# Detector Development for the CRESST Experiment

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## Abstract

Recently low-mass dark matter direct searches have been hindered by a low-energy background, drastically reducing the physics reach of the experiments. In the CRESST-III experiment, this signal is characterised by a significant increase of events below 200 eV. As the origin of this background is still unknown, it became necessary to develop new detector designs to reach a better understanding of the observations. Within the CRESST collaboration, three new different detector layouts have been developed, and they are presented in this contribution.

## 1 Introduction

CRESST is a direct detection dark matter experiment located in the underground laboratory of Gran Sasso (LNGS) [1]. CRESST operates cryogenic calorimeters consisting of a scintillating target crystal instrumented with a transition-edge sensor (TES) coupled to an auxiliary cryogenic calorimeter to measure the scintillation light, called a light detector (LD) [2]. CRESST is one of the leading experiments in the search for dark matter particles with masses $\lesssim 1\,\mathrm{GeV/c^2}$ (light dark matter) [3].

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Recently, direct searches for light dark matter have been hindered by an unexplained background at low energy, reducing the experiments' sensitivity [4]. In the CRESST experiment, this background is characterised by a sudden increase in the number of events at energies below 200 eV [5]. The cause of this phenomenon is still unclear. The resulting energy spectrum is featureless and could be mistaken for a signal from dark matter interactions [6].

Similar observations have been made in many other experiments that focus on low energies, such as [7–14], and more. This observation has garnered the attention of many scientists, and nowadays, this background is well-known as the low-energy excess (LEE) (see [4]).

In Sect. 2 we provide an overview of the research conducted in CRESST for understanding the LEE. In Sect. 3 we present three novel detector modules, specifically designed to study the LEE. Each of these modules is tailored to isolate and address a distinct hypothetical source of this background, facilitating its identification and mitigation.

## 2 Low-Energy Excess Hunting in CRESST

The first observation of the LEE was made using a CRESST-III detector module in 2019 [15]. The CRESST-III detector module consists of a $20{\times}20{\times}10$ mm$^3$ CaWO$_4$ scintillating crystal weighing approximately 24 g as main absorber and a smaller cryogenic calorimeter made of a $10{\times}10{\times}0.4$ mm$^3$ silicon-on-sapphire (SOS) as light detector. This detector concept is discussed in detail in [15]. Both calorimeters are equipped with a tungsten transition-edge sensors (W-TES) for temperature read out and are weakly connected to the thermal bath through a gold thermal link. The detectors are enclosed in a fully scintillating housing and equipped with instrumented holders (see Fig. 1).

During the first data-taking campaign with these detectors, a rise in the event rate at threshold was observed by multiple detectors, but the energy spectra of the different modules were not compatible with each other, ruling out the possibility of a single common source for these events. Extensive studies were made to address some possible origins of the LEE and are summarised in the following:

1. *Single photons hitting the TES sensor* All non-active scintillating parts inside the detector housing have been removed.
2. *Internal relaxation of the lattice stress* CaWO$_4$ crystals growth differently from different sources with measured internal stress have been measured and compared.
3. *Events transmitted to the crystal due to holding structure* The sticks made from CaWO$_4$ have been replaced with copper sticks or bronze clamps.
4. *Material dependence* Main absorbers of Al$_2$O$_3$, LiAlO$_2$[16] and Si [17] have been tested.
5. *Target geometry related* Light detectors have been analysed as individual detectors to verify the impact of mass, surface and sensor sizes.
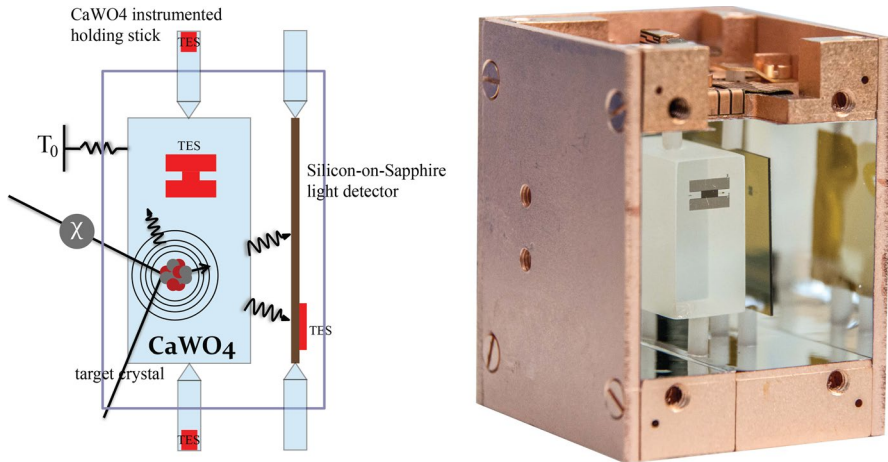
**Fig. 1** Left schematic view of the detector design for CRESST-III modules. An energy deposition produces phonons, measured by the TES deposited on the target crystal, and photons, collected by the SOS light detector. Both detectors are weakly coupled to a thermal bath at $T_0 \sim$10 mK. A fully scintillating housing and instrumented $CaWO_4$ holder sticks are used to veto possible background originating from surrounding surfaces. Right picture of an open CRESST-III detector module

Our studies did not clarify the origin of this phenomenon, only allowed to exclude several hypotheses. Meanwhile, the rate of the LEE was observed to decay over time with two time constants: a fast one (order of a few days) and a long one (order of 200 days) [5]. The former was observed to reactivate following thermal cycles from a working temperature of a few mK to a few tens of K.

## 3 Next-Generation Detector

In this section, we present three new detector modules designed with the objective of understanding the source of the LEE events, addressing the remaining hypotheses. Among those, the prevailing ones include events originating from the interface between the sensors and the crystal, internal stress of the crystal itself and secondary radiation resulting from interactions in the surrounding materials.

### 3.1 Mini-Beaker Module

To investigate external radiation as the LEE source, the first design enables the possibility of detecting and tagging surface radiation and events transmitted through the holder. This is achieved with a $4\pi$ veto and an instrumented holding structure.

### 3.1.1 Description

The mini-beaker module utilises a cylindrical $Al_2O_3$ crystal as a target; it measures 18 mm in diameter and 15.7 mm in height, resulting in a total volume of 4 cm³ equal to that of a standard CRESST-III target. The target is instrumented with a W-TES, directly deposited on a flat surface, and it is glued to a sapphire ring, on the same surface of the TES, through three spots of 50 $\mu$m thick bi-component epoxy. The ring has a diameter of 25 mm, is 3 mm in height, and it is instrumented with a W-TES, to allow for the identification of events transmitted through the holding structure. The ring features a 3 mm diameter opening in the centre to allow for electric contacts on the TES sensor of the target. A silicon beaker, also instrumented with a W-TES, surrounds the target, as illustrated in Fig. 2. The beaker has an external diameter of 23 mm and a height of 25 mm. Together with the ring, the beaker provides a nearly $4\pi$ veto against radiation originating from the surrounding of the crystal. The ring and beaker are held in position with Cu-Be clamps. The complete module features three active channels: the sapphire cylindrical crystal, the ring and the beaker. The two latter serve as veto channels. To minimise thermal interference between the different components of the module, the heaters are directly deposited onto the W-TES. They are insulated from the thermometer through a 350 nm thick layer of $SiO_2$. This approach results in improved operability and fewer constraints on the critical temperature of the sensors.

## 3.2 cm-Cube Array Module

This design features a single array of four 1 cm³ absorber crystals and two light detectors, with a holding scheme designed to minimise the forces acting on the crystals. The aim of this holding scheme is to investigate the influence of forces acting on the crystals on the LEE [18].

### 3.2.1 Description

The cm-cube module utilises four 1×1×1 cm³ $CaWO_4$ crystals, for the same total volume of 4 cm³ as the standard CRESST-III design. The module features two light
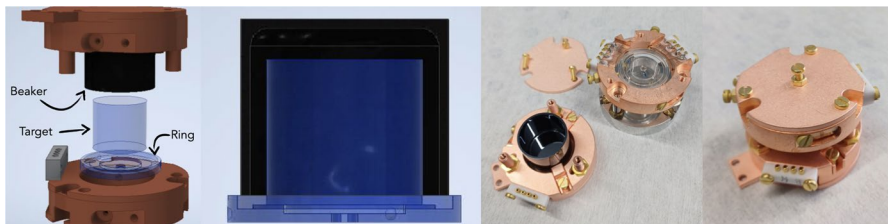


**Fig. 2** Design of the mini-beaker module. Left: detailed CAD view of the various components of the module, including the bottom copper holder, the sapphire ring, the target crystal, the Si beaker and the top copper holder, together with a CAD cross-sectional view of the three crystals in their working position. Right: photos of a mini-beaker module before and after the final assembly

detectors, one placed on top of the four absorber targets and one on the bottom. Thus, the complete module features six active channels.

The advantage of such a design, on the one hand, lies in the possibility to veto coincident events, and on the other hand, the smallness of the absorbers helps to lower the reachable threshold [19], a key parameter for the search of dark matter in CRESST. We expect that each of the cubes lowers the threshold by a factor of 2 compared to the standard CRESST-III target crystals. The novel holding scheme features targets placed on a minimal amount of copper and kept in place only by their weight, known as "gravity assisted" holder (see Fig. 3). This allows us to control, for the first time, the forces applied to the crystal.

### 3.3 DoubleTES Module

The final module we present is the doubleTES sensor module. The basic idea of this module is to equip the main target with two identical sensors that are independently read out. This module allows to investigate the possibility that the origin of the low-energy excess is sensor-related.

### 3.3.1 Description

The doubleTES utilises the same crystals as the standard CRESST-III module: a $CaWO_4$ crystal as the main absorber and a SOS crystal as a light detector. The main absorber crystal is instrumented with two identical W-TES, directly deposited on the top of the crystal surface simultaneously. To minimise the thermal interference between the two sensors, the heaters are directly deposited onto the W-TES and insulated from the thermometer through a 350 nm thick layer of $SiO_2$, as for the mini-beaker (see Sect. 3.1). The light detector is instrumented with one W-TES only, also evaporated on the crystal surface, and it is placed under the main absorber as shown in Fig. 4 (left). The holding scheme utilised in this design is an adaptation of the
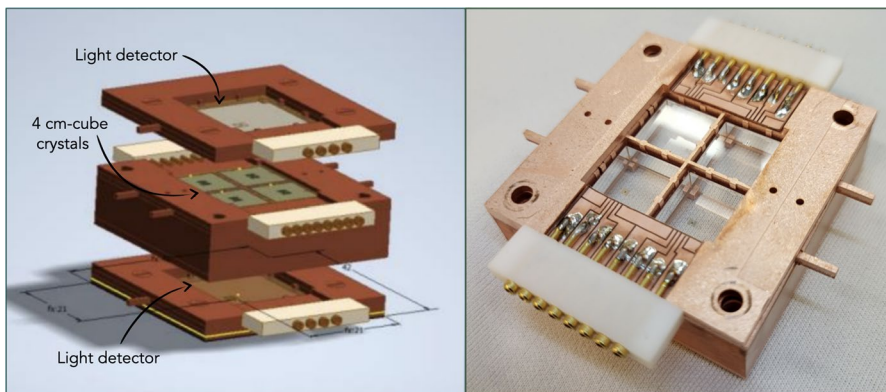


**Fig. 3** Design of the cm-cube detector module. Left: Detailed CAD view of the various components of the module, the four main absorbers, the light detectors and their copper holding structures. Right: A picture of the cm-cube main absorber crystals mounted in their test holder
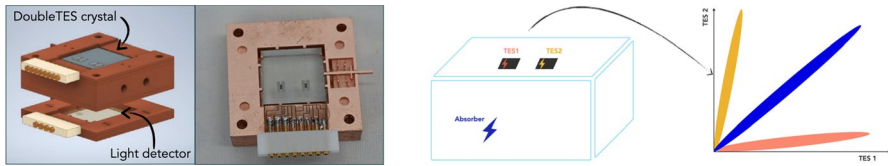
**Fig. 4** This figure illustrates the design of the doubleTES; one of the next-generation detector modules presented in this work. Left: Detailed view of the various components of the module. The holes on the side of the copper structure are used to easily place iron calibration sources when needed, and an actual picture of the doubleTES crystal showing the two identical TES seen from the top. Right: Schematic representation of the signal originating from different sources in the doubleTES. In a plot with the energies of the two TES on the axes, we expect a clear separation of the events originating from the crystal from those originating from the two different sensors. Indeed, the two TESs should measure similar energies for particle interactions in the crystal's bulk, while events originating in close proximity to one of the TESs are expected to have a stronger signal in one of the sensors

"gravity assisted" holding scheme employed in the cm-cube module (see Sect. 3.2), aimed at minimising the forces acting on the crystal.

Combining the information obtained with the two sensors, it is possible to study the origin of the events (see Fig. 4 (right)). More information on this module can be found in [20].

## 4 Conclusions

In summary, this contribution has introduced three cutting-edge detector modules designed for integration into the forthcoming CRESST-III measurement campaign, scheduled in early 2024. These innovative modules each play a pivotal role in advancing our pursuit of uncovering the origins of the LEE (low-energy excess), promising exciting prospects for furthering our understanding of cryogenic detectors at low energy.

**Declarations**

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