Modeling the Low Energy Excess in CRESST

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1. The CRESST Experiment

CRESST, short for **C**ryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers, is a **direct detection dark matter search** that is located in the LNGS underground laboratory. It operates crystals of different materials, equipped with **Transition Edge Sensors** (TESs) as cryogenic phonon detectors to observe **nuclear recoils** on an event-by-event basis.
Standard CRESST modules (Fig. 1) as they are considered here, contain a (20x20x10) mm³ bulk and a (20x20x0.4) mm³ wafer detector.

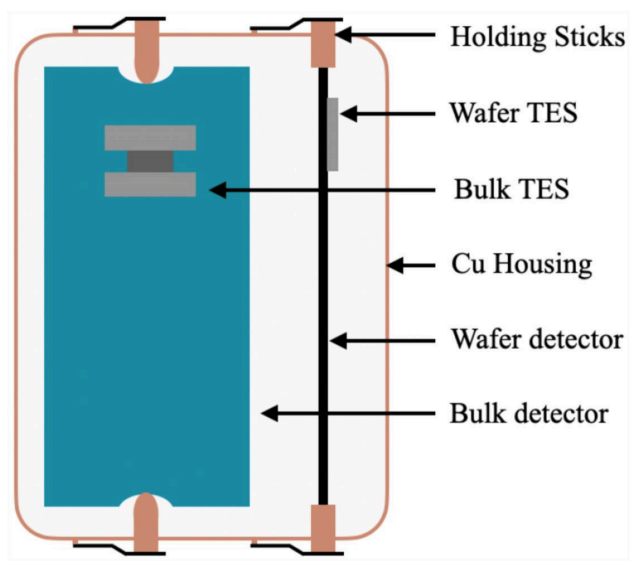

Fig. 1. Current CRESST standard detector module.

2. Low Energy Excess (LEE)

Current CRESST detectors reach thresholds well below 100 eV. In all detectors, regardless of the target material and holding structure, we observe an unexplained **sharp rise of events** (LEE) **below a few hundred eV**. Rate and specific rate **vary between detectors.** Furthermore, it has been observed that the LEE rate **slowly decays over time**.
Several explanations have been so far ruled out as the major origin of the LEE, among them noise triggers, artifacts, radiation and dark matter [1].

3. Warm-up Tests

In the last measurement campaign, CRESST conducted several **warm-up tests** during which the detectors reached different temperatures up to circa 130 K and were then cooled down again to their working temperature (~15 mK) (Fig. 2).
When restarting data taking after such warm periods, we observed an **increase in the low energy event rate** which was **decaying much faster** than the fraction of the LEE which was present since the start of the data taking [1].
The analysis of this data is still ongoing.

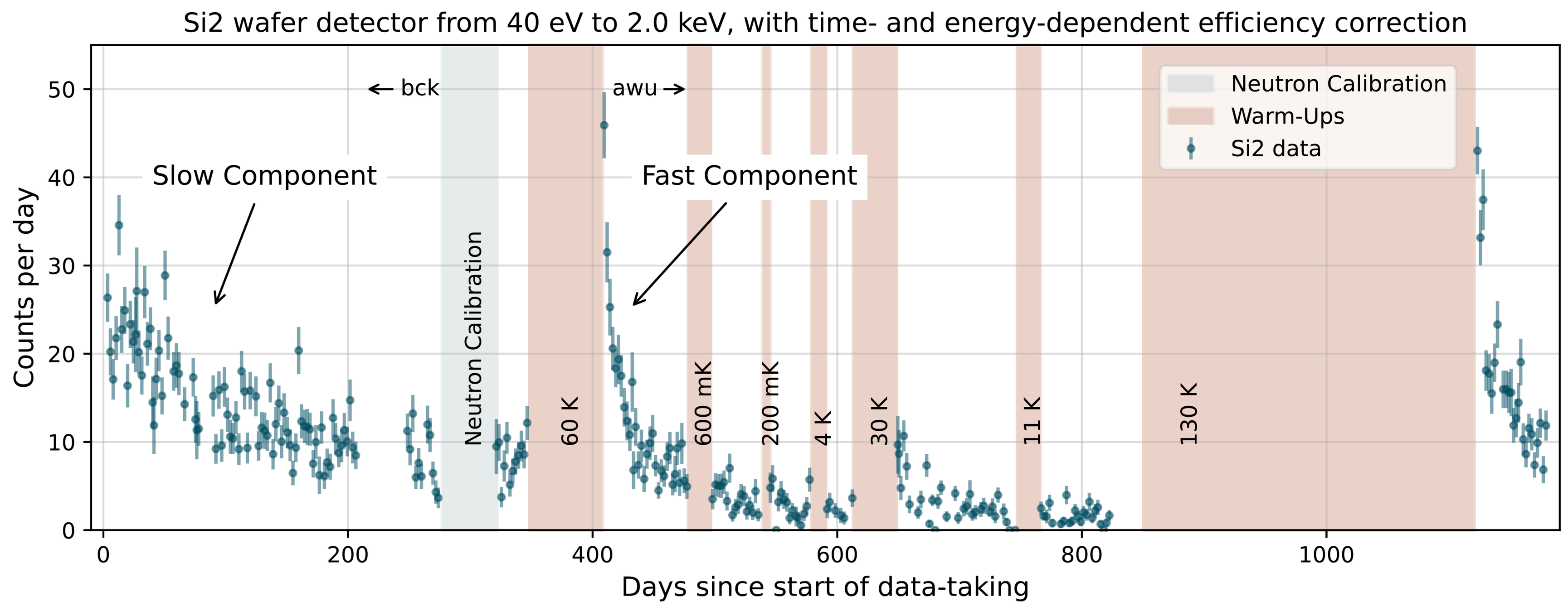

Fig. 2. Overview of the warm-up cycles. The data points show the event rate over time for the Si2 wafer detector for energies between 40 eV and 2 keV. The error bars show the 1σ statistical uncertainty. Each data point represents roughly 50 h of continuous data.

4. Detector Overview

Detector [1]	Fit Threshold [2]	Material
Comm2 – Bulk	37 eV	$CaWO_4$
TUM93A – Bulk	63 eV	$CaWO_4$
Sapp2 – Bulk [3]	61 eV	Al_2O_3
Sapp2 – Wafer	40 eV (12 eV) [4]	Si on Al_2O_3
Si2 – Wafer	40 eV (11 eV) [4]	Si

Tab. 1. Overview of the detectors used in this work.

[1] We only show detectors for which most of the warm-up data was usable and analyzed when this poster was finalized (Tab. 1).
[2] The fit thresholds are chosen to be a bit higher than the nominal thresholds of the detectors since the efficiency correction (see 6) does not work well directly at the threshold cutoff.
[3] In the Sapp2 bulk detector, we observe Gaussian structures that are still under investigation. We included them in the fits, so far assuming that they are constant in time. The validity of this assumption is currently tested.
[4] The fits in this work have been performed for energies above 40 eV. The fitting range can be extended to lower energies as specified in the brackets (see also 7).

5. GOAL:
Find a description of the LEE that works consistently for all CRESST detectors.
Provide a basis for comparing datasets and testing hypotheses on the origin of the LEE.

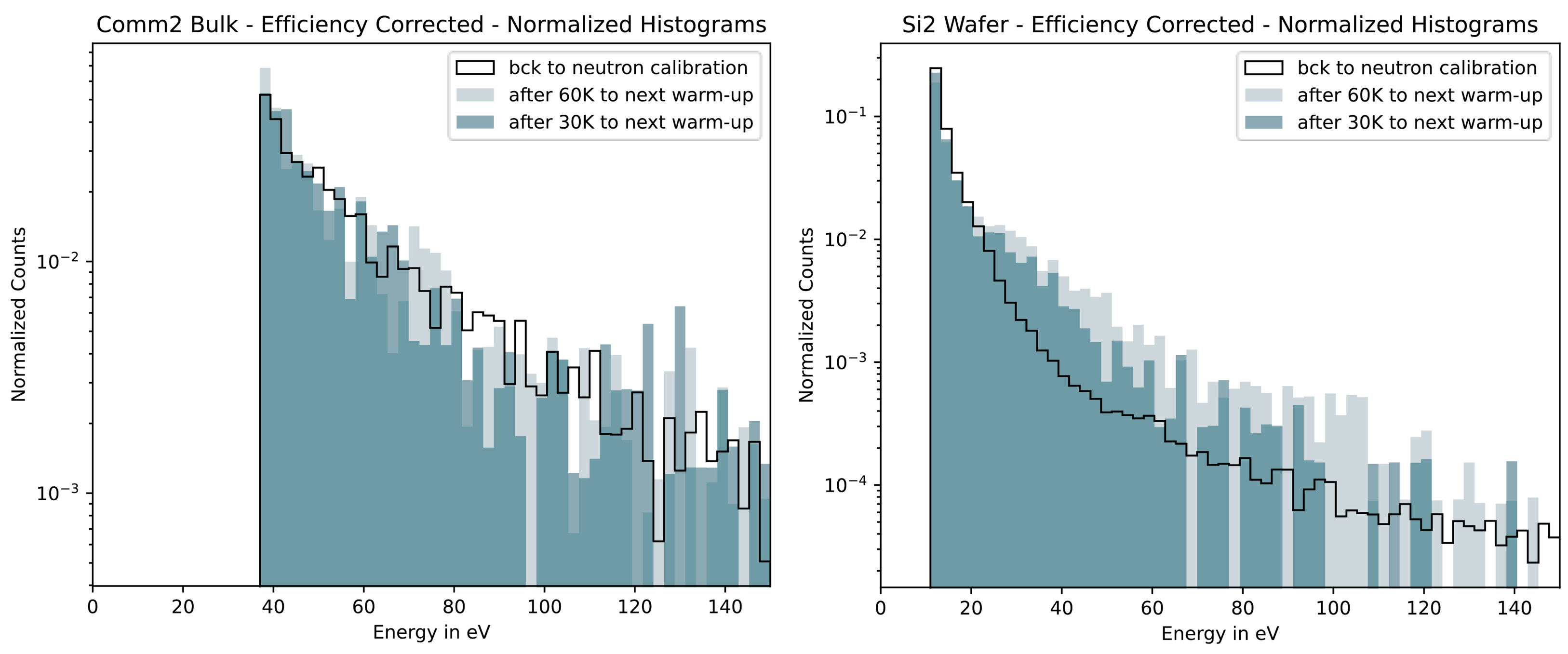

Fig. 3. Energy spectra of the Comm2 bulk (left) and Si2 wafer (right) phonon detectors for different time periods. The integral of each histogram is normalized to 1. The spectral shapes of both low-threshold wafer detectors change with time. The exact behavior and possible models for these changes are under investigation.

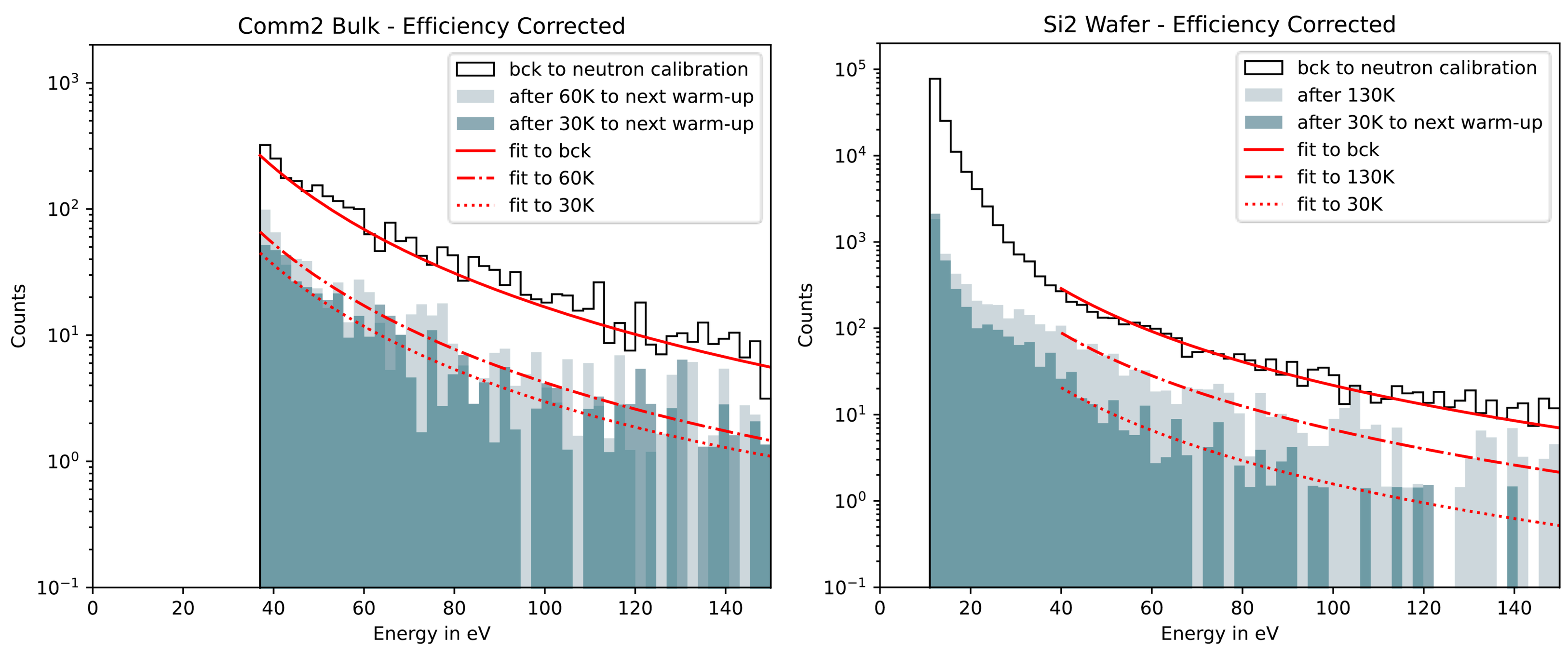

Fig. 4. Energy spectra and fit results for the the Comm2 bulk detector (left) and the Si2 wafer detector (right). The Si2 spectrum shows additional features at low energies, but the single power-law model still works for higher energies that are comparable with those of the bulk detectors. The Comm2 detector had a much higher energy threshold after the 130 K warm-up compared to the preceding data taking periods. This part of the Comm2 data is therefore not considered here.

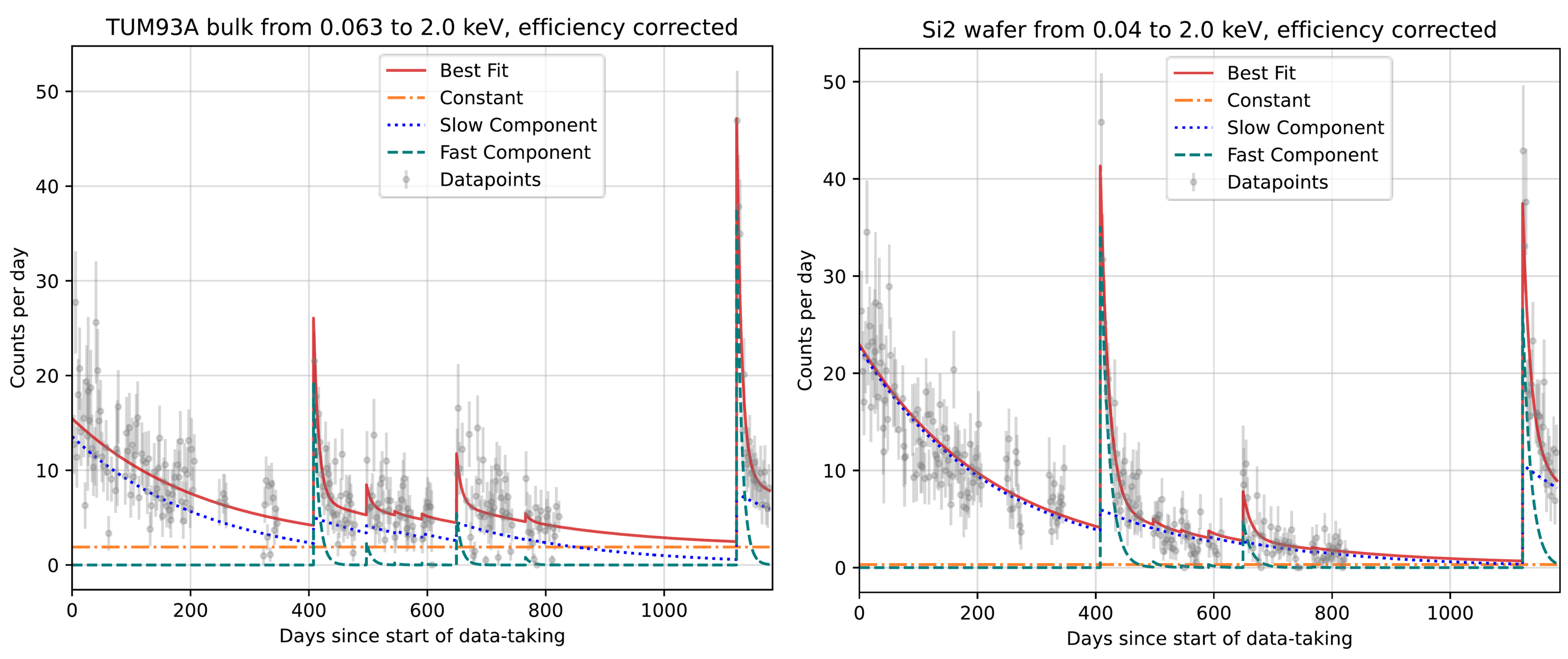

Fig. 5. Event rates over time and fit results for the time-dependent behavior of the TUM93A bulk detector (left) and the Si2 wafer detector (right). For Si2 we show only the data above the higher threshold where the single power-law model is valid. Each data point represents roughly 50 h of continuous data. The error bars show the 1σ statistical uncertainty. The cryostat is already cold for some time when the data taking starts, so the fast component is not expected to be present at the beginning of the bck data period.

6. Fitting Strategy – Method

- **Include as much information as possible:**
  - We include the data-taking period before the warm-up tests (bck) + all warm-ups.
  - We perform unbinned, two-dimensional fits.
  - We include the time- and energy-dependent efficiency which is calculated on a file-by-file basis (1 file ~50 h continuous data).
- **Python** and the **emcee** package [2]:
  - We use Markov Chain Monte Carlo (MCMC) Ensemble sampling.
  - The emcee package samples and maximizes the Bayesian posterior probability distribution (equivalent to the likelihood for a uniform prior).

7. Simplest Common Model For All Detectors – Results

- The best consistent description of the energy spectra found is a **single power-law** (Fig. 4.).
- The single power-law describes all five energy spectra above 40 eV where we observe that the **spectral shapes remain constant** in time for all the detectors (Fig. 3 left, Fig. 4). However, the wafer detectors allow us to investigate even lower energies down to ~10 eV. There we observe **changes in the spectral shape** over time (Fig. 3, right) which are currently under investigation.
- The proposed model (Tab. 2) also works well for the behavior over time, while assuming an **increased rate** after every warm-up (Fig. 5). There is a tendency observed for a higher increase in rate with increasing temperatures in the warm-ups (Fig. 7).
- The **parameters** (Fig. 6) for spectral shapes and time decays are **similar** between detectors.

Energy model	Time model	Excited by warm-up	Comment
Constant	Constant	No	Presence known from above excess energies
Power-law	Exponential – slow decay	Yes	Clearly seen in bck (before warm-ups) data
	Exponential – fast decay	Yes	Clearly seen after 30 K, 60 K and 130 K warm-ups

Tab. 2. The simplest model that fits all detectors. It can be written as: $N_1 + \sum N_{i(2-9)} E^{-\varepsilon} e^{-t/\tau_{s,i}} + \sum N_{j(9-17)} E^{-\varepsilon} e^{-t/\tau_{f,j}}$

Where N_1 is a constant, i are the enhancements of the slow decaying component (s), starting from the beginning of the data taking and j are the fast decaying (f) warm-up components. The energy E is inserted in keV.

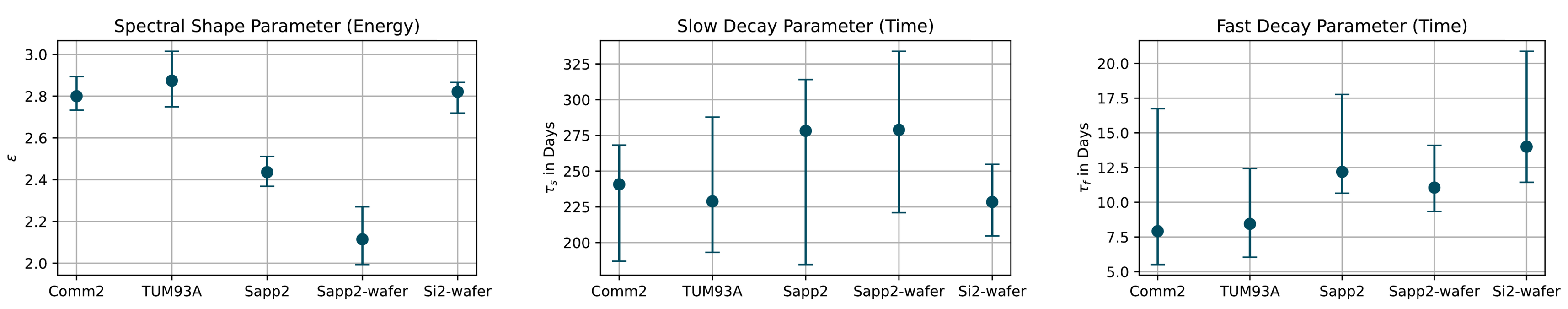

Fig. 6. Fit results for the spectral shapes (energy parameter) on the left. Fit results for the decay times: slow decay τ_s in the middle, fast decay τ_f on the right. The error bars show the highest posterior density interval (95%).

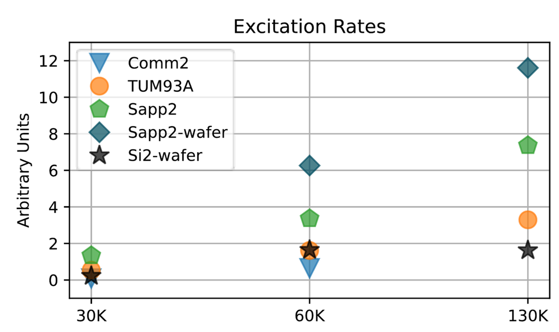

Fig. 7. Fit results for the total excitation rates *(s+f)* at the restart of warm-up data taking. For better readability, the rates are presented in arbitrary units. The data period after the 130 K warm-up for Comm2 and the data period after the 30 K warm-up for the Sapp2 wafer were not available.

8. What to do next?

- Model and compare the changes and features in the energy spectrum at very low energies (below 40 eV).
- If necessary adjust the model according to the outcome of the very low energy analysis and the results of the current measurement campaign (double TES, new TUM93A data).
- Perform dedicated tests of existing hypotheses on the LEE's origin (e.g. other models for the time behavior).

9. References

[1] G. Angloher, et al. (2023). Latest observations on the low energy excess in CRESST-III. *SciPost Phys. Proc.*, 013. doi: 10.21468/SciPostPhysProc.12.013

[2] Daniel Foreman-Mackey et al. "Emcee: The MCMC Hammer". Version 4. (2012). doi: 10.48550/ARXIV.1202.3665.