Direct Dark Matter Search with the CRESST III Experiment

Status and Prospects

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on behalf of the CRESST collaboration
July 10, 2024

Max-Planck-Institute for Physics

The CRESST Collaboration

Cryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers

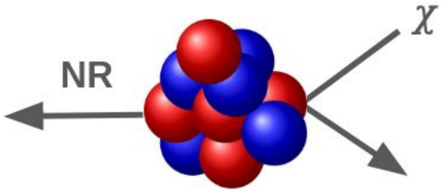
~60 members
9 institutions
5 countries

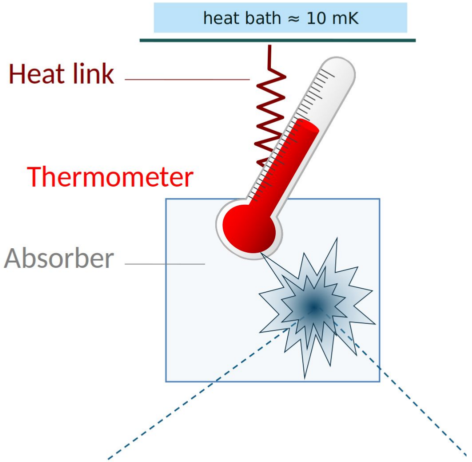
Located at LNGS

COMENIUS UNIVERSITY BRATISLAVA
UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386
HEPHY INSTITUTE OF HIGH ENERGY PHYSICS
TU WIEN
INFN LNGS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Gran Sasso
MAX PLANCK INSTITUTE FOR PHYSICS
EBERHARD KARLS UNIVERSITÄT TÜBINGEN
UNIVERSITY OF OXFORD
TECHNISCHE UNIVERSITÄT MÜNCHEN

The CRESST Experiment

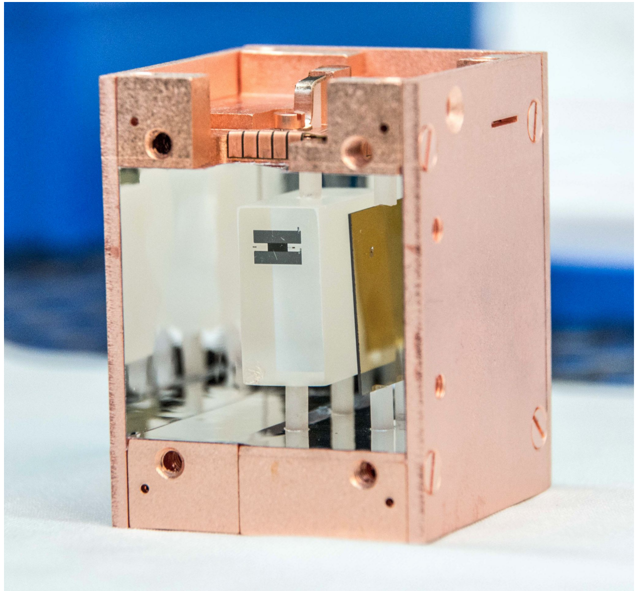
- Detects potential DM particles via scattering off nuclei
- A particle interaction causes an energy deposition in the crystal
  $\rightarrow \Delta T = \Delta E/C$
- Temperature measurement via Transition Edge Sensor (TES)





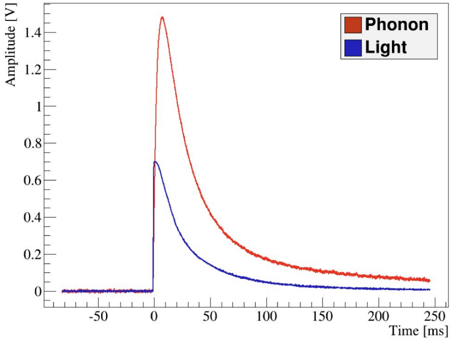
CRESST III Detectors

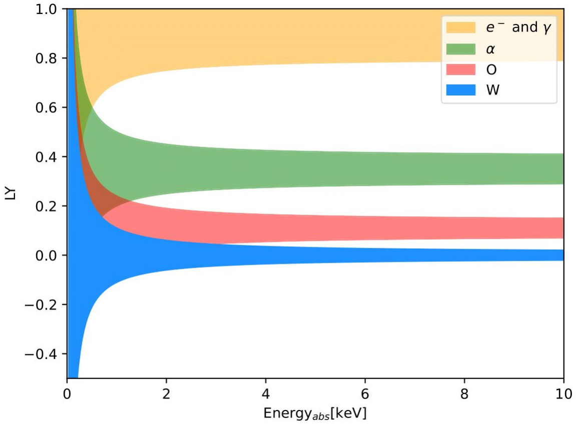
Aimed at detecting sub-GeV DM



Standard Detector:

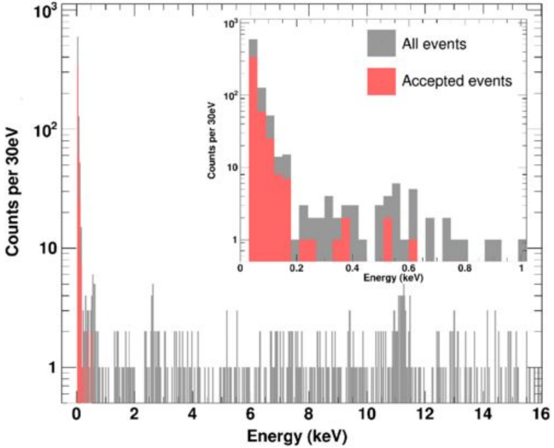
- Scintillating crystal ($CaWO_4$) as main absorber (2x2x1) cm^3
- Additional light detector for active background discrimination
- Simultaneous readout of both channels





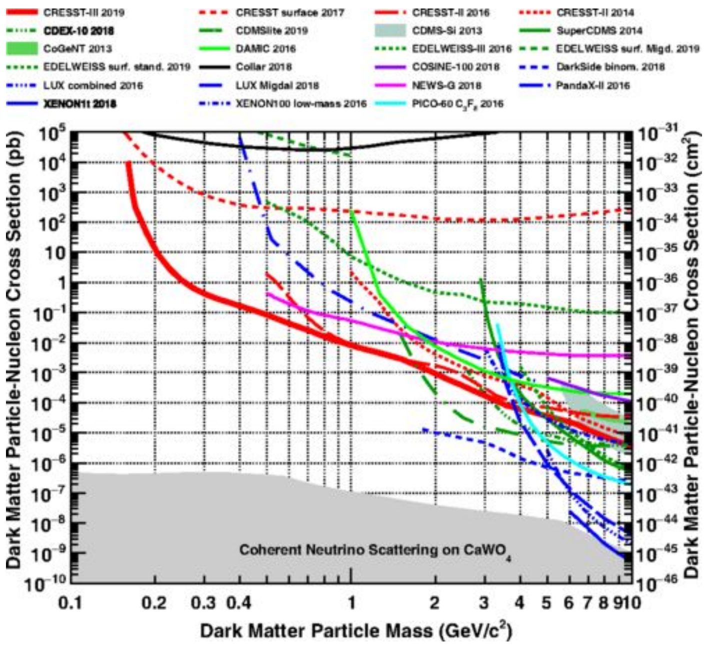
Reaching Low Energies

- Thanks to the CRESST III detector design we reached an energy threshold of **30.1 eV**



We observed an excess of events of unknown origin
“Low Energy Excess”

Phys. Rev. D 100, 102002



- Following run → dedicated **modifications** to the standard CRESST III detector design
→ probe possible LEE origins

Sensitivity at low masses limited by LEE

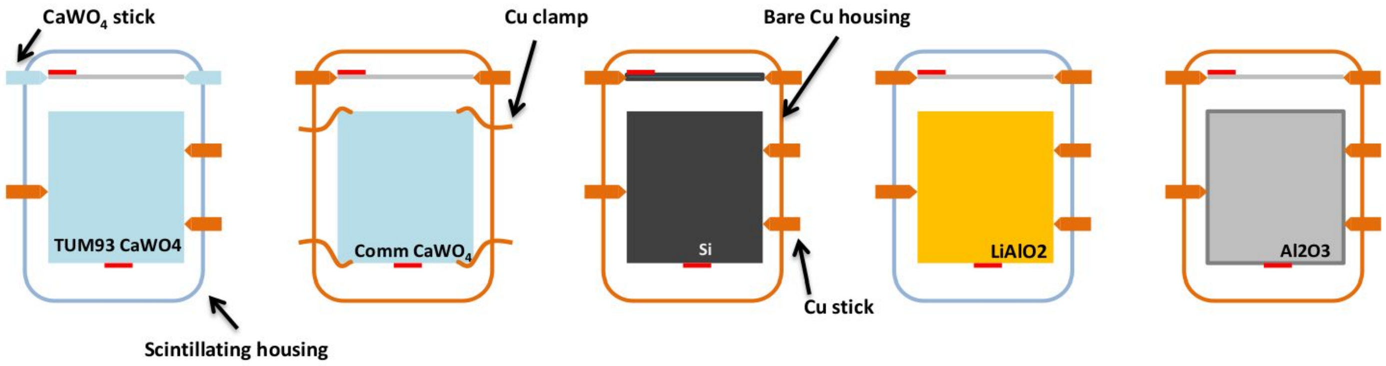
Possible Origins of the LEE

Related to target material?

Depending on crystal growth parameters?

Related to scintillating materials?

Dedicated modifications:



Caused by holder stress?

Depending on detector geometry?

Possible Origins of the LEE

Related to target material?

Tested several materials

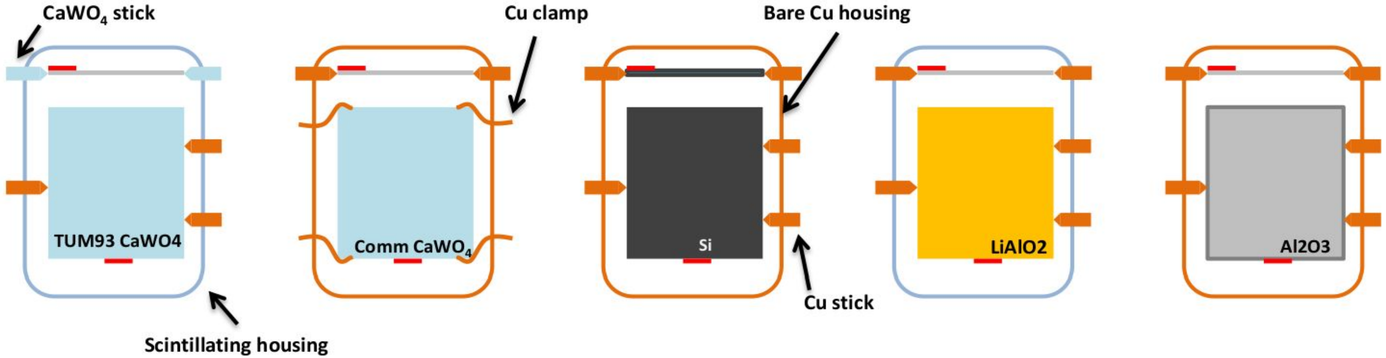
Depending on crystal growth parameters?

Tested slow grown crystal

Related to scintillating materials?

Removed scintillating materials

Dedicated modifications:



Adopted different holding mechanisms

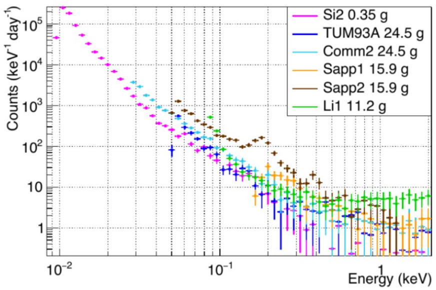
Caused by holder stress?

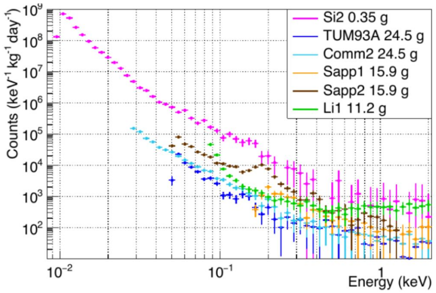
Analyzed LEE in a wafer detector

Depending on detector geometry?

LEE Energy Spectrum

arXiv:220709375v2





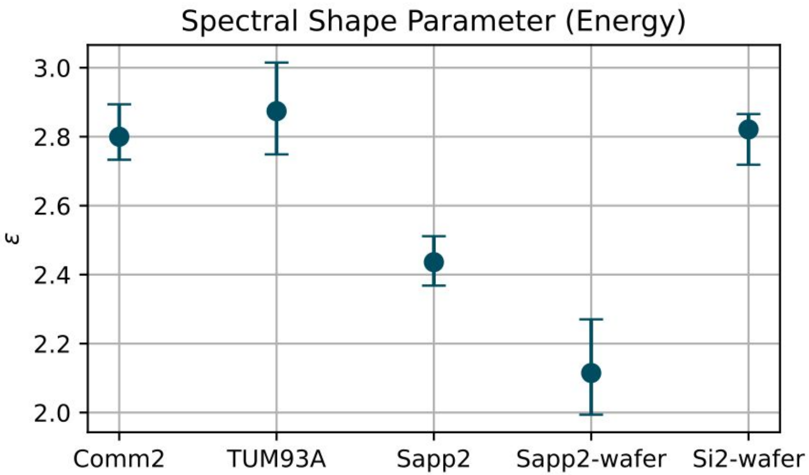
The LEE is observed in every material and geometry

Rate does not scale with mass

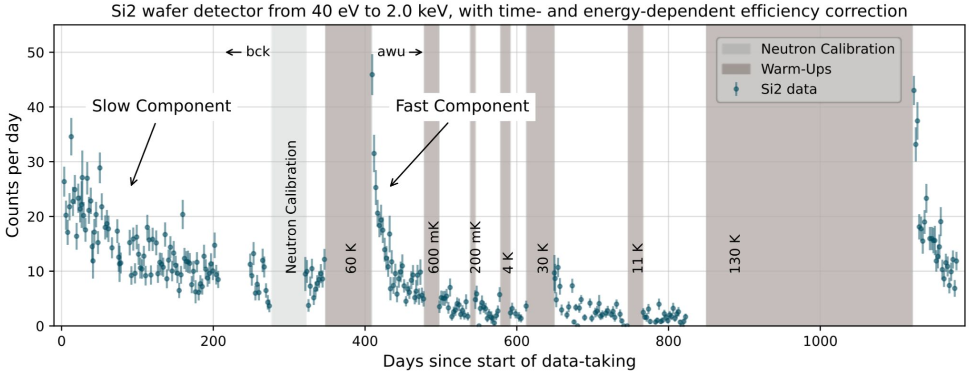
None of the modifications had a significant impact on the LEE

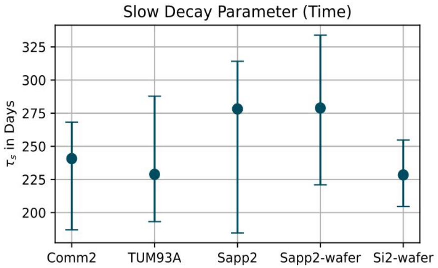
The spectral shape is well described by a power-law

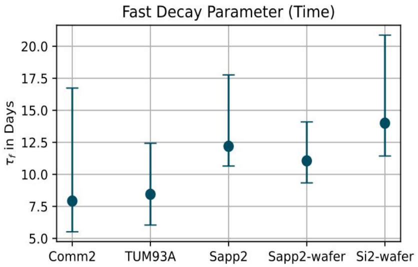
$$\boxed{N(E,t) = C + E^{-\varepsilon}}$$



LEE Time Dependence







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

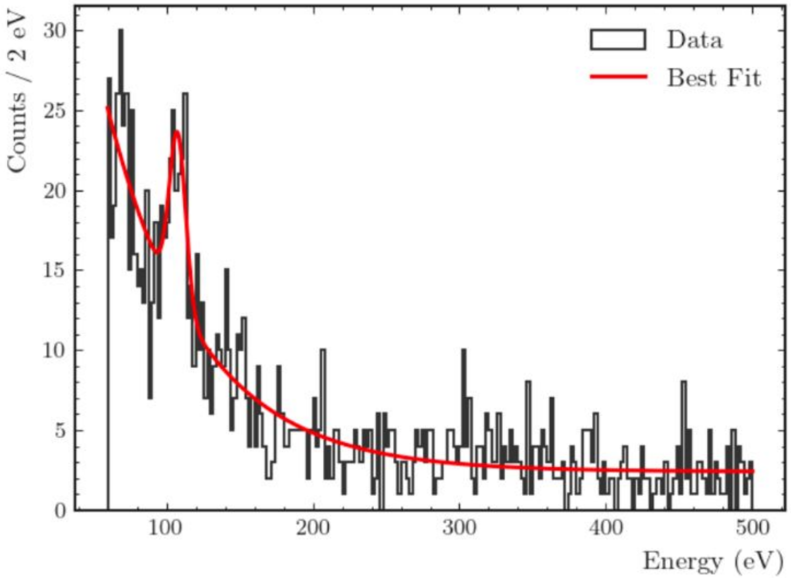
More details on poster by Sarah Kuckuk

New Calibration: Neutron Capture

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

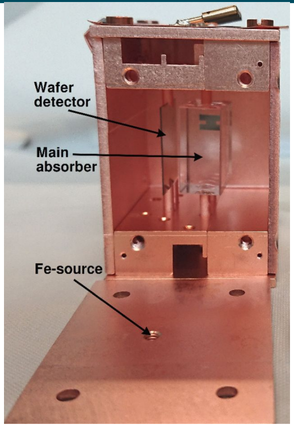
$^{182}W(n,\gamma)^{183}W$

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

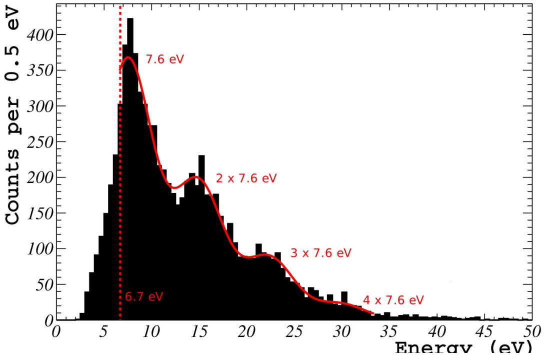
New Calibration: Sapphire VUV Luminescence



New calibration:
vacuum ultraviolet (VUV) luminescence **@7.6 eV** from the nearby sapphire crystal is observed in the wafer

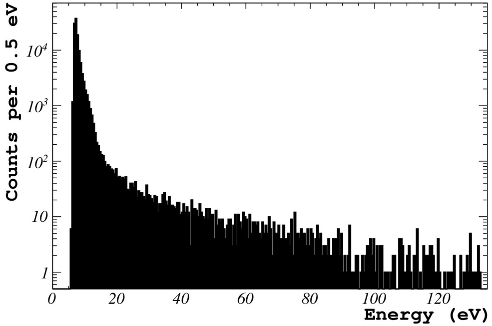
arXiv:2405.06527

Iron events

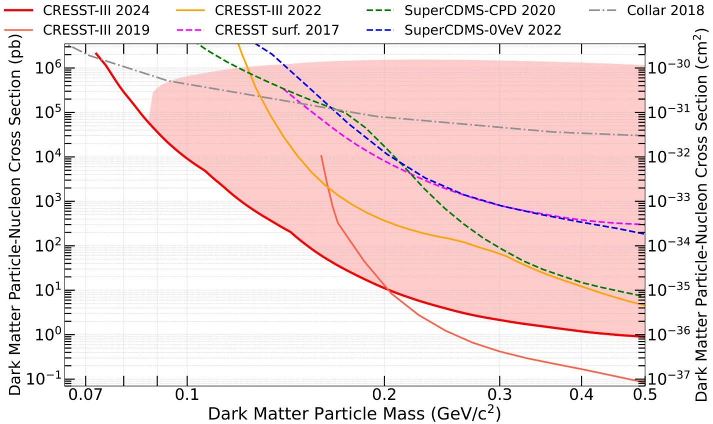


Single photon detection @N x 7.6 eV

Calibrated spectrum



Spin-Independent exclusion limits → probe new parameter space



Spin Dependent Limits

	$LiAlO_2$	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

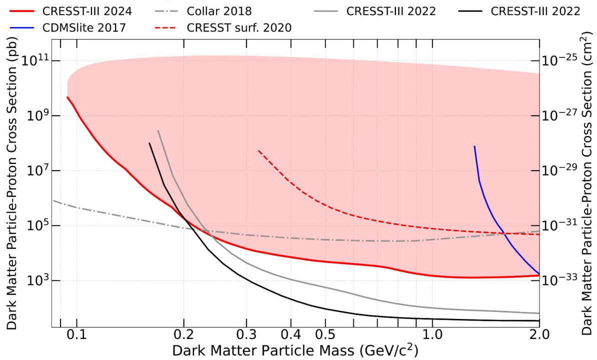
- Contains ^{6}Li, ^{7}Li, ^{27}Al
- High $\langle S_{p/n} \rangle$ values
  → high sensitivity

Sapphire

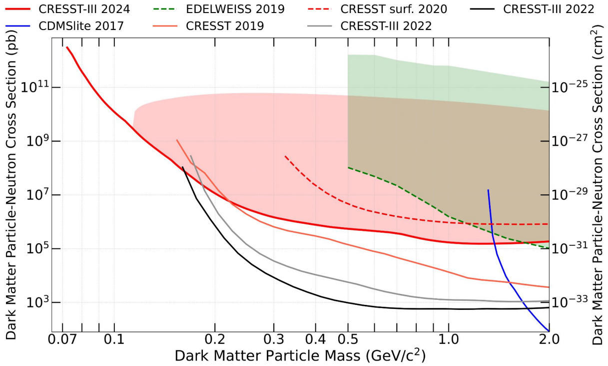
- Contains ^{27}Al
- Low energy threshold
  → sensitive to very low DM masses

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

proton-only



neutron-only



arXiv:2405.06527 — sapphire

Phys. Rev. D 106, 092008 — lithium aluminate

DM Self Interaction Limits

DM self interaction → 2 DM particles can build a **darkonium** state

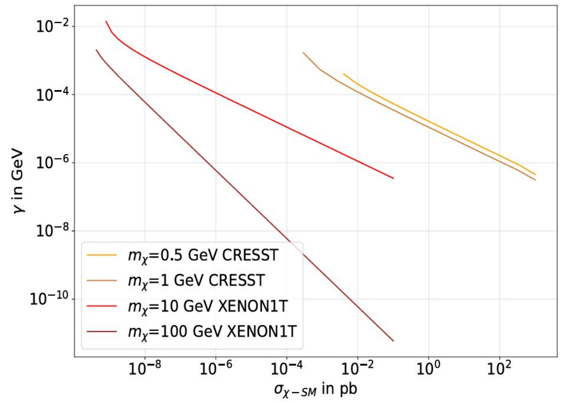
New differential cross-section ➡

$$\left(\frac{d(\sigma v)}{dE_R}\right)_{A+2} = \frac{2m_A}{\pi v}\cdot\frac{\pi\sigma_{SI}A^2F_N^2(q)}{\mu_n^2}\cdot\left|\frac{4\gamma}{q}\tan^{-1}\left(\frac{q}{4\gamma}\right)\right|^2\Theta(v-q/2\mu_2)$$

γ = inverse scattering length

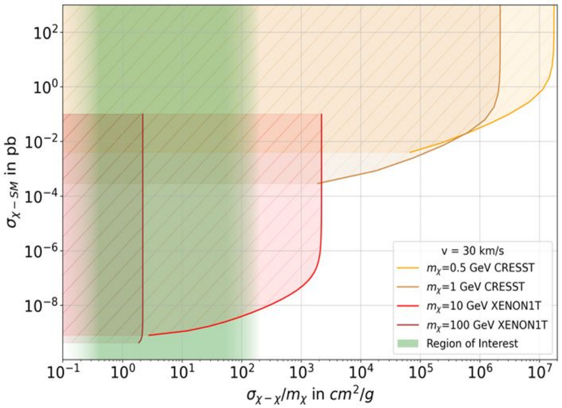
$$\sigma_{\chi-\chi} = \frac{8\pi}{\gamma^2+k^2}$$

Calculate limits on γ

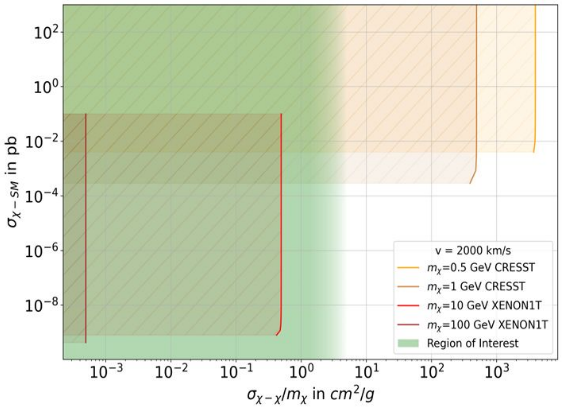


Translate into limits on self interaction

arXiv:2407.04004



Bounds at small scales



Bounds at cluster scales

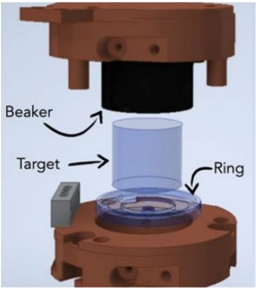
Novel Detector Designs

Results from previous run:
- Improved sensitivity for SI and SD searches
- Two new calibration methods

What we learned about the LEE:
- Rate decays over time and resets after warm-up
- LEE rate does **not** depend on
  - Material/growth parameters
  - Mass
  - Holding method
  - Scintillating materials
  - Detector geometry

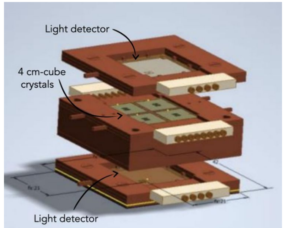
Development of three new detector designs

Mini Beaker



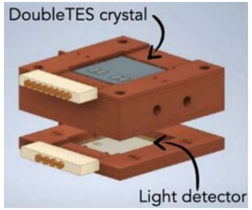
4π veto, sensitive to holder transmitted events

Cm Cube



Gravity assisted, size of target reduced to obtain low energy thresholds, suited to study coincidences between targets

DoubleTES



Gravity assisted, sensitive to events originating in the TES

JLTP s10909-024-03154-6

DoubleTES Module

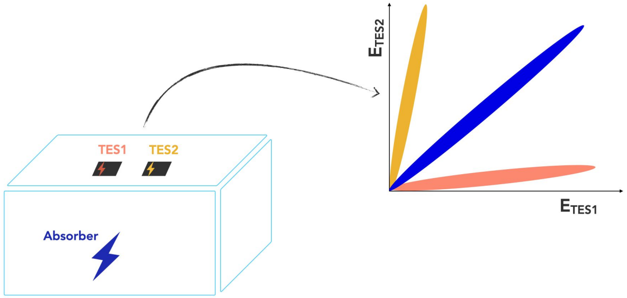
Idea:

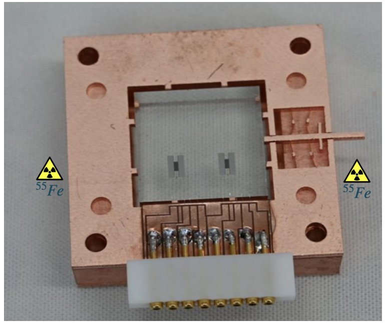
Instrument the crystal with two TES

- Events in absorber
  → two TES show same response
- Events in/close to the sensor
  → response is different

We can probe origin of LEE in:

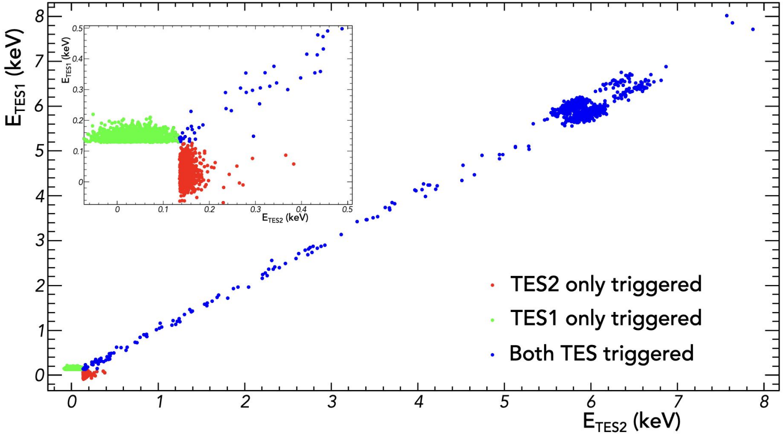
- TES induced events
- Interface between crystal and sensor



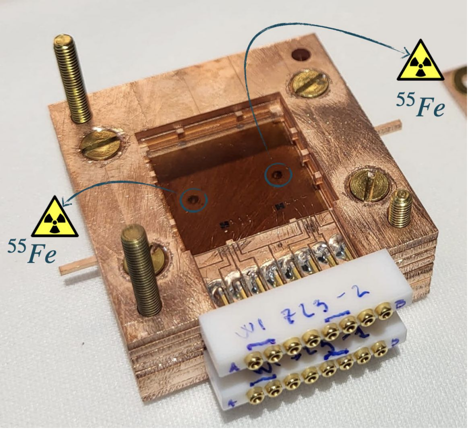


Test above ground

arXiv 240402607
EPJC final review



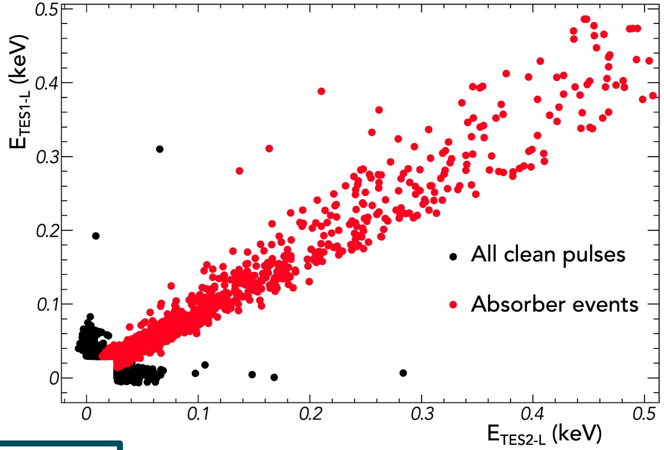
DoubleTES Module



Second measurement:
Double TES on sapphire wafer to access lower thresholds
→ Better study of LEE

Test above ground

arXiv 240402607
EPJC final review



Conclusion from both above ground measurements:

- There exist multiple components to the excess
- TES related events are one component of the excess

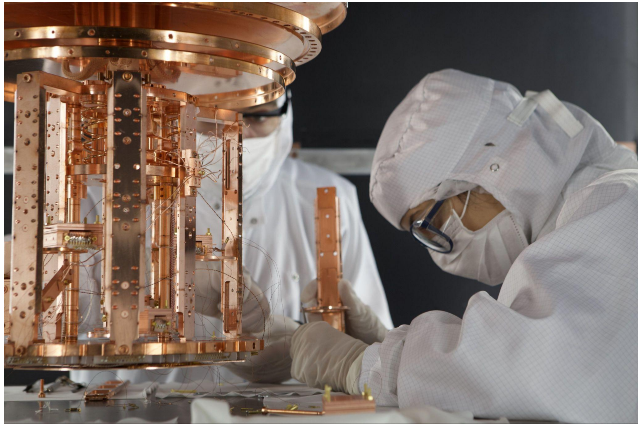
More details on poster by Francesca Pucci

Current Status

New run started in April 2024

- Several double TES running
- Optimization done
- Calibration ongoing

Stay tuned!



Posters at IDM 24:

Francesca Pucci
DoubleTES detectors to investigate the CRESST low energy background: results from above-ground prototypes

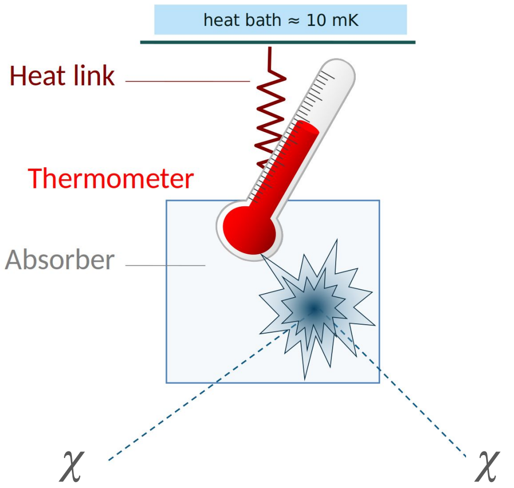
Lena Meyer
Optimum Filter Analysis in CRESST

Sarah Kuckuck
Modeling the Low Energy Excess in CRESST

BACKUP

Cryogenic Calorimeters

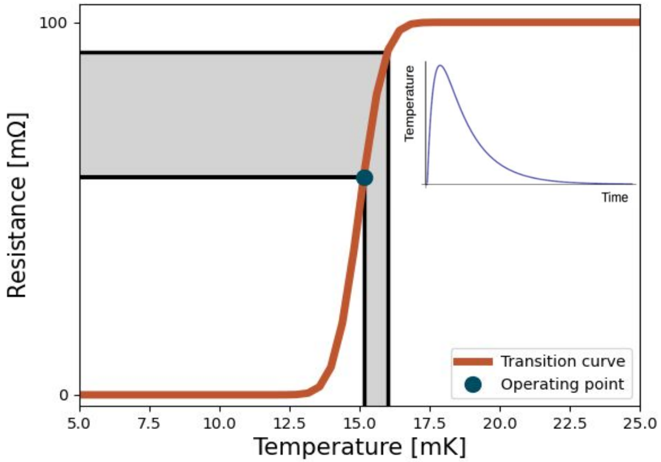
- Basic setup: crystal equipped with temperature sensor
- A particle interaction causes an energy deposition in the crystal
- Calorimeter equation: $\Delta T = \Delta E / C$



For low heat capacity (true at low temperatures)
⇨ low energy deposition can lead to significant temperature variation

- Read out by Transition Edge Sensor (**TES**)

The Transition Edge Sensor



Energy deposition in absorber ~keV

↓

Temperature rise in TES ~μK

↓

Resistance change ~mΩ

- 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