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In-situ study of light production and transport in phonon/light detector modules for dark matter search

M. Kiefer [a,*], G. Angloher [a], A. Bento [b], C. Bucci [c], L. Canonica [c], A. Erb [d,e], F.v. Feilitzsch [d], N. Ferreiro Iachellini [a], P. Gorla [c], A. Gütlein [f,g], D. Hauff [a], J. Jochum [h], H. Kluck [f,g], H. Kraus [i], J.-C. Lanfranchi [d], J. Loebell [h], A. Münster [d], F. Petricca [a], W. Potzel [d], F. Pröbst [a], F. Reindl [a], S. Roth [d], K. Rottler [h], C. Sailer [h], K. Schäffner [c,j], J. Schieck [f,g], S. Schönert [d], W. Seidel [a], M.v. Sivers [d], L. Stodolsky [a], C. Strandhagen [h], R. Strauss [a], A. Tanzke [a], C. Türkoğlu [f,g], M. Uffinger [h], A. Ulrich [d], I. Usherov [h], S. Wawoczny [d], M. Willers [d], M. Wüstrich [a], A. Zöller [d]

[a] *Max-Planck-Institut für Physik, D-80805 München, Germany*
[b] *CIUC, Departamento de Fisica, Universidade de Coimbra, P3004 516 Coimbra, Portugal*
[c] *INFN, Laboratori Nazionali del Gran Sasso, I-67010 Assergi, Italy*
[d] *Physik-Department, Technische Universität München, D-85748 Garching, Germany*
[e] *Walther-Meißner-Institut für Tieftemperaturforschung, D-85748 Garching, Germany*
[f] *Institut für Hochenergiephysik der Österreichischen Akademie der Wissenschaften, A-1050 Wien, Austria*
[g] *Atominstitut, Vienna University of Technology, A-1020 Wien, Austria*
[h] *Physikalisches Institut, Eberhard-Karls-Universität Tübingen, D-72076 Tübingen, Germany*
[i] *Department of Physics, University of Oxford, Oxford OX1 3RH, United Kingdom*
[j] *Gran Sasso Science Institute, I-67100 L'Aquila, Italy*

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ABSTRACT

The CRESST experiment (Cryogenic Rare Event Search with Superconducting Thermometers) searches for dark matter via the phonon and light signals of elastic scattering processes in scintillating crystals. The discrimination between a possible dark matter signal and background is based on the light yield.

We present a new method for evaluating the two characteristics of a phonon/light detector module that determine how much of the deposited energy is converted to scintillation light and how efficiently a module detects the produced light. In contrast to former approaches with dedicated setups, we developed a method which allows us to use data taken with the cryogenic setup, during a dark matter search phase. In this way, we accounted for the entire process that occurs in a detector module, and obtained information on the light emission of the crystal as well as information on the performance of the module (light transport and detection).

We found that with the detectors operated in CRESST-II phase 1, about 20% of the produced scintillation light is detected. A part of the light is likely absorbed by creating meta-stable excitations in the scintillating crystals. The light not detected is not absorbed entirely, as an additional light detector can help to increase the fraction of detected light.

1. Introduction

1.1. General context

The CRESST (Cryogenic Rare Event Search with Superconducting Thermometers) dark matter experiment aims at detecting WIMP-nucleus scattering [1] in inorganic scintillating crystals operated as cryogenic detectors. Energy deposited in the crystals creates phonons and scintillation light.

The phonon signal is measured by a transition-edge sensor (TES) evaporated onto the scintillating crystal. The scintillation light is detected by a separate light detector also read out by a TES [2]. The TESs in CRESST consist of a tungsten thin-film structure thermally stabilized at the transition between normal and superconducting state. In this regime, even the very small temperature variations $\mathcal{O}(\mu K)$ caused by individual particles depositing energy

* Corresponding author.
E-mail address: kiefer@mpp.mpg.de (M. Kiefer).

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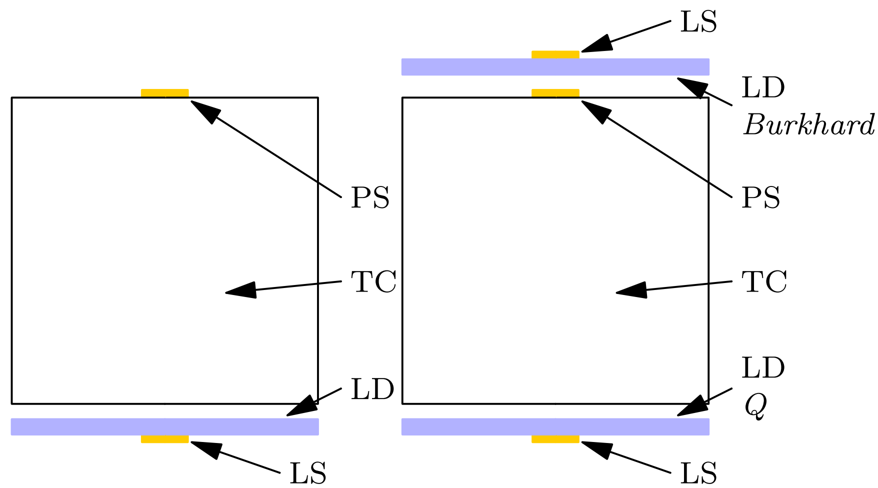

Fig. 1. Schematic drawing of the detector module designs considered in this work. In all modules, the interaction in the target crystal (TC) produces phonons and scintillation light. The phonons are read out by the phonon TES (PS). The light is absorbed in the light detector (LD) and read out by the light TES (LS). Target crystal and light detector are surrounded by a scintillating reflective foil (not shown here). The left sketch shows a detector of the standard design. The double light detector module (right) was equipped with two light detectors, LD *Q* and LD *Burkhard*. This non-standard design serves to investigate how scintillation light propagates within a module.

in the detector result in resistance changes that we can measure with a SQUID amplifier.

The scintillating crystal and the light detector are surrounded by a housing made of a scintillating and reflective foil, which (apart from masking certain types of background events by emitting light, cf. [3]) prevents light from escaping without contributing to the signal. The ensemble of crystal, light detector, foil and a surrounding copper structure is called a detector module.

The signal of the phonon channel is a measure of the deposited energy. The fraction of deposited energy that is converted to scintillation light depends on the nature of the interacting particle (e.g. αs or γs). Hence, the ratio of scintillation light to deposited energy is used to distinguish between different types of interacting particles. Increasing the amount of detected scintillation light per deposited energy is crucial for maximizing the background suppression capabilities of the detector modules —and hence the overall sensitivity of the experiment.

Only a fraction of the produced light is actually detected. This is due to the limited transparency of the crystal (which only partially emits the produced light), due to the geometry and the efficiency of the reflector as well as due to the size and absorptivity of the absorber of the light detector. Therefore, disentangling the factors that affect production and detection of scintillation light helps to identify the key factors for further improving the light signal and hence signal-background discrimination of experiments using the phonon-light technique to look for dark matter as well as for neutrinoless double-beta decay [4,5] or [6].

1.2. Concept of the new evaluation method

The typical, established methods for characterizing the crystals work by irradiating the crystal in a dedicated setup at room temperature and by measuring the scintillation light, e.g. with a photomultiplier tube. With the new method (for a detailed description cf. Section 2.3), we use data acquired in situ, with the cryogenic setup during dark matter data taking to determine the efficiencies at which light is being produced and detected.

We use two clearly identified lines originating from interacting particles of different nature (i.e. one α-line and one γ-line). Then, we know the energy deposited in the crystal (the *Q*-values of the lines), and we can measure the absolute energy deposited in the light detector. The energy of the phonon detectors is not on an absolute scale as it depends (and thus contains information) on how much of the deposited energy is converted into scintillation light. The fraction of light that is lost is the same in both cases. With these information, we derive production and detection characteristics of the detectors by evaluating the *Q*-values and phonon and light detector readings of the two lines.

2. Experimental setup, data and analysis

To verify the findings and in order to obtain more detailed information on how to possibly optimize the detector modules, we evaluated light production and light detection of two different detector designs. This section describes the designs we investigated and the method by which we analyzed the data.

2.1. Detector designs

All data analyzed here have been acquired in CRESST-II phase 1 [3]. The detector modules of the standard design (cf. Fig. 1, left) consist of a target crystal (in which the energy is deposited) equipped with a TES that detects the phonons. The crystals are usually calcium tungstate cylinders of 40 mm height and diameter. The crystal face opposite to the TES is roughened in order to facilitate light propagation towards the light detector.

The double light detector module depicted on the right in Fig. 1 allows an additional insight in the light propagation within the module. The light detector called *Q* is located adjacent to the roughened surface of the scintillating crystal. The light detector named *Burkhard* faces the crystal at the opposite side, near the phonon TES.

If the two light detectors in sum detected more light than a single detector,[1] this would suggest that the situation could possibly be improved by changing the light detectors and/or the path of the light within a module. If introducing the second light detector did not significantly rise the total amount of detected light (so that already a single light detector gathers all the available light), this would indicate that the reflectivity of the housing, the absorptivity of the light detector and the transparency of the crystal were nearly optimal.

[1] With the fact taken into account that individual crystals differ in light production efficiency.