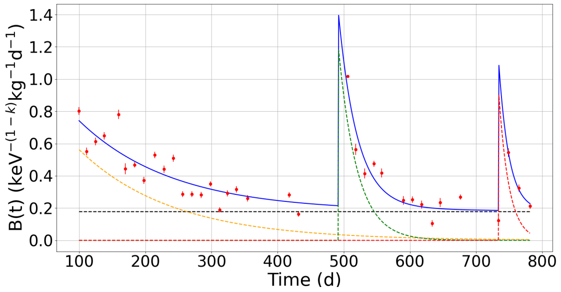
From the first observation in 2019:

- Spectra of low energy excess can be modelled with multiple components
  - Exponential component strongly influenced by warmups
  - Power law component less influenced
  - Power law very prominent at energies directly above threshold
  - Exponential more prominent further away from threshold

$$R(E) = \left(C + A \cdot e^{-E/\lambda} + B \cdot E^{-k} + \sum_{i=1,2} \frac{D_i}{\sqrt{2\pi}\sigma_i} \cdot e^{-\frac{1}{2}\left(\frac{E-\mu_i}{\sigma_i}\right)^2} \right) \cdot \Theta(E - E_{thr})$$







- $\tau_{bck} = (106.7 \pm 28.7)$ d
- $\tau_{awu} = (18.75 \pm 1.45)$ d
- $\tau_{awu2} = (13.46 \pm 4.61)$ d

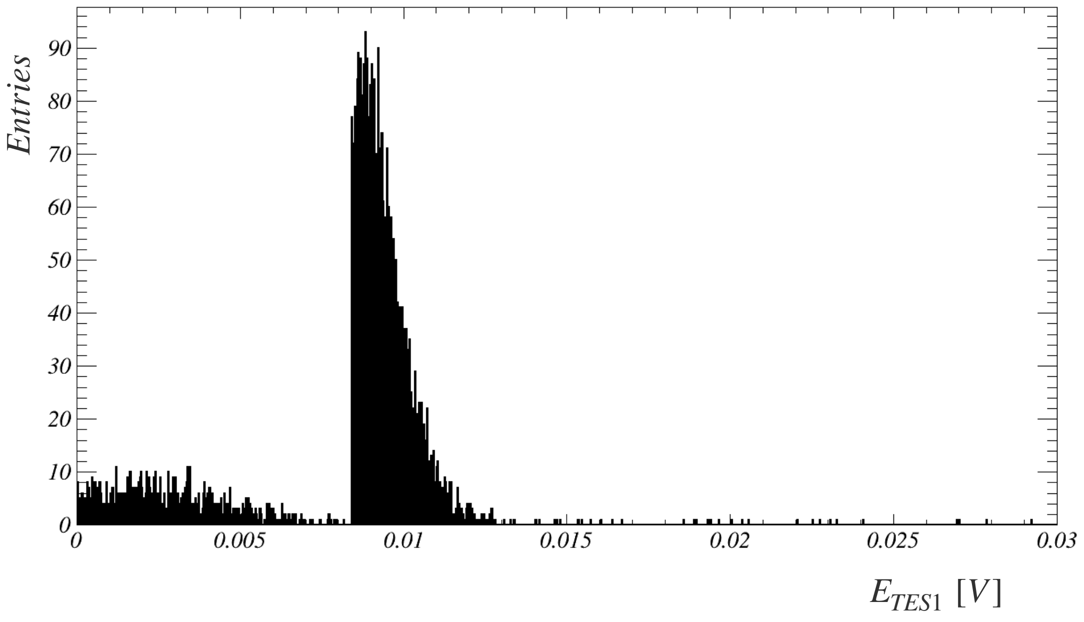
- $\tau_{bck} = (141.6 \pm 35.9)$ d
- $\tau_{awu} = (28.36 \pm 7.08)$ d
- $\tau_{awu2} = (15.59 \pm 9.90)$ d

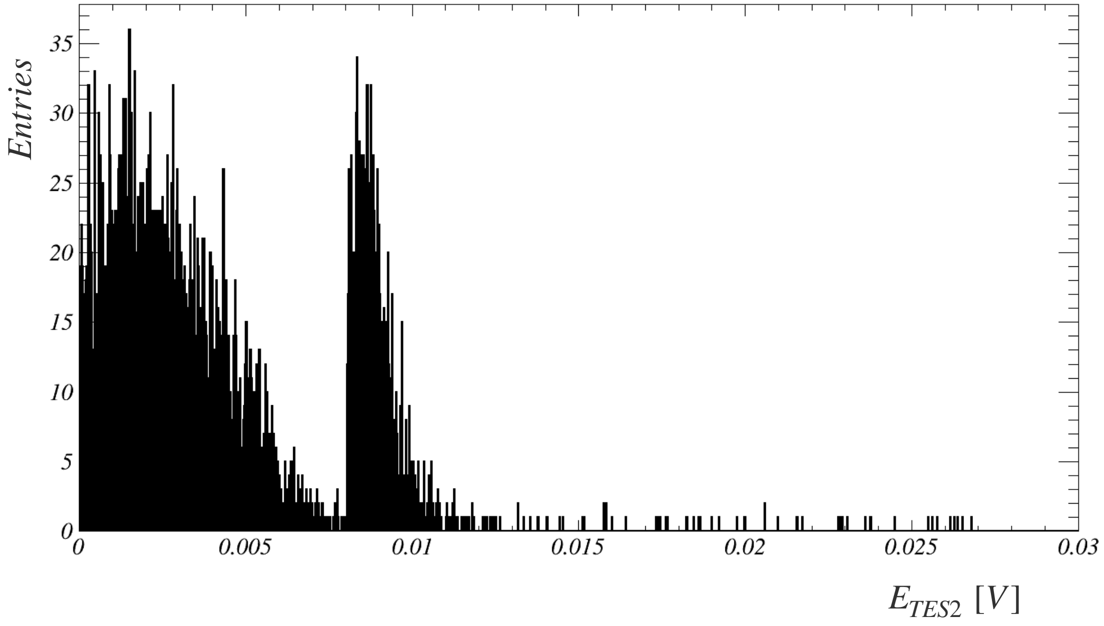
New Detector Design

CRESST

Details presented at the EXCESS workshop

- Non calibrated spectra below threshold
- Spectra not corrected with efficiency

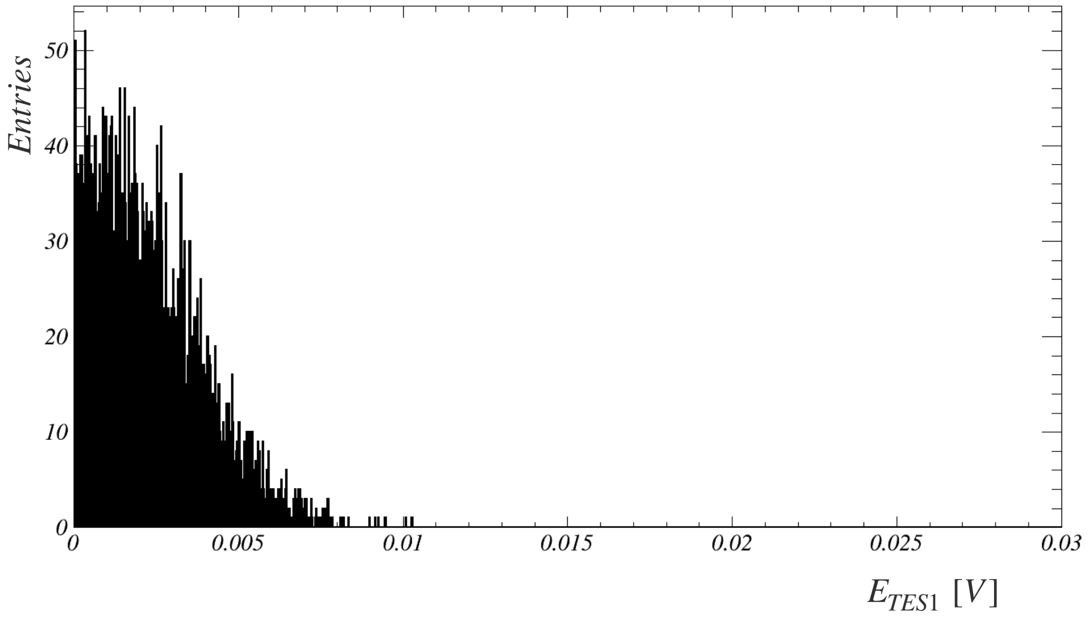


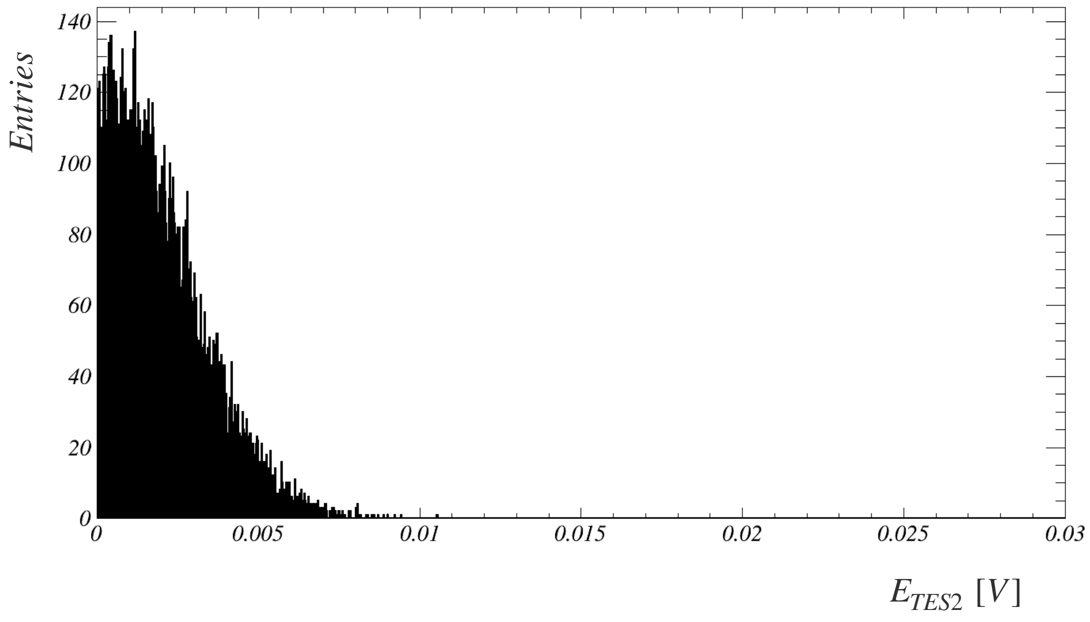


New Detector Design

Details presented at the EXCESS workshop

- Inverted stream analysis: non calibrated noise spectra from empty baselines





Calibration Of sub-keV Nuclear Recoils

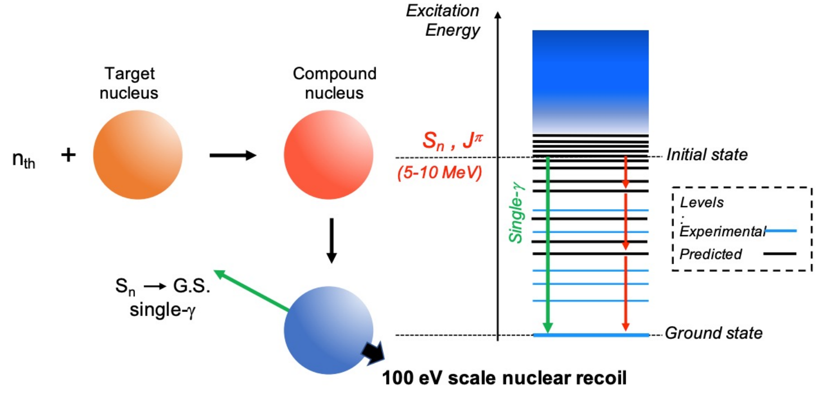
CRESST

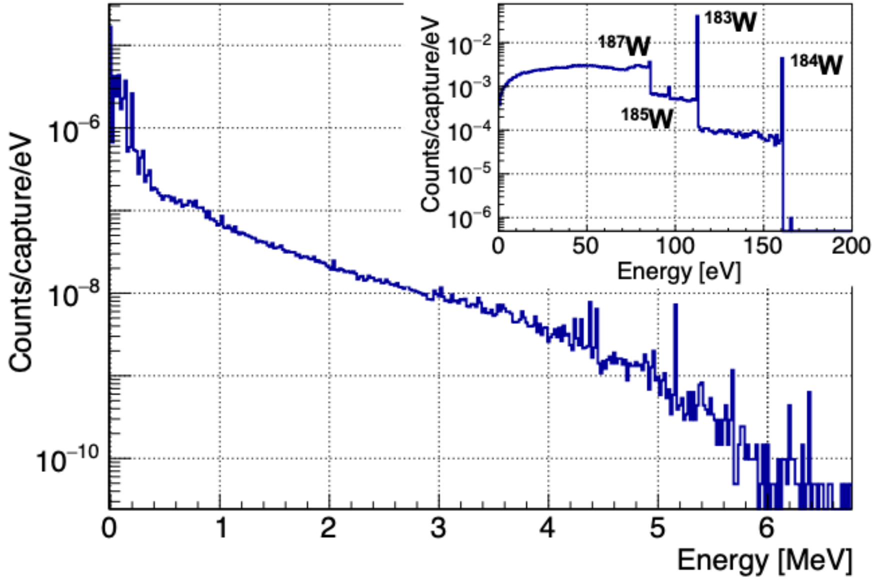
L. Thulliez *et al* 2021 *JINST* **16** P07032

Nuclear recoils induced by the capture of thermal neutrons can allow an accurate energy calibration in the energy range of *O*(100 eV).

In $CaWO_4$ crystals, thermal neutrons captured by W isotopes provide nuclear recoils in the range [80-160] eV.

Target nucleus (A)			Compound nucleus ($A+1$)		
Isotope	Y_{ab} [24] (%)	$\sigma_{n,\gamma}$ [25] (barn)	S_n [26] (keV)	I^s_γ [26, 27] (%)	Recoil (eV)
^{182}W	26.50	20.32	6191	13.94	112.5
^{183}W	14.31	9.87	7411	5.83	160.3
^{184}W	30.64	1.63	5754	1.48	96.1
^{186}W	28.43	37.89	5467	0.26	85.8





Experimental realization: commercial neutron source (activity in the range of *O*(MBq)) properly moderated and shielded, faced to cryogenic $CaWO_4$ detector.

CRESST calibration with W recoil

CRESST

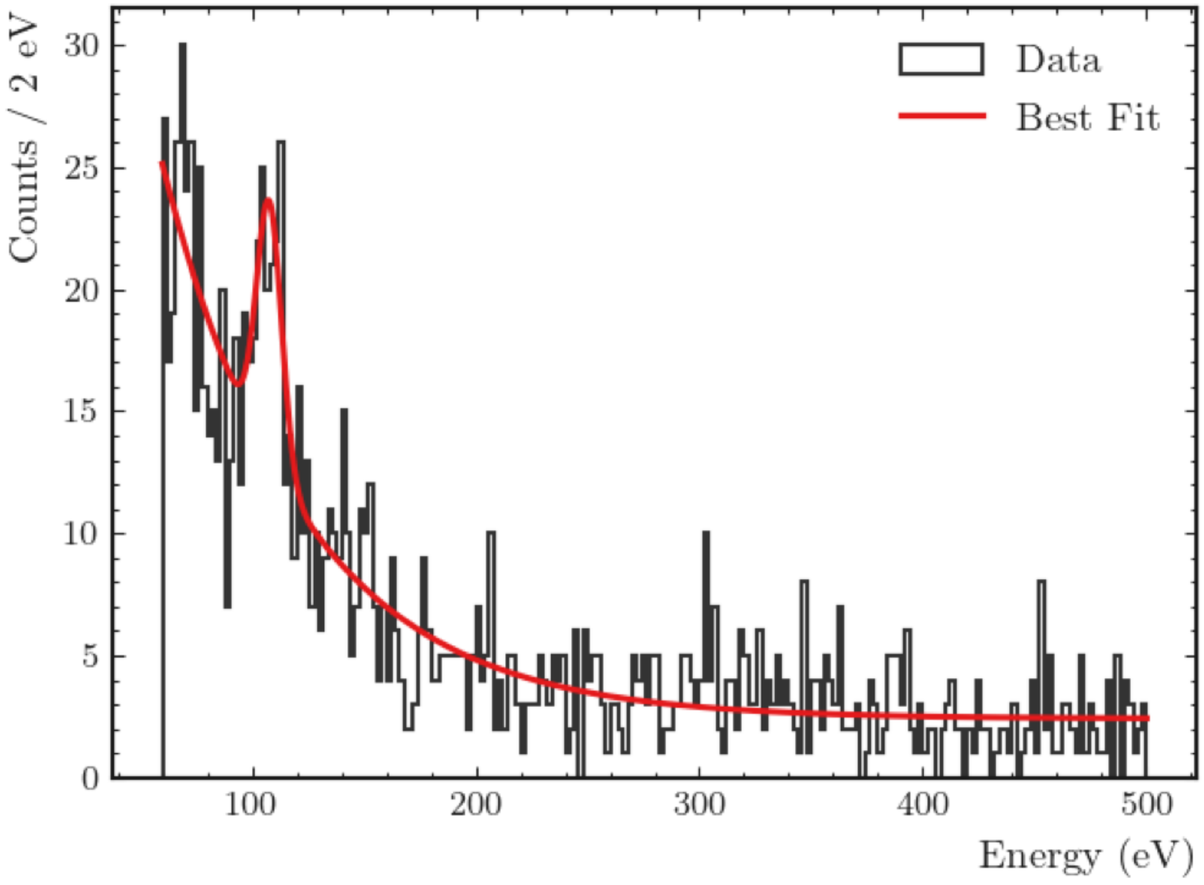
Observation of a low energy nuclear recoil peak in the neutron calibration data of the CRESST-III Experiment

arXiv:2303.15315 **[physics.ins-det]**

- Reliable method for sub-keV calibration without internal sources

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

- Calibration of the crystal volume
- Verification of the n-recoil energy scale down to 100eV
- Analogous peak at 1144eV for ^{27}Al visible in Sapphire



The CRESST-III Programme

Upgrade of CRESST-III to read-out 288 channels

Background
2021-2023:
Experimental campaign to pinpoint the origin of background

Readout
2021-2022:
Finalized procurement of:

- SQUID read-out electronics (MPG central funds)
- low T wiring

2024:
Installation inside CRESST facility at LNGS

Detector R&D
2021-2023:

- lower threshold
- complementary materials
- high production rate

2024:

- production and testing of detectors