Double-TES detector

A design & sensitivity study

On behalf of the CRESST collaboration

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

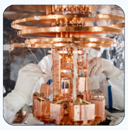
Danaé Valdenaire (MBI, TU Wien)
danae.valdenaire@oeaw.ac.at

IDM2026 ZARAGOZA

1 The CRESST experiment

CRESST (Cryogenic Rare Event Search with Superconducting Thermometers) is a **cryogenic dark matter experiment** operated at the **Laboratori Nazionali del Gran Sasso** (LNGS) in Italy.

- Located **1400 m underground**, reducing cosmic **muon flux by ~10^6**.
- Complemented by **passive shielding** and an **active muon veto**.
- Operating since 2000, wide range of target crystal from sapphire **(Al_2O_3)**, **calcium-tungstate** **$CaWO_4$** and **silicon-on-sapphire (SOS)**.
- Continuous **threshold** improvements, reaching **30 eV [1] ($CaWO_4$)** and 6.7 eV **(SOS) [2]**.



[1] Phys. Rev. D 100, 102002 (2019), [2] Phys. Rev. D 110, 083038

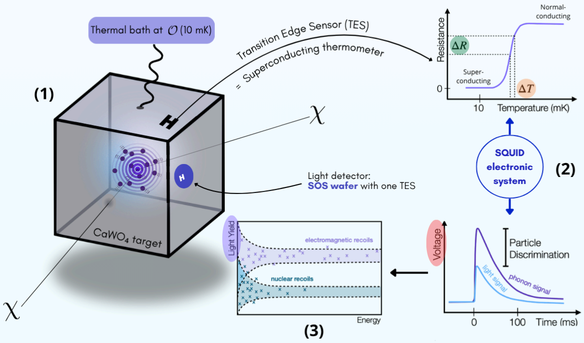
2 Detection principle

The experiment aims to **detect dark matter–nucleus interactions** using scintillating crystals operated at **millikelvin** (mK) temperatures equipped with **transition edge sensors** (TESs) to measure **phonon signals**, complemented by the simultaneous detection of scintillation light.

(1) **Particle interaction** in the crystal → **energy deposition** → **lattice vibration** (phonons) + scintillation light.

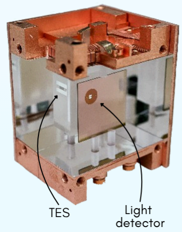
(2) Temperature rise ΔT(mK) → **TES resistance rise ΔR**(mΩ) → **Current variation ΔI** → **Induced magnetic field** measured by the **SQUIDs** → **Conversion** to voltage.

(3) The **ratio** of the **energy deposited** in the light detector (L) to the **total phonon energy** (E_p) is used for **particle discrimination (Light yield = L/E_p)**.



Standard $CaWO_4$ CRESST detector

- **Target crystal** equipped with a **W-TES** for **phonon** detection.
- Paired with a **light detector**: a **thin silicon-on-sapphire** (SOS) wafer also instrumented **with a W-TES.**
- **Both channels** equipped with a **resistive heater** to maintain their **operating point.**



3 Low energy excess

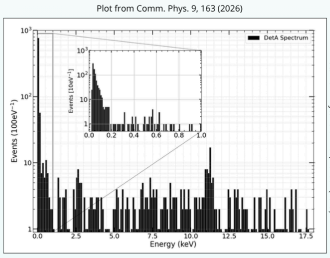
The **low-energy excess** (LEE) is an exponential rise of particle-like events **below 200 eV**. CRESST sensitivity is limited because of the presence of this population whose **origin is unknown**.

The LEE is **not consistent** with a **dark matter** origin:

- **Rate** and **spectral** shape **vary** between modules and materials.
- A **warm-up/thermal cycle** can **reset** the excess.
- Observed by multiple collaborations (EDELWEISS, SuperCDMS,...) [3]

[3] SciPost Phys. Proc. 9, 001 (2022)

Plot from Comm. Phys. 9, 163 (2026)



Hypothesis

A part of LEE events could come from a **stress release** at the **interface** of the **crystal** and the **TES**, or **within** the **TES** itself, while real **particle events** are generated **in the bulk**.
→ We need to **discriminate** bulk events from **surface events.**

→ Proposition: separate bulk from **surface/interface** events using **a second TES** on the crystal.

See **Judith Dohm's** poster for more about the LEE

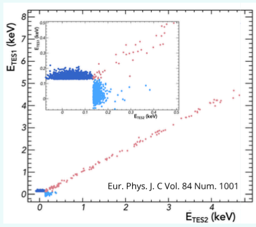
5 Double-TES above-ground measurement

First **above-ground measurement done at the Max Planck Institute of Physics in Munich (MPP)** with a **20x20x10 mm³ $CaWO_4$** crystal with two **^{55}Fe sources** for energy calibration.

TES1: baseline resolution σ (27.1 ± 0.3) eV, energy resolution (117 ± 3) eV at 5.9 keV
TES2: baseline resolution σ (29.6 ± 0.3) eV, energy resolution (128 ± 2) eV at 5.9 keV

- **Shared-band cut:** selecting **only events** where both TESs record a **comparable energy** deposition.
- The **energy resolution** from **both TESs** combined improves to **(81 ± 2) eV at 5.9 keV**.

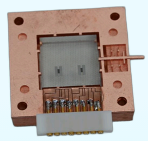
→ This **first** above-ground **measurement** demonstrates the **double-TES ability** to **discriminate** between **bulk** and **surface events**.

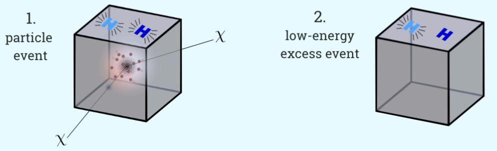


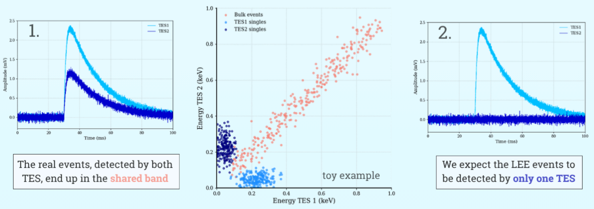
4 Double-TES detectors

Two identical W-TESs are fabricated on the **surface** of a **$CaWO_4$ crystal**

- **Same production process for uniform performance** & independently read out.
- Each **heater** is sitting on its **TES**, and **separated** by a 350 nm SiO_2 layer to **minimise thermal crosstalk**.
- The crystal is in a **copper holder** held only by its **own weight**, to not induce any extra stress.



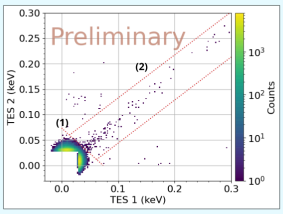




6 Double-TES underground measurement

Results from a **24g $CaWO_4$ target crystal** with double-TES read-out (double-TES2) operated in LNGS.

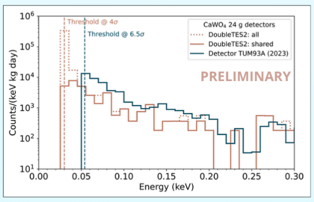
- The **baseline resolution σ** of each TES is approximately 7 eV.
- The **energy resolution** is in the **same order** as the **baseline resolution** in the low-energy region.
- The **trigger threshold** is set at **4 times** the **baseline resolution σ**.
- **(1)** The **population detected in one TES only** is removed by applying $E_{\mathrm{TES2}} + E_{\mathrm{TES1}} > 5\,(\sigma_{\mathrm{TES2}} + \sigma_{\mathrm{TES1}})$.
- **(2)** The width of the band is defined as ±5σ around the fitted line $E_{\mathrm{TES2}} = p_0 + p_1 \cdot E_{\mathrm{TES1}}$.



→ **Rate comparison** of a single-TES detector with similar baseline resolution σ (TUM93A) and double-TES2.

- Reduction of LEE by **~2 orders of magnitude** after the **shared-band cut.**
- With **same** number of **noise triggered events** and **same σ**, the **double-TES** reaches a **significantly lower threshold.**

→ This demonstrates that the **double-TES feature** is a **powerful tool to reduce the LEE** while **pushing** the detector **threshold** to lower energies.



7 Conclusion & outlook

- **Double-TES detectors** have demonstrated **powerful reduction** of LEE events.
- Enable **lower detector thresholds** → promising for next-generation cryogenic detectors.
- LEE is **reduced** but **still visible** and its **origin remains unknown**. Research is ongoing **across the community** to study more closely its **shape** & **behavior**.

- **Next step:** finalise analysis to derive **the first dark matter sensitivities** for **double-TES detectors** by CRESST.
  → A **publication** is in preparation

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